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Integration of ecological knowledge, landscape modelling, and public participation for the development of sustainable forest management

SFM Network Project: Development of an integrated approach for decision making in sustainable forest management

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EXECUTIVE SUMMARY

We propose a multidisciplinary framework, integrating biophysical, social, and economic indicators into a spatially explicit landscape-modelling tool, to facilitate decision-making for sustainable forest management (SFM). To do so, we first propose indicators relating to criteria for biodiversity, soils, aquatic environments, forest productivity, and people developed by a multidisciplinary team of researchers. We develop the concepts of planning and monitoring indicators and outline the importance of the role of adaptive management for SFM. The indicators are integrated into a modelling tool simulating various forest management scenarios. We explore the evolution of age class structure over time according to various forest management options, taking into account synergistic interactions between harvesting and wildfire. Since public participation in resource management has been shown to lead to improved decision-making, our process is driven by public deliberation for the definition of the objectives of forest management. The multiple outcomes of the modelling tool are to be used within the context of public participation for decision-making in forest management. Recommendations are made for the development of effective implementation of interdisciplinary and interagency collaboration.

Principle conclusions regarding indicators of SFM:

- For a management system to continually evolve towards SFM, **adaptive management is essential**; in this way new knowledge can contribute to the development of better practices.

- The development of two types of indicators will benefit adaptive management: **planning indicators** are used within the modelling tool and serve to project forest conditions according to various management plans, and **monitoring indicators** are measured in the field in order to verify and perfect the knowledge that was used in the development of the modelling tool and to refine the planning process.

- The range of ecological conditions caused by natural disturbances (**natural variability**) can be used as a benchmark for indicators, thus permitting a standardized approach for the development of indicator thresholds and comparisons among regions.

- We propose the following **planning indicators**: for **biodiversity**, age class structure, species composition, and configuration of the forest, and road density; for **water quality**, the ratio of disturbed watershed area to lake volume; for **soils**, a synthetic indicator related to rotation period, parent material, site index, stand type, and harvesting method; and for **forest productivity**, average microsite distance to seed tree, age and species of seed tree, and the proportion of exposed mineral soil.

- We propose the following **monitoring indicators**: for **biodiversity**, the structure and abundance of the avian community; for **water quality**, dissolved organic carbon concentration and light attenuation; for **forest productivity**, stocking rates of disturbed sites; and for **people**, the number of forest-users' groups involved in the process, the number of training programs

linking schools with local forest industry, acceptability of forestry practices, the number and proportion of direct jobs from the forest industry, the corrected mean household revenue, and the mean coverage ratio of local forestry-related businesses.

Principle conclusions regarding landscape modelling:

• The cumulative impacts (**landscape legacies**) of past disturbance and management (logging, fire suppression, etc.) that result in the present age class structure, may present challenges and/or opportunities for management objectives.

• Scenario simulations suggest that current **annual allowable cut levels exceed harvest levels required to maintain old growth** and other habitat types.

• Due to the inherent uncertainty in the timing or location of future fires, **flexible policies and guidelines** must be developed to maintain sustainable forest and wildlife.

Principle conclusions regarding public participation:

• Certification of forest management is leading to changes in the role of the provincial government; however, **governments must maintain their regulatory role**, since market mechanisms alone cannot ensure the safeguard of resources for future generations.

• Using **previous participation experiences** as guides and **limiting the number of initiatives** conducted at the same time in any given region will be more efficient for both the participants and the forest managers.

• **Relationship building** among stakeholders must be seen as an important outcome of any public participation process.

• Public participation will involve a **redistribution of rights and responsibilities**.

ACKNOWLEDGEMENTS

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INTRODUCTION

Whether the wants of society today will leave viable forests tomorrow is subject to conjecture. Meanwhile, public opinion and the influence of international political forums, such as the United Nations Conference on Environment and Development (UNCED, 2000), are increasing pressure on forest managers to develop practices that will ensure that productive and resilient ecosystems are passed on to future generations. Previous concern for sustained yield has been superseded by concerns for the health and resilience of forested ecosystems. Some maintain that decisions pertaining to resource management should be made exclusively by formally trained experts (e.g., Hunt 1987). However, there is growing agreement among observers of public process that a sense of responsibility towards the resource leads to responsible action, or action that takes into consideration all present and future members of society (Hoff 1998).

However, no amount of consensus will, de facto, make degradation of the forest a sustainable enterprise. There are biological limits on the processes that provide for the wants of society. If the biological material of the forest is strained beyond its capacity to recover, then the forest will eventually stop providing. Hence, it is important that the process of public participation involve the development of an understanding of forest ecology and the impacts of human activities on ecosystem process (Kneeshaw and Messier 1999). This is an essential part of the social learning (or capacity building) process. In order for enlightened decisions on forest management to take place, human society must redefine its niche within the forest ecosystem and act accordingly.

The collaborative learning process implies more in-depth public involvement on the part of forest managers, who have traditionally respected only the legal requirement of informing individuals and groups interested in forest management planning. The social components of this project were conducted in order to identify the pitfalls that may present themselves in the implementation of a collaborative learning process for forest management, and to identify possible impacts from such an exercise in the Quebec context. The bio-physical components of this project were conducted to develop a proposal of management unit level indicators of SFM. In order to integrate these indicators into the context of the structure and dynamics of the study area, and in order to develop a management tool for decision-making, work was also undertaken to develop a landscape-modeling tool.

Here, we propose a process through which public participation may guide forest ecosystem management. We have been developing this process for the Mauricie region, an area typical of the mixed-wood boreal forest of central Quebec (Canada), though the points we address should be relevant to forest management in general. Previous experience with public participation indicates that improved decisions on resource allocation will result from the empowerment of stakeholders and by the development of a sense of responsibility and belonging (Etzioni 1996, Benko and Lipietz 1992, Nozick 1992, Sample 1993). Thus, by developing a system that allows stakeholders to consider the myriad possible forest values through the use of local-level indicators solidly founded upon scientific knowledge, and by embedding this system into a loop of adaptive management (sensu Walters 1986), we hope to contribute to the development of sustainable practices of forest management. We have adopted the framework of Erdle and Sullivan (1998) and use "forest condition" to mean a biophysical description of the forest (e.g., stand composition and age, stem density) and "forest value" to mean any good or service, tangible or intangible, that is provided by the forest (e.g., clean water, wildlife, scenic beauty). In this project, we propose fundamental principles for the development of a process for sustainable forest management (SFM) guided by public participation, as well as practical considerations for the implementation of such a process.

PUBLIC PARTICIPATION

Public participation can contribute to the process of forest management in many ways. Given the scale and complexity of forest ecosystem management, decision-making can greatly benefit from the public's intimate knowledge of the forest, acquired through personal experience of the forest or through the transmission of traditional knowledge. As well, a more open and inclusive process can contribute to the resolution of conflict within communities (Singleton 2000). Recent examples of public participation have demonstrated that community groups that participate in resource management develop a sense of stewardship, as well as the skills necessary to make socially and ecologically sound decisions about the resource (Milbrath 1996, Mandondo 2000, Singleton 2000). Furthermore, in states where forested land is publicly owned, citizens must have the fundamental right to be involved in the process[1]. Public participation has come to be regarded as an essential component of resource management (Berkes 1989, Western and Wright 1994, CCFM 1997 and 2000).

There is no general agreement on the most appropriate constitution of a representative subset of society for public involvement (e.g.,Wagar and Folkman 1974, Hoff 1998, Buchy and Hoverman 2000). Divergent visions of the nature of democracy can lead to different models of public participation (Beierle 1998). We have chosen to call "stakeholders" all members of a society that value some aspect of that society's forested landscape. Whether these stakeholders originate from a community where forestry operations are focused or more remote urban centres, whether they are individuals or members of an organization, neophytes to ecology or scientists, we consider that any individual willing to commit to the process of public participation is entitled to a voice. The development of institutions for public participation will further define the nature and process for the representation of the diversity of visions for the forest.

As part of a study developed to study the structure and function of public participation processes (Côté, 2001), the following were retained as criteria of effective public participation.

- A diversity of interested parties participate in the process.

[1] Where forests are privately owned, property rights complicate involvement of the public in management. Côté (2001) provides a more detailed discussion based on involvement with a private land owner.

- Participants' concerns and expectations are identified throughout the process.

- Discussions focus on participants' concerns, meetings encourage interaction between participants, and new avenues are identified in order to address issues of concern.

- The initiative redefines the roles and responsibilities of participants.

- Participants can influence the decision-making process regarding management of the forest area.

- Issues raised by the participants are making a difference in the field.

While public involvement in decision-making may help to resolve conflicts in integrated resource management, the process can also amplify or simply obviate existing conflict. Observation of discussion and deliberation on forest management issues in the study area have led to the identification of several obstacles to harmonious and effective participation (Côté, 2001).

- New needs may come into conflict with old ones. These new demands have the potential to decrease the economic output of a forest area and consequently decrease the power of corporations and the revenues of government.

- The needs and concern of interested parties may be in contradiction with each other. Local people, national actors, and international actors may have conflicting objectives for the same territory. There are a number of public voices that may emerge at any time during the process. There is no single public voice.

- Proposed changes may be economically detrimental to the region and other participants.

- Interested parties may not be satisfied with the participation process. Groups that have not been invited to participate in the process may be frustrated. Is it enough to only invite local NGO's (non-governmental organizations)? Does a foreign NGO have the right to participate in the process?

- Participants may be unwilling or unable to accept the new roles attributed to them by other participants. For example, managers with the forest industry may be overwhelmed by demands to preserve biodiversity or to change practices on private land. Also, provincial regulations on forest practices may prevent managers from implementing the changes desired by participants.

- Social concerns may be in opposition to scientific knowledge.

- Groups and individuals may have difficulty communicating their needs and concerns during the process. Some interests may not be represented at the discussion table, while certain groups may have a strong influence on the debate.

- Some members of the public may chose not to participate in a public involvement process although they are concerned about forest management. Many concerned people may not feel represented by groups participating in the process.

An important trend is developing in the world, that of decreasing government intervention in the economic, environmental, and even social fields. The influence of neo-liberalism pushes nations to seek new policy instruments that provide economic incentives rather than impose sanctions. In addition, budget cuts and staff reductions have affected many countries in their ability to control forestry activities. Corporations campaign for processes that could enable them to achieve sustainability and growth through voluntary action, with few regulations. Some governments appear to be seeking to adopt a neutral position, relinquishing control (Bendall and Sullivan, 1996). This situation is not unique to the forestry sector. At present globalization seems to mean a loss of power from the State to the financial markets and other interest groups in every sector. Certification of forestry practices can be viewed as a decentralization process shifting decision-making and the establishment of standards from government to interest groups and consumer markets.

Governments, however, must not abdicate their role of standardization and regulation. Democratically elected governments are the only institutions accountable to all citizens. Governments have the responsibility of protecting natural heritage for future generations and are the only institutions that have the mandate to plan for the future. Thus, government controlled regulations, incentives, and penalties are needed to correct for market failure[2] (Barbier, 1990; Barbier et al., 1992).

THE DEVELOPMENT OF CRITERIA AND INDICATORS FOR SUSTAINABLE FOREST MANAGEMENT

The efforts of the Canadian Council of Forest Ministers in the development of criteria and indicators[3] of SFM have generated much useful discussion on the means to attain sustainability (CCFM 1997). However, it has become evident that indicators of sustainability

[2] Market failure occurs when property rights are attenuated through imperfections in the market system; for example, a commodity price that does not reflect the reduction, through pollution, of the property value of a producer's neighbor (an externality).
[3] We define criteria as broadly stated imperatives to be respected by forest management; e.g., "Biodiversity must be maintained". We use indicator to mean a specific measurement (simple or synthetic) that can be made on the forest landscape which informs as to whether the criterion is being respected or not.

must be relevant to the scale at which management decisions are made (Kneeshaw et al. 2000a). Furthermore, if the importance of public participation for sustainability has been acknowledged, it follows that criteria and indicators must be developed for use within the context of public deliberation. Thus, there is a need to develop local-level indicators that can address the concerns of stakeholders.

Scientists can contribute to this process in two distinct ways. First, as members of society possessing a particular attachment to the forest, researchers in forestry must be involved in the process of deliberation and the establishment of criteria of sustainability. Otherwise, management decisions will be made without the benefit of their understanding (Franklin 1995). Second, as criteria address broad and often subjective concepts (e.g., values such as diversity and productivity), indicators that inform on the status of criteria must be based on the most relevant and up-to-date knowledge and understanding. Scientists must therefore also contribute research effort, in linking forest values to forest conditions in order to develop meaningful indicators of SFM. As stated previously, stakeholders can contribute personal and traditional knowledge of a region's forests to the development of SFM. Hence, scientists should seek to incorporate the input of stakeholders in order to develop more meaningful and locally relevant biophysical and socio-economic indicators.

As a result of collaboration among researchers from various fields, we have developed a process for the development of ecologically based criteria and indicators. The criteria relate to forest values that potential stakeholders may wish to maintain or otherwise take into consideration throughout the process of management. The indicators translate these forest values into more concrete terms, in terms of quantities that can be measured within the forest landscape. In thinking about the process of SFM, we have found it necessary to define two types of indicators: planning and monitoring indicators (Kneeshaw et al. 2000a).

Planning indicators, as the name suggests, come into play during the planning phase: they are the terms used at the time of deliberation to concretely define the vision of the future forest. They describe the state of the landscape in terms of quantifiable forest conditions, for example, the maximum distance from any microsite to the nearest seed-tree, or ratio of the area of a watershed that is harvested to the area of the receiving body of water. Indicators translate conceptual criteria of SFM into measurable forest attributes. The assumption is that if the anticipated level of the indicator is within the range considered to be acceptable, then the criteria will be respected; i.e., the forest will provide the value that is desired. When we use planning indicators we assume that we understand the process that links the condition to the value. The contribution of research scientists is crucial to ensure that the assumptions are justified. From data on the initial condition of the forest, knowledge of natural disturbance regimes, and the schedule of planned interventions, forest conditions are modelled through time and the planning indicator values can be inferred from these conditions (the modelling phase is described further in the following section). The anticipated outcome values of planning indicators (Fig. 1) provide the basis for the evaluation of the implications of a given management scenario. Because the detail of ecological knowledge is not always transferable in precise parameters and management guidelines, it may be necessary in certain cases to calibrate the links among initial conditions, disturbances, and planning indicators for the area for which the management plan is being developed. This calibration can occur before initiation of the planning phase or as part of the follow-up to intervention, described in the following section.

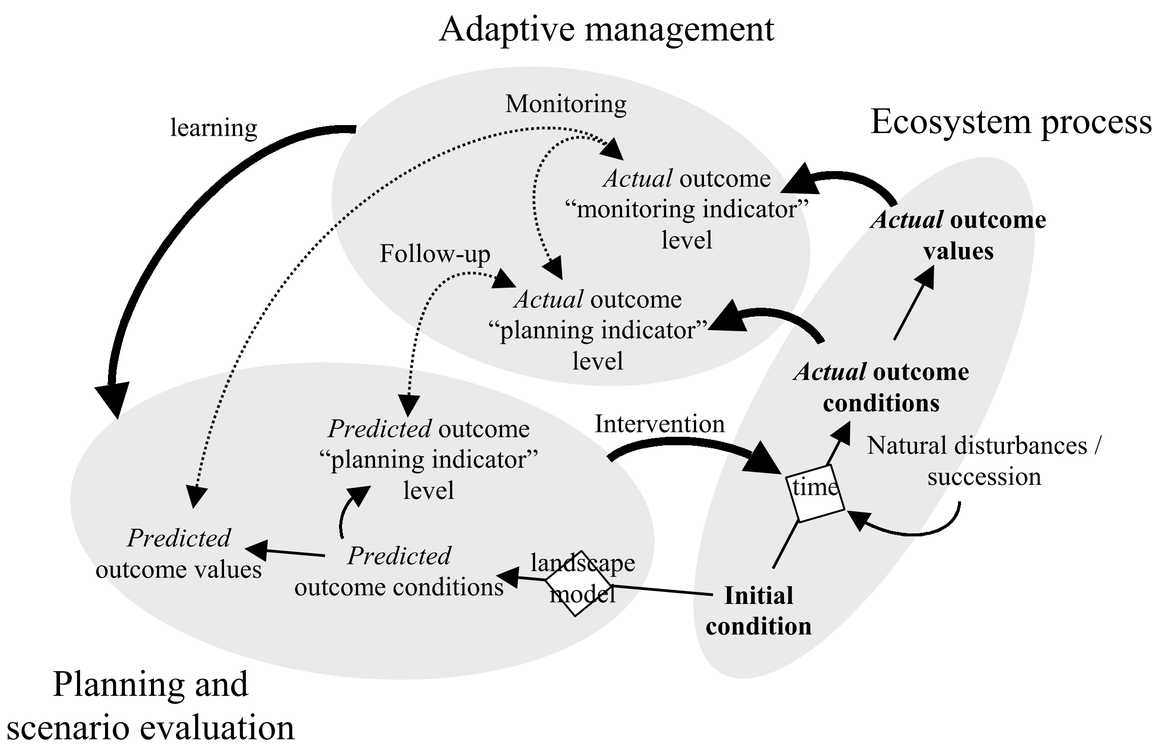

Fig. 1. Diagram illustrating the links among the components of the proposed process of sustainable forest management, including planning and scenario evaluation that results in decisions about intervention, ecosystem process driven by intervention and natural disturbance, and adaptive management where actual and predicted indicator values are compared. Adaptive management then feeds back into planning and scenario evaluation through learning and the refinement of knowledge.

Targets and tolerances for each indicator should be determined prior to the process of deliberation. Input from the scientific community will be important to determine where the thresholds are located, the points beyond which a criterion is no longer being fulfilled. It is important to avoid communicating either upper or lower thresholds as targets. It should be clear to all participants that pushing an indicator beyond a threshold means that the best available research suggests that the value will no longer be present in the forest. Stakeholders may wish to push certain indicators beyond their thresholds, but should do so fully aware that the criterion in question is no longer being respected.

In certain cases, the links between forest values and the forest conditions on which they depend are uncertain. In many fields, and in particular for the study of biodiversity, knowledge is only beginning to develop. Therefore, it is sometimes necessary to make assumptions about the links between certain forest conditions and their related forest values (when the link between predicted outcome conditions and predicted outcome values is uncertain, Fig. 1). While we need to be careful in imposing interventions when our knowledge is lacking, management plans can be adapted to maintain certain misunderstood forest values. It would be necessary, however, to verify the outcome in the field. Thus, monitoring indicators, which seek to inform on the status of forest values and determine if the established criteria are being met, come into play after management interventions have occurred. After the implementation of a management plan, monitoring indicators can be measured repeatedly throughout the managed area to test whether the assumptions used in planning were valid, and specifically, if the cultivation of a set of forest conditions yielded the expected forest values (monitoring, Fig. 1). In this way the underlying assumptions that led to the choice of planning indicators and the establishment of thresholds can be validated. Also, if little is known about the processes linking conditions to a given value, monitoring indicator data can be related to other indicator data to develop a better understanding of the processes controlling the forest value (monitoring, Fig. 1). In this way, fundamental ecological research can be inserted into the management process. This type of learning can become part of what many have called adaptive management (Walters 1986), which we discuss further in the following section.

It is crucial that monitoring indicators, as defined here, not be manipulated directly. For example, if forest fragmentation is chosen as a planning indicator of species diversity, and pine marten abundance is selected as a monitoring indicator of species diversity, then pine marten boxes (that provide shelter) should not be installed throughout the landscape[4]. The monitoring indicator data (pine marten abundance) would no longer be serving to verify the link between the forest condition (forest fragmentation) and the value of species diversity.

At the moment, we are not prepared to include socio-economic indicators into the planning process. Although the ecology of forests is closely and inseparably linked to human society, the links between socio-economic indicators and ecological indicators are of a different nature than the links among ecological indicators. Conditions measured by socio-economic indicators are, to varying degrees, controlled by factors outside the landscape under consideration, such as fluctuations of stock markets and government policy. More importantly however, there is little socio-economic research experience in the region and no research results available at this time quantitatively linking society and ecology. Therefore, we propose to begin by monitoring socio-economic indicators and, with time and as the management process evolves, to develop our understanding of the links between ecological and socio-economic indicators. Green-accounting efforts may help to bridge this gap in the future (e.g., Haener and Adamowicz 2000).

[4] This is not to say that pine marten abundance should not be promoted directly, but serves merely as an example.

For several operational (feasibility and cost) and analytical reasons, we feel it is important, at least initially, to limit the number of indicators. While the selected indicators must adequately inform on the status of the criteria, a restrained number of indicators may help to simplify the discussion surrounding the choice of a management scenario. Also, as we begin to develop the modelling tools for this work, a more solid evaluation of each scenario will result from the use of fewer but better-documented indicators. As participants and modellers gain experience with this type of exercise, the number of indicators may eventually be increased.

The data collected on indicators, if compatible from region to region, can serve to develop an understanding of forest ecosystem processes on a larger scale. Such scaling-up of information can be useful for many purposes, such as developing a greater understanding of threatened and endangered species, policy development, and climate change studies.

As society develops a greater appreciation for the detail of forest values, research needs may become apparent. This type of process may contribute to better management by identifying the gaps in our understanding of how forests provide the values we need and want. By bringing stakeholders together for the planning exercise and throughout the processes of follow-up and monitoring (described further), a need for a better understanding of the impacts of management practices and how forest values interact may become obvious.

PROPOSED CRITERIA AND INDICATORS OF SFM FOR THE MAURICIE REGION OF QUEBEC

Our group proposes indicators that correspond to five criteria. The five criteria deal with the following: 1) biodiversity, 2) aquatic environments, 3) soils, 4) forest productivity, and 5) people. The research projects that led to the development of these indicators were carried out principally in the area of the case study (the Mauricie region), though some of the research was also carried out in other boreal regions of Quebec (Canada). Indicators below followed by a (P) are planning indicators, and indicators followed by a (M) are monitoring indicators.

1. Biodiversity

Many international institutions have recognized the importance of maintaining the diversity of ecosystems, species, and genotypes, together referred to as biodiversity. Though biodiversity research is only beginning, there would appear to be some amount of consensus among scientists that the long-term viability and productivity of all ecosystems depend on biodiversity. There is, however, much less consensus regarding the means necessary to maintain biodiversity in ecosystems.

The forest characteristics required to maintain biodiversity, and in particular species and genetic diversity, are at the moment difficult to define. Maintaining habitat requirements for all species in any forest ecosystem would be essentially impossible given our limited knowledge of species and uncertainty about the habitat requirements of the many species we do know (Franklin 1993). There is a mounting quantity of literature proposing guidelines for the management of natural resources based on observations of natural disturbance regimes (e.g., Landres et al. 1999). Proponents of this approach suggest that biodiversity can be maintained through the maintenance of forest conditions within the range of natural variability. The assumption is made that, since organisms have adapted to disturbances of certain intensities, frequencies, and types, management practices that mimic the conditions encountered in a natural environment will maintain biodiversity. Though there may be much uncertainty surrounding this assumption, we adopt the approach and propose steps to verify its soundness within the process of management. We propose here two criteria for biodiversity: the first, that the diversity of ecosystems be maintained and the second, that the diversity of species be maintained. Maintaining ecosystem diversity is important in itself, but also contributes to the maintenance of the diversity of habitat types required by the communities of forest dwelling organisms. In this way, maintaining ecosystem diversity can help to maintain species diversity; this approach has been referred to as the coarse-filter approach to the maintenance of species diversity (Hunter 1990, Franklin 1993, Seymour and Hunter 1993).

Criterion 1.1 Maintenance of ecosystem diversity

Indicator 1.1.1 Age class structure of the forest (P)

Indicator 1.1.2 Species composition of the forest (P)

For any ecosystem where fire is the dominant natural disturbance, knowledge of the fire return interval allows us to define a characteristic natural age class structure for that system (Gauthier et al. 1996, Bergeron et al. 1999) (Indicator 1.1.1). In the same way, it is possible to reconstruct the tree species composition of a landscape based on an understanding of stand dynamics and successional pathways for a given area (Harvey et al., in press) (Indicator 1.1.2). Setting species composition objectives at the landscape level provides flexibility in meeting composition objectives. Instead of imposing strict composition objectives on each stand, a landscape with the desired species composition can be more efficiently obtained by applying alternative silvicultural methods based on knowledge of natural successional dynamics and their interactions with ecological characteristics (such as parent material, slope, and aspect) (Kneeshaw et al. 2000b).

Criterion 1.2 Maintenance of species diversity

Indicator 1.2.1 Road density (P)

Indicator 1.2.2 Configuration of the forest (P)

Indicator 1.2.3 Structure and abundance of the avian community (M)

Roads have been shown to have an important influence on forest dwelling organisms through their fragmentation of the landscape and by permitting access for hunting and fishing. (Brocke et al. 1990). Road density (length of road by unit area) is a forest condition influencing species diversity that can be controlled through management, making it a suitable planning indicator for biodiversity (Indicator 1.2.1). Following the natural disturbance theory, we have also chosen the configuration of the forest as an indicator of species diversity (Indicator 1.2.2). The assumption, as described above, is that maintaining the distribution of recently disturbed and mature forested sites in a spatial arrangement similar to that obtained following wildfire will help to maintain the diversity of species that live within the forest landscape (Fig. 2). In the years that follow intervention it will be crucial to verify the assumptions made under the natural disturbance theory. Hence, we propose the monitoring of avian communities as part of the monitoring process (Indicator 1.2.3). Birds represent 70% of vertebrate species in forest ecosystems and have demonstrated sensitivity to disturbance at the stand level, as well as to cumulative disturbances at the landscape level (Drapeau et al. 2000). Bird communities are relatively easy to inventory and represent the responses of many species rather than one or a few. Furthermore, since we have some understanding of the habitat requirements of many forest birds, it would be possible to interpret the indicator data, and relate forest conditions to the abundance of particular species.

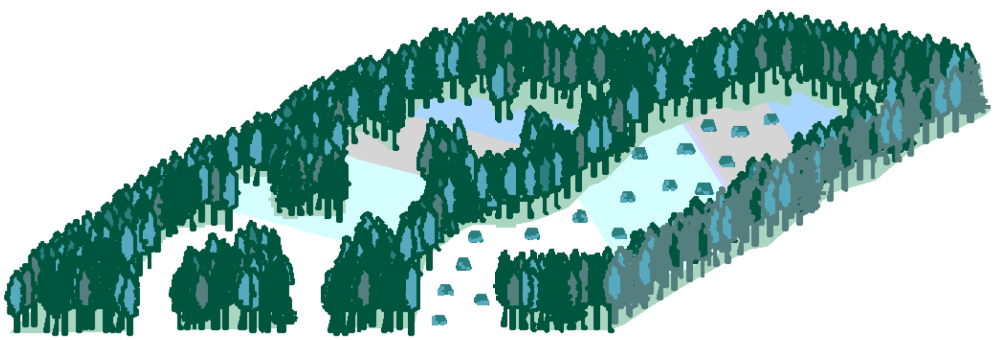

Fig. 2. Example of two recently disturbed areas. The area disturbed by fire (left) contains 11 km of inner perimeter, while the area disturbed by harvesting (right) contains only 2 km of inner perimeter. From Kneeshaw et al. (2000b).

2. Aquatic environments

Water quality is important for the health of humans and other organisms. Contaminants, such as mercury, that are leached into lakes and streams can contaminate drinking water and aquatic environments. Other characteristics of water quality such as nutrient concentrations and transparency can greatly affect the productivity and function of aquatic ecosystems.

Critrion 2.1 Maintenance of water quality

Indicator 2.1.1 Ratio of disturbed watershed area to lake volume (P)
Indicator 2.1.2 Dissolved organic carbon (DOC) concentration (M)
Indicator 2.1.3 Light attenuation (M)

The works of Carignan et al. (2000) have quantified the relationship between the area of a watershed that is disturbed and key characteristics of water quality. The water's light extinction coefficient and the concentrations of phosphorus and dissolved organic carbon (DOC), the latter a vector of mercury in aquatic systems, increased with an increasing ratio of disturbed area to lake volume (Fig. 3) (Indicator 2.1.1). Hence, it is possible to predict the values taken on by the descriptors of water quality following a given level of disturbance by harvesting. Stakeholders may then wish to maintain predicted levels within the range of natural variability.

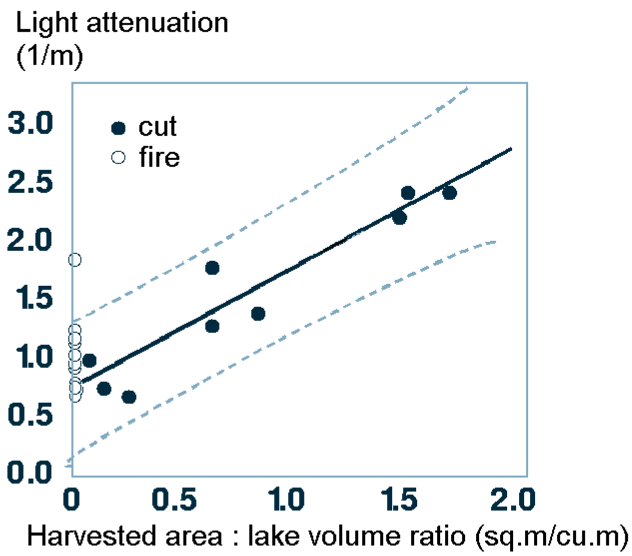

Fig. 3. Light attenuation in lake water as a function of the ratio of disturbed area to lake volume. From Carignan et al. (2000). Values of light attenuation resulting from fire (clear circles) indicate the range of natural variability.

The monitoring of water quality is important to ensure that operations yield the anticipated results. Therefore, we propose that water quality be monitored with two monitoring indicators: DOC concentration (Indicator 2.1.2) and light attenuation (Indicator 2.1.3) in lake water. The data for these indicators are relatively easy to collect and can contribute to the refinement of the modelling of aquatic environment planning indicator (Indicator 2.1.1).

3. Soils

The maintenance of soil fertility is essential for the function of forest ecosystems. When trees are harvested, important quantities of biomass and associated nutrients are exported from the site. With time, certain elements can be replaced through biotic and abiotic processes (Brady 1999). In order to maintain long-term soil fertility, it is essential that exports of nutrients in biomass and other losses not exceed the quantities of nutrients supplied to the ecosystem through the weathering of minerals and atmospheric inputs.

Criterion 3.1 Maintenance of soil nutrient budgets

Indicator 3.1.1 Rotation period, parent material, site index, stand type, and harvesting method (P)

Previous work in the boreal forest of Quebec has indicated that, particularly when using whole tree harvesting, long-term soil nutrient deficits can be incurred on certain sites if the rotation period is too short (Paré and Munson 2000) (Fig. 4). These research results can be applied to the management process in order to determine the minimum rotation period on a given site type (where type is based on site index, tree species, stem density, and surficial geology) that will not result in nutrient deficiencies, under a certain harvesting method (Indicator 3.1.1).

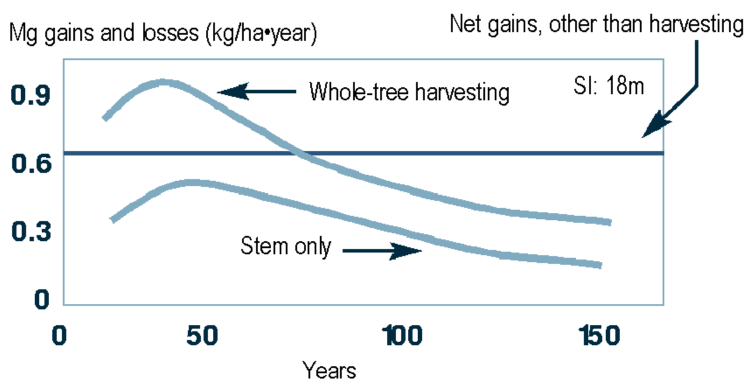

Fig. 4. Mean annual Mg net gains in soil (excluding harvesting) and net losses from harvesting for a high density spruce stand with 18m site index over a thick till. For whole-tree harvesting, if the rotation is too short (less than approximately 75m), mean annual losses are greater than net gains, resulting in a Mg deficiency. From Paré and Munson (2000).

4. Productivity of forest ecosystems

The maintenance of long-term forest productivity is one of the key elements for the sustainability of forest management. The renewal of the forest resource depends on the regeneration of stands after harvesting, either naturally or by plantation, and the growth of the appropriate mix of tree species following establishment. If species composition (Indicator 1.1.2) and age class structure (Indicator 1.1.1) at the landscape level are identified as important planning indicators of biodiversity, then stocking and species composition objectives at the stand level must be linked to these landscape level biodiversity objectives. Current regulations in Quebec dictate that harvested sites must regenerate with the same species composition as before harvesting. However, natural forests are constantly changing. For example, in many regions of boreal Quebec, aspen stands naturally develop into mixed stands, which gradually evolve into conifer stands with time (Bergeron 2000, Kneeshaw and Bergeron 1998). By formulating regeneration objectives at the landscape level rather than stand by stand, greater flexibility can be achieved in meeting those objectives.

Criterion 4.1 Appropriate stocking and composition of disturbed sites

Indicator 4.1.1 Microsite distance to seed tree (P)

Indicator 4.1.2 Age and species of seed tree (P)

Indicator 4.1.3 Proportion of exposed mineral soil (P)

Indicator 4.1.4 Stocking rates of disturbed sites (M)

By applying knowledge of the autecology of tree species it becomes possible to manipulate the regeneration of disturbed sites (Greene et al. 2000). For example, by knowing the distance from a given microsite to the nearest seed tree and the species of that seed tree, it is possible to derive the most likely future species composition of that microsite. If a given species regenerates by wind dispersed seed and the distance from the nearest seed tree and a given microsite is too great, then natural regeneration will be insufficient (Fig. 5). At the time of planning then, the distance to and species of the nearest seed tree (Indicators 4.1.1 and 4.1.2) can be used to derive the future composition of regenerating microsites[5]. Also, since the exposure of mineral soil facilitates the germination of the seeds of certain species, the proportion of exposed mineral soil (Indicator 4.1.3) is a useful planning indicator of regeneration. In order to monitor the regeneration of stands, the stocking rate of disturbed sites should be measured (Indicator 4.1.4) to ensure that regeneration is occurring as had been anticipated.

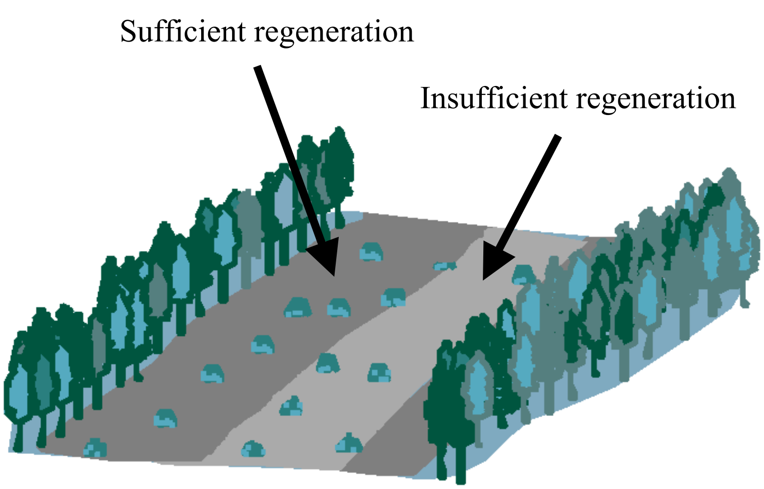

Fig. 5. Example of distance from seed trees and probabilistic seed dispersal effects on natural regeneration of a disturbed site. From Kneeshaw et al. (2000b).

[5] The size of the microsite for which regeneration may be predicted will be limited by the pixel size used during modelling. In certain cases, if the pixel size is close to the harvesting block size, average distance to seed tree should be inferred from block size.

Criterion 4.2 Maintenance of growth rates

Indicator 4.2.1 Total and incremental stem height and diameter growth of trees (M)

Once regeneration has been established, it is important to monitor the development of the stand. Stem height and diameter (Indicator 4.2.1) is easily measured in the field and, for seedlings and saplings, is strongly linked to overall vigour (Ruel et al. In press). Furthermore, since the determination of annual harvestable volume relies on estimates of current volumetric growth increment and since height and diameter growth increment of stems is strongly related to stem volume increment, this indicator may be useful to verify the appropriateness of current harvesting rates.

5. People

The sustainability of forest resources strongly influences the sustainability of forest dependant communities. Conversely, there is mounting evidence that the sustainable management of these resources depends on the sustainability of those same communities (Hoff 1998). Thus, sustainable management practices maintain the forest values on which communities depend, dependence on a resource coupled with a sense of responsibility leads to community stewardship, and stewardship of a resource leads to more sustainable management. Therefore, community sustainability must be addressed when considering the sustainability of forest management. Sustainability within communities can be promoted by the maintenance of two complementary components: long-term economic prosperity and social cohesion. Long-term prosperity can maintain the economic wealth and standard of living within communities, but alone cannot ensure the resilience of communities in the face of change brought on by the globalization of the economy and the modernization of industry and commerce. In order for communities to remain adaptable and resilient, the social fabric of communities must be maintained. Our understanding of social cohesion does not require uniformity of opinion or adherence to established cultural norms. Rather, we promote a concept of social cohesion that nurtures individuality and personal freedom, and allows for social evolution. It is our conviction that this kind of social cohesion will contribute to the development of a sense of belonging and stewardship within the community.

As mentioned previously, we are not prepared at this time to include in the modelling exercise planning indicators of socio-economic sustainability. Therefore, all our socio-economic indicators are monitoring indicators. As an understanding of the role of forest management decisions on the long-term sustainability of social and economic systems develops, it may become possible to include these elements into the modelling and scenario evaluation exercise. For economic indicators, it is important that the social context of the measurements be considered when interpreting indicator data. Though we have striven to produce meaningful economic indicators, there are many social factors that should influence the interpretation of economic indicator data. For example, though the number of jobs within a community is important, the quality of the working environment and fairness of compensation are as important in determining whether or not conditions are improving within the community. As with biophysical indicator data, if provisions are made for the scaling-up socio-economic indicator data, the development of sustainability within communities could be studied on a larger scale.

Criterion 5.1 Maintaining social cohesion

Indicator 5.1.1 Number of forest-users' groups involved in process (M)

Indicator 5.1.2 Number of training programs linking schools with local forest industry (M)

Indicator 5.1.3 Acceptability of forestry practices (M)

While participatory decision-making in forest management can generate conflict, the sustained involvement of community groups can lead to improved relations within the community (Frear 1973, Wagar and Folkman 1974, Sample 1993, Singleton 2000). We propose that monitoring the number of community groups involved in the decision-making process (Indicator 5.1.1) will inform on the potential for the resolution of conflict and social learning within the community. The development of skills for forestry related work might also contribute to improved social cohesion by developing rewarding job opportunities within the community. By developing training programs that seek to improve the employability of workers within forestry-related industries (Indicator 5.1.2), communities may improve their ability to adapt to change in the industry. Finally, we propose that monitoring the acceptability of forest practices (Indicator 5.1.3) may help to gauge the success of the public participation and adaptive management processes within the community. We propose that the information for this indicator be collected through surveys within the community at the time of the renewal of the management plan (which occurs every five years in Quebec). These surveys should seek to document the community members' perceptions of, for example, forest harvesting operations, road building, processing, and the public participation process itself.

Criterion 5.2 Maintaining long-term prosperity

Indicator 5.2.1 Number and proportion of direct jobs from the forest industry (M)

Indicator 5.2.2 Corrected mean household revenue (M)

Indicator 5.2.3 Mean coverage ratio of local forestry-related businesses (M)

As with biodiversity, more diverse economic systems possess a greater ability to adapt. Monitoring economic diversity within communities can therefore inform those interested in long-term regional planning of the evolution of the community's ability to deal with change. By monitoring both the number of direct jobs[6] from forestry and the proportion of these direct jobs

[6] Direct jobs are defined here as jobs involving work in extraction, transportation, or transformation of wood or wood fiber products.

to the total number of forest related jobs[7] (Indicator 5.2.1), the importance for and reliance of communities on the forest industry can be studied. For example, if the proportion of direct jobs decreases while numbers remain constant, then the community is moving away from its dependence on the forest industry. We would expect a more unstable economic environment if numbers of direct jobs increased while the proportion increased. In order to document the relationship between ecological and other socio-economic indicators and a more direct measurement of prosperity, we propose an indicator of mean household revenue, corrected for the regional cost of living and economic inflation (Indicator 5.2.2). While diversity in the economic base is important, the viability of the diversifying businesses can also inform on the potential for long-term prosperity. Hence, we propose to include the mean coverage ratio[8] of local forestry related businesses (Indicator 5.2.3) as an indicator of long-term prosperity.

THE MANAGEMENT TOOL AND TRACKING INDICATORS THROUGH TIME

A tool for decision-making in SFM must allow managers and stakeholders to take into account all ecosystem values judged to be of importance. In order for such a tool to be useful, it should permit a study of the implications of any given management plan in terms of these ecosystem values. It is crucial that, with the management tool, the long-term implications of a plan be interpretable by stakeholders. Since these forest values are inextricably linked to the condition of the forest (Erdle and Sullivan 1998), the tool should model the dynamics of forest conditions in order to derive the predicted state of forest values. Ecosystem structure and function result from both anthropogenic disturbances (such as forestry and recreation) and natural disturbances (including pest outbreaks, windthrow, and wildfire). Therefore, an ecosystem management tool must integrate anthropogenic and natural disturbance processes with the initial condition of the forest in order to predict potential future conditions. Furthermore, since the spatial arrangement of forest components influences the behaviour of certain ecological phenomena (such as wildfire and regeneration by seed) and is crucial for the evaluation of certain indicators (forest fragmentation, for example), the model must be spatially explicit. That is, the model must take into account the spatial arrangement of forest components and the role of proximity in ecological process. The modelling tool should provide the means to investigate and compare both the short- and long-term impacts of various harvesting scenarios at the landscape scale, given the occurrence of natural disturbance.

Such a tool requires that, prior to the planning phase, relationships among forest conditions and forest values, as well as their interactions with disturbance, be elucidated. This implies considerable research effort in order to characterize and parameterize natural disturbance regimes, identify the ecological factors that affect the forest values of interest, and determine the

[7] We include in forest related jobs, indirect jobs from forestry as well as other jobs that depend on the forest, such as jobs in eco-tourism and recreational hunting and fishing.
[8] the ratio of net profits (revenue – costs, before taxes and debt payments) to the sum of interest payments and repayment of principal.

impacts of various management practices on short- and long-term forest conditions. Also, the results from various fields of study must be pulled together into one integrated body of knowledge, and translated to the appropriate spatial (stand, landscape, watershed) and temporal (five years to one or several hundred years) scales. Research results will be applied more effectively if causality is expressed in terms of variables for which information is already available in numeric format, such as data contained in government or industry databases (e.g., topography, soil, forest cover-type). Causality will be difficult to integrate into the model if it is expressed in terms of variables that are unavailable, and difficult or prohibitively expensive to measure. Also, it must be possible to express causality in terms of maps and spatially explicit rules. Research results must also be relevant to the area for which plans are being prepared, which may require that some research be conducted in the area under consideration.

To facilitate the process of SFM while taking into account the considerations described above, we have been developing a forest disturbance model for the study area using the SELES (Spatially Explicit Landscape Event Simulator) spatio-temporal modelling tool (Fall and Fall in press). SELES is a flexible simulation language that is useful for the design of forest disturbance models that can incorporate important ecological processes and diverse harvesting strategies as well as the constraints of planning indicators. SELES offers a range of model elements and tools needed to define a landscape disturbance model. The user, by selecting the appropriate tools, can translate a conceptual model into a computer model by focussing on the main model features without having to be concerned with the detail of computer programming. Since the language of SELES is specific to landscape modelling, the assumptions made about process remain explicit and evident in the model specifications. It is thus easier to verify and gain confidence in such transparent models than so-called "black box" models (where the assumptions made about process become buried into the programming code). This is especially important for models attempting to support public participation processes for natural resource management, given the high level of uncertainty in our understanding of certain natural processes and the potentially diverse backgrounds of participants. By allowing modellers to focus on the ecological features of a model, SELES allows rapid implementation of models that are custom-designed to address the appropriate questions.

In order to adequately simulate landscape dynamics and relate these to planning indicators within SELES we require information at many spatial scales (Fig. 6) and process sub-models to integrate this multiple-scale information through time. Information contained in GIS systems can be linked to SELES in order to obtain information on static forest conditions (such as geology, drainage, topography, site index, and watershed boundaries) as well as certain dynamic forest conditions (e.g., stand age, species composition, and disturbance history). Other information on dynamic forest processes, such as characterizations of the wildfire regime and the effects of harvesting, must be obtained through research and then developed into the process sub-models. These sub-models define how the initial forest conditions change through time as a function of natural and anthropogenic disturbances, succession, and the interactions among these

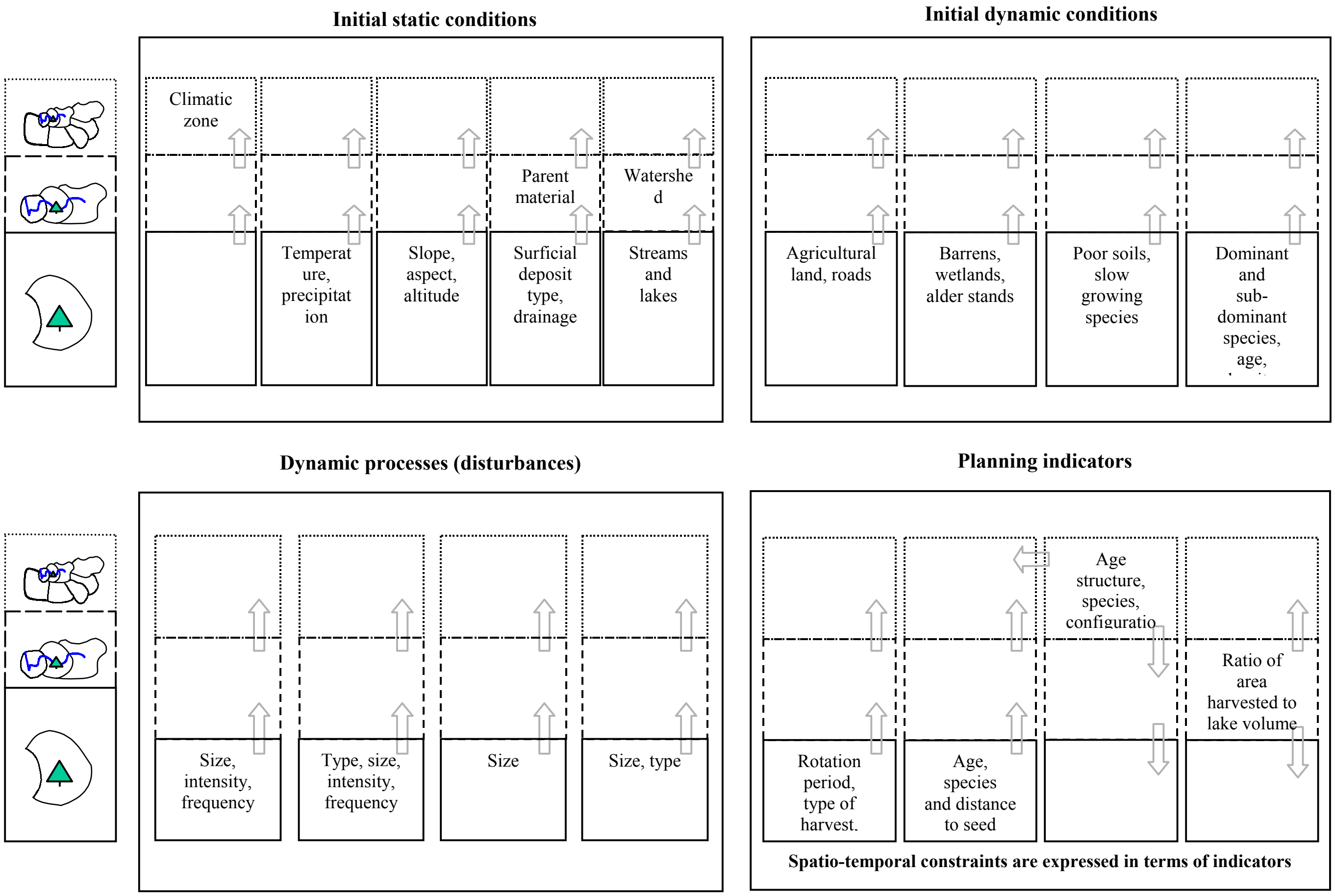

Fig. 6. Information requirements of the landscape modeling / decision-making tool for the planning phase, with the scale at which the information must be recorded (for forest conditions) or derived (for disturbances). Data is needed at different spatial scales in order to predict the impact of management practices and natural disturbance on forest conditions and corresponding planning indicators.

processes and existing landscape structures. In our landscape model, we have implemented management, wildfire, and succession processes as sub-models, which interact through their links with the dynamic forest conditions, and track the age-class structure indicator. Initial forest coverage was obtained by the SIFORT database (Pelletier et al. 1998). We present here the results of three scenarios: the Quebec status quo (clearcut harvesting of stands with a fixed rotation period of 100 years), an age-class driven harvesting scenario proposed by Burton et al. (1999), and the mosaic scenario (essentially, a two pass harvesting schedule) (Fig. 7). For all three scenarios, the annual harvesting target was set at 0.65% of the productive forest area. These examples illustrate, for example, how the mosaic scenario, which leaves behind after the first pass more mature forest than the status quo (data not shown), results in the same age class structure as the status quo after 200 years. The different strategies also lead to varying degrees of dispersal and aggregation of the different age classes. The issue of *landscape legacies* is highlighted by our preliminary findings. The cumulative impacts of past disturbance and management (logging, fire suppression, etc.) have resulted in the present age class structure. This legacy may pose challenges and/or opportunities for management objectives. Due to the inherent uncertainty in the timing or location of future fires, flexible policies must be developed to maintain sustainable forest and wildlife.

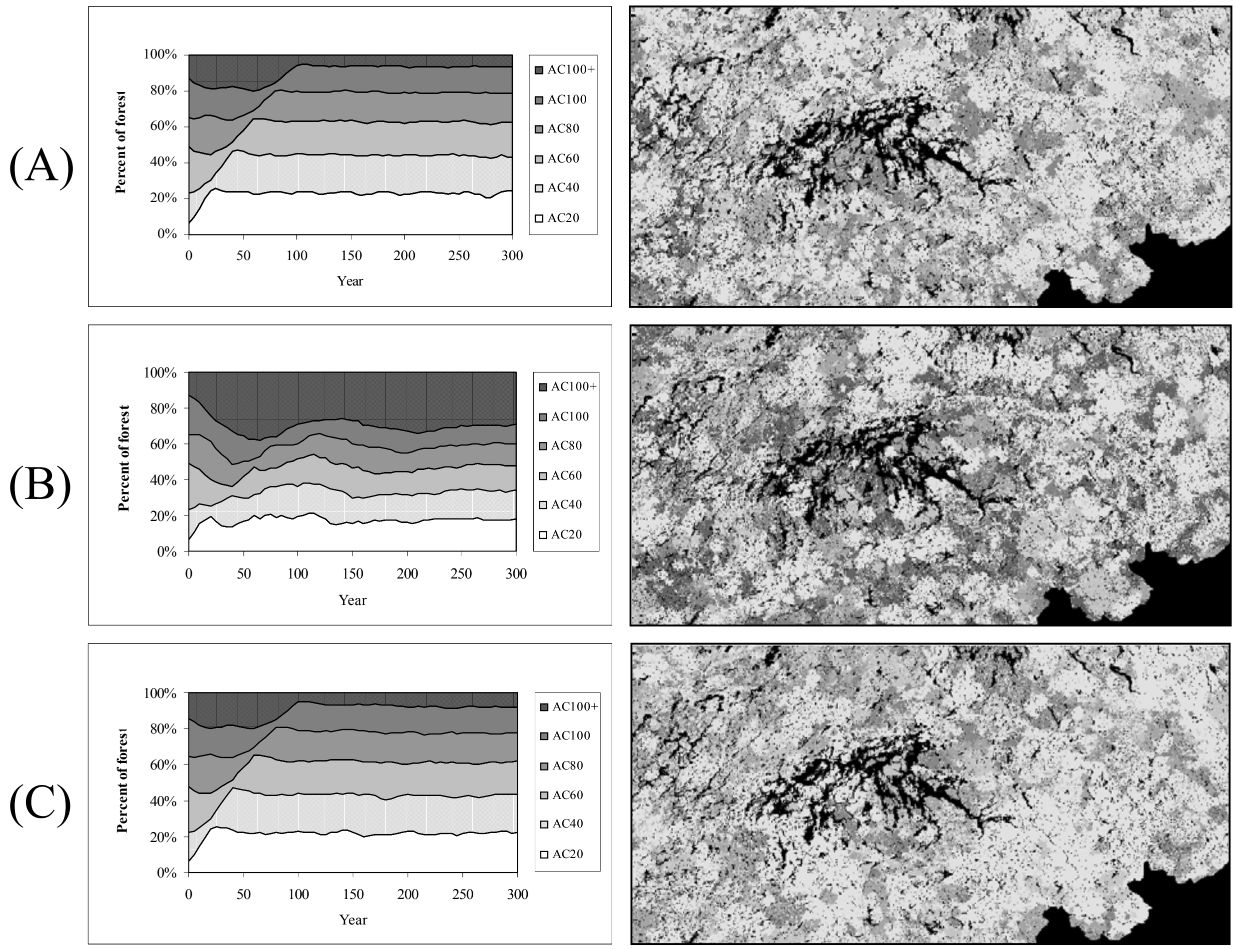

Fig. 7. Percent of forest in 20 year age-classes and corresponding age class cover maps for three management scenarios: (A) the Quebec status quo, or harvesting at fixed rotation period (B), the Burton age class scenario, and (C) the mosaic (2-pass) scenario; all scenarios were run at 0.65% of area harvested per year. Age class distributions represent mean percentages over 10 simulation runs and maps are taken from one of those runs at 200 years into the simulation. Shades of grey in map correspond to shades in age class charts and black represents water or absence of data. Scenarios were based on forest cover maps of the Quebec Ministry of Natural Resources and include the dynamics of harvesting and fire.

Thus, with the modelling tool, we can track forest conditions and their corresponding planning indicator levels over time through various management scenarios. In this way, the potential impacts of diverse harvesting scenarios can be measured in the terms defined by stakeholders at the beginning of the exercise. In presenting output from the modelling tool we can, among other things, identify areas where thresholds are expected to be crossed. For example, if a management plan calls for the harvesting of an area of a watershed that is expected to lead to unacceptable levels of dissolved organic carbon, then the area of the watershed can be flagged. In this way, managers and stakeholders can be warned that one of the indicators levels is outside the desirable range. Also, diagnostics at the landscape level can be output, such as the total area of the landscape in a certain age class, or the value of a fragmentation index for the landscape. With this type of management tool, managers and stakeholders should be able to discuss the advantages and disadvantages of various management scenarios by examining the predicted impact of each scenario on the set of chosen planning indicators.

Having deliberated and weighed the advantages and disadvantages of each proposed plan, the managers and stakeholders can attempt to arrive at an agreement on a given management plan. There are many ways in which this agreement can be reached (Sample 1993, Lawrence et al. 1997, Brosius et al. 1998, Pellow 1999). As mentioned earlier, the exact process through which the agreement will be reached will depend on the vision of democracy held by the organizing body. Suffice it to say for the moment that an agreement must be reached so that management can be carried out according to the plan agreed upon.

Two processes for adaptive management following intervention can be identified: follow-up and monitoring (Fig. 1). Follow-up involves comparing the actual outcome forest condition to the condition that was predicted by the model. Planning indicators are measured in the field and compared to the levels of the indicators forecasted for the selected management scenario. If these values do not fall within the specified tolerance, then one of two things occurred: either the operations were not carried out as had been understood during the planning phase, or the ecosystem did not respond to interventions exactly as had been anticipated. The former may signal the need to improve communication from the planning body through operations management to workers in the field. There may also be a need for supplementary training of operators or the modification of equipment. The other possibility, that the system did not respond as had been anticipated, suggests that either the structure or parameterization of the model must be refined. If there is sufficient information contained in the actual outcome planning indicator data, then the model can be recalibrated without further data collection. If data on planning indicators are routinely collected, then follow-up presents an efficient means of refining ecological knowledge and silvicultural prescriptions.

In certain instances, as described in the section on monitoring indicators, the link between forest conditions and forest values lies on theoretical rather than empirical foundations. Assumptions are made about how to maintain the forest value in question based on the hypotheses derived from a theoretical understanding of underlying processes. The maintenance of biodiversity is a case in point. We have postulated that the maintenance of forest conditions within the range of natural variability will maintain biodiversity. Monitoring indicators must therefore be measured in the field to either confirm or question the theory on which the hypotheses rest. The routine measurement of monitoring indicators can therefore contribute greatly to the development of fundamental ecological knowledge. The monitoring indicator data can be related to all other indicator data to define the links that control the forest value that had been misunderstood. If the scaling-up of indicator data was taken into consideration, then the data could be analyzed over many management units, potentially leading to more powerful statistical analysis. Adaptive management in this instance involves the development of new scientific knowledge.

THOUGHTS ON INCORPORATING SCENARIO EVALUATION IN PUBLIC PARTICIPATION

The process of management described above relies on the stakeholders' ability to define a vision for the forest in terms of the forest values that they wish to maintain or enhance. It is therefore important that, prior to beginning the phase of scenario evaluation, stakeholders discuss openly and freely the values that are important to them. Stakeholders who are inexperienced with the language and tools of forest management will require time and discussion to formulate their ideas. Social learning (or capacity building) takes place as participants develop the tools to communicate their point of view and gain knowledge about the scientific and technical aspects of forest management. Once participants have gained a fundamental understanding of all aspects of management and have identified the values that are important to them, meaningful scenario evaluation can take place.

It is crucial that the scenario outcome be interpretable by stakeholders and that criteria address their concerns. Thought must be devoted to the medium for the presentation of scenario outcomes and the nature of the information to be presented. Consideration must be given to the diversity of ways in which people understand nature and the types of information they can assimilate (Fernandez 1992). The final outcome and hence the sustainability of forestry practices depends on the stakeholders' ability to understand the long-term implications of management plans.

The process of public participation must be maintained over time. In order for the process to be rewarding for participants, decisions arrived at by the stakeholders must result in action (Frear 1973, Côté and Bouthillier 1999). Hence, there is some devolution of power inherent in what we are proposing. We are not suggesting a complete transfer power, at all levels of decision-making, from industry and government to stakeholder groups. In order to allow the current power structure to evolve into a more inclusive, adaptive, and sustainable alternative, productive dialectics must be established, in part through clearly defined rules for the imputation of responsibility among stakeholders. In the future, increasing overlap of public participation processes in communities may signal a need for permanent institutions of public participation. The will to participate must not become exhausted by the various initiatives present in a community (from the private sector, certifying agencies, and government).

INTERDISCIPLINARY AND INTERAGENCY COLLABORATION

Forest managers who wish to certify their work according to a sustainable forest management standard must address several new issues in their planning, such as the maintenance of biodiversity, the restoration of ecosystems, and public participation. Scientists from a wide variety of fields can be helpful to these managers in seeking to improve their practices. Formal contacts between managers and scientists in Quebec have already been established, but preliminary observations suggest that the relationships between these two groups need to evolve.

This research project served as a case study in inter-disciplinary and interagency collaboration. Scientists included specialists in soil science, hydrology, biodiversity, stand dynamics, tree regeneration, computer modelling, spatial statistics, as well as economics, sociology and politics. The project brought together university researchers, as well as forest managers, county officials, and workers with the federal and provincial governments. Interactions were observed and led to many conclusions about interdisciplinary and interagency collaboration. The relationship between forest managers and scientists, while generally motivated by a genuine wish to resolve issues collaboratively, was subject to certain difficulties revolving around misconceptions about the other's role (Côté et al. 2001). Forest managers tended to perceive researchers as consultants; managers expected delivery, in short periods of time, of workable tools that could function within the current framework of management and operations. Scientists meanwhile were asking fundamental questions about forestry; this questioning sometimes led to more profound changes to be recommended than had been anticipated by the managers. Also, because of the amount of uncertainty associated with the impacts of forestry practices on forest values such as biodiversity and soil fertility, scientists have been hesitant to develop clear guidelines. The scientists tended to view the managers as data providers, useful to fuel their research projects. Since these scientists were generally used to communicating with other specialists made exchanges of information difficult.

Through observation of the process, recommendations can be made to facilitate the process of inter-disciplinary and inter-agency collaboration. These are:

- researchers must dedicate the time required for inter-disciplinary collaboration
- research objectives must be very clear from the start
- researchers must be open to project initiatives originating from participants
- a global plan for integration is essential
- industrial partners must allocate time to collaboration
- researchers must take the time to understand operational constraints

- researchers must commit themselves to making recommendations despite imperfect knowledge

- managers must understand that recommendations will change with the development of new knowledge

CONCLUSION

It is becoming increasingly apparent that, in many jurisdictions, sustainability and the participation of stakeholders in decision-making will become a foundation for the process of forest management. A resource integrating and multi-disciplinary approach will be essential in order to maintain the value of forested landscapes. Whether for the purposes of certification or otherwise, we feel that the sustainability of the forest resource will benefit from the involvement of people who are committed to a stewardship of the forest based on ecological principles. Locally relevant and meaningful planning and monitoring indicators must be developed based on the best available scientific knowledge. Indicator thresholds for a given ecosystem can be developed based on the natural disturbance regime identified for that ecosystem. In the absence of more detailed knowledge, an understanding of natural conditions allows for the development of management that maintains ecosystem function within the range of past variability, that variability to which organisms and processes have adapted over time. Because our understanding is constantly developing, adaptive management must be an essential part of any process of forest management. Although sustainable forest management requires lists of criteria and indicators, such lists are not sufficient to ensure the continued evolution of management practices towards sustainability. The process of management must take into account the social and economic, as well as the ecological context of forestry in order to develop practices that will ensure viable forests for future generations. We have outlined such a process, including a modelling tool that allows management scenario testing and evaluation and the refinement of modelling through monitoring indicator data.

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