WORKING PAPER 1999-21

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Development of integrated ecological standards of sustainable forest management at an operational scale

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Abstract

Within Canada and internationally an increasing demand that forests be managed to maintain all resources has led to the development of criteria and indicators of sustainable forest management. There is, however, a lack of know how at an operational scale, to evaluate and compare forest management activities to ensure the sustainability of all resources. For example, nationally, many of the existing indicators are too broad to be used directly at a local scale of forest management; provincially, regulations are often too prescriptive and rigid to allow for adaptive management; and forest certification programs, often based largely on public or stakeholder opinion instead of scientific know how, may be too home made in nature to permit a comparison of operations across a biome. At an operational scale indicators must be relevant to forest activities and ecologically integrated. In order to aid decision-makers in the adaptive management necessary for sustainable forest management, two groups of indicators are identified: those that are prescriptive to aid in planning and those that are evaluative to be used in monitoring and suggesting improvements.

An integrated approach to developing standards based on an ecosystem management paradigm is outlined where the variability inherent in natural systems is used to define the limits within which forest management is ecologically sustainable. For this exercise, standards are proposed for biodiversity, forest productivity via regeneration, soil conservation and aquatic resources. For each of these standards, planning indicators are developed for managing forest conditions while forest values are evaluated by monitoring indicators, thus leading to a continuous cycle of improvement. Approaches to developing critical thresholds and corresponding prescriptions are also outlined. In all cases, the scale of evaluation is clearly related to the landscape (or FMU) level while the stand level is used for measurement purposes. In this view the forest should be managed as a whole even though forest interventions are usually undertaken at the stand level.

Keywords: Sustainable forest management, criteria and indicators, biodiversity, regeneration, soil conservation, aquatic resources, landscape level evaluation, planning and monitoring

Résumé

Au Canada et internationallement, des critères et indicateurs de gestion durable des forêts ont été proposés afin de garantir la pérénité de l'ensemble des ressources provenant de la forêt. Bien que nationalement valables, ces indicateurs sont trop souvent inaptes pour permettre une juste évaluation et comparaison de l'état de la forêt prévalant dans une unité territoriale opérationnelle. Entre autre, plusieurs des indicateurs proposés apparaissent davantage adaptés pour décrire la situation nationale plutôt que celle caractérisant une unité particulière d'aménagement forestier. À l'intérieur des provinces, les législations existantes sont souvent trop rigides pour se prêter à une gestion adaptative. Les programmes de certification quant à eux semblent avant tout s'appuyer sur les opinions des intervenants locaux et risquent de ne générer que peu de standards permettant la comparaison des opérations forestière ayant cours dans un même biôme. Pour être mieux adaptés à une échelle opérationnelle, les indicateurs devraient davantage être rattachés aux opérations forestières, scientifiquement valables et intégrées écologiquement. Afin de faciliter la prise de décisions, les indicateurs de gestion durable ont été regroupés en deux catégories soit: les indicateurs prescriptifs qui adressent les problèmes de planification et les indicateurs évaluatifs dont la principale fonction est de permettre le suivi environnemental et son bilan. Le concept de gestion écosystémique au sein duquel la variabilité naturelle des écosystèmes détermine les seuils critiques à l'intérieur desquels les conditions forestières doivent être maintenues, a été retenu afin de d'établir les bases d'une approche intégrée au développement de standards en matière de gestion durable. Pour ce faire, des standards de biodiversité, de productivité forestière (par l'intermédiaire de la régénération), de conservation des sols, et pour les ressources aquatiques sont proposés. Pour chaque standard, des indicateurs de planification sont développés afin de faciliter le suivi des conditions forestières tandis que les valeurs forestières sont évalués à l'aide d'indicateurs environnementaux. Mis en interaction, ces indicateurs pourraient assurés une amélioration continue des opérations forestières visant une gestion durable de l'ensemble des ressources de la forêt. Lorsque nos connaissances actuelles le permettent, les seuils critiques et les prescriptions associées à ces indicateurs sont également abordés. Pour l'ensemble des indicateurs proposés, l'évaluation devrait toujours être établie à l'échelle du paysage (ou de l'unité forestière aménagée) alors que l'échelle du peuplement serait utile davantage au niveau de la prise de mesures. Dans cet optique, les décisions concernant le devenir de la forêt devraient toujours s'appuyer sur une connaissance de l'ensemble de sa condition et cela même si l'échelle à laquelle on intervient en forêt est davantage celle des peuplements.

Mots clés : Gestion durable des forêts, critères et indicateurs, biodiversité, régénération, conservation des sols, ressources aquatiques, plannification et suivi.

Introduction

Sustainable forest management (SFM) is replacing sustained yield forestry as the goal of many forest managers. This change was precipitated by increasing concerns from ENGO's and the public about the impact of traditional timber management techniques on biodiversity, long-term productivity, indigenous peoples rights, the continued survival and prosperity of forest dependant communities, and other non-timber forest values. These concerns about forest management have led to numerous initiatives to better define and then insure the sustainability of all forest resources.

At the international level, political commitments were made to conserve biodiversity in the UNCED 1992 Convention of Biological Diversity. The following year, temperate and boreal region countries developed national level criteria and indicators of sustainable forest management in the Helsinki Process (for European nations) and the Montreal Process (for non-European nations) (Evans 1996). The criteria and indicators developed at the Montreal Process were an offshoot of work begun earlier by the Canadian Council of Forest Ministers (CCFM) (Woodley et al 1998) that has recently culminated in 6 criteria and 84 indicators of sustainable forest management. These criteria include the 1) conservation of biological diversity, 2) ecosystem condition and productivity, 3) conservation of soil and water resources, 4) global ecological cycles, 5) multiple benefits of forests to society and 6) accepting society's responsibility (CCFM 1997).

Inspection of the CCFM criteria suggests that they can be divided into either biophysical or socio-economic issues. Discussions on the development of social indicators and public involvement in forest management decision-making have been undertaken elsewhere (Perez 1996, Crossley 1996, Bouthillier et al 1999, Schindler 1998, OMNR 1997). In this paper we focus on identifying and defining indicators of biophysical (or ecological) criteria. In our view, an understanding of biophysical issues is a crucial and underlying precept of SFM. The developed biophysical indicators can then be used as a base for discussions of their relative weights and importance in social systems (Hauffler et al. 1996).

Traditionally Ministries of Natural Resources or Ministries of Forests were responsible for the management of forest lands in Canada. However, in the 1980's forest management was turned over to forest companies and the provincial ministries responsible for the forests became essentially regulatory and monitoring bodies (Kimmins 1990). Despite large changes that have occurred in our perceptions of forest management and the way that it is conducted (Erdle 1998), provincial ministries still generally use a legislative point-by-point method to solve forest management problems. In this approach, explicit, detailed, prescriptive regulations are developed to cover all facets of forestry operations from culvert placements, to the size of riparian zones, to visual quality objectives. Although these regulations are a testimony of the effort being made to increase environmental considerations in forest management, they are too inflexible to promote a proactive and adaptive management approach to deal with the environmental problems faced by forest managers (Charland 1996).

Recently, a number of independent voluntary certification programs (FSC, CSA, ISO, etc) have been developing to ensure that forest management does more than simply meet the minimum conditions set forward in government guidelines (Lyke 1996, Elliot 1996). These programs, instead require forest companies to commit towards continual improvement and, in this respect, may be more effective than the slow process of changing regulations in leading to sustainable forest management. Furthermore, these certification programs operate at a local level, in contrast to the national level CCFM approach (see discussion below), and hence can serve in the evaluation of the sustainability of forest management in a given forest management unit (FMU).

Essentially, there are two certification movements (see Evans 1996, Crosley 1996 for reviews): one developed by the Forest Stewardship Council (FSC) based on fixed environmental standards (Elliot and Hackman 1996) and another, in which we include ISO and the CSA, being developed along environmental management guidelines (Lyke 1996, Elliot 1996, Rotherham 1996). In general, all of these initiatives have well defined guiding principles. The translation, however, of these guiding principles into scientifically sound ecological standards that are both applicable at an operational scale and standardised so as to permit comparison from one region to another is problematic (Rawlinson 1996). Certification is thus, at present, at best an *ad hoc* approach to determining forest sustainability. Although conceptually interesting, the certification process suffers from a lack of scientific evaluation both at the level of the process itself as well as its implementation (Hughes 1996, Rawlinson 1996).

Furthermore both government and certification approaches to forest management are piece-meal approaches in which a long-series of often unconnected indicators are used. It is our hope that the development of a scientific base to indicators can be used to improve current certification programs at least with respect to the development of ecological indicators.

Whether in the goal of certification or simply to improve forest management, forest managers need standardised, accepted indicators of sustainable forest management which are designed for use at the operational scale of a FMU. These indicators should be integrated so that they truly represent real ecological links found in forest ecosystems. Stakeholder groups, local steering committees, and forest management decision-makers may then decide whether these factors should be objectives or constraints, and how different factors should be weighed in a socially accepted way. For local conditions, some standards may be added, specified or, in some cases, revised, however, a set of transferable minimum standards based on the best scientific knowledge is required for large forest zones (e.g. biomes) to ensure that statements regarding sustainability or the improved management of various resources are both comparable between FMU's and based on ecological principles.

In this regards, knowledge on natural disturbance regimes must therefore be used as a benchmark to determine thresholds and target levels of indicators. The rational behind this is that species are probably best adapted to disturbance characteristics that are close to those that would be generated by natural disturbance regimes for which they have evolved (Franklin 1993, McKenney et al. 1994, Gauthier et al. 1996). Current knowledge on natural disturbance regimes can be seen as a serious limit to the application of such an approach. However, a purist viewpoint, which states that scientific knowledge is too incomplete on varying and complex systems to provide useful guidelines for SFM, is not helpful. Scientists must participate in the development of ecological standards of SFM, otherwise ecological standards will be defined by others less qualified (Franklin 1995).

In this paper, our objectives are therefore to 1) define the essential attributes of integrated indicators of SFM and 2) show how scientific knowledge can and should be incorporated into their development. This paper is directed to both forest practitioners who will implement SFM and to researchers, especially but not uniquely to those working in the Canadian boreal forest, who want to contribute to the development of ecological standards of SFM. For this process to be truly effective a greater contribution from researchers into the development of scientifically credible operational indicators is essential. Finally, we hope that this paper will not only assist but will also incite forest industries and local stakeholders to use ecological standards in their evaluation of forest management undertaken in a FMU.

Background definitions and concepts

In the literature on *sustainable forest management*, different terms have been used to express a variety of similar concepts and ideas. The danger in such cases is that the debate becomes one over tautology and the underlying issues are ignored. The term *sustainability* is a particularly loaded term whose meaning has, on a number of occasions, been questioned (Grumbine 1994, Gilmore 1997, More 1996). In fact, the FSC has removed the use of this term altogether from the discourse regarding its certification process, which are now called certification standards for best forestry practices (FSC 1996). Despite, the potential ambiguity associated with '*sustainable forest management'* most of the international initiatives, as well as the CCFM, have, however, retained the term and define it as being the maintenance of a series of criteria and indicators. These criteria (guiding principles in FSC jargon) determine the large-scale objectives or values that must be maintained. For the purposes of this paper, these criteria define sustainable management.

In broader terms, the concept of sustainability systematically involves both the moral responsibility of the current generation toward its descendants and concerns about the preservation of all services and goods that can be provided by the forest, currently and in the future (Toman & Ashton 1996, Knight, 1996, Thomas and Huke 1996). Even when concentrating solely on ecological elements, as is our goal, our ability to identify the full range of future multiple-use values (see examples in Burton et al 1992) and to evaluate the long-term impact of current forest practices are obviously limited. Such uncertainty obviously increases the difficulty in making responsible decisions regarding forest resources. We must therefore develop cautious management practices which maintain key features and processes of forest ecosystems.

An *ecosystem management* approach appears to provide a workable framework (although see Stanley 1995). One of the baseline ideas of ecosystem management is that by maintaining *forest conditions* within their natural range of variation there is a greater chance to preserve all *forest values* which are historically present in a natural forest (Hauffler et al 1996, Thomas and Huke 1996). Knowledge of the historical range of variations of forest conditions is critical in defining management objectives and related threshold levels (Wallin et al 1996). This also implies that management objectives should be formulated in terms of a range of conditions to be respected instead of being viewed as a single, static target (Bunnell 1997). For sustainable management to be functional it must be viewed as a continuous and ongoing process rather than as an end in itself (Welsh and Vernier 1996).

Conflicts between scales of assessment

One of the potential problems regarding the currently proposed certification schemes, is that many of the decisions concerning the development of indicators are local in scope. This makes comparisons between several different forest management areas difficult to impossible. In contrast, the CCFM (1997) has developed criteria and indicators attesting to the state of Canadian forests at a national level where many indicators are not specific to forest management activities. For example, counts of the number of forest-dependant species that are classified as rare, endangered or threatened may be useful at a national level in reflecting the overall effects of country-wide forest policy but they are inappropriate at a management unit level. Although such species must be considered and protected within management areas, it is improbable that lists of their presence will reflect the sustainability of local practices

From a forest managers perspective, an approach towards SFM should not add extra-management activities to the agenda in order to contribute to national goals but rather should help in identifying both 1) management practices that are detrimental to ecosystem processes or species and 2) ways of modifying these practices to mitigate their impacts on the environment. Contrary to the national level where the approach used to define C&I is centred on forest values, an evaluation of SFM at a local level should focus on forest conditions over which foresters exercise some control.

Forestry operations, however affect forest conditions at both stand and landscape scales. Stand level indicators are thus required to monitor stand attributes that concern forest conditions (e.g. size of cutting area, residual stocking) or forest values (e.g biodiversity, aesthetics, eco-spirituality) for which patterns of variability and scales of measurement are more relevant at the stand level. In the same way, at the landscape level, indicators must again include considerations regarding forest conditions and forest values. These scales are obviously dependent, as management choices retained at the stand level have cumulative effects on forest conditions at the landscape level.

Forest Management Activities

If certification is to act as a real instigating mechanism in improving management strategies and practices, it is imperative that indicators be firmly rooted in local forest management activities (Rotherham 1996). This section describes forest management activities at an operational scale and identifies those which may need ecological indicators of sustainability.

The first step in forest management activities consists of a planning exercise (Fig 1) in which the location of forest roads and related infrastructure as well as cutting areas and associated harvesting modes are determined. Further planning and mapping will address areas with post-treatment activities (pre-commercial thinning, plantation zones, etc). These maps and plans will also indicate the year and season of activities. A management strategy, regarding the location and the rate at which to make interventions in a forest, needs to be designed to ensure sustainable yield. It may also include considerations about landscape configuration (by choosing adequate size and spacing between cutover areas), prevention of natural yield loss by giving priority to harvesting of stands that are most susceptible to insect defoliation or to disease or to multiple-uses occurring in an FMU. Management strategies may also have a lasting impact on the age structure and composition of the natural forest mosaic.

Another part of the planning exercise consists in making choices about the most appropriate silvicultural practices or prescriptions to achieve some predetermined objectives in a constrained environment context. Silvicultural practices guidelines may be defined to mitigate the impact of forest operations on soils (by using winter harvesting on fragile soil), to facilitate regeneration (by winter harvesting and/or limiting the movement of heavy machines), to increase stand productivity (by thinning young post-logged stands), etc. Whereas impacts of management strategies are usually observed at the landscape level, those of silvicultural practices are more generally detected at the stand level. As stated earlier, a large part of the evaluation of SFM must be undertaken on characteristics of management strategies and silvicultural practices. Performance indicators of SFM and associated thresholds must therefore be directly related to these characteristics.

At various steps during the planning process the forest company goes into a public consultation process to inform the public and to gather comments and suggestions regarding the proposed plans (OMNR 1997, MNRQ 198). It is during the period of public consultation that stakeholder groups and First Nations peoples are invited to present their pre-occupations and their expectations with respect to the forest resource. Amongst the forest certification programs, the CSA requires agreement to be reached on the definitions of local indicators of SFM through an arduous series of public consultations during the planning process (CSA 1996).

Once a management plan is in place, the application phase is started. Applying the forest management plan necessitates the contribution of many contractors and operators who do not necessarily share the same perception of their mandate. Quality control procedures must be undertaken to insure that formulated management prescriptions, as well as provincial forest regulations are respected during forest operations.

The monitoring phase is continuous and should provide feedbacks to the planning and consultation phases so that forest activities will constantly be improved. Traditionally this activity consisted of an environmental monitoring of post-logged sites to ensure sufficient stocking. However, monitoring is also required to insure the achievement of all of the goals of sustainable forest management.

Management and monitoring indicators

An evaluation of forest management activities shows that there are two distinct stages at which ecological indicators of SFM are needed: the management or planning stage and the environmental monitoring stage. Management indicators can be defined as indicators which are used to set targets to achieve specified SFM objectives. Management indicators are thus applicable in defining the overall forest management plan at the landscape level and also in planning silvicultural prescriptions at the stand level. As a follow-up, monitoring indicators are required to verify whether the indicators used in the planning stage have been successful in achieving their goals once applied in the field. Monitoring indicators should be applied in both the short-term (soon after interventions) and in the long-term (after many decades or at the rotation age). Whereas monitoring indicators evaluate the goodness of fit between the results of the operations and the management objectives the management indicators allow us to plan for and measure the field performance of forest operations in accomplishing management prescriptions. A monitoring indicator is thus more than simply a one-time assessment of forest resources after harvesting. As an example, if the goal is to reduce the time to commercial yield of a dense naturally established stand in a post-logged area, the management indicator may be a limitation on the density of saplings, which can be achieved using precommercial thinning to a predetermined threshold. It may also include the selection of saplings to preserve. A management indicator represents an objective and may not, in itself, permit an assessment of whether the goal has been achieved. An environmental or monitoring indicator, permitting the evaluation of the desired state is thus also required. In this example, a growth response will indicate only in the short-term that the operation has had a positive impact whereas in the long-term the number of years by which the rotation is shortened may be used as a measure of achievement. The development of both planning and monitoring indicators are thus required to ensure that forest management is continuously improving and moving towards sustainability. This distinction discriminates between our approach and those taken by the various certification programs or by provincial ministries.

Erdle & Sullivan (1998) also recognise this difference when they make a distinction between *forest conditions*, that designate the results of forest management and *forest values*, that reflect expectations about what should be provided by the forest. Management and monitoring indicators are thus related in an improvement loop in which management practices are continually improved through the achievement of environmental goals. Such an adaptive approach is also crucial to the development of SFM practices. It recognises that although both current technology and current knowledge of ecosystem processes and species requirements are not well enough developed to provide accurate environmental forecasting, they can be used to develop SFM practices through a continuous cycle of re-definition based on new knowledge and/or on the development of new technologies.

What are the attributes of good ecological standards of SFM?

The first step in the process of defining indicators is to determine what qualities or characteristics are necessary to insure that the proposed indicators will actually do the job and indicate whether forest management techniques are moving away from or towards sustainability (Table 1).

Although many of these points have been treated elsewhere (Bunnell 1997) they are still too often ignored in practice. Most certification processes, for example, ignore (at least partially) the need for scientifically developed indicators, relying on stakeholders opinions to define good indicators. The involved personnel may include some individuals with scientific backgrounds, however, it is unusual that specialists from all the different SFM criteria would be involved. As for operational feasibility, to date only the Centre for International Forestry Research (CIFOR) has been testing the operational feasibility of many proposed indicators. Of over 200 ecological indicators tested in North America more than 65 were found to be either impractical or unfeasible at an operational level and only 71 were eventually accepted (Woodley et al. 1998).

There is also a clear need to limit the number of indicators to a key group that respond to management activities although this list can be increased as sampling techniques and infrastructure increase or as new knowledge becomes available. In Ontario, a list of indicator species to be used in the evaluation of forest operations has been developed (MacLaren et al 1998). Although their formulation of criteria for selecting species is clear, rigorous and leads to an exhaustive list of indicators for Ontario's forests ecosystems, the operational feasibility of setting monitoring programs for each indicator at the scale of an FMU can be questioned.

Regional differences and variations in variables exist and must also be considered when evaluating SFM. However, a lack of standardisation will lead to either 1) a multiplicity of indicators developed to respond to local conditions but which result in an inconsistent evaluation of SFM in different FMU's (Evans 1996) or 2) to highly prescriptive, local indicators that fail to encompass the variability inherent in natural systems (Rotherham 1996). Achieving standardisation will require the use of standard methods of measurement and interpretation and not the use of national or provincial target levels nor the use of a particular species indicator. Standardised indicators may be adapted to local conditions using threshold and target levels specific to each FMU as well as by using equivalent species or guilds of species that are appropriate for each specific region. Target levels of indicators should be defined by a desirable range of variation that ensures the maintenance of natural processes.

The development of a clear process to define the variables to be measured is thus required if they are to be internationally credible. National organisations working on a variety of different themes, such as the Sustainable Forest Management Network of Centres of Excellence (SFMN), may provide the needed research and resources to respond to this mandate (http://www.biology.ualberta.ca/sfm).

To constitute a tool for improving management practices, an indicator must be coupled with silvicultural prescriptions and/or management guidelines. In a case where a threshold level is not obtained for some environmental indicator, management guidelines must be re-formulated to obtain forest conditions that equal or surpass target levels. There is obviously a gap between forests conditions, induced by management activities, and forest values, that people would like to achieve, that is dynamic through time. Forest values will change constantly as ecological knowledge increases and as public perceptions evolve. Similarly, forest conditions change with advances in technology and due to modifications in regulations governing the use of forest resources (Erdle 1998). The dynamic nature of the relationship between forest conditions and forest values means that the pursuit of SFM should be viewed as a continual process of improvement in management practices.

Examples of Ecological Standards for Forest Management:

The preceding sections have presented a critique of SFM criteria and indicators and our view-point on the required types of indicators as well as the qualities of good indicators. In this section, we present an approach for developing a series of indicators that are functional at an operational level and which will be useful in evaluating generally recognised sustainability criteria. The goal is not to create an exhaustive set of indicators that will unequivocally define sustainability but rather to create a process for the development of meaningful indicators through our examples. These indicators should also be readily applicable and should serve as an ecological base for discussions on SFM. We have thus chosen to limit ourselves to habitat and wildlife biodiversity, regeneration, soil productivity, and aquatic resources.

The proposed indicators are based on current scientific research developed to increase our understanding of forest ecosystems and which can thus be applied for use in manipulations of this resource. A more detailed discussion on the development and the application of each individual indicator will be found in follow-up papers.

A. Biodiversity indicators (terrestrial)

- *Age structure and stand composition*

Age structure and stand composition of forest mosaics are clearly identified as indicators of SFM in the CCMF documents. Maintaining forest mosaic diversity (age-class distribution and habitat types) in managed systems similar to those observed in natural landscape is often proposed as a coarse filter strategy to minimise the risk of losing important components of biodiversity (Hunter 1990, 1993). The current stand composition of a natural forested landscape reflects the response of forest cover to interactions between physical determinism (climate, topography, surficial geology, etc) and the disturbance regime associated with each region. Although topography and surface deposits have been relatively stable since the end of the last glaciation, climate and disturbance regimes have experienced temporal variability during this same period (Bergeron et al 1998, Johnson

1999). Therefore, the development of a coarse-filter approach in a managed landscape requires a knowledge of the historical range of variation of disturbance regimes and its relationship to forest composition features.

In order to determine thresholds and target levels of these indicators, we propose a two step approach. In the first step, the natural variability in age-class distribution both in time and space needs to be analysed at spatial scales relevant to the operational scale of a FMU. In the second step, the defined age-class distribution must be translated into an expected distribution of stand composition.

Up to now, scientists have worked within the framework provided by exponential and related models to predict the average age-class distribution of stands from knowledge of the region's fire cycle. Using this framework, Bergeron et al. (1999) have suggested target levels for the maintenance of broad age-classes in FMA's in relation to the fire cycle of different regions. However, the recent results of Boychuk *et al.* (1997) indicate that although these exponential models can give insights into the average age-class structure of a relatively large forest mosaic over time, they provide few details on the variance associated with this average age structure. This variance depends on the extent of the managed area on which the diagnosis is being made and on several parameters of the fire regime other than the length of the fire cycle (such as fire occurrence and fire size distribution). To define the historical range (or variance) of age-class distributions at the FMU level both empirical data and spatial modelling should be used.

Once the expected age-class distribution and its variability are defined, the next step is to relate it to stand composition or habitat types. This will be achieved using models of natural forest succession performance on different site types. Modelling exercises similar to those of Dansereau and Bergeron (1993), Gauthier et al. (1996) or Bergeron and Leduc (1998) can be used.

The end product of this modelling effort will be a method that determines historical threshold levels for the age structure and stand types in a particular FMU. In some cases, the current age structure and composition of an FMU may exceed the range of historical variation, which is the threshold (a situation that may be observed more often in the eastern Canadian boreal forest due to its longer management history). In such cases, concerns about the effects of these *habitat changes* on biodiversity (the coarse-filter) should be addressed through more precise field evaluations of the state of biodiversity (an approach to evaluating biodiversity in the field is suggested in the next example) and through the development and use of alternative silvicultural practices to rectify the situation (see the regeneration example and concluding remarks).

Biological diversity at the landscape level

An important assumption underlying the management of forest landscapes with an appropriate age-class distribution and stand types is that this maintenance of the forest mosaic will provide adequate conditions for all species. By providing conditions that maintain ecosystems diversity, species diversity will be sustained as a result. This assumption must, however, be verified. Monitoring indicators of species diversity are required to verify whether management indicators used in the planning stage have been successful in achieving their goals once applied in the field.

Even though species diversity implies all living organisms in a given ecosystem, the state of biological diversity cannot be assessed with a species-by-species approach for all organisms living in a forest ecosystem (Franklin 1991). For practical reasons, we must focus on components of species diversity (1) that are likely to respond strongly and quickly to changes in forest landscapes both at the stand and landscape levels, (2) that simultaneously occur in large number of species, (3) that are relatively easy to survey if we want to monitor forest ecosystem health with regard to biological diversity, (4) that can be surveyed at low cost, and (5) for which we have knowledge of their ecology. Songbirds represent such a key component, event though most species are migratory (Niemi et al. 1999) and populations trends may be influenced by factors other than those occurring in the breeding grounds. A considerable body of literature exists to show that songbirds respond to habitat changes in their breeding grounds (Robbins et al. 1989, Askins et al. 1990, Andren 1994, Robinson et al. 1995, McGarigal and Mc Comb 1995). They are also strongly influenced by changes in the structure and composition of the forest cover that occur at different spatial scales (Helle and Järvinen 1986, Anglestam 1990, Edenius and Elmberg 1996, Robinson et al. 1995, McGarigal and Mc Comb 1995, Drapeau et al. in press). Drapeau et al. (in press) found that variations in bird community composition determined by the landscape context (forest mosaic) were as important as local habitat conditions (stand level). Songbirds are thus indicators of both the impacts of silvicultural practices at the stand level and the cumulative effects of management practices at the landscape level. Furthermore, songbirds can be monitored with techniques that are easy to use and that allow us to simultaneously census many species at a low cost. Although birds are not the most diverse taxonomic group in forest ecosystems (insects or mosses are much more diverse), it is a group for which we have a good knowledge of species' ecological requirements and hence, for which we can recognise (unlike with insects or mosses) species that are sensitive to forest management practices with a degree of confidence. Finally, being mostly insectivorous, they are an important component of the food web in forest ecosystems (Holmes 1990). Several studies have shown that birds reduce insect densities (Holmes et al. 1979, Altegrim 1989, Crawford and Jennings 1989) and that bird predation of phytophagous insects can even have positive economic benefits on forest productivity (Takekawa and Garton 1984).

A preliminary step in the assessment of the state of species diversity in managed forest landscapes is to define the response of the monitoring indicator (songbirds) to desired thresholds and target levels of the management indicators (natural variability in stand types and age-class distributions) at spatial scales relevant to the operational scale of a FMU. This will be achieved by linking models of songbird response to landscape-scale changes in forest cover to the range of historical variation in forest conditions defined in the preceding age structure and stand composition example**.** This coupling of modeling efforts will provide a reference point for further comparisons of the state of biodiversity in FMU's. The second step will be to compare the predicted patterns of target conditions with the observed patterns in managed forests. This should be done both with empirical data from precise field investigations of the state of the avifauna at the scale of FMU's and modelling efforts where projections about landscape scale changes of forest cover and its effects on songbirds will be examined under different scenarios of timber harvesting.

This approach is somewhat different than what is usually proposed with lists of indicator species (MacLaren et al 1998). Here the emphasis is shifted from species to an ecosystems approach. Hence, the primary role of species diversity and its indicator (songbirds) is to assess whether or not the forest in a FMU is within or approaching the desired target conditions. In that sense we view the composition of songbird assemblages as a coarse-filter monitoring indicator of a coarse-filter management strategy. Note that although the overall avifauna is used as the monitoring indicator, this approach is concerned with species since it is based on single species models of songbird response to landscape and stand level changes in forest cover. Finally, this approach does not preclude the use of complementary fine-filter approaches to species that require additional management considerations (Block et al. 1995).

B. Forest regeneration and stand dynamics indicators

The notion that productivity must be maintained for a site to be sustainable is also the biological criteria that may most concern forest managers, at least with respect to the continued needs for wood products. Our choice of an indicator is based on the assumption that to ensure sustained-yield over the long-term period requires knowledge that will, at an early stage, let us know the future state of forest productivity. This, in our opinion, can be obtained from a reliable knowledge of forest regeneration coupled with soils productivity (see the following section). This regeneration indicator is the one for which foresters have had the most experience and for which they harbour a great knowledge. However, in the context of SFM, maintaining natural and continuously changing stand structure and composition are considerations that must be added to the goal of producing a productive commercial crop. This indicator should also be considered from the point of view that changes in forest regeneration will eventually have an impact on the forest mosaic composition and thus on biodiversity. Ensuring adequate regeneration of forest stands will also be a necessary pre-requisite to maintaining stand resilience and continued stand productivity. To achieve SFM we must thus ensure that regeneration is sufficient in quantity, quality and of the appropriate type to guarantee the development of stands that are as productive as pre-disturbance stands within a given period of time.

Controlling for future stand composition following harvesting requires an understanding of natural forest dynamics. This consideration links the regeneration indicator to the forest mosaic indicator. However, where the forest mosaic indicator will help to define the range of acceptable forest compositions to be maintained in a managed landscape, it is through an understanding of regeneration dynamics, such as the distinction between the effect of natural disturbances vs harvesting practices, that the long term impact of forest management activities on the forest mosaic will be made. In fact, it is recognised that harvest activities may transform the composition and structure of some forests mostly by altering regeneration processes (and forest age structures) and by promoting tree species that are better adapted to new conditions generated by cutting disturbance (Carleton and MacLellan 1994, Averill et al 1995, Whitney 1986, Sicama 1971, McIntosh 1972)**.**

The question of scale separates our approach from those being currently employed (Friedman 1999) and as such may require profound changes in forest management practices. Although practices affecting regeneration occur at the stand level, the sustainable regeneration of forests requires a consideration of the forest at a landscape level. In forests governed by natural disturbance dynamics, regeneration processes change temporally and spatially across the landscape. Planning for forest regeneration must thus also occur at the landscape level using the assumption that individual stands may differ in composition, structure and biomass production through time, although across the forest landbase these should remain constant or change slowly. Current rules that require stands to be regenerated to similar composition and stocking (as a surrogate for future volume production) may actually run counter to natural dynamics in which individual stands evolve.

Successional processes and stand development processes must therefore be acknowledged. On a given site type (defined by soils indicators), open stands may have a greater abundance and stocking than closed stands and investments may be more wisely used to improve the regeneration norms of such a stand well beyond provincial norms than to struggle to attain an arbitrary minimum threshold (e.g. 60%) for another more poorly stocked stand (as is the current practice). Similarly, taking advantage of abundant advance regeneration of tolerant species under an intolerant overstorey, or planting or coppicing intolerants in a stand formerly dominated by tolerant species but with sparse advance regeneration should not be considered as stand conversion, as current rules in many jurisdictions suggest, if relative proportions are maintained for each site type across the landbase (as determined by the forest mosaic indicator). Failure to reach regeneration objectives at the stand level can be more easily corrected and at much lower cost at the landscape level.

Three approaches are thus proposed to address the problems posed by this indicator. The first is a heuristic or ecosystem management approach in which natural ecosystem dynamics are used to suggest alternatives or complementary practices to current practices (see example in Bergeron et al. 1999). The second is based on the modelling of regeneration dynamics to allow for silvicultural gaming (evaluations of the effects of different silvicultural scenarios on regeneration dynamics compared to those following natural disturbances using computer simulations e.g : FORECAST, SORTIE/Bc and SORTIE-Boreal, FORSKA, ZELIG, etc). The first two methods can be used in developing and evaluating alternative silvicultural systems. Finally, an empirical approach in which the characteristics of different stages of stand development are identified in forest regeneration research (e.g. the abundance and stocking of germinants at time of establishment, the seedling stage, the sapling stage, etc) and summarised into field guides for use in avoiding or rectifying potential problems. Only this third approach will be useful in environmental monitoring.

The effectiveness of monitoring the regeneration planning process requires well defined objectives for each stand as part of the overall landscape during the planning stage. Judgements on regeneration success should thus always be based on initial planning goals and objectives for each stand to meet landscape level objectives.

The monitoring of the relative success of the regeneration in each stand will be based on determining whether regeneration abundance (or stocking) is sufficient and whether this regeneration is growing acceptably. Such monitoring is, in part, in place in many jurisdictions at least with respect to a short-term post-harvest evaluation. The quantity and quality of seedlings by species and their growth and survival potential after disturbance is a simple but effective measure of the regeneration potential. The quality of the regeneration may be judged by factors such as the stocking and spatial distribution of seedlings as well as seedling size, growth rate and crown form (whether injured or not, live crown ratio, etc). Species specific indicators of vigour are being developed for most of the boreal tree species (Ruel et al, In prep.). In many cases, stocking is more important in determining the future yield of a stand than is the quantity of seedlings (and at least one of these is usually evaluated). Low stocking will lead to stands with low yield as effective growing area is not being used. An understanding of the spatial distribution (e.g. clumped vs uniform but wide spacing) of seedlings will, however, be required for curative measures. Density (e.g. high densities will slow down stand growth and a curative measure would be to thin the stands) and species specific growth for different sites will however give an idea of the time required to achieve a target stand. In the long-term, it is the monitoring at rotation age that will verify if initial composition, structure and volume goals are attained. It is thus imperative that the use of post-harvest stocking be evaluated by determining the relationships between seedling stocking and subsequent merchantable stem stocking and volume for each species on different site types (Doucet 1991, Pominville and Doucet 1993). A strong link is therefore necessary with soil productivity indicators.

C. Ecological standards for soil productivity.

The general objective of this indicator is to insure the maintenance of the soil properties that would allow the resilience of forest productivity following disturbance. It is therefore important to address the question whether indicators should be soil or plant properties. The comparisons of wood volume of successive rotations is considered as the ultimate measure of long term productivity by most forest researchers (Morris and Miller, 1994). However, the use of a plant bioassay to monitor forest soil productivity has been criticised by Burger (1996) who pointed out that productivity is the results of several processes including soil, genotype, control of plant competition, pests, and other environmental factors and that monitoring of changes in critical soil properties may be the only sure way to monitor forest soil quality, productivity and sustainability in the long run. The interacting influence of all the factors contributing to plant productivity may in fact suggest that some practices are beneficial while key soil properties are still being degraded. Such cases have been observed in agriculture as yields during most of this century have increased despite the fact that soil quality was deteriorating, leading eventually to a levelling off or to yield decline (Burger 1996). The definition of soil quality is evolving rapidly in agriculture as physical, chemical and biological indices of soil quality are being implemented (Doran et al. 1994). We agree with Burger (1996) that forest soil quality should be monitored with soil parameters. However, to make this possible for boreal forests it must be recognised that:

- forest soil properties are highly variable over short distances and a high number of samples are required to monitor a single site. For example, a slight change in slope can affect drainage and have a strong effect on important properties such as soil organic matter content.
- unlike most agricultural soils, forest soils, and especially soils of the boreal forest undergo important changes with time since disturbance. It is easier to have an indicator in agricultural soils where soil properties should, for a given site, vary *only wi*th seasonal changes and not between years. Year to year variation and changes with stand age are an intrinsic property of forest soils (Paré et al. 1993).

For these reasons, a good indicator of soil quality should be site specific. The extensive management that is usually found in the boreal forest and the poor knowledge of soil variability makes this task difficult. Properties such as soil reserves of organic matter, the C to N ratio of soil organic matter and the foliar nutrient composition would be good indicators of soil fertility however, we lack information on the variability of these factors and on their relationships to permanent soil properties to use them at the moment. While waiting for this knowledge to be developed, a heuristic approach may be to identify the most stressful practices and the most susceptible sites.

Direct and indirect soil condition indicators

Physical damages to the soil such as erosion, mass-wasting, compaction and rutting are largely avoidable (Weetman 1998) and may be used to formulate numerous management indicators. A careful planing of operations, such as winter harvesting, with an identification of fragile sites and tight inspection can limit these problems. Indicators of severe physical disturbance to the soil are currently being implemented in Québec (L'Écuyer et Jetté, 1998). In such cases, it is a matter of regulation and inspection rather than a limitation in knowledge.

Monitoring of the mid- to long-term impact of forest operations on the soil nutrient providing capacity is however rarely undertaken. While most forests are deficient in nitrogen or phosphorus, nutrient budget analyses indicate that calcium is the nutrient most significantly depleted in most sites by harvesting (Johnson 1994). The rationale being that calcium and other cations are little affected by natural disturbance such as fire or insect outbreaks, while these elements are extracted from the site with the harvested biomass. The main source of these elements is the weathering of soil minerals. The amounts of elements provided by this flux is dependant on soil mineralogy, soil temperature, soil water content and soil acidity. It is possible to produce field guides that roughly rank soils by their cation providing capacity based on soil texture, depth, stoniness and drainage. Simulation models, such as PROFILE (Sverdrup and Warfinge 1992) can also provide estimates of mineral weathering for specific site types but these estimates have not been validated. These fluxes can then be compared with estimates of nutrient outputs in harvested products which are dependant on tree species, method of harvesting (whole-tree vs stem-only), stand site index, density and stand age. A tool estimating the exportation of nutrient in relation to these parameters is being completed (Paré and Rochon, in prep). The comparison of outputs in wood products with inputs from mineral weathering can determine situations that are likely to be most stressful to the soil nutrient budgets. This knowledge can help managers to direct stem-only harvesting to the most susceptible sites and to favour the establishment of the most demanding tree species on the richest sites.

Monitoring indicators of changes in soil nutrient providing capacity can also be evaluated indirectly be estimating vegetation recovery. This could be done by aerial photography or by evaluating vegetation colonisation for a given distance (e.g. 30m) along roadsides. The recovery of the Leaf Area Index (projection of the surface of leaf per area-m2/m2) as well as its distribution (frequency and importance of gaps) would allow a gross estimation of the degree of disruption of nutrient cycling. An important link will thus be made here between the soil productivity indicator and the regeneration/stand dynamics indicators. The importance of groups of vegetation known to be detrimental to soil fertility such as ericaceous plants and sphagnum mosses or of plants known to have a beneficial effects on soils, such as deciduous plants could also be evaluated and compared to what is observed on sites affected by natural disturbances.

D. *Aquatic resources*

There are over one million lakes and countless streams and rivers on the Canadian Shield, where they typically account for 10-15% of the landscape, and where they represent an important economical, recreational and subsistence resource. For these reasons, the protection of lakes and running waters must be an integral part of future strategies for sustainable forest development. Basic sustainability criteria and indicators applicable to these systems should address the following two objectives.

1- The preservation of functional and structural *aquatic* ecosystem integrity;
2- The preservation of natural resources associated with fresh waters (fisheries, drinking water supply, recreation).

Preserving aquatic ecosystem integrity requires the maintenance of key properties that should be maintained within their natural range of variation as determined by their response following natural disturbances. These properties can be functional, such as biological productivity, decomposition and nutrient cycling, or structural, such as biodiversity and community composition. Structural properties generally constitute the most sensitive indicators of ecosystem stress. Evaluating structural (and functional) ecosystem properties is, however, particularly time-consuming and expensive. For this reason, practical indicators of aquatic ecosystem integrity should be based on easily measurable and manageable biophysical factors known to affect the integrity and the economic value of fresh waters ecosystems. These factors can be divided into three broad classes:

1- Chemical (toxic contaminants, nutrient supply, organic carbon)
2- Physical (temperature, light, erosion)
3- Biotic (density of top predators such as salmonids, pike, walleye)

Each of these three classes includes key properties that can be used as monitoring indicators because they play central roles in determining ecosystem structure and function, they can be easily measured or sampled in the field, and are known to be influenced by forestry practices. In most cases, research has already established quantitative relationships linking these indicators to forestry practices. An understanding of the effects of different forestry practices on different watershed parameters and the temporal variation in these parameters following natural disturbances such as fire can thus be used to develop management indicators

Aquatic Management Indicators

Forest harvesting causes temporary but major disruptions to soil nutrient cycles and to hillslope hydrology. In turn, these effects produce significant changes to the chemical composition and the quality of surface waters. In boreal Shield lakes, the factors that are primarily affected e.g. dissolved organic carbon (DOC) and colour are empirically related to the drainage ratio (the size of the lake vs the size of the watershed), the topography and the proportion of the watershed that is harvested (Carignan et al 1999). A knowledge of the first two variables can thus be used to plan the proportion of the watershed that can be cut without causing deleterious effects (those effects that exceed the natural temporal variation). These same management indicators should also be effective in limiting increases in mercury inputs.

In streams, however, temperature is strongly influenced by the degree of canopy closure above streams and thus by the presence of fringing buffer strips. Furthermore, excessive erosion in the watershed and the transport of eroded material into streams and lakes can cause a deterioration of fish spawning grounds and recruitment failures, as reported by Magnan et al. (1999) and others. The main factors leading to an excessive loading of suspended material in streams and lakes are insufficient buffer strips, inadequate culvert installations, and excessive soil disturbance on steep slopes. Although residual buffer strips are an established practice in forestry, their resistance to blowdown and long-term effectiveness depend on prescribed width, species, stand age and vegetation type, which can vary considerably between regions. Buffer strip persistence should therefore be considered as a management indicator to protect the viability of aquatic habitats.

Aquatic biodiversity will be affected by changes in physical and chemical parameters following modifications to the forests in a watershed. Across the landscape aquatic biotic components should not be adversely affected if changes are maintained within the limits occurring following natural disturbances in watersheds. As with other components of biodiversity, road access, for which there is no natural analogue, to previously inaccessible areas should be carefully planned for as it may lead to pressure on some species (e.g. through overexploitation of fish stocks).

Monitoring indicators

Research conducted in boreal Shield lakes (Garcia and Carignan 1999; Carignan et al. 1999) reveals only minor disruptions to aquatic nutrient cycles. On the other hand, salient effects of clearcuts include increased concentrations of coloured dissolved organic carbon (DOC) and mercury. DOC strongly influences several chemical (e.g. formation of toxic trihalomethanes, related to mercury loading, etc), physical (an increase in surface water temperature, a decrease in thickness of the warm surface layer) and biological (loss of warmwater fish habitat due to temperature changes and, possibly, a loss in coldwater fish habitat through increased oxygen deficits in deep waters) properties in lakes because it imparts a significant brown staining to the water, thereby reducing photosynthesis and biological productivity.

Chemically, DOC degrades the quality of surface waters as drinking water source through the formation of toxic trihalomethanes in water treatment processes. Excessive toxic methyl-mercury concentrations in gamefish is an endemic problem in boreal Shield lakes, where concentrations often exceed the limit (0.5 mg/kg) recommended for safe human consumption. Research has shown that the problem is exacerbated in lakes draining clearcut watersheds (Garcia and Carignan 1999). Our present knowledge on the biogeochemistry of mercury in the boreal forest indicates that mercury loading to lakes are highly dependent on DOC loading.

Physically, temperature and light penetration (transparence) are two easily measured at low cost physical monitoring indicators. In unproductive Shield lakes, coloured DOC produced in the watershed is by far the main factor responsible for underwater light attenuation. Most invertebrate and fish species have well-defined temperature optima, and thus temperature is another obvious monitoring indicator. However, in lakes, other conditions being equal, surface water temperatures will largely depend, again, on coloured DOC concentrations. Excessive erosion in the watershed is also a problem (Magnan et al. 1999) and although no easily measured monitoring indicators for erosion have been proposed so far, the determination of the concentration of suspended material in streams at peak runoff is a promising tool.

Biologically, for fisheries, fish yield statistics appears to be the most straightforward monitoring indicator.

Integrating Ecological Standards

It is our view, that the proposed indicators could form a strong base for a truly sustainable forest management program. The interconnectedness between indicators (Figure 2) also suggests that a failure to achieve the defined goals in any area of concern may have important consequences on other indicators. For example, forest mosaic and regeneration indicators are both linked by evaluating composition at different scales. Similarly changes in soil productivity may affect stand productivity (even if the target number of stems have successfully regenerated) and also water quality if nutrients or sediments lost from soils are leached into waters. Aquatic and terrestrial biodiversity are both components of overall biodiversity affected by forest management activities (harvesting, road networks).

This important link between indicators is not often made in other SFM programs. Moving beyond an ecological perspective, similar consequences exist when socio-economic indicators are also considered (Chapin and Whiteman 1998). Without a strong understanding of ecological functioning and the relationship between different components the long-term sustainability of communities and forestry operations may in themselves be compromised. Until recently, natural resources were only considered from a social, political and economic perspective, with ecosystems themselves being an abundant but hidden backdrop (Shrivastava 1994). An understanding of ecological functioning must however form the base of any exercise that is to be truly sustainable with social and economic decisions being made fully conscious of potential ecological ramifications.

In such an exercise it is important to note that although weights of societal importance may be assigned to different indicators (based on some set of values) that the relationship between the indicators themselves can not be compromised. In other words, it is crucial to understand the intensity of the links between different indicators before assigning weights. For example, an exportation of nutrients from soil reserves will have a direct impact on nutrient levels in aquatic systems irrespective of the importance values that stakeholders may have arbitrarily assigned for the effects of forestry practices to lakes or to soil resources.

Furthermore, the complex of indicators used to define sustainability criteria proposed by other groups (CCFM 1996, FSC 1996, MNRQ 1999) are mostly based on a static, non-integrated view of forest resources. Although these documents recognise the importance of landscape level decisions most indicators are based on stand level observations which are often simply scaled up. Furthermore, for sustainable forest management to occur indicators must be firmly rooted in an understanding of natural processes and management practices for meaningful advances to be made. Friedman's (1999) review of how certification standards compare for regeneration practices provides at least one example of how good intentions may not necessarily maintain a natural composition in our forests: Concerns about the use of artificial regeneration result, in most of the reviewed standards, in the requirement of an overwhelming use of natural regeneration without considering whether natural regeneration following cutting and natural disturbance are the same. Without an integrated approach to the development of such standards it is also possible that conflicts between standards may arise. Such as between the desire to manage for large ungulates by increasing edge habitat and the maintenance of species that require large areas of interior habitat.

Similarly, if biophysical indicators are not well understood then there is a risk that they will not be implemented. There is also a risk that if the cost to society is perceived as being too high then the thresholds determined for these indicators will be ignored. The FSC maritime standards (http://www.canadian-forests.com/fsc-standard.html) for example, include a number of standards for which economic costs may be high but for which failure will void certification within a given period of time.

Varying forest management intensity as a tool to maintain ecosystems

As highlighted elsewhere (Bunnell 1997, Binkley 1997) multiple-use strategies of forested lands may lead to a compromise system in which society, economics and ecosystems all suffer. Most certification schemes however ignore the possibility of zoning strategies (such as the triad approach) in which some areas are managed primarily for timber resources, others for biodiversity, etc and others for multiple land-use goals within an FMU (Seymour and Hunter 1992, Hunter 1990). Instead they pursue multiple-use development of our forests despite the potential short-comings of this paradigm. For example, the use of exotic species other than in habitat restoration is prohibited by many certification standards (Friedman 1999) yet the use of fast-growing hybrids on a small part of a land-base may allow greater conservation of another part of the land-base.

In a practical sense, the formulation of silvicultural prescriptions has often been conceived of as an optimisation exercise leading to the determination of the best forest operation given constraints on equipment and financial resources. Such an approach has inexorably led to the creation of operating standards by government agencies that lead to a homogenisation of forest management practices at regional or provincial levels.

A number of approaches have, however, been proposed in which a diversity of forest practices would occur across a landscape (Bergeron et al. 1999, Seymour and Hunter 1992, Harris 1984, Burton et al. 1999). The standards that we propose would be compatible with these approaches in that an understanding of natural dynamics is being proposed to govern forest practices. In this view, temporal and spatial changes in certain attributes are to be expected at the stand level although these will be balanced across both the landscape and longer time horizons. The focus should thus be placed on desired outcomes rather then on a series of regulations (Bunnell 1996?).

Responsibilities for forest management practices

This then leads us to the question of who should be responsible (and also who will pay for it) for insuring that sustainable forest management will occur. In the past, provincial government agencies took the whole responsibility for protecting and maintaining natural resources (e.g. forest possibilities assessment, control of fire and insect outbreaks, development of new forest management strategies and practices) leaving and confining forest industries to the role of harvesters. This unequal share in management responsibilities contributed to the environmental carelessness of many local forest industries.

Whether the government or companies are responsible they should be governed not with strict rules, but with guidelines that can allow them to be creative and achieve higher levels of sustainability that could ever be accomplished by satisfying the minimum requirements of the law. There should thus be a real systems of rewards and incentives, based on sound ecological principles, put in place to encourage companies to achieve higher levels of management.

With the inclusion of new considerations about multiple land-use and the maintenance of biodiversity, forest management becomes closer to land management. As the principal user of forest resources and the main agent of changes in the forested landscape, forest industries must play a major role in planning the development of forested landscapes or regions. A fundamental shift in our thinking about forest resource management needs to occur in which ecosystem resilience is considered in economic and social decision-making processes (Chapin and Whiteman 1998) and also in which conservationists consider humans as part of the ecosystem (Bunnel 199?).

Conclusions

Government agencies and other bodies have been trying to develop systems of regulations, standards or indicators to judge and govern forest management. These various proposals all have the objective of ensuring the sustainability of all facets of the forest resource. Despite, the considerable effort put into these systems a number of drawbacks are inherent in them all. Thus although they may improve the current state of forest management, further steps are needed to ultimately ensure sustainability.

We propose an approach in which ecological principles grounded in scientific knowledge form the base on which discussions on the use of forest resources occurs. In this way social and economic issues can be discussed with the best knowledge on the capacity of forest ecosystems to support multiple uses for many generation of users.

Our approach is different from most of the others not only in its strong foundation on scientific knowledge but also in the fact that the indicators are strongly interelated as in real ecosystems. We view the ecosystem as a whole and not as an assemblage of different important parts that are not connected and which may at times be in conflict. Our approach to developing indicators is thus based on an understanding of the natural variability in ecosystems and how the different components react together. Since the invention of the assembly line we have become accustomed to working on small parts of a problem, and to seeing problems broken down into various components, but to successfully manage ecosystems we will have to learn to manage for the forest as a whole.

Acknowledgements

This research has been supported by the Sustainable Forest Management Network and Cartons St-Laurent. Contributions from the Fondation UQAM through the Societé St-Jean Baptiste and the National Science and Engineering Council of Canada were also greatly appreciated. We would also like to thank Marie-Josée Fortin, Benoit St-Onge and anonymous reviewers for their comments on this manuscript.

References

Abusov, K. and T.Rotherham. 1998. Canadian progress towards SFM system certification. For. Chron 74: 405-408.

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71: 355-366.

Anonymous 1997. Critères et indicateurs de développement forestier durable: Plan de mise en oeuvre. Ministère des Ressources naturelles du Québec, Direction de l'environnement forestier. Quebec City.118p.

Askins, R. A., J. F. Lynch, and R. Greenberg. 1990. Population declines in migratory birds in eastern North America. Current Ornithology 7: 1-56.

Atlegrim, O. 1989. Exclusion of birds from bilberry stands: impact on insect larval density and damage to the bilberry. Oecologia 79: 136-139.

Baharuddin, Hj. G. 1998. Timber certification: an overview. Unasylva 183: 1-8

Bergeron, Y., B. Harvey, A. Leduc and S. Gauthier. 1999. Silvicultural pratices and forest management strategies that emulate natural disturbances. For. Chron.

Binkley, C.S. 1997. Preserving nature through intensive plantation forestry: The case for forestland allocation with illustrations from British Columbia. 73: 553-559.

Booth, D.L., Boulter, D.W.K., Neave, D.J., Rotherham, A.A., and Welsh, D.A. 1993. Natural forest landscape management: A strategy for Canada. For. Chron. 69: 141-145.

Brunson, M. 1996. Integrating human habitat requirements into ecosystem management strategies: A case study. Nat. Areas J. 16: 100-107.

Bunnell, F. 1997. Operational criteria for sustainable forestry: focusing on the essence. For. Chron. 73: 679-684.

Bunnell, F.L. 1996. Toto, this isn't Kansas: Changes in integrated forest management. Proceedings from the Integrated forest management workshop, Sussex, New Brunswick, October 3-5, 1994.

Burger, J. A. 1996. Limitations of bioassays for monitoring forest soil productivity: Rationale and example. Soil Sci. Soc. Am. J. 60: 1674-1678.

Burton, P.J., A.C. Balisky, L.P. Coward, S.G. Cumming, and D.D. Kneeshaw. 1992. The value of managing for biodiversity. Forestry Chronicle 68: 225-237.

Canadian Council of Forest Ministers (CCFM) 1997. Criteria and indicators of sustainable forest management in Canada. Technical Report. Natural Resources Canada - Canadian Forest Service. Ottawa, Ontario. 137 p

Canadian Standards Association (CSA) 1996. A sustainable forest management system. Z808 & Z809. Canadian Standards Association, Toronto.

Carignan, R., P.Darcy, B. Pinel-Allouol, J. Kalff, D.Planas and P. Magnan. 1999. Comparative impacts of fire and forest harvesting on water quality in boreal shield lakes. P. 121-126. Sustainable Forest management Network Conference, Science and practice: Sustaining the boreal forest, Conference proceedings. Edmonton 14-17 February, 1999.

Carleton, T.J. and P. MacLellan. 1994. Woody vegetation responses to fire versus clearcut logging. Ecoscience 1: 141-152.

Carpenter, S.R., S.W. Chisholm, C.J. Krebs, D.W. Schindler and R.F.Wright. 1995. Ecosystem experiments. Science 269: 324-327

Chapmin, F.S. and G. Whiteman. 1998. Sustainable development of the boreal forest: Interaction of ecological, social and business feedbacks. Conservation Ecology 2 (2): 12, 15 p.

Charland, J.W. 1996. The 'Problem-Isolation' paradigm. J. For. 94: 6-9

Corona, P. and G. Pignatti. 1996. Assessing and comparing forest plantations proximity to natural conditions. J. Sust. For. 3: 37-46

Crawford, H. S., and D. T. Jennings. 1989. Predation by birds on spruce budworm *Choristoneura fumiferana*: functional, numerical, and total responses. Ecology 70: 152-163.

Crossley, R. 1996. A review of global forest management certification intiatives: political and institutional aspects. Proc. Conf. Economic, social and political issues in certification of forest management. 12-16 May, 1996. Kuala Lumpur, Malaysia

Dansereau, P. and Y. Bergeron. 1993. Fire history in the southern part of the boreal forest of northwestern Quebec. Canadian Journal of Forestry Research 23: 25-32.

Davis, R.G. and D.L. Martell. 1993. A decision support system that links short-term silvicultural operating plans with long-term forest-level strategic plans. Can. J. For. Res. 23: 1078-1095.

Doran, J.S., D. C. Coleman, D.F. Bezdicek, and B.A.Stewart. 1994. Defining soil quality for a sustainable environment. SSSA special publication number 35. Madison, WI. 245pp.

Doucet, R., 1991. The influence of stocking of regeneration on the yield of naturally regenerated jack pine and black spruce stands. Dans : Simpson, C.M. Proceeding of the Conference on natural regeneration management, Fredericton, N.B. 27-28 mars 1990. Forêts-Canada, Centre de For. des Maritimes : 181-192.

Drapeau, P., A. Leduc, J.-F. Giroux, J.-P. L. Savard, Y. Bergeron and W. L. Vickery. *In press.* Landscape-scale disturbances and changes in bird communities of eastern north american boreal mixed-wood forests. Ecology.

Duinker, P.N. and Pulkki, R.E. 1998. Community forestry, Italian style: The Magnifica Communità di Femme. For. Chron. 74: 385-392.

Edenius, L. and J. Elmberg. 1996. Landscape level effects of modern forestry on bird communities in North Swedish boreal forests. Landscape Ecology 11: 325-338.

Elliot, C. 1996. Forest management certification: ISO, FSC and CSA: What's going on. Taiga News 19

Elliot, C. and Hackman, A. 1996. Current issues in forest certification in Canada. World Wildlife Fund Canada, Toronto.

Erdle, T. 1998. Progress towards sustainable forest management: Insight from the New Brunswick experience. For. Chron. 74: 378-384.

Erdle, T. and M. Sullivan. 1998. Forest management design for contemporary forestry. For. Chron. 74: 78-82.

Evans, B. 1996. Technical and Scientific Elements of Forest Management Certification Programs. Proc. Conf. Economic, social and political issues in certification of forest management. 12-16 May, 1996. Kuala Lumpur, Malaysia

Franklin, J.F. 1993. Preserving biodiversity: species, ecosystems or landscapes? Ecological applications 3: 202-205.

Franklin, J.F. 1995. Scientists in wonderland: experiences in development of forestry policy. Bioscience Supplement: 74-78.

Freedman, B., Woodley, S. and Loo, J. 1994. Forestry practices and biodiversity, with particular reference to the maritime provinces of eastern Canada. Environ. Rev. 2: 33-77.

Friedman, S.T. 1999. Forest regeneration practices – How regional certification standards compare. J.For. 97: 23-32.

FSC 1996. Principles and criteria for forest stewardship. FSC Report. Mexico City

Galindo-Leal, C. and Bunnell, F.L. 1995. Ecosystem management: Implications and opportunities of a new paradigm. For. Chron. 71: 601-606.

Gauthier, S., A. Leduc, and Y. Bergeron. 1996. Forest dynamics modeling under a natural fire cycle: A tool to define natural mosaic diversity in forest management. Environ. Monitoring Asess. 39: 417-434.

Garcia, E., and R. Carignan. 1999. Impact of wildfire and clear-cutting in the boreal forest on methyl mercury in zooplankton. Can. J. Fish. Aquat. Sci. 56: 339-345.

Gilmore, D.W. 1997. Ecosystem management – A needs driven, resource-use philosophy. For. Chron. 73: 560-564.

Graham, R.T. and T.B. Jain. 1998. Silviculture's role in managing boreal forests. Conservation Ecology 2 (2): 8, 10 p.

Grumbine, R.E. 1994. What is ecosystem management? Conservation biol. 8: 27-38.

Guimier, D.Y. and Hedersdorf, E. 1998. Forestry operations into the next century. For. Chron. 74: 68-71.

Haila, Y., Hanski, I.K., Niemala, J., Punttila, P., Raivo, S. and Tukia, H. 1994. Forestry and boreal fauna - Matching management with natural forest dynamics. Ann. Zool. Fenn. 31: 187-202.

Hauffler, J.B., C.A. Mehl and G.J. Roloff. 1996. Using a coarse-filter approach with species assessment for ecosystem management. Wildl. Soc. Bull. 24: 200-208.

Helle, P., and O. Järvinen. 1986. Population trends of North Finnish land birds in relation to their habitat selection and changes in forest structure. Oikos 46: 107-115.

Holmes R. W., J.C. Schultz, and P. Nothnagle. 1979. Bird predation on forest insects : an exclosure experiment. Science 206 :462-463.

Hughes, R. 1996. Sustainable forest management certification: an auditor's perspective. For. Chron. 72: 265-267.

Hummel, R. and A. Sizykh. 1997. Sustainable development of forests as a way to preserve the natural basis of forestry. J. Sust. For. 4: 53-60.

Johnson, D.W. 1994. Reasons for concern over impacts of harvesting. P.1-12. In: Dyck, W.J., Cole, D.W. & Comerford, N.B. (eds.) Impacts of forest harvesting on long-term site productivity. Chapman & Hall.

Kangas, J. and J. Kuusipalo. 1993. Integrating biodiversity into forest management planning and decision making. For. Ecol. Manage. 61: 1-15

Kimmins, J.P. 1992. Balancing act : environmental issues in forestry. UBC Press, Vancouver, B.C. 244p

Kimmins, J.P. 1996. The health and integrity of forest ecosystems: are they threatened by forestry? Ecosystem Health 2: 5-18.

Knight, R.L. 1996. Aldo Leopold, the land ethic, and ecosystem management. J. Wildl. Manage. 60: 471-474.

Lapointe, G. 1998. Sustainable forest management certification: The Canadian programme. For. Chron. 74: 227-230.

L'Écuyer, H. and J.P. Jetté. 1998. Indicateur des perturbations physiques du sol. Note technique MRNQ.

Lyke, J. 1996. Forest product certification revisited: an update. J. Forestry 94: 16-20

Lu, H. and J. Buongiorno. 1993. Long- and short-term effects of alternative cutting regimes on economic returns and ecological diversity in mixed-species forests. For. Ecol. Manage. 58: 173-192.

Magnan, P., and I. St-Onge. 1999. Impact of logging and natural fires on fish communities of Laurentian shield lakes. p. 150-154. Sustainable Forest management Network Conference, Science and practice: Sustaining the boreal forest, Conference Proceedings. Edmonton 14-17 February, 1999.

McGarigal, K. and W. C. McComb. 1995. Relationships between landscape structure and breeding birds in the Oregon coast range. Ecological Monographs 65:235-260.

McIntosh, R.P. 1972. Forest of the Catskill Mountains, New York. Ecol. Monogr. 42: 142-161.

McKenney, D.W., R.A. Sims, F.E. Soulé, B.G. Mackey and K.L. Campbell, (Eds) 1994. Towards a set of biodiversity indicators for Canadian Forests: Proceedings of a forest biodiversity indicators workshop. Sault Ste. Marie, Ontario, Nov. 29-Dec.1, 1993, 133 pp.

McLaren, M.A., Thompson, I.D. and Baker, J. A. 1998. Selection of vertebrate wildlife indicators for monitoring sustainable forest management in Ontario. For. Chron. 74: 241-248.

Merrill, T., Wright, R.G., and Scott, J.M. 1995. Using ecological criteria to evaluate wilderness plannin options in Idaho. Environmental Management 19: 815-825.

Meslow, E.C., Holthausen, R.S. and Cleaves, D.A. 1994. Assessment of terrestrial species and ecosystems. J. For. 92; 24-27.

More, T.A. 1996. Forestry's fuzzy concepts – An examination of ecosystem management. J. Forestry. 94: 19-23

Niemi, G., J. Hanowski, P. Helle, R. Howe, M. Mönkkönen, L. Venier, and D. Welsh. 1998. Ecological sustainability of birds in boreal forests. Conservation Ecology [online] 2(2): 17. Available from the Internet. URL: http://www.consecol.org/vol2/iss2/art17

Norton, T.W. 1996. Conservation of biological diversity in temperate and boreal fores ecosystems. For. Ecol. Manage. 85: 1-7.

OMNR. 1997. A guide to forest management planning. Ministry of Natural Resources, Toronto, Ontario. 19p.

O'Laughlin. 1996. Forest ecosystem health assessment issues: definition, measurement and management implications. Ecosystem Health 2: 19-39.

Palmer, J. 1996. Monitoring Forest Practices. Proc. Conf. Economic, social and political issues in certification of forest management. 12-16 May, 1996. Kuala Lumpur, Malaysia

Paré, D., Y. Bergeron, and C. Camiré. 1993. Changes in the forest- floor of Canadian southern boreal forest after disturbance. Journal of Vegetation Science 4: 811-818.

Perrez, L.M. 1996. Analysis of social elements in forestry certification. Proc. Conf. Economic, social and political issues in certification of forest management. 12-16 May, 1996. Kuala Lumpur, Malaysia

Pominville, P. and R. Doucet, 1993. Coefficients de distribution de la régénération nécessaires au maintien de la production des peuplements de pin gris, d'épinette noire et de sapin baumier. Dir. de la rech., Note de rech. for. n° 48, 15 p.

Rawlinson, E. 1996. CSA sustainable forest management systems: getting ready. For.Chron. 72: 261-264.

Robbins, C. S., D. K. Dawson, and B. A. Dowell. 1989. Habitat area requirements of breeding forest birds of the middle Atlantic states. Wildlife Monographs 103: 1-34.

Robinson, S. K., F. R. Thompson, T. M. Donovan, D. R. Whitehead and, J. Faaborg. 1995. Regional forest fragmentation and the nesting success of Migratory birds. Science 267:1987-1990.

Rotherham, T. 1996. Forest management certification – Objectives, international background and the Canadian program. For. Chron. 72: 247 –252.

Seymour, R.S. and Hunter, M.L., Jr. 1993. New forestry in Eastern Spruce-Fir forests: Principes and applications to Maine. Maine Agricultural Experiment Station Miscellaneous Publication 716.

Schindler, B. 1998. Does the public have a role in forest management^ Canadian and U.S. perspectives. For. Chron. 74: 700-702.

Schindler, B., B. Steel and P. List. 1996. Public judgements of adaptive management. J. For. 94: 4-12.

Siccama, T.G. 1971. Presettlement and present forest vegetation in northern Vermont with special reference to Chittenden County. Amer. Mid. Nat. 85: 153-172.

Smith, P.G.R. and J.B. Theberge. 1986. A review of criteria for evaluating natural areas. Environmental management 10: 715-734.

Smith, P.G.R. and J.B. Theberge1987. Evaluating natural areas using multiple criteria: theory and practice. Environmental Monitoring 11: 447-460.

Sprugel, D.G. 1991. Disturbance, equilibrium, and environmental variability: What is 'natural' vegetation in a changing environment? Biol. Conserv. 58: 1-18.

Sverdrup, H. and P. Warfinge. 1992. Calculating critical loads of acids deposition with PROFILE-A steady-state soil chemistry model. Water, Air and Soil Pollution, 63: 119-143.

Takekawa, J. Y., and E. O . Garton. 1984. How much is an Evening Grosbeak worth? Journal of Forestry 82: 426-428.

Thomas, J.W. and S. Huke. 1996. The forest service approach to healthy ecosystems. J. Forestry 94: 14-18

Thomas, J.W. and M. Dombeck 1996. Ecosystem management in the interior Columbia River basin. Wildlife Soc. Bull. 24: 180-186.

Toman, M.A. and P. M.S. Ahston. 1996. Sustainable forest ecosystems and management; a review article. Forest Science 42: 366-377.

Wallin, D.O., F.J. Swanson and B. Marks 1994. Landscape pattern response to changes in pattern generation rules: land-use legacies in forestry. Ecol. Applic. 3: 569-580.

Weetman , G.F. 1998. A forest management perspective on sustained site productivity. For. Chronicle 74:75-77.

Whitney, G.G. 1986. Relation of Michigan'a presettlement pine forest to substrate and disturbance history. Ecology 67: 1548-1559.

Woodley, S. and Forbes, G. (Eds) 1997. Forest management guidelines to protect native biodiversity in the Fundy Model Forest. Greater Fundy Ecosystem Research Group. Moncton, New Brunswick.

Woodley, S., Alward, G., Gutierrez, L.I., Hoekstra, T., Holt, B., Livingston, L., Loo, J., Skibicki, A., Williams, C. and Wright, P. 1998. North American test of criteria and indicators of sustainable forestry. Final Report. Vol 1. USDA Forest Service Research.

Table 1. Characteristics of good ecological standards of SFM
1) Scientifically sound
2) Operationally feasible
3) Socially responsible and internationally credible
4) Measured following a standard method (Standardisation is also required to ensure consistency in the evaluation of the state of SFM in different FMU's)
5) Easily measurable and cost-effective
6) Easily interpretable and directly linked to environmental changes generated by local management practices (sensitiveness, responsiveness) and relatively insensitive to more global or external sources of variation
7) Integrated (as they are in the real world)
8) Linked to prescriptions

<u>Figure List</u>

Figure 1. The ongoing process of forest management. The planning phase (including consultation) is applied in the field, the results of these prescriptions are then monitored at short, intermediate and long-term time scales. Monitoring is thus used to identify problems which will then be addressed in subsequent rounds of planning.

Figure 2. An example of the types of links occurring between indicators. The solid arrows represent positive feedbacks and the dashed arrows represent negative feedbacks. The forest mosaic composition is used in forest planning to maintain habitat for biodiversity. This can be monitored by following songbird populations. Adjustments to harvesting practice can then be made using knowledge of the ecology of the declined species'. The forest mosaic will also determine the range of stands regenerating to different species, etc. This regeneration state will then lead to a future stand composition (productivity, etc) which may be different then the planned composition depending on the success in applying the forest plans. Future stand productivity will not only depend on the quantity and quality of the regeneration but also on soil conditions, and any modifications to soil condition (e.g. through leaching or erosion) will affect water conditions.

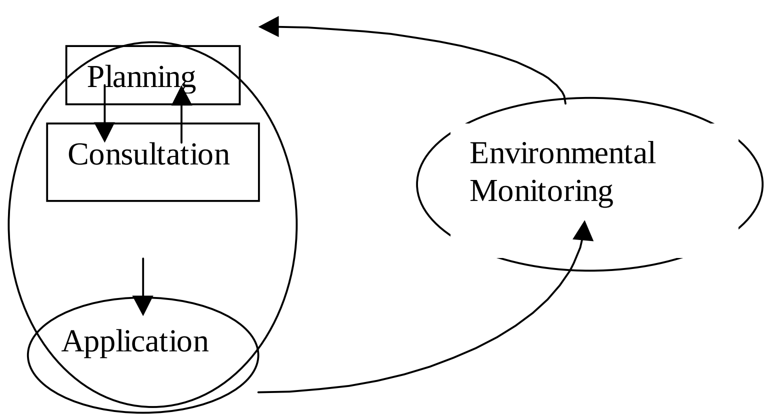

Fig 1. The ongoing process of forest management.

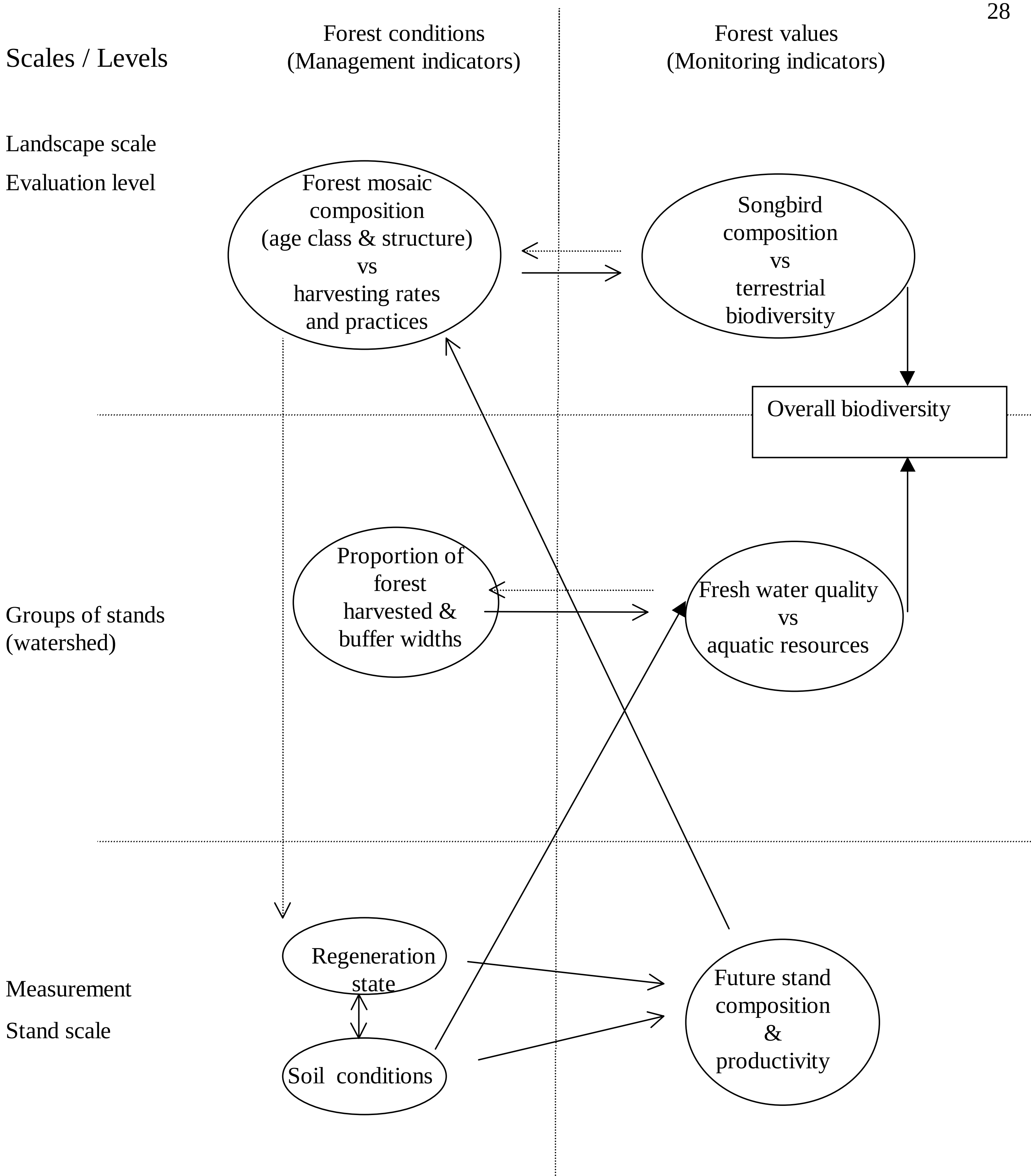
Scales / Levels
Forest conditions
(Management indicators)
Forest values
(Monitoring indicators)
Landscape scale
Evaluation level
Forest mosaic
composition
(age class & structure)
vs
harvesting rates
and practices
Songbird
composition
vs
terrestrial
biodiversity
Overall biodiversity
Proportion of
forest
harvested &
buffer widths
Fresh water quality
vs
aquatic resources
Groups of stands
(watershed)
Regeneration
state
Soil conditions
Future stand
composition
&
productivity
Measurement
Stand scale

Figure 2.