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Thinking and acting ***differently*** for a sustainable management of the boreal forest

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Abstract

Sustainable forest management has replaced sustained yield as the new management strategy for most countries and forest companies. This concept has generated a lot of interest and discussion, and a great deal of effort is being made to modify current forestry practices to be sustainable. In this paper, we argue that the still somewhat vague concept of sustainable forest management calls for a substantial modification in our way of thinking about and practicing forestry. To move toward that goal, we recognize important social and economic challenges to sustainable management and suggest nine essential notions: 1) manage the forest ecosystem as a whole and not in parts and only for the crop species; 2) conserve a significant proportion of the boreal forest (i.e. at least 12%); 3) practice intensive forestry on a small portion of the land to recover the fiber lost from notions 1 and 2; 4) strive for innovation in thinking and acting; 5) foster research and development to support notion 4; 6) balance regional needs with that of the global community; 7) encourage public participation; 8) consider the impact of substantial change in climate over the next 100 years (or next rotation); and 9) substitute regulations that are adaptive for those that are restrictive. An example of the kind of silviculture that could be used in ecosystem management for the black spruce forest is also discussed.

Key Words: Sustainability, ecosystem management, boreal forest, socio-economic and biophysical concerns, natural dynamics,

Introduction

Boreal forest management is an evolutionary process influenced by public perceptions, by numerous socio-economic and political factors, as well as by the state of our knowledge in the areas of biology and ecology. The impact of forest management on the boreal forest began to be a major issue during the 1970's when it was apparent that this immense biome was not inexhaustible. We now know that the boreal forest is an often fragile ecosystem and strongly limited by some unique biophysical constraints. In order to achieve a level of sustainable development, we must adjust to these changes in public perception while taking into account new scientific data concerning ecosystem management (Erdle 1998). The challenges are enormous, but Canada currently possesses all the tools and basic knowledge necessary to meet them. The greatest challenge, however, is in *thinking and acting differently*!

This article presents a very broad view of sustainable use of the boreal forest by human beings. It does not necessarily cover all aspects nor does it go into great detail, instead it presents some basic principles and directions for a truly sustainable use of a unique and vast biome, the boreal forest.

The Context

What is meant by « sustainable forest development » ?

If we go back to the original document concerning this very interesting concept, the Bruntland report (1987) defines sustainable development as "a development which meets the needs and the present aspirations of human beings without compromising those of future generations". In forestry, we refer to "a use of the forest ecosystem which maintains both the integrity and the health of the system while maintaining the socio-economic contributions" (Canadian Council of Forest Ministers 1997). Odum (1992) defines the concept in less palatable terms: "the aim of sustainable development is to diminish the human virulence to enable the human parasite to continue to profit from that which the planet offers". These three definitions essentially say the same thing: to achieve a sustainable development of the forest, it is necessary that forest practices be ecologically viable, economically feasible, and socially desirable. It is, however, much easier to enact the last two definitions than the first. The problem is that we do not yet know how to practice an ecologically viable forestry because there are few if any long term examples. If the objective was to limit human influence as much as possible, we could then ban all human activities in forests and drastically modify our way of functioning to reduce our impact on the environment. If instead the objective was to produce maximum benefits for human consumption, a simplification of forested ecosystems could be sought so as to direct the flux of energy towards the benefits which most interest us (ex.: wood, game, landscape aesthetics, etc.). There is, however, a risk associated with this exercise as it is based on the postulate that we have a great enough understanding of our forest ecosystems to modify them without causing mid to long term negative effects. New scientific data suggests that in order to maintain the ecological integrity of an ecosystem and to render it less vulnerable to numerous stresses, it is necessary to preserve biodiversity, including the diversity of species processes and structural characteristics, at both stand and landscape levels. Looking at a current issue, the Y2K, who would have predicted that limiting the date used in computers to two numbers would have produced such potential problems at the dawn of the new millenium? This is a question dealing with (1) a fairly short term effect since this problem involves only a period of about 40 years and (2) a relatively simple system, a computer, and yet we did not foresee it until recently! The current tendency in forest management worldwide seems to be heading towards a compromise in which we still want to use our renewable natural resources, but at the same time we are trying to use them in a way that maintains their ecological integrity.

The notion of sustainability can be discussed for a long time, but we need to start putting it into practice with our current knowledge, limitations and constraints. We believe that it can be agreed that the basic principle is to maintain the ecological integrity of the forest ecosystem for all future generations. The problem is how to achieve this without putting the socio-economic foundations of our society into peril. Do we really know what the ecological integrity of the forest ecosystem is? The truth is no, but we have made some important progress. In addition, we now know much more about the complex and often unpredictable character of forest ecosystems. We also understand the need to consider a level of management much larger than the stand level. The big question is therefore how to reconcile all the often contradictory needs without compromising something in return. Is it really possible to maintain the ecological integrity of a forest ecosystem while extracting an important quantity of its energy, in the form of wood or game? Should we not speak more about forest management as an exercise of continuous improvement, in which the maximum benefits from the forest are taken while minimising impacts by maintaining the most important ecosystem processes? It seems obvious that almost any level of exploitation by human beings has an impact. The task is thus to determine what level of impact is acceptable for us and for the ecosystem, while understanding that all anthropogenic interventions modify in some way the ecosystem, and that it is thus unbelievable to think that these ecosystems can be maintained in a completely natural state while removing an important quantity of fiber. The science of ecology could thus be useful in determining acceptable levels of impact and the possible consequences of different interventions, although the final decision is always a « social » decision. First and foremost it is important to accept to think and act differently. This is probably the greatest challenge that we must face.

To encourage a change in the way of thinking and acting, it is necessary, according to Muschett (1997), to propose an alternative vision that is interesting to the majority of individuals. This can apply to forestry, and it is up to us to work towards developing an interesting alternative vision, and that is what will be discussed in this paper.

What is the boreal forest?

The boreal forest covers 12 x 10^8 ha (Landsberg and Gower 1997) or about 20% of the forested region of the world. According to Woodward (1995), the boreal forest is characterised by a period of 3 to 5 months where the average temperature is above 10^o C, and another period of 6 to 8 months where the average minimum temperature is below 0^o C. Globally, day-length in the summer varies between 15 and 24 hours, the angle of the sun varies between 45 and 67^o, precipitation varies from 300 to 1400 mm with more than 50% of the annual precipitation occurring during the summer. The low temperatures in winter and the importance of snow accumulation are also factors which differentiate the boreal forest from the temperate forest (Zasada *et al*. 1997). All these factors strongly influence the soil which is generally characterized as being cold, often poorly drained, with a thick layer of organic matter, as well as having weak biological activity and a lack of nutrients, particularly nitrogen. A good part of the most northern boreal forest is also characterized by permanent or semi-permanent permafrost. Fire is the most important disturbance and occurs with a frequency of 30 to 500 years, depending on the species, the topographic position and the local climate. Fire is an important factor which influences species dynamics, availability of nutrients and forest productivity. The importance of insect and gap disturbance in boreal forest stand dynamics is, however, being increasingly recognized (Kuulavainen 1994, Kneeshaw and Bergeron

1998). Tree species richness is quite low, there are only 9 dominant boreal tree species in North America (Payette 1992) and 12 in Finno-scandinavia and Russia (Helmisaari and Nikolov 1989). The forest is also characterized by a low diversity in mammal and vascular plant species, but a high diversity of algae, moss, lichen, mushroom and arthropod species. We must therefore considering diversity from the top (the crown) to the bottom (the soil) of the forest while looking at both spatial and temporal variability in stands to best appreciate the true diversity of the boreal forest. The bogs and humid zones occupy about 20% of the boreal forest, but their distribution varies greatly from one region to the next. Most of the tree species arrived in the region 2000 to 5000 years ago, making the boreal forest one of the youngest forest biomes in the world. The productivity is low on average, but it varies greatly depending on the species, climate, and type of soil. Landsberg and Gower (1997) estimate that the average net primary production of the boreal forest varies between 1.2 and 4.3 t per ha per year. By comparison, these same authors estimate that the average net primary production of the temperate deciduous forest varies between 0.8 and 9.8 t ha -1 per year -1. The capacity to regenerate sites generally depends on seed dispersal capacity, the presence of species with serotinous cones and the presence of roots which can sprout (Greene et al. 1999). Tolerance to shade and the capacity to reduce growth in some conditions of low light availability are also important characteristics of shade tolerant conifers like fir and spruce (Messier *et al.*, 1999).

The composition and structure of the boreal forest varies a great deal from one region to another. Rowe (1972) identified 45 regions in the Canadian boreal forest based on climate, physiography and species composition. In North America, the boreal forest varies greatly from south to north as well as from east to west. The distribution of tree species varies from one region to another but generally, deciduous species with firs and spruces, except black spruce, dominate richer sites (in Russia larch as well), whereas pines and black spruce are found on drier and poorer sites. It is also thought that the boreal forest constitutes an important carbon sink and that its commercial use will affect these carbon stocks differently than under natural disturbance regimes (Price et al 1997; Fitzsimmons 1995; Binkley et al 1997; Apps et al. 1995, 1999; Kurz and Apps 1995, 1999; Kurz et al. 1998).

What is the current use by human beings?

The boreal forest is still a relatively unmanaged forest (except in Sweden and Finland) in which industrial forestry activity, although growing, is still relatively recent. There are still immense areas which remain largely untouched by industrial human activity (First Nations Peoples had a relatively minimal effect). Human populations are widely dispersed and depend on natural resources to survive. Most countries covered to a large degree by this forest, such as Sweden, Finland, Canada and Russia, depend strongly on natural wood resources for economic activity (see World Commission on Forests and Sustainable Development http://iisd1.iisd.ca/wcfsd/wcfsdsummary.pdf). In addition to forestry development, the boreal forest is also used for hunting, fishing, recreation, mining development and hydroelectric development.

The way in which forests have been managed has changed over the history of its use. The evolution of forestry has proceeded from a period of mostly local wood-use and of land-clearing without regulation (in Europe and Canada, until approximately the 1700's) to the first early regulations of forest development (Kimmins 1992). These early regulation were not based on any biological or ecological considerations and lasted until about 1900. In the next phase of development an emphasis was put on wood production and sustained yield forestry of a regulated forest often using even-aged management. This stage was successfully developed in Sweden and

Finland, although most regions of Canada are still far from attaining this objective. In the interim, multiple-use forest management (in Canada until the 1990's) has been developed and advocated in which other resources (such as hunting, fishing, recreation, aesthetics) are considered and areas may be allocated for different uses. The final stage, which has only just recently begun, is the notion of the ecosystem as a whole in which individual entities are interconnected and often inseparable. Ecosystem management is thus concerned with the maintenance of ecological integrity and the health of the ecosystem in its entirety and with all its components

Socio-economic and ecological challenges for a truly sustainable boreal forest

The challenge of attaining sustainable management for the boreal forest is in part rooted in current and historic thinking about the way that forests are managed. In order to change the way that we think about these forests and their management, it is important to identify (or perhaps confront) the important problems that limit our ability to sustainably manage this resource. These challenges come from two areas 1) socio-economic and 2) ecological concerns about forest management. The integration of social, economic and ecological issues into decision-making systems is thus a crucial step towards sustainability. It is, however, difficult as there is little to no tradition for such integration.

Socio-economic challenges

Among the historical problems has been that, in North America and other areas of the world in which natural forests are still being exploited, the current growing stock was treated as a free resource. In other terms, the wood that is being harvested cost nothing to grow and forestry's capital costs consisted primarily of developing the infrastructure needed to get the wood and process it. In fact, in Canada it was, until relatively recently, thought that this 'free-resource was inexhaustible and as such the forest industry was encouraged to develop through the cheap sale of this large natural capital. Such a strategy has led to few investments being made in long-term, large scale management strategies. Similarly, little long-term thought was given to potential conflicts in land-use for this believed limitless resource.

The use and management of what is generally a large publicly owned forest resource has developed along the precept that all accessible productive forests that are not set aside for parks or other conservation purposes should support timber extraction. In the last few decades it has been shown (Lash 1998, Munn 1998, Theophile 1995) that other uses of the forest such as ecotourism and the production of non-timber resources (ranging from game, to wild mushrooms, and pharmaceutical products – such as the production of the cancer treating taxol from yew, etc. see examples in Burton et al. 1992) may produce economic benefits that are as great or greater than those obtained from wood products in some areas. Many of these other uses are in direct conflict with forestry activities. One of our current and future challenges will be to re-think our current system of land allocation e.g. addressing the assumption that the forest land-base should be automatically available for timber harvesting as it has been traditionally. In some cases, other non-forestry uses of the landbase that are incompatible with forestry may be more profitable and more desirable to society as a whole than timber production.

Furthermore, until recently, little thought was given to investing in a resource that had always been abundant. In fact, traditional forest economics function on a time-scale that is different from even that required for the sustainable management of the timber resource itself. Chapin and Whiteman (1998) note, for example, that from a pure economic standpoint, a timber supply is needed only for the 20 years required to pay-off the mortgage on a mill and not for the 100 years that it will require to re-grow the harvested forest. It has further been shown that natural ecological rotations are longer than economic forest rotations associated with regulated forests (Bergeron et al 1999, Burton et al 1999) and we must thus find ways of considering, evaluating and managing these long time-scale resources.

We must also recognize that it is difficult for human beings to work on scales that exceed our own first-hand perceptions and knowledge. It is, for example, difficult to work on long time scales (> 10 yrs), especially for governments and businesses, and on large spatial scales (> 100,000 ha). We are still much more confortable with stand level decisions than with land-scape level or boreal-wide decisions. However these are the scales at which many of the potential problems with biodiversity and sustainability may be expressed (e.g. large scale patterns of fragmentation, etc).

Ecological challenges

In order to manage the boreal forest in a sustainable fashion an understanding of the natural range of forest conditions is needed. However, natural systems (such as the boreal forest) are dynamic and thus continuously changing on both short and long-time horizons. A number of different natural states may thus exist for any given area (Sprugel 1991, Cumming et al 1996). The challenge is therefore to find a reliable way of determining the natural variation that exists within an area on different soil types and for climatic conditions similar to the present.

We are also faced with the reality that harvesting of forest lands began in the most productive sites close to the mills and urban centres. As forest harvesting continues, we are moving to less productive lands, whether they be higher in elevation or in latitude, that require much longer periods of time to produce harvestable volumes of wood.

From an ecological perspective, forest management produces some effects for which there are no natural analogues. The development of road networks for example creates relatively permanent long, narrow open corridors that divides areas. Even small rarely used roads can create non-traversable habitats for some small mammals (Darveau et al. 1994). The direct effect of human access on hitherto inaccessible tracts of land has been shown to have negative effects on the presence of many large mammals (Crete et al 1981, Brocke et al 1990). Even from a social perspective, opinion may be divided about the desirability of opening up access to the forest among similar user-groups. Local hunters and fishers may wish for greater access whereas the survival of fly-in hunting lodges, etc. may depend on the distance of their grounds from any roads.

The extraction of wood itself from the forest is another activity for which there is no comparison in nature. Natural disturbances that kill trees, such as fire, insect outbreaks, disease, windthrow all leave dead wood in place as snags or fallen logs. Such coarse woody debris has been found to be important for species diversity and ecological processes. Cavity nesting species are directly dependent on this resource (up to 20-40% of bird species (Hunter 1990). Lists of other species, ranging from ectomycorrhizal fungi, to marten to salamenders, that are dependent or use coarse woody debris have also been presented (Keddy and Drummond 1996, Maser et al 1979, Harmon et al. 1986). Dead wood is also important in nutrient cycling, providing long-term stable release of nutrients, and may reduce run-off and erosion. Sustainable forest management, thus require that foresters manage for the conflicting goals of protecting the forest against agents that kill trees and reduce the wood value and generating the coarse woody debris necessary to maintain ecosystem processes (Hagan and Grove 1999).

There are also many other unknowns with respect to the ecological impacts of forestry on ecosystem components. The effects of forest fragmentation in boreal forests, for example, is elusive as the effects of harvesting are usually ephemeral. That is, fragmentation due to forestry does not produce permanent edges (except for roads) unlike fragmentation caused by agriculture, and it is in agricultural systems that most of the research has been done (Burgess and Sharpe 1981). Similarly, we do not know the size of minimum viable populations of most species. Habitat requirements of the majority of species are another unknown and thus another challenge for managers of forest ecosystems. Despite these unknowns, we must move forward using the best scientific knowledge available even if it is incomplete, if not decisions about resource management will be made using other criteria (Franklin 1996, Roe 1996).

Some Essential Notions for the Development of a Truly Sustainable Boreal Forest *(i.e., which respects the 6 major criteria outlined by the Canadian Council of Forest Ministers)*

(1) Adopt the principle of management at the ecosystem level (i.e.. **Ecosystem Management**). To do this, it is necessary to consider the following factors:

(a) To understand the dynamic nature of the forest. The forest is in continual change and we should not necessarily force the return to a previous state (i.e. of the same species) after cutting (Kneeshaw et al. 2000). Instead the forest should be managed to preserve its dynamic character. Respecting natural dynamics is important; we are only beginning to understand that changes in composition are crucial for the long term maintenance of productivity and biodiversity (Attiwil 1994). In many provinces, the management guidelines specifically state that the current forest composition forest should be maintained after cutting, however this goes directly against what happens naturally in many boreal forests following catastrophic disturbances.

(b) To manage the ecosystem in its entirety and not only the trees. A forest ecosystem possesses the following 6 attributes: (1) structure, (2) function, (3) complexity, (4) strongly interdependent interactions, (5) limits and spatial levels which vary depending on the situation and (6) successional dynamics, all of which vary in time (Kimmins 1987). Recent research on ecosystems has clarified the importance of structural complexity, at the stand level as well as the landscape level, to maintain ecosystem functioning and biodiversity (Franklin *et al*. 1997). In certain types of forests, it is important to maintain structures such as snags, conifer debris on the ground, a multitude of layers of vegetation cover, a multitude of sizes and conditions of trees, and the presence of gaps. The simplification of forest ecosystems in Sweden, for example, is the leading cause of the disappearance of numerous species (Berg *et al*., 1995). It is also necessary to understand that following natural disturbances, there is an enormous “biological legacy” on the site which influences the future dynamics of the forest. All forestry development which completely eliminates this biological legacy threatens to profoundly modify the future dynamics of the forest. We do not well enough understand the importance of this biological legacy, but it is clear that it varies among different ecosystems. An acknowledgement of the importance of this biological legacy for the maintenance of the ecological integrity of forest ecosystems has caused numerous countries and regions within Canada to experiment with new (silvicultural systems) ways of doing things (Arnott *et al*. 1995; John Spence (Project EMEND in Alberta); (Project SAFE in Abitibi, Harvey 1999); National Board of Forestry 1990; Swanson and Franklin 1992; Scientific panel for sustainable forest practices in Clayoquot sound 1995; Watanage and Sasaki 1993, Hagan and Grove 1999, and most of the articles in the Forestry Chronicle’s vol. 75, no.3 special on long-term silvicultural research). The recommendations vary among countries and regions, but they all propose maintaining a greater complexity of ecosystems by modifying the length of rotations while retaining an important part of the structure and encouraging a mechanism for regeneration which follows the natural dynamics of these ecosystems.

Some practical applications of approaches to managing all components of ecosystems can also be seen in the development of certification standards for different FSC *(Forest Steward Council; Web Site: http://www.fscoax.org/)* regions. The Maritime or Acadian FSC region for example require that companies protect biological legacies in order to be certified. In Sweden, the certification process is putting an emphasis on the retention of live trees, stumps and dead wood. Their goal is to conserve biological legacies following cutting in order to encourage the maintenance of the ecological integrity of the forest ecosystem. This is especially important in the south of Sweden where the forest has been completely modified by man and one finds few natural or mixed forests or dead trees on the ground.

(c) To adopt a management strategy which encompasses stand, landscape and regional levels (i.e. to manage a level larger than that which meets the eye). Planning for an entire area is necessary to evaluate the cumulative effects and to maintain an ecological diversity in a given area. The science of landscape ecology is not new, but it has only recently begun to be applied (Crow and Gustafson 1997). It is now used to evaluate the effects of the fragmentation of an area, to evaluate the larger spatial and temporal processes, to study the effects of structural changes among different elements of the landscape, the corridors, etc. For the forest manager, landscape patterns are modified by the size and shape of the cuts, the spatial arrangement of the cut units, the frequency of the cuts and the intensity of the cuts. Several things can be affected by a change in the landscape structure. For example, Roland (1993) has shown that the duration of epidemics of the forest tent caterpillar has increased in Ontario with the increase in fragmentation of forest areas. To better manage the landscape, it is necessary to consider the composition, size, form and distribution of cuts in time and space and their effects on the ecological processes including the dynamics of insects, biodiversity (Tillman et al. 1994), succession (Carleton and MacLellan 1994), susceptibility to natural disturbances (Lefort and Leduc 1998), etc. Many analyses have shown that the cumulative effects of human activities cause a simplification in the composition and structure of the landscape and the creation of landscape elements for which there are no natural analogues. Such changes have often been justified by a greater efficiency in harvesting, however such thinking is not compatible with maintaining the integrity of the ecosystem.

Beyond the landscape, the effects of forest management at the scale of a province or even the boreal forest as a whole needs to be considered. These large scale patterns, highly linked to road networks, show general patterns of development from south to north, from valleys to high elevations, from productive lands to less productive and less accessible lands and from eastern provinces to western provinces. Such patterns suggest that government agencies need to consider large scale effects and the adjacency of different forest management units across provinces. This may also be important in considering large scale dispersal and the movement of individuals between metapopulations. Important questions to ask are whether innovative, new forest management strategies may be more applicable in northern areas and western provinces where large uncut forest areas still exist and whether more restorative efforts may be needed in southern forests and eastern provinces where large landscapes have already been modified.

At least one forest company is now trying to manage its forest resource using a landscape approach based on natural disturbance dynamics. In the mixed-wood forests of Alberta, ALPAC (Web Site: http://www.alpac.ca/): is also trying as much as possible to vary the pattern of cuts and to increase what is left on the ground following the cut to reproduce a greater diversity of disturbances than achieved with traditional cuts. They have developed a field guide for the operators which explains this approach. The company has invested heavily in research and development and worked closely with the (Sustainable Forest Management Network (SFMN: Web Site: http://www.biology.ualberta/sfm) to develop its strategy of ecosystem management.

(d) To base our interventions on <u>our understanding of natural disturbances and autecology</u> of the species involved (i.e. to emulate nature in our interventions in such a way as to potentially minimise the impact and conserve biological diversity) (Attiwill 1994; Galindo-Leal and Bunnell 1995; Messier 1996; Lieffers *et al*. 1996; Bergeron and Harvery 1997; Angelstam 1998; Bergeron *et al*. 1999; Kelly *et al*, 1999). It is not possible to fully copy nature; in fact, it is probably impossible and potentially undesirable (i.e. for the size of extreme disturbance events that may be hundreds or thousands of square kilometres!). We should instead investigate the possibility of minimizing human impact while using nature as our guide. Although the paradigm has not yet been proven through scientific methods, the ecological knowledge acquired to date enables us to propose management systems which favour a composition, structure and variation in time and space of stands similar to those which characterise the natural environment to maintain biodiversity and essential functioning in forest ecosystems (Franklin 1993; Gauthier *et al*. 1995; Kohm and Franklin 1997). This approach comes from the principle of the coarse filter approach which stipulates that it is impossible to manage for all of the species present in an ecosystem, as they are far too numerous, still unknown or not well understood. However, we estimate that by preserving the natural ecological processes in a given area, it is possible to maintain the diversity of all species, even those which are still little known or totally unknown. Researchers believe that species fitness has evolved in concert with natural disturbances in the boreal forest (Booth *et al*. 1993).

(2) To conserve a significant proportion (at least 12% according to the Bruntland report, 1997) of the boreal forest to be able to compare the impact of our interventions with a "control" system. We do not know enough yet about the impact of our interventions to predict for certain the full effect on the integrity of the forest. A network of control forests is essential to help us to evaluate, and modify as needed, our forestry practices. In Canada, for example, we protect only 3.4% of all areas from industrial activities (categories 1 to 3 according to the International Union for the Conservation of Nature) (Cantin and Potvin 1996). Within the boreal forest biome in Canada and Russia there is still an important portion of the land in a virtually natural state and we must absolutely protect large areas that are representative of diverse ecosystems. Protected areas of the boreal forests vary, in a strict sense in Canada, between 1 and 7%, depending on the ecozone (Anonymous 1997). We still have a chance to conserve some natural forests and we must not miss this chance. We must choose sites in a very meticulous way to protect all representative forests not just unproductive, distant, inaccessible or mountainous regions (Nilsson and Gotmark 1992). The goal must be not only to conserve some areas or species groups, but also to preserve processes which encourage the maintenance of biodiversity and preservation of some important ecosystem elements (Smith *et al*. 1996). In fact, it has been suggested that minimal dynamic land areas needed for conservation must be sufficiently large to maintain all successional phases in relatively constant proportion through time despite the occurrence of disturbances. In concrete terms, these conservation areas should be at least 50 times greater than average disturbance events (Shugart 1984, Shugart and West 1981), or 3 times greater than the largest known disturbance event (Johnson and Gutsell 1994, Pickett and Thompson 1978). In boreal forests, given the large size of extreme fire events, this will require huge conservation zones. It may also be possible to conserve forest areas through replicated reserves that are spaced far enough apart not to be affected by the same disturbance event. In all cases the processes at the source of biodiversity need to be better understood if we are to effectively protect it.

The province of Ontario has recently announced that 12% of all forest lands, of which a significant land area is in boreal forests, will be set aside from industrial use (OMNR http://www.mnr.gov.on.ca/MNR/oll/news/harris1.htm). What makes this agreement noteworthy is that forest companies and environmental groups participated actively in the undertaking. Furthermore, individual forest companies (e.g. TEMBEC in northwestern Québec) are also investigating the possibility of setting aside a certain proportion of their FMA landbase (Leduc and Bergeron, communication personal).

(3) To encourage the principle of « the Triad » (Hunter 1990, Seymour and Hunter 1993) in forest management, involving a mixture of intensive and extensive management as well as forest conservation. A proposal could be for example to have extensive or semi-natural management (i.e. ecosystem management) on more than 70% of the forest, intensive management on approximately 15% of land, and complete protection for the remaining 15%. For Canada this would involve significantly increasing protected zones and those under intensive management. The quantity of biomass of wood produced (kg or m^3) per unit of surface (ha) per year varies greatly according to the species, regions, type of soil, climate and the stage of stand development. However, this quantity of biomass of wood could be significantly increased by intensive silviculture, a well-planned choice of species for rapid growth and through appropriate genetic improvements. Without further research or more in-depth studies, but simply by using a more intensive silviculture it should be possible to increase the quantity of wood produced per ha/year by about 3 to 9 times greater than we currently take from the Canadian boreal forest. Such increases may permit us to set aside greater proportions of land than simple one for one swaps of intensive land production for conservation or it could be used as a financial incentive for companies to embark upon the path of setting aside part of their land-base on a voluntary basis.

In some parts of the country there are still large areas that could be used for intensive production on a restricted area of the forest. It will be important when choosing sites for intensive production to also consider protecting and applying forest ecosystem management or conservation to some of the productive sites. Productive sites shouldn't be monopolised solely for intensive management, since we risk the destruction of habitats important for the maintenance of biodiversity. To be realistic we should envisage taking approximately 45% of our current wood needs from only about 15% of the land through intensive forestry. In so doing, we could then introduce the principle of forest ecosystem management on another 70% of productive land, which would not need to produce as much wood as current systems as long as we could take another 55% of wood which would still be needed. This will enable us to free up another 15% of the land for absolute conservation.

Such a system could also be used to promote the development of high quality wood in which part of the 70% of the productive land could be managed using silvicultural techniques to produce bigger boles with less low quality 'juvenile wood' (Oliver 1999). Such wood would have a higher market value and in this way might also help compensate for land removals for conservation. Oliver (1999) presents a detailed overview of how an integrated management approach may be used to produce such high value wood and the advantages when compared to the high risk investment costs of intensive plantation silviculture and quickly produced low value wood.

In Sweden, the goal of the FLAKALIDEN Project is to determine the maximal productivity of the boreal forest by manipulating and eliminating all biophysical constraints, with the sole exception of tree biology and climate. The results of this project may tell us how to produce more fiber on a smaller portion of land through intensive forestry in order to liberate a certain proportion of land for conservation. After 10 years, their results suggest it is possible to increase fiber production of a Norway spruce forest growing in northern Sweden (near Umea) from 5 m^3 ha^{-1} per year $^{-1}$, for a forest not subjected to any competition, to 18 m^3 ha^{-1} per year $^{-1}$ when all water and nutrient availability limitations are removed (Dr. S. Linder, Comm. Pers.). Whereas, in Canada, for example, we produce on average approximately 1m^3 of wood per hectare per year. It is thus possible to produce much more wood per hectare on a small area if we practice very intensive forestry. This project is also interesting because it shows us the biological limits of productivity for a typical boreal forest.

(4) To be innovative in our use of the forest it is necessary to avoid the *status quo* and always have an open mind about new ways of doing things. It should also be said that government and industry should invest in innovation and youth training and education. We must stop thinking that all changes cost too much, or are impossible, etc. We must take the initiative and continually evaluate how to improve the environment, society and our competitiveness. Natural history and human history teach us that anything which cannot change disappears!

An example from B.C. shows just such innovation when the forest company MacMillan Bloedal decided to stop fighting with environmental groups and start working with them. Such cooperation resulted in changes to forest practices, notably the modification of harvesting techniques so that traditional clearcuts would no longer be permitted. Similarly, a desire for FSC accreditation has also led the Irving forest company in New Brunswick to change their practice of converting hardwood stands to black spruce even on their private forest lands. In Quebec, despite initial concerns from the industry about the costs and implementation of cuts with protection of advance regeneration, such harvesting is now the accepted norm and cuts followed by planting are now viewed as more costly. In fact, a review of the past twenty years of forest management has shown continuous change (Erdle 1998), and this needs to maintain if not accelerated.

(5) To continually question our forestry practices through a rigorous follow-up and quality research. The forestry industry and governments should massively invest in research and development so that we keep learning and improving our forest management practices. Industry should continually avail itself of new information and techniques. It must especially follow and adapt more rapidly to the accelerating evolution of paradigm shifts in forestry. A progressive pro-active approach rather than a conservative wait-and-see (ride-out-the-storm) approach should be adopted. The new partnership developing between some forest companies and university researchers through the Sustainable Forest Management Network (SFMN: Web Site: http://www.biology.ualberta/sfm) illustrates a good example of how new thinking and knowledge about forest management can be quickly transferred to practice.

(6) To know the distinctive socio-economic features of each region being managed because sustainable forestry is first and foremost for the people, and the people of the region must completely subscribe to it. We must also understand that the boreal forest does not belong only to those people living in regions, but that it constitutes a world resource. Understanding and managing for the needs of local communities and societies at large should become a greater concern for resource managers at all levels. Thus forest should be used and managed for the common good of all.

Alternative models to traditional industrial forest management agreements are being devised in a number of jurisdictions in order to better address diverse social and economic activities. One such example is of the community based management agency being set-up in Bracebridge, Ontario (Carrow 1997). This non-government agency will replace the traditional government SFL (sustainable forest license) normally used as the forest management agreement for crown lands in order to reflect the varied socio-economic interests involved in the region's forests.

(7) To know that in order to attain a sustainable forest, it is necessary that the public be involved, and that to be involved, it is necessary that they are well-informed. We must work towards a better understanding by the public of environmental matters. A public which is well-informed constitutes a wealth of ideas and initiatives which can only benefit society.

A collaborative learning approach (Daniels and Walker 1996) may provide such a formula in which stakeholders exchange their knowledge, their values, their perceptions, and their expectations regarding forest resources. This approach is different from traditional conflict resolution and multiple decision making approaches in that it does not seek an immediate resolution to conflicts (e.g. through goal optimisation and constraints) but rather a gradual improvement of conditions through a shared understanding of problems. This participative formula has only quite recently begun to be applied to forest management with its first testing beginning in Canada in 1999 (e.g. a SFMN project in Québec on Cartons St-Laurent's private land).

(8) To acknowledge that climate will no doubt change in quite a pronounced way over the next 100 years and that there will be consequences for forestry (Pollard 1985). The climatic changes which have occurred over the last 12,000 years have greatly affected forest ecosystems and they continue to do so. Researchers believe that current forest communities are not perfectly adapted to current climatic conditions and they will continue to evolve. Although forest communities which make up the boreal forest are adapted to a certain point to changes in climatic conditions, the changes anticipated for the next 100 years constitute a rapid modification of climate which will totally change the current conditions and profoundly modify the dynamics of the boreal forest (Bergeron *et al.* 1998). We must therefore try to better understand the changes which will occur and maintain forest ecosystems which are most apt to adapt to these changes. A good understanding of the autecology of species is therefore necessary to predict and to influence the future composition of our forest in a way that minimises the effects of climatic changes. We must also work together to do our best to slow down the speed of predicted changes by decreasing the quantity of CO_2 produced. Some recent changes in climate (Chapman and Walsh 1993) and nitrogen deposits (Vitousek 1994) in the boreal region are already starting to cause changes in the productivity of the forest (Kauppi *et al*. 1992).

Results from the BOREAS Project in Canada (Web Site: http://boreas.gsfc.nasa.gov/), suggest that although the boreal forest continues to be a carbon sink that only a slight change in temperature could transform this sink into a source of carbon. The new understanding of energy exchanges between the boreal forest and the lower atmosphere developed in this project will allow us to improve our simulation models and our understanding of the influence of climate and of climatic changes on the functioning of this ecosystem, particularly concerning modifications of patterns of temperature and precipitation. Such information will be useful if we begin managing the boreal forest for its contribution to the atmosphere (Fitzsimmons 1995).

(9) To encourage regulations which are adaptive rather than restrictive. The legislative framework for forest management often does not encourage a forest ecosystem management approach. In its desire to simplify and regulate nearly all the forestry operations carried out in the forest, it tends to

make the operations uniform for all situations and does not take into account the incredible diversity of conditions which exist on the land. The regulations are absolutely necessary, but they must not become an obstacle to innovation, for they will instead become a source of problems rather than solutions. We must take another look at the way in which we do things and produce forestry management manuals which encourage creativity and innovation. There is more and more talk of the necessity for adaptive management (Walters and Holling 1990) to attain the objectives of sustainable development. It is therefore necessary that regulations be developed to encourage the emergence of such a system.

This message must be made clear to those developing and implementing forest certification systems if they are truly to be successful (CSA 1996, FSC 1996, see also web site http://www-personal.usyd.edu.au/~wnixey/contents.htm). Currently, at least this spirit exists in many of these programs and must be fostered. Other proposals have also been put forward to ensure the sustainability of ecological factors during forest management through an understanding of natural variability and the use of planning and then monitoring indicators in a feedback loop (Kneeshaw *et al.* 2000).

An Example

A panoply of alternative management strategies have been proposed recently for the Canadian forests. Ideas ranges from increasing the intensity of our forest management practices (Binkley 1997) to low intensity forest management practices that promote quality over quantity (Oliver 1999). These ideas deal mainly with issues of wood supply and cost, and not directly with that of maintaining healthy forests for all other living creatures that inhabit these ecosystems. In order to maintaining biodiversity in our forest, the idea of basing our silvicultural practices on natural disturbances has been proposed as an alternative to the current logging practices (Burton et al. 1999; Coates and Burton 1997; Lieffers et al. 1996; Kelly et al. 1999; Bergeron et al. 1999).

A good example of what forest ecosystem management using natural disturbance as a base for our management practices for black spruce could become is presented by Bergeron *et al*. (1999). These authors propose using a mix of silvicultural practices in time and space for a certain area to recreate the diversity of structure and function that we naturally tend to find in this forest biome. This simple conceptual model is based on (1) an understanding of the fire cycle and its relationship to composition, (2) the maximal age of harvesting of species being managed and (3) the autecology of the species involved. The basic principle is totally different from the normal goals in forestry in that it does not aim at producing a regulated forest. It encourages, instead, a lengthening of the rotation of a given stand on a good part of land-base as a function of a given fire interval. Such a system would maintain a proportion equivalent to that which is found naturally in old-growth stands of more than a normal forestry rotation (in this case 100 years). A part of the biomass potentially lost could be recuperated by carrying out partial and selective cuts between the total cuts but in order to maintain an old growth forest structure, it is necessary to conserve old trees, snags and dead wood on the ground (Graham and Jain 1998, Hagan and Grove 1999). Maintaining the biological legacy is essential to maintaining the ecological integrity of the ecosystem. As these authors have so elegantly shown, the desired proportion of different cohorts should vary according to the natural fire cycle in a region to be managed and the maximal age of harvesting for the species. The shorter the cycle of natural disturbances, and the greater the maximal age of harvesting, the more total cuts can be allowed without being overly concerned about maintaining older cohorts. For the black spruce forest of Canada, it has been suggested that the maximal age of harvesting does not vary much. The percentage of the total cut that could be carried out without great planning to maintain older cohorts should decrease from east to west as the fire system is much longer in the east than in the west. For a region with an average fire cycle of 100 years and a maximal harvesting age of 100 years, these authors estimate that about 63% of the land (or stands) can be cut after 100 years, 23% after 200 years (perhaps carrying out partial or selective cuts in between) and 14% after 300 years. This corresponds approximately to what is found naturally in the black spruce region with a fire cycle of 100 years. Such a management strategy risks producing less wood than a strategy which follows a regulated forest rotation of 100 years and it could be improved with intensive forestry on a small portion of the area. In addition, as previously mentioned, it is essential to introduce an extensive network of protected forests to conserve some control areas to evaluate our new models of management and modify them as needed.

This is obviously a simple example, but one which could be modified for other ecosystems, species or mixtures of species. It is also, in part, a stand level approach in that it doesn't at this point prescribe how the different cohorts should be allocated on the landscape. Some landscape planning in terms of adjacency constraints should be applied to truly manage for the maintenance of biodiversity. This model is not perfect, but it has the advantage of clearly and simply showing that by using the methods and techniques presently approved, as discussed by Graham and Jain (1998), through emulating nature, we can greatly improve the situation. This is in fact acting *differently*, but without getting rid of the whole system. It is important also to consider this proposition as an open experiment in which further improvement (adaptive management!) will be required as our knowledge and expertise increases.

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