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SUSTAINABLE FOREST MANAGEMENT

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ABSTRACT

A key theme of ecosystem management has been to attempt to maintain ‘natural’ processes and patterns. Due to recognition of the role of natural disturbances such as forest fires and insect outbreaks in population and ecosystem processes and patterns, these disturbances have been proposed as a model for sustainable forest management. However, in order to evaluate the usefulness of such a proposal, we require an adequate understanding of the specific role of these disturbances in determining and/or influencing population and metapopulation dynamics of the forest species and the silvicultural methods that may or may not mimic such effects. The speakers in this symposium discuss these issues as well as some more general topics of forest sustainability. Specific examples of attempts at both restoring and maintaining forest ecosystems are presented from a range of forest types around the world.

In the last few decades, there has been a rapid increase in demand for the products and services forest ecosystems supply. Concurrent with this demand has been a logical concern with the sustainability of these products and services. Of course, this is not the first time that growth has created concern for sustainability. Forest management has gone through several of these periods in which an ever-increasing list of forest products and services has required more all-encompassing management, e.g. from sustained yield, to multiple use, to integrated management, to adaptive management, to ecosystem management. The difficulty has always been how to implement the new, often vague ideas of forest management and sustainability with professional practices based on a scientific understanding. In the last decade, there has been a large number of different lines of research being conducted to help build a set of professional practices which allow the implementation of ecosystem-based management in different kinds of forests, in different social-cultural and political settings. The speakers in this symposium showed this great diversity of approaches. However, some useful lines did emerge and will be the subject of discussion here.

The largest collection of papers in this symposium was from boreal and northern temperate forests in which there is an attempt to test the ‘emulation of natural disturbance’ hypothesis. This hypothesis suggests that, since wildfires and insect outbreaks are important natural disturbances in these northern ecosystems, forest management could emulate these disturbances in order to approximate ecosystem-based management. Of course, the first step must be to know something about the natural fire- and insect-generated patterns that are to be emulated. Bergeron, Carcaillet, Flannigan, Gauthier, Prairie and Richard of the Université du Québec à Montréal, Université de Montréal and
the Canadian Forest Service have been interested in the Holocene variability of fire frequency and forest composition of the southern boreal region in western Quebec. Their studies at different time-scales stress the great variability in fire frequency and associated forest composition during the Holocene. They suggest that, in this region, warmer periods are associated with a decrease in drought frequency and thus are related to important decreases in fire activity. The fluctuating fire frequency can explain some of the observed changes in forest composition during the Holocene. However, the continual change of climate, together with the long periods of time required for the establishment of an equilibrium between vegetation and fire frequency, do not allow for a direct relationship between specific fire cycles and vegetation composition. This factor, together with the large fluctuations observed in fire frequency during the Holocene, limit the use of a single fire cycle to characterize natural fire regimes. This naturally occurring variability should be preserved by forest managers through the selection of silvicultural techniques that maintain a spectrum of forest compositions on the landscape.

Similar fluctuations in past fire regimes were found in western Canadian boreal forest and aspen parkland by Campbell, Collins, Flannigan and Campbell of the Canadian Forest Service and the University of Alberta. They used charcoal and pollen in lake sediments from several sites to investigate past fires. They concluded that two sites showed reduction in fire activity during periods of warmer climate, one site showed indirect effects of bison hunting, and the other sites showed an increase in fire activity with warmer climate. The southern edge of the North American boreal forest has been fragmented by settlement in the early part of the 1900s causing changes in fire frequency and forest composition. Gauthier, Lefort and Bergeron explored this in a 7000 km² area of the Clay Belt of western Quebec using a 236-year fire history. Their study area included two sectors which were devoted to different land use objectives since the first European settlements in the region around 1910: agriculture and forestry. The results suggest that fire frequency decreased in both sectors after 1850, but prior to the settlement of the study area, suggesting a response to a climatic signal. Moreover, in both sectors, no fire larger than 300 km² has been observed since 1930. Since colonization around 1910, the agricultural landscape has been characterized by a higher fire occurrence than in the forestry landscape, whereas the mean fire size is five times smaller in the agricultural than in the forestry landscape.

Clark, Gauthier and Bergeron from the Université du Québec à Montréal considered the large-scale effects of climate change and disturbance on forests using FORSKA2. Throughout the boreal forest, fire is of fundamental importance in controlling forest structure and composition at both the stand and landscape level. Additionally, spruce budworm outbreaks are another prominent boreal forest disturbance, particularly in eastern Canada. The closely coupled nature of fire and spruce budworm outbreaks requires an integrated modeling approach to understand the interaction between these disturbances. Furthermore, the consequences of future climate change on these disturbances have received considerable attention and are presently under debate. Natural disturbance processes in the boreal forest are of great significance, and thus Clark et al. hypothesized that the effect of climate change on the disturbance regime may be more consequential for forest dynamics than climatic change per se. Sustainable forest management aims to emulate natural disturbance processes and thus requires detailed information on both historical and future climate/disturbance interactions. The importance of modeling disturbances at different spatial resolutions, from the stand to landscape level, is central to this approach.
Hely, Flannigan and Bergeron studied the relative importance of vegetation and climate on fire behavior in the balsam fir-white birch forest in northwestern Quebec. Stand composition, fuel types and weather data were entered in fire behavior simulations using the Fire Behavior Prediction from the Canadian Forest Fire Danger Rating System and the BEHAVE Fire Behavior Prediction and Fuel Modeling from the United States National Fire Danger Rating System. Three different fire weather regimes (low, moderate and high) were simulated on three types of stands (deciduous, coniferous and mixed). The ultimate objective of their study was to incorporate fire behavior into the fire disturbance subroutines of forest dynamics models.

W.J. Reed of the University of Victoria, Canada examined the distribution of forest fire sizes. The empirical evidence has long shown that roughly one percent of the fires cause 99 percent of the area burned. Reed suggests that one approach to modeling this distribution is based on the notion of hazard rate functions which can produce a heavy-tailed distribution and some parametric forms for the fire size distribution which agree with observed data. Understanding these distributions is important since they are essential in determining the patterns of forest ages created by fires. This is the pattern to be emulated by forestry in ecosystem management.

Miyanishi, Bajtala and Johnson of the University of Guelph and the University of Calgary, Canada, discussed the patterns created by duff consumption by fires in the boreal forest. For boreal forest tree species with serotinous or semi-serotinous cones, a major factor in post-fire seedling regeneration is the availability of suitable seedbed conditions (i.e., exposed mineral soil). Duff consumption by wildfire and the resulting exposure of mineral soil is very patchy within burns. Duff consumption occurs by glowing combustion after passage of the flaming front and is influenced primarily by the amount of duff moisture. Thus, factors influencing the spatial pattern of duff moisture would be expected to determine the post-fire pattern of exposed mineral soil and of seedling establishment. These factors include within-stand variation in precipitation inputs due to canopy interception and rates of duff drying due to canopy shading. Variation in moisture inputs and loss would thus be affected by the density and sizes of trees, as well as species differences in crown architecture. In this study of a 1996 burn in central Saskatchewan, they found, as predicted, significant differences between *Pinus banksiana* and *Picea glauca* dominated stands in the amount and spatial patterns of duff consumption as well as significant spatial correlations between patches of duff consumption and standing fire-killed trees. Thus, suitable seedbed conditions tend to be located directly beneath the canopy of fire-opened seed-dispersing cones. This suggests that the density, species composition and spatial distribution of stems within these stands are likely to be similar before and after the fire.

Charron and Greene of Concordia University, Canada, then examined the reason for survival differences in *Pinus banksiana*, *Picea mariana* and *Picea glauca*, and for one deciduous species, *Populus tremuloides*. They found an allometric function relating initial germinant length (L) to seed mass (m): L = m^{0.33}. Thus, small-seeded species in the boreal forest produce small germinants which are invariably found only where high porosity (i.e. rapidly drying) organic layers are thin or absent. Mineral soil and humus, which on average represent about 50% of available seedbeds following a fire, account for 95% of the germinants that establish from dispersed seeds. Relative first year survival, which is the proportion of one year old germinants over the proportion of a particular seedbed, is on average 20 times greater for germinants on mineral soil and humus than on organic
seedbeds. Also, as expected from the previous study by Miyanishi et al., germinants showed a clumped distribution around tree boles due to the decreased organic layer depth. Around 90% of the dispersed seed of *P. banksiana* and *P. mariana* germinate within the first three years following a fire, due to the exhaustion of aerial seedbanks. It is therefore possible to get adequate stocking rates after harvesting by means of natural regeneration by knowing the proportions of seedbed types and the seed inputs of all species.

Greene then presented three models which predict the regeneration density after wildfire for eight boreal tree species. The first model (for *Populus* species) expresses asexual regeneration density (F) as a function of time since burning and of pre-fire basal area density (B). The second model (for the two species with aerial seedbanks: *Pinus banksiana* and *Picea mariana*) expresses sexual regeneration density (F) as a function of B and of first year cohort mortality. The third model (for all species) is for sexual recruitment from living sources and simply attaches a dispersal term to the second model. Recruitment was found to be predictable with the percentage of explained variance from five fires invariably greater than 50%. Further, both model predictions and empirical studies indicate that there is little change in species composition following fire.

Gutsell and Johnson of the University of Calgary, Canada, gave cohort life table reconstructions for the five upland tree species in the southern mixedwood boreal forest. Across the boreal landscape, *Pinus banksiana* occurs on the top and middle of glaciofluvial hillslopes, while *Picea mariana* occurs at the bottom of glaciofluvial hillslopes. *Populus tremuloides* occurs on the top and middle of glacial till hillslopes, *Abies balsamea* is found middleslopes and *Picea glauca* is found middle and at the bottom of glacial till hillslopes. Their results indicate that succession, i.e. species replacement in time, and gap-phase replacement do not play a significant role in the dynamics of these species. In *P. banksiana* and *P. mariana* stands, canopy composition is determined within the first three years after a fire. Age-height curves show that in mixed stands, a conspicuous change in the canopy from *P. banksiana* to *P. mariana* is due to differences in growth rates between the species. In mixed stands of *P. glauca*, *P. tremuloides* and *A. balsamea*, canopy composition is determined within the first five years after a fire and may include all three species. Age-height curves again show that the conspicuous change in the canopy from *P. tremuloides* to *P. glauca* to *A. balsamea* is due to differences in growth rates between the species. Seed dispersal can affect the recruitment rate of *P. glauca* and *A. balsamea*, which rely on the survival of live seed sources. Recruitment rates are higher where a live seed source is within 100 m of the burn edge, and becomes lower with increasing distance. Thus, the idea of mimicking natural disturbances such as wildfires in forest management in the boreal forest must focus on early establishment and seed dispersal processes rather than succession or gap phase replacement.

V. Lieffers of the University of Alberta, Canada, continued with the principle of silvicultural systems mimicking processes and stand development patterns that occur in natural forests. Although his talk focused on general principles, he used the Canadian boreal mixedwood forest as an example. Immediately after a disturbance, this forest type is dominated by the shade intolerant and clonal species, *Populus tremuloides*. The shade tolerant *Picea glauca* must recruit into these stands from seed and thus gradually dominates in later decades. This forest may have varying composition, depending on fire dynamics. *P. tremuloides* root systems and those of important competing species may be damaged by fires or may remain intact and capable of vigorous clonal reproduction. Similarly,
appropriate seedbeds for *Picea glauca* may or may not be produced depending upon the depth of the burn. The spatial distribution of surviving *P. glauca* seed trees may influence the density of seed rain. Both intensive and extensive management systems could benefit from this knowledge. Mechanical or fire treatments that influence upper soil layers could be used to promote clonal growth of *P. tremuloides* or develop seedbeds or planting sites for *P. glauca*. Partial retention of canopy to provide shade and maintain seed trees in the vicinity could be used to promote stands of various structures and composition.

P. Zedler of the University of Wisconsin, USA, considered plant conservation in fire-influenced shrub ecosystems. The minimum requirement of a successful conservation program is the preservation of all the constituent species. In systems subject to recurrent catastrophic fire, human modifications of the fire regime may have serious short and long-term consequences for the persistence of native species and may also influence the susceptibility of the system to invasion by exotic species. This problem is explored using examples from the semi-arid shrublands and woodlands of southern California by identifying two main risks: senescence risk, the risk of disrupting ecosystems by withholding disturbance; and immaturity risk, the risk caused by imposing disturbance too frequently or with too short intervals. Data on life history traits and on changes observed in long-term monitoring plots in chaparral and woodland are used to support the argument that senescence risk is of little concern in the short run, whereas immaturity risk is a serious problem, especially given the desire to impose management burns with the primary objective of improving public safety and reducing economic damage.

Julien and Lemperiere of Université Paris and Université Joseph Fourier, France studied the influence of the state of trees on damage caused by bark beetles (*Dendroctonus micans*). Their trials carried out in five areas of spruce forests in the Massif Central of France showed that some trees were subject to more frequent attack than others. However, they found that the number of attacks was the same for both damaged and undamaged trees. They suggested that *D. micans* may be a useful biological indicator of forest condition. Traditionally forest sustainability is rooted in forest practices, silviculture, forest development, diversity, and site conditions. Takahashi and Haibara of Chiba University and Tokyo University of Agriculture and Technology, Japan, considered ways of preventing soil fertility decline in Japanese cypress (*Chamaecyparis obtusa*) by growing them in different mixes with deciduous broad-leaved trees. Broad-leaved litter decomposes more easily than cypress litter and its presence in the mixed stands resulted in significant increases in soil permeability, carbon, pH, base saturation and net nitrogen mineralization rate. Generally the higher the proportion of broad-leaved trees in the stand, the greater was the improvement in soil quality.

Zagas, Tsitsoni and Gkanatsas of the University of Thessaloniki (AUTH), Greece, presented a ‘close to nature’ silvicultural strategy for sustainable forestry in Greece, based on natural regeneration and silvicultural treatments which attempt to emulate natural ecological processes. The main objectives of this silviculture are to improve stand stability, habitat conservation, and flora and fauna diversity with the ultimate goal of maintaining the natural diversity of stand structures and mixtures of different forest species found in Greece. They reported on successes such as the conversion of coppice forests to high forest through such silvicultural treatments. As a further example of forest stand improvement through silvicultural treatments, Zagas, Gkanatsas, Tsitsoni and Hatzistathis then presented the results of different
thinning intensities (10%, 20% and 30% of basal area) on coppice stands of *Quercus iler*. Initially, due to the lack of any silvicultural treatment and the resulting extremely high stem densities, stem quality and vitality of these stands were low. Two years after thinning, the quality and ecological stability of the stands showed improvement. The higher the initial density, the greater the thinning intensity required for such stand improvement. Fire resistance of the stands was also increased by thinning and thin-chopping of dead stems, branches and harvesting residues.

P. Sunil of Indira Gandhi Agricultural University, India reviewed the state of forestry practices in different forest types and different ecological zones of the southeast region of central India. The tropical dry and moist deciduous forests characteristic of this region have been strongly influenced by human activities through history, by clearing for cultivation, by collecting wood and non-wood products, and by grazing. In spite of these disturbances, the present forest cover is 43.2% more than stipulated by the National Forest Policy. However, in recent years, the forested area has been declining at an increasing rate. Rational use of forest resources lies in managing these resources to yield the greatest sustainable benefit to the present generation while maintaining their potential to meet the needs of future generations. Sunil indicated the need for improved forest management practices based on ecological principles.

The effects of selective logging on litter production, decomposition and C/N ratio in Brazilian Atlantic forest was described by Villela, Buffon, Aragao, Gama and Nascimento of Universidade Estadual do Norte Fluminense, Brazil. Since the Brazilian Atlantic forest now covers only 12% of its original area of 1,000 km² and is threatened by logging, the impacts of selective logging on the sustainability of this forest are of interest. While litter production was found to be similar in unlogged and selectively logged plots, rates of litter decomposition, carbon release and nitrogen accumulation differed significantly. Thus, selective logging does appear to affect ecological processes involved in nutrient cycling and forest sustainability. In evaluating forest sustainability, ecosystem and biodiversity monitoring have often been the approach of choice.

A. Faassen-Thiebes of the Technical University in Berlin, Germany, discussed some guidelines for ecosystem monitoring in the context of sustainability. The assumption of the proposed approach is that there is no general sustainability but only uses and functions that can be performed in a sustainable way. These uses and functions include timber production, recreation, generation of clean ground water, nature conservation, and air pollution sink. For these uses, the actual situation, long-term development and interactions between these different functions are evaluated separately. Two difficulties with this approach were identified: (1) the actual tree species composition often differs from the natural state in most sites; therefore, a change in composition may be desirable; (2) soil conditions have been changed by land use and regeneration may be a result of improved forest management, leading to changes in the ground flora. Furthermore, these two trends are interrelated with ecosystem changes from air pollution, invasive plants, changing groundwater levels and forest management but must be separated in the assessment. Clear-cutting of secondary mixed forests and planting of timber crop species are major forestry practices in mountainous areas in southern Kyushu, southwestern Japan. These forestry practices include leaving shelter belts with a regular width surrounding a cutting area in order to prevent landslides. However, no attention has been paid to the loss of species diversity.
Teraoka and Ito of Kagoshima University and the Miyazaki University Forest examined the impacts of different clear-cutting regimes on species diversity in this region on the basis of natural distribution traits of native species. The spatial distribution of native species in this region are strongly influenced by topography, because of the differences of environmental and natural disturbance regimes. The occurrence of native species were analyzed in relation to the distance from the stream in the investigated small watershed. From this analysis, the disappearance probabilities of each native species were simulated in relation to different cutting block sizes and rotation periods. The results showed that only species specific to ridges (i.e. Tsuga sieboldii, Quercus crispa, Carpinus laxiflora or Pinus densiflora) would be left after a large scale clear-cutting. This would result in the decline of species diversity with a loss of many riparian species. They suggested that the decline of species diversity might be prevented by selection of an appropriate cut block size and rotation period.

In addition, Ito, Nakagawa, Nogami, and Buckley of the Miyazaki University Forest and the University of London considered species richness in Cryptomeria japonica plantations. Richness of trees, shrubs and climbing plants were investigated in 40 C. japonica plantations of different ages and size in southern Kyushu, southwestern Japan. Altogether, 282 species were found, including 145 infrequent species. The average species number of these plantations was almost half that of natural stands in this region. Two groups were extracted from the infrequent species list: 67 species which tended to appear in older stands, and 28 species that tended to appear in younger stands. The younger stand group included a higher percentage of climbing plants and species with wind-dispersed seeds. The existence of this type was slightly dependent on stand age, but independent of stand area. In contrast, the older stand group contained major tree components typical of natural, broad-leaved evergreen forests in the region. The integrity of this group was not severely affected by stand areas more than 1 ha, but was heavily dependent on stand age, especially for species with gravity- and bird-dispersed seeds. The number of species of this type declined in restocked stands surrounded by conifer plantations. These results suggest that species richness is determined by the presence of old stand types and that the major components of natural forests disappear in younger stands lacking an adjacent seed source. The normal rotation period of C. japonica plantations (50 years) may therefore be too short for the conservation of the maximum potential species diversity.

Restoration in many parts of the world must be an integral part of recreating sustainable forest ecosystems. Shi, Cheng and Liu of the Chinese Academy of Forestry in Beijing studied changes in diversity during restoration of Quercus variabilis forests at Bao Tianman Mountain, one of the national reserves in Henan province which had been previously managed for harvesting and tree farming of oriental oak. Their study documented differences in three diversity measures (the Margalef richness index, the Shannon-Weaver variety index, and the Pielou evenness index) between original forest and forests that had been clearcut in 1968, 1978, and 1992. Trends in these indexes varied depending on the group of plants being considered (i.e. trees, shrubs, herbs, all species).

The restoration of Danube floodplain forests has been studied by J. Oszlanyi of the Slovak Academy of Sciences, Slovakia. Almost 80% of these floodplain forests are poplar clone monocultures that cannot survive without intensive intervention of foresters. Such forests are ecologically unstable; their only natural and stable part is the shrub layer. While such intensively managed monocultures are of high productivity, their ecological value is low. Replacement of monocultures by native species is the only way to solve this problem.
Regeneration of native dolomite grassland vegetation on burnt pine plantations in Hungary was studied by Csontos, Tamas and Kalapos of the Hungarian Academy of Sciences and Eotvos University. Greenhouse germination tests of soil samples collected from *Pinus nigra* Arn. stands planted on the dolomite slopes showed that the grassland species seed bank becomes depleted over time. Only a few species (e.g. *Carex humilis* Leyss., *Teucrium montanum* L., *Campanula sibirica* L.) maintained a seed bank for decades. Monitoring of a 0.6 km² burnt *Pinus nigra* stand surrounded by intact pine plantation showed extremely sparse vegetation cover (below 2%) in the first year after the fire, indicating both the low number of viable seeds in the soil and the lack of sufficient seed rain. Although vegetation cover increased 15-45 times by the second year, successional species contributed to this change 6-7 times more than the grassland species with *Conyza canadensis* (L.) Cronq. as the main colonizer. In a buried seed experiment, *Scorzoner a autriaca* Willd., was classified as transient, *Ferula sadleriana* Ledeb. showed short term persistence, while six species (*Carex liparicarpos* Gaud., *Dianthus pontederae* Kern., *Inula ensifolia* L., *Silene oitites* (L.) Wib., *Teucrium chamaedrys* L. and *Verbascum lychnitis* L.) maintained long term persistent seed banks. These results have implications for the regeneration of native grassland from years of land use as pine plantations.

Specific papers on products and services provided by forest ecosystems were also considered. J. Grau of the Instituto de Ecología de Cile Secretario General gave a colorful presentation of sustainable extraction of sap from the *Jubaea chilensis* palm. Sap from *J. chilensis* has been extracted in Chile for more than 200 years for the manufacture of palm syrup food products. The method used causes the death of palms older than 50 years of age. Two centuries ago there were millions of palm trees along the Chilean Coastal Mountain Range; today there are only one hundred thousand. Grau argued that sustainable sap extraction from living *J. chilensis* palms can be applied, thus stopping the continuous destruction of one of the most majestic palm species.

Finally, M. Hadley of UNESCO, Paris, gave a complete outline of the changing view of ecosystem products and services offered by tropical forests and how this must result in changes in forest research and management. Increasing attention to the rights and local knowledge of forest-dwellers, and the globalization of the economies and the increased presence of a powerful multinational private sector, are among the trends which are resulting in changing role and functions in forest management and research. Changing roles include the increasingly dominant position of the private sector in production forestry, the declining direct participation and changing function of government bodies in forestry, the return to older concepts of multiple use forestry in non-production forest and the corresponding emergence of ecosystem management as an overriding research paradigm, and moves to restore the responsibilities of local people in forest management.