Ecological Applications, 12(2), 2002, pp. 390–397

LANDSCAPE ECOLOGY AND FOREST MANAGEMENT: DEVELOPING AN EFFECTIVE PARTNERSHIP

STAN BOUTIN[1,3] AND DARYLL HEBERT[2]

[1]*Alberta Pacific Forest Industries Ltd., and Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada T6G 2E9*

[2]*Encompass Strategic Resources Inc., RR#2 599 Highway 21, South Creston, British Columbia, Canada V0B 1G2*

Abstract. Landscape ecologists have been eager to make their research applicable to forest management. We examine how landscape ecology has contributed to shaping the way forest management is currently practiced. Landscape ecology research in forested ecosystems can be divided into two general areas: (1) the study of fragmentation issues, which focuses on the effects of forest fragmentation on species conservation; and (2) the development of landscape projection models, which focuses on patch dynamics and the effects of spatial arrangement of patches on ecosystem processes. Fragmentation issues have become priorities in the minds of forest managers, but research to date has overemphasized the effects of landscape structure on species conservation. We suggest that the research focus should move toward the study of threshold effects of landscape change on the relative influence of habitat loss and habitat configuration on species conservation in forest-dominated landscapes. Landscape projection models are rapidly becoming important tools in forest management planning, and they hold great promise as a means to bring landscape ecologists and forest managers together. The ability to produce future landscapes under different management scenarios and to compare these to landscapes produced by natural disturbance regimes will help to focus both managers and scientists on understanding the key interactions among human activities, landscape features, and ecological processes.

Key words: conservation biology; disturbance dynamics; forest management; forest projection models; fragmentation; landscape ecology; partnerships of scientists and managers.

INTRODUCTION

The disciplines of natural resource management such as fisheries, wildlife, and forestry have been eager to adopt the science of landscape ecology. And why not? Landscape ecology appears to bring a fresh perspective to age-old problems by encouraging managers to expand the scale at which solutions are sought. Although managers have been painfully aware that the traditional focus on local populations studied at small spatial and temporal scales is problematic, the tools and science needed for a broader perspective have been slow to develop. This appears to be changing as remote sensing and Geographical Information Systems (GIS) technology allow us to obtain and analyze larger and larger amounts of spatial data. At the same time, spatial ecology has begun to take shape through concepts related to metapopulations, edge effects, patch dynamics, and percolation theory (Forman and Godron 1986, Gardner and O'Neill 1991, Gilpin and Hanski 1991).

Landscape ecologists have also been eager to seek wider applications for their work by addressing applied problems. Much of this work has focused on landscapes that have been highly altered by humans, and it is no coincidence that issues of species conservation figure prominently. The work of landscape ecologists has become increasingly influential in conservation biology and, in fact, one could argue that the marriage of the two disciplines is largely complete. Can the same be said for landscape ecology and forest management? It certainly seems like a possibility, given that forestry has immense potential to alter landscapes and biodiversity conservation within forested landscapes has become a priority. In addition, forestry has a history of "spatial consciousness" brought about by the need to plan road development, cut sequences, and long-term wood supply (Mladenoff and Baker 1999).

In this essay, we discuss how landscape ecology has contributed to shaping current practices in forest management. We think that landscape ecology has much to offer forest management, but this potential has yet to be realized because both sides have not formed a real partnership to solve problems. The intention of this paper is to provide the practitioner with a synopsis of some relevant key research thrusts in landscape ecology. In addition, we provide the researcher with a practitioner's perspective on how landscape ecology research may be made more relevant to forest manage-

Manuscript received 25 September 2000; revised 27 April 2001; accepted 9 May 2001; final version received 4 June 2001. For reprints of this Invited Feature, see footnote 1, p. 319.

[3] E-mail: stan.boutin@ualberta.ca

ment. We need to move from a situation in which the scientist casts stones at the fortress of conventional practice to one of true partnership whereby both the scientist and practitioner engage in solving problems. The paper is intended for landscape ecologists and forest managers who are serious about changing forest practices through the application of new science. Landscape ecology's impact on forest management will be assessed by the influence that it has on changing actual forest management practices (Hobbs 1997).

What Is Landscape Ecology?

Although the term "landscape ecology" is broadly familiar to most forest managers, there is considerable confusion as to what it encompasses. It might be best to start simply by defining a landscape as a spatially heterogeneous area (Turner and Gardner 1991). The important point here is the spatial nature of the heterogeneity: we view landscape ecologists as being primarily interested in how spatial heterogeneity affects ecological processes. Landscapes have emergent measurements that tend to be associated with the size, distribution, configuration, and connectivity of patches (Weins et al. 1993), whereas Lidicker (1995) listed emergent properties of landscapes such as edge effects, interpatch fluxes of energy, nutrients, and organisms, and stability of patch configuration. Confusion arises when landscape is used to designate a general spatial scale or level of ecological organization. King (1997) provides a particularly clear discussion of why it is important to be cautious when using the term "landscape" in these contexts. Spatial scales (Bissonette 1997) and hierarchy theory (King 1997) are strongly intermeshed with landscape ecology, but for the purposes of this paper we will focus on how spatial heterogeneity affects ecological processes; the spatial scale will be primarily one of multiple forest stands (patches).

Current Forest Management and Landscape Ecology

Forest management has undergone a major conceptual shift over the past 10 years that can be summarized as a transition from a focus on high-yield production of fiber and selected wildlife species to supplying a wide array of values, including maintenance of biodiversity (Kohm and Franklin 1997). Ecosystem management has emerged as the broad approach used to achieve this objective, and a fundamental tenet is that success depends on managing at large spatial, and long temporal, scales (FEMAT 1993). These spatial scales are often equated to landscape scales and the immediate assumption is that landscape ecology is a fundamental part of ecosystem management. However, working at a particular spatial scale, by itself, is not enough to be doing landscape ecology. Instead, the focus should be on how spatial heterogeneity affects ecological processes rather than on scale per se.

Despite managing for a wider array of values, the actual operational levers available to forest managers remain the same, namely, harvest rate, cutblock size and shape, cut sequence, and silvicultural practices (cutting and regeneration methods). As stated by one reviewer, managers have long been able to design future forests (landscapes) to meet the requirements of a group of mills. In a similar fashion, they also have been capable of simultaneously incorporating the needs of a handful of wildlife species if the species' habitat requirements are known. If forest managers have been practicing landscape planning, have they been using landscape ecology to do so? In other words, how often does our understanding of how spatial heterogeneity affects ecological processes play into forest management decisions? We discuss two general lines of research in the landscape ecology literature that have been influential in forest management. We call these the "forest fragmentation" and "patch dynamics" approaches. The former is focused on how forest fragmentation affects biodiversity conservation, whereas the latter is focused on patch dynamics and spatial modeling of habitat succession following disturbance in forested landscapes.

Forest Fragmentation

Habitat fragmentation occurs when a specific habitat is successively divided into pieces to form a mosaic of patches that vary in size, shape, and connectedness. Fragmentation is a common outcome of human resource development, particularly in regions converted to agriculture. A primary focus of landscape ecology has been the study of the persistence of species in specific fragments (patches) and in the landscape as a whole. Forest cutting, as it is currently practiced throughout the world, tends to fragment forest habitat because complete stands are not harvested in their entirety. Instead, cutblocks tend to be of uniform size and shape, and relatively small relative to existing forest patches. The result is a patchwork of cut-and-leave forest familiar to anyone who has flown over actively managed forest regions. Landscape ecologists have been quick to warn forest managers that such an approach might have negative consequences for the maintenance of forest species. Old-growth forest and its associated species have received the most attention because it is the older age classes that are most likely to be truncated by short rotation practices designed to maximize timber yields. The question, then, is whether or not fragmentation created by forest harvesting is significant enough to warrant a change in forest practices and if so, what should the new practices look like?

The fragmentation concept used in landscape ecology has two components. These are overall habitat loss (the total amount of suitable habitat removed from the landscape) and habitat configuration (patch size, isolation) (Haila 1986). Both habitat loss and changes in configuration could affect species presence (Andrén 1994, Fahrig 1997), and it is important to separate the two because forest managers may focus on very different practices, depending on the relative importance of each component. There is little controversy in the statement that habitat loss means a reduction in the average abundance and overall distribution of species using that habitat, and that once the amount of habitat drops below a critical threshold, the likelihood of species persistence becomes zero (Lande 1987). If habitat loss is the principle driver in species loss, forest managers could predict how well their practices will maintain various species simply by predicting the amount of various habitat types in future forests. The question of "How much is enough?" would still be important, but we would not need landscape ecologists to provide the answer.

Landscape ecologists however, have argued that habitat amount alone is not adequate to answer this question; instead, we also need to consider patch size, configuration, and the nature of the intervening matrix (for a review, see Fahrig 2002). This added dimension increases the complexity of forest planning considerably, and before this change is warranted, landscape ecologists must provide strong evidence that managing landscape configuration makes a significant difference to biodiversity maintenance over and above managing for habitat loss alone.

Forest fragmentation studies have focused primarily on the effect of patch size and isolation on the presence of selected species. Fewer studies have tried to separate effects of habitat loss from spatial configuration. A number of approaches have been taken, the most direct being the experimental fragmentation of a landscape, whereby fragments of variable sizes and degrees of isolation are created. These experiments have been summarized by Debinski and Holt (2000), who concluded that there was a surprising lack of support for the prediction that smaller fragments would maintain fewer species, have higher turnover rates, and experience more severe edge effects.

On first impressions, it would seem that fragmentation experiments could provide forest managers with direct guidelines as to the appropriate patch size for remnant old-forest patches. Although some might argue that these experiments simulate conditions that will arise as forest harvesting develops (small patches of old forest in a matrix of unsuitable habitat), this is only partially true for the following reasons. The experiments follow a traditional ANOVA design; given the effort required, treatment range and replication are limited (Debinski and Holt 2000). In most cases, selected experimental patch sizes are much smaller than the patches that would realistically be left by forest companies. Small patches hold fewer species. This is well documented, but the important issue is to determine if thresholds in patch size effects exist, particularly within the range of patch sizes that forest companies are capable of creating. Unfortunately, current fragmentation experiment designs have limited resolution at these relevant scales.

In the case of fragmentation experiments in forested regions, there is an additional complication. The experimentally created fragments are usually placed within a landscape that has considerable original habitat remaining. This would not necessarily be the case as the harvest rotation proceeds (Schmiegelow et al. 1997). Most fragmentation experiments have been followed for a short time relative to forest succession scales. Immediately following the creation of the treatment, the matrix becomes clear-cut forest, possibly the most inhospitable matrix for many old-forest dwellers. However, unlike forest remnants within an agricultural matrix, clearcuts regrow to forest, making the difference between the patch and matrix less obvious. Both the nature of the matrix and the proportion of habitat in the landscape are modifiers of patch size and isolation effects (Andrén 1994). Consequently, current results of fragmentation experiments should not be extrapolated to what may happen in future forests.

All in all, fragmentation experiments create the best conditions to test for the effects of patch size on the ability of that patch to contain species of interest, but the generality of the results will be limited. Apart from the general rule that bigger is better, there are no other prescriptions that managers could follow. Our statements are not meant as criticisms of the scientific merit of the experiments. We are simply saying that their design is not likely to give a forest manager direction on how much old forest should be maintained and what its configuration should be.

There are a growing number of observational fragmentation studies that take advantage of fragments created by human activities. Although these studies lack the controlled design of fragmentation experiments (McGarigal and Cushman 2002), they allow a much broader range of patch sizes, matrix types, and configurations to be explored. Much of the work involves birds as study organisms, and the results have been thoroughly reviewed a number of times (Andrén 1994, Freemark et al. 1995). Although the details vary somewhat, the general conclusion is that smaller or more isolated fragments hold fewer species. Most observational studies have been conducted in landscapes where natural forests exist as small patches surrounded by agriculture or tended conifer forests. McIntyre and Hobbs (1999) have operationally defined fragmented landscapes as those where natural habitat has dropped below 60% of the landscape; and relict landscapes are those with <10% of original habitat. Much of the work on fragmentation has been conducted in relict landscapes where edge effects, patch size, and patch configuration have strong effects on species persistence in the remaining habitat (Saunders et al. 1991). McIntyre and Hobbs (1999) suggest that forestry operations in native forests create examples of variegated landscapes where natural habitat still represents >60% of the landscape. As researchers begin to expand the range of landscapes studied to include the extensive forests of western and northern North America, patch size and isolation effects and edge effects are less pronounced or nonexistent (Andrén 1994, Freemark et al. 1995, McGarigal and McComb 1995, Drapeau et al. 2000, Schmiegelow and Mönkkönen 2002). These results raise the very real possibility that the fragmentation issues that have preoccupied landscape ecologists working in relict landscapes may not be a priority in the variegated landscapes created by forest planning (McIntyre and Hobbs 1999).

Fahrig (1997) has also suggested that the emphasis on habitat configuration is "misplaced" and that conservation efforts should focus on reducing habitat loss. She used a spatially explicit population model to show that total habitat amount had a far greater influence on species persistence in landscapes than did configuration. Configuration had little effect as long as suitable habitat made up >20% of the landscape. Some observational studies have tried to de-couple the effects of configuration from those of habitat loss. Andrén (1994) reviewed studies of birds and mammals and concluded that the total area of suitable habitat was of greater importance than spatial configuration, particularly in landscapes with >30% of suitable habitat left. The greater importance of habitat amount relative to configuration seems to be a consistent pattern, at least for forest birds (McGarigal and McComb 1995, Trzcinski et al. 1999, Drapeau et al. 2000, Flather et al. cited in Fahrig 2002). However, Villard et al. (1999) found that fragmentation and habitat amount had roughly equal influence in eastern deciduous forests within an agricultural matrix.

There has been one other approach to studying fragmentation effects. This involves the use of experimental model systems (EMS), whereby landscapes are artificially created at scales that researchers can effectively replicate (Ims et al. 1993, Wolff et al. 1997). Unlike large-scale manipulative experiments or comparative mensurative experiments, EMS actually study how spatial heterogeneity affects ecological processes as opposed to inferring process from patterns (see McGarigal and Cushman 2002). These studies have revealed some interesting effects of spatial configuration on population processes, but their relevance to forest management remains to be determined. We are skeptical of their utility for two reasons. Given that spatial scale appears to be so important to landscape ecology and forest management, one cannot assume that it will be straightforward to "scale up" from EMS to forest landscapes. Secondly, given the importance of the relationship between the patch matrix and animal movement, it is not clear how results from an artificially created matrix can be applied to the dynamic matrices found in forested systems.

Fragmentation Studies and Forest Management Practices

Based on results of the fragmentation research just outlined, we suggest the following operational guide for forest managers working in regions where forests of different age will remain as the predominant cover type in the region. Forest planning to conserve biodiversity should focus on maintaining habitat amount; there is little need to take configuration (patch size, corridors) into account unless habitats of interest drop below 20–30% of the landscape. Mönkkönen and Reunanen (1999) advise against managing according to a threshold rule because critical thresholds are species specific and the 20–30% threshold may be an underestimate for many species. We are not suggesting that this threshold should serve as a guide for the amount of habitat required to maintain target species. Rather, we suggest that current information supports the working hypothesis that forest managers need not worry about *patch configuration* until habitat loss reaches 70–80%. In other words, the amount of habitat should be the primary driver in forest planning, and it is only when projected loss of habitat is substantial that configuration should also be considered.

Given these recommendations, we provide a cautionary note. Most forest landscapes are more complicated than the dichotomous habitat and matrix design of landscape models and experiments. In particular, forests subject to large-scale natural disturbance events are naturally fragmented, and old forest may naturally comprise <20% of a landscape (Bergeron and Harvey 1997). Does this mean that landscape configuration effects are always present, or does the amount of old forest have to drop to <30% of "natural" levels before configuration becomes important? Current landscape models are of little help in this case because the predicted effects depend on how individual species respond to the landscape matrix (Fahrig 2002). The key parameters simply have not been measured in variegated forest systems and this continues to represent a major challenge to landscape ecologists. It is clear, however, that any practice that makes the patch matrix more hospitable will greatly reduce the potential for fragmentation effects associated with individual movements between patches (Fahrig 2002). So-called "New Forestry" approaches that leave some forest structure on newly cut areas may hold promise in this regard (FEMAT 1993, Franklin et al. 1997).

To summarize, there is little evidence to suggest that forest managers should place a priority on habitat configuration when planning for conservation of biodiversity in landscapes where forests will comprise the majority of the landscape in the future. Instead, managing habitat loss alone is probably the most reasonable guide. However, models and empirical data suggest that there is a threshold relationship between habitat loss and effects of configuration. It remains unclear, however, what the exact threshold level is, but it is probably below 50%. We suggest that researchers and forest managers identify these thresholds under conditions that are likely to exist in future managed forests.

Landscape Effects on Species Habitat Use

If forest managers are to conserve selected species by maintaining adequate amounts of habitat, species-specific habitat requirements need to be identified. Landscape ecology has added another dimension to this process by raising the possibility that spatial configuration might affect habitat use. Some species have been identified as "interior" specialists, or as having minimum patch size requirements (Whitcomb et al. 1981, Freemark and Merriam 1986, Hansen et al. 1993; see also Villard 1998). This has two implications for forest management. First, projections of habitat supply for a particular species would have to be readjusted to exclude patches below a minimum size. Second, cutting plans would need to be designed to create patches of adequate size and shape to meet the requirements of "landscape-sensitive" species. These adjustments are not substantive, given that patch size is commonly being tracked in most GIS forest inventories.

Along with patch size and configuration, another landscape variable that can affect habitat use is the juxtaposition of two habitat patches. Juxtaposition of habitats has received relatively little attention from landscape ecologists, but it is interesting to note that much of the traditional design of forest cutblock size and shape was actually driven by the perceived need to provide the appropriate juxtaposition of forage and cover for ungulates (Rempel et al. 1997). It is likely that more research will reveal that some species are associated with patch types arranged in a certain fashion. The question will then be whether this added habitat requirement would become an additional constraint on cutblock layout.

Accommodating the local and landscape habitat requirements of a limited number of species while maintaining wood supply is certainly possible, as long as the number of species considered does not become too large. However, Mönkkönen and Reunanen (1999) point out that it is impractical to generalize about landscape effects on species because of differences in scale, life history characteristics, and responses to landscape matrix. They recommend "applying case-by-case information" as a result. Although this approach may be possible for conservation of selected species, we think that it is unrealistic for the broader objective of maintenance of biodiversity. This "fine-filter" approach inevitably leads to making prescriptive decisions that favor one species over another. As an example, Bender et al. (1998) found that the effect of patch size on population size was negative for interior, but positive for edge, bird species. The effects differed between migratory and resident species and between carnivores and herbivores. It would be impossible to manage these species on a case-by-case basis. Landscape ecologists must seek general guides for planning forest landscapes if they wish to change forest practices.

Patch Dynamics and Forest Landscape Projection Models

The study of fragmentation effects in managed forests has tended to take a somewhat static view of the spatial nature of forest patches. For example, landscapes are modeled as patches within a matrix, with the spatial location, patches, and matrices remaining constant. This seems perfectly reasonable in relict landscapes, but managed forest landscapes are much more dynamic, and it is the dynamics of patch mosaics per se that may hold the key to maintenance of species diversity (Pickett and Rogers 1997). Landscape ecology has played a major role in our ability to describe the spatial arrangement of important elements at the regional scales necessary for forest management (Perera and Euler 2000). It also has the potential to help us understand the reciprocal effects of spatial pattern on ecological processes (Pickett and Cadenasso 1995). Foresters have always had some appreciation for the large spatial, and long temporal, nature of their business. Forest inventories are essential for calculating available wood supply, and the spatial location of that wood supply is crucial for determining road construction and cut sequence. However, until recently, the spatial map of forest inventory was largely a static snapshot that was updated at regular intervals as forest harvesting and planting proceeded. There was really no way to project current practices into the future to catch a glimpse of what the forest would look like some 30–100 yr into the future, nor were there tools to make rapid comparisons of landscape metrics between forest landscapes subjected to different practices. This is now feasible and landscape ecology has had a major role to play in this development.

Spatially explicit landscape projection models are rapidly becoming part of every forest manager's toolkit. There are now many versions of these types of models, and Mladenoff and Baker (1999) provide a good summary of the evolution of their development. The models are intended to take a spatially explicit current vegetation inventory and project it into the future. The rules for doing this are drawn from an understanding of vegetation succession, forest harvesting and silviculture plans, and natural disturbances such as fire and insect outbreaks. There are major challenges to producing realistic landscapes. These relate to "scaling up" from the individual tree or stand level to broad landscapes, and to capturing the spatial nature of many ecological processes. Many forest processes are likely to involve a spatial component, and a number of studies are beginning to explore this aspect (Turner and Romme 1994, Roland and Taylor 1997, Greene and Johnson 1999, Li 2000). The challenge will be in determining when spatial pattern truly matters (Turner et al. 1995), because its inclusion in landscape projection models increases computing time immensely.

Landscape projection models are strategic in nature and, as such, their utility is not in tracking exact changes in a landscape. Rather, they provide a general guide to how forest landscapes might look, "on average," under different management practices. As such, they provide a vital tool for planning at large scales and allow various management scenarios to be projected into the future. These hypothetical landscapes can then be compared using a wide range of descriptive metrics (McGarigal and Marks 1995). Doing so quickly reveals how forest-cutting practices act to change landscape elements such as patch size, amount of edge, and degree of connectedness (Franklin and Forman 1987, Spies et al. 1994, Wallin et al. 1994). In addition, this approach also leads to formulation of hypotheses as to how these practices actually affect ecological processes. However, it should be stressed that many of the proposed spatial effects on ecological processes are still at the hypothesis stage. The challenge to landscape ecologists is to find creative ways to test these hypotheses at the large spatial scales upon which they are proposed to operate.

Different Forest Management Scenarios Produce Different Landscape Patterns: What Does It Mean?

Landscape projection models produce future landscapes that have clearly different landscape metrics depending on the forest management scenario employed. The question becomes "What do forest managers do with this information?" In any type of resource management, the key to success is to know the functional relationship between the values being managed for and the conditions that managers actually manipulate. Following on this, landscape ecologists should work with forest managers to determine how spatial heterogeneity affects ecological processes, and how forest management might affect these functional relationships. Armed with this information, it should then be possible for one to functionally link the values for which we manage and the management practices actually available. Unfortunately, current research in landscape ecology is not yet at the stage that allows us to do this. Fragmentation and patch dynamics studies remain largely at the pattern description stage; the crucial functional relationships between spatial pattern and ecological processes and the effects of forest practices on these processes, remain unknown.

How should forest management proceed? Swanson et al. (1993) proposed an approach that might provide a solution. It is based on designing forest management approaches to maintain the range of natural variability in habitat types that are created by the interaction of physical factors and disturbance regimes. Natural disturbances such as fire have a characteristic frequency, size, and severity within a given region, and this, in turn, produces the forest vegetation and age distributions observed on a landscape. The natural disturbance regime also plays a major role in creating the natural pattern of patches, edges, and connectivity present on a landscape. Managing landscape effects under this approach becomes a matter of trying to pattern landscapes with human activities after those created by natural disturbances.

Trying to maintain the range of natural variability in landscapes is a "coarse-filter" approach to management based on a key assumption that species are adapted to the landscapes created by natural disturbance regimes. The emphasis is on large-scale general patterns of habitat mosaics rather than on meeting the fine-filter needs of individual species (Hunter 1993). The approach remains to be tested, but it has gained considerable support, particularly in forests where large disturbances such as fire are common features (Hunter 1993, Bergeron and Harvey 1997, Angelstam 1998, Perera and Baldwin 2000). It is attractive because it does not require a detailed understanding of how landscape features affect processes. Instead, management is guided by the comparison of managed landscapes to those created by historical disturbance patterns. This approach allows both the manager and the researcher to identify areas that require immediate attention. In the case of the manager, this might mean designing new cut patterns to more closely match disturbance patterns; in the case of the researcher, it helps to direct research priorities to key landscape parameters and processes. This raises an important point. Forest management practices are continually undergoing change and landscape ecologists must be in tune with those changes. Otherwise, the experiments that make perfect sense now will seem trivial under future regimes.

To summarize, we see a growing interaction between forest managers and landscape ecologists in the area of understanding how ecological processes are affected by spatial heterogeneity. There is a great opportunity to foster this interaction by focusing on the development of realistic landscape projection tools. At present, these tools still lack key functional relationships between spatial heterogeneity and ecological processes. As these relationships are developed, an interim approach may be to use the range of natural variability in patch dynamics created by disturbance and succession as a management guide. Doing so would provide a common framework that managers and landscape ecologists can use to determine priorities.

Conclusions

We have been critical of the contribution of "fragmentation" studies to forest management. This is due partially to a failure to see the real landscape. By this, we mean that the implications of forest management for biodiversity must be considered within realistic current and future forest landscapes. The forests of Scandinavia and Australia give us a clear glimpse into the future of what the extensive forests of Canada and northwestern United States could look like, and fragmentation studies give a clear indication of what is likely to happen under these conditions. However, there is immense opportunity to change practices now to create very different future forest conditions. Landscape ecologists must work closely with forest managers to develop practices that do not create future forests where fragmentation is an issue. We think that the challenge to landscape ecologists studying fragmentation in managed forests is to determine possible thresholds of landscape change where landscape configuration becomes an important component over and above the absolute loss of habitat. If such thresholds can be identified, managers can then begin to plan their activities accordingly.

We have been less critical of the contribution of landscape ecology to the development of forest landscape projection models. This is not to say that such models have provided the solutions to planning forest landscapes. The important aspects of how landscape features affect ecological processes have yet to be scientifically validated. However, landscape projection modeling provides a framework to focus managers and scientists on the important spatial interactions at the relevant spatial and temporal scales. We believe that both landscape ecologists and forest managers can benefit from considering how historical natural disturbance regimes and underlying physical features act to shape landscape patterns in space and time. The patterns created should provide the basic template for designing forest practices at landscape scales, and for understanding how organisms may be adapted to the interplay between ecological processes and landscape features.

Acknowledgments

We are grateful to Marc-Andre Villard for organizing this special feature and for providing helpful comments on the manuscript. We also wish to thank Gordon Baskerville for sharing some of his insights into forest management issues.

Literature Cited

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos **71**:355–364.

Angelstam, P. K. 1998. Maintaining and restoring biodiversity in European boreal forests by developing natural disturbance regimes. Journal of Vegetation Science **9**:593–602.

Bender, D. J., T. A. Contreras, and L. Fahrig. 1998. Habitat loss and population decline: a meta-analysis of the patch size effect. Ecology **79**:517–533.

Bergeron, Y., and B. D. Harvey. 1997. Basing silviculture on natural ecosystem dynamics: an approach applied to the southern boreal mixed-wood forest of Quebec. Forest Ecology and Management **92**:235–242.

Bissonette, J. A. 1997. Scale-sensitive ecological properties: historical context, current meaning. Pages 3–31 *in* J. A. Bissonette, editor. Wildlife and landscape ecology: effects of pattern and scale. Springer-Verlag, New York, New York, USA.

Debinski, D. M., and R. D. Holt. 2000. A survey and overview of habitat fragmentation experiments. Conservation Biology **14**:342–355.

Drapeau, P., A. Leduc, J.-F. Giroux, J.-P. Savard, Y. Bergeron, and W. L. Vickery. 2000. Landscape-scale disturbances and changes in bird communities of boreal mixed-wood forests. Ecological Monographs **70**:423–444.

Fahrig, L. 1997. Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management **61**:603–610.

Fahrig, L. 2002. Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecological Applications **12**: 346–353.

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team. U.S. Government Printing Office, Washington, D.C., USA.

Forman, R. T. T., and M. Godron. 1986. Landscape ecology. John Wiley, New York, New York, USA.

Franklin, J. F., D. R. Berg, D. A. Thornburgh, and J. C. Tappeiner. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. Pages 111–139 *in* K. Kohm and J. F. Franklin, editors. Creating a forestry for the 21st century. Island Press, Washington, D.C., USA.

Franklin, J. F., and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. Landscape Ecology **1**:19–28.

Freemark, K. E., J. B. Dunning, S. J. Hejl, and J. R. Probst. 1995. A landscape ecology perspective for research, conservation, and management. Pages 381–421 *in* T. E. Martin and D. M. Finch, editors. Ecology and management of neotropical migratory birds, a synthesis and review of critical issues. Oxford University Press, New York, New York, USA.

Freemark, K. E., and H. G. Merriam. 1986. Importance of area and habitat heterogeneity to bird assemblages in temperate forest fragments. Biological Conservation **36**:115–141.

Gardner, R. H., and R. V. O'Neill. 1991. Pattern, process, and predictability: the use of neutral landscape models for landscape analysis. Pages 289–307 *in* M. G. Turner and R. H. Gardner, editors. Quantitative methods in landscape ecology. Springer-Verlag, New York, New York, USA.

Gilpin, M. E., and I. Hanski, editors. 1991. Metapopulation dynamics: theoretical models and emperical investigations. Academic Press, London, UK.

Greene, D. F., and E. A. Johnson. 1999. Modelling recruitment of *Populus tremuloides*, *Pinus banksiana*, and *Picea mariana* following fire in the mixedwood boreal forest. Canadian Journal of Forest Research **29**:462–473.

Haila, J. 1986. North European land birds in forest fragments: evidence for area effects. Pages 315–319 *in* J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, Wisconsin, USA.

Hansen, A. J., S. L. Garman, B. Marks, and D. L. Urban. 1993. An approach for managing vertebrate diversity across multiple-use landscapes. Ecological Applications **3**: 481–496.

Hobbs, R. J. 1997. Future landscapes and the future of landscape ecology. Landscape Ecology and Urban Planning **37**: 1–9.

Hunter, M. L., Jr. 1993. Natural disturbance regimes as spatial models for managing boreal forests. Biological Conservation **65**:115–120.

Ims, R. A., J. Rolstad, and P. Wegge. 1993. Predicting space use responses to habitat fragmentation: can voles (*Microtus oeconomus*) serve as an experimental model system (EMS) for cappercaillie grouse (*Tetrao urogallus*) in boreal forest. Biological Conservation **63**:261–268.

King, A. W. 1997. Hierarchy theory: a guide to system structure for wildlife biologists. Pages 185–212 *in* J. A. Bissonette, editor. Wildlife and landscape ecology: effects of pattern and scale. Springer-Verlag, New York, New York, USA.

Kohm, K. A., and J. F. Franklin, editors. 1997. Creating a forestry for the 21st century. Island Press, Washington, D.C., USA.

Lande, R. 1987. Extinction thresholds in demographic models of territorial populations. American Naturalist **130**:624–635.

Li, C. 2000. Fire regimes and their simulation with reference to Ontario. Pages 115–140 *in* A. H. Perera, D. L. Euler, and I. D. Thompson, editors. Ecology of a managed landscape: patterns and processes of forest landscapes in Ontario. University of British Columbia Press, Vancouver, British Columbia, USA.

Lidicker, W. Z., Jr. 1995. The landscape concept: something old and something new. Pages 3–19 *in* W. J. Lidicker, Jr., editor. Landscape approaches in mammalian ecology. University of Minnesota Press, Minneapolis, Minnesota, USA.

McGarigal, K., and S. Cushman. 2002. Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. Ecological Applications **12**:335–345.

McGarigal, K., and B. J. Marks. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. USDA Forest Service General Technical Report **PNW-GTR-351**. Portland, Oregon, USA.

McGarigal, K., and W. C. McComb. 1995. Relationships between landscape structure and breeding birds in the Oregon Coast Range. Ecological Monographs **65**:235–260.

McIntyre, S., and R. Hobbs. 1999. A framework for conceptualizing human effects on landscapes and its relevance to management and research models. Conservation Biology **13**:1282–1292.

Mladenoff, D. J., and W. L. Baker, editors. 1999. Spatial modeling of forest landscape change: approaches and applications. Cambridge University Press, New York, New York, USA.

Mladenoff, D., and W. L. Baker. 1999. Development of forest and landscape modeling approaches. Pages 1–13 *in* D. J. Mladenoff and W. L. Baker, editors. Spatial modeling of forest landscape change: approaches and applications. Cambridge University Press, New York, New York, USA.

Mönkkönen, M., and P. Reunanen. 1999. On critical thresholds in landscape connectivity: a management perspective. Oikos **84**:302–305.

Perera, A. H., and D. J. B. Baldwin. 2000. Spatial patterns in the managed forest landscape of Ontario. Pages 74–99 *in* A. H. Perera, D. L. Euler, and I. D. Thompson, editors. Ecology of a managed landscape: patterns and processes of forest landscapes in Ontario. University of British Columbia Press, Vancouver, British Columbia, Canada.

Perera, A. H., and D. L. Euler. 2000. Landscape ecology in forest management: an introduction. Pages 3–11 *in* A. H. Perera, D. L. Euler, and I. D. Thompson, editors. Ecology of a managed landscape: patterns and processes of forest landscapes in Ontario. University of British Columbia Press, Vancouver, British Columbia, Canada.

Pickett, S. T. A., and M. L. Cadenasso. 1995. Landscape ecology: spatial heterogeneity in ecological systems. Science **269**:331–334.

Pickett, S. T. A., and K. H. Rogers. 1997. Patch dynamics: the transformation of landscape structure and function. Pages 101–127 *in* J. A. Bissonette, editor. Wildlife and landscape ecology: effects of pattern and scale. Springer-Verlag, New York, New York, USA.

Rempel, R. S., P. C. Elke, A. R. Rodgers, and M. J. Gluck. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. Journal of Wildlife Management **61**:517–524.

Roland, J., and P. D. Taylor. 1997. Insect parasitoid species respond to forest structure at different spatial scales. Nature **386**:710–713.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology **5**:18–32.

Schmiegelow, F. K. A., C. S. Machtans, and S. J. Hannon. 1997. Are boreal birds resilient to forest fragmentation? An experimental study of short-term community responses. Ecology **78**:1914–1932.

Schmiegelow, F. K. A., and M. Mönkkönen. 2002. Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest. Ecological Applications **12**:375–389.

Spies, T. A., W. J. Ripple, and G. A. Bradshaw. 1994. Dynamics and pattern of a managed coniferous forest landscape in Oregan. Ecological Applications **4**:555–568.

Swanson, F. J., F. A. Jones, D. O. Wallin, and J. H. Cissel. 1993. Natural variability—implications for ecosystem management. Pages 89–103 *in* M. E. Jensen and P. S. Bourgeron, editors. Eastside forest ecosystem health assessment. Volume II. Ecosystem management: principles and applications. USDA Forest Service, Portland, Oregon, USA.

Trzcinski, M. K., L. Fahrig, and G. Merriam. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. Ecological Applications **9**:586–593.

Turner, M. G., and R. H. Gardner, editors. 1991. Quantitative methods in landscape ecology. Springer-Verlag, New York, New York, USA.

Turner, M. G., R. H. Gardner, and R. V. O'Neill. 1995. Ecological dynamics at broad scales: ecosystems and landscapes. BioScience (Supplement):S29–S34.

Turner, M. G., and W. H. Romme. 1994. Landscape dynamics in crown fire ecosystems. Landscape Ecology **9**:59–77.

Villard, M.-A. 1998. On forest-interior species, edge-avoidance, area sensitivity, and dogmas in avian conservation. Auk **115**:801–805.

Villard, M.-A., M. K. Trzcinski, and G. Merriam. 1999. Fragmentation effects on forest birds: relative influence of woodland cover and configuration on landscape occupancy. Conservation Biology **13**:774–783.

Wallin, D. O., F. J. Swanson, and B. Marks. 1994. Landscape pattern response to changes in pattern generation rules: land-use legacies in forestry. Ecological Applications **4**: 569–580.

Weins, J. A., N. C. Stenseth, B. Van Horne, and R. A. Ims. 1993. Ecological mechanisms and landscape ecology. Oikos **66**:369–380.

Whitcomb, R. F., J. F. Lynch, M. K. Klimkiewicz, C. Robbins, B. L. Whitcomb, and D. Bystrak. 1981. Effects of forest fragmentation on avifauna of the eastern deciduous forest. Pages 125–205 *in* R. L. Burgess and D. M. Sharpe, editors, Forest island dynamics in man-dominated landscapes. Springer-Verlag, New York, New York, USA.

Wolff, J. O., E. M. Schauber, and W. D. Edge. 1997. Effects of habitat loss and fragmentation on the behavior and demography of gray-tailed voles. Conservation Biology **11**: 945–965.