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Perception of scale in forest management planning: Challenges and implications

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Abstract

Forest management practices imposed at one spatial scale may affect the patterns and processes of ecosystems at other scales. These impacts and feedbacks on the functioning of ecosystems across spatial scales are not well understood. We examined the effects of silvicultural manipulations simulated at two spatial scales of management planning on landscape pattern and assessed the implications for forest-interior bird species. Landscape context was taken into consideration in determining harvest locations in the landscape-base management planning scenario but not in the stand-base planning scenario (where the focus of planning activities was at the level of individual stands and the context in which stands were located was not considered). We also compared ecological implications of patterns created at the stand and landscape levels by even- and uneven-age silvicultural systems. We used a harvest simulator (HARVEST) to simulate even-age, uneven-age and a combination of even- and uneven-age management systems for a period of 5 decades in the two forest management planning scenarios. Clearcuts of 5 to 16 ha were simulated to represent even-age management and small openings of 0.09 to 0.22 ha scattered throughout a stand were simulated to represent uneven-age management. Forest management that considered landscape context generated greater landscape total core area compared to that of the stand-base planning. There was a difference in landscape mean patch size, interspersion index, Simpson's diversity index and total core area for patches defined by stand age between stand- and landscape-base management planning. These results indicate that different landscape patterns can be produced by management planning conducted at different spatial scales. The scale of focus should depend on the management goals. Silvicultural manipulations at the stand level can cause the creation of different patterns at the stand and landscape levels. Such differences can lead to different ecological implications at each of those levels, thereby making it difficult to simply aggregate stand-level responses to the landscape-level. Furthermore, the ecological effects of landscape patterns on processes can be highly variable as the effects depend on how patches are defined. © 1997 Elsevier Science B.V.

Keywords: Forest management planning; Scale; Spatial pattern; Forest birds; Timber harvest; Fragmentation; Landscape metrics

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1. Introduction

The concept of scale is a rich but complex one. This concept is recognized as an important factor in many ecological studies, such as those related to disturbance processes (Pickett and White, 1985; Turner et al., 1989a; Simard, 1991), forest dynamics (including implications for habitat preservation and species conservation) (Burgess and Sharpe, 1981; Dunn et al., 1991), ecophysiology (Ehleringer and Field, 1993), biodiversity (Noss, 1990; Franklin, 1993), and global change (Rosswall et al., 1988; Wessman, 1992). Studies have found that there are implications of changing spatial and temporal scale on the perception of ecosystem structure and function (Turner, 1989, Turner et al., 1989b; Wiens, 1989). For example, rare cover types are not observed as map resolution becomes coarser. As a consequence, guidelines and models have been developed to help understand how information can be translated across scales (King, 1991; Rastetter et al., 1992; Pacala and Deutschman, 1995). However, models do have limitations. Scaling up models that predict individual or stand-level responses to predict responses at the landscape level may be complicated by the presence of processes that act at higher levels of organizations not captured by individual or stand-level models. For example, a forest stand might be suitable habitat for an ungulate population but the successful migration of the population across a heterogeneous landscape is more dependent on the aggregation of patches than the composition of a particular patch. Recent investigations of edge effects in forested landscapes have found the presence of effects caused by adjacent land cover types (Laurance, 1991; Chen et al., 1992). Bird population sizes and viability are determined by interactions between local habitat factors, and regional/landscape features, such as habitat area, habitat context and biogeography (Thompson et al., 1995). All these studies suggest that interactions among individual patches often result in nontrivial aggregations and do not permit a simple accumulation of quantities and processes across the landscape. These interactions and cumulative effects cannot be ignored and the cumulative effects between patches need to be made within the context of the broader landscape where the patches are located (Bedford, 1996).

Scale issues permeate all management decisions. Studies on the effects of forest management activities on ecological function have generally been focused at a single spatial scale. For example, Probst et al. (1992), Thompson (1993), and Thompson et al. (1995) examined the effects of alternative silvicultural systems on stand attributes and the implications for bird species. Other studies have focused on effects of landscape-level management on landscape structure, and the ecological implications of landscape structure on migratory birds (Flather et al., 1992; Flather and Sauer, 1996). Resource managers have traditionally planned forest management activities focused on individual stands. However, forest management practices imposed at one spatial scale may affect the patterns and ecological processes of systems at other spatial scales and vice versa. These impacts and feedbacks on the functioning of ecosystems across scales are not well understood. The purpose of this study was to (1) examine the implications of the implementation of silvicultural systems on landscape pattern and (2) the potential effects these landscape patterns might have on habitat for forest interior bird species. The first forest management planning scenario is the landscape-base management scenario, where the landscape context is considered in the planning and layout of harvest units, and the second is the stand-base scenario, where the focus of management is on individual stands and where the context in which stands are located is not taken into consideration. We also compared the pattern produced at the stand and landscape levels when implementing two silvicultural systems—even-age and uneven-age management.

Ecological systems and patterns exist in a hierarchical pattern. Hierarchy theory has been proposed as a way to understand scale effects on ecological patterns and processes (e.g., Simon, 1962; Allen and Starr, 1982; Urban et al., 1987). This theory provides a conceptual framework in which the role of scale is well-defined, and states that our understanding of a phenomenon depends on referencing the next higher and lower levels of resolution. A phenomena or an organism is thought to be bounded by processes generally operating at larger scales above it, and to impose bounds on processes and organisms at the level below it. For example, the spread of fire across a landscape is not only determined by the vegetation composition of the landscape but also by topographic features and spatial distribution of the vegetation across the landscape. While we are able to arrange scales in hierarchies, this does not mean that we understand how to translate pattern-process relationships across the nonlinear spaces between domains of scale. This study specifically examines the implications of the implementation of silvicultural systems in forest management planning scenarios at two spatial scales.

2. Methods

2.1. Study area

The study area encompasses 38,925 ha within the Nicolet National Forest, Wisconsin (Fig. 1). The Nicolet National Forest is located in northeast Wisconsin (45°30′N, 88°30′E) and covers about 262,000 ha. Glaciation has produced an irregular topography including an undulating to broken topography associated with pitted outwash and moraines, and level topography associated with lakes and swamps of the outwash plains. Elevations in the Forest range between 450 and 600 m.

Approximately 82% of the forest is suitable for commercial timber production. The forest is a northern hardwood forest characterized by a mixture of coniferous and deciduous tree species. More than 220 species of migratory and resident birds inhabit the forest. Windthrow is most important in gentle topography while fire is common in jack pine barrens, which are concentrated in areas of rolling topography not broken by kettle lakes. The primary land uses in this area include recreation, and forest management for timber, pulp, and wildlife.

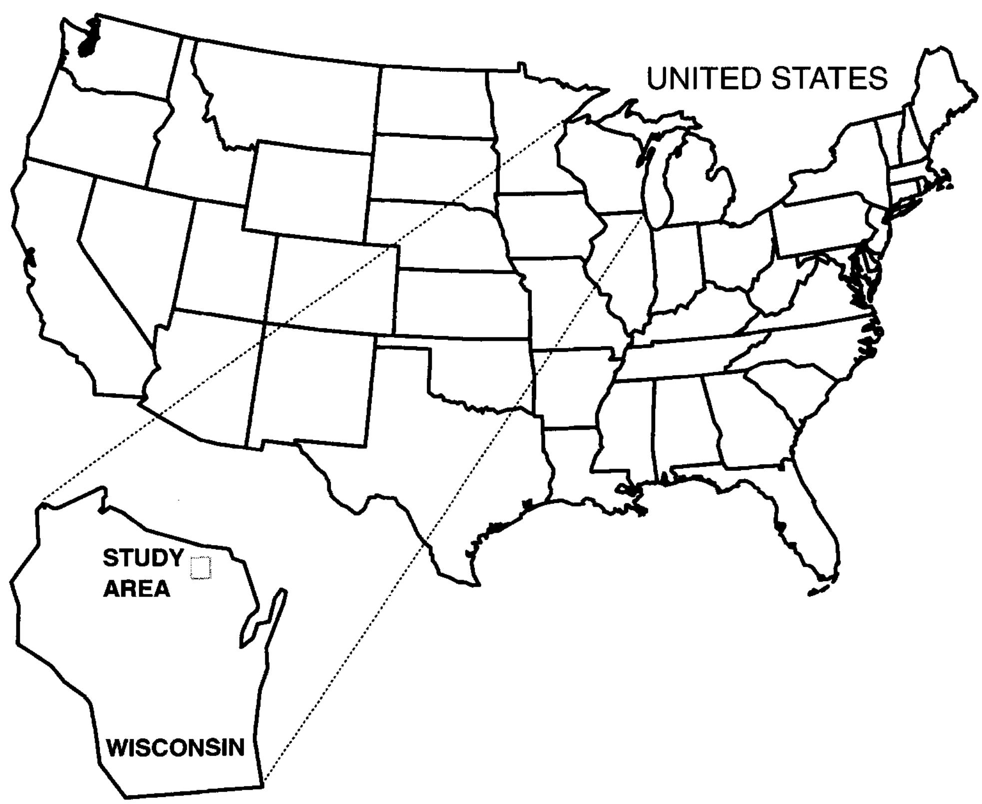

Fig. 1. Map of study area within the Nicolet National Forest, Wisconsin.

2.2. Study design

A digital stand age map of the study area was derived from an Arc/Info vegetation coverage of the Nicolet National Forest generated by NNF personnel. This map provided a realistic pattern of stands that can be used to compare the landscape patterns produced by harvesting plans that consider only one stand at a time and those that consider multiple stands.

The two forest management planning scenarios examined in this study were landscape-base and stand-base forest management (Fig. 2). Landscape-base management planning refers to a consideration of the landscape context, that is, constraints are placed on where harvest activities can be allocated to meet the landscape-level goals. In the landscape-base management scenario, riparian areas and wilderness areas, and a 50-m buffer around wetlands and along streams were protected from harvest simulations. In the stand-base management scenario, no constraints were imposed on harvest activities other than those imposed by stand-level attributes (e.g., stand age). We simulated different silvicultural systems using a timber harvest allocation model (HARVEST) (Gustafson and Crow, 1996). HARVEST allows the input of specific rules to allocate forest stands for even-age (clearcuts and shelterwood) and uneven-age (group selection) harvest units. The silvicultural systems simulated within each landscape- and stand-base forest management planning scenario included even-age management (even-age, landscape-base scenario (EL), and even-age, stand-base scenario (ES)), uneven-age management (uneven-age, landscape-base scenario (UL), and uneven-age, stand-base scenario (US)), and a combination of even- and uneven-age management (even-uneven-age, landscape-base scenario (EUL), and even-uneven-age, stand-base scenario (EUS)) (Fig. 2). Three percent of the total study area was harvested each decade under each scenario. Clearcuts of 5–16 ha were simulated to represent even-age management, and group selections (small openings of 0.09–0.22 ha scattered throughout a stand) were simulated to represent uneven-age management. The size of harvest units used here is representative of harvest unit sizes currently used on many public forest lands. Scenarios where a combination of even- and uneven-age management were simultaneously applied in the study area consisted of managing 20% of the study area by clearcutting and the remaining 80% by group selection.

2.3. Spatial analyses

Forest patches were identified in the simulation output. Forest patches were defined by stand age, while core area patches were defined by canopy closure (forested cells greater than 20 yrs old). To determine the extent of canopy closure, stands of 20 yrs of age and under were considered to have open canopies while stands older than 20 yrs of age were considered to have a closed canopy. Core area was defined as forest pixels located at distances greater than 210 m from an opening (DellaSalla and Rabe, 1987; Andren and Angelstam, 1988). Landscape mean patch size, landscape total core area, interspersion index and Simpson's diversity index were calculated using FRAGSTATS 2.0 (MacGarigal and Marks, 1995). The interspersion index measures the extent to which stand age patch types are interspersed (not necessarily dispersed); higher values occur in landscapes where patch types are well interspersed (equally adjacent to each other), while lower values characterize landscapes where patch types are poorly interspersed (disproportionate distribution of patch type adjacencies). This index is not directly affected by the number, size, contiguity, or dispersion of patches. Simpson's diversity index represents the probability that any two stand age patches selected at random will be different ages; the higher the value, the greater the diversity. Because Simp-

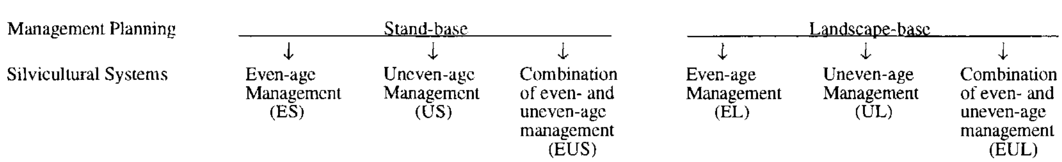

Fig. 2. Study design.

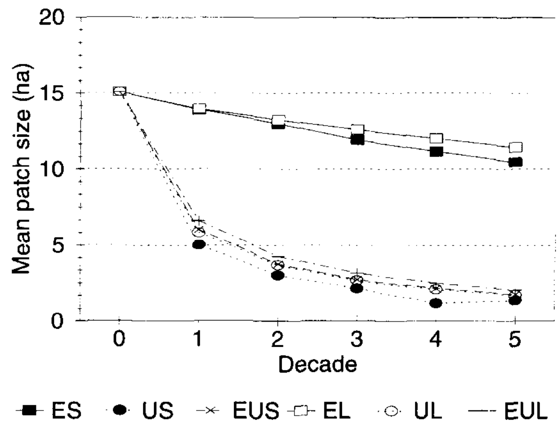

Fig. 3. Mean stand age patch sizes for forest patches generated from simulations of even-age (ES, EL), uneven-age (US, UL) and combined even- and uneven-age (EUS, EUL) silvicultural systems in the stand- and landscape-base management planning scenarios.

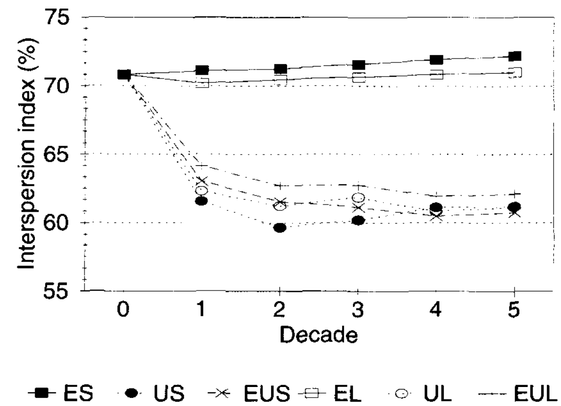

Fig. 4. Interspersion index values for stand age forest patches generated from simulations of even-age (ES, EL), uneven-age (US, UL) and combined even- and uneven-age (EUS, EUL) silvicultural systems in the stand- and landscape-base management planning scenarios.

son's index is a probability, it can be interpreted in both absolute and relative terms. The paired *t*-test was used to test the difference in metrics generated from stand- and landscape-base management planning (Zar, 1984). To evaluate the effects of landscape structure on forest interior bird species, all tree species are assumed to have the potential to provide suitable habitat for the forest interior bird species.

3. Results

There was a significant difference in mean stand age patch sizes for all silvicultural systems generated under the stand- and landscape-base management planning scenarios ($P = 0.05$). Simulations of uneven-age management (group selection) in the landscape-base management scenario produced the smallest mean stand age patch sizes because harvested patches were small (Fig. 3).

A significant difference in interspersion index between stand- and landscape-base management planning was found for even-age and combined even- and uneven-age management ($P = 0.001$) but not for uneven-age management. Simulations of even-age management generated higher interspersed stand age patches than those produced from simulations of uneven-age and combined even- and uneven-age silvicultural systems because the large even-age openings have smaller edge-to-area ratios than the smaller group openings (Fig. 4). Landscape diversity of stand ages for stand-base management was found to be significantly higher from those generated through landscape-base management simulations ($P < 0.001$) (Fig. 5).

Simulations of forest management plans formulated at the landscape scale produced a landscape with more total core area than those generated under the stand-base scenario (i.e., without landscape-level

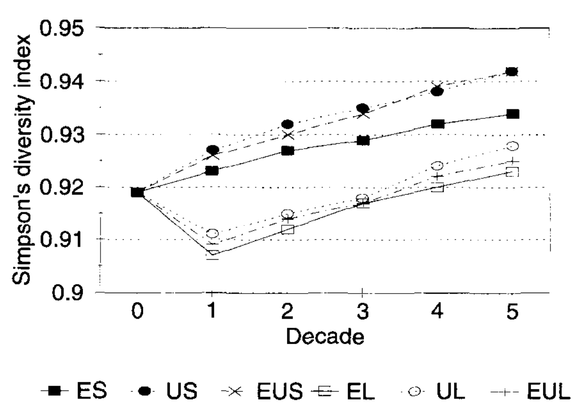

Fig. 5. Simpson's index of diversity for stand age patches generated from simulations of even-age (ES, EL), uneven-age (US, UL) and combined even- and uneven-age (EUS, EUL) silvicultural systems in the stand- and landscape-base management planning scenarios.

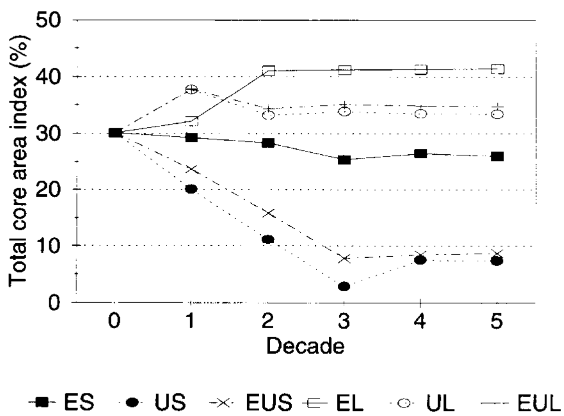

Fig. 6. Total core area index for forest patches generated from simulations of even-age (ES, EL), uneven-age (US, UL) and combined even- and uneven-age (EUS, EUL) silvicultural systems in the stand- and landscape-base management planning scenarios.

constraints) ($P < 0.01$) (Fig. 6). Landscape total core area was the highest for forest patches generated by simulations of even-age management under the landscape-base management planning scenario. In general, there was higher total core area with even-age management simulations than uneven-age and combined even- and uneven-age management options because fewer openings were produced by clearcutting than by group selection.

4. Discussion

Forest patches are commonly delineated based on their species composition. We chose to delineate forest patches in this study based only on stand age because forest stand age affects stand attributes such as tree size, foliage volume, foliage stratification, horizontal patchiness, coarse woody debris, and cavity formation, which in turn affects plant and wildlife species habitat condition (Thompson et al., 1995). Stand age distribution on a landscape can also affect animal species population sizes and viability. Thus, any change in forest stand age apart from species composition will have ecological implications on habitat condition for species at both the stand and landscape levels.

Total core area index was calculated based on canopy closure and is higher for all silvicultural treatments simulated under the landscape-base management planning scenario (where wilderness, riparian management areas and stream buffers were protected from harvest simulations). This suggests that protection of certain parts of the landscape will help preserve unfragmented 'core' areas that are crucial in conservation strategies of forest interior species (e.g., Temple and Cary, 1988; Li et al., 1993). Results from this study indicate a difference in mean patch size, interspersion index and landscape diversity between stand age patches generated through implementation of silvicultural systems planned at the stand- and landscape-base levels. This indicates that stand- and landscape-base management can create different landscape patterns which in turn may have different ecological implications. The appropriate ecological scale to manage our landscapes varies with both the organisms and questions of interest (Wiens, 1989). There is a need to plan activities at the broader landscape context where stands are viewed within the context of a heterogeneous landscape if the purpose is to manage for landscape-level goals, such as the conservation of interior species. The effects of edge and openings created by timber harvest on nest predation may depend on the landscape context (Martin, 1992). A consideration of the broader landscape context allows us to consider the value of critical elements (such as large unfragmented forest, riparian buffers) in the conservation of bird species (e.g., Ambuel and Temple, 1983; Robbins et al., 1989; Machtans et al., 1996), and how dynamics within these areas can be affected by external factors that vary as the heterogeneous landscape changes (Wiens, 1995). Even though there is a statistical difference between landscape patterns created by the simulation of silvicultural systems at the stand- and landscape-base level of planning, we do not know if there is ecological significance to this result. It is important to determine what constitutes a significant difference in spatial metrics, both statistically and ecologically. Empirical data needs to be gathered on the ecological implications of landscape patterns created by management activities at different spatial scales (Turner et al., 1995).

Forest patches can be delineated by many characteristics (e.g., age, canopy closure, forest type, vertical structure, understory species), and each characteristic may have a unique spatial pattern (Chen et al., 1996). Landscape metrics of mean patch size, interspersion index and diversity index were calculated based on forest patches delineated by stand age. The quantification of landscape pattern based on forest patches delineated by some other stand attribute may produce different results, and hence will lead to different interpretations of the effects of landscape pattern on ecological function (e.g., Mladenoff et al., 1993; Chen et al., 1996). It is important to define forest patches based on the attribute that is related to the ecological function of interest, especially when one is attempting to examine the effects of landscape pattern on ecological processes.

On the comparison of silvicultural systems, our results indicate that even-age management maintained larger mean stand age patch sizes, higher interspersion index and greater total core area than uneven-age management. This means that at the landscape-level, there will be more interior bird species due to the presence of larger patch sizes with greater core area (e.g., Thompson, 1993). Also, the stand age patches are more evenly spaced. Interspersion of habitats throughout an area means that multi-habitat species are more likely to be supported in the area. This can maintain diversity and stability throughout the landscape during stress periods (Thompson et al., 1995). The well interspersed forest patches favor neo-tropical migratory birds (Flather and Sauer, 1996). However, high interspersion values could also mean greater boundary length thus supporting edge-adapted species. Uneven-age management generally creates forest stands that are of at least three age classes, usually resulting in smaller patch sizes and fine-scale spatial heterogeneity in the landscape-level. The multiple age classes resulting from uneven-age management tends to create several well-developed vegetation levels and complex habitat structure which results in higher within-stand bird species diversity than in even-aged stands (Thompson et al., 1995). Although uneven-age management maintains a mature tree component at all times at the landscape-level, it does not provide for species that require larger openings or early seral conditions or a diversity of even-age stands. So, even though uneven-age management may produce greater within stand-level bird species diversity at the landscape-level it may create smaller mean stand age patch sizes which may not favor species that require large patches of mature forest habitat. Thus, forest management practices implemented at the stand-level may increase within-stand diversity but not necessarily diversity at the landscape-level. Furthermore, ecological stand-level responses is sensitive to the broader landscape context, and landscape-level responses are influenced by stand-level management. It is difficult to translate ecological responses of forest management activities at the stand-level to the landscape-level as it is not just a simple matter of aggregating information across scales. There is a need to link management planning activity for individual stands to landscape-level objectives, and to develop landscape-level empirical models that will take into account the spatial patterning of ecosystems and their interactions at the landscape level.

5. Conclusions

Although there is increasing interest in managing our forest resources at the landscape-level, most layout and planning are still conducted at the stand or management unit level. The protection of wilderness and riparian management areas, and areas surrounding wetlands from timber harvest activities did produce a difference in mean patch size, total core area, interspersion index, and diversity index of stand age patches when compared with management of the landscape without the protection of these areas. Forest management planning implemented with a focus at individual stands or one that incorporates the landscape context can produce different landscape patterns which may lead to different ecological implications at the landscape level. Silvicultural treatments that are implemented at the stand-level can have quite different ecological implications when measured at the stand and landscape levels because of the differences in structure or pattern created at each of those levels. This implies that we cannot simply aggregate stand-level ecological responses to the landscape-level when we need to determine how forest management activities at the stand-level affect ecological processes at the landscape-level. It is difficult to predict patterns across spatial scales and even more complicated to translate implications across scales.

Stand attributes can influence several characteristics of forest patches, such as the number, size, adjacency, shape, and length of boundary. These characteristics in turn can affect ecological and physical processes on the landscape. Therefore, the effects of patterns on processes can be highly variable and our understanding of the effects is dependent on how the patterns are defined.

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