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Bridging the gap between landscape ecology and natural resource management

18.1 Introduction

In every respect, the valley rules the stream. Noel Hynes (1975)

The challenges facing natural resource managers occur over entire landscapes and involve landscape components at many scales. Many resource managers are shifting their approach from managing resources such as fish, wildlife, and water separately to managing for the integrity of entire ecosystems (Christensen *et al.*, 1996). Indeed, nearly all resource management agencies in the USA have recognized that informed management decisions cannot be made exclusively at the level of habitat units or local sites. It is generally accepted that ecological patterns and processes must be considered over large areas when biodiversity and ecological function must be maintained while the goods and services desired by the public are provided. For example, forest managers must determine the patterns and timing of tree harvesting while maintaining an amount and arrangement of habitats that will sustain many species. Managers of parks and nature reserves must be attentive to actions occurring on surrounding lands outside their jurisdiction. Aquatic resource managers must broaden their perspective to encompass the terrestrial and human landscape to manage stream and lake resources effectively (Hynes, 1975, widely regarded as the father of modern stream ecology and quoted above; Naiman *et al.*, 1995). Landscape ecology also is implicit in the paradigm of ecosystem management (Grumbine, 1994; Christensen *et al.*, 1996).

Despite the acknowledged importance of a landscape perspective by both scientists and resource managers, determining how to implement management at broader scales is very much a work in progress. It is pertinent for managers to determine what is the appropriate scale of analysis when managing natural resources because a manager must investigate the trade-offs of different natural resource uses while applying an ecosystem management approach

(Chapter 6, this book). Most managers are faced with having to satisfy multiple conflicting uses of a particular management unit with different relevant scales of analysis for each resource (Romm and Washburn, 1987; Chapter 6, this book). These scale differences require a manager to determine the appropriate landscape scale of analysis where the boundaries vary with the resource being managed and the structural and functional characteristics of the landscape matrix (Maxwell *et al.*, 1999; Parry and Vogt, 1999).

The science of landscape ecology, which deals explicitly with the causes and consequences of spatial heterogeneity (Turner, 1989; Pickett and Cadenasso, 1995; Turner *et al.*, 2001), offers concepts and tools that are directly relevant to natural resource management on heterogeneneous landscapes. Applied problems clearly helped catalyze the development of landscape ecology. However, the richness of the theory, methods, and language of landscape ecology has not yet been fully integrated in resource management, despite the rapidly increasing demand from managers for knowledge, tools, and personnel trained in landscape ecology. Many landscape ecologists do not understand the needs of resource managers, and many resource managers are not familiar with developments in landscape ecology. In this chapter, we illustrate some resource management challenges that reflect the need for a landscape perspective, synthesize our viewpoints to identify gaps between landscape ecology and resource management and their causes, and offer some suggestions for bridging the gaps.

18.2 What can be gained from a landscape perspective?

In what areas of resource management may landscape ecology be particularly helpful? We highlight two general areas – aquatic resources and forest management – to provide context for our discussion of the gaps between the science of landscape ecology and its application. These examples were chosen to illustrate areas in which basic research has identified important landscape linkages that may provide a basis for management implementation. Many other examples can be found in other chapters of this book.

18.2.1 Aquatic resources

Freshwater ecosystems are integrators and centers of organization within the landscape, touching nearly all aspects of the natural environment and human culture (Naiman *et al.*, 1995; Naiman, 1996). Understanding the degree to which land uses in the uplands, and the spatial arrangement of these land uses, influence habitat and water quality in streams and lakes is a common theme underlying many studies of land–water interactions. Freshwaters are degraded by increasing inputs of silt, nutrients, and pollutants from agriculture, forest harvest, and urban development (Carpenter *et al.*, 1998). The incorporation of landscape ecology into stream management promises to contribute to the understanding of these influences. Although landscape concepts have been incorporated into stream ecosystem theory (e.g., Vannote *et al.*, 1980; Frissell *et al.*, 1986; Wiley *et al.*, 1990; Townsend, 1996), lake ecosystem theory (e.g., Kratz *et al.*, 1997; Magnuson and Kratz, 2000), and as part of watershed analyses that combine geographical information systems (GIS) and modeling (Young *et al.*, 1989; Dubayah *et al.*, 1997), they are less well integrated into real-world management. New management perspectives and approaches are necessary to restore degraded aquatic ecosystems and to maintain those that are in satisfactory condition.

Land use and water quality

The landscape mosaic is important for water quality. For example, Osborne and Wiley (1988) analyzed the nitrogen and phosphorus concentrations of streams in the Salt River Basin, Illinois, and used regression analysis to determine whether there was a relationship with land-use patterns mapped from aerial photos. Their results demonstrated that the amount of urban land cover and its distance from the stream were the most important variables in predicting nutrient concentrations in the stream water. In 33 lake watersheds in the Minneapolis–St. Paul area, Minnesota, landscape and vegetation patterns were obtained from aerial photographs and then compared with measured lake water quality (Detenbeck *et al.*, 1993). Lakes with forest-dominated watersheds tended to be less eutrophic and have lower levels of chloride and lead. In contrast, lakes with substantial agricultural land uses in their watersheds were more eutrophic. When wetlands remained intact in the watersheds, less lead was present in the lake water. Other studies have also found significant relationships between land use and concentrations of nutrients in lakes and streams (e.g., Geier *et al.*, 1994; Hunsaker and Levine, 1995; Johnes *et al.*, 1996; Soranno *et al.*, 1996; Bolstad and Swank, 1997; Johnson *et al.*, 1997; Lowrance, 1998; Bennett *et al.*, 1999).

A simple model of phosphorus transformation and transport for the Lake Mendota watershed, Wisconsin, has provided useful insights into the effects of the landscape mosaic on water quality (Soranno *et al.*, 1996). This study highlighted the importance of identifying both the spatial extent and geographic location of sources of P within the watershed. Most of the watershed did not contribute phosphorus loading to the lake, and the magnitude of input from the watershed varied based on precipitation levels. For example, the watershed contributed about 17% of loading to the lake during low-precipitation years and 50% during high-precipitation years. Riparian vegetation was also very important in attenuating phosphorus runoff. In other examples, the geomorphology of the riparian zone and the soil processes occurring adjacent to streams can have an overriding control on the nutrient retention capacity of this zone (McDowell and Wood, 1984; McDowell, 1998) and define its spatial extent (Scatena, 1990). Management actions will be most effective when they are spatially explicit with respect to the resource and consider both sources and sinks of phosphorus as well as the structural and functional characteristics of the area.

Landscape ecologists have taken particular interest in characterizing and understanding the function of patches or corridors of riparian vegetation because their functional importance is large relative to their size (Lowrance *et al.,* 1997; Naiman and Decamps, 1997; Lowrance, 1998). The spatial pattern of riparian vegetation – i.e., variation in length, width, and gaps – influences its effectiveness as a nutrient sink. Weller *et al.* (1998) developed and analyzed models predicting landscape discharge based on material release by an uphill source area, the spatial distribution of riparian buffer along a stream, and retention of material within the buffer. Again, a strong influence of the spatial characteristics of the riparian zone was demonstrated. For example, variability in riparian buffer width reduced total buffer retention and increased the width needed to meet a management goal (Weller *et al.*, 1998). Variable-width buffers were less efficient than uniform-width buffers because transport through gaps dominated discharge, especially when buffers were narrow; average buffer width was the best predictor of landscape discharge for unretentive buffers, whereas the frequency of gaps was the best predictor for narrow, retentive buffers (Weller *et al.*, 1998). The sensitivity of freshwater quality to changes in the riparian zone again underscores the need for a spatially explicit view of the watershed.

Fish habitat

Habitat for a fish may be defined as the "local physicochemical and biological features of a site that constitute the daily environment of fish" (Milner *et al.*, 1985). Although fish clearly respond to local conditions, habitat quality is influenced by activities and conditions that may occur far from the stream. Channel morphology and stability, water temperature, nutrients, dissolved oxygen, and flow variation and regime at any one site are influenced by conditions in the watershed in which the stream is embedded. These watershed influences may determine the overall habitat quality of a stream and its potential capacity to support fish (Rabeni and Sowa, 1996). Thus, fish populations and communities must be viewed in the context of the entire watershed. Intense efforts to remedy particular fisheries problems locally (i.e., within a stream reach) may be ineffective if watershed influences exert the overriding control. Managers usually do consider beyond-reach effects, but funding levels rarely permit implementation of projects at the broader scales.

Because land use within the watershed may strongly influence fish communities, there is a clear need to analyze management issues at a landscape level. In a study of fish in Wisconsin streams, the health of fish communities was negatively correlated with the amount of upstream urban development (Wang *et al.*, 1997). Fish community health was positively related to the amount of upstream forest in the watershed and negatively related to the amount of agricultural land. The response of the fish community to land-use changes was not linear: declines in the condition of the fish fauna occurred after about 20% of the watershed was urbanized. No impacts were attributed to agriculture until about 50% of the watershed was used for this purpose. Similar results obtained in other studies also demonstrate the importance of regional land use as the prime determinant of local stream conditions (e.g., Richards *et al.*, 1996; Allan and Johnson, 1997). Theoretical studies of landscape pattern have identified critical thresholds in the abundance of particular habitat that produce qualitative differences in habitat connectivity (e.g., Gardner *et al.*, 1987; Pearson *et al.*, 1996) or spatial processes that move across a landscape (e.g., Turner *et al.*, 1989). Empirical support exists for the effects of critical thresholds in habitat abundance on bird and mammal communities in terrestrial landscapes (e.g., Andren, 1994); it would be very interesting to know whether similar thresholds are widely applicable for aquatic fauna.

Land-use changes have altered the water table and runoff patterns with predictable impacts on fishes. In the tallgrass prairie biome of North America, agricultural activities have decreased water tables and increased siltation, turning small, clear-flowing perennial streams into turbid intermittent creeks (Rabeni, 1996). Altered hydraulic regimes contribute to changes in stream-channel morphology and now the typical situation is a wider, shallower, heavily eroded channel. Fishes adapted to clear water, stable substrates, and aquatic vegetation have been replaced by fishes less specialized in their feeding habits, reproductive requirements or physiological tolerances. For example, since 1850, two-thirds of the fish species in the Illinois River system have declined in abundance or been eliminated from parts of their historic range. Additionally the historical ecological ratios of species have been altered to where omnivores now predominate over the more specialized carnivores, insectivores, and herbivores (Karr *et al.*, 1985).

Land-use changes that propagate slowly and unpredictably through drainage networks are termed "complex responses" by geomorphologists (Kooi and Beaumont, 1996; Dominick and O'Neill, 1998). In larger drainage basins, many different land-use changes and natural climatic variations may take place simultaneously. Understandably, fisheries management is complicated by land-use activities that result in differential alterations of runoff and sediment yield – two important variables affecting physical habitat of fishes. For example, agricultural practices in the eighteenth and nineteenth centuries in Maryland Piedmont watersheds increased soil erosion which resulted in stream aggradation (the streambed elevated) because of excess sediment yield (Jacobson and Coleman, 1986). The recent institution of soil conservation practices and the retirement of marginal lands from cultivation in some watersheds have reduced sediment yields to the streams. Runoff continued to be higher than historical levels, however, causing the streams to incise (downcut) because of bed erosion and coarsening their beds, thus preventing historical physical habitat for fishes from being re-established.

The state of the art concerning land use–aquatic biota interactions is still primitive and limited to rather gross associations. Nevertheless, studies detecting correlations between stream biota and landscape-level activities are essential first steps in the efficient management of aquatic fauna. The next step toward management must be the elucidation of underlying mechanisms. For example, does urbanization negatively influence fishes because it results in too much water or sediment, too little water or sediment, altered water quality, all of the above, or some other factors? Understanding when the landscape mosaic is important and identifying the landscape elements critical for particular aquatic resources (and any thresholds) would contribute to more effective management of lakes and streams. These issues present a challenge to management at the watershed scale.

18.2.2 Management of forest landscapes

Understanding the dynamics and heterogeneity of natural forest landscapes has become increasingly important as management objectives for forests broaden to include maintenance of biological diversity (Spies and Turner, 1999). At the same time, multiple conflicting demands are being placed on forests by continued harvest of timber and non-timber forest products (Vogt *et al.,* 1999a,b). Forest certification developed to aid assessment of the sustainability of social and natural systems that are closely linked to natural resources (Vogt *et al.*, 1999a,b). Management has to consider the impacts of both natural and anthropogenic factors whose impacts occur at variable scales within the landscape. Natural disturbances, such as fires or storm events, create a mosaic of stand ages across forest landscapes. Forest harvesting operations also are explicitly spatial, having an immediate impact on landscape structure by creating harvested patches of varying size, shape, age, and spatial arrangements (Larson *et al.*, 1999). Understanding the interactions among the processes generating patterns in forest landscapes and the many ecological responses to these patterns and how they change through time is key to effective forest management (Franklin and Forman, 1987; Oliver *et al.*, 1999; Spies and Turner, 1999).

Forest harvesting patterns

A clear signature of forest cutting on patterns is observed in many forest landscapes (Burgess and Sharpe, 1981; Krummel *et al.*, 1987; Spies *et al.*, 1994; Turner *et al.*, 1996). Landscape ecologists have quantified many of the effects of harvesting on forest landscape structure. In the upper Midwest, for example, a harvested forest landscape had more small forest patches and fewer large patches than an unharvested landscape, and forest patches in the disturbed landscape were simpler in shape (Mladenoff *et al.*, 1993). In addition, certain types of juxtapositions between different forest community types (e.g., hemlock–lowland conifers) were present in the old-growth landscape but absent in the disturbed landscape.

Landscape ecological models have been used to explore the implications of different patterns of harvesting timber from forested landscapes (e.g., Franklin and Forman, 1987; Li *et al.*, 1993; Liu, 1993; Wallin *et al.*, 1994; Gustafson and Crow, 1996). These models typically take an area like a watershed or a national forest and simulate different sizes and arrangements of harvest areas, as well as how much time elapses until the next harvest. For example, small dispersed cuts and large aggregated cuts have been compared in terms of their effect on landscape structure. Similarly, the effects of varying the time between successive harvests – sometimes called rotation length – from 50 to 100 to 200 years have been studied. In addition to projecting the configuration of forests of different age on the landscape, the models often examine the effects of each scenario on the potential distribution of suitable habitat for wildlife populations.

Some important insights for forest management have emerged from studies using landscape models of forest harvesting. The deleterious effects of small-dispersed cutting patterns for habitat connectivity are readily apparent from simulation studies (Franklin and Forman, 1987; Li *et al.*, 1993; Wallin *et al.*, 1994; Gustafson and Crow, 1996). The small dispersed cuts such as those practiced on federal lands in the Pacific Northwest during the past 40 years created a highly modified forest landscape that contains very little forest interior. For the same total area cut, fewer but larger aggregated cuts actually can maintain greater connectivity of forest habitats. However, it is important to remember that the shift to the small dispersed cutting patterns was in part a response to negative public perceptions of large clear-cuts. Another important insight gained from these models is an estimate of the amount of time required for the patterns established by a cutting regime to be erased from the landscape.

Simulation modeling studies demonstrated that once established, the landscape pattern created by dispersed disturbances is difficult to erase unless the rate of cutting is substantially reduced or the rotation period is increased (Wallin *et al.*, 1994). To overcome the problems of dispersed disturbances, alternative cutting plans are now being considered and implemented in the Pacific Northwest (Franklin *et al.*, 1999; Halpern *et al.*, 1999)

Natural disturbance regimes

Disturbance is a major agent of pattern formation in forests and many other landscapes, and disturbance may even be required for the maintenance of ecosystem function. Results of natural disturbances range in size from small "gaps" in a forest canopy or rocky intertidal region created by the death of one or a few individuals, to larger patches created by severe windstorms, fires, and landslides occurring after hurricanes. Landscape ecologists have focused considerable effort on studying disturbance dynamics – often in forest landscapes – because disturbance is often responsible for creating and maintaining the patterns we observe (e.g., Romme, 1982; Pickett and White, 1985; Turner, 1987; Foster *et al.*, 1998). Many studies have demonstrated how intentional or unintentional shifts in the disturbance regime may dramatically alter the landscape, and these have important implications for forest management.

Baker's (1992) study of changing fire regimes in the Boundary Waters Canoe Area of northern Minnesota provides an illustration of how landscape structure varies with fire frequency. Prior to European settlement, fires were relatively large in extent and infrequent. As the upper Midwest was settled by Europeans, fire frequency increased substantially because of indiscriminate burning by early settlers, land speculators, and prospectors. A period of fire suppression followed. Settlement and fire suppression both produced substantial shifts from the pre-settlement disturbance regime and resulted in significant effects on landscape structure (Baker, 1992). Interestingly, the Boundary Waters Canoe Area was affected by a massive severe windstorm on July 4, 1999, which resulted in >100 000 ha of windthrown trees; the potential exists for large high-intensity fires to occur for several years due to this storm.

Disturbance has been increasingly recognized by ecologists as a natural process and source of heterogeneity within ecological communities, reflecting a real shift in perception from an equilibrial to non-equilibrial view of the natural world (Wiens, 1976; Pickett *et al.*, 1994). This shift clearly has significant implications for management of forest landscapes. Managing human disturbances to mimic the spatial and temporal patterns of natural disturbances and minimize deleterious effects has also been debated (e.g., Hunter, 1993; Attiwill, 1994; Delong and Tanner, 1996). Of course, meeting such an objective requires understanding the dynamics of the natural disturbance regime in a given landscape. More generally, managers must understand the consequences of naturally induced landscape heterogeneity in order to understand and manage the consequences of human-induced heterogeneity.

Managing forests from the landscape perspective is a relatively recent addition to the usual forest management approaches (Mladenoff *et al.*, 1994; Oliver *et al.*, 1999). Prior to this, the scheduling of forest harvest was based on more simplistic silvicultural rules and was done with little consideration for the consequences of harvesting regimes on spatial and temporal changes in stand structure. Integration of landscape ecological concepts and methods allows spatial dynamics and constraints to be considered (Oliver *et al.*, 1999).

18.3 Gaps between landscape ecology and natural resource management: What are they, and why are they there?

The strength and vitality of landscape ecology are due in large part to the integration of scientific insights with applications to real-world problems. Landscape ecology offers a perspective to applied questions about natural environment that complements those emerging from other levels in ecology. By linking patterns and processes, landscape ecology may provide insight into many practical problems regarding the land, how it is managed, and how it will change. This theme runs through virtually all of the textbooks and symposia proceedings in landscape ecology and is prevalent in the papers published in *Landscape Ecology*, *Landscape and Urban Planning*, and a host of other journals in a variety of disciplines. But is this expectation of real-world applications more promise and potential than practice? Is landscape ecology delivering on its stated commitment to integrate science and practice? If not (and we suggest that this potential has been only partially fulfilled), how might such an integration be fostered?

Landscape ecology has certainly fostered an increased awareness of some of the fundamental problems that confront both basic and applied ecologists. Landscape ecology tells us that homogeneity is an illusion, that scale matters, and that the effects of heterogeneity and scale will differ among organisms or ecosystems. Landscape ecology has had considerable success in bringing a variety of tools to bear on these problems, tools such as spatial modeling, remote sensing, GIS, and spatial statistics. These tools allow us to describe and analyze spatial patterns in great detail, and to explore the consequences of various forms of heterogeneity in an apparently limitless array of "What if" scenarios. As a result, we are rapidly developing a richer understanding of the first two components of landscape ecology, the effects of heterogeneity and of scale. We can realistically expect that, before very long, developments in these areas will lead to theory that actually generates useful predictions. Less progress has been made, however, in dealing with the third component of landscape ecology, the seemingly idiosyncratic nature of species and of ecosystems.

The current state of development of landscape ecology as a science bears directly on the gaps between a landscape perspective and the management of natural resources. Some of these gaps derive from the imperfect state of the science or the mismatch between the needs of managers and the current state of our basic understanding. Others relate to the current state of resource management and its ability to embrace new paradigms. Table 18.1 summarizes the major gaps between landscape ecology and natural resource management.

18.3.1 Goals

A major gap between landscape ecology and natural resource management is the difference in their goals. The main goal of landscape ecology is to understand the causes and ecological consequences of spatial heterogeneity across landscapes, whereas natural resource management aims toward maintaining or altering natural resources for societal values (e.g., timber, wildlife, fish, water quality, and biodiversity). The goal of landscape ecology is relatively easy to define and evaluate through procedures such as hypothesis testing. But how should landscape management goals be specified and success evaluated? Goal setting and evaluation are crucial for resource managers, yet the basic science of landscape ecology has not yet provided satisfactory guidance. It is more challenging to define landscape-level management goals than traditional natural resource management goals because traditional resource management emphasized the amount of product, and landscape-level goals remain difficult to translate into management schemes (Perera *et al.*, 2000). Landscape-level management goals must include the amount of product as well as the spatial patterns and ecological processes in the landscape. For example, given a certain amount of wildlife habitat, how should such habitats be arranged spatially (e.g., size, shape, and distribution of patches), and exactly what does the manager gain from such arrangements? What is the effect of alternative arrangements on aesthetics and other societal values? Note that the shift in management goals from extraction to sustainability leads directly to consideration of spatial relationships and scales, as these affect the likelihood of achieving sustainability.

18.3.2 Incongruities of scale

Issues of scale are multi-faceted and fundamental to the science and applications of landscape ecology. Scaling issues involve a coupling between the heterogeneity and spatial structuring of landscapes and the ways in which

Table 18.1. *Major gaps between landscape ecology and natural resource management and suggestions for bridging the gaps*

	Landscape ecology	Natural resource management	Means to bridge the gaps
Goals	Understand causes and ecological consequences of spatial heterogeneity	Maintain or alter natural resources for societal objectives as guided by local, state, and federal statute	Couple the goals such that both are considered important; share language
Scales	Ecologically meaningful scales	Management-oriented scales	Reconcile scales through multi-scale study and management
Tools/methods	Spatial modeling and analysis, geographic information systems, experiments	Harvest, prescribed fires, wildlife management, restoration, habitat manipulation	Apply tools in landscape ecology to evaluate management consequences; use management practices to create landscape ecological experiments; work together to develop models
Training/ experience of personnel	Training in ecology, no management experience	Out-dated or little training in ecology, rich management experience	Provide updated information for managers and offer management experience to ecologists; create opportunities for continued dialogue and education that are conducive to exchange of ideas and information
Data	Observation results, simulation results, experimental results, remote sensing data	Observation results, remote sensing data	Share data, and collaborate on obtaining data to avoid duplication of effort
Institutional culture	Publish or perish	Crisis control and problem-solving	Recognize outreach efforts of ecologists in solving real-world problems, and reward managers' participation in research endeavor for better management decisions and practices

different kinds of organisms or ecological processes respond to this heterogeneity and structure. We summarize here four incongruities of scale that are of particular importance for resource management (see also Peterson and Parker, 1998; Wiens, 1999).

One incongruity of scale is that management units are often smaller than the scale of ecological dynamics or the scale of the human ecosystem, leading to a mismatch in ecological and management scales. Watersheds, for example, are ecologically meaningful landscape units, yet their boundaries often do not match administrative boundaries – indeed, the stream or river often serves as a political boundary. Mechanisms for funding broader-scale management programs remain limited, and thus, influencing the political process becomes important. Resource management decisions within a watershed are often made by multiple independent owners or institutions. In the United States, land-use decisions – if they are made at all – are usually made at a local level (Dale *et al.*, 2000). There are regional planning commissions in some parts of the country, but they often lack the authority to influence land-use decisions. Individual changes in land use may appear to have only local significance. In total, however, the large number of local changes transforms the landscape (Turner *et al.*, 1998). Gradual but widespread change significantly impacts vegetative cover, wildlife habitat, soils, and water quality. These ecological changes also feed back to impact the human ecosystem and the type and intensity of management that will occur in a natural system (Chapter 6, this book). This can result in natural resource management occurring at the wrong scale so that sensitive indicators are not being used when making management decisions (Maxwell *et al.*, 1999).

A second important incongruity in scales relates to the scales at which data are collected and the scales at which management decisions must be made. How are the findings of research conducted at fine scales to be incorporated into management decisions made at broad scales? This is essentially a question of translating among scales; we wish to derive "scaling functions" that portray how the phenomena of interest vary with scale and whether there are sharp thresholds or non-linearities that might limit our ability to extrapolate. Although scaling functions have a long history in comparative anatomy and ecology, derivation of scaling functions in landscape ecology is more complicated because one must consider simultaneously how patterns and processes in the physical environment vary with changes in scale *and* the scale-dependency of the responses of organisms to those environmental factors. However, it also is inappropriate to assume that it is *always* necessary to scale information from the fine to broad scales to understand or manage a system. It is preferable to identify the sensitive scale and focus research on that scale (Chapter 6, this book), but identifying the "correct" scale(s) for management remains a practical challenge. In practice, managers often find their choices of scale constrained by the scales of the available data.

The third general incongruity in scales has to do with translating between ecological systems. How can we move from providing situation-specific recommendations to developing generalizations about organisms and ecosystems that will be useful to managers? This question involves whether the same principles or scaling functions can be applied to suites of species or similar types of ecosystems. Although some practical approaches to developing such generalizations have been proposed (e.g., Addicott *et al.*, 1987), we lack a generally accepted construct for achieving this.

Fourth, there is often an incongruity of scales between data in the social and the natural sciences, yet both are important for landscape management decisions (Chapter 6, this book). For example, the state of an aquatic system may be strongly influenced by human population density and development in riparian areas. Population and building data are often available for political units such as counties, towns, or census tracts, yet relating these units to water quality for individual lakes is difficult. Linking information collected at political and ecological scales was successfully used by Grove and Hohmann (1992) to assess the health of watersheds associated with the city of Baltimore (see case study in Chapter 6, this book). However, few examples are available where the information collected at the political scale was similar to the ecological scale and an analysis comprised of both scales could be used as an effective management tool. Scales should be chosen based on the patterns and processes to be characterized, with forethought given to the integration of different data sets.

18.3.3 Tools and methods

Appropriate tools and methods are essential to achieve the goals of landscape ecology and natural resource management. Numerous metrics for quantifying spatial patterns and how they change through time have emerged from landscape ecology, and these are now widely available (e.g., McGarigal and Marks, 1995). However, many potential users are not well informed about the assumptions and caveats that influence their appropriate use and interpretation (Gustafson, 1998). Spatial analyses should not become codified such that a suite of standard tools is automatically transferred from one system to the next or from one scale to another, but informed use of these methods is critical.

Models are important tools in landscape ecology, and they will continue to be powerful complements to empirical studies. It is often impossible to conduct experiments over large areas that span the range of many treatments of interest or that permit responses of the system to be followed over long periods of time. Models provide at least a partial substitute for landscape-level experiments. Most landscape models, however, have been developed as research tools rather than management tools. They are often complex, requiring information that is simply not available for most species. Only a few species, such as the northern spotted owl (*Strix occidentalis*; McKelvey *et al.*, 1993), Bachman's sparrow (*Aimophila aestivalis*; Pulliam *et al.*, 1992; Liu *et al.*, 1995), and the Cowbird (*Molothrus ater*; Gustafson and Crow, 1994; Coker and Capen, 1995; Hobson and Villard, 1998) have been sufficiently studied such that spatially explicit models can be parameterized over entire landscapes. Parameterization of the functional aspects of ecosystems over spatially heterogeneous landscapes is even more data-limited. In addition, many of the models are location-dependent and cannot easily be transported to other landscapes. For example, the spatial model used to simulate winter grazing by elk and bison in northern Yellowstone National Park (Turner *et al.*, 1994) cannot easily be run for a different landscape.

What is the relationship between the complexity of models, theories, and approaches and their actual application in management settings? Should models be relatively simple? Does increased complexity in models/theory necessarily lead to decreased likelihood of application to natural resource problems? How general can models be without sacrificing ecologically important detail? Furthermore, predictive models are not well developed. For instance, although the importance of understanding the current and past ecological effects of land use is now recognized (Turner *et al.*, 1998; Dale *et al.*, 2000), we do not have predictive models of the effects of various land-use patterns on ecological function, nor are we able to predict future land-use patterns very well.

Other tools such as spatial statistics (Turner and Gardner, 1990; Klopatek and Gardner, 1999) and geographic information systems (Johnston, 1990; Haines-Young *et al.,* 1993) have been widely used in landscape ecology to analyze spatial patterns. FRAGSTATS (McGarigal and Marks, 1995) is probably the most frequently used software for calculating landscape indices. Global positioning systems (GPS) are being used to collect georeferenced data (Farina, 1997).

Maintenance and alteration of natural resources depend on a variety of tools and methods. For example, harvest is a classic method for controlling population sizes and obtaining natural resource products such as timber (Burton *et al.,* 1999; Liu and Ashton, 1999), game (Steinert *et al.*, 1994; Lovell *et al.,* 1998), and fish (Klyashtorin, 1998). Release of wildlife is becoming a major practice to restore populations of endangered species like gray wolf (*Canis lupus*; Fritts *et al.*, 1997). Prescribed fires are a common approach to manipulating habitat for wildlife (Kwilosz and Knutson, 1999) and plants (e.g., Tveten and Fonda, 1999).

18.3.4 Training and experience

Most landscape ecologists are skillful in using tools for landscape analysis, but often lack management experience. As a result, they do not have a deep understanding of what managers need and what urgent management problems are. On the other hand, many resource managers received their technical training years or decades ago and have not had the opportunity to learn new skills that would enhance their ability to use and interpret ecological models or to measure and interpret measures of landscape pattern. In addition, computer software (e.g., modeling or analysis packages) often is not in a form that managers can use readily, or if it is, it is often ecologically simplistic. These factors inhibit application of some of the tools developed in landscape ecology to real-world management settings. In addition, there may be misconceptions about what landscape ecology actually has to offer. Even within the research community, it is often important to emphasize that landscape ecology is *not* equivalent to the quantification of spatial pattern. Quantifying pattern is a necessary component of understanding the causes and consequences of spatial heterogeneity for ecological processes – the heart of landscape ecology – but it is not an end in and of itself.

18.3.5 Technical infrastructure and data

The generation, maintenance, and interpretation of large volumes of landscape data are not trivial tasks. Such data, generated by field observation, remote sensing, manipulative experiments, and simulation modeling, must often be comprehensive across or beyond the entire management area. Availability of a common spatial data set from which stakeholders can work is necessary (but not sufficient) for landscape-level resource management. As anyone who has built a geographic database is painfully aware, data development is both expensive and time-consuming. Many management agencies are well along in their development of such spatial databases (e.g., Michigan Resource Information System developed by the Michigan Department of Natural Resources, 1978), and this is an asset to scientists and managers. However, many data owned by resource agencies and landscape ecologists are not shared and thus the potential of the data is not fully realized. In addition, effective uses of spatial data require adequate technical support and development of metadata that document the development, scales, and limits (e.g., accuracy) of the data.

18.3.6 Institutional culture

In academic settings, the major criteria for promotion and rewards are publications and grants. This academic culture often discourages the participation of faculty and graduate students in resource management activities (Carpenter, 1998) because management activities often do not result in peer-reviewed publications. In contrast, management agencies judge work performance not by the number of publications, but by whether crises are solved, problems are fixed, and legal requirements (e.g., in the United States, National Environmental Policy Act, Endangered Species Act) are met. These criteria for hiring and promotion discourage the collaboration between landscape ecologists and resource managers, impeding participation of landscape ecologists in resource management processes and involvement of resource managers in landscape-level research. Furthermore, shift within management organizations from the traditional organization of separate divisions for fisheries, wildlife, and water resources into management units based on ecosystems is not always smooth. Academic reward systems are usually biased in favor of research that is narrowly focused because it is more difficult and time-consuming to involve people from other disciplines, including personnel at management agencies.

18.4 Bridging the gap between landscape ecology and resource management

We offer the following suggestions for bridging the gaps identified in the previous section (see Table 18.1).

18.4.1 Goals

Although the goals of landscape ecology and natural resource management are different, they are not in conflict and should be coupled. Indeed, landscape ecology and natural resource management can be mutually beneficial. Perhaps more importantly, land use and its management are realities of the future, and landscape ecology must deal with these issues directly. What does landscape ecology offer to natural resource management? Landscape ecology offers a conceptual framework for understanding spatial heterogeneity and scale. Theory in landscape ecology leads to testable predictions about how patterns develop, persist, and change in the landscape, and about how ecological processes respond to these patterns. Landscape ecology also offers tools – a set of techniques to quantify and track changes in space and time. Models that permit the implications of alternative land-management scenarios to be evaluated from a natural resource perspective are also being developed by landscape ecology practitioners. Often formulated as spatially explicit simulation models, they can allow managers to visualize the effects of different options from which they must choose. For example, ECOLECON is a spatial model that links ecological and economic considerations in forest harvesting and permits resource outputs and population dynamics to be evaluated under alternative harvest scenarios (Liu, 1993; Liu *et al.*, 1995).

What does resource management offer to landscape ecology? Natural resource management provides a wide array of opportunities for further development of the theory and empirical underpinnings of landscape ecology. Landscape ecologists are typically limited in their ability to conduct manipulative experiments, yet close collaboration with natural resource managers may offer just such opportunities (Chapter 13, this book). Management actions can be viewed profitably from an experimental viewpoint, and landscape ecologists should avail themselves of the opportunities to see how well predictions hold up to actual manipulations on the land. In addition, landscape ecology is still in the process of developing a library of empirical studies that relate patterns and processes in ways that contribute to our understanding of ecological processes over broad scales of space and time. Natural resource managers have a wealth of data, often for large areas and long time periods, that may prove valuable as we continue to build our knowledge base and seek generality in the relationships we observe. Closer collaboration can yield much more robust answers to perplexing management questions.

18.4.2 Incongruities of scale

The scale issues must be explicitly addressed and discussed by landscape ecologists and resource managers. Landscape ecological research should consider the scales that are most meaningful for ecological processes and must determine how management can be scaled appropriately (e.g., by cooperation of multiple landowners and by the timing and spatial characteristics of management actions). Although management is often implemented locally (e.g., stand), the effects of management actions may extend well beyond the management sites (e.g., entire forest landscapes and adjacent areas). Thus, landscape ecological research must evaluate ecological consequences of management practices at both local and broader scales (Liu and Ashton, 1999; Liu *et al.*, 1999). Similarly, local watershed management goals and objectives can be couched in frameworks at larger spatial scales, as done in the Oregon Plan for Salmon and Watersheds (2001). As remote sensing data have become more widely available, it is now feasible to assess the ecological effects of management at broad scales.

When scaling data, special attention should be paid to the fact that information often changes with scale. When designing new monitoring schemes, the sampling should be made as congruent as possible with the scales at which decisions must be made.

18.4.3 Tools and methods

Many landscape-level models are indeed complex, and they may be site-specific. Their importance among the many tools available for landscape ecologists and resource managers mandates an improvement in training both scientists and managers in model development, implementation, and interpretation. For instance, when faced with a practical question involving land-use patterns, landscape ecologists and resource managers should seek and encourage collaborative development of models (conceptual models as well as more complex mathematical models). The role of institutions (e.g., management agencies, political institutions, and non-governmental organizations) should be considered as they affect land-use patterns, and tools should be developed to evaluate and monitor ecological and socioeconomic impacts of landscape context (beyond natural, political, and management boundaries) across landscapes.

Management methods used in natural resource management, such as harvesting techniques and patterns, provide valuable opportunities to address many fundamental landscape ecological issues like the role of disturbance in spatial patterns (Franklin and Forman, 1987) and the importance of corridors in population persistence (Haddad, 1999; Chapter 8, this book). For example, by working together with resource managers at Savannah River Site, South Carolina, Haddad (1999) created many spatial patterns that are not easily or frequently observed in natural landscapes. These patterns were essential to test a series of landscape ecological hypotheses in a more efficient and timely manner.

18.4.4 Training and experience

To shorten the time lag between landscape ecology research and applications to natural resource management, training is needed for both landscape ecologists and resource managers. Landscape ecologists should gain some management experience and understand management needs, whereas resource managers should grasp new concepts and become familiar with tools and methods in landscape ecology. The training may take different forms. Landscape ecologists may gain management experience through participating in actions led by resource managers and can offer workshops to resource managers about new concepts and approaches. For example, more than 500 people (including over 100 resource managers) attended the 1998 annual meeting of the US Regional Association of the International Association for Landscape Ecology (US-IALE) held at Michigan State University, as the theme of the meeting was "Applications of landscape ecology in natural resource management." At the meeting, a workshop entitled "Bridging the gap between landscape ecology and natural resource management" was held and resulted in this chapter. Besides scientific and technical sessions, there were several field trips to resource management areas in Michigan for the meeting attendees, and dozens of landscape ecologists took field trips led by resource managers. It is also necessary to form close communication networks and effective dialogues between landscape ecologists and natural resource managers at the local, regional, national, and international levels to foster *regular* interchange. However, new research and teaching settings that are truly interdisciplinary and go well beyond engaging good managers in a classroom setting are also urgently needed.

18.4.5 Technical infrastructure and data

Researchers and managers should work together to build and share common databases. This may require pooled resources to acquire, process, and manage data, and attention to metadata is crucial. Resource management agencies should strive toward improvements in technical infrastructure and data. For example, the Michigan Department of Natural Resources has developed a Michigan Resource Information System (MIRIS), a statewide digital archive of spatial data including base maps (e.g., political boundaries, transportation corridors) and land-cover/use maps depicting 52 categories of urban, agricultural, wooded, wetland, and other land-cover types. To facilitate the use of digital map data from MIRIS, the Center for Remote Sensing and Geographic Information System at Michigan State University specifically designed a C-Map GIS which includes comprehensive digitizing tools, an automated polygon construction module, GIS analysis functions and extensive data conversion capabilities. MIRIS data are very useful for landscape-level research, which in turn contributes to the MIRIS database (Chapter 12, this book).

Data design and sharing between landscape researchers and resource managers is increasing. For those who did share data, files were commonly exchanged using floppy diskettes and most recently CD-ROMs. Electronic technologies such as the World Wide Web (WWW) and File Transfer Protocol (FTP) are very efficient tools to facilitate data sharing among groups at different physical locations. An example of successful collaboration between resource managers and the use of WWW technology is the Colorado Natural Diversity Information Source (NDIS). NDIS supports planning by local communities by providing readily accessible information on the impacts of development on wildlife habitat (Cooperrider *et al.*, 1999; Theobald *et al.*, 2000). Through the World Wide Web (see NDIS, 2001), users can interactively specify an area to be developed in the future and assess potential impacts on wildlife. We suggest that landscape researchers and resource managers might learn from these successful applications and take full advantage of these advanced technologies.

18.4.6 Institutional culture

Institutional support is perhaps most critical to the success of bridging the gap between landscape ecology and natural resource management. In universities, where most landscape ecologists reside, recognition should be given to outreach efforts of landscape ecologists in solving real-world problems. Academic institutions, especially land-grant universities, should not be ivory towers. Besides teaching, publishing papers, and writing research grant proposals, information dissemination and outreach to the resource management community should be encouraged and rewarded. Work on resource management problems should be regarded as highly as work on basic scientific issues. In addition, scientists must be sensitive to the institutional inertia and fundamental changes being experienced within many resource management agencies at local and national levels. In management agencies, resource managers should be provided with opportunities to update their knowledge, to learn new skills, and to participate in research endeavors with landscape ecologists so that more informed management decisions can be made.

One way to strengthen the interactions between management agencies and academic institutions is to establish a close partnership, like the Partnership for Ecosystem Research and Management (PERM) between Michigan State University (MSU) and resource management agencies (Michigan State University, 2001). PERM was formally established in 1993 as a novel approach to promote active cooperation among the partners, facilitate cutting-edge natural resource research, and apply research results to resource management activities. The resource management agencies include three divisions (Fisheries Division, Forest Management Division, and Wildlife Division) of the Michigan Department of Natural Resources, the US Geological Survey, and the Great Lakes Fishery Commission. The resource management agencies provide financial support to fund more than ten tenure-track faculty positions in five different departments (Fisheries and Wildlife, Forestry, Agricultural Economics, Geography, and Sociology) at Michigan State University. These appointees are regular faculty members at the University, but each has a 20% appointment to provide outreach services (e.g., providing information and advice for resource management) to the agencies. In addition, many research projects of these faculty members and their graduate students/research associates are identified as high-priority management issues and conducted together with agency personnel. Both the agencies and Michigan State University have benefited from the arrangement.

Within academic institutions, interdisciplinary research should be encouraged and supported financially. Because interdisciplinary research projects usually take longer to complete and considerable effort to coordinate, different assessment criteria are needed. In the United States, it is encouraging that more attention is being paid to interdisciplinary projects by funding agencies such as the National Science Foundation and US Environmental Protection Agency.

Within management agencies, divisional boundaries should be bridged as well. For example, the Michigan Department of Natural Resources has historically managed Michigan's natural resources on a "divisional" basis. Each of the divisions (Wildlife, Forest Management, Fisheries, and Parks and Recreation) focused on the resources for which it was directly responsible, rarely with input or impact analyses on resources managed by other divisions. In mid-1997, the Department began a "joint venture" which brought different divisions to work together on defining goals, objectives, and infrastructure required for implementing a holistic approach to managing various natural resources across landscapes (Michigan Department of Natural Resources, 1997). If successful, the efficiency and effectiveness of resource management will be enhanced. Although it is too early to forecast the likelihood of success, it is promising to see that management agencies have been discussing these important issues and have begun to implement changes.

Clearly, both landscape ecology and natural resource management will benefit from bridging the gaps between them. To make progress, it is essential that landscape ecologists and managers communicate with one another, so that they actually ask the same questions and share the same objectives. The key areas of landscape ecology that are most likely to contribute to resource management should be identified more clearly, along with the critical issues in resource management that may benefit most from landscape ecology. Landscape ecologists must tailor their studies to the goals of management if those studies are to be directly relevant to management. By the same token, however, managers must realize that the findings that follow from landscape studies may entail implementing management at scales other than the traditional, anthropogenic scales. If resource management is to realize long-term sustainability, it must be conducted at scales most relevant to what is to be managed, rather than for whom it is to be managed.

18.5 Summary

The challenges facing natural resource managers increasingly occur over entire landscapes and involve spatial interdependencies among landscape components at many scales. Nearly all resource management agencies in the USA have recognized that informed management decisions cannot be made exclusively at the level of habitat units or local sites, and many are shifting toward management of integrated ecosystems. A landscape perspective is acknowledged as important by both scientists and resource managers, but determining how to implement management at broader scales remains challenging. Landscape ecology deals explicitly with the causes and consequences of spatial heterogeneity and offers concepts and tools that are directly relevant to natural resource management. In this chapter, we illustrated challenges in the management of aquatic resources and forests that reflect the need for a landscape perspective, synthesized our viewpoints to identify gaps between landscape ecology and resource management and their causes, and offered some suggestions for bridging the gaps.

(1) *Goals.* Landscape ecology seeks to understand the causes and consequences of spatial heterogeneity, whereas natural resource management seeks to maintain or alter resources to achieve goals set by society. These goals are not in conflict, however, and we suggest that they be better coupled so that both can be better achieved.

(2) *Incongruities of scale.* Scale issues are multi-faceted. Ecological scales and management scales are often mismatched, management decisions must often rely on data collected at disparate scales, the degree to which principles can be extrapolated to different species or ecosystems is not known, and the scales of data in the natural and social sciences often differ. The scale issues must be explicitly addressed and discussed by landscape ecologists and resource managers.

(3) *Tools and methods.* Landscape ecologists use a wide variety of tools including models, spatial statistics, and spatial pattern analyses, whereas managers actually manipulate resources and habitat. The importance of models among the many tools available for landscape ecologists and resource managers mandates an improvement in training both scientists and managers in model development, implementation, and interpretation. In turn, management actions can be profitably viewed from an experimental viewpoint, and landscape ecologists should avail themselves of the opportunities to see how well predictions hold up to actual manipulations on the land.

(4) *Training and experience.* Most landscape ecologists are scientifically and technically trained, but lack management experience. Many resource managers have not had the opportunity to learn the new models and tools of landscape ecology. To shorten the time lag between landscape ecology research and applications to natural resources management, training is

needed for both landscape ecologists and resource managers. Landscape ecologists should gain some management experience and understand management needs, whereas resource managers should grasp new concepts and become familiar with tools and methods in landscape ecology.

(5) *Technical infrastructure and data.* Spatial databases are becoming essential for both research and management, yet building and maintaining them requires considerable cost and effort. Researchers and managers should work together to build and share common databases. This may require pooled resources to acquire, process, and manage data, and attention to metadata is crucial.

(6) *Institutional culture.* The cultures within resource management agencies and academic institutions may not provide sufficient support for more collaborative efforts. Institutional support is critical to the success of bridging the gap between landscape ecology and natural resource management. Within academic institutions, interdisciplinary research should be encouraged and supported financially. Within management agencies, divisional boundaries should be bridged as well.

Both landscape ecology and natural resource management will benefit from a bridging of the gaps between them. It is essential that landscape ecologists and managers communicate with one another, so that they actually ask the same questions and share the same objectives.

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