Linking Restoration and Landscape Ecology

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Abstract

Landscape ecology focuses on questions typically addressed over broad spatial scales. A landscape approach embraces spatial heterogeneity, consisting of a number of ecosystems and/or landscape structures of different types, as a central theme. Such studies may aid restoration efforts in a variety of ways, including (1) provision of better guidance for selecting reference sites and establishing project goals and (2) suggestions for appropriate spatial configurations of restored elements to facilitate recruitment of flora/fauna. Likewise, restoration efforts may assist landscape-level studies, given that restored habitats, possessing various patch arrangements or being established among landscapes of varying diversity and conditions of human alteration, can provide extraordinary opportunities for experimentation over a large spatial scale. Restoration studies can facilitate the rate of information gathering for expected changes in natural landscapes for which introduction of landscape elements may be relatively slow. Moreover, data collected from restoration studies can assist in validation of dynamic models of current interest in landscape ecology. We suggest that restoration and landscape ecology have an unexplored mutualistic relationship that could enhance research and application of both disciplines.

Introduction

The study of habitat restoration has alerted ecologists to some of the problems associated with both the practical and the theoretical issues of rehabilitating damaged habitats. This is evident in the continual refinement of methodologies for successfully establishing and maintaining vegetation in damaged habitats, often summarized as protocols for revitalizing sites (Kusler & Kentula 1990; Thayer 1992; NRC 1994). Beyond the practical aspects, restoration efforts offer an opportunity to address theoretical questions about population, community, and ecosystem-level processes. However, problems with balanced experimental design, statistical analyses, and agreement on criteria for assessment of successful rehabilitation are apparent (Fonseca et al. 1997). Some of these problems are characteristic of an emerging discipline, but may require new approaches to the field of restoration. Many of the papers in this issue (e.g., Michener 1997) speak to these difficulties and offer a variety of tactics to advance the field of restoration research.

In our paper we argue that a landscape-level approach may be useful in addressing restoration topics that are of both theoretical and practical concern. Naveh (1994) explored the relationship between landscape-level processes and restoration and suggested that those involved in restoration needed to expand their focus from small degraded island areas to areas encompassing a larger landscape scale. He provided persuasive arguments not only for the advancement of technical methodology but also for the recognition of cultural values in discussions of landscapes and their restoration. Herein we build upon the link between landscapes and restoration, focusing on two different yet complementary questions: (1) How can principles developed from landscape ecology be used to improve restoration procedures? and (2) How can restoration studies be used to advance the field of landscape ecology?

Linking Landscapes and Restoration

Landscape ecology is the study of processes occurring across spatially defined mosaics (landscapes) and the abiotic and biotic responses to those processes (Turner 1989). This discipline represents a melding of a wide diversity of fields, including ecology, sociology, human geography, land management, and landscape architecture. Recent attempts to include experimentation and modeling in landscape ecology to improve predictive capabilities have provided additional dimensions to the field, especially with respect to topics such as disturbance or organismal dispersal (Gardner & O'Neill 1991).

Landscapes can be defined by their *structure*—the spatial relationships among distinct elements or structural components of the landscape; *function*—the interaction among spatial elements, and *change*—the temporal alterations in the structure and function of landscape elements within a matrix. A matrix refers to the most

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extensive and connected landscape element type present which plays the dominant role in landscape functioning (Forman & Godron 1986). The emergence of landscape ecology has been strongly linked not only to technological advances (i.e., computer speed and capacity) but also to the development of management procedures, given that much of the alteration of landscapes may be the result of increasing human population densities and their impact on their environment (Bunce & Jongman 1993). Thus, a landscape approach for restoring damaged habitats provides an interesting complement given that the field of "landscape ecology" was largely conceived as a result of human alteration of the environment.

Typically, researchers utilizing a landscape approach to address ecological questions focus on broad spatial scales with coarse resolution (Forman & Godron 1986). Kilometer-wide or greater ranges of scale are commonplace in most systems unimpacted by agriculture or urbanization. Landscape ecologists investigate elements (i.e., structure, such as vegetation) within a matrix and the element/matrix combination composing the spatial mosaic of a characteristics scale (Schneider 1994). Through the use of georeferenced maps of vegetation, soils, and elevation within a mosaic, landscapes can be described in terms of a number of features, including patch isolation, patch contiguity, and patch size and shape (complexity) that are known to affect strongly animal and plant populations (Turner & Gardner 1990; Robbins & Bell 1994). A number of representative studies spanning a variety of habitats exist (Bell & Hicks 1991; Wu & Levin 1994; Ellison & Bedford 1995; Pearson et al. 1995; Steuter et al. 1995).

A wide range of analytical techniques has been developed to interpret landscape patterns in a quantitative manner (Rossi et al. 1992). Spatial analyses and landscape ecology are closely associated in that both emphasize spatial relationships and are rooted in theory set forth in island biogeography (MacArthur & Wilson 1967), where island geometry or patch size and proximity to recruitment sites are of paramount importance to the dispersal and diversity of organisms. Presently, some of the principles guiding construction of biological reserves or conservation areas are imbedded into landscape-level investigations, and landscape features such as corridors and patch shape are widely discussed in conservation studies (SLOSS: Single Large or Several Small; Wiens 1995). Current discussions of metapopulations (Hanski & Gyllenberg 1993) have refocused efforts to increase the spatial scale of demographic studies. Therefore, landscape ecology embraces spatial heterogeneity as a central theme, but, unlike many spatial ecology studies, more frequently covers larger geographic areas that commonly encompass a number of ecosystems and/or landscape elements of different types. Likewise, across-scale comparisons are often utilized in a landscape approach, and hierarchical examinations of the landscape can provide comparative interpretations as one proceeds from small to intermediate to large spatial scales (Andrew & Mapstone 1987; O'Neill et al. 1989). Landscape studies have indicated that the arrangements of elements within a matrix can impact movement of organisms and/or function of landscapes (Gustafson & Gardner 1996), and this may be true at a variety of spatial scales (With & Crist 1995). Importantly, these studies have illustrated that movement of organisms through a landscape composed of multiple types of structure differs from that through a landscape of uniform patch composition (Robinson et al. 1992), a dominant condition of smaller-scale spatial ecology.

In order for principles of landscape ecology to be incorporated into restoration efforts, we suggest that the concept of "landscape ecology" needs to be more inclusive, and that this inclusiveness can be beneficial to the field of ecology in general. First, while most information on landscapes comes from terrestrial studies, the same principles should be applicable to aquatic systems if an accurate spatial representation of landscape elements is possible (Steele 1991; Robbins & Bell 1994). Spatial mosaics exist in aquatic (Paine & Levin 1981; Callaway & Josselyn 1992) as well as terrestrial systems (McGarigal & McComb 1995). As in terrestrial habitats, destruction of aquatic systems is widespread and restoration of aquatic habitats common (Fonseca 1990; Zedler & Langis 1991; Fennessy et al. 1994; NRC 1994). Therefore, although aquatic habitats are not "land based," they are appropriate systems in which to use a landscape approach. Second, we reiterate the argument that the arbitrary range of 1 km scale usually attributed to landscape-level studies (Forman & Godron 1986) need not be mandatory (Robbins & Bell 1994). While a 1 km distance may be necessary to cross landforms, other systems, especially those altered by anthropogenic activities (Naveh & Lieberman 1994), may have matrices with distinct changes in landscape elements over much smaller areas, with all the features of a larger landscape. Another approach is to let the landscape scale (i.e., appropriate range and resolution for study) be defined by the organisms that use the landscape (Wiens et al. 1993; Robbins & Bell 1994); the size of the landscape can thus be scaled to the appropriate organism. If this broadening of the landscape concept is embraced, then employing principles developed for landscape ecology may be applicable to restoration projects that span a range of spatial scales in both terrestrial and aquatic systems. Moreover, new methodologies in the development of data acquisition, handling, and analyses such as GIS and geostatistics, which are typically associated with landscape analyses, can be utilized for similar purposes in restoration studies at different spatial scales. This would require resolution sufficient to detect the spatial organization that could be expected to influence function of the habitat (Constanza & Maxwell 1994).

Landscape Ecology for Restoration Studies

A landscape approach may assist in addressing issues related to practical constraints in restoration studies, such as ensuring that the establishment of the restored elements has appropriate spatial configuration to facilitate recruitment of flora/fauna. Assessment of spatial heterogeneity in natural environments may provide a basis for developing successful planting strategies that consider landscape metrics such as patch configuration, continuity, and landscape percolation. Practices associated with the establishment of forest plantations in abandoned rural areas in temperate regions have employed such a landscape approach (Corona 1993). Other examples include constructing a restored area in a rural area with a mixture of patch types (elements) as an alternative to a set of uniform patches.

Consideration of landscape features may be especially germane to the issue of evaluating success of restoration efforts. For example, a restored patch in a rural setting might have a set of parameters to define "recovery" different from that of one located in an urban locale. A landscape approach can be used in establishing goals and selecting reference sites for restoration projects in the context of the setting. Embracing a larger scale assessment of the spatial relationships between a restored area and other landscape elements that extend beyond the boundaries of the restoration project itself may assist in interpreting the success or failure of the restoration efforts. The concept of "context" as setting realistic performance expectations for restoration projects has been discussed by Bedford (1996), Mitsch and Wilson (1996), and Race and Fonseca (1996), who point out that disjunct and isolated habitats may not function as do restored sites that are contiguous with comparatively unaltered areas. Thus, expanding our view of the spatial extent of an area used to evaluate the success or failure of a restoration project will likely become a necessary activity in restoration efforts.

At the boundaries of patches, edge effects may exist that modify environmental factors such as light penetration and air and water flow and thereby influence the flow of materials through a landscape (Holland et al. 1991 and references within; Robinson et al. 1992). Accordingly, it is instructive to determine if spatial characteristics, such as high interior to edge ratios of patches, facilitate ecosystem processes including nutrient exchange, recruitment of propagules, or export of detritus. Palmer et al. (1997) discuss how some systems rely on the continual flux of individuals to and from regional "sources" to maintain community structure, and this suggests that alteration of recruitment by boundaries may have implications for community resilience. Using this information, restoration elements might be configured for specific purposes, illustrating the applicability of landscape approaches to the restoration process.

As habitats are restored, some new questions will emerge as functional equivalency (Brinson & Rheinhardt 1996) is evaluated from a landscape perspective. One of the most pressing questions is whether landscapes that develop from human-controlled restoration represent (or closely represent) those that are present in natural environments. Also, we theorize that the tempo of recovery depends upon the spatial context in which the restored site is constructed. In both cases, inclusion of landscape indices (such as patch shape, dispersion, and contiguity) allows information on spatial dynamics to be collected and compared over large scales or multiple habitat types. If material flux and plant/animal community development can be linked with various spatial attributes of a landscape, then measuring those attributes may enhance our insight into the response of constructed habitats and provide new or potentially more rigorous metrics of restoration success.

Despite the absence of consistent measurement techniques, researchers have either implicitly or explicitly recognized the usefulness of a landscape approach to restoration activities. In a restoration of mined areas, McChesney et al. (1995) identified the importance of site location within the larger landscape matrix when comparing seedling emergence in restored versus natural sites. Likewise, Robinson and Handel (1991) discussed how the successful rehabilitation of plant populations in an urban landfill was dependent upon the presence of nearby remnant vegetation. Fimbel and Kuser (1993), working in restored pine forests on a former military installation, discussed how spacing of plants (landscape elements) could be altered to increase diversity of structures. Thus, landscape issues that relate to context and spacing of structural elements have received attention in these representative terrestrial studies.

In coastal areas, restoration of salt marshes provides implicit examples of landscape principles. Broome et al. (1988) recognized that the context into which a restored site is placed may be extremely important for restored salt marshes, as adjacent sand dunes can alter salinity by water retention. Sacco et al. (1994) and Moy and Levin (1991) discussed how increased proximity of restored salt marsh sites to natural marsh areas accelerated the development of infaunal communities. Haven et al. (1995) also reported differences in faunal utilization of restored and natural marshes, suggesting that either the size/shape of the restored area, the presence of rivulets, or the difference in plant stem density could be responsible for discrepancies in animal assemblages, especially because soil differences were not detected. A similar argument was expounded by Minello and Zimmerman (1994), who found that adding tidal creeks to salt marshes enhanced use of edges by fauna. In a seagrass habitat, Bell et al. (1993) evoked the location of a restored site within the larger context of a shallow embayment to explain differences in benthic-dwelling fauna in areas with similar plant densities and soil characteristics. A general message emerging from these representative studies is that evaluation of restoration efforts often requires a large-scale perspective, and this has been a major objective of at least some agency work (Dobson et al. 1995).

Restoration Ecology for Landscape Studies

Just as a landscape approach can likely be used to improve/extend restoration studies, so too can restoration studies be useful to the field of landscape ecology. Restoration efforts may be one of the few examples of human-controlled experimentation at a relatively large spatial scale. Thus, restoration sites should act as test systems for evaluating many of the ecological phenomena under the purview of landscapes. Restored sites may serve as microcosms (Drake et al. 1996) for landscape studies, with the important distinction that problematic "container" boundaries are not present. The usefulness of microcosms for testing ecological theory has been debated recently (Carpenter 1996), but many of the criticisms of microcosms may not apply to restored sites, because, once they are initiated, restored sites are usually not artificially maintained, and they integrate responses at spatial scales to those of interest.

From a temporal perspective, restoration studies are designed to accelerate what might otherwise be a slow natural process. Often, changes in both flora and fauna can be discerned within a few years (Fonseca et al. 1996; see studies cited above). The time course of experimentation and landscape change is usually beyond logistical (funding) limitations (Fonseca et al. 1997). Therefore, restoration studies can facilitate the rate of information gathering for expected changes in landscapes. Additionally, restoration studies can provide data to assist in validation of spatially and temporally dynamic models popular in landscape ecology. Models that predict the spread of disturbance (Baker 1992) or the ability to resist disease under certain landscape configurations may be directly tested if restoration practitioners and landscape ecologists can implement creative planting designs that address scaling questions.

There are serious obstacles to overcome before large-scale landscape planning can be accommodated, however. Race and Fonseca (1996) point out a potential problem between a landscape approach, which may evaluate cumulative impacts, and compensatory mitigation practices. Conflicts arise when a landscape management plan, because of its large scale, impacts a substantial number of property owners. Dealing with such management procedures that span large spatial scales will therefore require creative solutions as well as extensive re-education and political resolve by legislators. Likewise, developing a workable plan for mitigating landscape-level changes caused by alterations of ecosystems will necessitate a well-defined understanding of how to identify and treat cumulative impacts (small scale) on the larger landscape level (Rastetter et al. 1992). More research is required to determine how measures of ecological function scale up and exactly what kind of data would be most amenable to scaling from small to large scale (Andrew & Mapstone 1987).

Given the general lack of guidance at this time, does this mean that a landscape approach should be shunned? We suggest not. As Kessler et al. (1992) argue, there is an increasing need for a landscape-level approach to address adequately the ecosystem responses that cannot be gleaned from scaling up results from small plots. From a research perspective, innovative approaches that evaluate the change in variance with scaling up to large-scale processes will be required (Rastetter et al. 1992). From the management point of view, if resources are to be managed over a large spatial scale, then radical new approaches to mitigation will be required that will most likely necessitate collaboration beyond traditional scientific fields. Some of the solutions may be imbedded in landscape studies based in Europe that extend beyond the theoretical discussions that pervade much of landscape ecology in North America and focus upon human activities as part of the landscape, emphasizing sustainability and a problem-solving approach (Naveh 1994; Naveh & Lieberman 1994).

Conclusion

We submit that landscape and restoration ecology have an unexplored mutualistic relationship. The benefits of utilizing restoration efforts to test landscape principles are relatively straightforward. Landscape ecology, in striving to be quantitative and predictive, can utilize the information provided by restoration projects to improve and test basic questions, especially those linked to habitat function and fragmentation. Moreover, restoration efforts can profit from landscape concepts, application of techniques, and developing technology. However, we note that although some landscape principles such as patch arrangement may be relatively easy to apply to restoration, identification of proper metrics for comparing areas over large scales is not obvious at this time. Both restoration and landscape ecology are relatively young and in formative stages; the opportunity for researchers to influence future development is apparent. A landscape/restoration linkage is discernable in previous studies and seems a logical path for future investigations. If the health and integrity of landscapes are of vital importance for global survival (Naveh & Lieberman 1994), then restorationists will be forced to consider a wide range of approaches to habitat rehabilitation that combine both ecological and social goals.

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