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LANDSCAPE ANALYSIS IN ECOSYSTEM MANAGEMENT[1]

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INTRODUCTION

Objectives of forest management until 20 yrs ago were directed at maximum timber production with only minor consideration of other ecosystem properties such as habitat for game animals. Based on this historical emphasis on commodity production, forest management has done an excellent job. However, over the past 20 yrs we've come to realize that our success in meeting these timber management objectives has come at the expense of a wide array of ecosystem properties. The loss of species diversity and the degradation of resources, e.g., water quality, have sparked interest in expanding forest management objectives to encompass other ecosystem values such as sustainability of ecosystem structure and function (=biodiversity) in addition to the economical yield of timber volume.

Determining how best to manage forested ecosystems in a sustainable manner is a fundamental question facing managers throughout North America. One way to proceed is to evaluate and overcome the problems of previous management practices. In general, two very important concepts have been overlooked - Spatial Pattern and Scale. Lack of consideration of the cumulative effects of spatial pattern is best illustrated by the decline in salmon stocks in the PNW. Mismanagement of spawning streams all along the extensive network of the Columbia river has lead to substantial declines in several salmon stocks. Proximate causes include: clearcutting on steep slopes, leading to extensive debris flows into spawning streams; and unrestricted logging in riparian zones resulting in increased siltation and the reduction of large log input into streams which provide necessary cover for fish and their prey base. At any single point along the Columbia river drainage the effects of anthropogenic disturbance appears negligible. The effects of forest management actions are not clear until we integrate across patterns within the whole drainage.

Scaling issues are best epitomized by the habitat relationships of the spotted owl in the PNW region. Habitat requirements have been identified at multiple scales; ranging from tree-level nest sites and stand size, to dispersion of oldgrowth patches across a landscape. Habitat management for owls at the tree level (e.g., saving oldgrowth trees) has little effect when the size of oldgrowth patches and the

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connectivity of these patches across a large area are not taken into account. The current level of fragmentation of oldgrowth patches in the PNW and the declining populations of spotted owls is testimony to the need for considering scaling issues when designing forest management scenarios.

Based on results of past forest management, we see that future management of forested ecosystems in a sustainable manner must account for patterns and processes at a variety of spatial and temporal scales, especially over large landscapes. Traditional disciplines of forest management as well as wildlife and fisheries management tend to be inadequate in this respect owing to their historical emphasis on stand- and species-level scales.

Landscape Ecology is a relatively recent discipline motivated by the increased awareness of the effects of spatial pattern on ecological processes and is viewed as a better method to encompass multilevel scales in analysis and management of large and spatially complex areas. Landscape Ecology is defined as the study of the structure (e.g., dispersion of patches), function (e.g., material and energy flow, habitat), and change in a heterogeneous land area composed of interacting ecosystems (Forman and Godron 1986). It provides a growing set of tools and protocols for analyzing and simulating landscape characteristics at different spatial and temporal scales. Landscape Analysis is the application of these principles and tools in the assessment of landscapes.

The purpose of this paper is to provide a brief overview of some of the basic concepts of landscape analysis and the quantitative metrics used to characterize landscape structure.

LANDSCAPE ANLAYSIS

Objectives

An initial and very important step in landscape analysis is to explicitly state the objectives. The objective(s) will determine the types of analyses performed as well as the appropriate metrics. Landscape analysis usually deals with some type of map typically generated for a geographic information system (GIS). How the data are generated is beyond the scope of this paper. But it is important to realize that the objectives of a landscape analysis dictate the spatial and temporal resolution as well as the type of classification used in generating map information. Map information can always be aggregated to a more coarse resolution, but seldom if ever can be disaggregate into a finer resolution. Thus, its imperative that the classification of data be specified at the finest resolution required by the objectives of the landscape analysis.

Analysis of Structure

A basic part of landscape analysis is characterizing the elements (i.e., patches) within a landscape. Numerous metrics are used to evaluate structure; too many to cover in detail in this paper. Descriptions of landscape metrics as well as software packages that calculate these metrics can be found in McGarigal and Marks (1993), Baker and Cai (1992), Mladenoff et al. (1993), and Scheiner (1992). For simplicity, metrics can be categorized into four main groups - Patch Shape, Patch Size & Extent, Patch Connectivity, and Patch Dispersion.

Extent of Patches

The importance of the extent of patches of a particular vegetative or habitat type is intuitive. Assuming a direct correlation between species and habitat type, it follows that the amount of habitat directly affects species abundance. If you don't have a required habitat type for a species, the landscape can't support that species. The more habitat present, the greater the potential capacity of a landscape to support a species. The threshold size for species or ecosystem functions is totally dependent on the species or process of interest. A metric used to characterize the extent of patches is simply **# of patches.**

Patch Size

Patch size determines the amount of resources available for species as well as the buffering capacity of a patch. Resource availability decreases with decreasing patch size. The susceptibility to environmental catastrophes as well as random events of extinction increases with decreasing patch size. **Acreage of patches by type** is typically the metric used to quantify patch size.

Patch Shape

Confounding the effects of patch size is the shape of a patch. The significance of patch shape is related to the amount of patch edge. Patches can be of similar area but have varying amounts of edge depending on shape. e.g., Circular patches have a minimal perimeter/area ratio whereas a highly irregular polygonal patch will have a high perimeter/area ratio. In a landscape context, with increasing edge there is a greater amount of surface area in contact with adjacent patches. The ramifications of this will vary with the types of adjacent patches.

Forest management practices in eastern US deciduous forests as well as in the PNW have created an extensive mosaic of clearcuts in the original closed canopy matrix; resulting in a forested landscape containing considerable amount of edge. The contrast between these two stand types is quit extensive. For these edges, there is substantial decreased resistance to energy flow from the clearcut to the closed-canopy forest patch. Studies by Chen et al. (1993) in the Washington Cascades have found higher air temperatures in closed canopy forests 90-240 meters (ca. 2 tree heights) from the edge compared to the interior of the patch. These micro-climatic differences provide significantly different types of habitat for plant and invertebrate species compared to the interior of patches.

Predation by certain mammalian and avian predators and nest parasitism by bird species tend to be higher along these type of well defined edges. Studies in the eastern US deciduous forest have shown a substantial decline in avian neotropical migrants owing to increased cow bird nest parasitism. Predation by great horned owls on spotted owls in the PNW increases with degree of fragmentation because of the tendency of the former species to hunt along edges of closed and open canopy forests.

Certain species of avian neotropical migrants tend to avoid edges, possibly due to microclimate conditions and/or decreased vegetative cover. For very large patches, the overall effects of edge may be of little consequence. For small irregular patches with a high perimeter/area ratio, the amount of interior habitat (amount of a patch a certain distance from the edge) can be substantially reduced. Although a patch may be of a size deemed suitable to contain one or many home ranges of a species, the shape of the patch will determine the realized amount of suitable interior habitat for an edge-sensitive species.

Certain species, however, such as cow birds, great horned owls, and olive-sided flycatchers use edges and thus may actually benefit from increased fragmentation of forested systems.

In evaluating the ability of a landscape to sustain processes such as species diversity, sensitivity (or lack of) to edge as well as patch size in general must be taken into account to determine how the landscape patterning relates to habitat suitability for indigenous species.

Commonly used patch shape metrics include: **amount of edge, perimeter/area ratio, fractal dimension, and edge density (amount of edge/unit area).**

Connectivity

Integrity of patches will be substantially altered with increasing degree and duration of isolation. Isolation effects are similar to those of small patch size. With increasing isolation, patch integrity suffers owing to decreased resource availability, decreased flow of genetic material, and increased susceptibility to environmental catastrophes. For many species and processes, connectivity of patches is essential to ensure long-term existence. Linkages or corridors connecting otherwise isolation patches act as conduits for material and energy flow between and among patches on a landscape. Linkages themselves need not be suitable as habitat or an essential component of some ecosystem function. They simply provide for the exchange of material. Field and simulation studies have demonstrated the importance of landscape connectivity for long-term survival for numerous taxa [e.g., small mammals (Lefkovitch and Fahrig 1985) and birds (Lamberson et al. 1992)].

Useful measures of connectivity include: **nearest neighbor probability and percolation index (Turner et al. 1989).**

Patch Dispersion

The spatial configuration of patches on a landscape influences dispersal capabilities as well as propagation of processes. Spatial statistics are most often used to evaluate patch dispersion. e.g., **Semivariance** is a measure of the degree of spatial dependence between samples and summarizes the variance as a continuous function of scale. Metrics such as **semivariance and wavelet analysis** are used to determine the grain of existing patterns. This information can be used to determine appropriate sampling schemes for characterizing ecosystem properties. Other commonly used spatial metrics include: **GISfrag (Ripple et al. 1991), contagion index, and mean nearest neighbor.**

Spatial Modeling

Dynamical analyses of landscapes may sometimes be of interest, especially to evaluate potential future effects of natural and anthropogenic disturbance on landscape function and structure. Spatially articulate simulation modeling provides the opportunity to synthesize current knowledge of landscape processes and landscape change, to formulate and test hypothesis of ecosystem structure and function, and to make predictions to evaluate proposed land-management strategies. Examples of spatial modeling in land-use planning can be found in Bradshaw and Garman (1993), Hansen et al. (1993), Mladenoff et al. (1993), Garman et al. (1992), Garman (1991), and Baker (1989).

Which Metric to Use

The landscape metric(s) employed in a landscape analysis is dependent on the objective(s) of the analysis. e.g., If a landscape analysis is to evaluate habitat suitability for edge-sensitive species, then measures related to edge, interior habitat, and patch size should be used. Measures of connectivity and patch dispersion may be applicable in evaluations of propagation of disturbance and/or species. No one set or group of metrics has been deemed most appropriate under all circumstances. Determining which metric(s) to use comes with an understanding of the behavior of a metric under different circumstances, and with experience in use of landscape metrics. There have been limited studies of the sensitivity of metrics to different patterns. e.g., Ripple et al (1991) have shown that a similar number of patches of equal size can give rise to significantly different measures of dispersion. Evaluating a landscape pattern using only a couple metrics may lead to erroneous conclusions. However, an important point to remember is that landscape metric packages provide a sundry of measures, but not all of them are independent of another and not all will necessarily be appropriate for the problem at hand.

Structure and Function

Measures of landscape structure and patterning provide only limited insight into the functional aspects of a landscape. Associations between habitat suitability and patch size and shape are established to a limited degree for only certain key and well studied species. The association between landscape patterning and disturbance propagation, and degree of connectivity necessary to support a range of processes are topical issues requiring detailed field and simulation studies. Making the causal connection between pattern and processes such as biodiversity requires extensive evaluation and is likely beyond the scope of currently available data sets. Selecting surrogates of biodiversity, although risky, may however provide an initial ability to investigate effects of landscape patterning on ecosystem function. Causal links between landscape patterning and processes would best be determined, however, from well designed and replicated landscape-level experimentation.

CONCLUSION

The mechanical nature of measuring pattern has lead to development and use of numerous metrics to characterize landscape structure. Relating landscape metrics to processes, however, is a much needed area of research. Associations between pattern and processes exist, but tend to be very species or taxa specific, or are very general in nature. Making land-use decisions by assigning characteristic processes to patterns without detailed investigation or a thorough understanding of ecosystem process-pattern relationships may have devastating consequences over the long term.

The type of metric(s) used in evaluating a landscape must be a function of the objective(s). Measuring just one characteristic of a landscape in isolation is often not appropriate (e.g., the amount of edge of a specific patch type may provide little understanding of potential edge-related problems; the quantity and type of patches sharing a common edge may be of greater value). Also, use of just one metric doesn't tell the whole story. Several measures will likely be more appropriate to identify differences between somewhat similar yet distinct patterns.

Spatial modeling of ecological change provide an opportunity to evaluate dynamics of landscapes. Modeling offers a formal opportunity to synthesis existing information, to formulate and test hypotheses, and to make futuristic predictions of system states. Testing of model results, however, is difficult owing to the temporal extent of predictions. Spatial modeling does provide us with an ability to view potential results given our current understanding and aids us in making better, or at least, more informed decisions.

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