

LANDSCAPE ECOLOGY, CONSERVATION BIOLOGY AND PRINCIPLES OF ECOSYSTEM MANAGEMENT

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INTRODUCTION

The objective of this paper is to discuss a few principles of landscape ecology as they apply to ecosystem management (EM) currently implemented by the U.S. Forest Service and other federal agencies. The work presented herein is a component of the Eastside Forest Health Assessment (EFHA), sponsored in 1992-1993 by Representative Tom Foley, the former Speaker of the House, and Senator Mark Hatfield, and led by Dr. Richard Everett. Former Speaker Foley and Senator Hatfield, responding to concerns of their constituents, requested that the USDA convene an interagency science panel to evaluate current ecological system sustainability and appropriateness of management practices, and to make recommendations for restoring stressed ecological systems. The U.S. Forest Service was thus directed by the Secretary of Agriculture to create such an interagency science panel to address the major points in the Hatfield/Foley letter. The final report of the panel consisted of five volumes. Two of the seven questions addressed in the congressional letter were concerned with the formulation of a framework to generate and evaluate alternative EM scenarios and to evaluate the adequacy of the scientific information for the sustainability of ecological systems (Everett et al. 1994). The technical and conceptual answers to these two questions were provided in Volume II of the report (Jensen and Bourgeron 1994). This paper summarizes the findings and recommendations, as well as the theoretical and scientific basis for putting EM into practice and for evaluating the effects of management practices on ecological systems.

STARTING POINTS

The formulation of a scientific framework must be based on a clearly defined mandate and one or more objectives. The general mandate for implementing EM by the USFS was formulated by Overbay (1992) in the form of five starting points to the general USFS framework to EM: (1) people desire a wider array of uses of public land than they had previously; (2) biological diversity is a key consideration of management; (3) integrated inventories are required; (4) outside groups need to be involved in the planning process; and (5) scientists and resource managers need to play more prominent roles in EM, as compared to planners and decision makers.

From these five starting points, the EFHA science panel formulated an EM framework based on five criteria (Jensen and Everett 1994): (1) determine the public's desires; (2) describe the land's ecological potential; (3) integrate public desires with land's ecological potential; (4) consider available technology;

and (5) consider economic factors. When considering the public's desires, it is important to include (1) the various definitions of the publics (e.g., local, regional, national) and how their respective present values may be in conflict, and (2) what will happen if these values change over time. The definition of ecological land potential is necessary to integrate the social desires with the biological and abiotic capacity of the land.

THE ROLE OF LANDSCAPE ECOLOGY AND CONSERVATION BIOLOGY PRINCIPLES IN LANDSCAPE EVALUATION, ECOSYSTEM CHARACTERIZATION AND ECOSYSTEM MANAGEMENT

Landscape evaluation and ecosystem characterization (LEEC) have been conducted in one form or another for 80 years worldwide (see discussion in Golley 1994). The process associated with LEEC has been formalized by Beek and Bannema (1972) and adopted by the Food and Agricultural Organization (FAO 1976) and the International Society for Soil Sciences (Zonneveld 1988) for use as the basis for many sustainable land development projects. The FAO framework (Figure 1, adapted from Zonneveld 1988) visually summarizes the EM framework. The five EM criteria are found within the FAO diagram: technology and economics, human desires and needs, and landscape ecology. Ecosystem management is concerned with the overlap among the three circles in the Venn diagram (Figure 1). This overlap represents a sustainable state of an ecologic-socio-economic system.

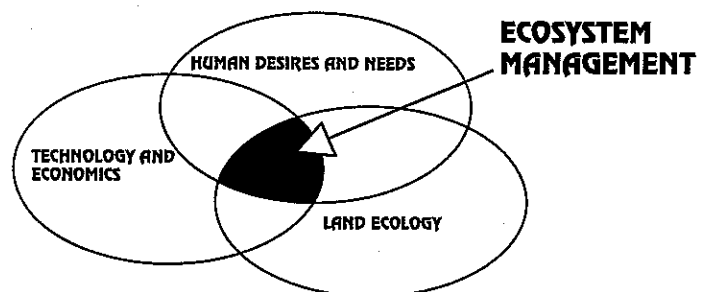


Figure 1.—The FAO framework visually summarizes the ecosystem management framework.

In order to define the ecology of the land, three questions must be addressed: (1) What is out there? (2) Where is it? (3) How does it work? Hatfield/Foley's request asked whether we have the science to answer these three questions in a credible fashion. The EFHA science panel's answer was that, indeed, we have the science required to conduct LEEC and proceed with EM.

The scientific principles underlying LEEC and EM are part of landscape ecology and conservation biology. These principles are used in a four step process: (1) the description of ecological systems; (2) the definition of ecological hierarchies; (3) the definition of the range of natural variability (i.e., of the dynamics of the ecological systems of interest); and (4) the definition of an appropriate coarse/fine filter strategy.

DESCRIPTION OF ECOLOGICAL SYSTEMS

To describe ecological systems, pattern recognition techniques are used. These techniques have been used for many years in the medical and social sciences. Ecological systems can be described at many different scales (Levin 1992). Hence, the spatial and temporal relations of specific ecological systems, or any of their components, need to be clearly defined. The scientific products generally used in conservation and management are descriptions, predictions, and prescriptions. Describing ecological systems of interest is a routine scientific endeavor that leads to the generation of classifications and maps.

Making predictions about future states of the ecological systems under various scenarios require the determination of relationships between patterns and hypothesized causal factors, or agents of pattern formation. Once a correlation or a cause-effect relation between pattern and process is determined, predictions are made using (1) the summarization of data and information performed during the classification process and/or the generation of maps, (2) statistical or simulation ecological models, and/or (3) a combination of the first two approaches. While many scientists establish a relationship between pattern and ecological factors to make predictions, the process of doing so is not always as rigorous as it could be. The formulation of prescriptions consists of integrating predictions into conservation and management actions.

HIERARCHY THEORY

General Principles of Hierarchy Theory

Four tenets of hierarchy theory are necessary to forge an understanding of landscape patterns and their dynamics, and to use that knowledge for EM (Allen et al. 1984; O'Neill et al. 1986).

- (1) The whole/part duality of systems states that every component of a system, ecological or otherwise, is a whole and a part at the same time. For example, a forest (a whole) is made up of trees (the parts). However, at larger spatial scales, the forest is part of a regional landscape. In that case, the regional landscape is the whole and the forest becomes a part along with others. The notion of

whole/part duality is very important for the characterization of ecological systems.

- (2) Patterns, processes and their interactions can be defined at multiple spatial and temporal scales. These scales need to be clearly identified.
- (3) There is no single scale of ecological organization that is correct for all purposes. This is an important consideration because often scientists provide information/interpretations on ecological systems at a single or limited number of scales.
- (4) The definition of an ecological hierarchy (component patterns and processes) is dictated by the objectives of a study or conservation/management planning. In EM, objectives are defined by planning considerations.

Definition of Ecological Hierarchies

The definition of ecological hierarchies needs to be an orderly four step process that must take into account the ecological patterns of interest and the ecological factors that shape these patterns, i.e., the agents of pattern formation (Urban et al. 1987). For example, consider vegetation patterns as the ecological patterns of interest (Figure 2a). It is intuitive that vegetation exhibits different patterns of organization along different spatial and temporal scales, ranging from seedlings on the ground to individual canopy trees, stands of specific plant communities, cover types, and formations (e.g., boreal forest). The formal definition of the hierarchical arrangement of the vegetation patterns is important because it requires explicit statements about (1) the spatial and temporal bounds of each pattern and (2) the order in which these patterns are nested. Such an objective-specific exercise provides the basis for identifying the agents of pattern formation (Urban et al. 1987).

It is convenient to organize these agents of pattern formation into separate hierarchies of biotic processes (Figure 2b), disturbances (Figure 2c) and environmental constraints (Figure 2d). Biotic processes that are important in understanding vegetation patterns include seed germination at the level of seedlings, tree replacement in the canopy at the level of an individual canopy tree, succession at the stand level, etc. (Figure 2b). The specific relationships between patterns and biotic processes, and the fact that these processes are spatially and temporally bounded, emerge readily. The same treatment can be applied to disturbances (Figure 2c) and environmental constraints (Figure 2d), where each phenomenon of interest (e.g., a disturbance or an environmental constraint) must be clearly specified and its spatial and temporal bounds clearly stated. For example, at the level of individual canopy trees, treefall is a significant disturbance, and slope and aspect are significant environmental constraints.

Ecosystem Characterization

In the field, the ecological hierarchies of the four templates are superimposed. Figure 3 shows the example of subalpine fir forests in the northern Rocky Mountains. In this example, the relationship of each pattern to specific biotic processes, distur-

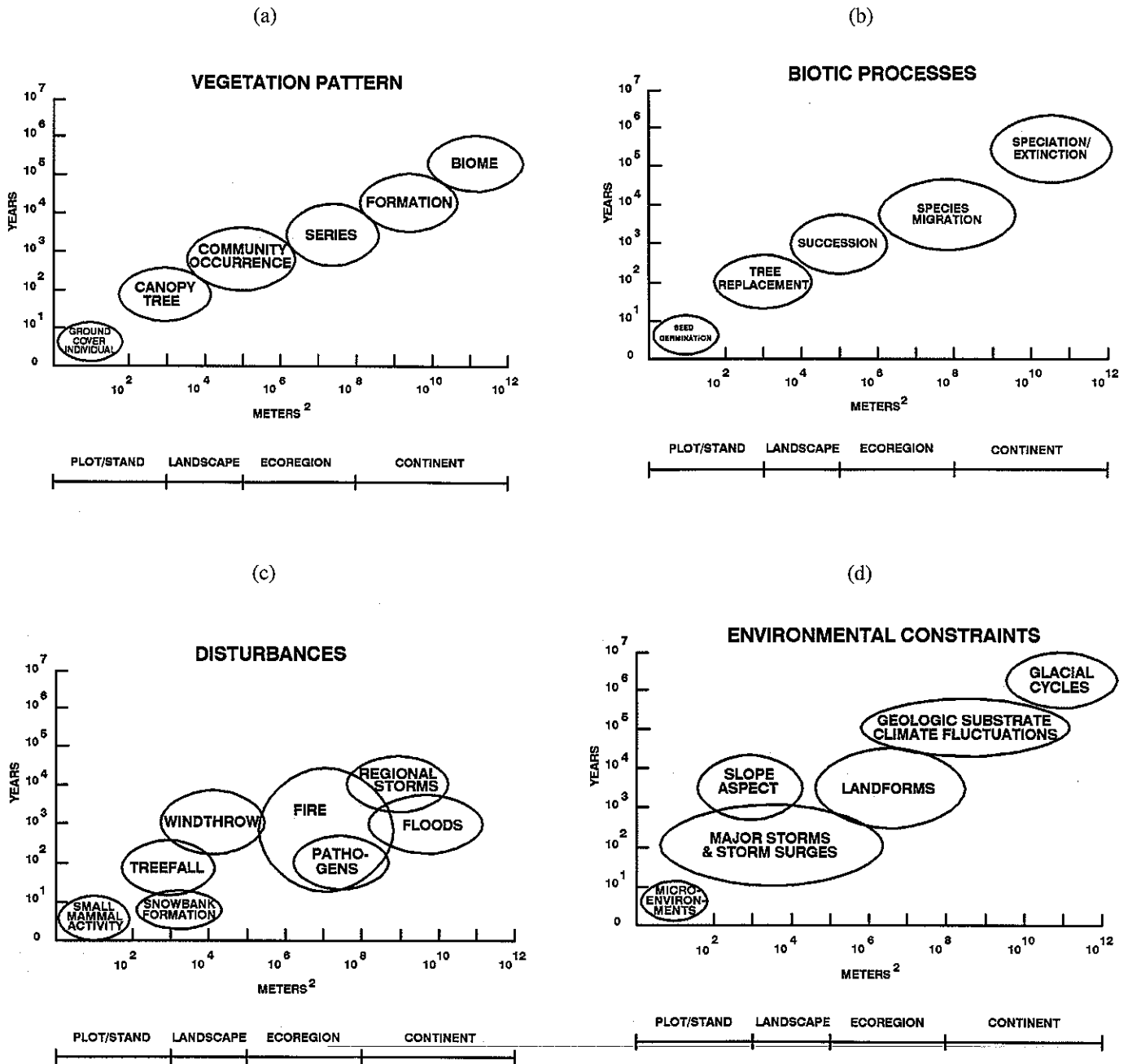


Figure 2.—Agents of pattern formation.

bances and environmental constraints emerge. For example, at the level of an individual tree in the canopy, the corresponding biotic process is tree replacement (e.g., from lodgepole pine to subalpine fir), tree fall constitutes a disturbance which can trigger tree replacement as well, and slope and aspect are environmental constraints affecting which tree species may be established successfully. At a finer scale than the individual tree level, the pattern is the seedling, the process is germination and a constraint is the snowbank on the ground in the understory. The amount and

timing of snowmelt constrain tree regeneration in the understory. Above the individual tree level, the stand becomes the whole of which the individual tree is a part. The biotic process is succession, which integrates individual tree replacement at larger spatial and temporal scales. Indeed, stand level succession from lodgepole to subalpine fir may take over two hundred years. Disturbances may include windthrows and stand fires. Environmental constraints include slope, aspect, and landform.

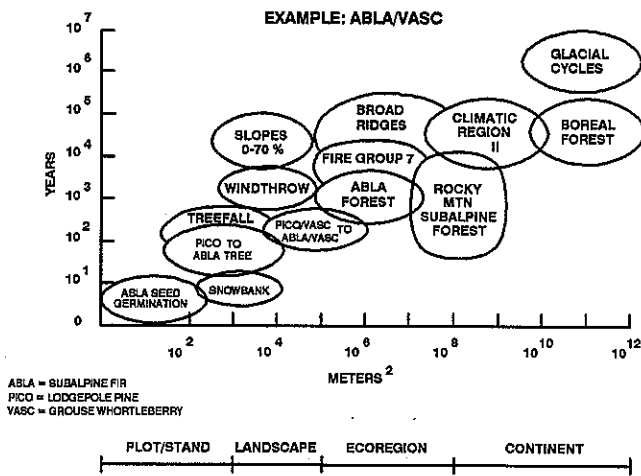


Figure 3.—Example of subalpine fir forests in the northern Rocky Mountains.

The process of matching patterns and processes is called ecosystem characterization (Levin 1992). It is the process that is used for mapping (e.g., ECOMAP, USDA Forest Service 1993; Zonneveld 1989) and landscape evaluation from the site level to the continent. In defining ecological land types (e.g., Zonneveld 1989; Bailey et al. 1994), the idea is to draw boundaries around ecological systems and to define the relevant patterns and agents of pattern formation at all appropriate ecological and planning scales. The proper match of patterns and agents of pattern formation is very important because any wrong coupling of pattern to agents impedes our ability to make predictions about the future state of the ecological system of interest, and hence severely restricts the value of conservation and management actions and prescriptions. The relevance and practicality of the concept of whole/part duality to ecological systems for characterization is obvious. It becomes the basis for making predictions, establishing meaningful correlations and build sensible ecological models.

NATURAL VARIABILITY

Establishing the long-term past dynamics of ecological systems is important for two distinct purposes: (1) to establish the nature of the ecosystem dynamics (e.g., stochasticity) and (2) to determine periodicities and trends in the system dynamics. The second purpose is commonly used by scientists who study time series in medicine, fisheries, climatology, etc. In natural resource management, the determination of periods and trends over time has led to the notion of historic variability experienced by a specific ecological system (Swanson et al. 1994). The historic range of variability is used for three reasons: (1) to understand the formation of contemporary patterns; (2) to determine whether there is any long term trend of changes in the ecological system; and (3) to assess whether there is any short term change in pattern that can be correlated with global climate change, landscape fragmentation, or any other management scenario.

Figure 4 shows the relative percentage of ground fires versus crown fires in forests of the Northern Rockies. Until fire suppression, both types of fire were varied over time within a certain range. Since fire suppression, the ratio ground/crown fires changed abruptly. Compared to the past 300 years, these forests are now outside of the historic range of variability with respect to fire dynamics. The results of this type of assessment does not necessarily imply that past patterns have to be recreated. The assessment provides a larger context for the temporal dynamics of a system (Swanson et al. 1994). In practice, it also permits the determination of whether present conditions have been experienced historically or not. In the latter case (i.e., being outside of the historic range of variability): (1) the ecological system of interest is in a state for which we have no information; (2) therefore our present knowledge and predictive abilities may not be useful for understanding system behavior; and (3) present technology may be useless in preventing rapid large-scale changes in the system (Hann et al. 1994). For example, in the case of the Northern Rockies forests (Figure 3), it is clear that the ecological systems have been pushed to conditions that have never been experienced before. Therefore there is little or no ability to make predictions about the future of these forests under any scenario of conservation and management and fire suppression technology has been made obsolete by the magnitude of spatial changes in closed forests and associated fuel loading classes. The historic range of variability can be established for any pattern of process of interest. It is a simple tool that, if used wisely, helps with assessing the consequences and costs of management decisions.

THE COARSE AND FINE FILTER CONCEPTS

The coarse and fine filter concepts are consequences of the hierarchical structure of ecological systems and of their long-term dynamics. In simple terms, the coarse filter concept states that if an entire ecological system (community, ecosystem, landscape) is managed, the parts (e.g., species) would be managed as well. The coarse filter has been advocated as a more cost efficient way to maintain common species for which little detailed data might exist (Scott et al. 1990). The converse of the coarse filter is the fine filter which states that parts need to be managed individually. In practice, the fine filter has been used to manage rare species or communities which otherwise would have fallen through the cracks of the coarse filter approach (Jenkins 1976).

It has become fashionable to oppose both management strategies. However, it is most useful to consider the two approaches in the light of ecological hierarchies developed for specific ecological systems and purposes. For example, in a northern Rockies subalpine forest landscape, consider the goal of maintaining the landscape within its historic range of variability (i.e., maintaining all communities and species found within that landscape). The plant community (e.g., subalpine fir/grouse whortleberry) is the appropriate level of ecological organization (the coarse filter) for managing the vegetation at the landscape level (Figure 2a). The individual plants (species) become the parts (fine filter), as components of the higher level scale (plant

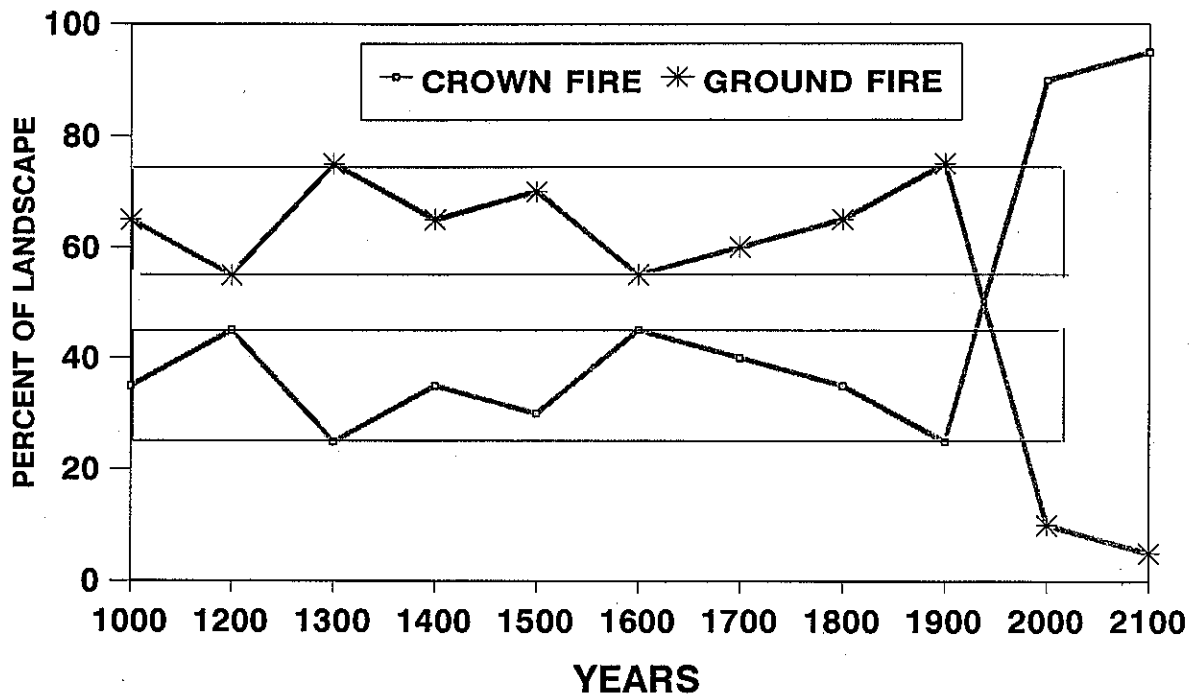


Figure 4.—Change in ground and crown fire regimes in the Trail Creek Landscape in the Northern Rockies.

community). The biotic processes, disturbances and environmental constraints are defined for both the coarse filter (in this case the plant community) and the fine filter (the species) (Figure 3). If the management goal is vegetation management at the level of an ecoregion, an appropriate scale of ecological organization is the cover type (e.g., subalpine fir forests). Plant communities become the relevant parts (e.g., the fine filters). Management objectives define the ecological system and the scales of ecological organization of interest, and thus the coarse and fine filters. The selected hierarchical scales determine the relevant patterns and agents of pattern formation. It is appropriate to have schemes in place to ensure that at all scales, the patterns of interests are monitored in time and space. A switch from one management strategy to another might be necessary to meet conservation and management objectives.

LANDSCAPE BOUNDARIES AND ECOSYSTEM MANAGEMENT

Once the ecological hierarchies (patterns and agents of pattern formation) are established, the first issue to address in conservation and management is whether all patterns and agents of interests are incorporated within the managed area(s). Pattern persistence is a major goal of conservation and management. However, this persistence, also called stability, is a function of scale (O'Neill et al. 1986; Urban et al. 1987; Levin 1992). A landscape that is large enough to encompass all aspects of the processes that generate them will be in a shifting mosaic steady state (Urban et al. 1987; Baker 1989, 1992a), i.e., although the landscape will be ever changing, its overall composition over time will show no loss of pattern. A landscape that is small

compared to the scale of its agents of formation will not exhibit stability over space and time.

Incorporation is the definition of landscape boundaries that include the full complement of biotic processes, disturbances and environmental constraints that generate the ecological patterns of interest (Urban et al. 1987). In practice, the problem of scaling landscape boundaries requires the knowledge of spatial and temporal fluctuations in the patterns and the agents of pattern formation. Baker (1989) showed that, in a large conservation area in northeastern Minnesota, there was no spatial scale which would allow for a temporally stable patch-mosaic because of temporal fluctuations in the fire regime. A consequence of this observation is that knowledge of the historic range of variability of the patterns and processes in the area is needed at a regional scale that historically contained the patterns of interest, i.e., the vegetation patches that made up the landscape prior to European settlement (Baker 1989, 1992a; Swanson et al. 1994; Turner et al. 1994). A possible management strategy would be to define target patch mosaics in light of the conservation goals of the area and to mimic the effect of fires at all scales at which they used to impact the area. In that case, knowledge of frequency, magnitude, intensity and timing of historical fires, as well as of the size, shape and location of burned areas, and the distribution of these attributes at regional scales, is needed to implement a fire restoration strategy (Baker 1992a; Hann et al. 1994). Beside the scaling aspect, another consideration prior to restoring ecological processes such as fires is the assessment of the degree of deviation of the current landscape structure from pre-management times. Such assessments need to be area specific. For example, a study suggested that in the Greater Yellowstone area,

unusually large intense fires that occurred historically might be detrimental to the goal of restoring pre-suppression patterns and processes (Baker 1992b) because of the current degree of structural deviation in the landscape (Bonnicksen and Stone 1985). In that case, a strategy could be to restore the structure of the landscape, mostly by removing fuels and prescribed burning, before attempting to restore historic levels of fire regimes. Alternatively, a study suggested that in the northeastern Minnesota landscape such a structural restoration was not required prior to re-establishing presuppression patterns of fire regimes (Baker 1992b).

While attempts to incorporate most agents of pattern formation or mimic their impact is necessary, it should be recognized that from a regional/continental perspective some processes will never be incorporated, nor could their impact be mimicked easily. For example, global climatic changes are likely to induce changes in biome boundaries and in the frequency and size of suitable habitats (Neilson et al. 1992). These changes have impacts on the patterns of migration and regional distribution of species and are reflected in the patterns of local extinction and regional colonization of species. Before European settlement, shifts in overall patterns of distribution and abundance were possible in order to accommodate such global changes. Species could have thus survived global changes until conditions became more favorable. At present, human activities are likely to have altered the structure of the environment (e.g., fragmentation, isolation, etc.) to an extent that affects key biotic processes. For example, as a result of change in overall patch mosaic structure affecting the amount of suitable habitats, the probability that a given species becomes locally extinct may be very high compared to historic levels. As a result of landscape fragmentation, the ability for the species to disperse might be much lower, resulting in a low rate of regional colonization. The net result of these two changes is a decline in overall distribution range and abundance. Therefore, in many cases it is necessary to consider active manipulation of species, communities, or ecosystems, whether a coarse or fine filter is used. As Neilson and others (1992) have pointed out, conservationists and land managers need to become observers and facilitators of changes to allow ecological systems to function within the historic range of variability of patterns and processes.

CONCLUSIONS

The science required to develop and implement EM exists. This paper discussed the key science principles of landscape ecology and conservation biology that contribute to the maintenance of ecological systems at regional to local scales. The first step is to clearly define the planning objectives and match those with the ecological patterns and processes of interest. A basic understanding of landscape patterns is required because of the focus on the development and dynamics of pattern in ecological phenomena, the role of disturbances in maintaining ecosystems, and the spatial and temporal scales of ecological events (Urban et al. 1987).

Five central science principles should guide conservation and management from an ecosystem perspective:

- (1) Planning objectives must be clearly defined.
- (2) Ecological hierarchies must be defined according to management goals.
- (3) Ecological patterns must be understood in terms of processes, disturbances and constraints generating them.
- (4) The goal of sustaining ecological systems must include maintenance of all ecosystem attributes across their historic range of spatial and temporal scales.
- (5) The range of spatial and temporal variability across all scales must be defined if patterns and processes are to be maintained at all appropriate scales of ecological organization.

Finally, it must be recognized that EM and the science that supports it are experimental in nature and should be adaptive. Monitoring schemes that recognize the hierarchical nature of ecological systems must be designed to assess changes of multiple attributes. Monitoring data provide the basis for assessing ecosystem changes and trigger any management change (i.e., adaptive) if necessary.

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