Landscape and Urban Planning 40 (1998) 9–20

LANDSCAPE AND URBAN PLANNING

Ecosystem management: what is it really?

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Abstract

Ecosystem management is managing areas at various scales in such a way that ecological services and biological resources are conserved while appropriate human uses are sustained. Major ecological services include allocation of productivity (energy flow), maintenance of soil fertility (nutrient cycling), and operation of the hydrologic cycle. Biological resources encompass all natural variation found in genes, species, and communities along with the processes that maintain this variation. The appropriateness and sustainability of human uses are dictated by the constraints imposed by the biological and physical environment and by legal mandates for land use. There are seven critical steps in ecosystem management. These are: (1) delineate (define) the ecosystem to be managed; (2) define strategic management goals; (3) develop a comprehensive understanding of the ecosystem; (4) obtain socioeconomic data; (5) link the socioeconomic and ecological data in an appropriate model; (6) implement experimental management actions; and (7) monitor management results to determine long-term success or failure. The significance of ecosystem management is that it focuses on ecological systems as a whole rather than on just some of their parts, includes public involvement in the goal-setting process, integrates conservation into economic activity, and represents a paradigm shift from 'linear comprehensive' management to 'cyclic-incremental' or 'adaptive' management. © 1998 Elsevier Science B.V.

Keywords: Ecosystem management; Cultural ecosystems; Implementation; Ecosystem Services

1. Introduction

Short-sighted uses of natural ecosystems have led to widespread biotic impoverishment—the systematic decline of biological resources (Woodwell, 1990, 1994). Although some view the conservation of these resources as a nuisance or a luxury, it is clear to many others that human welfare and economic stability are strongly linked to ecological well-being (e.g., Myers, 1983; Oldfield, 1984). The decision to take a broader view of resource issues now has taken root in US land management agencies, academic journals, and the popular press under the rubric of 'ecosystem management.'

At present the concept of ecosystem management is fairly fuzzy. Uses of the term include: (1) the protection of native ecosystem types, usually plant communities; (2) the protection of native species richness and diversity; (3) the protection of ecosystem health or integrity; (4) the protection of ecosystem processes; (5) the protection of ecosystem services; (6) the integration of the human economy and ecological principles; and (7) harvesting ecosystem products in a sustainable way to ensure long-term economic stability (Grumbine, 1994). The US Forest

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PII S0169-2046(97)00094-7

Service defines ecosystem management as, ‘‘a holistic approach to natural resource management, moving beyond a compartmentalized approach focusing on the individual parts of the forest. It . . . integrate[s] the human, biological, and physical dimensions of natural resource management. Its purpose is to achieve sustainability of all resources’’ (Thomas, 1994). Other definitions include, ‘‘the interaction of ecological, economic, and social principles to manage biological and physical systems in a manner that safeguards the long-term ecological sustainability, natural diversity, and productivity of the landscape’’ (Bureau of Land Management, 1993), and ‘‘integrating scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting ecosystem integrity’’ (Grumbine, 1994).

In our view, the major objective of ecosystem management is to ensure that ecological services and biological resources do not erode irreversibly as a result of human activities. Thus, our definition of ecosystem management is, managing areas at various scales in such a way that ecosystem services and biological resources are preserved while appropriate human uses and options for livelihood are sustained. Ecological services are biological, physical, and chemical processes that occur in natural or semi-natural ecosystems and maintain the habitability of the planet. The major services are allocation of energy flows, maintenance of soil fertility, and regulation of the hydrologic cycle (Fig. 1). Biological resources include the natural range of variation in genes, species, and ecological communities, along with the processes that maintain them (Wilson and Peter, 1988). The appropriateness and sustainability of human uses of ecological systems and options for livelihood are largely dictated by the constraints imposed by biological and physical environment; however, legal mandates for land use are another important consideration. Private lands, multiple-use public lands, wildlife refuges, national parks, and wilderness areas have widely varying legal constraints on human activities within them.

A number of impediments exist before ecosystem management can be implemented (Office of Technology Assessment, 1992; Government Accounting Office, 1994). First among these is a lack of scientific knowledge. Ecosystem management will require

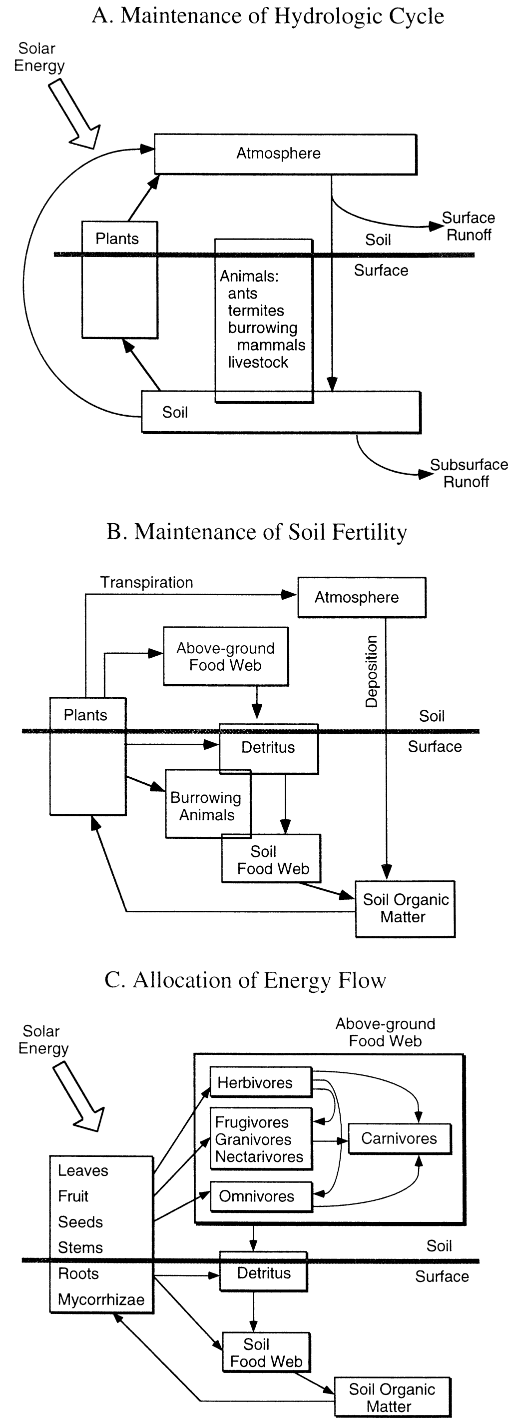

Fig. 1. Major ecosystem services, including (a) allocation of energy flow, (b) maintenance of soil fertility, and (c) maintenance of the hydrologic cycle. Understanding the flows, storage, and major participants in these interaction webs is critical to ecosystem management.

(1) collecting and linking necessary data on ecosystems at several spatial scales, and (2) collecting and analyzing socioeconomic data to determine the relationships among ecological conditions and human activities and the tradeoffs between ecological and socioeconomic values. In most cases, the data to do either are inadequate or lacking. Other impediments include controversial policies resulting from scientific uncertainty and data interpretation, problems with interagency cooperation, and constraints on collaboration with non-federal parties.

2. Scientific background

2.1. Ecosystems and biological resources

An ecosystem consists of an assemblage of species plus the interacting physical and biological processes upon which the species depend. In classical ecology, individuals, populations, communities, and ecosystems were thought to constitute different levels of organization in an hierarchical system. Aggregations of individuals formed populations; populations of different species comprised communities; communities and the abiotic environment within a given area comprised an ecosystem. However, these traditional levels of organization should not be regarded as hierarchical; hierarchy implies upper-level control over lower-level processes, and ecological events that occur at supposedly higher levels, such as ecosystems, may or may not control events at community or population levels (Allen and Hoekstra, 1992). The non-hierarchical nature of these levels of organization means that ecosystem management has to have a population, community, and ecosystem perspective simultaneously. Managing to optimize energy and nutrient dynamics alone will not automatically ensure that key population or community processes will be maintained.

Ecosystems are not bounded, balanced, cybernetic systems, although there are some self-reinforcing interactions among some of their components. Furthermore, ecosystems rarely have discrete boundaries because all ‘leak’ individuals, species, nutrients, and energy to one degree or another. Some ecosystems, such as a lake, may be more self contained than others, but it is always the case that events happening outside of the lake influence ecological processes within it. Lake ecosystems are imbedded in and influenced by events within their drainage basins which in turn are imbedded in and influenced by larger regional ecosystems. Thus, defining the appropriate scale and boundaries of ecosystem management units can be a problem.

Traditional ecology has usually dealt with small-scale systems—study areas the size of tennis courts and square meter sample plots, and the principles learned at small scales are not necessarily applicable to larger ones. When a change of scale occurs an ecological system can undergo a chaotic flip to a completely different set of constraints (e.g., Morris, 1987). When that occurs, a different set of explanatory principles is required (Allen and Hoekstra, 1992). Some levels of organization scale up rather easily; for example, populations often can be studied at scales of kilometers or tens of kilometers without the need to consider a new set of constraints. On the other hand, different species in a community occupy their environments on different scales, and inter-species interactions on the scale of square kilometers very likely require quite different explanatory principles from those occurring in 10-ha study plots (Brussard, 1993). Thus, ecosystem management generally must look beyond classical ecological methodology to other approaches such as landscape ecology and conservation biology for theoretical guidance at large scales.

The inherent complexity of ecosystems is made easier by distinguishing three attributes (Franklin, 1988; Noss, 1990). These are *composition*, the identity and variety of biotic units at any level; *structure*, the organization or pattern of these elements; and the various physical, ecological, evolutionary, and biogeographic *processes* that affect composition and structure. These attributes exist at several scales (Table 1). Ecosystem management requires considering the impacts of actions on all ecosystem attributes at all scales.

At what scales can ecosystem management be effective? At a landscape scale, it is possible to manage the size, configuration, and type of landscape elements. It also is possible to manipulate some aspects of the disturbance regime (e.g., certain fires) but not others (e.g., droughts or heavy storms).

Table 1
The scales and attributes of ecosystems including examples of indicator variables for each (after Noss, 1990)

	Structure	Composition	Processes
Regional	Major physiographic features	Total species lists	Climate, weather
Landscape	Landscape patterns	Landscape types	Disturbance regime
Community	Physiognomy	Species composition	Competition, predation
Population	Population structure	Genetic diversity	Breeding success

Management also can manipulate to some extent the physiognomy and composition of habitat types and alter food-web relationships (e.g., by predator control, harvest) at the community scale. In the end, however, most management actions will be directed at the population or species level.

It is worth pointing out that processes occurring at one scale can have important effects on attributes at other scales and that no single scale has primacy in regulating species abundances or ecosystem processes. For example, the dynamics of butterfly populations often are driven by weather (a regional-level variable) and disturbance regime (a landscape-level variable). Butterfly populations also may be influenced by competition and predation (community-level variables) and dispersal (a population-level variable) (Andrewartha and Birch, 1954).

2.2. Ecological viability and integrity

Ecosystems with *high integrity* show little influence of human actions and maintain their historical structure, species composition, and disturbance regime solely through natural ecological, evolutionary, and biogeographic processes, i.e., they are self-sustaining without management intervention (Karr, 1991; Angermeier and Karr, 1994). High-integrity ecosystems are self-sustaining because their structure, composition, and function have been shaped through millenia by biogeographic, ecological, and evolutionary processes. The species found in these ecosystems usually have been tested repeatedly by environmental challenges such as 100-year droughts or 500-year freezes; consequently, they tend to be well-adapted to the prevailing patterns of disturbance and are generally the ones most likely to help provide ecological services in the immediate future. High-integrity ecosystems also contain rare species which may become more common and assume important functional roles when environmental conditions change—as they inevitably will. Current rarities may be the necessary buffers for such events (Peters and Darling, 1985) in much the same way that genetic variability within a species can buffer it against environmental changes (Frankel and Soulé, 1991).

High-integrity ecosystems are also valuable because they provide baselines for assessing the relative condition or state of other ecosystems. An interesting philosophical debate involves whether or not ecosystems modified by native humans have high integrity. This debate is further complicated by a general lack of relevant data on the extent to which native humans have modified their environments in specific cases (e.g., Diamond, 1991; Milberg and Tyrberg, 1993).

The presence of non-native species degrades ecosystem integrity. Exotics generally affect native species negatively, often leading to their extinction, although some seem to coexist successfully with native species (Laycock, 1966). Many invading exotic species alter key ecosystem attributes. Even if this alteration is not obvious, ecosystems dominated by exotics rarely perform life-support services as effectively as those composed largely of native species (Ehrlich and Mooney, 1983).

There seems to be general agreement in the scientific and popular literature that maintaining ecosystem integrity should take precedence over other management goals (Keiter, 1989; Grumbine, 1992, 1994; Noss, 1992). We agree that this should be the case for national parks, nature reserves, wilderness areas, critical watersheds, and multiple-use lands of particularly high conservation value. These lands should be maintained in, or restored to, high-integrity states. This will require hard choices, for example, it would mandate the removal of non-native species, even ‘desirable’ ones, which are currently in the system.

Impacted ecosystems are natural or semi-natural ecosystems that have been modified sufficiently by human activity to have lost much of their original integrity. An impacted ecosystem could be an approximation of the one historically found at the site (e.g., a previously logged area) or it might have a quite different structure, composition, and functional organization (e.g., a reservoir). Although impacted ecosystems often have large numbers of exotics, many native species also use these ecosystems extensively. Impacted ecosystems still provide many services, and some of the non-native species they support (e.g., bullfrogs, rainbow trout) often are valued more highly than many native species.

Impacted ecosystems are characteristic of multiple-use public lands and many private lands which are used for commodity production. These lands should be managed for ecosystem viability or ‘health’ (a less than perfect term but perhaps a useful metaphor), the preferred state of sites modified by human activity (Karr, 1994, 1995). Impacted ecosystems may be considered viable if they meet the following criteria: (1) *current utility* wherein the ecosystem is providing the goods or services (e.g., preventing erosion, detoxifying wastes) expected from it with reasonable efficiency; (2) *future potential* wherein present uses are not disrupting processes that generate and maintain the desired composition, structure, and functional organization of the ecosystem; (3) *containment* wherein present uses or current conditions do not degrade areas beyond the system’s borders; (4) *resilience* wherein the system has the capacity for self-maintenance and self-regeneration (i.e., it can maintain the desired structure, composition, and functional organization after moderate external stresses or perturbations).

For example, a viable stream ecosystem might have the same basic structure as the original one, but its composition now includes introduced rainbow, brown, and brook trout. The presence of these non-native species may have altered some of the original processes in the system as well as its species composition. However, if the stream currently has utility (it is in a desired state), is not contributing to the degradation of other streams (it is not exporting excess nutrients or non-native species to other stream reaches or watersheds), is retaining its future potential (the remaining native species in the system seem to be persisting), and it has resilience (the stream can return to this particular state after a serious flood or drought), the ecosystem is viable. Viable impacted ecosystems can coexist with high-integrity ecosystems.

Cultural ecosystems, such as agricultural fields and urban areas, have a structure, composition, and functional organization that have been transformed completely by human activity. Although cultural ecosystems clearly are important to the human economy of a region, they are maintained in their current states by large and continuing inputs of energy and materials. These ecosystems are not self-sustaining. When the subsidies are removed they undergo succession toward natural ecosystems at best or revert to highly degraded states at worst. Although few native species are found in cultural ecosystems, those that are often reach high population densities. It is also possible that some cultural ecosystems (such as riparian vegetation along irrigation ditches) function as refuges for some species whose natural habitats have largely disappeared. The extent to which cultural ecosystems are important to native species diversity needs to be investigated much more thoroughly.

It is highly unlikely that cultural ecosystems are in an ecologically viable state. Although they have current utility, they have no resilience and little future ecological potential except perhaps in the long term; most also fail the containment criterion. However, any comprehensive plan for ecosystem management necessarily must consider how cultural ecosystems affect, and are integrated into, the entire system.

3. Implementing ecosystem management

Ecosystem management will require radically new approaches for management agencies if it is adopted seriously rather than just used as a catchy new term for business as usual (e.g., Reed, 1995). First, it will require substantial organizational change within agencies. Goals for fish and wildlife management, watershed management, commodity production, and recreation management must be set in a highly coordinated fashion and should always work toward lessening impacts that reduce ecosystem integrity or viability. Another major component of organizational change will involve strengthening the relationships between research and management. In particular, there should be increased effort to construct research programs that dictate management possibilities, that evaluate management decisions, that investigate alternatives where management actions have failed, and that evaluate the management process (Underwood, 1995). Ecosystem management also will require unprecedented cooperation from various state, federal, and local agencies and from numerous constituencies in the private sector. Meaningful cooperation at a minimum will require resolving conflicting legal mandates and integrating management goals.

Noss (1990) presented protocols for biodiversity management, which has some aspects in common with ecosystem management. Grumbine (1994) reviewed the literature on ecosystem management found in the conservation biology, resource management, and popular literature. Although he identified a number of recurrent, dominant themes in ecosystem management, he provided no practical framework for its implementation. Here we provide this framework by enumerating seven critical steps in the ecosystem management process.

First, it is necessary to define and delineate the ecosystem to be managed and to understand clearly that whatever boundary is chosen the ecosystem will leak individuals, species, nutrients, and energy. The second step is to define explicitly strategic management goals which are socially and politically possible. Management goals must be compatible with an ecosystem-management approach and consistent with the existing legal framework. Considerable public education and a great deal of inter-agency cooperation is required at this step. Third, it is necessary to have a comprehensive understanding of the ecosystem to be managed. This involves detailed knowledge, at appropriate spatial scales, of: (1) the composition of the ecosystem (what is there); (2) how it is put together (its structure); and (3) how it works (its processes). Data on composition should include both historical records and up-to-date inventories of species and communities. Structural information should include good maps of physiography and vegetation and data on landscape pattern and horizontal and vertical vegetation structure. Data on processes should be focused on the basic interaction webs that drive major ecological services (defined above) and on key mutualistic interactions (e.g., co-evolved guilds of plants, pollinators, and seed dispersers, mycorrhizal and rhizobial associations, etc.). In addition, information is required on natural variation in critical inputs (e.g., the precipitation regime), the kinds and periodicities of natural disturbances (e.g., fire), and the extent to which these have been modified by human activities. Fourth, socioeconomic data must be collected and analyzed to determine the relationships among ecological conditions and human activities.

The fifth step is linking the ecosystem data and the socioeconomic data into a meaningful model. This model is used to define experimental management actions that will help achieve the previously defined strategic goals. The sixth step is to implement these experimental management actions. This is done by formulating specific hypotheses (e.g., action x will result in response y), selecting appropriate indicators, identifying control and treatment areas, and following an appropriate sampling scheme. If the management experiment indicates that the treatment did result in the desired outcome, the management action should be applied elsewhere as appropriate. If not, additional management experiments must be conducted. The seventh and final step is to monitor all management actions well into the future so that their ultimate success or failure and their impacts on achieving the strategic goals can be assessed. These steps are discussed in detail below.

3.1. Delineate ecosystem to be managed

An ecosystem management unit can be defined at any scale depending on management goals, the type of disturbance, or the limiting resource that is stressing the system. It can correspond with a natural boundary (e.g., a watershed), a topographic feature (e.g., a mountain range), or even a political unit (e.g., a grazing allotment). Leakage (of species, individuals, nutrients, and energy) will be less of a problem in larger areas because of the perimeter/area relationship, and ecosystem management will be most effective biologically when the management unit is as large as possible. However, politics are likely to be less of a problem in smaller areas.

Watersheds make a robust natural boundary for ecosystems because a number of critical processes reach their limits at the edges of catchment basins (Allen and Hoekstra, 1992). An ecosystem management approach based on watersheds makes sense in areas where water has been identified as a critical limiting resource. However, watershed boundaries are usually meaningless to wide-ranging species (such as birds and large mammals) and species that undergo local or altitudinal migrations. Managing for such species requires a good understanding of the scale, dynamics, and linkages among different communities and habitat patches on entire landscapes. Thus, landscapes also are appropriate boundaries for ecosystem management units.

Some landscape elements, such as riparian zones, can be particularly important management targets in their own right while others are mainly important as mechanisms to ensure species persistence. For example, many species require habitat patches that are greater than some critical size, that are in a suitable geometric configuration, that are not highly fragmented, or that are connected by effective corridors —all of these attributes must be measured and assessed on a landscape scale. Scenic vistas are also landscape attributes which are of concern to the recreational aspects of land management although not necessarily to the ecological system itself.

Special habitats, such as isolated wetlands, rare plant sites, and springs, are often small enough that they would ‘fall through the cracks’ at a landscape or watershed scale. These sites require additional explicit consideration.

3.2. Establish strategic management goals

Strategic management goals should focus on the concepts of ecological integrity and viability. In some circumstances maintaining or restoring ecological integrity will be most appropriate, in others, managing for ecological viability will be the most reasonable option. In large, multiple-use systems, management goals should focus on creating a mosaic of high-integrity areas imbedded in a matrix of ecologically viable areas used for commodity production. The high-integrity areas function as core reserves for biological diversity, provided that they are large enough, are configured correctly on the landscape, and are connected by functional corridors (Grumbine, 1992; Noss, 1992; Noss and Cooperrider, 1994). Such a pattern not only should preserve biological diversity and ecosystem services but also should ensure sustainable harvests of resources from matrix areas provided that the scale and intensity of human uses do not compromise ecosystem viability in the long term. Matrix lands that fail to meet one or more of the criteria for ecosystem viability should be restored to a viable state if at all possible.

Creating a sociopolitical climate supporting ecosystem management requires public involvement in the goal-setting process. Clearly, strategic goals must be compatible with an ecosystem management approach, and they must be consistent with the existing legal framework. The people who live, or make their living, within the ecosystem must have a strong voice in goal-setting, but if public land is involved, a broader constituency must be heard as well.

To lessen the inevitable conflicts that will arise, agencies must begin an aggressive campaign to convince the public that achieving ecosystem management objectives will retain the long-term economic viability of the area as well as conserve its ecological processes and biological resources. Public mores in the US for too long have emphasized the rights of individuals to use resources while discounting ecologically responsible behavior (Grumbine, 1994); people need to understand clearly that resources will flow sustainably from the land only if basic ecosystem processes and patterns are maintained. As the ability of ecosystems to produce goods and services is eroded, economic output is lost and options for the future are diminished. Aesthetic considerations also are important; degraded land has less value, economically and otherwise, to humans (Norton, 1987). Eventually, the public also must come to understand that ecosystems have value beyond their traditional commodity and amenity uses (Kessler et al., 1992), but achieving this understanding probably will require a full generation or more.

3.3. Develop a comprehensive understanding of the ecosystem

An extensive data base on ecosystem structure, composition, and processes at appropriate spatial scales is a prerequisite for ecosystem management. All of these data should be in a spatially explicit format. Geographic information systems (GIS) combined with relational databases are important tools to characterize natural and cultural landscapes and the constraints that geology, hydrologic variation, and human activity place on their ecological potentials.

Data on composition should include historical and current information on species distributions and community types. Data on structure should include GIS coverages of regional physiography, landscape patterns, and natural vegetation types and ecological descriptions, measurements, and photographs of horizontal and vertical vegetation structure. Data on processes should include the basic interaction webs that provide basic ecological services (Fig. 1), and an understanding of key mutualistic interactions (e.g., co-evolved guilds of plants, pollinators, and seed dispersers, mycorrhizal and rhizobial associations) found within the system.

Other important data include records of natural variation in driving inputs (e.g., precipitation), the kinds and periodicities of natural disturbances (e.g., the fire regime), the extent to which these have been modified by human activities, and current stressors (e.g., point and non-point sources of pollution). While many of these data are available from the published literature and other records, other data will have to be obtained by surveys, inventories, and field experiments.

Reducing the complexity of ecosystems is best accomplished by developing a reliable set of indicators for ecosystem attributes at various scales. All indicators must be tested to show that they indicate what they are supposed to; this cannot be automatically assumed.

3.3.1. Structural indicators

Structural indicators are necessary to describe the physical organization or pattern of the ecosystem at various scales. For example, vegetation structure, an indicator of habitat complexity, can be assessed at a local scale with a classification system that uses both physiognomy and species composition (e.g., Paysen et al., 1982).

3.3.2. Compositional indicators

Compositional indicators assess the identity and variety of elements in the system. Because many taxonomic groups, particularly invertebrates and microbial phyla, are known very poorly, indicator taxa must be chosen that will serve as useful surrogates for the majority of groups. The taxa chosen should be well known taxonomically and ecologically, readily surveyed, and sensitive to habitat changes (Furness and Greenwood, 1993; Pearson, 1994). It is important to use a variety of indicator taxa and species that represent different uses of the habitat and habitat use at different scales. For example, indicators might include wide-ranging carnivores (regional scale), birds that use several habitats over the course of the year (landscape scale), small vertebrates whose populations are confined to a single drainage, and invertebrates whose populations are limited to specialized habitats within a single drainage. The use of a single 'indicator species' is strongly discouraged (see Landres et al., 1988).

Compositional data usually focus on species diversity, and *species richness*, the number of species in a sample, is generally accepted as the least biased indicator of species diversity (Hurlburt, 1971, Whittaker, 1972; Peet, 1974). However, species richness data also need to be interpreted in light of species *composition*. Qualitative changes in community composition are often the best indicators of ecological disruption. Thus, the percentage of exotic species is an important compositional indicator as is the relative proportion of widespread ecological generalists vs. endemic specialists.

3.3.3. Process indicators

Process indicators assess the viability of ecological and evolutionary processes. These include patch dynamics and fragmentation in various vegetation types, metapopulation dynamics and genetics of selected species, and reproduction and recruitment in key indicator groups such as amphibians or neotropical migrant birds. Compositional elements also are used frequently as process indicators because they are typically quite sensitive to degradation, better understood, and less expensive to monitor. For example, the presence of dippers (*Cinclus cinclus*) should indicate high water quality (Omerod and Tyler, 1993).

Some processes, such as primary productivity, can be assessed by remote-sensing techniques. However, many subtle community processes, such as pollination or seed dispersal, can involve rare species and generally will have to be assessed on the ground. A thorough literature review very likely would provide information on many important community interactions and their major participants in many ecosystems. This would allow the identification of species important to ecosystem processes, keystone species (e.g., Daily et al., 1993), co-evolved food webs (e.g., lepidopterans and their larval food plants), and important mutualisms.

Data on structure, composition, and process at local and landscape scales will permit a preliminary assessment of the state of the ecosystem to be managed. For example, useful indicators of ecosystem integrity in a watershed might include the structure and composition of riparian habitat, fish habitat quality, and extent of remaining historic wetlands (structural indicators), status of native species and extent of exotics (compositional indicators), and food web complexity, water quality, and frequency and magnitude of floods (process indicators). Such data will allow key questions to be addressed such as: is the structure of the ecosystem appropriate to achieve management goals?; do compositional indicators suggest that major components are missing or 'ecologically extinct?'; do process indicators suggest dysfunction? Answers to these questions also will allow the system to be classified tentatively as high-integrity, impacted but viable, or heavily impacted. In doing this exercise it is important to sort out short-term effects, due, for example, to drought or past grazing, from longer-term effects related to the character and quality of habitat.

3.4. Obtain socioeconomic data

Data on land ownership and management should be a coverage in the GIS. Other critical data include relationships between ecological conditions and human activities in the ecosystem, a realistic valuation of biodiversity and ecosystem services, and the potential tradeoffs between ecological and socioeconomic values. Obtaining these data will rely on the participation of social scientists, particularly economists and sociologists, in the ecosystem management process.

3.5. Link ecological and socioeconomic data in an appropriate model

Management decisions generally have both ecological and socioeconomic consequences. A model that examines these relationships and tradeoffs should be used to define experimental management actions which will help achieve the strategic goals.

3.6. Implement experimental management actions

All management actions should be targeted to help achieve the strategic management goals, and all management actions should be treated as experiments. The appropriate steps are the following.

3.6.1. Formulate specific management hypotheses

All management should be hypothesis based (e.g., action x will result in response y), followed by appropriate tests.

3.6.2. Execute management experiments

Management hypotheses must be tested in a scientifically rigorous manner; such tests always should follow sound principles of experimental design.

3.6.2.1. Select indicators. Structural, compositional, and functional indicators which will be necessary to establish baseline (initial) conditions and track the progress of management experiments. Such indicators must be relevant to the specific questions at hand, sufficiently sensitive to provide evidence of change, able to differentiate natural variation from anthropogenic change, relatively independent of sample size; and easy and cost-effective to measure.

3.6.2.2. Identify control and treatment areas. This is the only way in which the efficacy of management actions can be assessed in a scientifically valid way. Prior to any manipulations (i.e., management actions), all attributes of interest in the experimental and control plots must be inventoried. After the manipulations, the experimental and control plots must be monitored for a sufficiently long time (probably several years) to distinguish treatment effects from natural variation. In some circumstances experiments need not be manipulations. It is sometimes possible to find control areas that are not subjected to certain stressors which can be compared to treatment areas which are. However, these experiments are less desirable because treatments cannot be assigned randomly, and the possibility of a systematic, unknown bias exists.

3.6.2.3. Design and implement a sampling scheme. Sampling points or plots should be selected randomly within treatments and controls, and all treatments and controls must be properly replicated. For ecosystem-scale studies, it may be necessary to stratify by vegetation type and then sample randomly within the strata (e.g., Bibby et al., 1993). Many samples from small plots are generally superior to a few samples from large plots in large-scale studies because of increased statistical power (Cohen, 1988).

3.6.3. Test relationships between indicators and hypotheses

Statistical tests are necessary to determine whether or not the management actions have or have not falsified the management hypotheses. Such tests must involve all the structural, functional, and compositional indicators measured. In many cases a long time series of data will be necessary to distinguish signal (effects of treatment) from noise (natural variation).

3.6.4. Base management decisions on experimental results

This is the key step in adaptive management—interfacing science and policy. For example, if action x does result in a desirable response y, the management action should be applied elsewhere, as appropriate. Management actions adopted through this procedure will be based upon rigorously established scientific evidence, not tradition, hearsay, or whim. However, if the experiment does not show that action x results in response y, additional management experiments must be conducted.

3.7. Monitor to determine long-term success or failure

All management actions must be monitored over the long term so that their ultimate success or failure can be assessed. A management experiment lasting 3 years may not capture much of the natural variability in a system; response under drought conditions may be very different from response under a more normal precipitation regime.

4. Significance of ecosystem management

The significance of ecosystem management is that it focuses on ecological systems as a whole rather than on just some of their parts (such as timber or forage), includes public involvement in the goal-setting process, integrates conservation into economic activity, and represents a paradigm shift from 'linear comprehensive' management (managing as if there were comprehensive, quantitative, and continuous knowledge of the system being managed) to 'cyclic-incremental' management (managing to enhance accumulation of meaningful local information on the system being managed) (Bailey, 1982). Cyclic-incremental management is another word for *adaptive management*—changing management protocols in response to experimental results or other reliable sources of new information. Adaptive management allows flexibility and response to uncertainty. It also involve risks and requires that managers accept the potential for irreversible impacts. Nevertheless, it is the only way in which science can be integrated meaningfully into the management process.

Perhaps the most significant aspect of ecosystem management is that it might be the way by which humans reestablish a meaningful and understanding relationship with the land upon which we depend.

Acknowledgements

This paper has profited from discussions with staff and students in the Biological Resources Research Center, in particular Lianne Ball, Hugh Britten, Susie Deller, Erica Fleishman, Scott Fleury, Chris Mullen, Mary Peacock, Jan Simpkin, and Ulla Yandell. Jim Nelson, Supervisor of the Toiyabe/Humboldt National Forest, provided the inspiration for its genesis. Funding was provided by the Nevada Biodiversity Initiative and the Nevada Agricultural Experiment Station.

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