Natural Resources and Environmental Issues

Volume 5 *Ecosystem Management of Natural Resources in the Intermountain West* Article 4

1995

Object or context: an ecologist's view of ecosystem management

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Object or Context?

An Ecologist's View of Ecosystem Management

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Abstract

There is a need to recognize a duality of object and context perspectives on ecosystems, and a need to synthesize the two in a way which clearly identifies the distinctions and links between them. This paper proposes a new terminology of spatially-fixed atoms, diffuse entities, and molecules to represent ecological entities; and it argues the need for identifying the processes linking them.

Ecosystem management will require development of simple, mechanistic models of local ecosystem dynamics which incorporate basic successional dynamics, disturbance response, and management response. It will require development of statistical, predictive models of ecosystem distribution on the landscape. And it will require development of simple, spatial integration algorithms linked to a spatially explicit database in a GIS.

INTRODUCTION

Ecosystem management has emerged as a critical issue in land and resource management. While ecosystem management encompasses a broad range of perspectives and disciplines, I will allow other scientists and managers to address the breadth of issues concerned, and restrict my remarks to the "ecology" in ecosystem management. Specifically, I will first comment on the ecological basis of resource and land management in the recent past and present, and then discuss a range of problems and controversies inherent in developing of the concept of ecosystem management. Finally, I will follow with some recommendations concerning helpful concepts and tools for practical ecosystem management. It must be remembered that these recommendations are the views of an ecologist, rather than an ecosystem-management specialist, and are necessarily too narrow to address all the issues of ecosystem management. They reflect, however, the views of a scientist with strong interests in both ecological theory and the design of ecological-management systems.

Ecosystem management has been defined by a broad range of individuals and organizations, with emphases ranging from preservation (Grumbine 1994), to the importance of policy and broader social concerns (Slocombe 1993), to utilization (USDA 1992, USDI 1993). It is not my purpose here to review those definitions comprehensively, but rather to comment on the general nature of these definitions. As an example, let us use a simple definition.

> Management of ecological entities and processes to achieve and sustain desirable ecosystem structure, composition, and function, while providing, to the extent possible, those commodities and services desired by the public.

While we could argue the merits and shortcomings of the above definition, it is the abstract and general nature of the definition I wish to call attention to. While the general intent of the definition is clear, the specific implications of the definition are much less clear. By analogy, let us look at the following definition of cooking:

> Combining food items in a specified order and manner, generally applying heat of a specified duration and intensity, to produce an aggregate that is pleasing to the palate and the eye, and is highly nutritious.

Again, we could argue the merits of this definition of cooking, but that wouldn't help put food on the table, or by analogy, put ecosystem management into practice. What we need are some recipes. While we are all aware of the limitations and dangers of "cookbook solutions" to ecological problems, we need some place to start to learn the art and science of ecosystem management. Once we have a little experience, we can dispense with the cookbook, and design solutions to specific problems or opportunities.

ECOLOGICAL CONTENT OF RESOURCE MANAGEMENT

Foresters, range managers, wildlife biologists, and other natural-resources managers all recognize that we have always had a great deal of ecological theory and insight underlying the principles and practices of natural-resources management. In the past, however, this scientific basis has largely been developed from the disciplines of ecophysiology (study of the relationship between organisms and their environment) and population biology (study of population change as a function of time and resources available). These disciplines were highly applicable to the paradigm of sustained yield-multiple use, as they formed the scientific basis for maximization of production efficiency which was clearly in line with the objectives of sustained yield. This emphasis on production efficiency, however, has led to a great simplification of ecosystem structure and function, which is now generally recognized as undesirable (Roberts 1991).

In ecosystem management, the disciplines of ecophysiology and population biology will remain cornerstones of the scientific basis of resource or wildland management, but must be augmented by additional disciplines to achieve a more balanced approach. Specifically, in the future we must emphasize the roles of:

- ecosystem ecology—study of the components and processes of ecosystem function
- landscape ecology—study of the importance of spatial juxtaposition and patterning of ecosystems on ecological processes
- conservation biology—study of the maintenance of biodiversity and minimal viable populations of all native species.

In contrast to sustained-yield multiple use, the emphasis must be on achieving and sustaining diverse and complex ecosystem structure and function in the broadest sense (Roberts 1991).

A TALE OF TWO PERSPECTIVES

Adding additional ecological disciplines to the mix already present will greatly increase the ecological content of land and resource management. However, it will also add complexity to the way land and resources are viewed. Different ecological disciplines (and ecologists) see the world in different ways (Allen and Hoekstra 1992, Rowe and Barnes 1994). While undoubtedly a range of viewpoints exists among ecologists, I believe that there are two fundamentally different ways of viewing ecosystems: object and context.

From the object perspective:

- Ecosystems are tangible, identifiable, mappable entities with boundaries discernible by objective criteria.
- The object of management is the ecosystem itself.

Accordingly, the procedure for ecosystem management is as follows:

1. Classify and map ecosystems.
2. Define desired future conditions for each ecosystem.
3. Determine and implement the management activities required to achieve the desired future condition.

The object perspective is described in detail in a series of papers by Barnes and colleagues (Barnes et al. 1982, Barnes 1983, Pregitzer and Barnes 1984, Albert et al. 1986, Barnes 1993) who describe the concept as "the landscape ecosystem approach."

The context perspective emphasizes the following:

- Every ecological process has its own spatial and temporal scales.
- Every ecological entity perceives its environment at its own spatial and temporal scale.
- There are no ecosystem boundaries appropriate for all or even many ecological processes or entities.
- The object of management is the ecological entity or process, and the ecosystem forms the context of this management.

From this perspective, the procedure for management is:

1. Identify the appropriate spatial and temporal scales for a given entity or process.
2. Identify the role a given entity or process plays in the ecosystem, and the other entities or processes influenced by changes in this entity or process.
3. Determine and implement the management activities required to achieve the desired change while mitigating or compensating for undesirable concomitant changes in the ecosystem.

The context approach is best described by Allen and colleagues (Allen and Hoekstra 1992, O'Neill et al. 1986). While the two perspectives are clearly different, both are means to implementing ecosystem management, and the choice between them is not always clear.

OBJECT PERSPECTIVE

If we accept the object perspective as most appropriate for implementing ecosystem management, a number of issues emerge. First, there is no agreement on the correct or most appropriate way to classify ecosystems. Ecosystems are complex, dynamic, multi-dimensional entities and the number of possible ways to classify and map them is nearly infinite.

A common suggestion and approach is to use watershed boundaries as ecosystem boundaries. This approach has the advantage that the boundaries are generally identifiable on objective criteria both in the field and on maps or digital representations of the landscape. Watersheds have also served as the system entities for "ecosystems" for a large number of scientific studies of nutrient cycling and ecosystem function, as well as for studies of stream ecology and riparian-area analysis. Unfortunately, watershed boundaries are really only appropriate for ecological issues dominated by hydrological processes, or perhaps fire behavior. Free-ranging terrestrial organisms certainly pay little attention to watershed boundaries, and may cross into and out of these watersheds daily, seasonally, or on longer time scales. Even for sessile terrestrial organisms, such as plants, watershed boundaries are often inappropriate. Forest vegetation in the headlands of one watershed is often more similar to forest vegetation in the headlands of adjacent watersheds than to other vegetation types within the same watershed. Clearly, these forests are more connected to other forests by such ecological processes as propagule dispersal, pollination, pathogen dispersal, and herbivory. Delimiting the ecosystems along watershed boundaries is clearly only appropriate for a subset of the issues we are concerned with, and may make other ecological issues more complex, rather than more manageable.

Another common approach is to delimit areas homogeneous with respect to geology, geomorphology, soil, potential natural vegetation, and current vegetation. Barnes and colleagues (see above) advocate a holistic, multifactor approach based essentially on work done in Canada (Hills 1952, 1960, 1977) and Germany (Barnes 1984). This approach is extremely intensive and data demanding, however, and is likely to be infeasible for much of the public lands in the U.S. due to lack of data and effort. In addition, given these basic homogeneous units, there is no obvious way to aggregate them into higher-order, larger geographic units. A proposal for a national or regional hierarchical classification of ecosystems has been developed by Avers et al. (1994) and Bailey (1980). This system is top-down rather than bottom-up, and proceeds primarily by subdivision of climatic and geomorphic units. The problem, however, is that any criterion of aggregation will work for some subset of ecological processes, and obfuscate others. This point is elaborated below in the discussion of the context perspective. Finally, another suggestion is to use critical habitat for specific animal species as the ecosystem boundary. Examples include grizzly bears or elk in the Greater Yellowstone Ecosystem. The assertion is that free-ranging animal species don't observe political boundaries, and that political boundaries often divide what appear to be "natural" ecosystem boundaries observed by animals. One problem with this definition is that different animal species would cause the boundaries to be drawn differently. If we employed neotropical migrant bird species as our object of concern, much of the western hemisphere would be included in a single ecosystem. Another significant problem is that ecosystems bounded by such a definition are frequently so large that they offer no site-specific management guidelines. If all decisions about the Greater Yellowstone Ecosystem require considering all areas included by that definition, then we have lost the local focus required by many ecosystem-management issues.

This last point anticipates a more general problem. No matter whether we use watersheds, homogeneous units, or animal home ranges, there is no single appropriate size for ecosystems. If the units are too small, as is likely with the homogeneous-unit definition, then we lose the context required for effective ecosystem management. Many of the problems of the previous multiple-use sustained-yield paradigm have been the emphasis on local conditions without consideration for the larger landscape consequences of local site management. If, however, the units are too large, then too much variability is included within units, and the predictive or prescriptive power of the units is greatly reduced. In general, all units are simultaneously too small and too large, depending on the specific issue at hand.

Finally, there is the problem of defining "desired future condition." Most definitions emphasize that areas should be "natural" in some sense, but such determinations are problematic. What factors or entities do we include or exclude on what basis? If we recognize that humans are a significant component of the ecosystem, then what level of technology do we include as part of a "natural" human society? Recent archeological evidence and ecological research makes clear that humans have been significantly modifying ecosystems in western North America with fire for a long period of time (Arno 1985). In many areas we have no idea what ecosystems would have looked like in the absence of human modification. We may simply settle upon "pre-European" vegetation as the desired condition, but these ecosystems have been changing in response to environmental dynamics for thousands of years (Covington et al. 1994). Why choose a certain century? Much of the forest we now call "old-growth" established during the Little Ice Age, when the climate was significantly colder and wetter than at present. Should we choose to maintain ecosystems that are out of equilibrium with current and future conditions?

Morgan et al. (1994) and Risbrudt[1] present an elegant argument that the basis for determining "desired future condition" should be the "historic range of variability," where the definition of historic emphasizes the multiple time scales on which ecosystem processes operate. The historic range of variability at least puts bounds on the range of desired future conditions, if it does not point to a specific condition. However, as Morgan et al. (1994) note, it is foreseeable that society may choose a desired future condition outside of the historic range for a variety of social, economic, or political reasons.

I would argue that there is no such thing as a desired future condition for dynamic entities subject to inherent dynamic processes and disturbances. Rather than speak of a desired future condition, we should speak of a desired future trajectory or dynamic for specific elements of the ecosystem. We should speak of a desired future dynamic mosaic for landscapes. We have to recognize the dynamic tendencies of ecosystems, and incorporate disturbance as a management tool.

CONTEXT PERSPECTIVE

The context perspective is also fraught with difficulties. Proponents of the context perspective maintain that each ecological entity or process operates at its own spatial and temporal scale, and that general ecosystem boundaries cannot be drawn (Allen and Hoekstra 1992). However, without boundaries ecosystems are probably unmanageable by existing land-management agencies; for practical purposes boundaries must be drawn. Given a set of boundaries, the context perspective requires us to manage multiple spatial and temporal scales simultaneously, which is obviously extremely difficult. In addition, the context perspective emphasizes

[1] See Risbrudt, this volume.

ecosystem processes, rather than states or conditions, and processes are much more difficult to measure and monitor than are states or conditions (Roberts 1991). While in theory ecosystem functional and structural objectives could be set, estimating the appropriate values to maintain, and determining our progress in meeting objectives, would be difficult.

While the context perspective appeals to many ecosystem ecologists, it is in many ways too abstract and intangible to appeal to a broader public. Managing to maintain a minimal decomposition rate, a specific nitrogen mineralization rate, or even a minimum net primary productivity does not have the same appeal as maintaining a specific timber productivity, deer-herd size, or water yield. Even among ecologists, maintaining ecosystem function does not have the same appeal as maintaining minimum viable populations or biodiversity. We may recognize that objectives of biodiversity cannot be met without maintaining the ecosystem processes which sustain that biodiversity, but this is a rather indirect level of support that will likely prove insufficient.

THE ROLE OF ECOLOGISTS

Given the above dichotomy of viewpoints among ecologists (or more properly perhaps, range of viewpoints), what is the appropriate role for ecologists in implementing ecosystem management? There is again a wide range of views, and the following is a personal perspective:

- Ecologists must take responsibility for designing management systems that tell us not WHAT to manage for, but rather what CAN BE managed for, and what the ecological behavior of such systems would be.
- We have to achieve a synthesis of the object and context perspectives, and develop management systems that incorporate the essential elements of each.
- We have to clearly distinguish when we are operating in the object and context modes.

The first point concerns essentially philosophical issues. As ecologists, we obviously have strongly held views on the desirability of complex, intact ecosystems with well-developed ecosystem structure and function. However, I believe that ecological science is neutral on the appropriateness of different possible states for these ecosystems, and we should recognize that our preference for specific states or conditions is a value judgement. It is a value judgement based on ecological knowledge and insight, perhaps, but a value judgement nonetheless, and we should guard against portraying our value judgements as ecological science. The issue for ecologists is not to determine what is the "best" or "most natural" state for these ecosystems to be in, but rather to determine the set of possible states and the characteristics and behavior of each of these possible states. Specifically, what are the inherent dynamics from each state, are they sustainable, and to what extent do they achieve the specific objectives for each entity or process?

The second and third points are more technical in nature, and relate to our responsibility to develop management systems that reflect our ecological understanding, rather than the production-efficiency bias employed in previous resource-management systems. These two points emphasize what I feel is the critical challenge of developing ecosystem management. While I portrayed the object and context perspectives as a dichotomy, we must come to an understanding of the duality of ecosystem management, and we cannot afford to allow either perspective to become lost in the design of ecosystem-management systems.

RECOMMENDATIONS FOR IMPLEMENTATION OF ECOSYSTEM MANAGEMENT

ATOMS, ELEMENTS, AND MOLECULES

Given the above discussion and the desire to incorporate both the context and object perspectives of ecosystem management, I offer the following recommendations. The ideas presented here are the outgrowth of analysis of the above issues, and represent a starting point for discussion on ecosystem management. The nomenclature employed below is strictly for the sake of communication of ideas, and I do not propose it as a new standard.

First, let us recognize that we have to delimit ecosystems, and design systems that capture the best elements of both perspectives. Of the various proposals for recognizing ecosystem boundaries, I recommend the homogeneous-land-unit approach. I will call each unique combination of geology, geomorphology, potential natural vegetation, and soils an "element," and each actual example of an element on the landscape an "atom." Mobile organisms that occupy the landscape at a larger scale (e.g., wildlife and recreationists) I will call "diffuse entities." Atoms and diffuse entities interact through ecological processes, e.g., herbivory, dispersal, and provision of habitat.

For each element we need to develop a model (conceptual at first and then quantitative) that specifies the set of possible states for that element, and the set of possible processes associated with each state of that element. These models must include the inherent dynamics, disturbance response, and management response of each element. We need to know the effects of change in the atom on the diffuse entities, as propagated through ecological processes, as well as the effects of diffuse entities on the state of the atoms.

Finally, we need to develop a method of aggregation which reflects our understanding of ecological principles. I believe that this aggregation must not be hierarchical, but rather reticulate and anastomosing, reflecting the particular ecological processes which are most important. Individual atoms on the landscape are aggregated in higher-order structures which I will call "molecules." As examples, consider the aggregation of a specific atom, called the focal atom, into the following molecules. The hydrological molecule includes all those atoms in the same watershed, as well as the atoms in the nested higher-order watersheds downstream. The vegetation molecule containing the focal atom contains all those atoms within pollination or seed-dispersal range, regardless of the watershed in which they occur, and regardless of differences in geology, vegetation, or soil among the atoms.

The animal-habitat molecule containing the focal atom depends on the role of that particular atom to individual species or guilds, and the home ranges or migration paths of the animals, emphasizing the role of the focal atom not just as habitat but in maintaining landscape connectedness. The recreation molecule includes all atoms linked to the focal atom by trails, roads, or streams, with some consideration for viewsheds.

The critical point is that each atom is simultaneously in multiple-overlapping, but not nested, molecules, each defined by a specific ecological process or resource use. The molecules are highly variable in size and shape, with their distribution and boundaries again determined by ecological processes or resource uses. Whether or not two particular atoms in a landscape are part of the same atom depends on the process under consideration, not on proximity or adjacency. This suggestion is completely at odds with the current preference for nested hierarchical units, designed to mimic traditional taxonomic classifications (Avers et al. 1993, Bailey 1980, McNab and Avers 1994). For the reasons outlined above, I believe that nested hierarchical units will not work, and I realize that this is likely to be the most controversial element of my recommendations.

DIFFUSE ENTITIES

The effect of a change in an atom on the diffuse entities is determined by their response to the change in all associated molecules. For example, change in the vegetation of one atom will affect animal species by:

- direct effect of change on animal habitat
- indirect effects of change on habitat for potential predators or prey
- change in landscape connectedness as it affects corridors and barriers to movement.

Managing diffuse entities directly will affect the range of molecules with which they interact. For example, when changing the population size of a specific herbivore:

- The vegetation molecule includes all atoms likely to experience significant changes in vegetation structure or composition resulting from change in the herbivore.
- The biodiversity implications include the direct effects of the population change as well as the indirect effects from the change in vegetation within the vegetation molecule.

INFORMATION NEEDS AND TECHNOLOGICAL REQUIREMENTS

To implement ecosystem management in the manner I am recommending, a number of specific information needs must be met, and a significant amount of work on information analysis will have to be performed.

All areas within the largest boundary must have sufficient information to determine their atom type. Thus, there can be no missing pieces within the landscape, where a critical component of the definition of atoms is lacking. It is better to have comprehensive, qualitative, extensive information than detailed isolated information. This element of the information need I refer to as the need for homogeneity of detail in information.

We have insufficient manpower and money to perform the field-based inventory required to obtain the homogeneous data bases we require. Consequently, we will have to rely on statistical predictive models of resource distribution linked to GIS systems to achieve the homogeneity of data required. Considerable research effort will have to be expended in the design and testing of suitable predictive modeling approaches, including intensive field validation of prediction accuracy. Roberts and Cooper (1989), Lees and Ritman (1991), and Moore et al. (1993) discuss a range of useful techniques for this effort.

I have indicated a preference for a land systems-based ecosystem classification as most appropriate for ecosystem management. Whatever system is selected, it must be completed as soon as possible as it represents the basic information layer from which all management information must be abstracted. Given the work to date, however, I believe that it should be relatively easy to achieve this goal. Barnes and colleagues have demonstrated an extremely useful approach, but it remains to generalize the approach to areas with less site-specific data, or more general data such as collected by remotely sensed imagery or generated by predictive models.

We need mechanistic models of succession, disturbance response, and management response for all elements. I emphasize mechanistic models, as opposed to empirical models, as we will be required to predict the response of systems that have never been observed before to stimuli that perhaps have never been considered before. These models must calculate structural, compositional, and functional responses of the ecosystems. While the models should be comprehensive, they need not be highly detailed. For succession, we are in relatively good shape, and have a number of candidate, prototype succession models to evaluate. Work by Steele (1984), based on previous work by Huschle and Hironaka (1980), provides a strong basis for development of such a system. Roberts and Morgan (1989) describe a range of development issues based on these and similar models, and Roberts (1995a, 1995b) demonstrates the use of these models in spatially-explicit landscape simulation incorporating variable disturbance regimes. For broad-scale disturbance and management response we are in less good shape. Models which predict ecosystem response to fire, insect infestation, and pathogen outbreak are only in the initial stages of development.

The ecosystem dynamics models must retrieve data and display results on a spatially-explicit basis, with direct links to the GIS. Whatever databases are developed must reside in the GIS, and the predictive models we develop must use these data as the basic inputs in calculation. This implies, of course, that any information required by the models must be universally available. With respect to this issue, we are in pretty good shape for the basic vegetation and ecosystem dynamics models, but in very poor shape for the diffuse entities. How a herd of herbivores affects ecosystems in a spatially explicit manner, for example, requires the integration of animal behavior and foraging models with the vegetation and topographic elements of the GIS. We need to develop the conceptual models of how processes link specific locations across the landscape. I have previously given a few examples in outline, but the specifics of spatial integration of ecological processes are still largely unknown. Given these conceptual models, we need to develop computer algorithms which mimic the conceptual models, and implement the mechanisms of the conceptual models on data contained in the GIS. While we are struggling with the first objective, we are in our infancy with regard to the second. Significant amounts of research are required before we can tackle these problems for real ecosystems and landscapes of the size required to implement ecosystem management.

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