LANDSCAPE AND URBAN PLANNING

Landscape and Urban Planning 40 (1998) 131-139

The role of fish, wildlife and plant research in ecosystem management

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Abstract

This paper examines the concepts of ecology, ecosystems, and ecosystem management and then further examines the role of fish, wildlife, and plant ecology research in ecosystem management, past, present, and future. It is often assumed that research in support of ecosystem management will entail comprehensive studies of entire ecosystems whereas research programs that focus on one species do not constitute ecosystem management level research. The supposed dichotomy between single species and ecosystem level approaches has been the focus of considerable debate. However, this is a false dichotomy and ecosystem studies and single-species studies simply represent two ends of a spectrum of approaches for understanding ecological processes. Given that the level of scientific investigation (e.g., individual species, community, or ecosystem) does not differentiate ecosystem management research from more traditional approaches, what are the distinguishing features? Ecosystem management research is broader in scope than more traditional ecological studies. A greater emphasis is also placed on integrating results of various studies and programs to understand larger scale interactions and the structure and function of ecosystems. Model building also plays a greater role in ecosystem management research efforts as a means of not only understanding ecosystem processes but also as a means of generating hypotheses. Although the primary responsibilities of research and management are different, there is much room for interaction and integration of functions. Consequently, adaptive management has become an important part of ecosystem management and will likely become a larger part of basic research programs. However, adaptive management experiments should not be the endpoint. Instead, results from adaptive management studies should be used to generate hypotheses that can be tested with more traditional and rigorous scientific methods. As managers begin to deal at larger spatial and longer temporal scales changes in the end-products of research will be necessary. The task of assessing present as well as future conditions will greatly increase the need for user-friendly analytical tools (e.g., simulation models) that allow managers to visualize conditions on a large scale. A balance of adaptive management and traditional experimental designs will ultimately lead to better models of management. © 1998 Elsevier Science B.V.

Keywords: Ecosystem management; Adaptive management; Fish, wildlife and plant research

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0169-2046/98/$19.00
PII S0169-2046(97)00105-9

1. Introduction

Recently, many ecologists and resource managers have suggested that an ecosystem approach is necessary to effectively manage and sustain our forests and grasslands for a variety of resources, including biodiversity and products (e.g., Behan, 1990; Franklin, 1993; Kessler et al., 1992). Scientists involved with fish, wildlife, and plant ecology research programs have long used ecological approaches in their investigations of biodiversity, species conservation, and fish and wildlife management. However, even to many researchers in this area, it is not clear how ecosystem management, the new ecosystem approach recently taken by the US Government, is to be implemented, either from a research or management perspective. Further, what is the role of fish, wildlife, and plant ecologists who normally focus on species level research in ecosystem management'? The goal of this paper is to examine the concepts of ecology, ecosystems, and ecosystem management and then further examine the role of fish, wildlife, and plant ecology research in ecosystem management, past, present, and future.

In its most general form, ecology is the study of the interrelationships between organisms and their biotic and abiotic environment (Ricklefs, 1976). Ecologists often describe themselves as physiological ecologists, behavioral ecologists, population ecologists, community ecologists, or systems ecologists, depending on the level of interactions being investigated. However, no matter what the level of interaction, it must always be remembered that each level is influenced by (and influencing) interactions and processes at the other levels. In other words, all levels of ecological research are conducted within the context of an ecosystem. An ecosystem, as first defined by Tansley (1935), is ''. the whole *system* (in the sense of physics), including not only the organism complex, but also the whole complex of physical factors forming what we call the environment-the habitat factors in the widest sense." One of the more important concepts in ecosystem science is that of the transfer of energy and matter within the system (Whittaker, 1975).

Although ecosystems are physical entities, delineating specific boundaries around them is often difficult. No system is completely closed so that there is some transfer of energy and matter between ecosystems as well as within. Further, the interface between two systems may also be of importance or interest (e.g., the interface between a forest and lake): thus, it may even be neither desirable nor productive to define boundaries.

If ecosystems cannot be explicitly delimited, how can they be managed'? Pomeroy et al. (1988) suggest that, "the truly holistic study of the ecosystem brings together ecosystem and population processes as a continuum of functional response to changing conditions." Thus, understanding ecosystems entails knowledge of ecological processes at all levels, from the individual to the system (including interactions among systems). Managing ecosystems entails sustaining these ecological processes.

The reason a multi-faceted or ecosystem perspective is needed is simple. Continued growth in human populations and increases in their production, use and disposal of resources are not matched by corresponding growth in the land base available to meet those demands under traditional resource management approaches while sustaining desired levels of environmental quality (Szaro et al., 1996). The USDA Forest Service translated these issues into four reasons for exploring ecosystem management (Overbay, 1992): (1) people need and want a wider array of uses, values, products, and services from public lands than in the past, especially, but not limited to, the amenity values and environmental services of healthy, diverse lands and waters; (2) new information and a better understanding of ecological processes highlight the role of biodiversity as a factor in sustaining the health and productivity of ecosystems and the need for integrated ecological information at various spatial and temporal scales to improve management; (3) people want more direct involvement in the process of making decisions about public resources; and (4) the complexity and uncertainty of natural resources management call for stronger teamwork between scientists and resource managers than has heretofore been practiced.

The USDA Forest Service has made a commitment to take an ecological approach to the multiple-use management of the National Forests and Grasslands of the United States. Knowledge and understanding of the ecological processes at various spatial and temporal scales will be used to produce desired resources. products. and services while maintaining the diversity and productivity of the ecosystem (Overbay, 1992). The principles of ecosystem management include: (1) sustainability of ecological processes. including biodiversity, population viability. and productivity of the soil; (2) a consideration of the dynamics and complexity of ecological processes in providing options for the future; (3) a consideration of the ecological, social, and economic factors when describing desired future conditions; (4) cooperation and coordination across administrative, jurisdictional, and ownership boundaries; (5) the use and maintenance of accurate and accessible databases and analytical tools for land management; and (6) greater integration of research and management to provide the necessary scientific data to successfully manage in an ecological manner. Ultimately, managers using the ecosystem management approach will consider the biological (e.g., diversity of plants and animals), economic, and social factors affected by various management alternatives and base their decisions on joint constraints.

Management of ecosystems will entail not only a change in the range of considerations, but also a change in scope. When dealing with ecosystems the major factors to consider are the interactions of species and the flow of energy and matter. These phenomena are likely to have far greater spatial scales and be far more difficult to delineate than the units we have traditionally dealt with (e.g., stands and compartments). Thus, our focus will have to shift from units of land to units of interactions. However, the information and tools to deal with these new challenges are not readily available. Providing the scientific data and predictive models to aid in making decisions concerning animal and plant viability and diversity at larger temporal and spatial scales will be a crucial role for fish, wildlife, and plant ecology researchers in the future.

2. Research and management-their respective roles

The goal of research is to learn about the world through a process of observation and scientific inquiry (i.e., testable hypotheses, valid experimental designs, appropriate data analysis, interpretation) and to predict or model how the system will respond to perturbations and successional change. The role of management is to manipulate the system for a desired outcome. Social and economic considerations are only important in the initial stages of ecological research, particularly in setting the direction and scope of research programs. In contrast, social and economic considerations influence almost every stage of the management process and help to determine the shape of the desired future condition.

Although the primary responsibilities of research and management are different. there is much room for interaction and integration of functions. When researchers collect data that are relevant to management problems, they must transfer the information and technology in a timely and useable manner. For their part, managers must communicate their information needs to researchers. As managers begin to deal at larger spatial and temporal scales, the information needs are likely to become far more complex. Thus, it will be necessary for managers to determine their information needs early in the process.

Due to the spatial and temporal scales of many ecosystem management questions, it may not be possible to conduct traditional experimental studies to arrive at timely answers with sufficient levels of confidence. Instead, we may have to proceed with management strategies despite some level of uncertainty about the outcomes. If the responses to management are closely studied and evaluated, the management strategy can be adjusted in accordance with the new data.

This is what is known as ‘adaptive management’, an integrated research/management program with continuous feedback loops to progress from one management strategy to sequentially improved strategies based on new data (Walters and Holling, 1990). However, adaptive management entails more than simply monitoring and evaluating existing management strategies. Instead, alternative management strategies are generated, hypotheses about the outcome of implementing these strategies are developed, and the relative risks and benefits of employing the alternatives strategies are estimated and evaluated. Further, it is often assumed that adaptive management experiments do not require replication and control. The design of adaptive management experiments, although different from traditional scientific designs, is still critical and the ability of these experiments to provide meaningful data is dependent on their design (Walters and Holling, 1990). As in most research programs, the initial stages are the most critical. However, in the initial stages of adaptive management experiments it is also critical to have the joint input and interaction of researchers and policy makers.

Although much of the research associated with ecosystem management will focus on specific management problems, the important role of basic or fundamental research program cannot be forgotten. Clearly, this will require improving our understanding of the structure and function of ecosystems through long-term basic research on ecological processes at a variety of spatial and temporal scales. Thus existing Long-term Ecological Sites (LTER) supported by the National Science Foundation will become even more valuable and new sites may need to be established in areas where they are lacking. Much of the data collected from the basic research programs can provide a baseline for evaluating new management strategies. Furthermore, basic research programs allow scientists to predict future problem areas and alert managers. In this way, scientists conducting basic research can play a proactive role.

3. Approaches to ecosystem management research

It is often assumed that research in support of ecosystem management will entail comprehensive studies of entire ecosystems whereas research programs focused on one species do not constitute ecosystem management level research. The supposed dichotomy between single species and ecosystem level approaches has been the focus of considerable debate (e.g., Franklin, 1993, 1994; Tracy and Brussard, 1994). However, this is a false dichotomy and ecosystem studies and single-species studies simply represent two ends of a spectrum of approaches for understanding ecological processes (Wilcove, 1994; Jones and Lawton, 1995). Both approaches are valid and both have their advantages and disadvantages.

Forest ecosystem level studies, by definition, are large, comprehensive, and entail large commitments of time and money from both scientists and supporters. Most studies are interdisciplinary and thus, require a great deal of coordination. One of the most crucial steps in designing ecosystem studies is definition of the spatial and temporal scales of investigation (Shugart and Urban, 1988). When these are not clearly defined and matched among studies, the program is likely to fail and will not be truly interdisciplinary in nature. In contrast, well coordinated and planned ecosystem-level research programs can provide a wealth of data on ecosystem processes, Two excellent examples of successful ecosystem level research programs are those that have been conducted at Coweeta Experimental Forest in North Carolina (Swank and Crossley, 1988) and the Hubbard Brook Experimental Forest in New Hampshire (Likens and Bormann, 1995). The many integrated studies conducted at these sites have contributed greatly to our understanding of energy and nutrient flow in forested ecosystems.

Ecological studies of individual species can also add a great deal to our understanding of ecological processes and ecosystem function, particularly when the species is a 'keystone' species (a species with which a large number of other species interact or depend) or a top predator. Because these species have a large number of ecological links to other species, comprehensive investigations result in the acquisition of much additional data on other species, interactions, and processes within the system.

The Northern Spotted Owl Conservation Strategy (Thomas et al., 1990) prepared by the Interagency Scientific Committee clearly illustrates how a great deal of knowledge about the structure and function of an ecosystem can be attained from focusing on one species. Studies of northern spotted owls have resulted in investigations on the mammalian prey base, fungi and lichens (a major food source for many of the prey), large woody debris, and habitat patch dynamics. The Scientific Analysis Team further examined ecological processes and interactions within the old-growth ecosystem of the Pacific Northwest by analyzing the effects of the Northern Spotted Owl Conservation Strategy on 328 species or taxa within the system including 38 plant species, 149 invertebrates, 112 fish stocks, 12 amphibians, nine birds, and eight mammals (Thomas et al., 1993).

The large-scale geographic and multi-resource approach taken by the Northern Goshawk Scientific Committee is another example of a single-species focus with ecosystem-level implications (Reynolds et al., 1992). Because the northern goshawk can best be managed by creating the conditions that provide for the foraging, nesting, and landscape requirements of the goshawk and its prey (14 commonly eaten species of birds and mammals and 36 less commonly eaten species), the management recommendations essentially outline the elements of a healthy, functioning, southwestern forested ecosystem. Recommendations deal with a large array of resources including soil productivity, fire, large woody debris, microorganisms, small birds and mammals as well as specific recommendations concerning the goshawk.

Research on Pacific salmon in Southeast Alaska is another excellent example of 'single-species' research that has led to our understanding of a multi-species complex (Meehan, 1991). Pacific salmon constitute a major food resource for many fish and wildlife species. Birds (e.g., dippers and gulls) and fishes (e.g., Dolly Varden charr) feed on salmon roe whereas herons, kingfishers, mink, and other salmonids feed on young salmon. Spawning runs of salmon attract many wildlife species including at least three species of gulls, crows, ravens, bald eagles, and bears that congregate on streams and forage on mature and/or dead and dying adults. Studies of these freshwater/terrestrial interactions have generated several hypotheses about the importance of salmon to wildlife (Willson and Halupka, 1995). For example, salmon probably constitute a readily harvested food resource for recently fledged eagles and may contribute significantly to their survival in the early weeks and months of their live outside the nest. Another hypothesis is that salmon provide a critical resource for bears which require large amounts of food to prepare for hibernation and that the reproductive success of female bears may depend, in part, on plentiful supplies of salmon.

4. What is ecosystem management research?

Given that the level of scientific investigation (e.g., individual species, community, or ecosystem) does not differentiate ecosystem management research from more traditional approaches, what are the distinguishing features? To some degree, all ecological research has relevance to ecosystem management. However, ecosystem management research will be broader in scope than more traditional ecological studies. For example, scientists interested in addressing ecosystem management issues in their research are more likely to ask questions about population processes than autecology, population viability than population dynamics, and between patch dynamics than within patch dynamics (e.g., landscape level questions). A greater emphasis will also be placed on integrating results of various studies and programs to understand larger scale interactions and the structure and function of ecosystems. Model building will also play a greater role in ecosystem management research efforts as a means of not only understanding ecosystem processes but also as a means of generating hypotheses.

For example, early studies on red-cockaded woodpeckers examined basic autecological questions such as cavity tree and stand selection. While these studies have been very important in understanding the habitat relations of red-cockaded woodpeckers, long-term (10–15 years) demographic studies conducted on the Francis Marion National Forest and in the Piedmont of Georgia have been crucial to understanding the relationship between habitat quality and population dynamics (Kulhavy et al., 1995). Similarly, although many studies have documented the relationship between northern spotted owl density and habitat quality (e.g., Bias and Gutiérrez, 1992; Mills et al., 1993), the long term demographic studies (e.g., Franklin, 1992) that have been conducted have provided the data necessary to detect population trends. Further, data from these demographic studies have been used to develop models of population dynamics (e.g., Noon and Biles, 1990) which allow researchers to determine the life history stages that have the greatest influence on population growth rate and subsequently, allow managers to focus their activities on factors that affect these vulnerable life history stages.

Population viability analysis takes demographic studies to the next step. In addition to understanding how variation in demographic parameters contributes to population increase or decline, population viability analysis also considers environmental variability, genetic variability, and chance catastrophic events to predict the probability of population extinction under various management schemes (Gilpin and Soule, 1986; Shaffer, 1981). Thus, population viability analysis integrates the social, demographic, habitat, and landscape factors of a species' biology over a relatively long (100–200 years) time scale. For example, population viability analyses developed were used extensively in designing the Habitat Conservation Areas which are the basis for spotted owl conservation (Murphy and Noon, 1992).

One of the greatest differences between ecosystem management and previous management approaches is the emphasis on managing the land at a larger spatial scale. Managing each stand as if it was an isolated and autonomous parcel of land is obviously not consistent with ecosystem management. Some of the impetus to take a broader approach to management has come from concerns about the effects of forest fragmentation on biodiversity (Gavin, 199 1; Harris, 1984; Noss and Harris, 1986). As habitat patches become smaller and more dispersed, the size of the populations they are able to support decreases, thus increasing the chance of local population extinction. Other problems associated with fragmentation include edge effects and patch isolation which may affect the ability of organisms to recolonize depopulated patches and affect genetic diversity if gene flow becomes limited. Finally, because of the interchange of energy and matter between patches, activities on one patch of habitat may have effects on surrounding patches through changes in the rates and amount of material flow among patches.

Population processes at the landscape level have been the focus of many recent investigations of the impacts of forest management practices on forest bird populations. For example, simulation models, which incorporate the pattern of various age classes across the landscape, bird sensitivity to patch age and edges, and demographic processes, have also been developed to predict landscape level changes in forest interior bird populations resulting from long term application of different forest management practices (Thompson, 1993). Some of these patterns have also been verified by landscape level field research (Thompson et al., 1992). Further, landscape and regional patterns have been examined to determine how they affect the density and distribution of brown-headed cowbirds, an avian brood parasite (Thompson et al., 1993). Regional and landscape level patterns in land use may impose important 'top–down' constraints on neotropical migratory bird populations at the habitat or stand level through their effects on regional coubird and predator numbers. This top-down, multiple-scale approach has been used to develop recommendations for integrating timber harvest and neotropical migratory bird conservation.

5. Adaptive management-the application of ecosystem management research

Ecosystem management calls for close interaction between Research and Management. For many years, many fish, wildlife, and plant research ecologists have worked closely with managers on National Forests and Grasslands as well as other agencies such as the Bureau of Land Management and the Fish and Wildlife Service. However, as the importance of scientific data as a basis for policy decisions grows, scientists are playing ever increasing roles in management decisions. The Interagency Scientific Committee's 'A Conservation Strategy for the Northern Spotted Owl' (Thomas et al., 1990). 'The California Spotted Owl: A Technical Assessment of Its Current Status' (Vemer et al., 1992), and 'Management Recommendations for the Northern Goshawk in the Southwestern United States' (Reynolds et al., 1992) are all illustrations of scientists consolidating the existing data to help make management decisions.

Recognizing the need for these assessments on a much larger scale, Forest Service scientists and managers worked together to develop Inter-Regional Habitat Conservation Assessments. The Inter-Regional Habitat Conservation Assessments address sensitive species needs within wide geographic distributions and will be used to design and coordinate management across Forest and Regional boundaries. Teams of scientists produced comprehensive, state-of-knowledge documents that describe the species' population status and trends, habitat requirements, and limiting factors as well as discuss management considerations. Assessments were prepared for the Californian spotted owl, northern goshawk, furbearers, forest owls, bull trout, salmon and stealhead, cutthroat trout, and marbled murrelets (Hayward and Vemer, 1994; Ralph et al., 1995; Ruggiero et al., 1994; Vemer et al., 1992; Young, 1995). These assessments represent the first phases of adaptive management: assembling the data. assessing the problem. developing alternative models, and assessing the uncertainty. Once a management plan is agreed upon and implemented, researchers will collect and collate the data to evaluate and adjust the management plan and its implementation.

One of the best examples of adaptive management at work occurred on the Francis Marion National Forest after Hurricane Hugo in 1989. Prior to the hurricane, the population of endangered red-cockaded woodpeckers on the Francis Marion National Forest was the second largest extant population and considered crucial to the recovery of this species. However, Hurricane Hugo killed 63% of the birds and destroyed 87% of the cavity trees on which they depend (Hooper et al., 1990). Cavities take several months to several years for the birds to complete and most of the potential cavity trees had also been destroyed by the hurricane. Thus, it was thought that the population was likely to decline even further without some intervention. Two new technologies to create artificial cavities for the birds had recently been developed by researchers but not tested to any extent. Thus, there was a great deal of uncertainty as to whether the birds would utilize them and which technology, if either, was superior. However, because of the birds reliance on cavities for survival and reproduction, a plan was developed jointly by researchers and managers whereby cavities were created utilizing both techniques and a study to monitor the use and response of the birds to cavities was initiated (Watson et al., 1995). Subsequently, the techniques to create and install artificial cavities have been modified and improved (e.g., Taylor and Hooper, 199 1). Based on the initial positive response of the birds to the artificial cavities, the techniques are now being used on National Forests, National Wildlife Refuges, and State Forests throughout the Southern United States to increase the populations of birds in areas where potential cavity trees are limiting (see Kulhavy et al. (1995) for examples).

6. Future directions and conclusions

To fully support ecosystem management, some changes or additions to US Government-sponsored research emphases will be necessary as will some adjustments in research approaches. Two on-going areas of research, population viability research and research on landscape or regional level processes, are directly related to ecosystem management. Viable populations are the cornerstone of sustainable ecosystems and methods to assess and maintain viable populations are needed. Models of population viability incorporate data on all aspects of a species biology including habitat requirements, demography, genetics, interspecific interactions, and the effects of large scale landscape patterns on the population. These models are still in their infancy and have only been developed for a few species. Because of the large amount of data needed to generate these models and the long-term nature of much of the data (e.g., demographic data), concerted and multi-disciplinary efforts must be established soon to develop new and more sophisticated models.

Changes in the end-products of research and in our approach to research may also be necessary. These include increased interdisciplinary efforts and greater involvement in adaptive management projects. Research on ecosystem management should focus on providing the technological advances and new scientific information essential to meeting current and future resource needs (Szaro et al., 1996). Even questions at the species or community level will necessitate more interdisciplinary research. For example, viability analysis will require expertise in autecology, demographics, population genetics, mathematical modeling, spatial statistics, and GIS as well as other disciplines depending on the organism. As studies begin to address broader questions such as ecosystem function, the role of interdisciplinary work will become even more critical. However, no matter what the organizational level, coordination and planning among investigators in the various disciplines is crucial.

Adaptive management is an important part of ecosystem management and will likely become a larger part of basic research programs. However, adaptive management experiments should not be the endpoint. Instead, results from adaptive management studies should be used to generate hypotheses that can be tested with more traditional and rigorous scientific methods. Results of these studies should then be used to design the next iteration of adaptive management alternatives. A balance of adaptive management and traditional experimental designs will ultimately lead to better models of management. The process of designating northern spotted owl Habitat Conservation Areas is an excellent example of the use of iterative planning, hypothesis testing, and re-planning to produce a scientifically credible conservation plan (Murphy and Noon, 1991, 1992).

To truly manage at the ecosystem level, the spatial and temporal scales that we have traditionally worked at must be increased. We must consider size, shape, connectivity, and context of habitat patches as well as the diffusion dynamics at their boundaries. As managers begin to deal at larger spatial and longer temporal scales, the task of assessing present as well as future conditions will greatly increase. Therefore the need for user-friendly analytical tools (e.g., simulation models) that allow managers to visualize conditions on a large scale will become essential. One of the biggest obstacles to managing at the ecosystem level will be the definition of the appropriate landscape. This is not a matter of ecosystem classification, although ecosystem classification and GIS will be important tools in this research. Instead, it is a question of scale and methods to define the appropriate scale needed for each management objective. However, management objectives (also termed by many as desired future conditions) are ultimately set by humans. Therefore, these methods will involve determining how the interactions within and between ecosystems vary with scale and human influence and should provide the keys to managing sustainable ecosystems in the future.

Acknowledgements

We are grateful to the many scientists who contributed to this paper in various ways including discussing their ideas on ecosystem management, making us aware of relevant research, and reviewing previous drafts. We thank J. Fenwood, D.M. Finch, D. McArthur, B.R. Noon, R. Tausch, F.R. Thompson, J. Vemer, and M.F. Willson for their many contributions.

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