**Managing Forests as Ecosystems:
A success story or a challenge ahead?**

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Abstract. To manage forests as ecosystems, the many values they hold for different users must be recognized, and they must be used so that those assets are not destroyed. Important ecosystem features of forests include nutrient cycling, habitat, succession, and water quality. Over time, the ways in which humans value forests have changed as forest uses have altered and as forests have declined in size and quality. Both ecosystem science and forest ecology have developed approaches that are useful to manage forests to retain their value. A historical perspective shows how changes in ecology, legislation, and technology have resulted in modern forest-management practices. However, current forest practices are still a decade or so behind current ecosystem science. Ecologists have done a good job of transferring their theories and approaches to the forest manager classroom but have done a poor job of translating these concepts into practice. Thus, the future for ecosystem management requires a closer linkage between ecologists and other disciplines. For example, the changing ways in which humans value forests are the primary determinant of forest-management policies. Therefore, if ecologists are to understand how ecosystem science can influence these policies, they must work closely with social scientists trained to assess human values.

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*“There is as yet no ethic dealing with man’s relation to land
and to the animals and plants which grow upon it. “*

Aldo Leopold, 1949

I. Introduction

Almost 50 years after Leopold’s writings, a forest ethic is still not in place. Such an ethic would serve as a guide for managing forest resources under diverse conditions. In the same sense that social ethics include a responsibility to “do the right thing,” a forest ethic would set the standards used by both private and public landowners in protecting the diverse values of forests. Leopold’s viewpoint clearly defines the role of ecologists: they can convey to forest managers the ecological principles upon which such a standard is built.

This paper considers the benefits imparted to forest management by using ecological information. First, the management goals are set forth by discussing forest attributes that people value. The implementation of forest practices is influenced not only by changes in ecological understanding but also by legislation and technology developments. Therefore, ecological, legislative, and technological changes relevant to forest management are considered together. Next, ecological principles used in forest management to retain the valued attributes are discussed. Finally, future challenges for managing forests as sustainable ecosystems are proposed. Throughout this discussion, impacts that forestry itself has had upon ecological thought and research are mentioned.

II. Attributes of Forests that People Value

Managing forests as ecosystems requires an awareness of the diverse attributes of forests and how they relate to human values. The benefits from forests are many. Forests serve as watersheds that

provide purified water for rivers, streams, and municipal use. Forests are important habitats for wildlife. Dry forests have widely spaced trees interspersed with grass and shrubs that serve as grazing lands. Forests offer many recreational opportunities, including hiking, camping, hunting, and fishing. Some people value forests for their beauty and the spiritual experience they provide. Trees also supply the raw materials for paper, building supplies, furniture, and pharmaceutical supplies. Finally, forests are a critical part of the global carbon cycle, for trees store large amounts of carbon in their tissue and, in mass, provide the largest storage site for terrestrial carbon (Post et al. 1990). When the carbon cycle is out of balance, it can instigate global changes in temperature and precipitation.

Although an economic benefit relates to some of these forest attributes, considering only the monetary aspects of the forest is unsatisfactory. Even in the 1940s, Leopold discussed the difficulty of putting a value on forests other than in an economic sense. He argued that many of the benefits arising from the natural interconnectedness of the environment are not appreciated until they are lost or at risk. Indeed, a gradual and largely unnoticed loss of forest-ecosystem components frequently occurs until a threshold is reached at which point these losses impact human values. Once a threshold is reached, people cry out for a return to a system that provides some of the benefits that are now in jeopardy. This possibility of going beyond the threshold was best made clear in a science fiction book entitled *The Word for World is Forest* by Ursula LaGuin. In this novel, the forest is so valuable that it actually becomes the name by which the planet is called. In the book, interplanetary expansion and the need for wood products decimates the forest and diminishes the life that is dependent upon the diverse attributes of the forest. This novel may not be far from one future path that Earth could proceed along. To avoid this possibility, ecologists argue for a long-term perspective on the use and value of forest resources.

Too often, however, no short-term impact of these gradual losses of forest attributes is obvious. People can substitute one organism for another, or may synthesize a pharmaceutical product that formerly came from a forest plant or animal. But lost ecosystem properties, aesthetic qualities, or spiritual attributes may be more difficult to mimic. Moreover, forest ecosystems provide and protect water quality, water yield, and habitats that support other flora and fauna. For example, the fungus-induced demise of the chestnut trees in the early twentieth century resulted in

the loss of not only timber but also seeds, which are an important food for squirrels and other forest fauna. In addition, it changed nutrient turnover from a system dominated by chestnut trees (which have high nutrient turnover rate of the leaves and slow nutrient turnover of woody tissue) to one just the opposite (the chestnut oaks that largely replaced the chestnut trees have slow nutrient turnover in leaves, and the wood decays rapidly). Because this replacement caused such a complex alteration in ecosystem properties, the full extent of the changes may never be known.

Forest-management policies reflect the changing values that people have for forests. Thus it is important to determine how the ways that humans value forests have changed over time. Throughout history, forests have served as a source of building materials and fuel and as habitat for game. As forests became scarce in Europe, commercial forestry arose as a means to assure a sufficient supply of wood and wildlife. One goal of forest management is to maintain sufficient quality, quantity, and diversity of wood products for commercial uses. Tree diversity is an important aspect of management because the qualities of individual tree species affect their use. For example, Port Orford cedar was preferred for venetian blinds and ship masts because of its strength when cut in long sections. Oak is preferred for floors because of its hardness. Douglas fir and pine make excellent structural material for buildings because they grow rapidly yet are strong. At any one time, the forest industry seeks to have sufficient wood of appropriate size, species, and quality available for each of its mills distributed across the country. About 130 years ago, wood became a source of pulp for paper. Since that time, many tree plantations have been established to meet the need for pulp. Recently, the value of maintaining species habitats and forest health (e.g., resistance from fire and insect outbreaks) has been reemphasized. Great strides have been made in recognizing the ecological values of forests and in communicating to public and private owners how to preserve these values (Swanson and Franklin 1992, National Research Council 1992, Salwasser 1990, Kessler et al. 1992, Franklin 1989). Yet there are still gaps. For example, the public does not do a good job of integrating the many attributes of forests, nor have ecosystem scientists adequately demonstrated the integration process (Naiman, in press). Also, because no single stand maintains all these values simultaneously, a coordinated effort between federal and state land holders, private forest companies, citizens, and citizen groups is necessary to maintain an appropriate balance of forest resources within a region.

Adaptive management of forest systems recently arose as a way to preserve diverse values amid complex forest ownerships. This approach monitors how environmental decisions affect forests by tracking such ecosystem attributes as trophic dynamics, succession, and nutrient cycling (Christensen et al. 1996). The management is adaptive in the sense that the lessons learned from past actions and their effects are used to guide future actions.

Monitoring forest attributes provides a challenge in itself. The USDA Forest Service in coordination with the Environmental Protection Agency (EPA) has monitored attributes meant to reflect the diverse values of forests, including the ecological perspective [as measured by EPA's Environmental Monitoring and Assessment Program (EMAP)] (Table 1) (Lewis and Conkling 1994). Despite the fact that these efforts were meant to cover a comprehensive range of ecological attributes, animal conditions in forests were largely ignored. Even so, the attributes included are too numerous and technical for the general public to grasp a basic understanding of them.

Therefore, how these ecological attributes relate to human values must also be determined. Russell et al. (submitted) are in the process of examining how human values relate to the EMAP forest metrics. They have identified dimensions that map between ecological indicators and human values (Table 1). These dimensions are both understandable to the public and focus on forest management goals. Research is currently underway that asks members of the public if the dimensions capture their values and to query trained ecologists to determine if the mapping strategy is appropriate. Results from interviews to date suggest that even people who have never been in the forest understand these dimensions and feel that they relate to forest values. However, the exact set and definition of such a set of dimensions are likely to vary by community and by communities' relations to forests. (How much of the community's economy depends on forest products? Do forests play a role in the religious beliefs of the community?) In addition, the importance of specific dimensions may vary over time as changes in ecological understanding, legislation, and technology occur.

III. The Influence of Changes in Ecological Understanding, Legislation and Technology on Forest Management

To understand a science it is necessary to know its history.

August Comte (1798-1857)

The ecological, legislative, and technological context in which forests are grown and used is illustrated in Figure 1. By considering changes in these arenas, one can gain a better understanding of the forces that influence forest use and the effects of those forces on forest ecosystems.

Ecological Advances

Great advances have been made this century in the ecological understanding of how forests grow and interact with their environment. The roots of this understanding go back to the introduction of plant geography between 1765 and 1812, which explored the relationship between the spatial location of a forest and environmental gradients. In 1840, Liebig presented what is now known as the *Law of the Minimum*, which states that the growth and distribution of a species is dependent on the factor most limiting in the environment. [This theory was later modified by Shelford (1913) and Good (1931, 1953) to acknowledge that limitations act in concert with one another]. The first ecological textbook was authored by Warming in 1895. Merriam's concept of life zones (1894, 1898) set the stage for considering environmental factors responsible for the elevational and latitudinal distribution of species. Shortly thereafter, work by Cowles (1911) and Clements (1916) led to an interpretation of succession as the gradual changes in species composition and site conditions that occur in the aftermath of a disturbance. Gleason's (1926) perceptions on succession were contrary to the individualistic notions of Clements and led Gleason to introduce the idea of plant associations, which formed the basis for the concept of the *ecosystem*, a term coined by Tansley (1939). The concept of environmental gradients and their effect on plant distribution was demonstrated by Whittaker (1956).

The International Biosphere Program (IBP) marked an intense focus on biome properties that stretched from 1960 to 1974 (e.g., Van Dobben and Lowe-Connell 1975, Levin 1976, Waring 1980, O'Neill et al. 1975). Experimental forests were established and monitored that demonstrated the intricate ecological relationships within an entire watershed (Bormann and Likens 1981). The

large amount of data collected and analyzed during this period was complemented by a set of ecosystem models that were developed and exercised to assess the major components and interactions of ecological systems. The area of systems ecology arose from the understanding that resulted from these efforts. Forest-simulation models were developed that considered various factors affecting forest growth and development (Botkin et al. 1972). The IBP also stimulated research in evolutionary ecology and plant demography.

During the past two decades several new directions in ecological analysis have arisen. Landscape ecology, for example, focuses on the spatial relations of sites and considers the size, shape, and location of ecosystems (Foreman and Godron 1986, Turner 1989, Turner and Gardner 1991). This perspective forces ecologists to consider more than just natural systems. The large spatial context of landscape ecology requires an acknowledgement of the role that anthropogenic influences have had on shaping the landscape.

More recently, the concept of a sustainable biosphere (Lubchenco et al. 1991) has led ecologists to consider ways in which human actions can result in the long-term viability of an ecosystem and the planet. The more general need to protect the habitats of species that may become at risk led to the development of *ecosystem management* as a tool to consider the diversity of resources within a forest (FEMAT 1993, Christensen et al. 1996, Slocumbe 1993). The basic concept of this approach is to maintain the critical functional aspects of the forest and riparian systems. These practices are now being adopted by the Forest Service and lead to a holistic view of forest values and management practices. Today's resource managers are challenged to implement successful ecosystem management (Carpenter 1996).

Legislative Changes

At the same time that ecological understanding was advancing, changes in legislation pertinent to forests was occurring. Steps to preserve and manage federally owned forests arose from the growing conservation movement. Although forest reserves were set aside in the United States as early as 1891, the establishment of the USDA Forest Service in 1905 marks the formal start of forest management and the establishment of national forests.

Gifford Pinchot brought the German traditions of forestry to the United States, where he was

instrumental in establishing the USDA Forest Service and became the first chief. The multiple forest uses that Pinchot instilled into the Forest Service are still maintained and provide the underlying justification for having wilderness, recreation, and timber-management areas in the Forest Service lands of today. Yet, in many cases, noncommercial tree species are not recognized as valuable ecological members of the forest community; nor has there been long-term promotion of the nonmonetary value of forests (e.g., building soils).

During the twentieth century, a steady stream of legislation provided the means to establish and manage federally owned forests. The Weeks Law of 1911 authorized purchase of forests that serve as watersheds for important rivers. In 1924, the Clarke-McNary Act expanded forest management to include fire protection and permitted the purchase of land for timber production. The Forest Pest Control Act of 1947 provided federal cooperation for states and private landowners to manage insect pests and diseases. The Multiple Use-Sustained Yield Act was passed in 1960 to require national forests to produce a sustained yield of timber while protecting other forest resources (reflecting some of Gifford Pinchot's goals for forest management). In 1964, the Wilderness Act was passed, which preserves wilderness areas within national forests where no road or buildings may be built and timber harvest is prohibited. Because of numerous controversies that arose over the use of clear-cutting, the Forest and Rangeland Renewable Resources Planning Act of 1974 established procedures for the review and management of forests. In 1976, the National Forest Management Act and the Federal Land Policy and Management Act focused attention on the need to manage riparian areas (Gregory 1997).

Two laws that are generally applicable have greatly influenced forest-management practices on federal lands. The National Environmental Protection Act (NEPA), passed in 1970, requires formal review before changes can be made on federal lands. The Endangered Species Act, passed in 1973, requires protection of threatened and endangered species. Legal actions to protect the red-cockaded woodpecker and the spotted owl have dictated forest-management practices in forests containing those species. Basically, in some locations the forest managers must retain the forest structure necessary for these rare and endangered birds. Although these legal actions only pertain to sites where rare species occur, they have implications for forest management in general. In the case of the forests in the U.S. Pacific Northwest, a process has emerged that bases the

management plan on socioeconomic values as well as ecosystem attributes of the forest (FEMAT 1993). This process involves deliberation between the interested parties and consideration of the spatial locations of forests of particular interest for specific values (Shannon 1997). For example, some locations are critical for timber harvest because of their location relative to sawmills. Other forests may have the old trees and large enough area to be important habitat for spotted owl.

The same conservation movement that spawned protection and management of federally owned forest also promoted responsible management of state and private forest lands. Between 1890 and 1917, state forest agencies were established, forest research and educational institutions were put in place, and pest-management programs were organized (Irland 1982). Beginning in the late 1940s, increased housing and business development have threatened some suburban forests. But the new conservation movement of the 1960s sparked an emphasis on open space. The Land and Water Conservation Fund and the beautification programs established under Johnson's administration brought a new interest in forest acquisition for recreation and conservation. Beginning with the Oregon Forest Practices Act of 1972, some states have implemented laws regulating forest practices on state and private lands that provide some riparian protection and a diversity of criteria for forest management that varies from state to state (Gregory 1997). The adoption of a state forest-protection law is currently under debate in other states (e.g., Tennessee).

Today there is a conflict between the rights of private landowners and federal and state laws, epitomized by the Wise Use movement. Some private landowners feel that their management should be entirely open-ended, yet federal and state regulations may restrict some actions (e.g., in the case of wetlands). Again, this conflict is an arena in which ecological knowledge can contribute to development of a land-use ethic that would guide the standards used by landowners in protecting the diverse values of forests

International trade practices and regulations also affect forest practices within countries. For example, the concern for using wood that has been harvested from sustainable plantations rather than from old growth has led for a need to define and certify sustainable-forestry practices. Also, forests and biodiversity issues received much attention as a part of the 1992 U.N. Conference on the Environment and Development (UNCED), which resulted in a number of instruments,

including the Conventions on Climate Change and Biological Diversity and the Statement of Forest Principles. These agreements all reflect concern for the sustainable use and management of biodiversity in forests and put international pressure on developing a means of determining the diversity of forests and estimating potential effects of specific management policies (Stork et al. 1997).

Technological changes

Technological advances have influenced what laws could be put in place and which aspects of ecological systems could be analyzed. In the early 1900s trees were cut by hand; horses or mules removed the logs from the forest, and rivers often provided long-distance transport (Karamanski 1989). Today's logging operations rely on machines. Paper mills established by the 1920s greatly increased the demand for wood, particularly from small trees. Motorized trucks became common in the forests in the 1920s. The railway expansion of the 1920s also had direct and indirect effects on forests. Trains could be used to transport trees from the forest to the mill. Also, trains allowed food products to be shipped from the Midwest, allowing the less-profitable agricultural lands in the eastern United States to be turned back into forests. However, in the process of establishing the railway system many trees were harvested and used for railway ties. All of these technological advances expanded the area cleared and increased the number of trees harvested from a site.

The chain saw may be the invention that most influenced the amount of wood taken from a site. The chain saw was invented in 1926 but did not become prevalent in the United States until the 1940s (Hall 1977). The chain saw not only allowed more wood to be cut in a set time interval but also permitted more trees to be cut within a stand. Thus, not only was timber more easily harvested, but more branches and cull trees were cut for firewood or other purposes. Thus chain saws result in a "cleaner" forest but one with less dead wood, which serves as animal habitat and is part of the nutrient-cycling and water-purification processes. Although there was great concern that the chain saw would replace jobs, more people are now employed in the timber industry than were at the turn of the century. Also, chain saws have made the work of logging much more efficient and safe.

The economic value of chain saws was made clear in a recent survey of farmers in Rondonia,

Brazil (Dale and Pedlowski 1992). In 1991, none of the 89 farmers we surveyed owned a chain saw. Yet shortly thereafter, the eventually successful candidate for governor of the state gave away chain saws as part of his campaign. The effect on forests of the rapid introduction of chain saws into the region is just beginning to be observed. The major tool for observing these changes is satellite imagery.

Satellite imagery is now commonly used in the planning process and to monitor changes in forest resources over time. The development of the normalized-difference vegetation index (NDVI) that relates reflectance, as measured in the image, to forest conditions was the breakthrough that made remote imagery a useful tool (Tucker 1979). The use of global positioning systems (GPS) now allows accurate recording of a location on the ground and thus augments the value of remote imagery. Satellite imagery is particularly important for international forestry. As late as 1990 (Dale 1990), we still did not know how much of the Earth's surface was covered by forests. Also, the extent of large-scale natural disturbances and anthropogenic clearing was not known. For example, a large fire burned millions of hectares of land in southeast Asia, but the area was not even known to be burning until it was identified in a satellite image.

The use of helicopters and small planes in forests became a part of some forest operations in the 1970s. Aircraft are used to distribute seeds, control fires, perform controlled burns, spray herbicides, spread fertilizers, and occasionally to harvest trees from otherwise inaccessible sites. Because of their high cost, helicopters and planes are not routinely used except for cost-effective applications of herbicides and fertilizers.

The development of computers also changed the logging industry. The control room in modern paper mills contains sophisticated computers to monitor and alert the operators of all aspects of the papermaking process. Computers are also used to decide how to cut a tree to maximize the value of the wood and minimize waste. Computers allow for the development and use of detailed simulation models of forest development. These models project situations in which sets of species grow and compete for resources. Geographic information systems (GIS) are the hardware and software combination that allows spatially explicit information to be integrated into a map of site conditions. The combination of simulation models with GIS technology allows the spatial arrangement of trees to be analyzed. The models have been used both for improving

understanding of forest interactions and for planning harvest and selection regimes. As mentioned previously, this spatial integration of information is critical to the adaptive management policy now being espoused for forest management (FEMAT 1993).

Machines for whole-tree harvesting are routinely used in Finland and Sweden to harvest trees in such a fashion that the soil and roots are not disturbed, minimizing impacts on soil runoff and nutrient cycling. Furthermore, the trees can be cut and lifted with these machines so that damage to adjacent trees is negligible, retaining the economic value of those trees, while preserving the forest as habitat for animals.

Overall some technologies (e.g. chain saws) have resulted in cleaner forests which are less likely to support ecosystem characteristics such as habitat and water purification. Whole tree harvesters may be the best example of a technology that retains many of the ecosystem features of forests.

IV. Integrating the Landmarks in Forest Management

Together, these ecological, legislative, and technological advances during the past century allow foresters to implement a diversity of management practices. But just because the means are available does not always imply that the practice will be used. For example, helicopter logging now allows trees to be removed from slopes more steep and inaccessible than was previously possible, but helicopters are generally not cost effective and are rarely used for harvesting. In addition to technological advances, awareness of some basic ecological concepts as well as legislative restrictions frame today's management practices. A review of the ecological concepts taught to foresters and their management implications clarifies how ecological knowledge has helped forest managers understand the diversity of forces that determine which species grow where, how forests develop, and how disturbances affect forests. These concepts were derived by examining forestry text books (e.g., the text by Oliver and Larsen 1996).

Gradient Concept: Environmental gradients are partially responsible for the distribution of species, ecosystems, and biomes. **Use:** Sometimes silvicultural practices take advantage of the ecological understanding of gradients and encourage planting or maintenance of species mixes and

densities appropriate for a site and a region. Often however, these natural gradients are ignored, and monocultures of trees are planted over large areas.

Limitation Concept: Leibig (1840) introduced the concept that the growth and distribution of species depend on the most limiting environmental factor. This *Law of the Minimum* is now understood to imply that most factors provide both upper and lower limits and frequently factors act in concert. **Use:** Forest management for sustained yield depends upon this concept. For example, thinning regimes are put in place to minimize competition for scarce resources and thus to maximum tree volume for a given stand age.

Disturbance: Disturbances, such as fire, windthrows, and insect outbreaks, are a natural part of many forests and affect forest structure, composition, and function. **Use:** Forestry, more than any other area of resource extraction, manages for the long term (with rotation times ranging from 10 to 110 years). Thus, foresters must recognize the potential for a disturbance to occur within a management cycle. Practices are in place to either manage the disturbance (e.g., by fire breaks) or manage the system so that it is less susceptible to a disturbance (e.g., by reducing the amount of flammable litter or thinning trees so they are less likely to be attacked by beetles).

Succession: Succession is the gradual replacement over time of one species by another that results in an increase in biomass in forests, a change in species-life-history characteristics, a change in light levels, a switch from high to low net primary production, and an alteration of the storage of nutrients from the soil to the standing biomass. **Use:** Knowledge of successional processes pervades forest management. Some practices create initial stages of succession by spreading seeds, planting seedlings, or leaving seed trees in place. The overall goal of silviculture is to artificially move stands through seral stages by such activities as thinning. Harvesting is scheduled to maximize profitability of timber yield by cutting trees prior to their peak in net primary production. Harvesting trees at a time when much of the nutrients are still being cycled within the soil and leaving branches onsite reduce the loss of nutrients from the site.

Watershed Concept: Forests cleanse water and reduce runoff. Changes in the upland forests affect the riparian system. **Use:** Some management practices are designed to enhance water quality and quantity, reduce soil erosion, and maintain the riparian system. Trees are not cut on steep slopes or adjacent to rivers. Downed branches are left onsite, and the litter layer is disturbed as little as possible. Stream-bank corridors of trees are left in place, and logging roads are maintained by providing proper drainage that reduces the chances of landslides into streams.

Structure Concept: Many ecological attributes can be linked to structural elements of the forest (e.g., size of live and dead trees and canopy configuration). Thus, many functional and compositional features of the forest can be preserved by maintaining structural features. **Use:** Ecosystem management is largely built upon maintaining or establishing structural features. This approach suggests ways that forest products can be harvested yet structural features, such as large trees or downed trees, can be left in place.

Recent Trends in Ecosystem Science

The major advances in ecosystem science in recent decades have been built upon these concepts. In the 1960s, forest management operated under the belief that actions to promote timber production are not necessarily good for other forest-related values. However, ecosystem science demonstrated that structural complexity is an important feature of natural forest ecosystems and that complexity is created naturally through disturbances. Because these disturbances occur on a scale larger than a stand, a landscape view was adopted. Traditional practices of clear-cutting even-aged stands do not recognize the importance of structure or disturbance in shaping the forest. Major questions for ecologists that accept these concepts are, therefore, how much structural complexity is needed and how can management activities (e.g., logging) be arranged in time and space to promote these features. Finally, it is important to know the relationships between forest stands and nonforest sites and the relative importance of those relationships.

This review shows that many forest practices are built upon ecological concepts and vice versa. Much of what ecologists know about forests has been learned by working with foresters. Even so, a gap remains between current ecological understanding and forest practices. This gap is

evident in practice where, for example, forest management is frequently targeted at timber harvest in small parcels, instead of considering multiple uses of the entire landscape. Unfortunately, some recent textbooks also focus on management for timber at a stand level rather than promoting ecosystem-management practices (e.g., Oliver and Larsen 1996).

However, new forestry approaches are being developed to promote practices that will enhance ecosystem properties (Kohm and Franklin 1997). For example, long rotations and variable-retention harvesting will both maintain ecologically important structural features of forests while allowing harvest to continue (Franklin et al. 1997). Alternatively, previously unproductive agricultural lands can now grow fiber for energy with intensive short rotations (e.g., 10 years). Proposals for these management practices take many forms, but one basic ecological impact is a return to the size structure more typical of natural forests, consideration of long-term and broad-scale implications of forest management, and the perspective of the forest as an interacting system.

The public understanding of ecosystem processes is also deficient. The public typically associates ecology with the environmental movement and does not understand critical aspects of ecosystems, such as feedbacks, changes over time and space, or the concept of a system itself. For example, Naiman (in press) points out that the public does not understand how water affects land processes and vice versa.

V. Challenges Ahead for Managing Forests as Sustainable Ecosystems

The position statement posed by the editors of this volume was that the transfer of ecological knowledge into forestry practices has been a success story. However, I would have to respond to this statement in a qualified manner. Many current forestry practices have developed from ecological studies, but it is also clear that the forest practices are not based on the most recent ecosystem science. Rather, forestry is a success story for ecosystem science in the sense that there is an established process for moving ecological theory into practice in our national forest as well as in the private forest industry. However, this process takes some time and is largely based on personal interchange and experiences. An example of this transfer is given by looking at the authors of the recent book on *Creating a Forestry for the 21st Century* (Komb and Franklin

1997). Many of those authors are from the research branch of the Forest Service. A gap exists between the practicing foresters and the research foresters, but because some members of these two groups are in the same organization and professional societies, it is not as wide as it is in other fields.

Finally, a wide difference exists in application of forest-protection laws. For example, in the United States, some state laws protect streams, whereas other states have no such protection. The challenge for ecosystems scientists is not just to publish their papers, but also to present their new ideas and understanding in a way that is useful and applicable for resource managers.

As I close this paper, I am reminded of the words said upon by my father, who was a researcher, a surgeon, and somewhat of a poet.

Now I hear the closing music. I see the autumn leaves. I remember the be-all and end-all of the surgeon. I see the green clad figures converge upon the still form beneath the brilliant overheads ... I balance the anguish of the bereaved against the happiness of the salvaged success. I bow beneath my failure and search for surer judgement, wider knowledge, and greater skill. Finally, supported by education, backed by training, and borne upward by my association with you [my colleagues], the reason for research and the end-point for experience is revealed. I see the patient who relies upon us. (Dale 1981)

These words make me wonder if we as ecologists recognize the ultimate use of our research. Do we see the natural resource manager as a “patient” who needs the understanding and tools we develop? Do we recognize the environment as the be-all and the end-all of our efforts? I believe the answer is both yes and no. Natural-resource management is much improved by the many contributions of ecologists. Yet, too often, we as ecologists do not consider the end use of our work. We may get involved in investigating interesting scientific hypotheses but may not consider the management implications of our research. Often, the working forester or land manager is most familiar with the pertinent land-management issues. Yet, ecologists too infrequently discuss their research with managers. Therefore, more contact is needed between these two endeavors.

Addressing this issue strikes at the balance between directed and undirected research programs. Much of the applied forestry research is funded by the USDA Forest Service and private timber companies that have a clear mandate to meet current management regulations. Although some of

the more innovative forestry approaches have arisen out of basic research endeavors, it may be years before the knowledge is applied. Programs directed at resolving particular forestry issues may provide the best balance between basic and applied research. For example, the Forest Ecosystem Management Team (FEMAT 1993) took on the task of defining ecosystem management in such a way as to make use of the latest ecological thinking.

Products from our research efforts need to be evaluated in the context of reaching the relevant audience. Social scientists can help ecologists identify the characteristics of the interested parties and what forest values are important to them. Scientific papers may elegantly lay out results, but these results may not be attainable by land managers. Too many times our products are immersed in jargon, complicated analysis, or theory, with the management implication being unclear. A recent analysis of tools used by environmental decision makers shows that the results of research efforts need to be available to managers and not just described in papers (Dale and English in press). Thus the challenges ahead for scientists are to find ways to deliver research results to the forest manager,

Irland (1992) has summarized future trends in forest use: Suburban sprawl will continue. The values that the public attributes to forests will change, with many people recognizing multiple uses of forests and others appreciating only wood products. Demand for wood and forest products will increase with a corresponding rise in prices that will add to existing pressures to harvest forests. Speculative booms in rural land will diminish the size and increase the turnover of privately owned forest parcels. Less private land will be available for hunting, fishing, and hiking. Mechanization of the forest industry will reduce the number of jobs.

Up to now, for some small landowners forest management for timber in the United States has reflected the lack of wood shortage. Future trends will exert pressures to manage forest lands more efficiently. Currently, ineffective thinning, sloppy harvesting, and inappropriate clear-cutting led to loss of productivity. Of the 21% of U.S. land that is managed as commercial forest (195 million hectares, 480 million acres), only 8% was seeded or planted between 1950 and 1978 (Oliver and Larsen 1996, p.7). The rest was allowed to regenerate naturally. Rapid turnover in land ownership, land fragmentation, and land-use conversion result in loss of forests or erode the value of forests for wildlife habitat or as watersheds. Large landowners, on the other hand, have

been increasing productivity significantly through improved genetics, fertilization, planting, and more efficient harvesting.

Ecological science offers a long-term and broad-spatial perspective that is essential to sustainable management of forest resources. The long view instills a sense of responsibility for the forest resources. Forestry companies that own their lands, rather than lease them, tend to cut and replant the forest in such a way that promotes long-term benefits. When land management is performed for the long term, the ecological interactions are an integral aspect of the changes in the forest. Yet even in the short term, forest resources can be appropriately managed based on a knowledge of succession, effects of gradients, environmental limits, and the roles of disturbance and watershed properties. It is the responsibility of science to educate land managers about how these principles come into play in forest management, and it is the responsibility of the public to challenge land managers to develop an ethic that can preserve the ecosystem features of the forests. Ethical resource management built upon sound ecological principles is the key to appropriate forest stewardship.

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Literature Cited

Bormann, F. H., and G. E. Likens. 1981. Pattern and process in a forested ecosystem. Springer-Verlag, New York, New York, USA.

- Botkin, D. B., J. F. Janak, and J. R. Wallis. 1972. Some ecological consequences of a computer model of forest growth. *Ecology* 60:849-872.
- Carpenter, R. A. 1996. Ecology should apply to ecosystem management. *Ecological Applications* 6:1373-1377.
- Christensen, N. L., A. M., Bartuska, J. H. Brown, S. R. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological Applications* 6:665-691.
- Clements, F. E. 1916. Plant succession: An analysis of the development of vegetation. Carnegie Institution of Washington Publication 242: Carnegie Institution of Washington, Washington, D.C., USA.
- Cowles, H. C. 1911. The causes of vegetation cycles. *Botanical Gazette* 51:161-183.
- Dale, V. H. 1990. Strategy for monitoring the effects of land use change on atmospheric CO₂ concentrations. *In* Proceedings of "Global Natural Resource Monitoring and Assessments: Preparing for the 21st Century," Venice, Italy, September 25-30, 1989. American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, USA. Vol I: 422-431.
- Dale, W. A. 1981. Then and now. Presentation to the International Society of Surgery, Dallas, Texas, USA.
- Dale, V. H., and M. R. English. In press. Tools for aiding environmental decision making. Springer-Verlag, New York, New York, USA.
- Dale, V.H. and Pedlowski, M.A. 1992. Farming the forests. *Forum for Applied Research and Public Policy* 7: 20-21.
- FEMAT [Forest Ecosystem Management Assessment Team] 1993. Forest ecosystem management: An ecological, economic and social assessment. U.S. Government Printing Office, Washington, D.C., USA.
- Foreman, R. T. T., and M. Godron. 1986. Landscape ecology. John Wiley & Sons, New York, New York, USA.
- Franklin, J. F. 1989. Toward a new forestry. *American Forestry* 11:37-44.
- Franklin, J. F., D. R. Berg, D. A. Thornburgh, and J. C. Tappeiner. 1997. Alternative silvicultural

- approaches to timber harvesting: variable retention harvest systems. Pages 111-140 *in* K. A. Kohm, and J. F. Franklin, editors. Creating a forestry for the 21st century. Island Press, Washington, D.C., USA.
- Gleason, H. A. 1926. The individualistic concept of the plant association. *Bulletin of the Torrey Botanical Club* 53:1-20.
- Good, R. E. 1931. A theory of plant geography. *The New Phytologist* 30:149-203.
- Good, R. E. 1931. The geography of the flowering plants. 2nd edition. Longmans, Green, and Co., New York, New York, USA.
- Gregory, S. V. 1997. Riparian management in the 21st century. Pages 69-86 *in* K. A. Kohm and J. F. Franklin, editors. Creating a forestry for the 21st century. Island Press, Washington, D.C., USA.
- Hall, W. 1977. Barnacles Parp's chain saw guide. Rodale Press, Emmaus, Pennsylvania, USA.
- Irland, L.C. 1982. Wildlands and woodlots: The story of New England's forests. University Press of New England, Hanover, New Hampshire, USA.
- Karamanski, T. J. 1989. Deep woods frontier: A history of logging in northern Michigan. Wayne State University Press, Detroit, Michigan, USA.
- Kessler, W. B., H. Salwasser, C. W. Cartwright, Jr., and J. Caplan. 1992. New perspectives for sustainable natural resource management. *Ecological Applications* 2:221-225.
- Kohm, K. A., and J. F. Franklin, editors. 1997. Creating a forestry for the 21st century. Island Press, Washington, D.C., USA.
- Leopold, A. 1949. A Sand County Almanac. Oxford University Press, New York, New York, USA.
- LeGuin, U. K. 1972. The Word for World is Forest. Berkley Publishing Corporation, New York, New York.
- Levin, S. A., editor. 1976. Ecological theory and ecosystem models. The Institute of Ecology, Athens, Georgia, USA.
- Lewis, T. E., and B. L. Conkling. 1994. Forest health monitoring: Southeast loblolly/shortleaf pine demonstration interim report. EPA Project Summary, Report Number EPA/620/SR-94/006, Washington, D. C., USA.

- Liebig, H. 1840. Chemistry in its agriculture and physiology. Taylor and Walton, London, England.
- Lubchenco, J. A., A. M. Olson, L. B. Brubaker, S. R. Carpenter, M. M. Holland, S. P. Hubbell, S. A. Levin, J. A. MacMahon, P. A. Matson, J. M. Melillo, H. A. Mooney, C. H. Peterson, H. R. Pulliam, L. A. Real, P. J. Regal, and P. G. Riser. 1991. The sustainable biosphere initiative: An ecological research agenda. *Ecology* 72:371-412.
- Merriam, C. H. 1894. Laws of temperature control of the geographic distribution of animals and plants. *National Geography* 6:229-238.
- Merriam, C. H. 1898. Life zones and crop zones of the United States. United States Department of Agriculture Biological Survey Division Bulletin 10:9-79.
- Naiman, R. In press, Watersheds, landscapes, and society. *Landscape Ecology*.
- National Research Council. 1992. Conserving biodiversity: A research agenda for development agencies. Nation Academy Press, Washington, D.C., USA.
- Oliver, C. D., and B. C. Larsen. 1996. Forest stand dynamics. John Wiley & Sons, New York, New York, USA.
- O'Neill, R. V., W. F. Harris, B. S. Ausmus, and D. E. Reichle. 1975. A theoretical basis for ecosystem analysis with particular reference to element cycling. Pages 28-40 in F. G. Howell, J. B. Gentry, and M. H. Smith, editors. Mineral cycling in southeastern ecosystems. ERDA-CONF-740513. U.S. Energy Research and Development Administration, Washington, D.C., USA.
- Post, W. M., T.-H. Peng, W. Emanuel, A. W. King, V. H. Dale, and D. L. DeAngelis. 1990. The global carbon cycle. *American Scientist* 78:310-326.
- Russell, C., V. H. Dale, M. Hadley, M. Kane, and R. Gregory. Submitted. Applying multi-attribute utility techniques to environmental valuation: A forest ecosystem study. *Growth and Change*.
- Salwasser, H. 1990. Gaining perspective: Forestry for the future. *Journal of Forestry* 88:32-38.
- Shannon, M. A. and A. R. Antypas. 1997. Open institutions: uncertainty and ambiguity in 21st-century forestry. Pages 437-446 in K. A. Kohm, and J. F. Franklin, editors. *Creating a forestry for the 21st century*. Island Press, Washington, D.C., USA.

- Shelford, V. E. 1913. Animal communities in temperate America. University of Chicago Press, Chicago, Illinois, USA.
- Slocombe, D. S. 1993. Implementing ecosystem-based management. *BioScience* 43:612-622.
- Stork, N. J., T. J. B. Boyle, V. Dale, H. Eeley, B. Finegan, M. Lawes, N. Manokaran, R. Prabhu, and J. Soberon. Criteria and indicators for assessing the sustainability of forest management: conservation of biodiversity. Center for International Forestry, Bogor, Indonesia.
- Swanson, F. J., and J. F. Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. *Ecological Applications* 2:262-274.
- Tansley, A. G. 1939. The plant community and the ecosystem. *Journal of Ecology* 27:513-530.
- Tucker, C. J. 1979. Red and photographic infrared linear combinations monitoring vegetation. *Remote Sensing of Environment* 8:127-150.
- Turner, M. G. 1989. Landscape ecology: The effect of pattern on process. *Annual Review of Ecology and Systematics* 20:171-197.
- Turner, M., and R. H. Gardner. 1991. Quantitative methods in landscape ecology: The analysis and interpretation of landscape heterogeneity. Springer-Verlag, New York, New York, USA.
- van Dobben, W. H., and R. H. Lowe-Connell, editors. 1975. Unifying concepts in ecology. Dr. W. Junk, The Hague, The Netherlands.
- Waring, R. H., editor. 1980. Forests: Fresh perspectives from ecosystem analysis. The fortieth annual biology colloquium. Oregon State University Press, Corvallis, Oregon, USA.
- Warming, J. E. 1895. *Plantensamfund, Gruntraek af den Okologiske Plantegeografi*. Philipsen, Copenhagen, Denmark.
- Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. *Ecological Monographs* 26:1-80.
- USDA Forest Service. 1992. Ecosystem management of the national forests and grasslands. Memorandum 1330-1. USDA Forest Service, Washington, D.C., USA.

Table 1. Example indicators, dimensions, and values for forest systems.

Indicators	Dimensions	Values
Soil acidity	Forest type	Aesthetics
Foliar chemistry	Tree size	Recreation
Soil class	Visible plant damage	Cultural importance
Crown measures	Fragmentation	Religious importance
Leaf area	Visibility	Consumptive use
Branch evaluations	Recreation use	Services of nature
Plant diversity	Extractive use	
Ozone bioindicators		
Lichen diversity		
Visible damage		
Vegetation structure		

Figure 1. Landmarks in U.S. forestry. Acronyms are as follows: NEPA (National Environmental Protection Act), NFMA (National Forest Management Act), FLPMA (Federal Land Policy and Management Act), NDVI (normalized-difference vegetation index), GIS (geographic information system) and GPS (global positioning system).

Landmarks in U.S. Forestry

	ECOLOGICAL	LEGISLATIVE	TECHNOLOGICAL
Year			
1900	Lifezones Succession	Forest Service Weeks Law	
1920	Plant associations	Clark-McNary Act	Paper mills Motorized trucks Railway expansion
1940	Ecosystem	Forest Pest Control Act	Chain saws
1960	Gradients IBP	Multiple Use - Sustained Yield Act Wilderness Act NEPA and Endangered Species Act Forest and Rangeland Renewable Resources Planning Act	Computers Helicopters
1980		NFMA and FLPMA	NDVI GIS
2000	Landscape ecology Sustainable biosphere Ecosystem management	Conventions on Climate Change Statement of Forest Principles	GPS Whole-tree harvesters