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OVERVIEW

Factors Influencing the Context and Principles of Ecosystem Management

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Abstract

The earth's population has grown eleven-fold in the last 300 years, therefore there are fewer resources and less space available for each individual, living thing: hence the biodiversity crisis. Human use of resources has increased at a greater rate than population growth. Agricultural and natural resources use and efficiency gains will be required to stop ecosystem degradation. All ecosystems have biological and physical limits, are complex and interconnected in space and time, are constantly changing in only partially predictable ways, and are renewable. Sustainable development, though a nebulous statement of intent, affirms maintaining healthy, productive land and natural resources.

Ecosystem management can be defined as the process of seeking to produce (i.e., restore, sustain, or enhance) desired conditions, uses, and values of complex communities or organisms that work together with their environments as integrated units. The working guidelines for implementing ecosystem management include the key steps of delineating ecosystems, statements of problems, assessing and understanding choices, and acting, learning, and adapting. The necessary steps are getting people involved; working within the scope of the processes; integrating information, technology, management, and research; revitalizing conservation education and interpretation; and, developing, monitoring, and evaluating vital signs of ecosystem health. Biological diversity, the variety of life, is valuable within an ecosystem for ecological, economic, educational, and aesthetic reasons and, thus, its conservation should be included in ecosystem management.

To fully shape ecosystem perspectives in land and resource management, social, biological, and physical sciences must become better integrated. By using the working principles of the model known as adaptive management, ecosystem management can develop a new model for the scientific basis of conservation—interdisciplinary teams working with all constituencies to address both short- and long-term relationships between people and the land.

A GLOBAL PERSPECTIVE ON PEOPLE, LAND, AND RESOURCES

During the past 300 years—since the industrial revolution—the global human population has grown by 11-fold. Where 500 million people once lived, there are now more than 5.5 billion people. These 5.5 billion people are spreading out into more and more of the earth's land spaces. They are using more and more of the earth's natural resources with every passing year. And they, we actually, are increasingly changing the structure, composition, and function of terrestrial, oceanic, and freshwater ecosystems. These realities and their various ramifications dominate how and for what earth's ecosystems are managed. They will continue to dominate as far into the future as we might care to plan.

A simple and unavoidable fact of ecology is that every living being on earth uses space and resources to survive. The more of any particular species there is, the more space and resources are directed toward that species' existence. Thus, 11-fold growth in the global human population means that people use an increasing share of earth's space and resources. One way to envision this is "earth per person" over the years: there is now only one-eleventh the amount of earth's space per person as there was at the dawn of the industrial revolution. Hence the increasing strife—gang warfare in some cases—between competing segments of society in countries the world over (Kaplan 1994). It also means that less space and resources are now available for all the other living things on earth except for those that benefit from human-modified habitats. Hence, the so-called biodiversity crisis (Wilson 1992). These are some of the global implications of the human population and its effects on earth's ecosystems. Local dimensions are often scaled-down versions of the global situation.

According to data cited in the book State of the World 1994, human impacts on earth's ecosystems are far from stable; they are accelerating as the global human population has doubled in the last 40 years. As a direct consequence of this doubling, plus technological advances, our collective economic output has increased 5 times; use of oil has grown 6 times; industrial wood production has doubled and is now exceeded in volume by the use of wood for fuel; use of water has tripled; and the gap between affluent and poor people has doubled (Postel 1994). Using various international data sources, Postel projects significant downward global trends in basic resources between 1990 and 2010 as the human population grows by another 33% and continues to appropriate more space and resources to meet its needs and desires (Table 1):

- Fish catch is predicted to increase by 20% but on a per-capita basis this will represent a 10% decline because of population growth.
- There will be 17% more irrigated land but this is a per-capita decline of 12%.
- Cropland will increase 5%, yielding a per-capita decline of 21%.
- Pastures will increase by 4% for a per-capita decline of 22%.
- Forests will be where most of the cropland and pastures come from, declining by 7% for a per-capita reduction of 30%.

Humans will continue to appropriate more of earth's space and resources. Yet, because of inequities in affluence and distribution of food and material goods, not all people are likely to benefit equally from the fruits of economic development. Ecologists should pay as close attention to the political ramifications of this likelihood as they do to its biological ramifications because nature's ecosystems and their biological diversity rarely if ever fare well during times of war.

With less land available per person to meet the burgeoning needs of people for resources, significant improvements—efficiency gains if you will—will be required in agricultural and forest productivity on lands devoted to those purposes. Even greater gains in water-use efficiency and recycling will be needed. Otherwise, ecosystems now in use for resource production will be further degraded and more native ecosystems will be overrun by human uses. Thus, global trends in population growth and resource use mean that the work of natural-resource management is going to become harder and more important as time goes on. Whether the projected trends are precise is not critical. What is important is that we understand the direction and magnitude of these trends as driving forces of ecosystem management.

This paper explores ecosystem management based on the premise that the human population will continue to grow and that people will continue striving to improve their material standard of life. Other fundamental premises are possible, though I doubt very realistic. For example, philosophical arguments can be waged about whether the human population is already too large or whether segments of it should have their access to desired resources constrained. I do not question the usefulness of such arguments but they will not be waged here. The reality of recent and projected trends is what natural-resources managers and scientists must confront.

THINKING ABOUT ECOSYSTEM MANAGEMENT

More than 40 years ago, American forester and wildlife biologist Aldo Leopold said that people should take care of land as a "whole organism" and try to keep all the cogs and wheels in good working order (Leopold 1949). If we humans did this, he implied, the productivity and renewability of land for the many things we value would fare well, for example timber yield, water quality, wildlife, scenery, and livestock forage. What Leopold had in mind, I think, was to sustain the diversity and productivity of ecosystems while still meeting people's needs for livelihood. Lately, natural resources scientists and managers in the United States have begun to call this holistic concept ecosystem management. It encompasses or is directly linked to several other natural resources concepts, namely biodiversity conservation, sustained yield of multiple uses, ecosystem health, and sustainable development.

The concept of ecosystem management—that knowledge and technology can be skillfully used in taking actions to encourage desired conditions of ecosystems for environ-

TABLE 1. GLOBAL TRENDS IN PEOPLE, LAND, AND RESOURCES PROJECTED FROM 1990 TO 2010 (AFTER POSTEL 1994).

People & Resources: 1990 to 2010

Resource	1990	2010	Total Change	Per Capita Change
Population (million)	5,300	7,000	+33%	
Fish Catch (mil. tons)	85	102	+20%	-10%
Irrigated Land (mil. ha)	237	277	+17%	-12%
Cropland (mil. ha)	1,444	1,516	+5%	-21%
Range/Pasture (mil. ha)	3,402	3,540	+4%	-22%
Forests (mil. ha)	3,413	3,165	-7%	-30%

mental, economic, and social benefits, both now and for future generations—is not entirely new. During the past four decades, foresters, rangeland managers, wildlife ecologists, and fisheries and watershed managers have tried to bring ecosystem concepts into natural resources management (for example see Watt 1968, Van Dyne 1969, Kimmins 1987, Savory 1988, Aplet et al. 1993). In response, several U.S. federal laws enacted during the 1960s and 1970s discussed or alluded to ecosystems in their mandates (Keiter 1994).

But the laws did not anticipate the magnitude of shifts that would occur during the 1970s and 1980s in how people value wildlands and natural resources as our society completed a century-long exodus from rural to increasingly urban settings and lifestyles, and a general philosophical shift from utilitarian to preservation perspectives. So, while the concept of ecosystem management has been around for a while, views on what it comes to mean might be very different than Leopold's ecological-evolutionary perspective (Callicott 1991) or what the scientific and legal work of recent decades might originally have envisioned (Keiter 1994).

BUILDING A COMMON BASE OF UNDERSTANDING

For any concept or approach to land and resource management to work, people need a common understanding of basic principles and a shared vision for expected outcomes. This starts with fundamental definitions. A standard dictionary tells us that ecosystems are complex communities of organisms working together with their environments as integrated units. As an abstract concept this is fine. But it does not provide a tangible meaning of what an ecosystem is, one that nonscientific people can grasp or comprehend. Rowe (1990) says that ecosystems are where organisms live; they are the home places of all living things including humans. This is more tangible.

Ecosystems provide all the resources of life and they receive all the wastes, wanted or not. Some organisms do not need much space or may live as parasites inside the body of another organism; their ecosystems are very small. Other organisms, such as humans, eagles, ponderosa pine, chinook salmon, and wolves, occupy very large areas; their ecosystems are large. Thus, ecosystems are not just abstract, scientific concepts. They are also real places that occur at many geographic scales. The smaller places are nested within the context of the larger places. So, ecosystems form a hierarchy from the smallest to the whole biosphere. There is no single geographic scale that defines what an ecosystem is; the issue at hand determines the appropriate scale. And many people take their identity from the ecosystems in which they live and gain livelihood.

Beyond knowing what ecosystems are, we need a common understanding of how they work if the "new" management concept is to be successful. The writings of Hardin (1985), Kimmins (1987, 1992), and Botkin (1990) are particularly useful to this understanding. I cannot cover all the basic principles of ecosystem function in this brief paper but a few principles will illustrate the point.

All ecosystems are defined or delimited by specific issues, concerns, or resource characteristics. For example, a lake ecosystem is defined by its perimeter and the watershed within which it occurs. A forest ecosystem is delimited by the extent of trees. A "grizzly bear" ecosystem or a migratory salmon ecosystem is defined by the extent of the seasonal movements or home ranges of the animals in question.

All ecosystems have biological and physical limits; without added inputs such as energy, water, new plants or animals, and nutrients, they can only achieve certain kinds of conditions or levels of outputs. For example, growing high yields of corn where a tall-grass prairie used to be requires continual inputs of genetically modified plants and fertilizers.

Ecosystems are complex and interconnected in space and time; every action in an ecosystem causes a sequence of responses, some of which are immediate and on site while others are delayed in time or occur off site (needless to say some of the responses will run counter to desires such as forests with high fuels that result from years of fire suppression).

Ecosystems are constantly changing and evolving in ways that are only partially predictable; we cannot hold ecosystems constant or precisely regulate them to produce constant flows of desired outputs or conditions, whether those be scenery, water, "old-growthedness," wildlife diversity or wood products. Look at time-sequence photos from early expeditions to the West, and recent decades to see vivid examples of this trait.

Ecosystems are renewable because solar energy and photosynthesis allow them to counteract the natural tendencies of things to "wear down" over time; humans can use the renewal capacity of ecosystems in perpetuity if our removals do not deplete long-term productivity. This, of course, is a basic concept behind sustained-yield strategies for rangeland forage, wildlife cropping, and timber management.

How people use ecosystems changes over time and from place to place in response to cultural, economic, and value changes. Thus, the future course of all ecosystems on earth is influenced by human choices whether those choices are to save endangered species, create wilderness areas, or build shopping malls.

As a general "rule-of-thumb," diversity in the physical, biological, cultural and economic conditions of ecosystems is positively correlated with adaptability to stress and change, and options for future ecosystem conditions.

SUSTAINABLE DEVELOPMENT AS A GOAL

Knowing what ecosystems are and how they work is essential but not sufficient to tell us what to manage ecosystems for. Population size and the growing effects of meeting human needs no longer make laissez-faire a responsible land ethic if ever it was. So, we must decide what to do and how to do it. Clawson (1975) posed a question for forest management several decades ago that is also relevant for ecosystem management—Ecosystems for whom and for what? One search for answers that is receiving considerable attention is sustainable development (World Commission on Environment and Development 1987, United Nations 1992). Sustainable development means meeting the needs of present humans without unduly compromising the capacity of future humans to meet their needs.

But what is it exactly that is to be sustained to meet these present and future needs? How? Where? For whom? By whom? For how long before a new goal appears? Sustainable development, nebulous though it may be as a statement of intent, is affirmative about the human enterprise, not retrogressive or static. It recognizes, for example, that improving knowledge and technology or modifying attitudes and ethics can lead to enhanced capacity in the future. But continued degradation of the productive capacity of land might not be fully mitigated by such enhancements. Therefore, maintaining healthy, productive land and natural resources is generally accepted as a precursor to sustainable development.

Developing a common vision for what specifically is to be sustained (or restored or enhanced) in ecosystems at various geographic scales is the challenge we now face. It is a challenge we face as communities of people. It is not just government's job to do this for us as the final arbitrator of conflicting special interests. Nor is it a job solely for ethicists, economists, or scientists. Science does not determine what should be sustained, only what is possible and the likely consequences of alternative choices. Economics illuminates financial and tradeoff costs and benefits of choices, but economics does not tell us what is possible or desired. Neither science nor economics provides a society with its values, and values are what inform people on what is desired and guide their choices. But, then, values do not identify what is possible or what is affordable. Thus, for sustainable development to occur, a community or society as a whole must blend necessary and complementary roles for science, economics, and ethics in finding constructive ways to reconcile competing interests. This is not a social or political adjunct to ecosystem management; it is perhaps more fundamental than sophisticated economic or bio-physical understandings of ecosystem capabilities and responses.

FORESTS, WOOD, AND ENERGY: SOME CHALLENGES IN ECOSYSTEM MANAGEMENT

Forests, because of their many values and uses, not the least of which is that they moderate our atmosphere and hold the soil in place on about 30% of the land surface of the planet, are the focus of much attention as ecosystem-management and sustainable-development concepts evolve. Historical estimates tell us that forests and woodlands covered about 50% of the land surface of the planet around 1700. They now cover about 31%, a 33% decline in 300 years. Forests in the U.S. now cover 32% of the nation's land surface, also a decline of 33% since 1700. About 90% of forest reduction in the U.S. occurred from 1850 to 1910, at the approximate rate of 12,000 acres per day for 70 years running prior to major agricultural improvements and scientific forestry. Population growth during the past 300 years translates these trends into dramatic per capita changes: from 30 hectares of forest per global citizen in 1700 to 0.75 hectare per person today. Corresponding U.S. trends (assuming 10 million human inhabitants of what is now the U.S. in 1700) are 45 hectares per person down to 1.2 hectares today.

Most global forest losses were to agricultural development and other human occupancy. Some of the losses are permanent as long as humans are around; others are more ephemeral. Yet amidst the pessimistic and almost apocalyptic rhetoric about forests, we should realize that these historic losses of forest are not as severe as they might have been. Improvements in agricultural technology, internal combustion engines replacing farm draft animals, fossil fuels replacing wood fuels in developed nations, and the high value of wood as an economic incentive to keep forest lands in forest cover for sustained wood yields have all mitigated even more drastic potential impacts of humans on the world's forests (MacCleery 1993).

Nevertheless, people continue to convert forests to other land uses in developing countries and to draw ever more amounts of wood from the world's forests for fuel, packaging, paper, lumber, and other materials in developed nations. The global picture on forests gains clarity with every passing year: humans use forests for more values and products, more intensely, while the total area of forests to supply those values and uses continues to shrink, compounding the pressure on what is left.

Meanwhile, wood remains one of nature's "wonder materials." It comes from a renewable resource: forest ecosystems and trees. The process of producing the raw material, i.e., growing trees in forests, has environmental benefits that usually exceed those of other uses of the land. And the use of wood in place of alternative materials has environmental as well as aesthetic benefits. Koch (1992), for example, estimates that the energy and atmospheric costs of replacing wood products from 1 billion board feet of timber harvest—the U.S. uses about 45 billion board feet of wood products per year in construction—with products derived from steel, aluminum, concrete, and brick in U.S. home construction might be as much as 700 million gallons of oil consumed and 7.5 million tons of CO_2 produced that would not have occurred had wood been used instead. Replacing domestically produced wood products with similar products from elsewhere also has environmental as well as social costs. Lippke (1992), for example, estimates that 15 times the area of forest must be harvested in Siberia to produce an equivalent amount of wood products from timber harvested in the more productive forests of the Pacific Northwest of the U.S. Furthermore, producing wood products in Siberia is likely to involve local boom and bust economies and cultures and it must be transported from there to here using more fossil fuel.

Clearly, managing forest ecosystems will entail more than deciding where to save primary forests, how many "biological legacies" are needed for forest health, and where to put wilderness areas or tree farms. It certainly must address these concerns. But it must also address the transfer effects of a growing global demand for wood on where and how the supply is going to be produced, what can reasonably be accomplished to reduce demand for raw material through new technology and higher prices for wood, and what effects our combined choices on forest stewardship and wood use might have on local to global economies, environments, and communities. The U.S., with 5% of the world's human population, uses about 33% of the industrial roundwood produced in the world each year and itself only produces about 26% of the total. Thus, U.S. citizens are net importers of wood from the forests of other nations despite the fact that the U.S. is biologically and economically capable of being a net exporter if it so chooses. The issue of addressing domestic self-sufficiency and global transfer effects of U.S. wood use should therefore be central to U.S. forest-ecosystem-management policy.

Wood production is one important outcome of forest-ecosystem management, but by no means the only important one. Most affluent cultures in the world today acknowledge that some forests should be protected to feature their spiritual and environmental values; that some should be managed intensely to produce the wood products that people need and desire; and that yet others should be managed in ways that balance the protection of environmental values with the production of desired products. Let us refer to these three categories of forests as nature preserves, production forests, and multi-benefit forests.

This is not a new classification of forests by any means. Nor does it imply what kind of land ownership should fall into each category; conceivably any ownership could be in any category. However, it is still not recognized by some people that these three values must complement one another, and each is as important to the full array of for what and whom forest ecosystems should be managed as the others. The task we face is how to obtain optimum overall value from options to have different forests in each kind of use at various points in time. This landscape-scale challenge that often entails coordination across multiple forest ownerships is also fundamental to ecosystem management.

MAKING ECOSYSTEM MANAGEMENT AND SUSTAINABLE DEVELOPMENT DOABLE

Ecosystem management and sustainable development have a similar goal: the sustenance of desired conditions of lands, waters, biota, human communities, and the economic enterprises that depend on healthy, productive land and natural resources. Both also have a similar compelling urgency: the growing human population is putting increasing pressures on the health and productivity of lands, waters, air, and resources, jeopardizing the ability of communities and nations to reach that goal (Silver and DeFries 1990, Postel 1994).

DEFINING ECOSYSTEM MANAGEMENT IN PRACTICAL TERMS

Ecosystem management is variously defined by those who are shaping its course. Beginning with a standard dictionary definition, management is the process of taking skillful actions to produce desired outcomes. If we combine this with the term ecosystem, ecosystem management is the process of seeking to produce (i.e., restore, sustain, or enhance) desired conditions, uses and values of complex communities of organisms that work together with their environments as integrated units.

This integrated systems concept of land and resource management is broader than traditional approaches to the preservation of nature as historically practiced in national parks, wilderness areas, and nature reserves. It is also broader than multiple-use land and resource management as it has been traditionally practiced on American public lands. Certainly it is broader than contemporary intensive agriculture. Ecosystem management emphasizes the integration of ecological, social, and economic factors at different temporal and spatial scales to maintain a diversity of life forms, ecological processes, and human cultures.

Traditional approaches to land or resource preservation attempt to either freeze ecological conditions at a desired state—which is not biologically possible—or allow natural forces to run without human interference—which is appropriate in some cases but not always socially or politically acceptable. Traditional approaches to multiple-use land and resource management tend to focus on sustaining yields of desired resources and uses—such as timber, wildlife, water, minerals, energy, livestock forage, fish, and recreation opportunities—in compatible blends (Gale and Cordray 1991). Conflict among the various resources and their human constituencies is common in multiple-use schemes (Wondolleck 1988). The primary focus of agriculture is to sustain the production of desired crops of plants or animals. This is usually achieved through simplification of ecosystems to guide net primary productivity into the desired crops.

An ecosystem perspective enlarges the focus of land management and resource conservation to whole ecosystems rather than selected parts, outputs, or processes. It does not deny the importance of producing resources needed by people. Nor does it deny the need to protect certain places from certain kinds of human activities or to actively restore natural ecological processes or conditions on human-impacted sites. It seeks a broad focus on sustaining desired ecosystem conditions of diversity, long-term productivity, and resilience, with yields of desired resources and uses being commensurate with the larger goal of sustaining those conditions. This is not what many practicing biologists, foresters, fisheries managers, or range conservationists were taught about management of their featured resource.

HOW ONE U.S. FEDERAL AGENCY EVOLVED TOWARD ECOSYSTEM MANAGEMENT

Some insight into how a transition to ecosystem management can be made comes from looking at how one U.S. Federal agency evolved the concept. The U.S. Department of Agriculture Forest Service, with responsibility for the 191 million acre National Forest System in the U.S., began moving toward ecosystem management during the 1980s, though not explicitly under that name. By the latter part of that decade, the agency recognized four major reasons for formally exploring new perspectives in land and resource management (Overbay 1992):

> 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.
>
> New information and a better understanding of ecological processes highlight the role of biological

diversity 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.

People outside the Forest Service want more direct involvement in the process of making decisions about public resources.

The complexity and uncertainty of natural resources management calls for stronger teamwork between scientists and resource managers than has heretofore been practiced.

In response, the Forest Service chartered a Service-wide set of New Perspectives projects (more than 250 separate projects in all) of research and on-the-ground management demonstrations to do five things:

1. Learn how to better sustain diverse and productive ecological systems.
2. Better integrate the different aspects of land and resources management.
3. Improve the effectiveness of public participation in resource decision making.
4. Continue building partnerships between forest users and forest managers.
5. Strengthen teamwork between researchers and managers.

People from academia, industry, non-governmental conservation organizations, and other state and Federal agencies were enlisted at the outset and throughout to help guide the projects. In summer 1992, as a direct result of experiences with New Perspectives projects and recommendations from a review and evaluation process held in December 1991, the Forest Service announced its intent to develop ecosystem management as a strategic approach for sustaining desired conditions of ecosystem diversity, productivity, and resilience for the multiple uses and values of national forests and grasslands (Robertson 1992). Ecosystem management was proposed as a process for change, not a goal in and of itself. The goals for ecosystem management would come from ecological capabilities of the land together with legal mandates and public needs and aspirations.

The Forest Service has a Congressional mandate to manage lands and resources entrusted to its care under the concepts of multiple use and sustained yield, without impairing the long-term productivity of the land (MUSY 1960). The Forest Service also has a legal mandate to conserve threatened or endangered species (ESA 1973, as amended) and to "provide diversity of plant and animal communities ... to meet overall multiple-use objectives" (NFMA 1976).

The Chief of the Forest Service, therefore, defined ecosystem management within this legal mandate: "an ecological approach will be used to achieve the multiple-use management of the national forests and grasslands by blending the needs of people and environmental values in such a way that the national forests and grasslands represent diverse, healthy, productive, and sustainable ecosystems" (Robertson 1992). Other federal and state land-management agencies are implementing similar ecosystem-management policies (see especially The Keystone Center 1993 and GAO 1994).

WORKING GUIDELINES FOR ECOSYSTEM MANAGEMENT

Field managers and scientists in both the public and private sectors in the U.S. are now implementing ecosystem management through changes in agency regulations, national program direction, amendments to land-use plans, field projects that carry out the direction in those plans, research programs, and cooperative endeavors with conservation partners in universities and other government agencies and businesses. At this point, principles or working guidelines for ecosystem management have evolved from a variety of theoretical and empirical projects (Salwasser 1991, Robertson 1992, The Keystone Center 1993, GAO 1994, Grumbine 1994, Kaufmann et al. 1994, Salwasser 1994, Wood 1994). These principles and guidelines are open for refinement and are presented here only to show the state of thinking about ecosystem management in the mid-1990s.

Key Steps

1. **State the problem(s)** to be addressed and expected or desired outcomes (social, economic, and environmental) from the anticipated solutions to the problem(s). Rigorous adherence to the scientific method would have problems stated as falsifiable hypotheses. This might be possible in some situations, but in all cases the problems should at least be stated in terms that can guide inventory, analysis, development of alternative solutions, and evaluation of the potential effectiveness of those alternatives. Absent a problem statement, planning and evaluation could wander widely without ever coming to grips with why action is needed in the first place. Furthermore, without clear problem definition the geographic and temporal scales of analysis will not be clear.
2. **Delineate ecosystems** based on biological, physical, economic, and cultural criteria relevant to the specific issues to be addressed. Small-scale issues, such as protection of a patch of native plants or a unique pond or spring, might require delineation of small ecosystems, say a local watershed. Larger-scale issues, however, such as anadromous fish, migratory wildlife, large predators, air quality, or the sustainable flow of forest products to regional industries will require delineation of much larger, regional ecosystems.
3. **Assess and understand ecosystem capabilities** relevant to the problem(s) being addressed and likely responses to management choices and actions. Collect and assemble pertinent data and information on ecological, economic, and social factors important to understanding conditions, trends, and likely responses of the ecosystem(s) in question to management alternatives. This is an integrated analysis that will require an interdisciplinary team of scientists and technicians.

4. **Make informed choices** for goals and actions that address the defined problem(s) and are likely to lead to desired and achievable end results, that is desired future ecological and social conditions and the land-use classes and management actions that will best attain them. Use landscapes as a basic unit for planning and managing lands to meet specific objectives for conditions that will yield both desired future ecological conditions and desired economic and social goals while reconciling conflicts between competing uses and values.
5. **Act, learn, and adapt.** Coordinate strategies for conservation of shared resources. Many natural-resource issues and concerns cross jurisdictional lines. Examples include migratory fish and wildlife, wide-ranging endangered species, long-term regional timber supplies, air quality, and water flows. Regional-scale ecosystems are logical units in which to coordinate land uses and management actions to achieve desired conditions regarding these resources.

Complementary roles for different land tenures, including the legitimate rights of private land holders, may be blended by using existing authorities (Salwasser et al. 1987) or concepts such as Biosphere Reserves (Gregg and McGean 1985) and landscape linkages (Harris and Gallagher 1989).

Process Principles

1. **Get people involved** in all aspects of public-resource decision making so that managers will know their needs and views; so that people will understand their personal responsibilities, what is possible, and what the relative tradeoffs are; and to obtain informed consent on the course of action selected. Use consensus building and negotiated problem solving (Wondolleck 1988) as primary approaches to conflict management. People who are affected by resource management and conservation strategies must feel a strong commitment to being part of the solution.
2. **Work within the scope of natural, social, and economic processes and their variability** that shape landscape, community, and ecosystem conditions. Work within the ecological capabilities and natural processes of different ecosystems and communities of people, maintaining as much diversity as possible and minimizing the energy costs of management to sustain or restore desired ecosystem conditions and functions. Always think about scale effects, both spatial and temporal, at least one scale higher and one scale lower than what you're working on and at least several generations into the future, more and longer if possible. Ecosystems are complex, but models should be relatively simple and management should strive to maintain options.
3. **Integrate information and technology**, such as ecological classifications, inventories, data-management systems, and predictive models, and use them routinely in landscape-scale analyses and conservation strategies. Agencies and affected interest groups and enterprises should contribute to common inventories of the basic conditions of soils, waters, and biota, and share data and other information as appropriate to their missions and property rights. Inventories of biological diversity in the U.S. should build from the foundation of state Heritage Programs (Jenkins 1988) and multi-resource inventories conducted by various state and federal agencies. They should allow prudent choices to be made based on realistic assessments of needs and priorities for investment and protection actions (e.g., Scott et al. 1987, Scott et al. 1991).
4. **Integrate management and research** to continually improve the scientific basis of ecosystem management. Agencies, universities, and affected interest groups and enterprises should cooperate in long-term, interdisciplinary ecosystem research and development. Managers need practical tools and methods for planning and evaluating the expected effects of management options. They also need expanded choices for sustainable harvest and management of resources.
5. **Revitalize conservation education and interpretation.** Agencies, universities, and affected interest groups and enterprises should cooperate in comprehensive programs of interpretation, education, and demonstration of ecosystem management. The result should be a better understanding among the citizenry about the effects of personal actions in sustaining desired ecosystem conditions and better support for the complementary roles played by different agencies and ownerships in overall conservation strategies.
6. **Develop, monitor, and evaluate vital signs of ecosystem health.** Agencies, universities, and affected interest groups and enterprises should cooperate in identifying and monitoring carefully selected indicators of ecosystem health and diversity, including conditions and trends of valued resources. Monitoring should be guided by the use of decision-analysis tools (Maguire 1988, 1991) to ensure that the most vital information is being collected in usable quality and in a timely fashion for the specific purpose of adapting management based on new information (Holling 1978, Walters 1986).

A BIGGER ROLE FOR RESEARCH

Research has a significant role in ecosystem management, including the use of scientific methods in understanding the basic capabilities of different ecosystems; discerning the needs and wants of people; setting ecologically, economically, and socially sound management goals; and designing monitoring systems that will allow for periodic adaptation to new knowledge (National Research Council 1990, Lubchenko et al. 1991). However, scientists are not the only source of information for solutions to difficult political and social choices. For example, there are no unique or scientifically perfect answers for how a balance of goals and practices for ecosystem management should be struck. People's values, preferences, and aspirations are crucial factors in policy making.

The role of science in ecosystem management is to help define what is possible and what is desired: to shed light on how best to attain a desired set of conditions or benefits and help people understand the estimated costs, benefits, and consequences of alternative courses. To fulfill this role effectively, social, biological, and physical sciences must be integrated to reflect the complexity of how ecosystems actually function.

BIOLOGICAL DIVERSITY AND ECOSYSTEM MANAGEMENT

The variety of life—plants, animals, and various microorganisms and fungi—and its many processes in ecosystems determines ecological capabilities. This variety is known by the term biological diversity (The Keystone Center 1991). It includes variation and variability in genes, species, plant and animal communities, and the many processes through which they are all interconnected through space and time.

Biological diversity is a valuable characteristic of ecosystems for ecological, economic, educational, and aesthetic reasons. It is key to the productivity and sustainability of earth's basic life-support systems. It provides numerous current and future resources for human well-being. It provides opportunities for better understanding the myriad of relationships between people and their sources of existence. And it contributes greatly to the beauty and wonder of the world we live in. Biological diversity also has an ethical element: how well we conserve biological diversity demonstrates our respect for other forms of life and our commitment to the well-being of future generations (Leopold 1949).

Scientists do not know all the ecological roles or potential values of biological diversity. Nor do they understand all the processes that keep ecosystems functioning. It is not likely that they ever will. But complete knowledge is not necessary to understand that retaining the natural parts and processes of biodiversity is important for the future health and productivity of all ecosystems (Leopold 1949). How to do this in the face of a growing human population is a major challenge (UNCED 1992).

Incorporating the conservation of biological diversity into ecosystem management requires actions aimed to achieve specific objectives for species, biological communities, and ecosystem conditions. A strategic framework for such actions and objectives has been developed for U.S. federal lands through a national policy dialogue (The Keystone Center 1991). Though the recommendations of the Keystone dialogue are not Federal- agency policy at the current time, they have been adapted here to offer land and resource managers and scientists a framework of specific and measurable goals. To guide on-the-ground actions, the following goals should be reflected in land-use allocations, standards in land and resource management plans, and working guidelines for project activities in specific places.

THREATENED OR ENDANGERED SPECIES

Listed species are the most vulnerable, officially recognized elements of biodiversity. A net removal of species from listed status in an area covered by a plan or program is an ideal goal to consider in ecosystem management. To accomplish this, management must follow approved recovery plans or habitat-conservation plans to protect existing populations and habitats of listed species and restore them if necessary.

VIABLE POPULATIONS OF NATIVE PLANT AND ANIMAL SPECIES

Species whose demographic or habitat trends are negative but not yet to the point of endangerment may be the next most vulnerable elements of biological diversity. Some such species may even be more vulnerable than officially listed species. The ideal goal is to secure the places and functions of native species in regional ecosystems before they reach the point where formal listing as a threatened or endangered species calls into play the extreme measures of protecting species under crisis conditions (Salwasser 1991).

To sustain viable numbers of native species habitats, human activities and artifacts, and wild populations of plants and animals must be managed to assure that they are numerous and well-distributed throughout their geographic ranges. This requires a combination of actions to protect, restore, and enhance sufficient kinds, amounts, qualities and distributions of sub-populations and habitats. Especially important in achieving population viability is the perpetuation of multiple, interconnected, demographically resilient local populations; the characteristic genetic variation of the entire species; and the full range of the species' roles in ecological processes. Principles of conservation biology (Soule and Wilcox 1980, Soule 1986, Soule 1987, Primack 1993, Meffe and Carroll 1994) are useful in this task.

NATIVE BIOLOGICAL COMMUNITIES AND ECOSYSTEMS

Rare, unique, or sensitive biological communities or successional stages (often highly productive sites, riparian areas, wetlands, and mature or old-growth successional stages) are likely to be vulnerable elements of biological diversity in certain landscapes. Lands, human activities and artifacts, and wildlife habitats must be managed to assure that a network of representative, native biological communities and developmental stages of ecosystems are maintained across the landscape (Noss and Cooperrider 1994). This may involve ecological restoration in some cases.

Especially important are communities or assemblages of species that are rare or imperiled in the region or nation (Jenkins 1988). The matrix conditions of a landscape should provide essential resources for all species to the degree this is possible, including conditions needed for normal movement of plants and animals throughout the landscape and for the full range of ecological processes characteristic to the area. Where this is not possible, a specific network of sites and connections between them may be needed. The sites and connections must be sufficiently large and diverse to accomplish their intended purposes.

STRUCTURAL DIVERSITY

Natural elements of structural diversity such as snags, caves, fallen trees, and seeps provide habitats for many species that would not occur in an area without them. These elements can be jeopardized by intensive human uses such as fuelwood gathering, heavy livestock grazing, clearcutting, and water diversions. Elements of structural diversity should be perpetuated in qualities, amounts and distributions within patches, and across landscapes to assure their roles in sustaining desired conditions of ecosystem diversity, productivity, and resilience from site to regional geographic scales (Franklin 1988).

GENETIC DIVERSITY

The genetic variation of intensively managed wild plant and animal populations can decline if sufficient attention is not paid to the effects of human selection for various traits. Species and habitats, especially those of high commercial value and thus intensively harvested, should be managed to sustain natural levels of genetic variation within and among populations, and the genetic integrity of representative and extreme populations (Ledig 1986, Millar 1987).

RESOURCES NEEDED FOR HUMAN WELL-BEING

Human well-being ultimately depends on natural resources (Chappelle and Webster 1992). People will obtain those resources from somewhere. The key is to produce them in ways that do not lead to undesired environmental effects at local, regional, or global scales. If resources can be produced in some ways and in some places that allow human pressures on biological diversity in other places to be reduced, then resource-production zones can have a positive and critical overall effect on biodiversity conservation. High-productivity sites such as flat ground with deep loamy soils, and featured species such as pines, firs, oaks, elk, and trout should, thus, be managed with state-of-the-art efficiency to sustain the production of resources needed by people, thereby meeting human needs for natural resources with minimal impacts on more fragile sites and more sensitive species.

ECOSYSTEM INTEGRITY—SOILS, WATERS, BIOTA, AND ECOLOGICAL PROCESSES

Any human activity has some effect on lands, waters, or biota. The removal of biomass or the introduction of toxics, exotic species, or nutrients has some effect on the composition, structure, and function of the local ecosystem. Ideally, these effects can be minimized through sensitivity to ecosystem integrity. Actions that are known to degrade site conditions or long-term ecosystem diversity, productivity, or resilience should be avoided if possible or mitigated promptly when not. The natural restorative powers of ecosystems should be employed in resource-management activities. Consider the kinds, amounts, and distribution of living and dead organic matter to be left in ecosystems for long-term diversity, productivity, and resilience following resource harvest along with how much biotic production of the system is to be removed for human uses. This is essentially a principle of treating the ecosystem as "capital" and the production as "interest" (Rowe 1992).

DEGRADED ECOSYSTEMS

Biological communities, waters, and soils that have been damaged by natural events or past human actions should be placed under restoration and renewal programs, embracing the concepts and methods of restoration ecology and management (Bonnicksen 1988, Cairns 1986, Jordan et al. 1987, Jordan 1988).

There is more to the conservation of biological diversity in ecosystem management than identified in this framework but these actions are a reasonable start on a comprehensive conservation program.

CLOSING THOUGHTS

The need for ecosystem perspectives in land and resource management is forcing people to try some new and some old thinking. Five themes characterize this integrated thinking:

- Sustain diverse and productive ecological systems.
- Integrate the different aspects of land and resource management, research and conservation.
- Improve the effectiveness of public participation in resource decision making.
- Build partnerships between resource users and resource managers.
- Strengthen teamwork between researchers and resource managers.

Sustaining desired ecological, economic, and social conditions in wildland ecosystems that are managed by different owners for multiple purposes is a big challenge. But it is not an impossible task if people realize that no single objective can dominate ecosystem management at all geographic scales or even at the same site for all times. Success in sustaining desired ecosystem conditions will depend on having scientifically sound, economically feasible and socially acceptable strategies for achieving combinations of ecological and social goals.

For example, it will depend on meeting specific objectives for viability of native species and biological communities such as spotted owls, grizzly bears, elk, and tall-grass prairies. It will depend on meeting specific objectives for the characteristics of landscapes such as habitat conditions that are aesthetically pleasing and allow for free movement of plants and animals over time. It will depend on coordination among people responsible for species or resources that transcend administrative boundaries such as the spotted owl, large predators, eagles, migratory birds and mammals, and timber and mineral resources. It will depend on practical management standards for the desired characteristics of distinct patches in a landscape, such as diversity of species, structures, and functions provided by snags, fallen trees, riparian areas, and prairie barrens. It will also depend on better integration of research with management, especially in monitoring conditions pertinent to objectives.

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