ECOSYSTEM MANAGEMENT AND MOOSE: CREATING A COHERENT CONCEPT WITH FUNCTIONAL MANAGEMENT STRATEGIES

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ABSTRACT: Ecosystem management is a popular but poorly defined concept in conservation biology. Current vague, non-operational definitions provoke criticism of the concept and undermine credibility of its associated principles. We propose a definition of ecosystem management that emphasizes essential qualities of the concept rather than its accidental associations or properties, and that explains functional and operational attributes of ecosystem management rather than its descriptive characteristics. Based on these criteria, we offer a definition of ecosystem management as "a pattern of prescribed, goal-oriented environmental manipulations that: (1) treat a specified ecological system of identifiable boundaries as the fundamental unit to be managed; (2) has, as its desired outcome, the achievement of a state or collection of states in the ecosystem such that historical components, structure, function, products, and services of the ecosystem persist within biologically normal ranges and with normal rates of change; (3) uses naturally occurring, landscape-scale processes as the primary means of management; and (4) determines management objectives through cooperative decision-making of individuals and groups who reside in, administer, and/or have vested interests in the state of the ecosystem". Achieving workable ecosystem management is currently hindered by the lack of a unified vision and system of values for ecosystems, the absence of permanent inter-agency bodies with authority to manage ecosystems across multiple jurisdictions, and the lack of administrative mechanisms for the translation of ecosystem research findings into ecosystem management policies. We propose strategies to overcome these obstacles and examine moose (*Alces alces*) as an example of a species that is both important to ecosystem management and may benefit from it.

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The concept of ecosystems dates to early in the twentieth century (Tansley 1935), but the concept of managing ecosystems is more recent. Of all modern efforts in the management and conservation of natural resources, none has proven more elusive in definition or more controversial in implementation than "ecosystem management." Speaking of the idea with unconcealed disdain, conservationist Michael Bean wrote, "rarely has a concept gone so directly from obscurity to meaninglessness without any intervening period of coherence" (Bean 1997). Less cynically, but not less optimistically, Berry et al (1998) wrote, "No single operational definition of ecosystem management exists, although its basic principles are understood."

In the United States, 18 federal agencies have adopted or are considering adoption of programs based on ecosystem management concepts (Congressional Research

Service 1994, Christensen et al. 1996, Haeuber 1996, Haeuber and Franklin 1996, Prato 1999). Representatives of 5 of these federal agencies participated in a signing of a joint agreement to proceed with ecosystem management at the Ecological Stewardship Workshop held in Tucson, Arizona in 1995 (Czech and Krausman1997). To support such efforts, a wealth of attempted definitions of ecosystem management exists, many written by the agencies themselves (Table 1). However, despite the intensity of effort and variety of expression, current ecosystem management has been described as "a loose collection of agency specific concept papers, policy guidance documents, and potential – or only partially implemented – administrative changes" (Haeuber 1996).

While some professionals view the concept of ecosystem management as an important paradigm shift, others see it is as the opposite, a vacuous phrase "desperately seeking a paradigm" (Lackey 1998). Various positions are: (1) that ecosystem management is not a new paradigm at all (Slocombe 1993, Taylor 1993, Czech 1995, Haeuber 1996); (2) that it is what managers have been doing all along (Irland 1994, More 1996, Berry et al. 1998); (3) that it is a dressed-up version of the U. S. Forest Service's old "multiple use" management (Czech and Krausman 1997); (4) that it should be called "public lands management because public lands are ecosystems" (Czech 1995); (5) that it is the same as conservation because it has the same goal and therefore should be renamed "ecosystem conservation" (Czech 1995); (6) that it is a conspiracy to reduce the extractive use of natural resources and expel private citizens from public lands (Christensen et al. 1996); and (7) that Aldo Leopold thought of it first (Czech 1995, Knight 1995, Grumbine 1998).

Vague, non-distinctive definitions of ecosystem management encourage and justify criticisms of the concept (Czech 1995). If we follow a classical authority such as Aristotle, a useful definition of ecosystem management would be one that expresses the essence or nature of the entity and not merely its accidental properties (Abelson 1967, More 1996). The ideal definition would be one that includes "all instances and only those instances" of the category we define, a definition specifying both the essence of ecosystem management and its boundaries. Equipped with such a definition, we would be able to determine immediately if something is or is not ecosystem management (More 1996). But to make progress in our understanding we must determine the essence or distinctive nature of ecosystem management compared to other management strategies.

Valuable as an operational definition of ecosystem management might be, the definition alone is insufficient. Mechanisms to enforce ecosystem management practices, and to overcome inherent and systemic obstacles to an ecosystem management approach must be constructed. In addition, the concept and practice of ecosystem management also raise legitimate concerns for those with vested interests in a particular species or resource. Specifically, is ecosystem management such a broad concept that it will prove insensitive to the values of individual species, such as moose (*Alces alces*)? For example, Crichton et al. (1998) warn that "moose management is not counter to conservation biology or most other administrative program orientations (such as ecosystem or habitat management), [however] a danger exists to the resource – moose – if management attempts to be too inclusive and if readjustment occurs at the sacrifice or compromise of programs that have been the mainstay of professional management all along." Thus, to be effective, ecosystem management

Table 1. Definitions of "ecosystem management" in 10 federal agencies in the United States (Congressional Research Service 1994).

Agency	Definition
Department of Agriculture	The integration of ecological principles and social factors to manage ecosystems to safeguard ecological sustainability, biodiversity and productivity.
Department of Commerce	
National Oceanic and Atmospheric Administration	Activities that seek to restore and maintain the health, integrity, and functional values of natural ecosystems that are the cornerstone of productive, sustainable economics.
Department of Defense	The identification of target areas, including Department of Defense lands, and the implementation of a "holistic approach" instead of a "species-by-species approach" in order to enhance biodiversity.
Department of Energy	A consensual process, based on the best available science that specifically includes human interactions and management; and uses natural instead of political boundaries in order to restore and enhance environmental quality.
Department of the Interior	
Bureau of Land Management	The integration of ecological, economic, and social principles to manage biological and physical systems in a manner safeguarding the long-term ecological sustainability, natural diversity, and productivity of the landscape.
Fish and Wildlife Service	Protecting or restoring the function, structure, and species composition of an ecosystem, recognizing that all components are interrelated.
National Park Service	A philosophical approach that respects all living things and seeks to sustain natural processes and the dignity of all species and to ensure that common interests flourish.
U.S. Geological Survey	Ecosystem management emphasizes natural boundaries, such as watersheds, biological communities, and physiographic provinces, and bases resource management decisions on an integrated scientific understanding of how the whole ecosystem works.
Environmental Protection Agency	To maintain overall ecological integrity of the environment while ensuring that ecosystem outputs meet human needs on a sustainable level.
National Science Foundation	An integrative approach to the maintenance of land and water resources as functional habitat for an array of organisms and the provision of goods and services to society.

must demonstrate that it is not only an operational concept, but that it can successfully meet needs of individual species of special importance in ecosystem function or of particular value to individual stakeholder groups. The role of individual species in ecosystem management must be stressed because some species are "drivers" and some are "passengers" in ecosystem processes. The drivers are active determinants of the characteristics of the ecosystem in which they live because of ecological functions that they perform in the system. The passengers "ride along" on the effects created by the drivers. Moose are unquestionably "driver" species, or, in more familiar terms, "keystone" species, in every ecosystem in which they have been carefully studied. They have disproportionate effects on community or ecosystem processes and, as a result, disproportionately affect the abundance of other plant and animal species, as well as habitat composition in the landscape. We evaluate the problems of defining ecosystem management operationally, suggest mechanisms for its implementation and offer moose as a "test case" regarding its effects on an individual species.

PARADIGM DEVELOPMENT OF ECOSYSTEM MANAGEMENT

Since the 1960s, managers of public lands and academics in applied sciences like wildlife management, range management, and forestry have written about "ecosystem concepts in management" (Major 1969; Van Dyne 1969; Wagner 1969, 1977). By the 1970s, the term "ecosystem management" was in common use (Czech and Krausman 1997). However, authors from this period almost always used such terms to describe either the management of populations as commodities or the manipulation of processes, structures, and functions of ecosystems in order to produce desired levels of animal populations or plant biomass (Major 1969; Wagner 1969, 1977).

If this is all that "ecosystem management" means, then the concept would certainly not meet the criteria for a scientific paradigm, nor would it represent a genuine "paradigm shift" to any new concepts or ideas. Ultimately, paradigms come to incorporate and express the values, theories, methods, and tools that a professional community prescribes and believes to achieve a desired condition (Kuhn 1970, Czech 1995). Although the modern concept of ecosystem management still struggles with the problem of poor definition, its connotative attributes are nevertheless very different from concepts about "ecosystems and management" that were expressed in the 1960s and 1970s. Today the increasing adoption of what is called "ecosystem management" does represent a genuine transfer of popular and professional loyalty from one group of ideas and values to another. This shift reflects a transfer of loyalty from the traditional "resource management" paradigm to values associated with ecosystem management.

Distinctions of the Ecosystem Management Paradigm

In the United States, major federal agencies have always had "jurisdiction" over ecosystems, but they have, until recently, never attempted to manage their jurisdictions "as ecosystems". Governed by a paradigm of resource management (RM), the entity of value was a particular "resource," either an individual species or an abiotic component of the system, such as water, soil, or a mineral. The resource was seen as a commodity and its value was "use." Biologically, this meant that, in a RM paradigm, the value units of management were the species or abiotic components and the spatial units of management were the sites on which they occurred. The outcome of RM at the biological level is single-species management, either as commodities (harvestable species of plants and animals) or as units of rarity to be preserved (endangered species). In RM, the mechanisms of management are site-specific activities performed by humans, usually through direct intervention. Time scales are relatively short-term, and jurisdictional authority and management decisions are within the boundaries of individual agencies. The long-term goal is optimal, renewable, and sustainable production of natural resources as commodities for multiple uses, and, within this larger aim, individual management objectives are set and determined by demand for commodities that the system can supply.

Ecosystem management has emerged as a meaningful alternative to the RM paradigm and to more local, site specific management approaches, largely through 4 recent scientific and technical achievements: (1) the estimation of minimum viable populations (MVPs) and population viability analysis (PVA), leading to the scientific consensus that small populations of individuals in isolated reserves will not persist in the long term; (2) the development of remote sensing data collection techniques and geographic information systems (GIS), which make the collection and analysis of landscape-scale data manageable; (3) increasing scale and complexity of environmental problems and associated threats that frustrate conservation efforts for individual species and habitats at local scales; and (4) a shift in public attitudes away from valuing the commodities produced by ecosystems for human use to valuing experience and appreciation of the functioning ecosystem itself. Thus, ecosystem management owes its emergence not only to shifting public values, but also to increased technical opportunity.

Entity of value and sustainability. – The ecosystem management (EM) paradigm has gained support because of its ability to deal with changing biological and sociopolitical structures that frustrate the RM paradigm. What gives the EM paradigm this advantage is a fundamental shift in the entity of value. In contrast to a former emphasis on the value of resources as commodities, EM assumes that the entity of value is the ecosystem itself. That is, the ecosystem, on its own, is perceived as an object worthy of respect and admiration, valued for its beauty, complexity, history, and cultural significance. Further, what is valued in the EM paradigm is a state or collection of states of the ecosystem that permit long-term delivery of overall ecosystem services, the stability and persistence of ecosystem components (resident populations and communities), and the continuing, long-term stability of transfers of matter and energy within the system. The purpose of achieving such a state is to ensure the persistence of the ecosystem and its functions. Specific management goals of how much can be taken from or used in the system are set by the capacity of the system to deliver the desired goods and services, not by the demand for the goods and services. The value of the ecosystem then rightfully entails human obligation to see that the ecosystem persists, and, although goods and services may be outputs of the ecosystem, the ultimate goal is the sustainability of the system, not the deliverability of resource commodities.

Biodiversity. – In the EM paradigm, the significance of individual elements of the ecosystem, whether communities, habitats, species, or abiotic features of climate, landscape, topography, soil, water, or elements are understood and determined in relation to their role in the stability and functioning of the system. All such components may have roles in the ongoing structure and function of the system, and as such they are considered and conserved at appropriate levels in management. Thus, EM is more attractive to current managers and conservationists than RM. Faced with continued increases in endangered and threatened species, managers are learning that management of ecosystems and landscapes often represents the only way to save both endangered species and overall biodiversity (Wilson 1986, Franklin 1993), as well as a means to preserve rare or poorly known habitats and ecological subsystems (Franklin 1993).

Management mechanisms and decisions. — In EM, the mechanisms of management are primarily through identification and manipulation of landscape-scale processes. Management time scales are long-range, and units of management are large areas that may not fall within the jurisdiction of a single agency or government control, but may include jurisdictions of various levels of government as well as private ownership. Thus, management decisions must incorporate decision-making strategies that involve all agencies with jurisdiction over lands or processes in the ecosystem, private landowners within or adjacent to the system who depend on outputs and services from the system, and nonresidents who have an interest in the state of the system.

With these concepts in mind, we offer a definition that distinguishes ecosystem management from other types of land and resource management. We propose that ecosystem management be defined as "a pattern of prescribed, goal-oriented environmental manipulations that: (1) treat a specified ecological system as the fundamental unit to be managed; (2) has, as its desired outcome, the achievement of a state or a collection of states in the ecosystem such that historical components, structure, function, products, and services of the ecosystem will persist within biological and historical ranges and rates of change over long time periods; (3) uses naturally occurring, landscape-scale processes as the primary means of achieving management objectives; and (4) determine management objectives through cooperative decision-making of individuals and groups who reside in, administer, and/or have vested interests in the state of the ecosystem".

Grumbine's 10 themes of ecosystem management (Grumbine 1994), the ESAs 8 primary characteristics of ecosystem management (Christensen et al. 1996), and More's (1996) 5 dimensions of ecosystem management can be seen as parallel expressions of similar values and concepts. These dimensions include; (1) the long-term sustainability of the ecosystem; (2) the maintenance of viable populations of all native species; (3) the representation of native ecosystem types across their natural range of variation within protected areas; (4) management through ecological processes; and (5) the accommodation of human use and occupancy within management constraints.

The development of ecosystem management has consistently included and stressed 3 premises. First, the ecosystem, rather than individual organisms, populations, species, or habitats, is considered the appropriate management unit. Second, emphasis is placed on the development and use of adaptive management models, which treat the ecosystem as the subject of study and research, and treat management activities as experimental and uncertain. This means that in ecosystem management, management decisions represent hypotheses about how ecosystems work. Management actions that implement such decisions are therefore to be viewed as experimental tests of such hypotheses, and the outcomes of such management actions represent the results of these tests. Thus, in ecosystem management, management decisions should carefully consider all reasonable alternatives. Management actions should, whenever possible, follow careful experimental design, include environmental controls (untreated sites or subjects), and be carefully monitored over time. The outcome of the management action should be viewed in terms of whether it supported or refuted the hypothesis of the management decision, and future decisions should be considered accordingly, under the full light of professional scientific scrutiny and public accountability. If the experimental design is sound, the results of the management action should be relatively unambiguous, but must still be interpreted stochastically (within a range of outcomes with differing probabilities), rather than as deterministic outcomes generated by simple cause-and-effect relationships. Finally, ecosystem management is characterized by processes in which those with vested interests in the health and services of the ecosystem (stakeholders) participate in management decisions.

Defining the Value and Function of Ecosystem Management

More (1999) defined public parks (such as national parks or national forests) as "organizations of natural and social resources that have been set aside in the public domain to accomplish a function or set of functions. Generally these functions concern the preservation of a unique or …scarce resource in the service of the public good, both for present and future generations." In the modern concept of ecosystem management, the ecosystem replaces the more limited concept of "park" as the entity of organization, but the need to define the function of the entity remains essential. For ecosystem management to succeed, managers must begin by defining explicitly what function or functions are to be accomplished by the ecosystem and its management. Specific functions will vary according to individual ecosystems. Most functions will require management for provision of essential ecosystem services, including climate and water regulation, conservation of native species, protection of interests of stakeholder groups, efficient use of ecosystem production that can be used as commodities, and long-term persistence of the ecosystem to ensure continuance of these services.

A clear articulation of the function and values of ecosystem management is required to develop a unified set of values and objectives with the public, other government agencies and legislative bodies, and with specific stakeholder groups. Stakeholders are operationally defined as "persons or groups that have, or claim, ownership, rights, or interest" in the ecosystem and its management, past, present, or future (Clarkson 1995). Following values analysis, a management agency should subsequently conduct a "stakeholder analysis," identifying various stakeholder groups and the nature of the vested interest of each in the management of the system (Stead and Stead 2000). Stakeholders generally claim interest, ownership, or rights (legal, moral, individual, or collective) in a system as a result of past transactions between themselves and at least one of the managing agencies (Clarkson 1995). If managers can successfully define and articulate the function of the ecosystem and its management in a manner that addresses the legitimate claims, rights, and ownership of stakeholders, they can then evaluate ongoing and proposed management activities by objective guidelines. In turn, managers are then accountable for those guidelines.

Managing Ecosystem Components, Structure, and Ecological Function

Historically, a problem in managing ecosystem components, such as species, at the ecosystem level has been the lack of a generally accepted classification system of what constitutes a fundamental biological conservation unit in ecosystems. A first step is to categorize ecosystems at regional, coarse, intermediate, and local geographic scales (Fig. 1, Poiani et al. 2000). Once identified, ecosystem conservation requires identification and protection of focal ecosystems and the ecological processes that sustain them (Pickett et al. 1992, Meyer 1997). One methodology to meet these requirements is through the identification of "functional conservation areas," defined as geographic domains that "maintain focal ecosystems, species, and supporting ecological processes within their ranges of variability" over the long-term (100-500 years) (Fig. 2, Poiani et al. 2000). Three scales for functional conservation areas are recognized: sites, landscapes, and networks. Sites conserve a small number of ecosystems or species at scales below landscape levels, while landscapes conserve many ecosystems and species at scales below regional levels. Networks are integrated sets of sites and landscapes designed to protect regional scale species (Poiani et al. 2000). An ecosystem can be judged to be "functional" according to 4 criteria: (1) it possesses the historic composition and structure of the ecosystem and its species within a natural range of variability; (2) its dominant environmental regimes are controlled by natural processes; (3) it is sufficiently large to possess at least one minimum dynamic area (50 times the size of the average disturbance patch) (Pickett and Thompson 1978); and (4) it is connected to other essential landscape elements and its species are free to move among those elements.

Managing Stakeholder Groups, Ecosystem Jurisdiction and Political Process: The Obstacles to Ecosystem Management

In the United States, one of the intentions of the elaborate planning and complex procedural requirements inherent in the Forest and Rangeland Renewable Re-

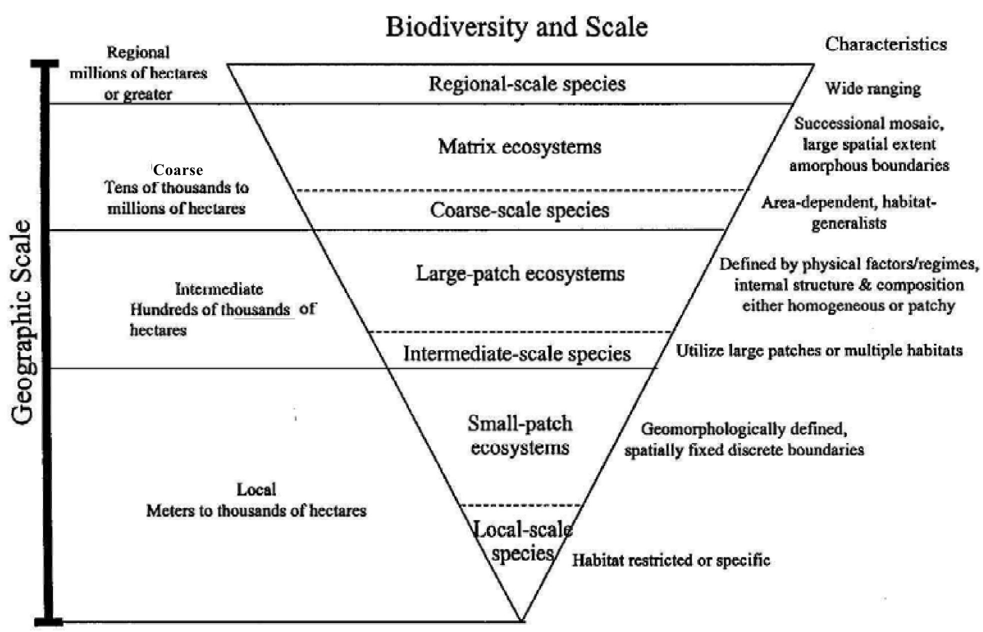

Fig. 1. A method of categorizing ecosystems at regional, coarse, intermediate, and local geographic scales. Modified from Poiani et al. (2000) - ©2001 American Institute of Biological Sciences.

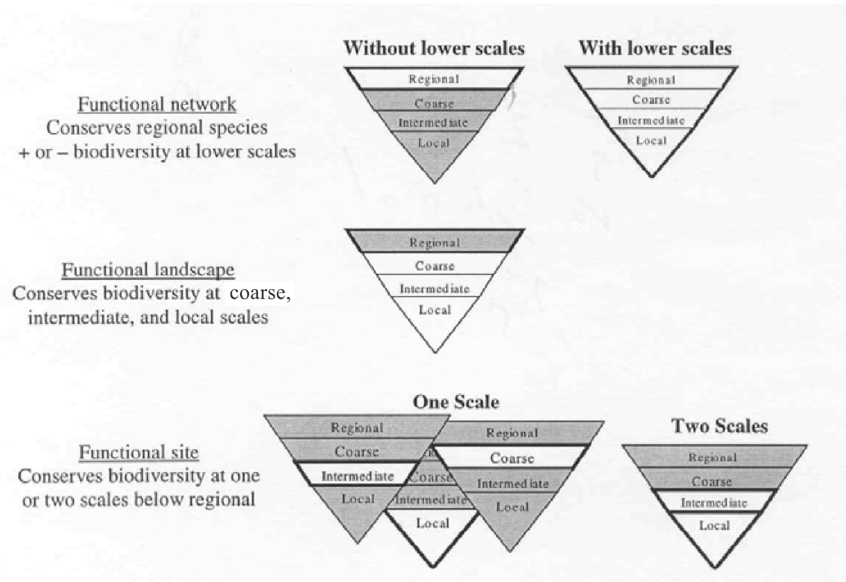

Fig. 2. Definitions of functional sites, landscapes, and networks and their relationships to biodiversity at various spatial scales. Modified from Poiani et al. (2000). © 2001 American Institute of Biological Sciences.

sources Planning Act of 1974 (RPA) and the National Forest Management Act (NFMA) of 1976 was to improve decision-making and reduce conflict over use of the nation's forest and range resources. In fact, the opposite has occurred. The RPA has become an object of ridicule within and outside of government agencies because it mandates long-range assessment and planning, but contains no funding mechanisms to achieve it (J. Kie, personal communication). Forest planning under the NFMA has not fared much better. By 1990, 14 years after the passage of the NFMA, 92 of 94 completed forest plans were under appeal. Five were in court and one was declared illegal. Further, 332 active appeals were pending against these plans, brought by conservation groups, commodity interests, off-road vehicle enthusiasts, state and local governments, Native American tribes, and private citizens (Behan 1990). Such litigation manifests, in part, the long and difficult process of achieving a consensus about values in ecosystem management. The NFMA directed the Forest Service toward an ecosystem management approach, and engagement in that process requires a long-term commitment to achieve lasting agreement over ecosystem values and management actions. However, the necessary conditions of public cooperation and trust remain unrealized.

Such failures in public cooperation and trust will be a fatal obstacle to ecosystem management if they are allowed to persist. Successful ecosystem management will require the creation of permanent inter-agency committees, boards, and working groups in which all agencies and all primary stakeholders from the private sector are presented. Such bodies must then move the concept of ecosystem management from the "discussion agenda" (visions discussed or defined by individual agencies) to the "decision agenda" (ideas that are submitted for decisive agency action). We identify 3 obstacles that such groups must overcome to achieve functional ecosystem management and ultimately produce effective procedures that translate ecosystem management into policy.

The need for unified vision and values for ecosystems and ecosystem management. — The resource management paradigm invested all decision making within the individual agency judged responsible for a particular resource, or for a particular land unit within the agency's jurisdiction. In contrast, ecosystem management is actually a management system of stakeholder groups and management agencies. Therefore stakeholders and agencies must have unifying values and purposes to participate constructively in managing ecosystems. The present reality is one of polarized, fragmented groups of stakeholders and agencies with different and conflicting values and visions of ecosystems, leading to separate agendas that foster distrust and conflict.

For example, one research tool used to evaluate the interests of corporate stakeholders is the "survey inventory," a list of up to 50 different issues important to stakeholders in corporate cultures (Clarkson 1995). In a personal interview or written response, stakeholders rank listed issues according to their perceived importance. Managers then use these responses as a first step to identify stakeholder interests, and begin to build value systems and management strategies informed by these rankings. The rankings collected directly from the stakeholders not only better inform managers of stakeholder interests, but also help managers to distinguish between "social issues" of ecosystem management (matters of importance to society at large, often already regulated by existing laws and regulations) and "stakeholder issues" (matters of importance to particular groups, often unregulated and not addressed by existing laws and regulations).

Tools such as survey inventories could help managing agencies and stakeholders to more clearly define and reach agreement on the management agencies' "responsibilities to stakeholder groups". If responsibilities for management are made explicit, they help to define what the prescribed outcomes of ecosystem management ought to be. If these responsibilities are fulfilled, agency-stakeholder relations grow in trust, move toward effective cooperation, and improve prospects for long-term success in ecosystem management. The performance of the agency can then be better evaluated by the stakeholders, and serve as a basis for discussion of future management strategies.

The need for unified sources of information and analysis. — To cooperate effectively in ecosystem management, diverse agencies need a common clearinghouse of information and analysis regarding ecosystem processes and their responses to management systems. However, current information is dispersed among scientific literature, proceedings of professional conferences, and agency reports. The information varies in quality, reliability, focus, format, and accessibility, and there are currently no uniformly accepted standards for data collection among agencies. We propose that such a clearinghouse be created, with appropriate oversight by agencies with jurisdiction over the ecosystem, before a management plan be developed for any particular ecosystem.

The need to translate research into policy — If ecosystem management is to have a basis in science and a foundation of professional credibility, it must have the means to smoothly translate reliable research findings into informed policy. This condition requires established and ongoing channels of communication and high levels of trust among researchers, managers, and lawmakers. Berry et al. (1998), for example, call for a radical restructuring of the ecosystem management effort. Their proposal includes: (1) a federal, legislative mandate to achieve ecosystem management in all federal land management agencies; (2) establishing regional "Boards of Ecosystem Management Research" with representatives of all major stakeholders; (3) a common information clearinghouse to set clear and consistent standards for ecosystem research and serve as a single source for getting results of past studies; (4) an independent science oversight group, responsible to the board and appointed independently of any one agency or interest group to provide direction and review of current research and management efforts; and (5) a Project Management Team responsible to the Board that would collect research, development, and operational funds from agencies and stakeholder groups and allocate them to appropriate research efforts. The team would be advised of the merits of proposals and outcomes by outside researchers through independent peer review.

IMPLICATIONS OF ECOSYSTEM MANAGEMENT FOR MOOSE

Currently, most jurisdictions with large moose populations manage moose as a featured species because of recreation, aesthetic, and economic considerations (Thompson and Stewart 1998). As noted earlier, some have voiced concern that ecosystem management represents such a broad approach that individual species, such as moose, might not be effectively managed (Crichton et al. 1998). In contrast, we suggest that moose populations may benefit from ecosystem management. Moose have an affinity for early successional vegetation that tends to increase under management that actively employs ecosystem processes such as fire and flooding. Moose also have high value among multiple stakeholder groups. Finally, moose are often associated with habitats of high species richness. We also explore the potentially negative effects of large predators on moose populations. These effects may increase under ecosystem management practices that encourage the persistence, and even growth, of such predator populations.

Moose and Ecosystem Processes

In both aquatic and terrestrial environments, moose can exert profound influence on the plant species composition, habitat distribution, and nutrient cycling of ecosystems. For example, in northern boreal forests, moose prevent saplings of preferred species from growing into the tree canopy, resulting in a forest with fewer canopy trees and a well-developed understory of shrubs and herbs (McInnes et al. 1992). At light to moderate levels, browsing leads to increased production efficiencies (higher rates of production per biomass) in shrubs and saplings. Through browsing, moose also reduce the quantity and quality of litter and soil nutrients, driving a complex set of ecological interactions between browse, litter quality, and soil nutrients (McInnes et al 1992). Similar effects are seen in mixed deciduous-coniferous forests, where moose typically browse preferentially on deciduous hardwoods. This pattern of feeding not only changes forest composition, but, more generally, reduces nitrogen mineralization, nitrogen inputs, and overall primary productivity of the forest because the browsing reduces the quantity and quality of litter returned to the soil (Pastor et al. 1993). Moose, in conjunction with snowshoe hare (*Lepus americanus)*, also can reduce fine root production in plants as a result of their herbivory on aerial biomass (Ruess et al. 1998). In lakes and ponds, moose may consume up to 95% of submerged aquatic vegetation, particularly various species of pond lilies, which can trigger significant declines in such plant populations and induce major changes in plant species composition in the pond (Belovsky 1981a).

Habitat Relationships

The intermediate disturbance hypothesis predicts that maximum species diversity, particularly plant species diversity, is most likely to occur in habitats experiencing intermediate or moderate levels of disturbance (Loucks 1970, Connell 1978, Petraitis et al. 1989), because disturbance removes a subset of pre-existing species, making a portion of the area available for colonization. Too little disturbance reduces areas available for colonization, and too much eliminates too many pre-established species, creating a "species debt" that new colonist species cannot fill in a short time. Thus, ecosystem management must seek to incorporate both natural and prescribed patterns of environmental disturbance at intermediate levels to achieve its goal of enhancing the persistence of native species and the overall species richness of the ecosystem. While the terms "intermediate" and "moderate" are not always well-defined, they are often used to refer either to the magnitude of the disturbance or to its frequency or both (Bendix 1997).

On historic range, moose have typically occupied habitats associated with intermediate levels of disturbance, specifically habitats where vegetation is dominated by relatively short-lived species that are adapted to disturbances of intermediate strength and frequency, such as fire and flooding. In south-central Montana, for example, Shiras moose (*A. a. shirasi*) preferred aspen (*Populus tremuloides*) habitats in all seasons compared to all other available habitat types Table 2, Van Dyke et al. 1995). Aspen is a short-lived deciduous tree whose presence in the surrounding landscape of a coniferous forest is strongly dependent on recurrent fire of intermediate frequency and magnitude. Fire does not automatically ensure prolific growth and regeneration, but, on suitable sites, mature aspen with sufficient pre-burn root biomass will produce a strong suckering response with densities of up to 110,000 shoots per ha (Renkin

Table 2. Seasonal habitat selection by 3 male (M) and 10 female (F) moose in the Fiddler and Fishtail Creek drainages, south-central Montana, 1989-93. Numbers indicate percentages. Symbols in parentheses indicate selection for (+), selection against (-), or no selection (0). P (P = probability that difference between use and availability is due to random variation)< 0.01 for all cases of selection and for differences between sexes, except where noted. After Van Dyke et al. (1995). Used by permission.

		Moose locations %				Annual		
Cover type	Available	Winter	Spring	Summer	Autumn	M use	F use	Pattern
Aspen	17.5	43.0 (+)	40.2 (+)	56.5 (+)	36.0 (+)	60.0 (+)	40.2 (+)	M>F
Shrub-dominated wetland	8.1	23.9 (+)	20.7 (+)	8.7 (0)	17.4[1] (0)	17.1[1] (0)	16.5 (+)	M=F
Lodgepole	55.0	21.8 (-)	20.7 (-)	17.4 (-)	31.1 (-)	12.6 (-)	25.4 (-)	M<F
Other coniferous forest	7.5	7.7 (0)	13.2 (0)	10.9 (0)	5.0 (0)	8.0 (0)	10.0 (0)	M=F
Other non-forest	11.9	3.5[2] (-)	5.2 (0)	6.5 (0)	10.6 (0)	2.2 (-)	7.9 (0)	M<F

[1] $P = 0.06$.

[2] $P = 0.02$.

and Despain 1996). Forest ecosystem management regimes that stress the importance of both natural and prescribed fires are likely to increase frequency of aspen and other fire induced species in a landscape otherwise dominated by coniferous forests. Aspen and other fire-induced vegetation are consistently associated with high-quality sites for moose (Geist 1999:44).

Moose also make extensive use of shrub-dominated wetlands (Peek 1974, Van Dyke et al. 1995), typically willow (*Salix* spp.) and alder (*Alnus* spp.) swamps associated with the banks and floodplains of streams, especially in spring (Geist 1999:42). Not only do floodplain communities provide high quantities of digestible and accessible forage, but plants that grow on silt carried in seasonal flows also tend to contain high levels of minerals, meeting important nutrient demands for moose (Geist 1999:42). Thus, floodplain communities are best maintained by seasonal, variable waterflows, an important element of ecosystem management for riparian systems (Leopold 1994). Management for variable, rather than constant, flows of water also contributes to the persistence of small, shallow lakes. These systems have been referred to as "pulse-stabilized" ecosystems because they are the products of seasonal peaks ("pulses") of water, scouring by floods and ice, and recurring sediment deposits (Geist 1999:44). Moose often use such lakes extensively to obtain aquatic vegetation high in specific nutrients, such as sodium (Belovsky 1981b).

Predators

Ecosystem management is likely to encourage the persistence of large predators, such as grizzly bears (*Ursus arctos*), black bears (*U. americanus*), and wolves (*Canis lupus*), if such predators are already present, to permit their persistence if the predators invade the area from another ecosystem, or to actively encourage their introduction. The question of whether predators limit moose populations is controversial (Boutin 1992, Van Ballenberghe and Ballard 1998) and may depend on forage quality (Crête and Courtois 1997), moose density, or predator species and assemblages (Crête 1987, Gasaway et al. 1992). Some trends have been established however. Moose likely modify their use of habitat in the presence of large predators, restricting their use of optimal foraging areas (Kie 1999) and making demonstrable trade-offs between risk minimization from predators and forage maximization (Bowyer et al. 1999). Such restrictions may limit moose population size and growth. Further, the direct mortality inflicted by predators may hold moose populations below carrying capacity under certain conditions (Gasaway et al. 1992, Van Ballenberghe and Ballard 1994, Kunkel and Pletscher 1999), and especially where moose are at low densities (Crête 1987, Gasaway et al. 1992).

Value Among Stakeholder Groups

Although ecosystem management must serve the good of society, it is stakeholder groups and their interests, not society as a whole, that must be identified for ecosystem management to be effective (Clarkson 1995). Moose are an important species to some major stakeholder groups, whose support is essential to successful ecosystem management, including such diverse constituencies as hunters, non-consumptive recreationists (especially hikers, campers, backpackers, and photographers), First Nation peoples, and professional game and forest managers. The identification of the values that each stakeholder group ascribes to moose, and the methods of optimizing such values, is critical to successful involvement of such stakeholders in the forest management process. Such involvement has financial implications, as well as implications for social and political participation. For example, user fees, while remaining controversial, are likely to increase as funding components in an ecosystem approach to management, particularly in cases where management activities must be supported by cooperative revenue-sharing among different public agencies and between public and private sectors. In fact, user fees may be an essential factor in full political representation for some stakeholder groups, because user fees can contribute to increased funding for budgets of non-commodity programs and management activities (Morton 1997), thus providing for an equity of budget representation that is essential to ecosystem management. Moose represent an entity that specific users are likely to pay for, whether the users are hunters oriented by commodity consumption (license fees), campers and backpackers oriented towards esthetic experiences, non-hunting recreation, and education (campground and trail fees in areas where moose are likely to be seen), or skill-oriented users like photographers who might pay user fees for the opportunity to photograph moose at specific locations.

Conservation of Native Species and Enhancement of Species Richness

Enhancement of habitats that are used by moose is likely to increase the species richness of the forest ecosystem, an outcome consistent with the goals of ecosystem management. For example, plant species richness is higher in aspen communities than in other types of surrounding montane forest communities such as lodgepole pine (*Pinus contorta*) and Ponderosa pine (*P. ponderosa*) (Stohlgren et al. 1999). However, aspen forests also contain more exotic species and may be more susceptible to invasion by exotics (Stohlgren et al. 1999). Thus, an increasing abundance of aspen, although of benefit to moose, may pose special challenges to ecosystem managers because such habitat can be a source for invasion and subsequent spread of non-indigenous species (NIS). NIS, among their other effects, tend to alter natural fire cycles (D'Antonio and Vitousek 1992), nutrient cycling (Vitousek 1990), wildlife forage quality (Medina 1988, Trammell and Butler 1995), and wildlife grazing patterns (Trammell and Butler 1995).

SYNTHESIS

Ecosystem management represents a conceptual shift from a former focus on resource management to an emerging focus on seeing ecosystems themselves as the primary entity of management. Contemporary managers live in an uncomfortable transition period between the former philosophies of resource management (which made individual commodity resources the primary entity of management) and the emerging paradigm of ecosystem management. For such a transition to continue, ecosystem management must be articulated in a clear, operational definition that provides operational criteria to agency decisions. Without such rigorous definition, the value-oriented terms associated with ecosystem management will simply be appropriated to describe traditional agency objectives in new, more socially acceptable prose. If a functional definition of ecosystem management can be enforced, many obstacles yet stand in the way of its achievement. Essential elements to overcome these obstacles are: (1) development of a shared system of visions and values for ecosystem management, with intentional translation of such values into explicit proposals for agency action and decisions; (2) greater inter-agency cooperation through the creation of inter-agency boards of ecosystem management with independent budgets and administrative jurisdictions to implement ecosystem management strategies; (3) greater use of theories of stakeholder management, from business and administrative science, and greater inclusion of non-agency groups in decision making to successfully incorporate stakeholder interests into management decisions; and (4) common clearinghouses of information on ecosystems accessible to all participating agencies and stakeholders. Properly understood and enforced, ecosystem management holds promise as a paradigm that can address the increasing complexity of environmental problems on public lands in the context of an emerging national consensus of ecosystem value and, at the same time, provide management options sensitive to individual species, such as moose, of particular value to individual stakeholders.

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