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Ecosystem management decision support for federal forests in the United States: A review[1,2]

H. Michael Rauscher*

USDA Forest Service, Southern Research Station, Bent Creek Research and Demonstration Forest, 1577 Brevard Rd., Asheville, NC 28805, USA

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Abstract

Ecosystem management has been adopted as the philosophical paradigm guiding management on many federal forests in the United States. The strategic goal of ecosystem management is to find a sensible middle ground between ensuring long-term protection of the environment while allowing an increasing population to use its natural resources for maintaining and improving human-life. Ecosystem management has all the characteristics of 'wicked' problems that are tricky, complex, and thorny. Ambiguities, conflicts, internal inconsistencies, unknown but large costs, lack of organized approaches, institutional shock and confusion, lack of scientific understanding of management consequences, and turbulent, rapidly changing power centers all contribute to the wickedness of the ecosystem management paradigm. Given that ecosystem management, like human survival and welfare, is a wicked problem, how can we proceed to tame it? Managers need to use the same tools that people have always used for handling such problems – knowledge, organization, judicious simplification, and inspired leadership. The generic theory of decision support system development and application is well developed. Numerous specific ecosystem management decision support systems (EM-DSS) have been developed and are evolving in their capabilities. There is no doubt that given a set of ecosystem management processes to support and adequate time and resources, effective EM-DSS can be developed. On the other hand, there is considerable doubt that sufficiently detailed, explicitly described and widely accepted processes for implementing ecosystem management can be crafted given the current institutional, educational, social and political climate. A socio-political climate in which everyone wants to reap the benefits and no one wants to pay the costs, incapacitates the federal forest management decision making process. Developing a workable ecosystem management process and the decision making tools to support it is probably one of the most complex and urgent challenges facing us today. This paper offers a concise review of the state of the art of decision support systems related to implementing ecosystem management. A conceptual model of the context in which ecosystem management is expected to function is presented. Next, a candidate for an operational ecosystem management process is described and others are referenced. Finally, a generic ecosystem management decision support system is presented and many existing systems briefly described. © Published by Elsevier Science 1999.

Keywords: Ecosystem management; Decision analysis; Management systems; Management philosophy; Decision support system

*Corresponding author. Tel.: +1-828-667-5261; fax: +1-828-667-9097; e-mail: mrauscher/srs_bentcreek@fs.fed.us

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1. Introduction

After almost 20 years of increasingly contentious public unhappiness with the management of national forests, the USDA Forest Service officially adopted ecosystem management as a land management paradigm (Overbay, 1992). Other federal forest land management agencies such as the USDI Bureau of Land Management, the USDI National Park Service, the USDI Fish and Wildlife Service, the USDC NOAA, and the Environmental Protection Agency have also made the commitment to adopt ecosystem management principles (FEMAT, 1993; GAO, 1994). Many excellent historical reviews trace the history of environmental management on forest lands in the United States (Botkin, 1990; Kimmins, 1991; Kennedy and Quigley, 1993; Caldwell et al., 1994; Shands, 1994).

Ecosystem management represents different things to different people. A recent report by the United States general accounting office states that ecosystem management is a popular concept partly because "there is not enough agreement on the meaning of the concept to hinder its popularity" (GAO, 1994). At the heart of the ecosystem management paradigm lies a shift in emphasis away from sustaining yields of products towards sustaining the ecosystems that provide these products (Thomas, 1995). Overbay (1992) provided the definition of ecosystem management that the USDA forest service uses: 'Ecosystem management is the means we use to meet the goals specified in our programs and plans. Ecosystem management is the means to an end. It is not an end itself. We do not manage ecosystems just for the sake of managing them or for some notion of intrinsic ecosystem values. We manage them for specific purposes such as producing, restoring, or sustaining certain ecological conditions; desired resource uses and products; vital environmental services; and aesthetic, cultural, or spiritual values".

In contrast, non-governmental scientists tend to define ecosystem management in terms of sustaining 'intrinsic ecosystem values.' For example, Grumbine (1994) identified 10 dominant themes of ecosystem management which led to his formulating the following definition: "Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting native ecosystem integrity over the long term."

In this view, ecosystem management is specifically not aimed at resource management, but rather on protecting ecosystem integrity and the needs of non-human life for its own sake – both 'intrinsic ecosystem values' (Grumbine, 1994). As the ecosystem management concept evolves, debates over definitions, fundamental principles, and policy implications will probably continue and shape the new paradigm in ways not yet discernible. A strategic goal for ecosystem management on federal forests might be to find a sensible middle ground between ensuring the necessary long-term protection of the environment and protecting the right of an ever-growing population to use its natural resources to maintain and improve human life.

The ecosystem management paradigm was adopted quickly. No formal studies were conducted to identify the consequences of the changes ushered in by this new approach nor was any well-documented, widely accepted organized methodology developed for its implementation (Thomas, 1997). Today, ecosystem management remains primarily a philosophical concept for dealing with larger spatial scales; longer time frames; and the requirement that management decisions must be socially acceptable, economically feasible, and ecologically sustainable. As the definition and fundamental principles that make up the ecosystem management paradigm have not yet been resolved and widely accepted, the challenge is to build the ecosystem management philosophical concept into an explicitly defined, operationally practical methodology (Wear et al., 1996; Thomas, 1997). Effective ecosystem management processes are urgently needed to allow federal land managers to more effectively accommodate the continuing rapid change in societal perspectives and goals (Bormann et al., 1993).

Ecosystem management represents a shift from simple to complex definitions of the ecosystems we manage (Kohm and Franklin, 1997). Ecosystem management will require the development of effective, multi-objective decision support systems to: (1) assist individuals and groups in their decision making process; (2) support rather than replace the judgement of the decision makers; and (3) improve the quality, reproducibility, and explainability of the decision process (Janssen, 1992; Larsen et al., 1997; Reynolds et al., 1998). The complexity of environmental dynamics over time and space; the overwhelming amounts of data, information, and knowledge in different forms and qualities; and the multiple, often conflicting, management goals virtually guarantee that few individuals or groups of people can consistently make good decisions without powerful decision support tools (Janssen, 1992).

This paper reviews ecosystem management decision processes, the decision support systems available to implement them, and discusses some issues that must be settled before ecosystem management can evolve from a philosophical concept to a practical tool.

2. The nature of the ecosystem management problem

The lengthy and ongoing struggle to manage federal forests over the last 20 years has taught managers many characteristics of the ecosystem management problem. First, societal goals, preferences, and values are numerous, ambiguous, and often in conflict. Second, legal mandates are complex, unclear, and at times self-contradictory. Third, policy direction is missing, ambiguous, or incomplete with a tendency to rapidly shift in response to political pressure. Fourth, no well-defined and widely accepted decision making process exists. Decisions and the decision making process are usually based on trial-and-error methods and local, pragmatic inventions of necessity. Fifth, participating decision makers and stakeholders vary in the amount of time and effort they contribute to any one decision while engaging only sporadically in the decision making process. Sixth, no widely accepted method is available for producing concensus among often contentious stakeholders. Individuals or small minorities have the power to block decisions at any time through judicial challenges resulting in managerial gridlock. Seventh, decisions must be made about actions and their consequences based on missing and uncertain data, and often inaccessible scientific knowledge about ecosystems. Also, the ecosystem management problem is not as much about science as it is about politics (Rittel, 1972; Grumbine, 1994). The ecosystem management debate is a competitive, conflict-laden social process that determines how power flows in resource management (Grumbine, 1994; Chase, 1995).

2.1. *The characteristics of wicked problems*

Clearly ecosystem management is a ‘wicked’ or unstructured problem as defined by Rittel and Webber (1973) and introduced to forestry by Allen and Gould (1986). ‘Wicked’ is used here in the sense of tricky, complex, and thorny. Wicked problems have no definitively correct formulations. Stakeholders can define the problem on their own terms. Any one definition can only be more or less useful depending upon the definition of useful. Wicked problems have no stopping rule to identify when they are ‘solved.’ Solutions are not true or false, but good or bad and the only way to test the goodness or badness of solutions is to execute them. Wicked problems do not have an enumerable or an exhaustively describable set of potential solutions. Since they tend to be important with significant consequences, decision makers have no right to be wrong, making the decision process intensely agonizing and usually frustrating (Allen and Gould, 1986). Finally, we do not have a theory that tells us how to identify a socially best state such as ‘the greatest good for the greatest number’ (Rittel and Webber, 1973). Problem-solving processes for ecosystem management and other wicked problems can be developed, but perhaps not by exclusive use of rationally based, operations research or systems analysis methods (Rittel, 1972; Allen and Gould, 1986; Hashim, 1990). Such methods have worked well for the ‘tame’ problems of science and technology where the impact of the human dimension on the problem is eliminated or strictly controlled. Using tame problem-solving methods on wicked problems often results in failure. Barber and Rodman (1990) provide a devastatingly powerful illustration.

Given that ecosystem management, like human survival and welfare, is a wicked problem, how can we tame it? We must use the same tools people have always used for handling wicked problems – knowledge, organization, judicious simplification, and inspired leadership. The remainder of this section focuses on examining a number of organizational structures for implementing ecosystem management. Three levels of organization are important in the

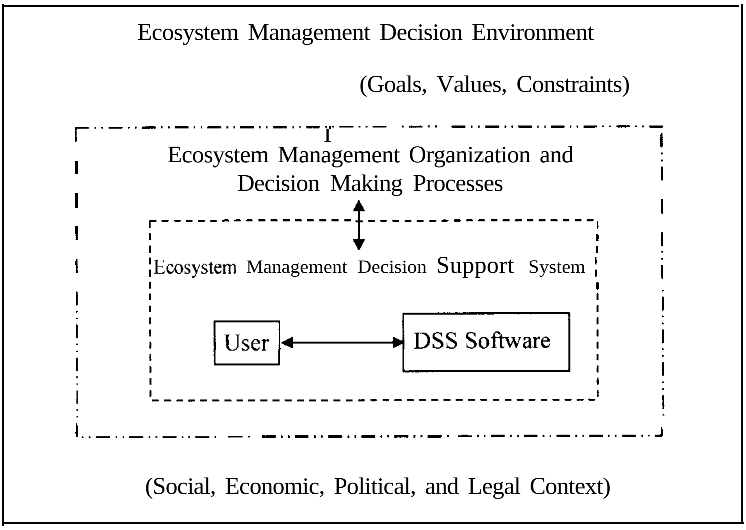

Fig. 1. Three levels of organization important in the ecosystem management decision making process

ecosystem management decision process (Adelman, 1992): the decision making environment, the decision-making organization and process(es), and the EM-DSS which 'includes human decision maker(s) and their software support tools (Fig. 1).

2.2. *The decision-making environment*

Creating a vision of the decision making environment in which ecosystem management must function is itself a wicked problem with no single best answer. However, thanks to Bonnicksen (1991), we do have a useful illustration of an ecosystem management decision environment (Fig. 2). Ecosystem management is composed of two parts: an ecological subsystem and a management subsystem. Ecosystems are communities of organisms and their environment whose boundaries are defined by an observer to facilitate some human purpose such as research or management. People need to be considered as part of the community of organisms that inhabit, use, or directly influence an ecosystem (Behan, 1997). Thus people, in their role as users, are part of the ecological subsystem, like trees, soil, and wildlife. Management is defined as making decisions about and controlling systems to achieve desired ends. People in the management role participate in ecosystem management in a very different role. They are the risk takers, the objective setters, the judges of value, the substituters, in other words, the decision makers.

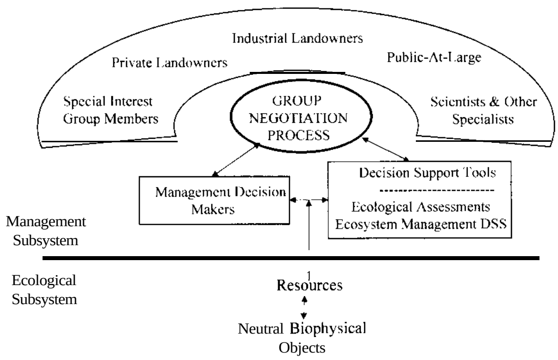

Fig. 2. The ecosystem management decision environment.

Local management of ecosystems occurs within and is influenced by national and international social, economic and political systems. Similarly, local ecosystems operate within and are influenced by larger biophysical systems such as eco-regions or biomes. An important distinction that Bonnicksen (1991) makes is that both the ecosystem and the management subsystems of ecosystem management are part of an interlocking, nested hierarchy. FEMAT (1993) and Kaufmann et al. (1994) support this important point. Ecosystem management can and should occur at many scales – global/international, biome/national, eco-region/multi-state, or forest landscape/national forest (GAO, 1994, p. 62). At the regional, national, and international scales, the ecosystem management decision process should render the mosaic of environmental issues manageable by: (1) labeling the issues; (2) defining the problems; and (3) identifying who is causing the problems, who has the responsibility of solving the problems, who are the stakeholders associated with the problems, who will pay for finding and implementing solutions (Hannigan, 1995). The decision process at this macro-scale should also coordinate solution efforts and supervise social and ecological system sustainability (Tonn et al., 1998). Decision support systems that operate on the multi-state and national scale have been developed and tested in Europe and can serve as illustrations of what is needed for United States federal forest management (Van den Berg, 1996). There is as much work to be done in ecosystem management at the larger scales as there is at the local national forest scale. At present, no one agency, committee, or other organized body in the United States manages ecosystems at the scale suggested by Bonnicksen (1991) and Tonn et al. (1998). It is not obvious that our society has addressed the need to manage ecosystems at the biome/national and eco-regional/multi-state scale to cope with the complex environmental problems we have created for ourselves at that scale (Caldwell, 1996). It seems reasonable that we should try.

The specific values, goals, and constraints that characterize public preferences and needs may be identified through a group negotiation process involving a variety of stakeholders and management decision makers (Fig. 2). Management decision makers organize and lead the group negotiation process and ensure that the resultant goals and desired future conditions are socially acceptable, legal, economically feasible, and ecologically sustainable. If ecosystem management decision support systems (EM-DSS) are available, all participants need to be able to rely on them at a reasonable level of confidence for relevant information and analyses. This group negotiation process is probably the most difficult part of ecosystem management (Bormann et al., 1993).

The ecological subsystem contains physical or conceptual objects such as trees, birds, deer, rivers, smells, sights, and sounds. Each of these physical or conceptual objects can be a resource if it has positive value in the minds of people or a pest if it has negative value. Otherwise it is value-neutral (Behan, 1997). A critical feature of this view is that as goals and desired future conditions change, objects can change from being resources to value-neutral or even to being pests (Bonnicksen, 1991). For example, the white-tailed deer, once regarded as a sought after resource, is now considered a pest in some eastern United States forest ecosystems. Most forest managers, administrators, and scientists are much more familiar with the structure and function of the ecological subsystem than with the management subsystem. This state of affairs is indicative of where we have put our attention and energy in the past. One of the new messages of ecosystem management is that forest managers, administrators, and scientists need to rapidly redress this imbalance.

While biophysical scientists at the national and international scale struggle to understand local, regional, and global environmental systems, social and institutional scientists must struggle to understand how to sustain societal systems that will protect the ability of humans and nature to co-evolve (Bormann et al., 1993; Tonn et al., 1998). Thus, defining and understanding the nature of sustainable societies and the nature of sustainable ecosystems are equally important. Tonn and White (1996) described sustainable societies as wise, participative, tolerant, protective of human rights, spiritual, collaborative, achievement-oriented, supportive of stable communities, able to make decisions under uncertainty, and able to learn over time. One of the defining characteristics of a society will be how effectively it manages to sustain both itself and its ecosystems. Even a cursory review of history reveals numerous extinct civilizations that did not successfully sustain both society and ecosystem (Toynbee, 1946).

The study of the management subsystem must include understanding the dynamics of public preferences, conflict management and resolution, and cost evaluation and containment as it relates to ecosystem management. Defining and understanding stakeholders and their preferences is an important part of ecosystem management (Garland, 1997). Stakeholder and general public preferences are volatile and sensitive to manipulation through the control of information transmitted through public media (Montgomery, 1993; Smith, 1997). Understanding the dynamics of social preferences and how they can be influenced over both the short- and long-term is a vital part of the ecosystem management process. Ecosystem management processes and the institutions that use them must be able to detect and accommodate rapid, and sometimes radical, changes in public preferences (Kohm and Franklin, 1997).

Successful social conflict management is as important as understanding stakeholder preference dynamics. Currently, the dominant means of settling public land disputes have been either litigation or quasi-judicial administrative appeals. Such contentious methods of handling disputes expend much goodwill, energy, time, and money. These methods produce winners and losers, may leave fundamental differences unresolved, and potentially please few or none of the parties (Daniels et al., 1993). Decision makers need a fundamental understanding of the nature of environmental conflicts and disputes and how to use conflict-positive dispute management techniques effectively (Daniels et al., 1993). New approaches to managing the social debate surrounding ecosystem management, such as alternative dispute resolution (ADR) techniques (Floyd et al., 1996). should be evaluated, taught, and used. Adaptive management techniques are as applicable to the management side of ecosystem management as they are to the ecosystem side. They could be used to suggest a series of operational experiments that study actual public participation and conflict management activities to quickly determine what works and what does not (Daniels et al., 1993; Shindler and Bruce. 1997).

The ability of federal land managers to avoid gridlock is heavily dependent on stakeholder willingness to negotiate and ultimately agree on the goals for ecosystem management (Bormann et al., 1993). Unfortunately, people sometimes have preferences based on core values that are so strong and so conflicting that no solution is acceptable (Smith, 1997). To avoid societal gridlock, we must design and implement robust strategies that encourage voluntary conflict resolution among contentious stakeholders and explore other options leading toward a settlement if voluntary resolution is impossible. Such options might include binding arbitration, an agreed upon delay in order to improve our data and knowledge about the ecosystem, or various other forms of conflict resolution.

2.3. *The cost of ecosystem management*

Ecosystem management cost evaluation and containment is a critical area for economists to study. As a general rule, increases in problem complexity and the degree of wickedness increase the cost of finding satisfactory solutions (Klein and Methlie, 1990). Ecosystem management should accommodate limits on time, expertise, and money (Smith, 1997) because sustainable forest management is impossible if there are unsustainable social and economic costs (Craig, 1996). Documentation of costs needs to be prepared and made public because few people know or appreciate the costs of efforts to solve wicked problems. For example, the USDA forest service has spent approximately US$ 2 billion, equal to 16% annually of the entire national forest system budget, on planning since the National Forest Management Act was passed in 1976 (Behan, 1990). The additional cost of implementing ecosystem management prescriptions and monitoring and evaluating the results has not been estimated. Are we willing or able to marshal the funding to implement ecosystem management that wil! ensure that federal forest managers can comply with the law and satisfy public preferences? The amount of money that could be spent on ecosystem management nationally may be extremely large and identifying clear benefits may be difficult (Oliver et al., 1993).

In the last century of federal forestland management, timber harvesting has largely paid for multiple-use management activities. Many forecast that the level of timber harvesting under ecosystem management will greatly decline while the cost of ecosystem management will greatly increase. Until managers evaluate the true cost and benefits, it will be difficult to determine whether the public is willing to pay for ecosystem management programs. In any case, a new and rational means of capital resource allocation will be required to fund the ecosystem management process adopted (Sample. 1990; Kennedy and Quigley, 1993; Oliver et al., 1993). Refusing to fund ecosystem management and opting for the ‘do nothing’ alternative is likely to result in unacceptable desired future conditions. “Plant and animal species do not stop growing, dying, and burning; and floods, fires, and windstorms do not stop when all management is suspended” (Oliver et al., 1993). Nature does not appear to care – either about threatened and endangered species or about humans. People care and people must define goodness and badness. Nature will not do it for us. “Nature in the 21st century will be a nature that we make; the question is the degree to which this molding will be, intentional or unintentional, desirable or undesirable” (Botkin, 1990). Making the nature that we want may be expensive. A good understanding of ecological economics will help society make rational choices.

2.4. *Administering ecosystem manugement*

Recently, regional ecological assessments have been used to describe the large-scale context for ecosystem management and therefore can be considered a decision support tool (Fig. 2). Regional assessments have been large, collaborative interagency efforts, often with public stakeholder participation, that have taken 2-5 years and several millions of dollars to finish. The objectives for integrated ecological assessments are to provide: (1) a description of current and historic composition, structure, and function of ecosystems; (2) a description of the biotic (including human) and abiotic processes that contributed to the development of the current ecosystem conditions; and (3) a description of probable future scenarios that might exist under different types of management strategies (Lessard, 1997). The Southern Appalachian Assessment (Southern Appalachian Man and the Biosphere, 1996) is an example although it does not address objective (3). Currently, precisely how these regional assessments fit into the ecosystem management process is unclear. One alternative would be to view regional assessments as ecosystem management at the eco-region/multi-state scale. In that capacity, the current objectives for assessments focus entirely too much on the ecosystem component of ecosystem management. SAMAB, for example, examines the social and economic activities of people within the southern Appalachian region, but only in their roles as ecosystem members and users. The role of people as managers of ecosystems, including their role as managers of social, economic and political systems in the region, is ignored. To correct this deficiency, another list of objectives for regional assessments might include the following: (1) identify a set of regional scale desired future conditions and compare these to the current conditions; (2) identify regional stakeholders, their preferences and values, and how they compare to the general public in the region; (3) identify the legal and political climate within which ecosystem management must function; (4) identify the regional costs and who will bear them as well as the regional gains and who will reap them; and (5) identify the major problems, who is responsible for solving them, and who has supervisory responsibility to monitor progress and assure that a satisfactory solution is eventually reached.

3. **Ecosystem management processes**

The decision making environment consists of the social, economic, political, and legal context in which a federal ecosystem management organization operates. This decision making environment determines the goals, values, and constraints for the organization (Fig. 1). Organizational policy then translates the mandates of the decision making environment into specific decision making processes. A decision making process is a method or procedure that guides managers through a series of tasks from problem identification and analysis to alternative design and finally alternative selection (Mintzberg et al., 1976). Ideally, decision support systems should not be developed until the ecosystem management decision making processes they are to support have been articulated. In reality, both the ecosystem management decision processes and the software systems needed to support them are evolving simultaneously, each helping to refine the other.

‘First generation’ ecosystem management processes have evolved from two sources: (1) academia where several ecosystem management processes have been described at a general, conceptual level and their macro-level structures and functions have been identified; and (2) federal forest managers at the field level where numerous, local ad hoc processes have been developed and tested under fire. The academic, high level descriptions of ecosystem management processes do not supply adequate details to guide the development of decision support systems and are theoretical, lacking adequate field testing to determine how they work in practice. The local, ad hoc ecosystem management processes are too numerous for effective software-based decision support (approximately 400 ranger districts in the U.S. national forest system each have their own process) and few, if any, have been studied and described formally so that similarities and differences can be identified. Moreover, no particular ecosystem management decision process(es) have been widely accepted and implemented in federal forest management. We should devote as much creative attention to devising good ecosystem management decision processes as we do in assuring the quality of the decisions themselves (Ticknor, 1993). In this section the major elements of a generic ecosystem management process are identified based on a synthesis of the literature.

Adaptive management is a continuing process of planning, monitoring, evaluating, and adjusting management methods (Bormann et al., 1993; FEMAT, 1993; Lee, 1993). The usefulness of adaptive management as an ecosystem management process is being field-tested by the Forest Service in the Northwest and in other regions of the country (Shindler et al., 1996). Described at the most general level, adaptive management consists of four activities, PLAN-ACT-MONITOR-EVALUATE, linked to each other in a network of relationships (Fig. 3). At each cycle, the results of the evaluation activity are fed back to the planning activity so that adaptive learning can take place. Without adding further detail to this definition, almost any management activity could erroneously be labeled adaptive management. In reality, adaptive management is a well-described, detailed, formally rigorous, and scientifically defensible management-by-experiment system (Walters and Holling, 1990). Baskerville (1985) prescribes a nine-step process for implementing adaptive management correctly. Adaptive management requires that a series of steps be followed for each of the four major activities described.

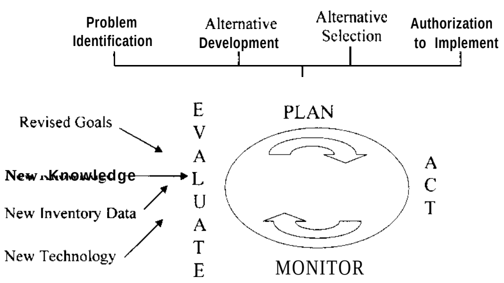

Fig. 3. The adaptive management process for ecosystem management.

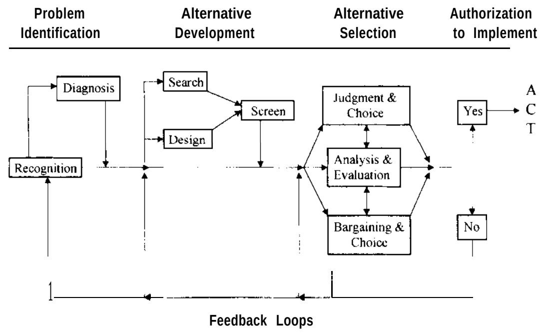

Fig. 4. A detailed view of the planning activity in the adaptive management process for ecosystem management.

3.1. *Plan*

The Mintzberg et al. (1976) planning process can be viewed as a detailed description of the planning stage of the adaptive management process (Fig. 4). Janssen (1992) argued that the planning stage of any decision process will generally need to be some variant of the Mintzberg et al. (1976) method. The planning stage of the adaptive management process consists of four steps: (1) problem identification including goal selection, (2) alternative development, (3) alternative selection, and (4) authorization to implement the selected alternative (Figs. 3 and 4). Each of these major steps can be decomposed into one or more phases (Janssen, 1992).

The problem identification step consists of two phases: (la) recognition – to identify opportunities, problems, and crises; the need for a decision launches the decision process and (lb) diagnosis – to explore the different aspects of the problem situation, identify goals and objectives and decide how to approach the problem. If the diagnosis phase, step lb, is unnecessary, it can be skipped (Fig. 4). The alternative development step consists of three phases: (2a) search – to find previously designed and tested solutions to the entire problem or to any of its parts; (2b) design – to develop new alternatives; and (2c) screen - to determine whether the number and quality of the alternatives found, developed, or both, provide an adequate range of choices for the selection step. The selection step consists of three phases: (3a) analysis and evaluation – to evaluate and understand the consequences over space and time of each of the proposed alternatives and communicate these results clearly to the decision makers; (3b) judgment and choice – where one individual makes a choice; and (3c) bargaining and choice – where a group of decision makers negotiates a choice. The authorization step consists of two outcomes: (4a) authorization achieved – approval inside and outside the institutional hierarchy is obtained, marking the end of the planning process and the beginning of the implementation process; and (4b) authorization denied – evaluation of the cause for denial and looping back to the appropriate part of the decision process to make another attempt at achieving authorization (Janssen, 1992).

A particular decision can take many pathways through Fig. 4 and iterative cycles are a normal part of how environmental decisions are actually made (Janssen, 1992). These cycles occur as the decision participant's understanding of a complex problem evolves and when alternative solutions fail to meet administrative, scientific, or political standards. Mintzberg et al. (1976) maintained that problems can be classified into seven types and that the solution cycle for each type can be mapped on Fig. 4. Janssen (1992) illustrates this point by presenting and discussing the solution cycles of 20 actual environmental problems in the Netherlands ranging from measures to reduce NH_3 emissions, to clean-up of a polluted site, to protecting forests from acid rain. The effectiveness of competing EM-DSS may be evaluated by how many of the above phases are supported, how well they are supported, and whether the complex iterative cycling of real-world problems is supported (Janssen, 1992).

3.2. *Act*

The planning stage of adaptive management, described above, results in decisions about goals and constraints. The action stage determines how, where, and when to implement activities to achieve the goals and adhere to the constraints. Given a clear statement of management goals and objectives, the implementation stage creates testable adaptive management hypotheses, explicitly describes the assumptions supporting them, and generates an appropriate set of targeted actions (Everett et al., 1993). How each hypothesis is tested must be carefully and clearly documented (Walters and Holling, 1990; Lee, 1993; Kimmins, 1995).

3.3. *Monitor*

Documentation in the action stage is stressed because the monitoring stage often occurs months to years later, and the individuals who implemented the actions may not be involved in monitoring or subsequent evaluation. Documentation may be the only link between the two stages. The monitored results of experimental actions must also be recorded carefully and in detail so that a complete, understandable package exists for the evaluation stage.

This definition of the monitoring stage of adaptive management has immediate consequences. What variables are monitored and when, how, and where they are monitored depend almost entirely on the hypotheses created in the action stage and on the type of actions determined necessary to test those hypotheses. A unique goal – hypothesis – action sequence will probably need to be designed for each specific management unit. Each unit will probably have its own unique monitoring requirements to distinguish between the adaptive experimental hypotheses proposed for that it. Therefore, no general, broad-spectrum monitoring program can or should be designed to support adaptive management. Adaptive management means management-by-experiment. Management-by-experiment requires hypotheses that must be implemented and tested. Monitoring can only occur after the hypotheses have been designed and their tests devised so that it is clear what needs monitoring (FEMAT, 1993).

3.4. *Evaluate*

Finally, the documentation describing each adaptive management experiment must be analyzed and the results evaluated. Promising statistical methods have been identified (Carpenter, 1990), but using them requires considerable expertise. At the end of the adaptive management cycle, a written report will communicate the results publicly to stakeholders and managers and influence future cycles of the planning activity of adaptive management (Everett et al., 1993). In fact, an analysis of all adaptive experimental results should be compiled periodically and forwarded to the next higher planning level for corrective change leading to new actions.

Adaptive management, when implemented as defined by Walters and Holling (1990), FEMAT (1993), and Lee (1993), is a complex and challenging process. The adaptive management process is not a license to manipulate forest ecosystems haphazardly simply to relieve immediate socio-political pressure (Everett et al., 1993). Adaptive management must be applied correctly and rigorously as management-by-experiment if we are to achieve our stated goals. "Managing to learn entails implementing an array of practices, then taking a scientific approach in describing anticipated outcomes and comparing them to actual outcomes. These comparisons are part of the foundation of knowledge of ecosystem management" (FEMAT, 1993). The whole point of adaptive management is to generate change in the way ecosystem management is applied.

A number of institutional challenges must be addressed before adaptive management can make its expected positive contribution in the ecosystem management process (Lee, 1993). Adaptive management requires a greater level of statistical experimental design and analysis expertise than other competing decision processes. Kessler et al. (1992) suggested that adaptive management can only be done through close collaboration between forest managers and scientists. "Finding creative ways of conducting powerful tests without forcing staffs to do things they think are wrong or foolish is of central importance to the human part of adaptive management" (Lee, 1993). Managers and interested stakeholders must accept that adaptive management means making small, controlled mistakes to avoid making big ones. Keeping adaptive management unbiased may be difficult. Research that has consequences is research with which managers may try to tamper or keep from happening (Lee, 1993). The costs of monitoring the results and documenting the entire managerial experiment properly are unknown, but anticipated to be high (Smith, 1997). Adaptive management, supplemented by the Mintzberg et al. (1976) planning process, is an attractive candidate for an ecosystem management process at several operational scales. Despite much supportive rhetoric, the institutional and funding changes needed to implement adaptive management as an ecosystem management process for federal forestland management have not yet been widely accomplished.

The adaptive management concept appears to be the most well-developed candidate for an operational ecosystem management process. However, others should be investigated. Lindblom (1990), cited by Smith (1997), advocated a concept called 'probing' as a candidate for the ecosystem management decision process. Probing is an informal process of observation, hypothesizing, and data comparison in which people of all backgrounds can engage. Jensen and Everett (1993) pointed to a method called a 'land evaluation system' as a candidate for an ecosystem management process. The land evaluation system (Zonnefeld, 1988) has been used by the United Nations Food and Agricultural Organization and by the International Society for Soil Sciences in forestry land-use planning. Howitt (1978), cited by Allen and Gould (1986), offered a 'simple' approach to dealing with decision processes for wicked problems that might be useful for ecosystem management. Rittel (1972) advocated a 'second generation systems approach' to wicked problem solution based on the logic of arguments (Conklin and Begeman, 1987; Hashim, 1990). Problems and their consequences can be made understandable to individuals and groups by asking and answering crucial questions while diagramming the process using the formal logic of argumentation. Vroom and Jago (1988), cited in Sample (1993), suggested their 'contingent decision process' may be used for problems like ecosystem management. Any of the above-named decision making processes used to implement ecosystem management in the United States must satisfy the requirements of the 1969 National Environmental Policy Act (NEPA) and the 1976 National Forest Management Act (NFMA).

Several formal, well-described candidates for an ecosystem management decision process have been introduced here. In addition, numerous local, ad hoc decision processes have been developed and tested under fire in every ranger district in the U.S. National Forest System. Few case studies (e.g. Steelman, 1996) have been published and not many evaluations (e.g. Shindler and Bruce, 1997) of the strengths and weaknesses of these informal decision making processes have been conducted. Surely a concerted effort to study the existing formal and informal ecosystem management processes would result in some powerful candidates to implement ecosystem management. As the adaptive management concept can also be used to improve our management systems, it may not be overly important which particular ecosystem management decision processes we choose. It is, however, critically important that we choose several and then use the adaptive management philosophy to test and improve them in real-life situations (Kimmins, 1991).

4. Decision support systems (DSS) defined

DSS help managers make decisions in situations where human judgment is an important contributor to the problem solving process, but where limitations in human information processing impede decision making (Rauscher, 1995). The goal of a DSS is to amplify the power of the decision makers without usurping their right to use human judgment and make choices. DSS attempt to bring together the intellectual flexibility and imagination of humans with the speed, accuracy, and tirelessness of the computer (Klein and Methlie, 1990; Sage, 1991; Turban, 1993; Holsapple and Whinston, 1996).

A DSS contains a number of subsystems, each with a specific task Fig. 5. The first, and most important, is the subsystem composed of the decision maker(s). The decision makers are consciously diagrammed as part of the DSS because without their guidance, there is no DSS. The group negotiation management subsystem helps the decision maker(s) organize their ideas, formulate relationships surrounding issues and arguments, and refine their understanding of the problem and their own value systems (Jessup and Valacich, 1993; Holsapple and Whinston, 1996). Examples of group negotiation tools include: AR/GIS (Faber et al., 1997), the issue-based information system (IBIS) (Conklin and Begeman, 1987; Hashim, 1990), and various socio-ecological logic programming models (Thomson, 1993, 1996). Group negotiation tools are used to construct issue-based argument structures using variants of belief networks to clarify the values and preferences of group members in the attempt to reach group consensus. For example, IBIS uses formal argument logic (the logic of questions and answers) as a way to diagram and elucidate argumentative thinking (Hashim, 1990). By asking and answering crucial questions, you can begin to better understand the problem and its solution set. Understanding the meaning of terms, and through them our thoughts, lies at the heart of collaborative management. Greber and Johnson (199 1) illustrated how the malleable nature of terms, in this case 'overcutting,' creates logically defensible differences of opinion which have nothing to do with a person's honesty or dishonesty in the argument. DSS should specifically deploy mechanisms by which biological realities guide and, if appropriate, constrain the desires of the stakeholders (Bennett, 1996). For example, compromise is not acceptable for some issues. If the productive capacity of an ecosystem is fixed while key stakeholders all want to extract a product from that ecosystem at a higher level, a compromise midway between them will be unsustainable.

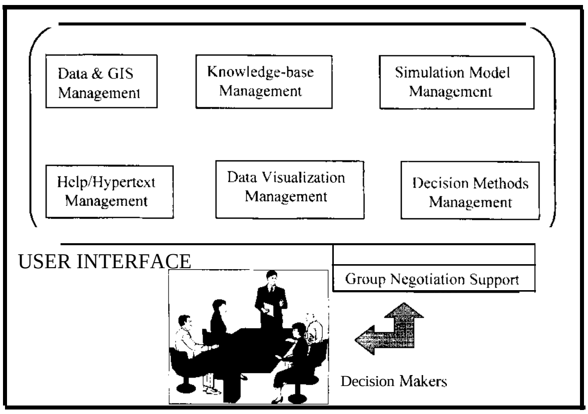

Fig. 5. The major components of a generic DSS

The next major subsystem, spatial and non-spatial data management, organizes the available descriptions of the ecological and management components of ecosystem management. Data must be available to support choices among alternative management scenarios and to forecast consequences of management activities on the landscape. There is tension between the increasing number of goals and desired future conditions that decision makers and stakeholders value and the high cost of obtaining data and understanding relationships that support these choices. Monitoring disturbance activities, both natural and human originated, as well the disturbance-free dynamics of the forest ecosystems under management is also extremely important if the EM-DSS is to accurately portray the decision choices and their consequences. Barring blind luck, the quality of the decision cannot be better than the quality of the knowledge behind it. Poor data can lead to poor decisions. It is difficult to conceive of prudent ecosystem management without an adequate biophysical description of the property in question.

The next four subsystems – knowledge base, simulation model, help/hypertext, and data visualization management – deal with effectively managing knowledge in the many diverse forms in which it is stored, represented, or coded (see Rauscher et al., 1993 for more detail). Non-language-based knowledge is either privately held in people's minds or publicly represented as photographs, video, or graphic art. Language-based knowledge is found in natural language texts of various kinds, in mathematical simulation models, and in expert or knowledge-based systems. Data visualization software has been developed that can manipulate photographic, video, and graphic art representations of current and future ecosystem conditions. Data visualization software is beginning to be incorporated into EM-DSS on a routine basis to help decision makers see for themselves the likely impact-of their decisions on the landscape.

In the last 20 years, an impressive amount of mathematical simulation software has been developed for all aspects of natural resource management. Schuster et al. (1993) conducted a comprehensive inventory of simulation models available to support forest planning and ecosystem management. They identified and briefly described 250 software tools. Jorgensen et al. (1996) produced another compendium of ecological models that incorporate an impressive amount of ecosystem theory and data. The simulation model management subsystem of the EM-DSS is designed to provide a consistent framework into which models of many different origins and styles can be placed so the decision makers can use them to analyze, forecast, and understand elements of the decision process.

Despite our most strenuous efforts to quantify important ecological processes to support a theory in simulation model form, by far the larger body of what we know can only be expressed qualitatively, comparatively, and inexactly. Most often this qualitative knowledge has been organized over long years of professional practice by human experts. Theoretical and practical advances in the field of artificial intelligence applications in the last 20 years now allow us to capture some of this qualitative, experience-based expertise into computer programs called expert or knowledge-base systems (Schmoldt and Rauscher, 1996). It is still not possible to capture the full range and flexibility of knowledge and reasoning ability of human experts in knowledge-based software. We have learned, however, how to capture and use that portion of expertise that the human expert considers routine. The knowledge management subsystem of the EM-DSS is designed to organize all available knowledge-based models in a uniform framework to support the decision making process.

Finally, a large amount of text material exists that increases the decision maker's level of understanding about the operation of the DSS itself, the meaning of results from the various modeling tools, and the scientific basis for the theories used. This text material is best organized in hypertext software systems. The oak regeneration hypertext (Rauscher et al., 1997a) and the hypermedia reference system to the FEMAT report (Reynolds et al., 1995) are recent examples of the use of hypertext to synthesize and organize scientific subject matter. Examples of the use of hypertext to teach and explain software usage can be found in the help system of any modem commercial computer program.

The software subsystems of an EM-DSS described so far help the decision maker(s) organize the decision problem, formulate alternatives, and analyze their future consequences. The decision methods management subsystem (Fig. 5) provides tools and guidance for choosing among the alternatives, for performing sensitivity analyses to identify the power of specific variables to change the ranking of alternatives, and for recording the decisions made and their rationale. There are many facets or dimensions that influence the decision making process. The rational/technical dimension, which concerns itself with the mathematical formulation of the methods of choice and their uses, is the one most often encountered in the decision science literature (Klein and Methlie, 1990; Rauscher, 1996). But there are others including the political/power dimension (French and Raven, 1959; O'Reilly, 1983) and the value/ethical dimension (Brown, 1984; Klein and Methlie, 1990, p. 108; Rue and Byars, 1992, p. 61). The decision maker(s) might find themselves at any point along the political/power dimension defined by a dictatorship (one person decides) on the one extreme and by anarchy (no one can decide) on the other. Intermediate positions are democracy (majority decides), republicanism (selected representatives decide), and technocracy/aristocracy (experts or members of a ruling class decide). Currently three approaches seem to be in use at multiple societal, temporal and spatial scales: management by experts (technocracy), management by legal prescription (republicanism), and management by collaboration (democracy) (Bormann et al., 1993). No one approach predominates. In fact, the sharing of power between these three approaches creates tensions which help make ecosystem management a very wicked problem.

In the context of ecosystem management, the value/ethical dimension might be defined on the one extreme by the preservationist ethic (reduce consumption and let nature take its course) and on the other by the exploitation ethic (maximum yield now and let future generations take care of themselves). Various forms of the conservation ethic (use resources, but use them wisely) could be defined between these two extremes. The rational/technological dimension is defined by the normative/rational methods on one hand and the expert/intuitive methods on the other. Numerous intermediate methods have also been described and used (Janssen, 1992; Rauscher, 1996). The formal relationships between these dimensions affecting the decision process have not been worked out. Informally, it is easy to observe decision making situations where the political/power or value/ethical dimensions dominate the rational/technical dimension. Choosing an appropriate decision making method is itself a formidable task (Silver, 1991; Turban, 1993) which influences both the design of alternatives and the final choice. Many EM-DSS do not offer a decision methods subsystem due to the complexity and sensitivity of the subject matter. Unfortunately, providing no formal support in EM-DSS for choosing among alternatives simply places all the burden on the users and may make them more vulnerable to challenges of their process and choice mechanisms.

5. A comparison of existing ecosystem management DSS

Mowrer et al. (1997) surveyed 24 of the leading EM-DSS developed in the government, academic, and private sectors in the United States. Their report identified five general trends: (1) while at least one EM-DSS fulfilled each criteria in the questionnaire used, no single system successfully addressed all important considerations; (2) ecological and management interactions across multiple scales were not comprehensively addressed by any of the systems evaluated; (3) the ability of the current generation EM-DSS to address social and economic issues lags far behind biophysical issues; (4) the ability to simultaneously consider social, economic, and biophysical issues is entirely missing from current systems; (5) group concensus-building support was missing from all but one system – a system which was highly dependent upon trained facilitation personnel (Mowrer et al., 1997). In addition, systems that offered explicit support for choosing among alternatives provided decision makers with only one choice methodology. The reviewers noted that little or no coordination had occurred between the 24 development teams resulting in large, monolithic, stand-alone systems, each with a substantially different concept of the ecosystem management process and how to support it.

Different EM-DSS appear to support different parts of the ecosystem management process. Table 1 lists 33 EM-DSS, the 24 systems surveyed by Mowrer et al. (1997) plus nine DSS not included in that study. Nineteen of the 33 are labeled full service EM-DSS at their scale of operation because they attempt to be comprehensive EM-DSS, offering or planning to offer support for a complete ecosystem management process. These EM-DSS can be further classified by the scale of support which is their primary focus: regional assessments, forest planning, or project level planning. The remainder, labeled functional service modules, provide specialized support for one or a few phases of the entire ecosystem management process. These service modules can be organized according to the type of functional support they provide: group negotiations, vegetation dynamics, disturbance simulation, spatial visualization, and interoperable system architecture.

5.1. Full service EM-DSS

5.1.1. Regional assessments

The ecosystem management decision support (EMDS) program is a software system specifically

Table 1
A representative sample of existing ecosystem management decision support software for forest conditions of the United States arranged by operational scale and function

Full-service EM-DSS		Functional service modules	
Operational scale	Models	Function	Models
Regional assessments	EMDS	Group negotiations	Ar/GIS
	LUCAS“		IBIS”
		Vegetation dynamics	FVS
Forest level planning	RELM		LANDIS
	SPECTRUM		CRBSUM
	WOODSTOCK		SIMPLLE
	ARCROREST		
	SARA	Disturbance simulations	FIREBGC
	TERRA VISION		GYPSES
	EZ-IMPACT’		UPEST
	DECISION PLUS;		
	DEFINITE”	Spatial visualization	UTOOLS/UVIEW
			SVS[a]
Project level planning	NED		SMARTFOREST
	INFORMS		
	MAGIS	Interoperable system	LOKI
	KLEMS	Architecture	CORBA
	TEAMS		
	LMS	Economic impact analysis	IMPLAN
		Activity scheduling	SNAP

“References for models not described in Mowrer et al. (1997): EZ-IMPACT (Behan, 1994); DECISION PLUS (Sygenex, 1994); IBIS (Hashim, 1990); DEFINITE (Janssen and van Hervijnen, 1992); SMARTFOREST (Orland, 1995); CORBA (Otte et al., 1996); SVS (McGaughey, 1997); LMS (Oliver and McCarter, 1996); LUCAS (Berry et al., 1996)

designed to support the development of ecological assessments, usually at the regional or watershed scales. It provides a general software environment for building knowledge bases that describe logical relations among ecosystem states and processes of interest in an assessment (Reynolds et al., 1997). Once these knowledge bases are constructed by users, the system provides tools for analyzing the logical structure and the importance of missing information. EMDS provides a formal logic-based approach to assessment analysis that facilitates the integration of numerous diverse topics into a single set of analyses. It also provides robust methods for handling incomplete information. A variety of maps, tables, and graphs provides useful information about what data are missing, the influence of missing data, and how data are distributed in the landscape. EMDS also provides support for exploring alternative future conditions. Finally, EMDS is general in application and can be used at the scale relevant to an assessment problem (Reynolds et al., 1997).

LUCAS is a multidisciplinary simulation framework for investigating the impact of land-use management policies (Berry et al., 1996). LUCAS has been used to support regional assessments of land-use change patterns as a function of social choices and regulatory approaches (Wear et al., 1996). LUCAS can be used to compare the effects of alternative ecosystem management strategies that could be implemented over any sized eco-region. These alternatives could be evaluated based on any number of social choice assumptions ascribed to private landowners (Wear et al., 1996). LUCAS could also be used to address the effects of land cover changes on natural resource supplies and local incomes. The advantage of EM-DSS operating at the eco-regional scale is that regional decision making activities and their consequences can be forecast with reasonable credibility.

5.1.2. *Forest level planning*

For 17 years, from 1979 until 1996, a linear programming, harvest scheduling model was turned into a forest-level planning tool, FORPLAN, and all national forest supervisors were required to use it as the primary analysis tool for strategic forest planning. After years of increasingly fierce criticism that the normative, rational, optimization approach to decision analysis implemented by FORPLAN and its successor, SPECTRUM, was not adequate, the Forest Service finally removed its formal requirement to use FORPLAN/SPECTRUM (Stephens, 1996). The specifics of the arguments critical of FORPLAN/SPECTRUM as an analysis tool for forest planning are beyond the scope of this paper and can be readily found in the following publications: Hoekstra et al. (1987), Barber and Rodman (1990), Canham (1990), Howard (1991), Kennedy and Quigley (1993), Morrison (1993), Shepard (1993), Behan (1994), Liu and Davis (1995), Behan (1997), and Smith (1997).

Forest-level planning, which corresponds to the strategic planning process of each national forest, may be more successfully performed using soft, qualitative decision analysis formalisms than the hard, quantitative methods employed in rational, linear or non-linear optimization schemes. Many other decision analysis formalisms exist (see Rauscher, 1996; Smith, 1997) along with the tools that make them useful and practical (Table 1). Many of these techniques may offer greater support for dealing with power struggles, imprecise goals, fuzzy equity questions, rapidly changing public preferences, and uneven information quality and quantity (Allen and Gould, 1986). In particular, EZ-IMPACT (Behan, 1994, 1997) and DEFINITE (Janssen and van Hervijnen, 1992) are well-developed and tested forest planning analysis tools which use judgement-based, ordinal, and cardinal data to help users characterize the system at hand and explore hidden interactions and emergent properties.

A forest plan should demonstrate a vision of desired future conditions (Jensen and Everett, 1993). It should examine current existing conditions and highlight the changes needed to achieve the desired future conditions over the plan period (Grossarth and Nygren, 1993). Finally, the forest plan should demonstrate that recommended alternatives actually lead towards the desired future condition by tracking progress annually for the life of the plan. The forest plan should be able to send accomplishable goals and objectives to the project implementation level and receive progress reports that identify the changes in the forest conditions that management has achieved. Ideally, all competitors in this class of EM-DSS should be objectively evaluated for their effectiveness in supporting these tasks, their ease of use in practice, and their ability to communicate their internal processes clearly and succinctly to both decision makers and stakeholders. Such an evaluation has not yet been conducted.

5.1.3. *Project level implementation*

"Forest plans are programmatic in that they establish goals, objectives, standards, and guidelines that often are general. Accordingly, the public and USDA forest service personnel have flexibility in interpreting how forest plan decisions apply, or can best be achieved, at a particular location. In addition, forest plans typically do not specify the precise timing, location, or other features of individual management actions" (Morrison, 1993). EM-DSS at the project level help identify and design site-specific actions that will promote the achievement of forest plan goals and objectives. Several project level implementation EM-DSS have been developed in the last few years (Table 1). Project level EM-DSS can be separated into those that use a goal-driven approach and those that use a data-driven approach to the decision support problem. NED (Rauscher et al., 1997b; Twery et al., 1997) is an example of a goal-driven EM-DSS where goals are selected by the user(s). These goals define the desired future conditions, which define the future state of the forest. Management actions should be chosen that move the current state of the forest closer to the desired future conditions. In contrast, INFORMS (Williams et al., 1995) is a data-driven system which begins with a list of actions and searches the existing conditions to find possible locations to implement those management actions. Both approaches have their strengths and weaknesses.

Goal-driven systems, by definition, tend to ensure that management actions move the ownership toward the specified desired future conditions by committing to a particular ecosystem management decision process. This reduces the utility of the EM-DSS to that set of decision makers who wish to use the particular decision process implemented. On the other hand, data driven systems offer no guarantee that the results of the sum of the actions have any resemblance to the desired future conditions as defined by the objectives of the owner(s). Data-driven systems, however, do allow competent and knowledgeable decision makers to choose the analyses they perform and how they put them together to arrive at a decision.

5.2. *Functional service modules*

Full-service EM-DSS rely on specialized software service modules to add a broad range of capabilities (Table 1). Tools to support group negotiation in the decision process are both extremely important and generally unavailable and underutilized. AIUGIS (Faber et al., 1997) is the most fully developed software available for this function and has been briefly described in Section 4. IBIS, another group negotiation tool, is an issue-based information system that implements argumentation logic (the logic of questions and answers) to help users formally state problems, understand them, clearly communicate them, and explore alternative solutions (Conklin and Begeman, 1987; Hashim, 1990). Vegetation dynamics simulation models, both at the stand and at the landscape scale, provide EM-DSS with the ability to forecast the consequences of proposed management actions. Disturbance simulators simulate the effects of catastrophic events such as fire, insect defoliation, disease outbreaks, and wind damage. Models that simulate direct and indirect human disturbances on ecosystems are not widely available. Models that simulate timber harvesting activities exist, but provide little, if any, ecological impact analyses such as the effect of extraction on soil compaction, on damage to remaining trees, or on the growth response of the remaining tree and understory vegetation. Models that simulate the impact of foot traffic, mountain bikes, and horse-back riding on high-use areas are largely missing. Models that simulate climate change, nutrient cycling processes, acid deposition impacts, and other indirect responses to human disturbance are rarely practical for extensive forest analyses. Stand and landscape-level visualization tools have improved dramatically in the last few years. It is now possible, with relatively little effort, to link to and provide data for three-dimensional stand level models such as SVS (McGaughey, 1997) as well as landscape level models such as UVIEW (Ager, 1997) and SMARTFOREST (Orland, 1995).

No single model is likely to provide adequate support for ecosystem management (Grossarth and Nygren, 1993; Mowrer et al., 1997). Familiarity with the entire range of available decision analysis methodology and modeling tools that implement these methods is required. Retraining decision analysts and decision makers to use different tools for different purposes and to teach how various techniques and tools fit together to address management objectives will be a critical component to successful application of the ecosystem management paradigm (Grossarth and Nygren, 1993).

Even a cursory review revealed that none of the available EM-DSS has been found capable of addressing the full range of support required for ecosystem management (Mowrer et al., 1997). The EM-DSS introduced in this section hold great promise, but this promise has not been fully achieved. A major reason for this situation is that system development has been primarily driven by technology, not by requirements. The requirements to guide EM-DSS development are unknown or poorly defined because the ecosystem management decision processes have been inadequately identified and described. The frequently observed tendency to substitute technology for an inadequate or non-existent ecosystem management decision making process should be avoided because it is rarely satisfactory. Although formal evaluation procedures are available (see Adelman, 1992), few of the current EM-DSS have undergone an in-depth, critical evaluation of their suitability for ecosystem management decision support. In the final analysis, EM-DSS software should be evaluated based on the question, "Does the EM-DSS improve the decision-maker's ability to make good decisions?"

6. **Toward a large system architecture for EM-DSS**

A key to effective decision support for ecosystem management is interoperability of software systems (Potter et al., 1992; Bevins and Andrews, 1994; Fedra, 1995; Mowbray and Zahavi, 1995; Otte et al., 1996). Open-architecture, interoperable systems provide a software interface standard which promotes communication between modules and provides for the integration of newly developed modules and refinements as they occur over time. Interoperable, large system architectures function like the conductor of an orchestra. The conductor is told by the user what composition to play. The conductor looks up the musical score for that composition (developed by the DSS version of the composer) and then assembles the necessary instruments and organizes the flow of music. Not all instruments play in all compositions and all instruments have a special role to play at a particular time and place in the composition. The conductor is then ultimately responsible for making sure that the music is pleasant, the score is followed, and the user is happy. The conductor (software architecture) only conducts. It neither composes nor does it play an instrument. Our current compositions (EM-DSS) are hardwired to play only one composition like a simple music box. They cannot play anything else unless extensively reworked; then they often only play the new composition.

The introduction and popular acceptance of the Microsoft Windows” and Apple Macintosh[3] operating systems serve as premier examples of the advantages of software interoperability. Monolithic software systems, which are essentially islands of automation, are now recognized as poor solutions to complex problems (Otte et al., 1996). "As software technology continues to evolve, there is a growing trend towards the construction of systems from pre-existing components" (Mowbray and Zahavi, 1995). There is much legacy software available with potential for use in support of ecosystem management (Schuster et al., 1993; Jorgensen et al., 1996). In addition, readily available, high quality commercial software exists to support many needs of the ecosystem management process. Finally, numerous, independently operating development groups are producing software solutions to ecosystem management problems that are potentially useful for a wide-ranging decision making audience. The integration of these independent software solutions in support of ecosystem management is essential to make rapid progress in the growth and evolution of effective EM-DSS.

Efforts at custom or localized integration are readily apparent in the present generation of EM-DSS. The USDA forest service's forest vegetation simulator (FVS) is an integrated, multi-module software system for modeling forest vegetation dynamics (Teck et al., 1996). It uses an event monitor to manage the user-defined stream of event activities that FVS can simulate. Postprocessors, which are independently developed computer modules, execute with FVS to reformulate results for specific purposes, including the design of input for the execution of subsequent modules. A Windows-style interface is being developed for FVS to facilitate designing complicated simulations and orchestrating the operations of linked but foreign computer modules. A different approach to interoperability was used in NED. NED uses a custom-developed Logic Server, based on the client-server paradigm, to create a communication and control channel between the user interface and data manager modules, written in C++, and the knowledge-base management module written in PROLOG (Rauscher et al., 1997b). The user interface module of NED is the only module permitted to communicate with the user, which enforces a uniform look and feel. All variable values are maintained by the data manager module. Rather than send every known value of all variables to the knowledge-base management module each time it is called to perform a particular task, the data manager responds to specific data requests from the knowledge-base module as they are needed. Such intelligent communication capability makes the entire system more flexible and efficient. The ecosystem management decision support (EMDS) project provides a final example of a different customized integration approach. EMDS links together two commercial software modules, the NetWeaver[3] knowledge-base system (Knowledge Garden, West Palm Beach, FL) and the ArcView geographic information system (Environmental System Research Institute, Redlands, CA) to provide a flexible and powerful tool for environmental assessment analysis (Reynolds et al., 1997).

Custom integration approaches to software module interoperability yield unique, point-to-point integration solutions (Otte et al., 1996). Custom solutions are difficult to extend into generic, general purpose interoperable software architectures. Therefore, custom integration of software modules should be viewed as a temporary, stop-gap solution until more robust and generally applicable large system architectures can be designed, tested, and adopted (Otte et al., 1996). Interoperable software architectures are not large monolithic systems; they only provide the com-

‘The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

munication and control framework standards that allow any number of independently developed software modules to function together.

The design, implementation, and maintenance of interoperable software architectures for EM-DSS are challenging activities. System integrators face computer science problems with 'different hardware platforms. software languages, compiler versions, data access mechanisms, module interfaces, and networking protocols' (Mowbray and Zahavi, 1995). In addition, the ecosystem management arena contributes challenges such as different data sources, ecosystem management process visions, decision making methods, and solution strategies. Future generations of EM-DSS must become more interoperable to provide the best possible support for ecosystem management processes.

7. Implementation issues

Effective ecosystem management processes and DSS to implement those processes are urgently needed in the federalforest management sector. A number of issues must be settled before ecosystem management can evolve from a philosophical concept to an efficiently functioning method. These issues can be grouped into four themes: scientific/technological, organizational/institutional, education/training, and social/political.

7.1. *Scientific/technological issues*

The scientific/technological issues are complex, but not wicked (Allen and Gould, 1986). There is no doubt that given a set of ecosystem management processes to support and adequate time and resources, effective EM-DSS can be developed. On the other hand, there is considerable doubt that explicit and widely accepted processes for implementing ecosystem management can be crafted given the current institutional, educational, social, and political climate.

Developing EM-DSS requires understanding of the ecological as well as management subsystems that make up ecosystem management. One of the foremost requirements toward that end is to establish clarity of concepts and definitions. In particular, it is necessary to reinforce the fact that ecology is a science and as such provides no value judgments. That principle has been one of the cornerstones of the scientific enterprise for over 400 years. Due to the highly charged socio-political climate in which today's environmental conflicts are played out, some scientists have become unclear about fact-value distinctions and have chosen to become advocates (Kimmins, 1993; Chase, 1995). The United States needs advocates who champion important causes and it needs scientists to objectively evaluate courses of action and implement mandates (FEMAT, 1993). But to maintain scientific credibility, scientists must be expected to disclose publicly when they are playing which role (Dombeck, 1997). The scientist who takes on the role of advocate "under the mantle of objective science is not serving that process whereby decisions are made that have profound consequences for the natural resources and on the people whose livelihoods and lifestyles may be in jeopardy" (FEMAT, 1993, p. 11-80). A clear demarcation between these two roles must be maintained to ensure that controversial decisions are based upon the best knowledge available, that poorly defined concepts are identified and improved, and that mistaken facts are uncovered and corrected.

7.2. *Organizational/institutional issues*

Making ecosystem management work in the USDA forest service and other federal agencies will require strong leadership, the willingness to accept organizational change as normal, the support of the President and Congress to change funding patterns, and a focus on results. Only strong leadership throughout an institution can produce: (1) clear objectives and policy direction; (2) provide clear priorities and assign responsibilities; (3) marshal adequate resources over a long enough time to meet commitments; and (4) assure that the desired results are achieved. It is axiomatic in management science that wicked problems, such as ecosystem management, should be the primary concern of top management, not middle- or lower-level management (Donnelly et al., 1995). The basis for this management principle is the fact that middle- and lower- level management staff typically do not have the time, money, organizational power, or expertise to deal effectively with wicked problems on their own. It is considered the responsibility of top-level management to ensure that unstructured problems, such as ecosystem management, are increasingly more structured as they move down the management levels to the field. All administrative levels within the USDA forest service and its partner federal agencies will need to accept their own share of responsibilities to make ecosystem management a local, regional, and national success (FEMAT, 1993; Kaufmann et al., 1994).

7.3. *Education and training issues*

Attempting to solve complex ecosystem management problems with inappropriate resources (lack of adequate knowledge, untrained people, or inadequate time) will is likely to produce poor decisions and questionable ecosystem management results (Rauscher et al., 1993; Stock and Rauscher, 1996). Sound decisions are primarily influenced by the nature and complexity of the problem, accessibility to high quality and relevant knowledge, competent leadership, and well-trained decision makers who know how to use the knowledge wisely (Rauscher, 1996). Decision makers need sufficient training and education in ecological decision analysis, decision support principles, and specific analytical technologies and tools. Maintenance of a consistently and uniformly high level of knowledge and skill at all levels in a large organization during turbulent times is difficult and potentially expensive, yet critical. Continuing education programs, implemented by many of the USDA forest service's administrative regions, show great promise. For example, the Northern Region's program consists of four modules: (1) basic ecological, evolutionary concepts; (2) ecosystem dynamics; (3) integrated ecosystem inventory and analysis; and (4) ecosystem management implementation (Bollenbacher et al., 1994). This course does not yet seem to adequately address decision analysis principles and practice, or evaluation and use of the available decision support tools.

A democratic, collaborative group negotiation process for ecosystem management can only work well where public control of policy preferences is informed control (Kimmins, 1991). Do federal land management agencies, such as the USDA Forest Service, have a role in creating and maintaining an informed public? "The politically effective, emotive, but often factually incorrect rhetoric of both environmentalists and industrialists must be challenged and put behind us since it does not provide an adequate basis from which to develop effective policy for sustainable ecosystems" (Kimmins, 199 1). One side of this issue urges that the public be proactively informed to increase the use of factually correct information to sway public preferences. The other side of this issue argues that federal land management agencies must not be allowed to enter the public national environmental management debate. In the past, federal agencies have had clear mandates to educate, train, and otherwise inform their perceived clients such as private forest landowners, local civic organizations, local environmental interest groups, local hunting clubs, etc. However, by custom, federal ecosystem management agencies have not usually used influential local or national media in a concerted effort to inform the general public about environmental issues. When they have done so, as in the case of the 'Smokey the Bear' campaign, they have proven to be very effective. Since the ecosystem management paradigm gives public stakeholders an important role to play in the entire process, it is important to revisit this issue. Who is the public – vocal, minority special interest groups or the greater majority of citizens? How can the public best be represented in ecosystem management? How can their interests be identified? How can their questions best be addressed? How can their factual misconceptions be corrected?

7.4. *Social/political issues*

A number of important social/political issues need local, regional, and national debate. These issues may not be amenable to resolution, but their essential elements should be understood by everyone because they help shape the deep-seated, core values on which individuals base their preferences.

Is sustainable ecosystem management even possible? Ecosystem sustainability has been defined as the overlap between what is biologically possible and what is socially desirable (Bormann et al., 1993; Maser, 1994). World population is expected to double from its present 6 billion people to between 11 and 16 billion people in the next 50 years (Marcin, 1993). Two hundred years ago, humans are estimated to have consumed about 1% of all energy captured by green plants (Zeide, 1994). Today this figure is about 40%, meaning that the proportion left over for all other species has shrunk from 99 to 60%. This basic biophysical fact makes species extinction and retrenchment inevitable and the belief that we can save every species a myth (Zeide, 1994). Despite numerous scientific conferences on global climate change, biodiversity, and air pollution which point to human overpopulation as the ultimate cause of these environmental ills, resistance to accepting the consequences of human population growth is common (Zeide, 1994). It may be that given the current population of the world (to say nothing of future increases) and peoples' aspirations for 'the good life,' there exists no overlap between what is biologically possible and what is socially desirable.

It seems unlikely that increasing environmental quality and achieving sustainable ecosystem management can be accomplished without sacrifices (Zeide, 1994). Our society has somehow come to expect that we can have all we want without paying a price. "Lacking the resources or the will to address our significant (environmental) problems (in a substantive way), we conduct a politic that is more and more characterized by images, rituals, and myths. Leaders simply joust symbolically with problems. When the issues are politically too costly to be settled by the legislative branch, symbolic legislation is passed that seems to address the problem but, in fact, simply passes the political hot potato to the bureaucracy and the courts. The bureaucracy is similarly stymied as it casts about for public relations solutions to what may be politically unwinnable situations" (Shepard, 1993; emphasis added). United States national politics have increasingly turned to a reliance on fantasy (perception is reality) instead of visionary leadership (reality is reality) with absurd promises, consumption of immediate benefits, avoidance of hard issues and choices, and postponement of costs to future generations (Shepard, 1993). Environmental costs are not adequately priced and tend to be passed on to publics with the least power, thus creating conflicts between individual, special interest group, and collective interests (Janssen, 1992). Such a socio-political climate incapacitates the federal forest management decision making process and until a resolution is found, ecosystem management will probably remain merely a symbolic solution to our environmental management problems.

Powerful environmental interest groups emphasize the benefits of doing nothing, assuming that nature will know best. But "nature in the twenty-first century will be a nature that we make; the question is the degree to which this molding will be intentional or unintentional, desirable or undesirable" (Botkin, 1990). Much of the answer to this question will depend upon whether we choose to manage human population growth and economic development. The species that make up ecosystems are continually changing and adapting to new stresses. "Nature, never having been constant, does not provide a simple answer as to what is right, proper, and best for our environment. There is no single condition that is best for all life." (Botkin, 1995). In fact, the extinction of existing species and the evolution of new species is a normal, natural process. Nature does not care-either about threatened and endangered species or about us humans. People care and it is up to people to define goodness or badness. Failure to make a decision is a decision and it is a different decision than to explicitly do nothing, knowing the consequences. Consequences will happen without opportunities to evaluate them or mitigate them if they are undesirable. The status quo will prevail and the range of our choices in the future is likely to shrink (FEMAT, 1993). In reality, there is no acceptable alternative to pro-active ecosystem management.

Finally, concern over sustainable ecosystem management is largely a luxury displayed by wealthy societies where people no longer need be concerned about food, shelter, or personal security (Kimmins, 1991). The increasing prosperity and greater urbanization of the American public changed their principal concerns from the supplying of economic wants to putting a greater emphasis on the non-consumptive uses of federal forest ecosystems (Caldwell et al., 1994). Urbanization obscures the human reliance on consumptive uses of natural resources (Fautin, 1995). Wood-framed single-family homes, toilet paper, wooden furniture and cardboard boxes were all made from trees that were cut in a forest somewhere. Many people seem to have lost the understanding that the two are fundamentally connected (Dekker-Robertson, 1997). Without a decrease in human consumption and/or numbers, environmental degradation is inevitable (Zeide, 1994; Goodland, 1995) and resource exploitation will, in all likelihood, continue (Ludwig et al., 1993). Deciding to reduce resource production by protecting and preserving ecosystems without simultaneously reducing consumption rates for that resource means that other areas of the world will be taxed to make up the difference (Moir and Mowrer, 1994). We have effectively exported our demand for that resource to ecosystems somewhere on earth that may very well be less resilient than our own. The only other way to increase production without decreasing demand is through scientific and technological advances (Dekker-Robertson, 1997). Advances in resource production can provide more products and advances in utilization can satisfy more demand per unit product. One positive step we could take to address this issue is to organize an analysis of world forest ecosystems that ranks their ability to produce consumable resources sustainably. World demand should be supplied primarily from those forest ecosystems best able to sustain the disturbance (Dekker-Robertson, 1997). We must all eventually realize and accept that only by developing and maintaining adequate national wealth can we afford to preserve the environment (Marcin, 1993).

Many of the social/political issues address strongly held core values of the American public and the stakeholders in ecosystem management. The more numerous and antagonistic the core values of stakeholders, the less likely satisfactory collaborative compromises can be reached and the less likely ecosystem management will be helpful in solving our environmental problems. In this situation, diversity is clearly a detriment, not a strength. In a democratic system, a meaningful national debate occurring primarily in the public media may be the most effective way to shape a national concensus about difficult environmental values and preferences for federal land management.

8. Summary

Ecosystem management has been adopted as the philosophical paradigm guiding federal forest management in the United States. The strategic goal of ecosystem management is, arguably, to find a sensible middle ground between ensuring the necessary long-term protection of the environment while allowing an increasing population to use its natural resources for maintaining and improving human life. Ecosystem management has all the characteristics of 'wicked' problems. Given that ecosystem management, like human survival and welfare, is a wicked problem, how can we proceed to tame it? We need to use the same tools that people have always used for handling wicked problems – knowledge, organization, judicious simplification, and inspired leadership.

Adequately described and widely accepted ecosystem management processes do not yet exist, but a concerted effort to study the many formal and informal ecosystem management processes that do exist would result in some powerful candidates to support the practical implementation of ecosystem management.

The generic theory of DDS development and application is well developed. Numerous specific ecosystem management DDSs have been developed and are evolving in their capabilities. Given a set of ecosystem management processes to support along with adequate time and resources, effective EM-DSS can be developed. However, major social and political issues present significant impediments to the efforts to make ecosystem management operational. A socio-political environment in which everyone wants to benefit and no one wants to pay incapacitates the federal forest management decision making process. The very laws that were adopted to solve the problem, RPA/NFMA, have led to procedural paralysis at exponentially rising costs (Behan, 1990). Developing a workable ecosystem management process and the decision making tools to support it, is probably one of the most complex and urgent challenges facing us today.

It is becoming increasingly obvious that the federal forest management situation in the United States is unsatisfactory and that the ecosystem management paradigm currently offers the best potential for improvement. The task is to end our paralysis and find ways to operationalize the ecosystem management decision process. One concrete method to operationalize ecosystem management is to design and build effective decision support tools. The theory and practice of multiple-use forest management in the United States specifically for the sustainable production of timber, wildlife, water, and recreation products has been researched and tested for over 100 years. It will very likely take at least as much time and effort to research and test the theory and practice of ecosystem management – a significantly more difficult problem.

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References

Adelman, L., 1992. Evaluating Decision Support and Expert Systems. Wiley, New York, 232 pp.

Ager, A., 1997. UTOOLS/UVIEW. In: Mowrer, H.T., Barber, K., Campbell, J., Crookston, N., Dahms, C., Day, J., Laacke, J., Merzenich, J., Mighton, S., Rauscher, M., Reynolds, K., Thompson, J., Trenchi, P., Twery, M., 1997. Decision Support Systems for Ecosystem Management: An Evaluation of Existing Systems. USDA For. Serv. Gen. Tech. Rep. RM296, pp. 144–148.

Allen, G.M., Gould Jr, E.M., 1986. Complexity. wickedness, and public forests. J. Forestry 84(4), 20–23.

Barber, K.H., Rodman, S.A., 1990. FORPLAN: The marvelous toy. J. Forestry 88(5), 26–30.

Baskerville, G., 1985. Adaptive management – Wood availability and habitat availability. The Forestry Chronicle 61(2), 171-175.

Behan, R.W., 1990. The RPA/NFMA: Solution to a nonexistent problem. J. Forestry 91, 20–25.

Behan, R.W., 1994. Multiresource management and planning with EZ-IMPACT. J. Forestry 92(2), 32-36.

Behan, R.W., 1997. Scarcity, simplicity, separatism, science – and systems. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating a Forestry for the 21st Century. Island Press, Washington, DC, pp. 411417.

Bennett, A.J., 1996. Sustainable land use: Interdependence between forestry and agriculture. Caring for the Forest: Research in a Changing World, Congress Report, vol. I, IUFRO XX World Congress, 6-12 August 1995 at Tampere, Finland, pp. 144-152.

Berry, M.W., Flamm, R.O., Hazen, B.C., MacIntyre, R.M., 1996. The land-use change and analysis (LUCAS) for evaluating landscape management decisions. IEEE Computational Science and Engineering 3, 24-35.

Bevins, C.D., Andrews, P.L., 1994. The Loki software architecture for fire and ecosystem modeling: A tinker toy approach. Proc. 12th Conf. on Fire and Forest Meteorology, 26-28 October, 1993 at Jekyll Island, GA, pp. 252-259.

Bollenbacher, B.L., Samson, F., O'Hara, K., 1994. Continuing education in ecosystem management (CEEM), an interdisciplinary approach. In: Foley, L.H. (compiler), Silviculture: From the Cradle of Forestry to Ecosystem Management. Proc. National Silviculture Workshop, 1–4 November 1993 at Hendersonville, NC, USDA Forest Service Gen. Tech. Rep. SE-88, pp. 224-228.

Bonnicksen, T.M., 1991. Managing biosocial systems: A framework to organize society–environment relationships. J. Forestry 89(10), 10-15.

Bormann, B.T., Brooks, M.H., Ford, E.D., Kiester, A.R., Oliver, C.D., Weigand, J.F., 1993. A framework for sustainable ecosystem management. USDA Forest Service Gen. Tech. Rep. PNW-331, 61 pp.

Botkin, D.B., 1990. Discordant Harmonies. Oxford University Press, New York, 241 pp.

Botkin, D.B., 1995. Our Natural History. G.P. Putnam and Sons, New York, 325 pp.

Brown, T.C., 1984. The concept of value in resource allocation. Land Economics 60, 231-246.

Caldwell, L.K., Wilkinson, C.F., Shannon, M.A., 1994. Making ecosystem policy: Three decades of change. J. Forestry 92(4), 7–10.

Caldwell, L.K., 1996. Science assumptions and misplaced certainty in natural resources and environmental problem solving. In: Lemons, John (Ed.), Scientific Uncertainty and Environmental Problem Solving, Blackwell Science, Cambridge, MA, pp. 394–421.

Canham, H.O., 1990. Decision matrices and weighting summation valuation in forest planning. Northern J. Applied Forestry 7(2), 77-79.

Carpenter, S.R., 1990. Large-scale perturbations: Opportunities for innovation. Ecology 71, 2038–2043.

Chase, Alston, 1995. In a Dark Wood: The Fight Over Forests and the Rising Tyranny of Ecology. Houghton Mifflin, Boston, 534 pp.

Conklin, J., Begeman, M.L., 1987. GIBIS: A hypertext tool for team design deliberation. Proceedings of Hypertext 87, 13-15 November 1987 at Chapel Hill, NC, pp. 104–115.

Craig, L.E., 1996. Letter from the United States Senate, Committee on Energy and Natural Resources, Washington, DC to The Honerable Dan Glickman, Secretary of Agriculture. 20 June 1996, 5 pp.

Daniels, S.E., Walker, G.B., Boeder, J.R., Means, J.E., 1993. Managing ecosystems and social conflict. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, National Forest System, pp. 347-359.

Dekker-Robertson. Donna, 1997. Is the Northern Spotted Owl worth more than the Orangutan? Proc. National Silviculture Workshop, Communicating the role of silviculture in managing the national forests, 19-22 May 1997, Warren, PA, Northeastern Forest Experiment Station Gen. Tech. Rep. NE-238, pp. 19-28.

Dombeck, Mike, 1997. Integrating Science and Decision Making: Guidelines for Collaboration Among Managers and Researchers in the Forest Service. USDA Forest Service, FS-608, 11 pp.

Donnelly Jr., J.H., Gibson, J.L., Ivancevich, J.M., 1995. Fundamentals of Management, 9th ed. Irwing, Chicago, pp. 127-128.

Everett, R., Oliver, C., Saveland, J., Hessburg, P., Diaz, N., Irwin, L., 1993. Adaptive ecosystem management. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, National Forest System, pp. 361-375.

Faber, B.G., Wallace, W.W., Croteau, K., Thomas, V.L., Small, L.R., 1997. Active response GIS: An architecture for interactive resource modeling. Proc. GIS World 97, Integrating spatial information technologies for tomorrow, 17-20 February 1997, at Vancouver, BC, pp. 296–301.

Fautin, Daphne G., 1995. Sustainability -- more than a buzz-word? Annual Review of Ecology and Systematics 26, pp. 5-9.

Fedra, K., 1995. Decision support for natural resources management: Models GIS, and expert systems. AI Applications 9(3), 3-19.

FEMAT, 1993. Forest ecosystem management: An ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team, US Government Printing Office, chap. I-IX plus Appendices.

Floyd. D.W.. Germain. R.H., ter Horst, K., 1996. A model for assessing negotiations and mediation in forest resource conflicts. J. Forestry 94(5), 29–33.

French, J.R.P., Raven, B., 1959. The bases of social power. In: Cartwright, D. (Ed.), Studies in Social Power. Institute for Social Research, University of Michigan, Ann Arbor, pp. 150-167.

GAO, 1994. Ecosystem management: Additional actions needed to adequately test a promising approach. A Report to Congressional Requesters, GAO/RCED-94-111, 87 pp.

Garland, J.J., 1997. The players in public policy. J. Forestry 95(1), 13-15.

Goodland, Robert, 1995. The concept of environmental sustainability. Annual Rev. Ecol. Systematics 26, 1-24.

Greber, B.J., Johnson, K.N., 1991. What's all this debate about overcutting? J. Forestry 89(11), 25–30.

Grossarth, O., Nygren, T., 1993. Implementing ecosystem management through the forest planning process. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, National Forest System, pp. 291-299.

Grumbine, R.E., 1994. What is ecosystem management? Conservation Biology 8(1), 27-38.

Hannigan, J., 1995. Environmental Sociology: A Social Constructionist Perspective. Routledge, London.

Hashim, S.H., 1990. Exploring hypertext programming. Windcrest Books, Blue Ridge Summit, PA, 365 pp.

Hoekstra, T.W., Dyer, A.A., LeMaster, D.C. (Eds.), 1987. FORPLAN: An Evaluation of a Forest Planning Tool. USDA Forest Service, Gen. Tech. Rep. RM-140, 235 pp.

Holsapple, Clyde W., Whinston, Andrew B., 1996. Decision support systems: A knowledge-based approach. West Publishing, Minneapolis/St. Paul. 713 pp and Appendices.

Howard, A.F., 1991. A critical look at multiple criteria decision making techniques with reference to forestry applications. Canadian J. Forest Res. 21, 1649-1659.

Howitt, W.S., 1978. The value of the simple approach. Interfaces 8, 64–70.

Janssen, R., 1992. Multiobjective Decision Support for Environmental Management. Kluwer Academic Publishers, Dordrecht, The Netherlands, 232 pp.

Janssen, R., van Hervijnen, M., 1992. DEFINITE: Decisions on a finite set of alternatives. Institute for Environmental Studies, Free University Amsterdam, The Netherlands, Kluwer Academic Publishers, software on 2 disks.

Jensen, M.E., Everett, R., 1993. An overview of ecosystem management principles. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, pp. 9-18.

Jessup, L.M., Valacich, J.S. (Eds.), 1993. Group Support Systems: New Perspectives. MacMillan, New York, 365 pp.

Jorgensen, S.E., Halling-Sorensen, B., Nielsen, S.N., 1996. Handbook of Environmental and Ecological Modeling. Lewis Publishers, Boca Raton, FL, 453 pp.

Kaufmann, M.R., Graham, R.T., Boyce Jr., D.A., Moir, W.H., Perry, L., Reynolds, R.T., Bassett, R.L., Hehlhop, P., Edminster, C.B., Block, W.M., Corn, P.S., 1994. An ecological basis for ecosystem management. USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Gen. Tech. Rep. RM-246, p. 22.

Kennedy, J.J., Quigley, T.M., 1993. Evolution of Forest Service organizational culture and adaptation issues in embracing ecosystem management: In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, pp. 19-29.

Kessler, W.B., Salwasser, H., Cartwright Jr., C.W., Chaplan, J.A., 1992. New perspectives for sustainable natural resources management. Ecol. Applications 2(3), 221-225.

Kimmins, J.P., 1991. The future of the forested landscapes of Canada. The Forestry Chronicle 67, 14-18.

Kimmins, J.P., 1993. Ecology, environmentalism, and green religion. The Forestry Chronicle 69, 285-289.

Kimmins, J.P., 1995. Sustainable development in Canadian forestry in the face of changing paradigms. Forestry Chronicle 71(1), 33-40.

Klein, M., Methlie, L.B., 1990. Expert Systems: A Decision Support Approach. Addison-Wesley, Reading, MA, 539 pp.

Kohm, K.A., Franklin, J.F., 1997. Introduction. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating a Forestry for the 21st Century. Island Press, Washington, DC, pp. l-5.

Larsen, D.R., Shifley, S.R., Thompson III F.R, F.R., Brookshire, B.L., Dey, D.C., Kurzejeski, E.W., England, K., 1997. 10 Guidelines for ecosystem researchers: Lessons from Missouri. J. Forestry 95(4), 4-9.

Lee, K.N., 1993. Compass and Gyroscope: Integrating Science and Politics for the Environment. Island Press, Washington, DC. 243 pp.

Lessard, G., 1997. A national framework for integrated ecological assessments. USDA Forest Service, Ecosystem Management, P.O. Box 96090, Washington, DC 20090-6090, p. 56, in press.

Lindblom, C.E., 1990. Inquiry and change: The troubled attempt to understand and shape society. Yale University Press, New Haven, CT, 334 pp.

Liu, G., Davis, L.S., 1995. Interactive resolution of multi-objective forest planning problems with shadow price and parametric analysis. Forest Science 41(3), 452–469.

Ludwig, D., Hilbom, R., Walters, C., 1993. Uncertainty, resource exploitation, and conservation: Lessons from history. Science 260, pp. 17 and 36.

Marcin, T.C., 1993. Demographic change: Implications for forest management. J. Forestry 91(11), 39-45.

Maser, Chris, 1994. Sustainable Forestry: Philosophy, Science, and Economics. St. Lucie Press, Delray Beach, FL, 373 pp.

McGaughey, R.J., 1997. Visualizing forest stand dynamics using the stand visualization system. Proc. 1997 ACSM/ASPRS Annual Convention and Exposition, 7-10 April, 1997. American Society for Photogrammetry and Remote Sensing, Seattle, WA, vol. 4. pp. 248-257.

Mintzberg, H., Raisinghani, D., Theoret, A., 1976. The structure of unstructured decision processes. Administrative Science Quarterly 21, 246–275.

Moir, W.H., Mowrer, H.T., 1994. Unsustainability: The shadow of our future. In: Covington, W.W., DeBano, L.F. (Eds.), Sustainable Ecological Systems: Implementing an Ecological Approach to Management. 12-14 July 1993 at Flagstaff, Arizona, USDA Forest Service Gen. Tech. Rep. RM-247, pp. 143-149.

Montgomery, C.A., 1993. Socioeconomic risk assessment and its relation to ecosystem management. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, pp. 325-335.

Morrison, J., 1993. Integrating ecosystem management and the forest planning process. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, pp. 281-290.

Mowbray, T.J., Zahavi, R., 1995. The Essential CORBA: Systems Integration using Distributed Objects. Wiley, New York, 367 pp.

Mowrer, H.T., Barber, K., Campbell, J., Crookston, N., Dahms, C., Day, J., Laacke, J., Merzenich. J., Mighton, S., Rauscher, M., Reynolds, K., Thompson, J., Trenchi, P., Twery, M., 1997. Decision support systems for ecosystem management: An evaluation of existing systems. USDA Forest Service, Interregional Ecosystem Management Coordination Group, Decision Support System Task Team, Rocky Mountain Forest and Range Experiment Station, RM-GTR-296, 154 pp.

Oliver, CD., Knapp, W.H., Everett, R., 1993. A system for implementing ecosystem management. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, pp. 377-388.

Oliver, C.D., McCarter, J.B., 1996. Developments in decision support for landscape management. In: Heit, M., Parker, H.D., Shortreid, A. (Eds.), GIS Applications in Natural Resource Management 2. Proc. 9th American Symposium on Geographic Information Systems, Vancouver, BC, pp. 501–509.

O'Reilly, C.A., 1983. The use of information in organizational decision making: A model and some propositions. In: Cummings, L.L., Shaw, B.M. (Eds.), Research in Organizational Behavior, vol. 5, pp. 103–139.

Orland, B., 1995. SMARTFOREST: A 3-D interactive forest visualization and analysis system. In: Power, J.M., Strome, M., Daniel, T.C. (Eds.), Proc. Decision Support – 2001 Conference. 12-16 September 1994 Toronto, Ontario, pp. 181–190.

Otte, R., Patrick, P., Roy, M., 1996. Understanding CORBA: The common object request broker architecture. Prentice-Hall, NJ, 267 pp.

Overbay, J.C., 1992. Ecosystem management. Proc. national workshop: Taking an Ecological Approach to Management, 27-30 April 1992 at Salt Lake City, UT. USDA Forest Service, Watershed and Air Management Branch, WO-WSA-3. Washington, DC, pp. 3-15.

Potter, W.D.. Byrd, T.A., Miller, J.A., Kochut, K.J., 1992. Extending decision support systems: The integration of data, knowledge, and model management. Annals of Operations Research 38, 501–527.

Rauscher, H.M., Alban, D.H., Johnson, D.W., 1993. Managing the global climate change scientific knowledge base. Al Applications 7(4), 17–40.

Rauscher, H.M., 1995. Natural resource decision support: Theory and practice. Al Applications 9(3), 1-2.

Rauscher, H.M.. 1996. Decision making methods for ecosystem management decision support. Caring for the forest: Research in a changing world, Congress Report, vol. II, IUFRO XX World Congress, 6-12 August 1995 Tampere, Finland, pp. 264–272.

Rauscher, H.M., Loftis, D.L., McGee, C.E., Worth, C.V., 1997a. Oak Regeneration: A knowledge synthesis. The Compiler 15(1): pp. 51-52, insert, 3 disks, 3.8 Megabytes; 748 chunks; 742 links (electronic).

Rauscher, H.M., Kollasch, R.P., Thomasma, S.A., Nute, D.E., Chen, N., Twery, M.J., Bennett, D.J., Cleveland, H., 1997b. NED-l: A goal-driven ecosystem management decision support system: Technical description. Proc. GIS World 97, Integrating spatial information technologies for tomorrow. 17-20 February 1997, Vancouver, BC, pp. 324–332.

Reynolds, Keith M., Rauscher. H. Michael, Worth, Christopher V., 1995. A hypermedia reference system to the forest ecosystem management assessment team report and some related publications. USDA Forest Service Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-357, 13 pp.

Reynolds, K., Saunders, M., Miller, B., Murray, S., Slade, J., 1997. An application framework for decision support in environmental assessment. Proc. GIS World 97, Integrating spatial information technologies for tomorrow. 17-20 February 1997, Vancouver, BC, pp. 333-337.

Reynolds, K., Bjork, J., Riemann Hershey, R., Schmoldt, D., Payne, J., King, S., Moeur, M., DeCola, L., Twery, M., Cunningham, P., Lessard, G., 1998. Decision support systems for ecosystem management. In: Szaro, R., Sexton, W., Johnson, N., Malk, A. (Eds.), Ecosystem management: A reference guide to concepts and implementation. Island Press, Washington, DC, in press.

Rittel, H., 1972. On the planning crisis: Systems analysis of the first and second generations. Bedriftokonomen 8, 390–396.

Rittel, H., Webber, M.M., 1973. Dilemmas in a general theory of planning. Policy Sciences 4, 155-169.

Rue, L.W., Byars, L.L., 1992. Management: Skills and Application, Richard C. Irwin, Homewood. IL, 421 pp.

Southern Appalachian Man and the Biosphere (SAMAB), 1996. The southern Appalachian assessment summary report. Reports 1-5, USDA Forest Service, Southern Region, Atlanta, GA, 332 pp.

Sage, A.P., 1991, Decision Support Systems Engineering. Wiley, New York, 344 pp.

Sample, V.A., 1990. The Impact of the Federal Budge Process on National Forest Planning. Greenwood Press, New York, 250 pp.

Sample, V.A., 1993. A framework for public participation in natural resource decision making. J. Forestry 91(7), 22-27.

Schmoldt, D.L., Rauscher, H.M., 1996. Building Knowledge-based Systems for Natural Resource Management. Chapman and Hall, New York, 386 pp.

Schuster, E.G.. Leefers, L.A., Thompson, J.E., 1993. A guide to computer-based analytical tools for implementing national forest plans. USDA Forest Service, Gen. Tech. Rep. INT-296, 269 pp.

Shands, W.E., 1994. National forests and the human legacy: Some history. In: Foley, L.H. (compiler), Silviculture: From the cradle of forestry to ecosystem management. Proc. National Silviculture Workshop, 1–4 November 1993 Hendersonville, NC, USDA Forest Service Gen. Tech. Rep. SE-88, pp. 3-l 1.

Shepard, W.B., 1993. Ecosystem management in the Forest Service: Political implications, impediments, and imperatives. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Eastside Forest Ecosystem Health Assessment: vol. II Ecosystem Management: Principles and Applications. USDA Forest Service, pp. 31-37.

Shindler, B., Steel, B., List, P., 1996. Public judgments of adaptive management. J. Forestry 94(6), 4-12.

Shindler, Bruce, Neburka, Julie, 1997. Public participation in forest planning: 8 attributes of success. J. Forestry 95, 17-19.

Silver, MS., 1991. Systems that Support Decision makers: Description and Analysis. Wiley, New York, 256 pp.

Smith, G.R., 1997. Making decisions in a complex dynamic world. Kohm, K.A., Franklin, J.F. (Eds.), Creating a forestry for the 21st century. Island Press, Washington, DC, pp. 419–435.

Steelman, T.A., 1996. Public participation in national forest management: A case study of the Monongahela National Forest, West Virginia. Proc. IEEE 1996 International Symposium on Technology and Society. Technical Expertise and Public Decisions, 21-22 June 1996 Princeton University, Princeton, NJ, pp. 226–230.

Stephens, J.A., 1996. A new era in planning analysis tools. Analysis notes, USDA Forest Service, WO/Ecosystem Management Analysis Center, Ft. Collins, CO, vol. 6, 2, pp. 1-2.

Stock, M.W., Rauscher, H.M., 1996. Artificial intelligence and decision support in natural resource management. New Zealand J. Forestry Sci. 26, 145-157.

Sygenex, 1994. Criterium Decision Plus: The Complete Decision Formulation, Analysis, and Presentation for Windows. User's Guide. Sygenex, 15446 Bel-Red Road, Redmond, WA 98052, 327 pp.

Teck, R., Moeur, M., Eav, B., 1996. Forecasting ecosystems with the forest vegetation simulator. J. Forestry 94(12), 7–10.

Thomas, J.W., 1995. The forest service program for forest and rangeland resources: A long-term strategic plan, Draft 1995 RPA Program, USDA Forest Service, Washington, DC.

Thomas, J.W., 1997. Foreword. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating a Forestry for the 21 st Century. Island Press, Washington, DC, pp. ix-xii.

Thomson, A.J., 1993. Paradigm green: AI approaches to evaluating the economic consequences of changing environmental viewpoints AI Applications 7(4), 61-68.

Thomson, A.J., 1996. Asimov's physchohistory: Vision of the future or present reality?. AI Applications 10(3), 1-8.

Ticknor, W.D., 1993. Sustainable forestry: Redefining the role of forest management. In: Aplet, G.H., Johnson, N., Olson, J.T., Sample, V.A. (Eds.), Defining Sustainable Forestry. Island Press, Washington, DC, pp. 260-269.

Tonn, B., White, D., 1996. Sustainable societies in the information age. The American Sociologist 27(1). 102-121.

Tonn, B., English, M., Travis, C., 1998. Frameworks for understanding and improving environmental decision making. ORNLINCEDR-7, Oak Ridge National Laboratory, Oak Ridge, TN, 45 pp.

Toynbee. Arnold J., 1946. A study of history. Oxford University Press, New York, 742 pp.

Turban, E., 1993. Decision Support and Expert Systems: Management Support Systems. MacMillan Publishing, New York, 833 pp.

Twery, M.J., Bennett, D.J., Kollasch, R.P., Thomasma. S.A., Stout. S.L., Palmer, J.F., Hoffman, R.A., DeCalesta, D.S., Hombeck, J., Rauscher, H.M., Steinman, J., Gustafson, E., Miller, G., Cleveland, H., Grove, M., McGuinness, B., Chen, N., Nute, D.E., 1997. NED-l: An integrated decision support system for ecosystem management. Proc. Resource Technology 97 Meeting, 7-l 1 April 1997, Seattle, WA, pp. 331-343.

Van den Berg, J.C.J.M., 1996. Ecological Economics and Sustainable Development: Theory, Methods, and Applications. Edward Elgar, Cheltenham, UK, 312 pp.

Vroom, V.H., Jago, A.G., 1988. The new leadership: Managing participation in organizations. Prentice Hall, Englewood Cliffs, NJ, 389 pp.

Walters, C.J., Holling, C.S., 1990. Large-scale management experiments and learning by doing. Ecology 71(6), 2060–2068.

Wear, D.N., Turner, M.G., Flamm, R.O., 1996. Ecosystem management with multiple owners: Landscape dynamics in a southern Appalachian watershed. Ecological Applications 6(4), 1173-1188.

Williams, S.B., Roschke, D.J., Holtfrerich, D.R., 1995. Designing configurable decision-support software: Lessons learned. AI Applications 9(3), 103-l 14.

Zeide, B., 1994. An unsustainable technology: Sustainable development. In: ECOTECH '94. Internet Address: et-tor@-searn.sunet.se, paper ET-004.

Zonnefeld, I.S., 1988. Basic principles of land evaluation using vegetation and other land attributes. In: Kuechler, A.W., Zonnefeld, I.S. (Eds.), Vegetation Mapping. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 142-157.