12 Decision Support for Ecosystem Management and Ecological Assessments

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12.1 Introduction

In the face of mounting confrontation and 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 (Government Accounting Office, 1994). Ecosystem management represents different things to different people. At the heart of the ecosystem management paradigm lies a shift in emphasis away from sustaining yields of products toward sustaining the ecosystems that provide these products (Thomas, 1995; Rauscher, 1999). The ecosystem management paradigm represents the latest attempt, in a century-long struggle between resource users and resource preservers, to find a sensible middle ground between ensuring the necessary long-term protection of the environment while protecting the right of an ever-growing population to use its natural resources to maintain and improve human life (Chase, 1995; Taylor, 1998). As the concept of ecosystem management evolves, debates over definitions, fundamental principles, and policy implications will probably continue and shape the new paradigm in ways not yet discernible.

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. Because 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 philosophical concept of ecosystem management into an explicitly defined, operationally practical methodology (Wear et al., 1996; Thomas, 1997). Effective ecosystem management processes are urgently needed so that federal land managers can better 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 that we manage (Kohm and Franklin, 1997). It will require the development of effective, multiobjective decision support systems to (1) assist individuals and groups in their decision-making processes; (2) support, rather than replace, the judgment of the decision makers; and (3) improve the quality, reproducibility, and explicability of decision processes (Janssen, 1992; Larsen et al., 1997; Reynolds et al., 1999). The complexity of environmental dynamics over time and space, over-

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whelming amounts of data, information, and knowledge in different forms and qualities, and 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).

Both the ecosystem and the management subsystems of ecosystem management are part of an interlocking, nested hierarchy (Bonnicksen, 1991; Forest Ecosystem Management and Assessment Team, 1993; Kaufmann et al., 1994). Local management of ecosystems occurs within and is influenced by national and international social-economic-political systems. Similarly, local ecosystems operate within and are influenced by larger biophysical systems, such as ecoregions or biomes. Ecosystem management can and should occur at many scales: global-international, biome-national, ecoregion-multistate, 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) identifying and labeling the issues, (2) defining the problems, and (3) identifying who is causing the problems, who has responsibility for solving the problems, who are the stakeholders associated with the problems, and 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 multistate 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 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 ecoregional-multistate scale to cope with the complex environmental problems that we have created for ourselves at these scales (Caldwell, 1996). It seems reasonable that we should try.

For the purposes of this chapter, we consider three spatial scales for which clear, precise, practical ecosystem management processes are needed: (1) the regional assessment scale, (2) the forest landscape management scale, and (3) the project implementation scale. These three scales are connected by complex information linkages that make it difficult to treat them separately. Indeed, decision support systems (DSS) have been developed to operate at each of these scales, with special attention given to what is needed from the higher scale and what needs to be supplied to the lower one. This chapter reviews the state of ecosystem management decision support across all three scales. Although most of the examples are drawn from experiences with USDA Forest Service research and management, the principles discussed are generally applicable to all federal land management agencies.

12.2 The Decision-making Environment

The decision-making environment consists of the social, economic, political, and legal context in which any agency charged with ecosystem management operates. Ecosystem management itself is composed of two parts: an ecological subsystem and a management subsystem (Figure 12.1) (Bonnicksen, 199 1). The ecological subsystem contains physical or conceptual objects such as trees, birds, deer, rivers, smells, sights, and sounds. Each object 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 change, objects can change in status from resource to value neutral or even to pest (Bonnicksen, 1991). For example, the white-tailed deer, once regarded as a sought-after resource, is now considered a pest in some forest ecosystems of the eastern United States. 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.

The management subsystem is defined as making decisions about and controlling ecosystems to achieve desired ends. People in the management role participate in ecosystem management in a very different manner. They are the risk takers, the setters of objectives, the judges of value, the substituters, in other words, the decision makers. It is useful to keep this distinction clearly in mind. Normally, many people participate in the management subprocess of ecosystem management. The specific values, goals, and constraints that characterize public preferences and needs may be identified through a group negotiation process involving

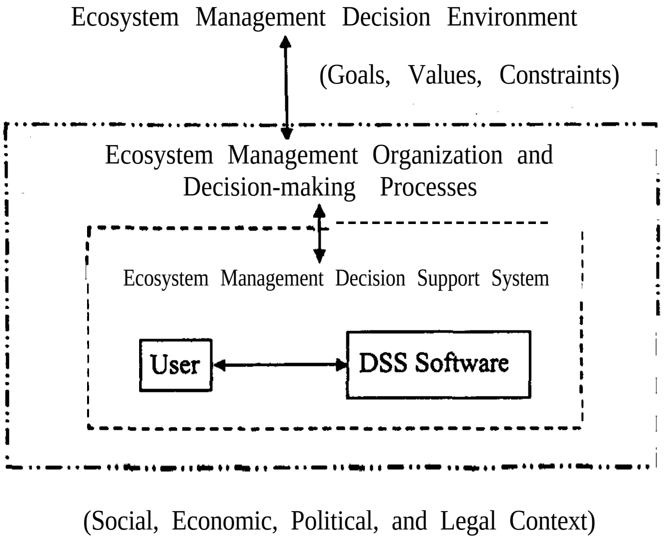

FIGURE 12.1. Decision environment for ecosystem management.

a variety of stakeholders and management decision makers (Figure 12.1). Management decision makers organize and lead the group negotiation process; they must ensure that the resultant goals 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).

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 new message for 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 coevolve (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) describe 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).

12.2.1 Major Elements of the Management Subsystem

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, p. 347). 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 Neburka, 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.

Ecosystem management cost evaluation is a critical area for economists to study. As a general rule, increases in problem complexity 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 should be prepared and made public, because few people know or appreciate the costs of efforts to solve complex ecosystem management problems. For example, the USDA Forest Service has spent approximately $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 costs of implementing ecosystem management prescriptions and monitoring and evaluating the results have not yet been estimated. Are we willing or able to marshal the funding to implement ecosystem management in a way that will 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 costs 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; Dombeck, 1997). Refusing to fund ecosystem management and opting for the "do nothing" alternative is likely to result in unacceptable 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" (Botkin, 1990). 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 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). Making the nature that we want may be expensive. A good understanding of ecological economics will help society make rational choices.

12.2.2 Regional Ecological Assessments Viewed as a DSS

Recently, regional ecological assessments have been used to describe the large-scale context for ecosystem management and therefore can be considered decision support tools (Figure 12.1). Regional assessments have been large, collaborative interagency efforts, often with public stakeholder participation, that have taken 2 to 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 (Jensen et al., 1998). For examples of regional assessments, see the case studies provided in this guidebook.

Currently, precisely how these regional assessments fit into the ecosystem management process is unclear. One alternative would be to view regional assessments as DSS for ecosystem management at the ecoregion-multistate scale. In this capacity, the current objectives for assessments focus entirely too much on the ecosystem component of ecosystem management. The Southern Appalachian Assessment (SAMAB, 1996), for example, examines the social and economic activities of people within the 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-political systems in the region, is largely ignored. To correct this deficiency, another list of objectives for regional assessments might include the following: (1) identify a set of regional scale goals and 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.

12.3 Ecosystem Management Processes

The decision-making environment determines the goals, values, and constraints for the organization. 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; Clemen, 1996). Ideally, decision support systems should not be developed until the ecosystem management decision-making processes that they are to support have been articulated. In reality, both the 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 macrolevel 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; also, they 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; other federal agencies have hundreds of additional field organizations), and few, if any, have been studied and described formally so that similarities and differences can be identified. Moreover, no particular 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 to 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, a continuing process of planning, monitoring, evaluating, and adjusting management methods (Bormann et al., 1993: FEMAT, 1993; Lee, 1993), provides a framework for describing a generic management process. 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 (Figure 12.2). At each cycle, the results of the evaluation activity are fed back to the planning activity so that adaptive learning can take

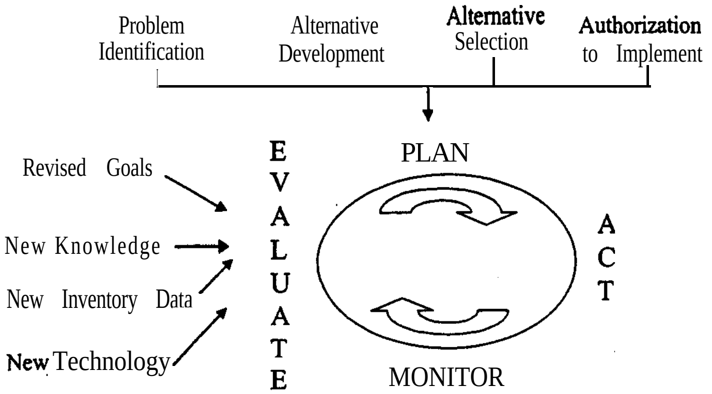

FIGURE 12.2. Adaptive management process for ecosystem management.

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.

12.3.1 Plan

The Mintzberg et al. (1976) planning process can be viewed as a detailed description of the planning stage of the adaptive management process (Figure 12.3). Janssen (1992) argued that the planning stage of any decision process generally would need to be some variant of the Mintzberg et al. (1976) method. The planning stage consists of four steps: (1) problem identification, including goal selection, (2) alternative development, (3) alternative selection, and (4) authorization to implement the selected alternative (Figures 12.2 and 12.3). 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: identifying opportunities, problems, and crises, launching the decision process; and (1b) diagnosis: exploring the different aspects of the problem situation, identifying the goals, and deciding how to approach the problem. If the diagnosis phase, step lb, is unnecessary, it

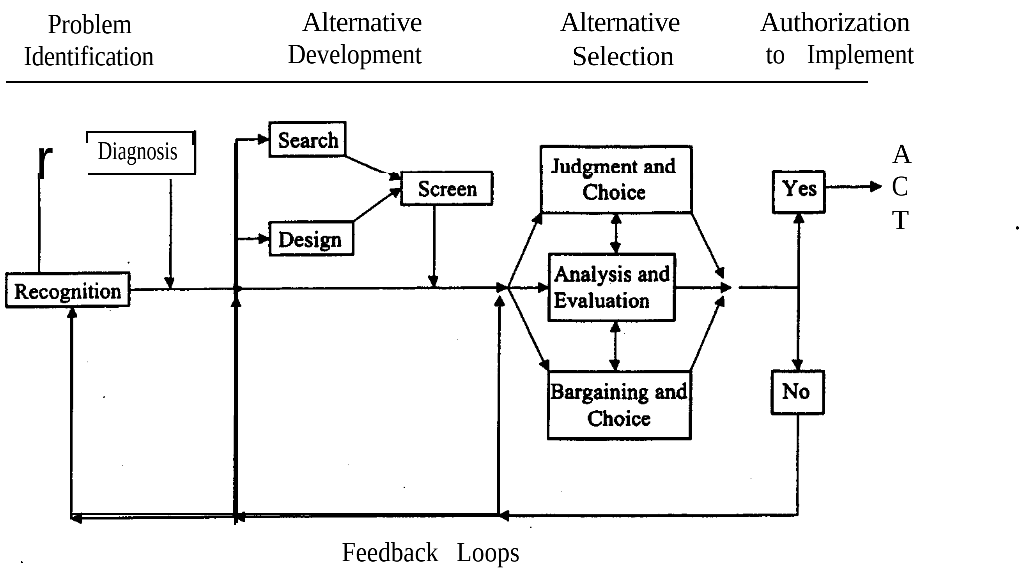

FIGURE 12.3. Detailed view of the planning activity in the adaptive management process for ecosystem management.

can be skipped (Figure 12.3). The next step, alternative development, has three phases: (2a) search: finding previously designed and tested solutions to the entire problem or to any of its parts; (2b) design: developing new alternatives; and (2c) screen: determining 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 also has three phases: (3a) analysis and evaluation: evaluating and understanding the consequences over space and time of each of the proposed alternatives and communicating these results clearly to the decision makers; (3b) judgment and choice: one individual makes a choice; and (3c) bargaining and choice: a group of decision makers negotiates a choice. The final step, authorization, may have 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: evaluating 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 these four steps, 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 Figure 12.3. 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-DSSs 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).

12.3.2 Act

The planning stage of adaptive management 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).

12.3.3 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. Which 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 deemed necessary to test those hypotheses. A unique ***goal-hypotheses-action sequence*** will probably need to be designed for each specific management unit. Similarly, each unit will probably have unique monitoring requirements to distinguish among the adaptive experimental hypotheses proposed for it. As a result, 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. Hence monitoring can only occur after the hypotheses have been designed and their tests devised so that it is clear what needs monitoring (FEMAT, 1993).

12.3.4 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 should communicate the results publicly to stakeholders and managers, influencing future cycles of the planning activity of adaptive management (Everett et al., 1993). In fact, a metaanalysis 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 ecosystems haphazardly simply to relieve immediate sociopolitical 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, p. 11-87). 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 to the ecosystem management process (Lee, 1993). Adaptive management requires a greater level of expertise in statistical experimental design and analysis than other competing decision processes. Kessler et al. (1992) suggested that adaptive management requires 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, p. 113). Managers and the 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 or stakeholders may try to tamper or prevent altogether (Lee, 1993). The costs of properly monitoring results and documenting the entire managerial experiment are unknown (Smith, 1997). Nonetheless, 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.

Although the adaptive management concept appears to be the most well developed candidate for an operational ecosystem management process, others also should be investigated. Lindblom (1990), cited by Smith (1997), advocated a concept called *probing* as a candidate for an ecosystem management decision process. Probing is an informal process of observation, hypothesis formulation, 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 another 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. Of course, any decision-making process 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, adhoc 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 Neburka, 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. Because 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).

12.4 Decision Support Systems Defined

DSSs 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. DSSs 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 (Figure 12.4). The first, and most important, is the subsystem composed of the decision maker(s). Decision makers are consciously diagrammed as part of the DSS because, without their guidance, there is no DSS. The group negotiation management subsystem helps decision makers to 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 the active response GIS system (AR/GIS) (Faber et al., 1997), the issue-based information system (IBIS) (Conklin and Begeman, 1987; Hashim, 1990), and various socioecological 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 (1991) illustrated how the malleable nature of many terms, in this case "overcutting," creates logically defensible differences of opinion that have nothing to do with a person's honesty or dishonesty in the argument. DSS should specifically deploy mechanisms by which the 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 ca-

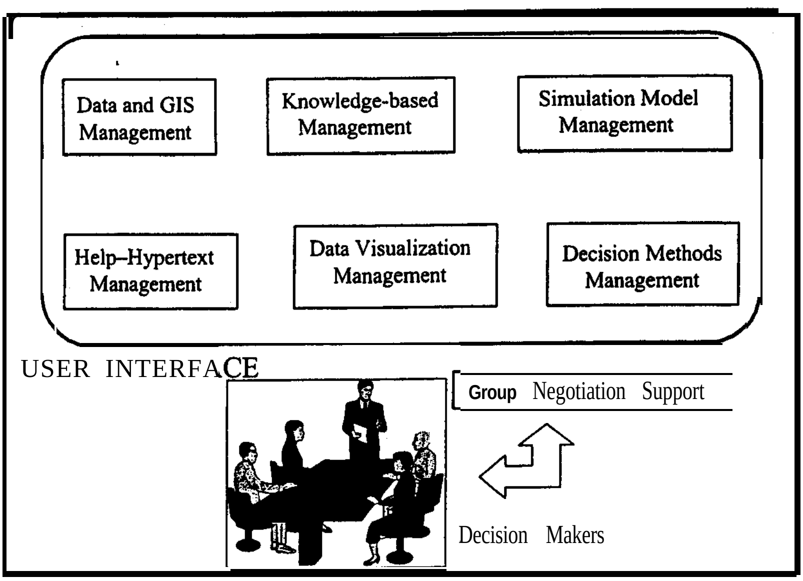

FIGURE 12.4. Major components of a generic decision support system.

pacity of an ecosystem is fixed, yet key stakeholders all want to extract a product from that ecosystem at a higher level, a compromise midway between the levels will be unsustainable.

The next major subsystem, spatial and nonspatial 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 the consequences of management activities on the landscape. There is a tension between the increasing number of goals that decision makers and stakeholders value and the high cost of obtaining data and understanding relationships that support these choices. Monitoring both natural and anthropogenic disturbance activities and disturbance-free dynamics of managed forest ecosystems are also extremely important if an 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-based, 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). Knowledge that is not language based 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 that 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-based 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 decision support system 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. Hypermedia methodology supports a high degree of knowledge synthesis and integration with essentially unlimited expandability. The oak regeneration hypertext (Rauscher et al., 1997b) 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 decision makers to organize the decision problem, formulate alternatives, and analyze their future consequences. The decision methods management subsystem (Figure 12.4) provides tools and guidance for choosing among the alternatives, for performing sensitivity analysis to identify the power of specific variables to change the ranking of alternatives, and for recording the decisions made and their rationale. Many facets or dimensions 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).

Decision makers might find themselves at any point along the political-power dimension bounded 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 among these three approaches creates tensions that help to make ecosystem management a very difficult 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 normative-rational methods on the one hand and expert-intuitive methods on the other. Numerous intermediate methods also have been described and used (Janssen, 1992; Rauscher, 1996). The formal relationships among 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) that influences both the design of alternatives and the final choice. Many EM-DSSs do not offer a decision method 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.

12.5 Comparison of Existing Ecosystem Management DSS

Mowrer et al. (1997) surveyed 24 of the leading EM-DSSs 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-DSSs 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; and (5) group consensus-building support was missing from all but one system, a system that was highly dependent on 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 of 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-DSSs appear to support different parts of the ecosystem management process. Table 12.1 lists 33 EM-DSSs, the 24 systems surveyed by Mowrer et al. (1997) plus 9 DSSs not included in that study. Nineteen of the 33 are labeled full-service EM-DSSs at their scale of operation because they attempt to be comprehensive EM-DSSs, offering or planning to offer support for a complete ecosystem management process. These EM-DSSs can be further classified by the scale of support that is their primary focus: regional assessments, forest planning, or project-level planning. The remainders, 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 that they provide group

TABLE 12.1. 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[a]		IBIS[a]
		Vegetation dynamics	FVS
Forest-level planning	RELM		LANDIS
	SPECTRUM		CRBSUM
	WOODSTOCK		SIMPPLLE
	ARCFOREST		
	SARA	Disturbance simulations	FIREBGC
	TERRA VISION		GYPSES
	EZ-IMPACT”		UPEST
	DECISION PLUS=		
	DEFINITE[a]	Spatial visualization	UTOOLS/UVIEW
			SVS[a]
Project-level planning	NED		SMARTFOREST[a]
	INFORMS		
	MAGIS	Interoperable system architecture	LOKI
	KLEMS		CORBA[a]
	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 Herwijnen, 1992); SMARTFOREST (Orland, 1995); CORBA (Otte et al., 1996); SVS (McGaughey, 1997); LMS (McCarter et al., 1998); LUCAS (Berry et al., 1996).

negotiations, vegetation dynamics, disturbance simulation, spatial visualization, and interoperable system architecture.

12.5.1 Full-service EM-DSS

Regional Assessments

The Ecosystem Management Decision Support (EMDS) program is a software system specifically designed to support the development of ecological assessments, usually at 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 users construct these knowledge bases, 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 which 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 an ecoregion of any size. 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 an EM-DSS operating at the ecoregional scale is that regional decision-making activities and their consequences can be forecast with reasonable credibility.

Forest-level or Strategic Planning

Forest-level planning corresponds to the strategic planning process of decision science (Holsapple and Whinston, 1996). Many federal agencies, including the USDA Forest Service, have relied on linear programming systems of various kinds as the primary strategic planning decision support tool. In 1979, a linear programming, harvest scheduling model, FORPLAN, was turned into a forest-level planning, too, and until 1996 all national forest supervisors were required to use it as the primary analytical tool for strategic forest planning. After 17 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 analytical tool for forest planning are beyond the scope of this chapter and can be readily found in the following publications: Barber and Rodman (1990), Hoekstra et al. (1987), Shepard (1993), Liu and Davis (1995), Behan (1994, 1997), Kennedy and Quigley (1993), Howard (1991), Canham (1990), Morrison (1993), and Smith (1997).

Forest-level planning may be more successfully performed using soft, qualitative decision analysis formalisms than the hard, quantitative methods employed in rational, linear or nonlinear optimization schemes. Many other decision analysis formalisms exist (see Rauscher, 1996; Smith, 1997) along with the tools that make them useful and practical (Table 12.1). A number of these techniques may offer greater support for dealing with power struggles, imprecise goals, fuzzy equity questions, rapidly changing public preferences, and uneven quality and quantity of information (Allen and Gould, 1986). In particular, EZ-IMPACT (Behan 1994, 1997) and DEFINITE (Janssen and van Herwijnen, 1992) are well-developed and tested analysis tools for forest planning that use judgment-based, ordinal, and cardinal data to help users to 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 planning period (Grossarth and Nygren, 1993). Finally, the forest plan should demonstrate that recommended alternatives actually lead toward desired future conditions by tracking progress annually for the life of the plan. The forest plan should be able to send accomplishable goals and objectives to the level of project implementation and receive progress reports that identify the changes in 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.

Project-level Implementation or Tactical Planning

"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, p. 284). EM-DSSs at the project level help to identify and design site-specific actions that will promote the achievement of forest plan goals and objectives. For example, a strategic-level forest plan might assign a particular landscape unit for management of bear, deer, and turkey, with minimum timber harvesting and new road construction and no clearcutting. The tactical project implementation plan would identify specific acres within this management unit that would receive specific treatments in a specific year. Project-level EM-DSSs have been developed to support the tactical-level planning process.

Project-level EM-DSSs (Table 12.1) 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., 1997a; Twery et al., 2000) is an example of a goal-driven EM-DSS. Rauscher et al. (2000) present a practical, decision-analysis process for conducting ecosystem management at the project implementation level and provide a detailed example of its application to Bent Creek Experimental Forest in Asheville, North Carolina. Because management is defined to be a goal-driven activity, goals must be defined before appropriate management actions can be determined. It cannot be overemphasized that, without goals, management cannot be properly practiced (Rue and Byars, 1992). Goal-driven systems, such as NED; assist the user in creating an ***explicitly defined goal hierarchy*** (Rauscher et al., ***2000).***

A goal is an end state that people value and are willing to allocate resources to achieve or sustain (Nute et al., 1999). Goals form a logical hierarchy with the ultimate, all-inclusive goal at the top, subgoals at the various intermediate levels, and a special goal, which may be called a desired future condition, at the bottom (Saaty, 1992; Keeney and Raiffa, 1993). A ***desired future condition*** (DFC) is a goal statement containing a single variable measuring some observable state or flow of the system being managed (Nute et al., 1999). DFCs are the lowest level of the goal hierarchy. They are directly connected to the management alternatives being considered (Saaty, 1992). Furthermore, DFCs precisely define the measurable variables that each alternative must contain (Mitchell and Wasil, 1989). In other words, each DFC provides a measure of the degree to which any given ecosystem state, current or simulated future, meets the goal statement (InfoHarvest, 1996).

For example,

Goal: Freshwater Fishing Opportunities Exist IF
DFC(1): pH of all (> = 90%) freshwater lakes > 5 AND
DFC(2): popular game fish are plentiful AND
DFC(3): access to all (> = 90%) freshwater lakes is adequate.

Given that "plentiful" and "adequate" are further defined so that they are measurable, the three DFCs above define three attributes, that is, pH, popular game fish, and access to freshwater lakes, that each alternative under consideration must have. Otherwise, it will be impossible to determine whether the alternative can satisfy the goal "Freshwater Fishing Opportunities Exist." DFCs should be objective in nature. That is, there should exist a commonly understood scale of measurement, and the application of that scale to the ecosystem should yield roughly the same results no matter who makes the measurement. DFC(1) is objective in this sense. On the other hand, DFC(2) and DFC(3) are using subjective, binary scales for "plentiful" and "adequate." Research results indicate that subjectively developed scales can be reliably used by qualified professionals (Keeney and Raiffa, 1993, p. 40). An operationally practical DFC should (1) provide the appropriate information on theoretical grounds and (2) also be obtainable. In other words, a DFC should accurately define the lowest-level subgoal and be measurable in practice.

Unlike goals, which depend primarily on value judgments, defining how to achieve a goal with a set of DFCs depends primarily on factual knowledge (Keeney, 1992). A set of DFCs that defines a lowest-level goal is not generally unique (Keeney and Raiffa, 1993). There are usually alternative ways to define the same lowest-level goal, and no a priori tests exist to show that one way is better or worse than another. This disparity typically results from competing scientific theories or professional judgment. Consequently, it is important to document the justification for defining the lowest-level goal in any particular way.

Constraints, like goals, have a standard that is either met or not (Keeney, 1992). This standard is meant to screen unacceptable goals, objectives, alternatives, and management prescriptions from consideration. Requirements are equivalent to constraints, but are phrased differently. Logically, "you must" do something is exactly the same as "you must not" do something else. Permissions are the logical inverse of constraints. Permissions make it explicitly clear that certain goals, objectives, alternatives, and silvicultural prescriptions are allowed if they naturally surface in the management process. Permissions are not mandatory; if they were, they would be requirements.

The development of a goal hierarchy, the constraint network, and the specification of DFCs for a complex decision problem is more art than science. Although no step by step procedures are possible, some useful guidelines have been developed and summarized by Keeney and Raiffa (1993), Clemen (1996), and by InfoHarvest (1996).

Alternatives are the courses of action open to a decision maker for satisfying the goal hierarchy (Holtzman, 1989). In ecosystem management, each alternative contains a set of ***action-location-time*** triples that is intended to change the landscape so that goal satisfaction is improved. These triples, called ***prescriptions***, embody the purposeful application and expenditure of monetary, human, material, and knowledge resources that define ecosystem management.

The design of alternatives, like the design of the goal hierarchy, is largely an art that relies heavily on decision science expertise, along with an expert-level understanding of forest ecosystem management (Klein and Methlie, 1990; Clemen, 1996). It is also very much an iterative process. High-quality decisions require the design of a set of promising, distinct alternatives to evaluate (Holtzman, 1989; Keeney, 1992). Given knowledge about (1) the current condition of the forest ecosystem; (2) the goals and DFCs; (3) the standards, guides, best management practices, and constraints in force at any given time; and (4) available management prescriptions, an experienced manager can craft alternatives that represent reasonable answers to the question of what state of organization we want for this forest ecosystem so that we can best meet the goals. The human mind is the sole source of alternatives (Keeney, 1992).

In contrast to goal-driven systems, INFORMS (Perisho et al., 1995; Williams et al., 1995) is a data-driven EM-DSS. Data-driven systems do not require the existence of an explicit goal hierarchy. Indeed, it is often the case that the only existing goals are implicit goals that reside in the private knowledge base of the manager. Data-driven systems begin with a list of actions that the user wants to explore and search the existing landscape conditions, as reflected in the system database, to find possible locations where these management actions can be implemented.

Both approaches have their strengths and weaknesses. Goal-driven systems tend to be rather prescriptive. They require the user to follow a certain sequence of events and force the user to make certain critical decisions in order to follow a predefined ecosystem management process. Data-driven systems allow users more freedom to craft their own process in an ad-hoc fashion; this provides great freedom of action, but places all the burden of knowing what to do and why to do it on the user. Goal-driven systems, by definition, tend to ensure that management actions move the landscape 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 this particular decision process. 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 strategic objectives. Data-driven systems, however, do allow competent and knowledgeable decision makers maximum flexibility in the analyses that they perform and how they put them together to arrive at a decision. Hybrid goal- and data-driven systems may offer users the advantages of both approaches.

12.5.2 Functional Service Modules

The full-service EM-DSSs rely on specialized software service modules to add a broad range of capabilities (Table 12.1). Tools to support group negotiation in the decision process are both extremely important and generally unavailable and underutilized. AR/GIS (Faber et al., 1997) is the most fully developed software available for this function. IBIS, another group negotiation tool, is an issue-based information system that implements argumentation logic (the logic of questions and answers) to help users to 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-DSSs with the ability to forecast the consequences of proposed management actions. Disturbance models 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. Although models that simulate timber harvesting activities exist, they 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 horseback 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 exist, but 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) and landscape-level models such as UVIEW (Ager, 1997) and SMARTFOREST (Orland, 1995).

12.6 Interoperability in Ecosystem Management DSS

Existing EM-DSSs (Table 12.1), with few exceptions, are islands of automation unable to easily communicate with each other. They have been written in different software languages, they reside on different hardware platforms, and they have different data access mechanisms and different component-module interfaces. For example, nongeographical databases may be written in Oracle, geographical information system (GIS) databases in ARC/INFO, knowledge bases in Prolog, and a simulation model in C or Fortran. Some execute only on a UNIX platform, others only in a Microsoft Windows environment. As a group, they have poorly developed mechanisms for achieving integrated operations with (1) other existing full-service EM-DSS; (2) the many available functional-service modules (Schuster et al., 1993; Jorgensen et al., 1996); (3) readily available, high-quality commercial software; or (4) new software modules that independent development groups are continually producing in their efforts to support ecosystem management.

Interoperability is the ability for two or more software components to cooperate by exchanging services and data with one another, despite the possible heterogeneity in their language, interface, and hardware platform (Heiler, 1995; Wegner, 1996; Sheth, 1998). Interoperable systems provide a software standard that promotes communication between components and provides for the integration of legacy and newly developed components (Potter et al., 1992; Liu et al., 2000). To date, efforts to achieve interoperability between EM-DSS modules have used ad hoc techniques yielding unique, point-to-point custom solutions. Although such unique solutions work, sometimes very efficiently, they are typically difficult to maintain and transfer to other developers because of their idiosyncratic nature. After evaluating several of the leading EM-DSSs, Liu et al. (2000) concluded that no comprehensive, theory-based interoperability standards currently exist for achieving integrated operations of EM-DSS.

In contrast, interoperability outside the ecosystem management domain has received extensive attention. There is heavy emphasis in the larger computer science field toward the construction of systems from preexisting components based on interoperability standards (Mowbray and Zahavi, 1995). Liu et al. (2000) evaluated four such approaches (see Liu, 1998, for details). The approaches addressed include CORBA (the Common Object Request Broker Architecture, 1997), DCOM (the Distributed Component Object Model, Microsoft 1995, 1996, 1997), intelligent agents (Finin et al., 1994; Genesereth and Ketchpel, 1994; Mayfield et al., 1996), and DIAS/DEEM (the Dynamic Information Architecture System/Dynamic Environmental Effects Model, Argonne National Laboratory 1995a, 1995b). These approaches encompass several different areas of computer science, including databases in which the emphasis is on interoperation and data integration, software engineering in which tool and environment integration issues dominate, artificial intelligence for which systems consisting of distributed intelligent agents are being developed and explored, and information systems.

With NED-l (Rauscher et al., 1997a; Twery et al., 1999) and FVS (Teck et al., 1996, 1997) as example EM-DSSs, Maheshwari (1997) used CORBA and Liu et al. (2000) used DCOM to develop a framework for achieving integrated operations. CORBA and DCOM both provide standard specifications for achieving language interoperability and platform independence. They define their own interface standards to deal with peculiarities of legacy applications. They support distributed processing, object reuse, and the Internet. Both architectures are well documented, and the documentation materials are easily accessible to the public, on line as well as through books and journal articles. CORBA can be purchased from multiple vendors, and DCOM is shipped with Windows NT/98 or can be downloaded free for Windows 95. Based on their tests, Liu et al. (2000) concluded that DCOM was easier to learn and more productive than CORBA.

The proposed DCOM-based interoperability design was found to be general and to make no assumptions about the software applications to be integrated (Liu et al., 2000). Its standardized interface scheme enables integration of a variety of applications. It is an open framework in the sense that application components can be added and/or removed easily without drastically affecting the functionality of the whole system. DCOM comes with Windows NT and 98, so there is no up-front cost. The prototype worked smoothly and was totally transparent to the user. Although no performance tests were carried out, there appeared to be no performance degradation as a result of using DCOM (Liu et al., 2000).

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.

12.7 Conclusions

Ecosystem management has been adopted as the philosophical paradigm guiding federal forest management in the United States. The strategic goal of ecosystem management is to find an acceptable 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. 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 is yielding results. Several powerful candidate processes to support the practical implementation of ecosystem management have been identified to date and are undergoing evaluation.

The generic theory of decision support system development and application is well established. Numerous specific ecosystem management decision support systems have been developed and are evolving in their capabilities. Given a well-defined and accepted set of ecosystem management processes to support, along with adequate time and resources, effective EM-DSSs can be developed. However, major social and political issues present significant impediments to the efforts to make ecosystem management operational. A sociopolitical environment in which everyone wants to benefit and no one wants to pay incapacitates the federal ecosystem management decision-making process. The very laws that were adopted to solve the problem, the 1969 National Environmental Policy Act and the 1976 National Forest Management Act, 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 forest ecosystem managers today.

To date, none of the available EM-DSSs has been found capable of addressing the full range of support required for ecosystem management (Mowrer et al., 1997). This is not surprising, because it is highly unlikely that a single DSS can provide adequate support for ecosystem management (Grossarth and Nygren, 1993; Mowrer et al., 1997), meaning that a familiarity with the entire range of available decision analysis methodology and related modeling tools is required. Many of the EM-DSSs introduced in this chapter hold great promise, but this promise has not been fully realized. A major reason for this situation is that system development has been primarily driven by technology, not by user requirements.' The requirements to guide EM-DSS development are unknown or poorly defined, because the ecosystem management decision processes themselves have been inadequately identified and described. The frequently observed tendency to substitute technology for an inadequate or nonexistent 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-DSSs have undergone an unbiased, critical evaluation of their suitability for ecosystem management decision support. Such an evaluation is long overdue. In the final analysis, EM-DSS software should be evaluated using a simple question: Does the EM-DSS improve the decision maker's ability to make good decisions?

A number of more specific conclusions about the current state of EM-DSS appear obvious:

1. 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 can consistently make good decisions without adequate support tools.
2. Ecosystem management, by definition, is concerned with both ecological and management science. Yet much of the effort seems to concentrate on ecological issues to the detriment of equally important management issues. Understanding and developing good decision-making processes is as important for the success of ecosystem management as understanding ecological structure and function (http://biology.usgs.gov/dss/def.html).
3. Ecosystem management ought to be practiced at many different scales: forest landscape-national forest, ecoregion-multistate, biome-national, and global-international. This fact has not been as widely recognized in the United States as it has in Europe. In the United States, we have, however, scaled ecosystem management up to the ecoregional scale by developing regional ecological assessments as a management tool.
4. People play two roles in ecosystem management. First, they are part of the communities of organisms that interact with each other and their abiotic environment. Second, they are the risk takers, the setters of objectives, the judges of value; in other words, the decision makers. We need to understand human behavior and characteristics in both roles.
5. Defining and understanding the nature of sustainable societies and the nature of sustainable ecosystems are equally important. Human societies and ecosystems are inseparable and cannot be understood or managed without reference to each other.
6. The study of the management subsystem must include understanding the dynamics of public preferences, conflict management and resolution, and cost evaluation as it relates to ecosystem management.

In closing, it is appropriate to discuss how ecological assessments and EM-DSS may be mutually supportive. From a decision support point of view, ecological assessments have not been as useful as they might be. The ecological assessments undertaken so far have concentrated mostly on providing (1) a description of current and historic ecosystem composition, structure, and function and (2) a description of the biotic (including human) and abiotic processes that contributed to the development of the current ecosystem conditions. Although such descriptive emphasis on the ecological foundations of the region is necessary, it is not sufficient. This is another example of how the management side of ecosystem management is often all but ignored.

We suggest that ecological assessments can be more effective decision support tools if some or all of the following items are included in their scope:

1. Clarify, label, and define the major regional issues that concern people.
2. Explicitly identify and define the major socio-political-biological problems facing the region.
3. Identify what or who is causing the problems, who has responsibility for solving them, who the stakeholders are that are associated with the problem, and who will pay for finding and implementing solutions.
4. Clarify how ecosystem management efforts are to be coordinated at the regional scale and how progress in social and ecological sustainability is going to be identified and tracked.
5. Develop a set of regional-scale goals and desired future conditions to measure these goals in terms of regionally appropriate variables.
6. Describe probable future scenarios that might exist under different types of regional-scale management strategies.

Including such management-oriented items in an ecological assessment is likely to make it politically more sensitive. However, the resultant document would help to organize the entire ecosystem management process at lower scales, set the tone and parameters of the public and professional debate, and explicitly state the problems as well as the desired solutions for examination by everyone concerned. It would help to diffuse the impact of purely emotional points of view and bring the debate back to a more reasonable, rational arena. More specifically, such a regional assessment would provide solid direction, through the regional goals and desired future conditions, to forest-level ecosystem management planning and implementation.

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