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A practical decision-analysis process for forest ecosystem management

H. Michael Rauscher [a,*], F. Thomas Lloyd [a],
David L. Loftis [a], Mark J. Twery [b]

[a] *Bent Creek Experimental Forest, Southern Research Station, USDA Forest Service, 1577 Brevard Rd., Asheville, NC 28805, USA*
[b] *Northeastern Research Station, USDA Forest Service, Burlington, VT, USA*

Abstract

Many authors have pointed out the need to firm up the 'fuzzy' ecosystem management paradigm and develop operationally practical processes to allow forest managers to accommodate more effectively the continuing rapid change in societal perspectives and goals. There are three spatial scales where clear, precise, practical ecosystem management processes are needed: the regional assessment scale, the forest-level scale, and the project-level scale. This paper proposes a practical decision analysis process for ecosystem management at the project-level scale. Goals are the focal point of management. To achieve them requires a formal, structured goal hierarchy, desired future conditions, several interesting alternatives, scenario analysis, and monitoring and evaluation of the results. The proposed process is firmly grounded in the body of theory and practice organized in the scientific literature under the heading of multi-objective decision analysis. An illustrative example of this decision analysis process is presented using the Bent Creek Experimental Forest of the Pisgah National Forest near Asheville, NC as a test case. Published by Elsevier Science B.V.

Keywords: Decision analysis; Forest planning; Adaptive management; Ecosystem management; National forests; Analytical hierarchy process (AHP)

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* Corresponding author. Tel.: + 1-828-6675261, ext. 102; fax: + 1-828-6679097.
E-mail address: mrauscher@fs.fed.us (H.M. Rauscher)

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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; Fedkiw, 1998). As a management paradigm to attain ecologically-based policy objectives, ecosystem management has become a magnet for controversy (Lackey, 1999). Ecosystem management represents different things to different people. Despite the many attempts to define ecosystem management, it remains an incredibly nebulous concept (More, 1996; Lackey, 1998; Rauscher, 1999).

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 were any well-documented, widely accepted theories or practical implementation guidelines developed (Thomas, 1997; Fedkiw, 1998). Since 1992, federal forest managers have attempted to use the planning and implementation process established under the authority of the National Forest Management Act of 1976 (NFMA) (www.fs.fed.us/forum/nepa/nfmalaw.html) as a vehicle to perform ecosystem management (Morrison, 1993). The result has been a decision analysis process that (1) is opaque and confusing rather than transparent and clearly understandable (Dombeck, 1998); (2) has tended to exacerbate the polarization and intensity of environmental conflicts rather than encouraging the formulation of compromise solutions (Smith, 1997); and (3) has led to procedural paralysis at exponentially rising costs (Behan, 1990). It is fair to conclude that the current ecosystem management planning and implementation process is unsatisfactory.

In recognition of this problematic situation, the Secretary of Agriculture chartered a Committee of Scientists to make recommendations on how to better accomplish sound resource planning within the framework of existing environmental laws and to provide technical advice leading toward a revision of the forest planning regulations (Committee of Scientists, 1997). Adequate forest ecosystem management planning and implementation processes need to satisfy several requirements. First and foremost, the process must be clear and understandable to the average citizen (Janssen 1992; Dombeck, 1998). People's preferences are notoriously subject to the context of the situation (Smith, 1997). If they cannot understand the context of the decision space, people find it difficult to make value judgments. Second, the process must focus on outcomes or desirable end states, not just inputs and outputs (Dombeck, 1998). Third, the process must deal easily and adequately with many different measurement scales, be they non-monetary, qualitative, or uncertain. Fourth, temporal and spatial patterns and effects must be adequately represented and incorporated in the decision process (Janssen, 1992). And finally, an adequate ecosystem management decision analysis process should explicitly recognize that there are limits on time, expertise, and money. Sustainable forest management is impossible if there are unsustainable social and economic costs (Craig, 1996).

Because the definition and fundamental principles that make up the ecosystem management paradigm have not yet been resolved and widely accepted, the current challenge is to build the ecosystem management philosophical concept into an explicitly defined, operationally practical methodology (Wear et al., 1996; Thomas, 1997). New ecosystem management decision analysis and implementation processes are urgently needed to allow federal land managers to accommodate more effectively the continuing rapid change in societal perspectives and goals (Bormann et al., 1993; Rauscher, 1999).

The purpose of this paper is to describe an operationally practical decision analysis process for conducting ecosystem management at the project level. This proposed project-level, decision-analysis process for ecosystem management will be illustrated by using an example data set and management scenario appropriate for the Bent Creek Experimental Forest Watershed of the Pisgah National Forest near Asheville, NC.

2. A process for project level ecosystem management

Ecosystem management on national forests occurs at two levels: forest and project. Decisions are made and need to be supported at each of these two levels (Holsapple and Whinston, 1996). *Forest-level management plans* represent the strategic planning scale and are required by the National Forest Management Act of 1976 (NFMA). In eastern National Forests, forest level plans apply to roughly 200 000 to over 500 000 ha. “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). *Project-level management plans* represent the tactical planning scale. Although project level plans are site-specific and are applied to areas no more than a few hundred acres, they typically consider a landscape context of between 2000 and 20 000 ha in eastern National Forests as the basis for an environmental impact decision analysis.

The adaptive management process can be applied at the project-level as well as the forest-level (Rauscher, 1999). Described at the most general level, adaptive management consists of four activities: planning, implementation, monitoring, and evaluation (Fig. 1) (Walters and Holling, 1990; Bormann et al., 1993). Planning focuses on deciding what to do. Implementation is concerned with deciding how to do it and then doing it. Monitoring and evaluation are the activities of analyzing whether the state of the managed system was moved closer to the desired goal state or not.

Management is defined as the process of achieving or sustaining goals by the purposeful application and expenditure of monetary, human, material, and knowledge resources (Holsapple and Whinston, 1996). In *forest* management, resources are applied to forest ecosystems in order to achieve or sustain goals. Because the purpose of management is to achieve them, *goals must be defined before appropriate management actions can be determined.* It cannot be overemphasized that without goals, management cannot be properly practised (Rue and Byars, 1992). There is simply no way to finesse this point. Without goals it is impossible to determine what to do or to evaluate how well you have done it (Nute et al., 2000).

2.1. The project planning subprocess

The adaptive management project planning subprocess is a method or procedure that guides decision makers through a series of tasks from goal identification and structuring into a hierarchy, through alternative design, analysis, and evaluation, to alternative selection (Fig. 2). The project planning process we propose is well grounded in decision-science theory, being a variant of the Mintzberg et al. (1976) process. Janssen (1992), as well as Klein and Methlie (1990), argue that the planning stage of any management process will generally need to be some variant of the Mintzberg et al. (1976) method. This study is concerned with ecosystem management processes at the project-level. Forest-level planning is considered only as it relates to the project-level. One major link between forest-level and project-level management is the structure of the goal hierarchy. Forest-level plans should contribute the majority of the goals that project-level plans are designed to implement, achieve, and sustain. Project-level plans identify and design site-specific actions that should, in the aggregate, achieve forest-level goals.

2.1.1. The project plan goal hierarchy

The first task in the project planning process is to develop a formal, structured goal hierarchy. A *goal* is an object or end that one tries to attain (Webster's New World Dictionary). In other words, a goal is an end-state that people value and are willing to allocate resources to achieve or sustain (Kleindorfer et al., 1993; Nute et

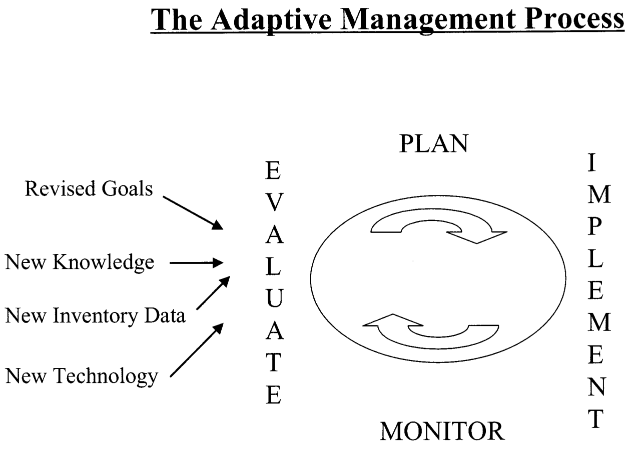


Fig. 1. A schematic diagram of the adaptive management process.

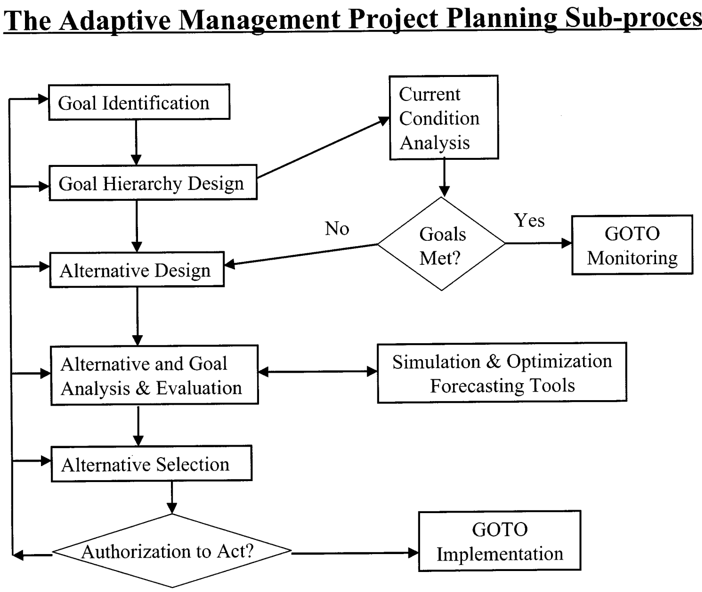


Fig. 2. A schematic diagram of a new project level ecosystem management process. The boxes represent major conceptual blocks and the arrows connote information and influence pathways.

al., 2000). Goals form a logical hierarchy with the ultimate, all-inclusive goal at the top, sub-goals at various levels in the middle, and a special goal, which we will call a desired future condition (DFC), at the bottom (Fig. 3) (Saaty, 1992). The ultimate top-level goal might be something like 'Make a wise decision' or 'Manage forest ecosystems well'. Top-level goals are extremely broad and identify the reason for being interested in the problem. They are far too vague for any operational purposes. The process known as goal specification is used to subdivide top-level goals into more detailed, lower-level goals, thus clarifying the intended meaning of the more general goals (Keeney and Raiffa, 1993). Care must be exercised to ensure that all aspects of the higher level goal are accounted for in the set of defining subgoals. The process of structuring goals results in a deeper and more accurate understanding of the decision context (Keeney, 1992). The goal hierarchy explicitly depicts the values of the decision makers and the stakeholders.

It is obvious that there can only be one ultimate top-level goal to which all other goals are related. There is, however, no obvious stopping rule that can be applied to know when to stop defining subgoals. Furthermore, there is no unique, 'correct' goal hierarchy for a particular problem (Keeney and Raiffa, 1993). Competing goal hierarchies can be designed for the same problem with no a priori method available to test whether one is better or worse than the other.

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., 2000). 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 (Figs. 2 and 3) (Mitchell and Wasil, 1989). In other words, each DFC provides a measure of the degree to which any given forest ecosystem state, current or simulated future, meets the goal statement (InfoHarvest, 1996).

Unlike goals, which depend primarily on value judgments, defining appropriate DFCs depends primarily, although not exclusively, on factual knowledge (Keeney, 1992). A set of DFCs that define 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 there exist no a priori tests 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.

The goal hierarchy is affected by a supporting network of constraints, permissions, and requirements found in the form of standards, guides, and best management practices. Constraints, like goals, have a standard that is either met or not

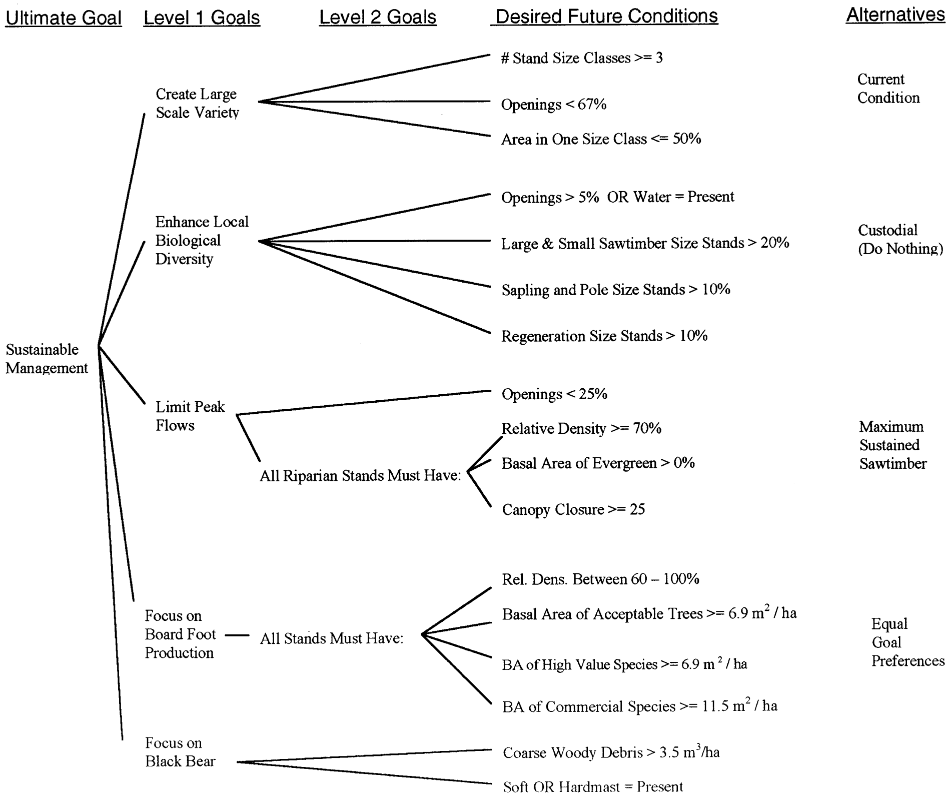


Fig. 3. The goal hierarchy, desired future conditions, and alternatives for the Bent Creek Experimental Forest. Note that each desired future condition is measured in each alternative.

(Keeney, 1992). This standard is meant to screen unacceptable goals, objectives, alternatives, and silvicultural prescriptions from consideration in the goal hierarchy. 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 or they become 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) and by InfoHarvest (1996).

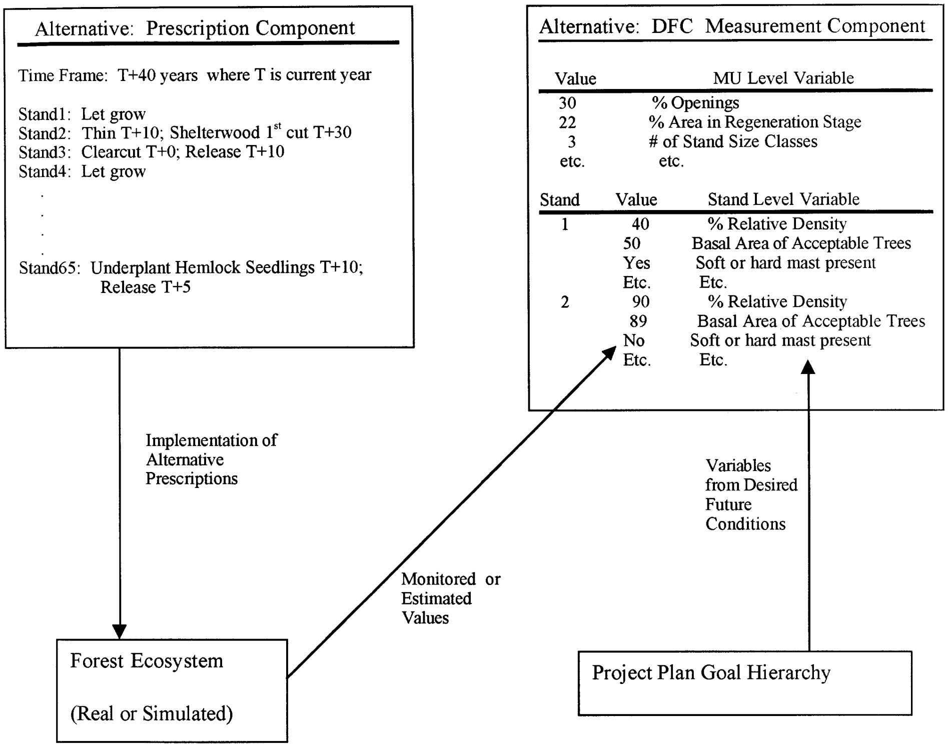
2.1.2. Alternative design and analysis

Alternatives are the choices a decision maker has for satisfying the goal hierarchy. Alternatives are the formal description of the courses of action open to decision makers (Holtzman, 1989). In forest 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 action–location–time triples, called prescriptions, embody the purposeful application and expenditure of monetary, human, material, and knowledge resources that define forest ecosystem management.

In particular, an *alternative* is a complex conceptual construct consisting of two different components: a prescription (action–location–time) component and a DFC measurement component (Fig. 4). The prescription component refers to a set of action–location–time triples that result in a change of the current condition of the forest over time. The particular sequence of the prescriptions is meaningful. Furthermore, the same set of prescriptions applied to a different current condition, e.g. a different forest ecosystem, is likely to result in different changes. The prescription component of an alternative defines ways to reduce the difference between the current and desired states of the forest ecosystem being managed (Kleindorfer et al., 1993).

The DFC measurement component is defined by two items: (1) a set of variables which come from the DFCs of the goal hierarchy (Fig. 3) and (2) the value for each of those variables which comes from monitoring the state of the real or simulated forest ecosystem after an alternative has been implemented (Fig. 1). The variables from the DFCs represent what we want to know about the end-state created by the alternative. The monitored values represent how much of the variable of interest has been attained (Fig. 4).

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). 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



Value	MU Level Variable
30	% Openings
22	% Area in Regeneration Stage
3	# of Stand Size Classes
etc.	etc.

Stand	Value	Stand Level Variable
1	40	% Relative Density
	50	Basal Area of Acceptable Trees
	Yes	Soft or hard mast present
	Etc.	Etc.
2	90	% Relative Density
	89	Basal Area of Acceptable Trees
	No	Soft or hard mast present
	Etc.	Etc.

Fig. 4. The two components of an alternative. Notice that the stand is the basic administrative unit that receives silvicultural prescriptions.

DFCs, (3) the standards, guides, best management practices, and constraints in force at any given time, and (4) available silvicultural prescriptions, an experienced manager can craft alternatives that represent reasonable answers to the question ‘What state of organization do we want for this forest ecosystem so we can best meet the owners’ goals?’

Few support systems exist for the design of alternatives. However, a number of full service, decision-support systems are currently available to help managers evaluate, if not design, alternatives by automating some components of the evaluation–prescription–simulation–monitoring cycle described in Fig. 2 (Mowrer, 1997; Rauscher, 1999).

2.1.3. *Alternative evaluation, selection, and authorization*

Having designed the goal hierarchy and a set of alternative courses of action, the final steps of the planning process are to select an alternative and to obtain authorization to implement that alternative. In order to evaluate alternatives, we need to forecast the consequences of implementing each candidate alternative on the current landscape over a specified period of time (Fig. 2) (Kleindorfer et al., 1993). These simulated future landscape states will provide the DFC measurement component of each candidate alternative for each variable of each DFC in the goal hierarchy (Fig. 4). Alternatives can then be compared with each other to determine their expected effectiveness in satisfying the management goals.

Methods that can be used to make choices between alternatives have been well documented and can be summarized only briefly here (Klein and Methlie, 1990; Janssen, 1992). For 17 years, from 1979 until 1996, a linear programming, harvest scheduling model was turned into a forest-level planning tool, FORPLAN (Hoekstra et al., 1987) 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 only FORPLAN/SPECTRUM (Stephens, 1996). The optimization strategy has proven invaluable for many problems, however, its practical application is severely limited by a number of factors such as: (1) inability to use qualitative, subjective criteria; (2) extremely costly in terms of time and effort; (3) cannot combine all scores for an alternative into a single overall measure of goodness or utility; (4) results are difficult to understand, explain, and modify logically and (5) so complex that it takes carefully trained specialists to implement thus effectively removing the decision maker from the decision analysis (Holsapple and Whinston, 1996, p. 76; Klein and Methlie, 1990, pp. 105–110; Larsen et al., 1990, pp. 12–15; Rauscher, 1996). Making an optimal decision is a noble notion that we feel is impractical for the complex, unstructured forest management decision environment.

Project-level planning 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 decision analysis formalisms exist, other than the normative/rational method (Rauscher, 1996; Smith, 1997) along with the tools that make them useful and practical. 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, CRITERIUM Decision Plus (InfoHarvest, 1996) and DEFINITE (Janssen and van Hervijnen, 1992) are well developed and tested alternative selection and evaluation tools which use judgment-based, ordinal, and cardinal data to help users characterize the system at hand and explore hidden interactions and emergent properties (Goodwin and Wright, 1998). Radcliff (1992) provides a critical review of seven other multi-criteria decision-making programs.

In summary, the project-planning subprocess described above defines a logically consistent hierarchy of goals, subgoals, and DFCs, and their relationships to management alternatives. Each higher-level goal in the hierarchy is satisfied if and only if every subgoal and/or DFC is satisfied. Every goal is ultimately reducible to a set of DFCs. Each DFC is defined by an observable component that can be compared to the value produced by any alternative (Saaty, 1992; Nute et al., 2000). Thus any management alternative can be evaluated for any set of goals. In addition, the process is clear, logically consistent, and can be understood by the average person.

2.2. The project implementation subprocess

The project implementation subprocess starts when an alternative has been selected and authorized through the project planning subprocess. The prescription component of an alternative consists of a set of silvicultural prescriptions, the action–location–time triples discussed in the last section, to be applied to specific sites over specified time periods in a particular sequence. *Silviculture* is the science and art of controlling the composition and structure of forest ecosystems to meet *any* management goals (Loftus and Fitzgerald, 1989). A *silvicultural system* is a planned program, defined by a timed sequence, of silvicultural prescriptions covering the entire life of a particular stand (Smith, 1986). Thus a timed sequence of action–location–time triples, silvicultural prescriptions, can be used to implement particular silvicultural systems for specific stands. Silvicultural prescriptions are the means by which we achieve our ends, the goals in the goal hierarchy. The selected alternative, then, is a set of *silvicultural systems*, one for each stand, covering the time-frame for which the alternative is valid (Fig. 4).

The need to make adjustments to implementing the selected alternative is always present because the real world is always changing. Therefore, the implementation subprocess should be viewed as an iterative process. These changes in the selected alternative need to be made within the constraint system defined by the standards, guides, and best-management-practices in force at the time, but they will need to be made. Although the implementation subprocess imposes managed, and thus purposeful, disturbances in the current condition of the forest, the response of the forest ecosystem to these changes is not always as expected. In addition, the current state of the forest is subjected to unplanned, unforeseen natural disturbances of various kinds and intensities. Therefore, the implementation of the chosen alternative should be capable of change as the responses of the forest to managed and natural disturbances unfold and become known (Keeney and Raiffa, 1993).

2.3. The project monitoring and evaluation subprocesses

Having produced the goal hierarchy, selected an alternative, and started to create managed disturbances in the landscape to implement the chosen alternative, we need to know whether the changing state of the forest is improving goal achievement or not. The monitoring and evaluation subprocess provides this key information. The monitoring process yields the values of the variables in the DFC measurement component of the alternative by measuring the current forest condition or by simulating some expected (predicted) future condition. Monitoring can be done in many ways: direct measurements, indirect measurements (i.e. remote sensing, data imputation, etc.), and forecasting through simulation of potential future scenarios. Recall that the measured variables are identified by the DFCs of the goal hierarchy. As the goal hierarchy changes so will the DFCs and therefore the variables that need to be monitored. Each unique goal hierarchy will most likely have a different set of variables that will need to be monitored thereby precluding any universal, generic monitoring program. The need for a unique monitoring system for each unique goal hierarchy is likely to make the monitoring task more expensive. On the other hand, only those variables specifically used by the desired conditions need to be monitored at all. *Information which is not needed in any of the DFCs has no value in the framework of a decision problem* (Klein and Methlie, 1990).

Because the monitoring process is costly, decision makers as well as stakeholders need to be aware that adding goals increases the cost of management. Goals ultimately lead to DFCs that must be monitored and to silvicultural prescriptions that must be implemented. Not all goals are equally expensive. Goals defined largely in terms of DFCs that are already required by other goals will be less expensive than those goals which add new DFCs to the hierarchy. DFCs that can be measured remotely or those that can be measured using a subjective, qualitative scale will be less expensive to add to the system than those that require precise, quantitative field measurement with equipment that is expensive and difficult to use or interpret. These issues of cost are simple and easy to understand. However, stakeholders involved in the goal hierarchy design process may not always understand the resource limitations of the management agency and may not feel bound by these limits. To remedy this situation, it should be standard practice to add financial goals to the goal hierarchy. In this fashion, goals can be added to the goal hierarchy only until all the resources to monitor and implement the goals have been absorbed. Once that point has been reached, a new goal can only be added by removing or modifying other goals.

The result of the monitoring process is then used to evaluate whether the implementation of the selected alternative is actually changing the state of the forest so that the difference between the goal state and the actual current state of the forest ecosystem is being reduced. This evaluation also produces information that can be fed back to the forest-level to evaluate whether and by how much the forest plan goals are being met. As a result of the evaluation process, *adjustments to the selected alternative will need to be made routinely and efficiently in order to achieve or sustain the desired conditions of the goal hierarchy as the forest ecosystem changes in unexpected and unanticipated ways*. These adjustments need to be viewed as normal and routine. Indeed, these adjustments lie at the heart of the adaptive management concept.

It should be evident from this description that the project-level management process is necessarily an iterative, cyclical activity (Janssen, 1992). The iterative, cyclical nature of the process allows decision makers to improve their understanding of a complex problem as well as adjust to unforeseen changes in both the goal hierarchy and the state of the forest ecosystem. Cycles occur for a large variety of reasons, such as when solutions fail to meet minimal standards, when new stakeholders raise unexpected objections, when court challenges to the selected alternative force a new evaluation, when unexpected changes occur in the forest landscape, etc. These cycles should be viewed as one form of adaptive management, the process of learning from and adjusting to a continuously changing, complex environment.

3. Project-level ecosystem management at the Bent Creek Experimental Forest in Asheville, NC

The previous section described the project-level ecosystem management process we advocate. This section presents an illustrative example of this process on the Bent Creek Experimental Forest of the Pisgah National Forest near Asheville, NC. The purpose of presenting this test application is to provide the reader with a concrete example of the methodology to further clarify the proposed project-level ecosystem management process.

3.1. The current condition of the Bent Creek Experimental Forest study area

The Bent Creek Experimental Forest is an approximately 2400 ha watershed which is part of Pisgah Ranger District of the Pisgah National Forest near Asheville, NC. The Experimental Forest is a management unit containing 65 forest stands. Most of these stands, 67% by area, are in the oak (*Quercus* spp.) forest type with 19% in the yellow poplar (*Liriodendron tulipifera*) forest type. The small sawtimber size class represents 76% of the forest area. Large sawtimber represents 19% and the pole size class another 5%. None of the 65 stands are classed as regeneration. The average basal area is 27.3 sq. m/ha (range: 10–54). The average number of trees per ha is 410 (range: 69–2937) and the average quadratic mean diameter is 31.2 cm (range: 12.2–65.5 cm).

3.2. Translating forest level goals to the project level

In national forest management, the immediate decision-making environment within which project-level ecosystem management must occur is defined by a Forest Plan. The governing Forest Plan for the Bent Creek Experimental Forest, the example management unit, is the Nantahala and Pisgah Forest Plan (Record of Decision, 1994). The process of developing a National Forest Plan is described by the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976. A description of the process used in the development of the Nantahala and Pisgah Forest Plan may be found in the Final Supplement to the Final Environmental Impact Statement (Vol. 1, EIS, 1994).

The Nantahala and Pisgah National Forest Plan, hereafter the Forest Plan, provides 'goals' that apply to the entire Forest as well additional, more specific 'goals' for each Management Area (Forest Plan Amendment 5, 1994). "Management Areas of the Nantahala and Pisgah National Forests are something like zones of a city plan: management areas are zoned to achieve different desired conditions, emphasize different activities, permit different uses of the forest, emphasize different wildlife species and landscape features" (Forest Plan Amendment 5, 1994). The Nantahala and Pisgah Forest Plan defines 21 Management Areas ranging in size from about 1619 to 93 890 ha for a total of 410 771 ha. These 21 management areas are non-contiguously distributed over the entire national forest. Each of these Management Areas inherits all of the forest-level goals and related sub-goals. In addition, each management area has been assigned a unique set of its own management area goals and sub-goals.

The Bent Creek Experimental Forest is zoned as a special Experimental Forest Management Area. For the purposes of this illustration, we will assume that the Bent Creek Experimental Forest is being managed as part of Forest Plan Management Area 4a. Area 4a surrounds Bent Creek and represents similar forest ecosystem conditions. Bent Creek also contains embedded within it Management Area 18, the riparian management area (Forest Plan Amendment 5, 1994). A general description of the goals for Management Area 4a include: most roads closed to motor vehicles, timber management activities are permitted, focus on providing quality scenery, focus on providing high quality wildlife habitat, especially for black bear (Forest Plan Amendment 5, 1994: III-77).

One major link between forest-level and project-level management has to be the goal hierarchy. Ideally, the forest-level goal hierarchy should terminate with DFCs (see discussion in previous section) defined in terms of the forest-level variables. The Forest Plan defines 10 strategic forest-wide goals that fit within the framework of the Forest Service's mission and address the issues raised by public participation in the planning process. These 10 goals are adequately broad in scope and address the major issues identified during the public participation process (Vol. 1, EIS, 1994). For example, Forest Goal #1 is: "Blend the needs of people and environmental values in such a way that the Nantahala and Pisgah National Forests sustain ecosystems that are diverse, productive, and resilient..." (Forest Plan Amendment 5, 1994: III-1).

Unfortunately, the Forest Plan fails to clearly and logically define more specific sub-goals for each of the 10 strategic goals. In other words, the Forest Plan fails to develop a complete goal hierarchy that defines each strategic goal into its component subgoals ending with the forest level DFCs. Without a completely specified goal hierarchy, the goal structure of the Forest Plan is not operationally useful. Furthermore, the Forest Plan (1) lacks internal, logical consistency so that the average reader is unable to comprehend the intent of the Forest Plan; (2) fails to clearly identify the relationship between the key concepts, such as goals, goods and services, directions, and standards; (3) fails to provide operational guidance to the project-level management effort; and (4) fails to clearly identify how project-level achievements are going to be used at the forest-level for evaluation and iterative improvement. Without such an explicit feedback loop, it is difficult to understand how national forest managers expect to know or be able to clearly demonstrate that the goals of the forest plan are being attained and/or sustained.

Lack of logical consistency and clarity of the Forest Plan made it difficult to identify the Forest-wide and Management Area level goal/subgoal structure and the associated DFCs that are needed as inputs to a project-level management process. We therefore selectively constructed a reasonable goal hierarchy for the Bent Creek Experimental Forest broadly consistent with the direction given for Management Area 4a in the Forest Plan.

3.3. Goal identification for the Bent Creek Experimental Forest

Five goals were selected for the Bent Creek Experimental Forest in order to illustrate the proposed project-level ecosystem management process. They represent five domains of interest: visual quality, ecology, timber production, water, and wildlife. For the sake of brevity and clarity, we selected only five goals of the many possible for this illustrative example. This small number of goals should not in any way be viewed as a limitation of the proposed ecosystem management process.

The first goal, Large-scale Variety is from the visual quality domain. It was one of a number of goals identified by a comprehensive literature review on measurable user preferences for visible aspects of forest environments (Hoffman and Palmer, 1996). Large-scale variety within a forested area is obtained by creating a few medium to large-sized openings that provide the desired variety when viewed from an overlook. These openings also provide variety over time and are perceived as incremental changes that occur as individual stands change in age and vegetation character. This goal would prevent the creation and maintenance of unbroken, relatively homogeneous forest areas.

Goal-1: Visual Quality Domain
Large-scale Variety is attained IF
DFC-1: The Number of Stand Size Classes ≥ 3; AND
DFC-2: Openings $< 67\%$ of the forest area; AND
DFC-3: % of Area in each Stand Size Class $\leq 50\%$.

The second goal, Local Biological Diversity, represents the ecological domain. Interest in enhancing local biological diversity stems from a desire to manage the forest for plant and animal species richness; to preserve or establish plants, plant associations, and habitats that are unique to this local area. Direct measurements of species richness are possible, however, in practice such measurements are seldom available. An alternative way to define local biological diversity is in terms of the state of the forest landscape that would enhance biological diversity. A wide variety of vegetative conditions is likely to perpetuate the maximum number of plant species and provide habitat for the maximum number of animal species. Therefore, the local biological diversity goal is defined as follows:

Goal-2: Ecological Resource Domain
Local Biological Diversity is attained IF
DFC-1: % Stands in Large and Small Sawtimber $> 20\%$; AND
DFC-2: % Stands in Sapling and Pole Size Classes $> 10\%$; AND
DFC-3: % Stands in Regeneration Size Class $> 10\%$; AND
(DFC-4: Openings $> 5\%$; OR
DFC-5: Water is Present).

The third goal, Continuous Quality Sawtimber Production, represents the timber commodity domain. The tree species that make up the southern Appalachian hardwood forests are particularly well suited to the production of large, high-quality sawtimber. Unlike the previous two goals, the third goal must be defined both at the management unit level and at the individual stand level.

Goal-3: Timber Resource Domain

Continuous Quality Sawtimber Production is attained IF
  Management Unit Level:
  DFC-1: % Stands in Large Sawtimber $\geq$ 10% and $\leq$ 15%; AND
  DFC-2: % Stands in Small Sawtimber $\geq$ 25% and $\leq$ 35%; AND
  DFC-3: % Stands in Sapling and Pole Size Classes $\geq$ 35 and $\leq$ 45%; AND
  DFC-4: % Stands in Regeneration Size Class $>$ 5% and $\leq$ 10%;
  Stand Level:
  DFC-5: Relative Density $\geq$ 60 and $<$ 100; AND
  DFC-6: Basal Area of Acceptable Growing Stock $\geq$ 6.9 m^2/ha; AND
  DFC-7: Basal Area of High Value Species $\geq$ 6.9 m^2/ha; AND
  DFC-8: Basal Area of Commercial Species $\geq$ 11.5 m^2/ha

DFCs for the management unit-level test for the existence of a balanced size class distribution throughout the forest in order to provide a continuous supply of sawtimber products. DFCs for the stand-level test that stands themselves are well stocked with trees of the appropriate species and quality.

The fourth goal, Limit Peak Flows, represents the water management domain. The goal to limit peak flows is focused on reducing erosion, silting, and flooding in the watershed by concentrating on the sensitive riparian zone stands.

Goal-4: Water Resource Domain
Limit Peak Flows is achieved IF
  Management Unit Level:
  DFC-1: % Openings $<$ 25%; AND
  DFC-2: Riparian Stands must meet all stand level DFCs; AND
  Stand Level:
  DFC-3: Relative Density $\geq$ 70; AND
  DFC-4: % Basal Area of evergreen trees $>$ 0 m^2/ha; AND
  DFC-5: Canopy Closure $>$ 25%.

Finally, the fifth goal, Black Bear, represents the wildlife management domain. This goal is designed to create and/or enhance habitat for black bear.

Goal-5: Wildlife Resource Domain
Habitat for black bear is achieved IF
  Management Unit Level:
  DFC-1: $>$ 30% of Stands must meet stand level DFCs; AND
  Stand Level:
  DFC-2: Coarse woody debris $>$ 3.5 m^3/ha; AND
  (DFC-3: Soft mast producing trees are present; OR
  DFC-4: Hard mast producing trees are present).

These five goals and their DFCs define a formal goal hierarchy for the project-level ecosystem management process for Bent Creek Experimental Forest (Fig. 3). This formal goal hierarchy explicitly and clearly defines a logical relationship between the top-level goal of successfully managing Bent Creek Experiment Forest and the five subgoals introduced above. In order to achieve or maintain any one subgoal, we need to satisfy each of its defining DFCs. The DFCs are defined in terms of variables that can be measured either in the real forest ecosystem as it currently exists or as it is forecast to exist in the future. Monitoring and evaluation can determine whether meeting defined DFCs does achieve a goal or if new DFCs are needed.

3.4. Current condition analysis

Given a goal hierarchy (Fig. 3) and a description of the current condition of the Bent Creek Study Area, usually supplied by the monitoring process, we can assess how well the current condition meets our desired condition. This current condition analysis allows us to understand how near or far the forest ecosystem currently is from achieving our goals. It also yields the knowledge we need to decide how to change the forest to better meet our goals. We seek this understanding in order to design a rich and interesting set of alternative courses of action (Fig. 2). The NED Ecosystem Management Decision Support System, the NED DSS for short, has been specifically developed to perform this function (Twery et al., 2000).

It is convenient to treat the current condition of the forest ecosystem as if it were an alternative. The current condition 'alternative' is defined by the DFC measurement component precisely like any other alternative (Fig. 4). The current condition 'alternative' is only different from other alternatives because it has no prescription component. The current condition is a very useful reference condition against which other alternatives can be compared.

It is important to notice that once the goal hierarchy has been defined, the current and future condition analysis assumes a 'closed-world' situation. A *closed-world assumption* means that all knowledge about the goals and their DFCs are present in the data base (Luger and Stubblefield, 1989). The desirability or undesirability of any and all changes of states of the forest landscape can only be evaluated with reference to the goal hierarchy. The *means* used to implement these state changes can be debated and evaluated with reference to the current constraint network. But that is a separate issue. If it turns out that there are hidden goals that surface, then they need to be added to the goal hierarchy along with their defining DFCs. Such a change in the goal hierarchy simply creates a new closed-world of goals against which current or future forest landscapes can be evaluated. This convention is a necessary condition of this process and is one of the powerful concepts that make this approach to ecosystem management relatively simple to understand.

The current condition analysis of Bent Creek results in the finding that goal G-1 Large-scale Variety is rated 'Not Satisfied' (Table 1). The goal completion report in the NED DSS presents the following facts:

Goal-1: Visual Quality Domain	Not Satisfied
Large-scale Variety is satisfied IF	
DFC-1: The Number of Stand Size Classes ≥ 3; AND	Minimally Satisfied (Value = 3)
DFC-2: Openings $< 67\%$ of the forest area; AND	Satisfied (Value = 0)
DFC-3: % of Area in each Stand Size Class $\leq 50\%$	Not Satisfied (Value = 76)

Table 1
Current condition goal analysis for Bent Creek Experimental Forest[a]

Goal name	Management unit rating	Stand rating				
		No. of stands	Fully satisfied (%)	Minimally satisfied (%)	Nearly satisfied (%)	Not satisfied (%)
Large-scale Variety	Not satisfied	0	N/A	N/A	N/A	N/A
Local Bio-diversity	Fully satisfied	0	N/A	N/A	N/A	N/A
Sawtimber Production	Not satisfied	65	8	14	0	78
Limit Peak Flow	Not satisfied	8	0	0	0	100
Black Bear	Minimally satisfied	65	25	0	0	75

[a] The column labeled 'No. of Stands' contains the number of stands for which the Stand Rating percentages apply. For example, there are only eight riparian stands in the Bent Creek Experimental Forest. Non-riparian stands are not considered in evaluating the goal 'Limit Peak Flow'. N/A, applicable.

From this analysis, it is evident what the problem is. Bent Creek Experimental Forest does not satisfy the goal 'Large-scale Variety' because more than 50% of the area, in fact 76%, is in one stand size class — the small sawtimber size class. Bent Creek is too homogeneous to satisfy this goal.

Goal G-2 Local Biological Diversity is rated 'Not Satisfied' (Table 1). The goal completion report in the NED DSS provides the following facts:

Goal-2: Ecological Resource Domain	Not Satisfied
Local Biological Diversity is satisfied IF	
DFC-1: % Stands in Large and Small Sawtimber $> 20\%$; AND	Satisfied (Value $= 95$)
DFC-2: % Stands in Sapling and Pole Size Classes $> 10\%$; AND	Not Satisfied (Value $= 5$)
DFC-3: % Stands in Regeneration Size Class $>$ 10%; AND	Not Satisfied (Value $= 0$)
(DFC-4: Openings $> 5\%$; OR DFC-5: Water is Present)	Satisfied (Value = present)

It is easy to see that Local Biological Diversity is not satisfied because the size class distribution of the forest is skewed toward the large-sized forest stands.

Goal G-3 Continuous Quality Sawtimber Production is rated 'Not Satisfied' (Table 1). The goal completion report in the NED DSS provides the following facts:

Goal-3: Timber Resource Domain	Not Satisfied
Continuous Quality Sawtimber Production is attained IF	
Management Unit Level:	
DFC-1: % Stands in Large Sawtimber $\geq 10\%$ and $\leq 15\%$; AND	Not Satisfied (Value $= 19$)
DFC-2: % Stands in Small Sawtimber $\geq 25\%$ and $\leq 35\%$; AND	Not Satisfied (Value $= 76$)
DFC-3: % Stands in Sapling and Pole Size Classes ≥ 35 and $\leq 45\%$ AND	Not Satisfied (Value $= 5$)
DFC-4: % Stands in Regeneration Size Class $> 5\%$ and $\leq 10\%$	Not Satisfied (Value $= 0$)

At the management unit level, Bent Creek does not have a balanced size class distribution that would provide a sustainable supply of high quality sawtimber. Unlike the previous goals, this goal is also defined at the stand level.

Stand Level:

DFC-5: Relative Density ≥ 60 and < 100; AND

DFC-6: Basal Area of Acceptable Growing Stock ≥ 6.9 m^2/ha; AND
DFC-7: Basal Area of High Value Species ≥ 6.9 m^2/ha; AND
DFC-8: Basal Area of Commercial Species ≥ 11.5 m^2/ha

Using the NED DSS to examine the goal report for each of the 65 stands in the management unit, it becomes clear that stands fail to satisfy the stand conditions for two major reasons. Either they are below or above the relative density range in DFC-5 or they do not have enough high value species (DFC-7). In contrast, DFC-6 and DFC-8 rarely make a stand unsatisfactory at Bent Creek.

Goal G-4 Limit Peak Flows is rated 'Not Satisfied' (Table 1). The goal completion report in the NED DSS provides the following facts:

Goal-4: Water Resource Domain	Not Satisfied
Limit Peak Flows is achieved IF	
Management Unit Level:	
DFC-1: % Openings $<$ 25%; AND	Satisfied (Value = 0)
DFC-2: % All Riparian Stands must meet stand level DFCs	Not Satisfied
Stand Level:	
DFC-3: Relative Density $\geq$ 70; AND	
DFC-4: % Basal Area of evergreen trees >0 m^2/ha; AND	
DFC-5: Canopy Closure $>$ 25%	

The Bent Creek management unit has no trouble meeting DFC-1 because there are no stand-sized permanent openings or regeneration size-class stands that would also qualify as an opening. There are only eight riparian stands on the Bent Creek Experimental Forest and none of them satisfy DFC-4. The problem is that none of the eight riparian stands have evergreen trees.

Goal G-5 Black Bear is rated 'Not Satisfied' (Table 1). The goal completion report in the NED DSS provides the following facts:

Goal-5: Wildlife Resource Domain	Not Satisfied
Habitat for black bear is achieved IF	
Management Unit Level:	
DFC-1: $>$ 30% of Stands must meet stand level DFCs	Minimally Satisfied (Value = 25)
Stand Level:	
DFC-2: Coarse woody debris >3.5 m^3/ha; AND	
(DFC-3: Soft mast producing trees are present; OR	
DFC-4: Hard mast producing trees are present)	

Because we did not have direct coarse woody debris inventory data for Bent Creek, we assumed that both regenerating stands and large sawtimber stands had more than the 3.5 m^3/ha of coarse woody debris per acre threshold value in DFC-2. All other size classes had less. Almost all stands in Bent Creek have either a soft or hard mast component and since the threshold is simply a presence/absence one, all stands meet DFC-3 or DFC-4. Only 25% of the stands currently satisfy DFC-2 which is within ± 10% of the required threshold value of 30% and therefore earns a ‘Minimally Satisfied’ rating.

3.5. Alternative design and analysis — the custodial alternative

In the previous section, we went into great detail in order to illustrate how to compare a goal hierarchy to the current condition. The same method is used to compare the goal hierarchy to any other alternative (Fig. 4). From this point forward, we will simply present and discuss the interesting results.

One popular alternative is to do nothing. This alternative may be labeled the Custodial Alternative. With no active human management activities allowed, the Custodial Alternative can be used to represent one end of the spectrum of choices. In order to evaluate the consequences of the Custodial Alternative we can forecast the natural dynamics of growth and death on the Bent Creek Experimental Forest to a common point in time in this case 40 years into the future. This forecasting simulation needs to provide us with an estimate of the effects of implementing the alternative under consideration on the landscape being managed. From this analysis we will gain an understanding of the consequences inherent in the proposed alternative. FVS (Teck et al., 1996), a general vegetation dynamics simulation model, was used to generate the forecast for this example. The resultant simulated future forest ecosystem was then compared to the goal hierarchy using the NED DSS.

Under the Custodial Alternative, Goal G-1 Large Scale Variety has lost ground (Table 2). Although the overall rating of ‘Not Satisfied’ has not changed, 40 years from now 93% of the Bent Creek management unit will be in the Large Sawtimber size class. From the perspective of satisfying goal G-1, having 93% of the area in a single size class is definitely worse than having 76% in a single size class, which is the current situation. Goal G-2, Local Biological Diversity, has also moved further away from being satisfied. Now, the small and large sawtimber sizes together make up 99% of the forest compared to the current condition of 95%. Goal G-3, Sawtimber Production, has also declined. Under the Custodial Alternative 87% of the stands do not meet the stand DFCs, up from the current 78%. The proportion of stands that were rated ‘Fully Satisfied’ dropped from 14 to 6% due to a reduction of the proportion of high value species as a percentage of total stand basal area. In other words, high value sawtimber species were losing the competition battle to more vigorous but lower value sawtimber species. A few stands improved their rating because their relative density increased. But overall, the Custodial Alterna-

Table 2
Custodial Alternative goal analysis for Bent Creek Experimental Forest[a]

Goal name	Management unit rating	Stand rating				
		No. of stands	Fully satisfied (%)	Minimally satisfied (%)	Nearly satisfied (%)	Not satisfied (%)
Large-scale Variety	Not satisfied	0	N/A	N/A	N/A	N/A
Local Bio-diversity	Not satisfied	0	N/A	N/A	N/A	N/A
Sawtimber Production	Not satisfied	65	6	5	2	87
Limit Peak Flow	Not satisfied	8	0	0	0	100
Black Bear	Fully satisfied	65	78	0	0	22

[a] The column labeled 'No. of Stands' contains the number of stands for which the Stand Rating percentages apply. For example, there are only eight riparian stands in the Bent Creek Experimental Forest. Non-riparian stands are not considered in evaluating the goal 'Limit Peak Flow'. N/A, applicable.

tive moved the forest away from satisfying goal G-3. Goal G-4, Limit Peak Flow, remained unchanged because evergreen species were still missing from the riparian stands.

Finally, Goal G-5, black bear, showed a marked improvement under the Custodial Alternative (Table 3). The overall rating for the management unit improved from 'Minimally Satisfied' to 'Fully Satisfied'. Due to numerous stands growing into the large sawtimber size class from the small sawtimber size class, the proportion of stands rated as 'Fully Satisfied' improved from 25 to 78%. Remember, that we are assuming that all large sawtimber-sized stands provide more than the required 3.5 m^3/ha of coarse woody debris while small sawtimber-sized stands do not. One could certainly argue that the desired conditions for black bear ought to be modified so that mast production is more than a presence/absence metric. One would expect a large sawtimber-sized oak stand to produce significantly more acorns than a small sawtimber oak stand. But the 'closed world assumption' forces us to ignore such considerations because they are not considered in the DFCs as currently defined. The goal hierarchy can be changed at any time by the decision makers, stakeholders, and domain experts to create a new 'closed world assumption' if the present one needs improvement.

In summary, the homogeneous large sawtimber management unit created by the Custodial Alternative is less successful than the current condition in satisfying goals G-1, G-2, and G-3. It improves the rating of goal G-5 compared to the current condition and is neutral with regard to goal G-4.

Several important points should be noted. First, these analyses are clear and understandable. Each goal can readily be compared to the current conditions and any hypothesized alternative. Some goals such as goals G-1, G-2, and G-3 move in concert with each other. Some goals, such as G-5, move in the opposite direction. Some goals, such as G-4, are neutral with respect to some kinds of changes in the forest ecosystem. Furthermore, it is easy to recognize which goals have which tendencies. Those goals that tend to move in concert over a wide variety of ecosystem state changes can be thought of as generally compatible with each other. Those which frequently move in opposite directions can be thought of as generally incompatible with each other. One byproduct of this process is therefore a clear and objective way to identify goal compatibility, neutrality, or conflict.

3.6. Alternative design and analysis — maximum sustainable sawtimber production

An interesting, and often used, contrast to the Custodial Alternative is the Maximum Sustainable Sawtimber Production Alternative. Under this alternative, Goal G-3 is favored and allowed to dominate all other goals. This means that goals that are compatible with goal G-3 will probably also improve their satisfaction rating. Those goals in conflict with goal G-3 will be negatively impacted.

We used a Southern Appalachian Hardwood Forest Regeneration Simulation Model suggested by Loftis (1990) and programmed by Kim et al. (2000) to forecast stand composition and size following a regeneration harvest. FVS was used for growth and mortality prediction of existing stands. FVS was also used to simulate

Table 3
Maximum sustained sawtimber production alternative goal analysis for Bent Creek Experimental Forest[a]

Goal name	Management unit rating	Stand rating				
		No. of stands	Fully satisfied (%)	Minimally satisfied (%)	Nearly satisfied (%)	Not satisfied (%)
Large-scale Variety	Fully satisfied	0	N/A	N/A	N/A	N/A
Local Bio-diversity	Fully satisfied	0	N/A	N/A	N/A	N/A
Sawtimber Production	Minimally satisfied	65	22	43	15	20
Limit Peak Flow	Not satisfied	8	0	0	0	100
Black Bear	Not satisfied	65	13	0	0	87

[a] The column labeled 'No. of Stands' contains the number of stands for which the Stand Rating percentages apply. For example, there are only eight riparian stands in the Bent Creek Experimental Forest. Non-riparian stands are not considered in evaluating the goal 'Limit Peak Flow'. N/A, not applicable.

various types and intensities of thinnings over the 40-year projection period. The NED DSS was again used to compare the resulting simulated forest with the goal hierarchy. We assumed no financial constraints.

To design this alternative, we need to understand what we have to do in order to improve quality sawtimber production at Bent Creek. By reviewing the current condition analysis, we realize that we have to create a better distribution of size classes. This implies regeneration harvesting. Beyond that, we need to make sure each stand is well stocked, not understocked and not overstocked. Stocking control is usually achieved by thinnings of various kinds. We also need to favor the high-value species whenever possible. We can discover which species are high value by looking at the species encyclopedia in NED. Releasing high-value species from competition also implies thinning prescriptions.

After examining the current conditions and the custodial alternative, we identified several types of stands where active management will move Bent Creek closer to the goal of sustained sawtimber production. First, there are many stands in the small sawtimber size class that become too dense if left alone for 40 years to grow and where the proportion of basal area in high value species declines in favor of less valuable commercial tree species. By thinning these stands from below we can keep the stand within the density range best for sawtimber production. By favoring the high value species while we are thinning and removing their immediate competitors, we can increase their proportionate basal area. Next, there are stands in the large and small sawtimber size classes with lower than optimum stand density. These stands become prime candidates for regeneration either by clearcutting or various shelterwood cutting methods (Loftis, 1983, 1990; Beck, 1988; Helms, 1998).

The maximum sustainable sawtimber alternative appeared to improve goal accomplishment dramatically (Table 3). Both goals G-1 (Large-scale Variety) and G-2 (Local Biological Diversity) became fully satisfied as we aggressively achieved a more balanced size-class distribution of stands in the management unit. Goal G-3 (Sawtimber Production) improved to minimally satisfied because 40 years was not enough time to repopulate the small sawtimber size class from stands growing out of the sapling and pole size classes. At the stand level, we can see that the thinning prescriptions were effective in reducing the number of stands in the 'Not Satisfied' category from 78% in the current condition to only 20% under this alternative. Goal G-4 (Limit Peak Flow) has still not been satisfied because there are still no evergreen trees in the riparian zone stands. As expected, Goal G-5 (Black Bear) changed from 'Minimally Satisfied' to 'Not Satisfied'. Recall that DFC-1 for Black Bear required greater than 30% of the stands to meet stand level DFCs. Although regenerating stands also provide enough coarse woody debris to pass DFC-2, these stands grow into the sapling and pole size classes after only 10 years. The transient nature of the regenerating stands and the reduction in large sawtimber stands contribute to the degradation of Black Bear habitat under this scenario.

3.7. Alternative design and analysis — equal preference for all five goals

Another possible alternative might be to give all five goals equal preference. The equal preference alternative would, in our example, lead to a more moderate management intensity. To improve the status of three of the five goals, we still need to strive for a more balanced size distribution. But because adequate coarse woody debris, which is a desired condition for the black bear goal, is associated with either regeneration or large sawtimber size classes, we might want to over-represent the large sawtimber size class. We can only keep a stand in the regenerating size class for 10 years but we can maintain a healthy large sawtimber size stand for a much longer time. We can also create more coarse woody debris by altering how we thin stands. If we prescribe that low value trees, either due to low value species, poor form, or size, be simply felled and left on the site during the commercial thinning operations, then we can artificially improve bear habitat at relatively low cost. Of course our assumption that small sawtimber size stands do not have adequate woody debris may not be accurate. Monitoring and evaluation of that assumption may alter it and thus produce a substantial change in the satisfaction rating for that DFC.

To implement this alternative, we thinned the same stands as under the maximum sustained sawtimber alternative. We also regenerated the stands in the large and small sawtimber size classes with lower than optimum stand density. The well stocked, small sawtimber stands with deficient high value species, however, were left to grow.

In addition, the equal preferences alternative provided the justification to spend resources to artificially introduce an evergreen component into the eight riparian stands in order to satisfy the ‘Limit Peak Flow’ goal. We simulated the underplanting of hemlock along with a light release thinning for each hemlock planted.

Implementing the equal preferences alternative just described resulted in satisfying all the goals to some degree (Table 4). As before, we used FVS, the Southern Appalachian Hardwood Regeneration Simulation Model, and NED to simulate implementing this alternative. Goal G-1 (Large-scale Variety) was rated as ‘Minimally Satisfied’ because the Large Sawtimber size class represented 46% of the area of the stand, which is just barely below the threshold of 50% in DFC-3. Goal G-2 (Local Biological Diversity) was ‘Fully Satisfied’. Goal G-3 (Sawtimber Production) was rated ‘Nearly Satisfied’ primarily because the percentage of stands in the sapling and pole size class was just under the minimum 35% threshold value and the large sawtimber size class was just over the maximum 15% threshold value. Within the time frame of the example we were unable to harvest and regenerate a sufficient number of stands to fully satisfy the balanced size class requirements of Goal G-3. At the stand level, this alternative was not as good as the maximum sawtimber alternative (Table 4) but was substantially better than the current condition or the custodial alternative (Tables 2 and 3). Because we planted the riparian stands with hemlock, we were able to fully satisfy goal G-4 (Limit Peak Flow). Finally Black Bear was ‘Fully Satisfied’ because many stands had enough coarse woody debris to satisfy the threshold in DFC2. This alternative fostered many large sawtimber-sized

Table 4
Equal preferences alternative goal analysis for Bent Creek Experimental Forest[a]

Goal name	Management unit rating	Stand rating				
		No. of stands	Fully satisfied (%)	Minimally satisfied (%)	Nearly satisfied (%)	Not satisfied (%)
Large-scale Variety	Minimally satisfied	0	N/A	N/A	N/A	N/A
Local Bio-diversity	Fully satisfied	0	N/A	N/A	N/A	N/A
Sawtimber Production	Nearly satisfied	65	12	18	42	28
Limit Peak Flow	Fully satisfied	8	100	0	0	0
Black Bear	Fully satisfied	65	69	0	0	31

[a] The column labeled ‘No. of Stands’ contains the number of stands for which the Stand Rating percentages apply. For example, there are only eight riparian stands in the Bent Creek Experimental Forest. Non-riparian stands are not considered in evaluating the goal ‘Limit Peak Flow’. N/A, not applicable.

stands, some regenerating stands, and, improved the amount of coarse woody debris in other size class stands by leaving coarse woody debris in thinned stands.

3.8. Alternative selection and authorization to implement

At this point we have created the goal hierarchy (Fig. 3) and designed alternative courses of action (Figs. 2 and 4). For each alternative, we simulated its implementation and forecast the resultant forest ecosystem at the end of a 40-year period of time. We then evaluated each alternative by determining whether the DFCs in the goal hierarchy were fully satisfied, minimally satisfied, nearly satisfied, or unsatisfied (Tables 1–4). We found it convenient to treat the current condition as if it were an alternative because it allows us to compare whether any of the alternatives improved on the current condition of the forest ecosystem. This body of information may then be used to objectively select an alternative for implementation.

Of the many possible choice methodologies available, we decided to use the Analytical Hierarchy Process (AHP) developed by Saaty (1992) as implemented by the commercial CRITERIUM DECISION PLUS software package (InfoHarvest, 1996). The AHP process was successfully applied to natural resource management by Schmoldt et al. (1995). Two further preparatory steps are required to apply the AHP choice methodology: (1) decide how important each goal of the same hierarchical level is in comparison with all others and (2) rate the performance of each DFC against each alternative. Recall that the design of our alternatives involved two separate positions on the relative importance of goals in the hierarchy. The one position was that all goals are equally important and the second position was that the goal G-3 Sawtimber Production was more important than the others. We will examine the influence of this value driven decision on the choice of alternatives.

If we assume that all goals in the goal hierarchy are equally important in the decision process and then rate the expected results of implementing each alternative against the DFCs in the goal hierarchy, we find that the ‘Equal Goal Preferences’ alternative is slightly better than the ‘Maximum Sustainable Sawtimber’ alternative (Table 5). The rating value of 0.89 in Table 5 is a composite score across all goals in the goal hierarchy calculated by the software using the AHP algorithm (Saaty, 1992). These composite values are meaningful only for ranking the alternatives on a common, relative scale. Both the ‘Equal Goal Preferences’ and ‘Maximum Sustainable Sawtimber’ alternatives are a considerable improvement over both the ‘Current Condition’ and the ‘Custodial — Do Nothing’ alternatives. The effect of the ‘Equal Goal Preferences’ alternative is to provide a good balance of achievement across all the goals. When we alter the preference values to make the ‘Maximum Sustainable Sawtimber’ objective twice as important as the other goals, we observe the expected shift in the preferred alternative (Table 5). The preferred alternative is influenced not only by the consequences of implementing that alternative on the forest ecosystem but also by the differences in the importance of the goals as reflected by the preferences used in the analysis. The ability to clearly understand and communicate both of these factors in alternative selection is an important attribute of the AHP methodology.

In this simple illustration, it is easy to review Table 4 and determine that we have satisfied all the goals to some degree, whereas in Table 3 it is readily apparent that the 'Maximum Sustainable Sawtimber' alternative leaves two of the five goals unsatisfied. A more realistic example with over 100 goals would be more difficult to synthesize using output in the format of Tables 1–4. For this larger problem situation, the composite scores generated by the AHP method would have clear advantages in alternative comparison and selection.

3.9. Alternative implementation

Once an alternative has been selected and authorized, it can be implemented (Fig. 2). Each of the prescriptions (action–location–time triples) of each silvicultural system for each stand (Fig. 4) can be scheduled and put on a work plan for implementation. Many implementation details must still be worked out. For example, it may be possible to group prescriptions in the same location or at the same time or of the same type of action together so they can be performed under a single contract. The changes in the forest landscape created by these prescriptions (i.e. managed disturbances) need to be recorded and the inventory updated to reflect the new conditions.

3.10. Monitoring and evaluation

The goal hierarchy could be evaluated by comparing it to the current conditions for each year for which an alternative is authorized. This annual evaluation will indicate whether we are achieving our goals or not. If we are, then the alternative and our implementation of it may be deemed effective. If we are not, then we need to analyze which goals are not being achieved and why. There is an infinite number of reasons why goals might not be achieved as planned. It could be that the forest

Table 5
Alternative comparison of results using the Analytical Hierarchy Process (AHP) as the ranking system[a]

Alternative name	AHP scores	
	Equal preference values for all goals	Double preference value for sawtimber production
Current condition	0.58	0.40
Custodial (do nothing)	0.60	0.41
Maximum sustainable sawtimber focus	0.82	0.81
Focus on achieving all goals	0.89	0.76

[a] The alternative name indicates the types of treatments that were selected to achieve a particular focus. The Current Condition is simply an analysis of how well the current forest ecosystem satisfies the goal hierarchy. Preference values are part of the AHP scoring system which is independent of how alternatives have been defined.

is changing in unplanned ways for which the current alternative is no longer appropriate. It could be that some prescriptions are not providing expected results. It could be that new constraints have been accepted into the constraint network that invalidate some prescriptions. This circumstance might then require a new alternative depending upon the availability of acceptable and effective substitute prescriptions. Perhaps budget reductions occur which prevent the implementation of the chosen alternative as planned.

In all cases, progress evaluations can only be done in a meaningful way if the response of forest ecosystems to managed and natural disturbances is accurately monitored and recorded in the appropriate databases. For the purposes of our proposed project-level ecosystem management process, monitoring is defined as measuring or estimating the current value of all the variables found in all of the DFCs in the goal hierarchy (Fig. 3). There is little point in setting goals, designing alternatives, and implementing them if there is no way of knowing whether and when the goals in the goal hierarchy have been achieved (Nute et al., 2000). Monitoring provides the key data that permits ecosystem managers to evaluate the state of goal achievement. Monitoring, however, can be extremely expensive. Nevertheless, the monitoring activity is equivalent to the eyes of the ecosystem manager. Without monitoring, the ecosystem manager is essentially blind.

If monitoring is considered during the goal hierarchy definition process, then DFCs might be established that are easier to measure, but at the same time, as effective as a more complicated and expensive alternative metric. Furthermore, examining the choice of DFCs at the time of goal setting forces the evaluation of the feasibility of the monitoring program as the decision process is being formed. The bottom line is that the ‘what’, ‘when’, and ‘how’ to monitor should be an integral part of the goal hierarchy definition process.

4. Discussion and conclusions

Many authors have pointed out the need to firm up the ‘fuzzy’ ecosystem management paradigm and develop operationally practical processes to allow ecosystem managers to accommodate more effectively the continuing rapid change in societal perspectives and goals. There are three spatial scales where clear, precise, practical ecosystem management processes are needed: the regional assessment scale, the forest-level scale, and the project-level scale. Rauscher (1999) presents a concise review of the decision environment and decision support systems for ecosystem management. He reviews primarily the regional assessment and the forest-level scales. The present paper proposes a practical decision analysis process for ecosystem management at the project-scale.

Our proposed decision analysis process is firmly grounded in the theory and practice of multi-objective decision analysis. The process is clear, transparent, and understandable to the average person. Each of the major subprocesses, e.g. goal hierarchy development, alternative design and analysis, and alternative choice are relatively simple to understand and communicate. Although in our illustration, we used the Forest Vegetation Simulator (FVS) as our choice of general vegetation dynamics model, any suitable simulation forecasting tool could have been used to predict the consequences of implementing any particular alternative. Similarly, we chose to use NED as our full-service DSS. Any other full-service DSS might be used so long as it has the ability to evaluate any particular goal hierarchy against the current landscape or some simulated future landscape. Similarly, we used the Analytical Hierarchy Process as our alternative selection method. Alternative selection can be performed using any of the numerous multi-objective choice methods available. The point is that we do not argue that our process is the only process. We do feel, however, that we have demonstrated that our proposed decision analysis process is a theoretically sound and practically attractive method that should be further explored and directly compared with competing methods.

Our small test case at the Bent Creek Experimental Forest is not complex enough to be completely convincing. The next step to further evaluate our proposed decision analysis process is to apply it to a more complex and more realistic situation.

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