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NED-1: integrated analyses for forest stewardship decisions☆

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Abstract

NED is a collective term for a set of software intended to help resource managers develop goals, assess current and potential conditions, and produce sustainable management plans for forest properties. The software tools are being developed by the USDA Forest Service, Northeastern and Southern Research Stations, in cooperation with many other collaborators. NED-1 is a Windows-based program that helps analyze forest inventory data from the

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perspective of various resources on management areas as large as several thousand hectares. Resources addressed include visual quality, ecology, forest health, timber, water, and wildlife. NED-1 evaluates the degree to which an individual stand or an entire management unit may provide the conditions required to accomplish specific goals. NED-1 users select from a variety of reports, including tabular data summaries, general narratives, and goal-specific analyses. An extensive hypertext system provides information about the resource goals, the desired conditions that support achieving those goals, and related data used to analyze the actual condition of the forest, as well as detailed information about the program itself and the rules and formulas used to produce the analyses. The software is constructed in C++ using an application framework; the inferencing component that handles the rule bases uses Prolog.

Keywords: Decision support; Natural resource management; Trade-offs; Multiple benefits

1. Introduction

1.1. NED suite

As natural resource management moves from a compartmentalized approach to multiple-use management to a more complex ecological approach wherein the interaction between components must be known and considered, the need for more powerful decision support system (DSS) tools is obvious (Rauscher, 1999). DSSs are computer programs that *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 (Turban, 1993). A key feature is that the human decision makers are as much a part of the DSS as any other component. People do not merely 'run' a DSS and use its outputs. Rather, they are an integral part of a DSS, providing the system with judgment and values that are critical to and often dominate the decision making process. The complexity of making coherent, integrated, and interdependent ecosystem management decisions has spurred the development of DSSs over the last 20 years. A recently released compendium of DSSs for ecosystem management describes 24 systems (Mowrer, 1997) of which NED is one.

The NED DSS for ecosystem management is a collection of software products intended to help resource managers develop goals, assess current and future conditions, and produce sustainable management plans for forest properties in the eastern United States. The development effort is being led by the USDA Forest Service's Northeastern Research Station in cooperation with the Southern Research Station and many other collaborators. The term 'NED' originated as an acronym for the 'NorthEast Decision model', but as the applicable territory has expanded, we have dropped the reference to the Northeast in the name and use simply NED. The vision driving NED is that demands for a variety of resource values can be evaluated and met best by first determining the priorities of all management objectives, then resolving trade-offs among them, and only subsequently selecting activities compatible with all goals to produce specified desired future conditions.

The intended clientele for NED include all who are interested in management of forest land in the Northeast, primarily those responsible for individual management decisions on specific units of land. Particularly on public lands, this means that NED is not intended to replace a land allocation system such as FORPLAN or Spectrum. The NED system facilitates translation of general goals into specific and compatible goals and then makes specific management recommendations for units of land with these goals. Silviculture often heads the list of tools used by resource managers to achieve their goals. In its broadest sense, silviculture includes any direct or indirect manipulation of forest vegetation. The most direct and most traditional method familiar to foresters is tree cutting, but planting, burning, and other activities are also components of silviculture. NED attempts to provide as much information as possible to a user regarding possible management goals for a particular property, the conditions necessary to meet those goals, and possible silvicultural activities that can help move conditions in the forest closer to the desired ones. Thus, the two primary groups of users are consulting foresters, either private or service foresters, and public forest resource managers such as district-level managers on National Forests. Private landowners with no training in resource management should be able to use parts of the system, but will not be expected to utilize NED's full capabilities. We anticipate that training in the use of the program will be beneficial even to professional natural resource managers.

1.1.1. Available programs

The development of such a comprehensive system requires considerable time and resources. To facilitate useful input from potential users in the design of the system, NED's developers have chosen to release independent software programs that implement the NED concept in stages. The initial freestanding programs such as NED/SIPS (Simpson et al., 1995), NEWILD (Thomasma et al., 1998), and the Forest Stewardship Planning Guide (Alban et al., 1995) have a large body of users, have generated considerable comment, and have influenced the design of additional work.

1.1.1.1. The Forest Stewardship Planning Guide (Alban et al., 1995). This is a program designed to provide people with exposure to and explanations of a wide range of practices used to produce a variety of benefits from forests. The program begins by providing a user with extensive background information on forests in general. It then attempts to determine the landowner's goals for the forest. The program runs under Microsoft Windows and guides the user through a process of selecting forest stewardship goals. This program makes limited recommendations on managing a forest for specific goals and describes the conditions that must be created or enhanced to accomplish them. A companion program, Stewplan, will be issued with the second version. Stewplan is a form-generating program that facilitates drafting standard Forest Stewardship Plans.

1.1.1.2. NED/SIPS (Simpson et al., 1995). This is an initial product from the development of NED. Subtitled Stand Inventory Processor and Simulator (SIPS), the program provides a means of creating, managing, and analyzing forest-inventory records at the stand level. Its interface simplifies entering and editing stand-inventory data. Once data are entered, many analytical tools are available to help understand the data. A variety of reports can be generated to describe the vegetation structure, timber value, and economics of the stand. Users can apply any of a set of standard treatments to the stand or design a customized cutting scheme, and use one of the four incorporated stand-growth simulators [NE TWIGS (Teck, 1990), SILVAH (Marquis and Ernst, 1992), OAKSIM (Hilt, 1985), and FIBER (Solomon et al., 1987)] to show what the stand may look like in the future. The NED/SIPS interface features pull-down menus and context-sensitive help, access to four growth-and-yield simulators using the same data file format, overstory summary tables for common measures of stand characteristics (such as density, species, and volume), and economic analyses of incomes and expenses over time.

1.1.1.3. NEWILD (Thomasma et al., 1998). This is designed to provide access to and evaluate information on species–habitat relationships for 338 terrestrial vertebrate species in New England. This program is based on publications by DeGraaf and Rudis (1986) and DeGraaf et al. (1992) that describe the habitat conditions used or preferred by these species of birds, mammals, reptiles, and amphibians. Some of the text from the publications has been incorporated into the HELP portion of NEWILD. A user can provide NEWILD with a habitat description and determine what species might be likely to use the area, or ask the program to identify the habitat preferences of a particular species of interest.

1.1.1.4. NED-Health. This is another Windows-based program that provides information on stress agents that affect the health of forest trees (Steinman, 1996). These agents include insects, fungi, weather, or people. The program analyzes composition of a particular forest and identifies potential causes of damage, methods to recognize particular agents, and actions that may be taken to avoid or mitigate damage. As a result, rather than identify 'pest management' as a goal, maintenance of a healthy forest is the goal, and pest management activities are a means to create or maintain the necessary conditions. The program is still unpublished, but a test version is available on the NED web site.

1.1.1.5. NED-1. This is a Windows program that emphasizes the analysis of forest-inventory data from the perspectives of various forest resources. The resources it addresses are visual quality, ecology, forest health, timber, water, and wildlife. The primary function of NED-1 is to evaluate the degree to which individual stands or the management unit as a whole provide the conditions required to accomplish specific goals (Fig. 1). An extensive hypertext system provides the user with information about the resource goals, the desired conditions that support achieving those goals, and related data used to analyze the actual condition of the forest. NED-1 is designed to begin to integrate the pieces from the initial programs into a single interface. It includes the multiple-resource, multiple-value goal sets defined within the Forest Stewardship Planning Guide, the evaluation of wildlife habitat as represented in NEWILD, and much of the timber inventory summary and economic analysis provided in NED/SIPS. Because NED-1 adds the complexity of a multiple-stand management unit and provides analysis for the management unit as a whole as well as the individual stands separately, the user can evaluate conditions across the entire property.

The stages we foresee in developing the full NED concept are as follows:

Stage	Name	Description
1	NED-1	Summarize current conditions and include user goal selection for comparison of existing conditions with desired future conditions (DFCs)
2	NED-2	Simulation of future forest development; link to independent modules based on data communications standards; comparison of multiple alternative scenarios
3	NED-3	User-specified silvicultural prescriptions; full expert prescription development; link with GIS capabilities

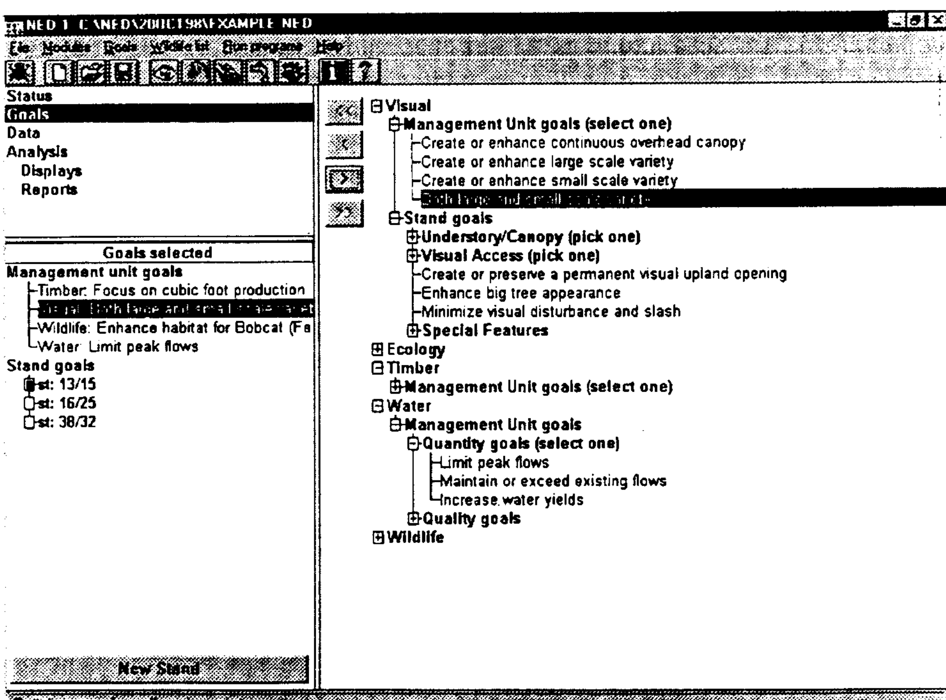

Fig. 1. A sample of the interface in NED-1 showing some of the goals available for selection and the list of goals selected.

NED's purpose is to improve the information available to a decision maker for natural resource management. The functions performed by the software include (1) the analysis and evaluation of a given state of the forest relative to the goals specified by the user, (2) the projection of future development of the forest under various management scenarios and the evaluation of the resultant conditions, and (3) the development of expert prescriptions to assist the user in choosing a management alternative that will enhance the ability of the forest to meet the decision maker's goals.

1.2. Background

The development of the NED suite of programs began in 1987 in meetings among researchers within the Northeastern Forest Experiment Station. The Station had begun a program to promote innovation and novel ways of sharing ideas and information. One of the ideas put forward was to develop a computer program that would combine all the previously independently produced growth and yield models developed by scientists within the Station (Marquis, 1990). A primary motivation of the project was to develop a single, easy-to-use program that could provide summary information and expert prescriptions for any forest type in the northeastern United States. The expectation that many of the Station's senior silviculturists would be retiring within 5 years was another motivating factor in the desire to capture their collective knowledge in a decision support system. A major difficulty was the challenge of convincing scientists accustomed to working and publishing independently that they would benefit from collaboration.

1.2.1. Expert committees

To collect the information needed for a multiple-resource system we organized committees of experts in each of the resource specialties. These committees consist of 8–20 professionals in a particular discipline such as silviculture, wildlife management, or visual resources. Each committee includes a mix of research scientists and practitioners; the coordinators of the NED project participate in all meetings. Within each committee, the definitions of potential desirable goals for that particular resource, plus a description of the conditions necessary to achieve each goal, are developed through a series of meetings and correspondences (Rauscher et al., 1995).

1.2.2. Collaborative structure

The identification of common terms with which to define conditions was an important step in the process, and still is being refined. For this step we have created a collaborative group, the NED Core Team, with at least one representative from each of the specific resource committees (Fig. 2). In regular meetings and correspondence over several years, this group has defined common inventory procedures for the various resources and structured the NED-1 analysis approach.

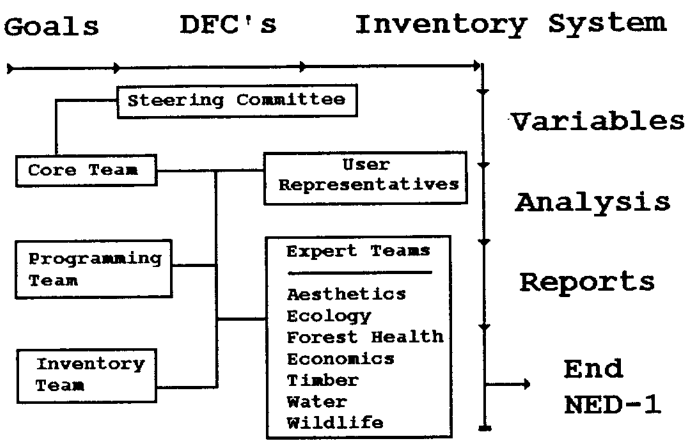

Fig. 2. Schematic diagram of the team organization for NED, and the information path for NED-1 development process.

1.2.3. User community

It is difficult to quantify the total number of current users of the NED software products because the software is distributed free of charge at scientific meetings, over the Internet (http://www.fs.fed.us/ne/burlington/ned/), through university classes, and the standard Forest Service publication distribution channels. We do know that regular users of NED/SIPS number in the hundreds, primarily consulting foresters in the northeastern United States. Numerous universities and colleges with forestry programs use both the Forest Stewardship Planning Guide and NED/SIPS in their mensuration, silviculture, harvesting, and forest management classes. NEWILD is in regular use as a reference resource by wildlife professionals in New England, and many forestry consultants also use outputs from the program in their reports to clients.

NED-1 is being used in its beta-testing form at several colleges and universities to replace the DOS-based NED/SIPS in their classes. We also conduct training sessions for National Forest managers in North Carolina and Tennessee using a data set with more than 100 stands and covering 5000 acres. Response to date has been very positive (Rauscher et al., 2000).

2. Goal-focused orientation

2.1. Relationship of goals to management

Management is necessarily a goal-driven activity. Generically, *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). Specifically, in forest management, resources are applied to forest ecosystems to achieve or sustain goals. A *goal* is a *desirable condition*, a situation to which someone is willing to allocate resources (time, effort, money, etc.) to achieve. Because the purpose of management is to achieve goals, these must be defined before appropriate management actions can be determined (Rue and Byars, 1992). Goals act as a major organizing framework for analysis, management recommendations, and accomplishment evaluation. Without goals it is impossible to determine what to do or to evaluate how well it has been done.

Whatever goals we are trying to achieve, there are at least four situations in which we need to measure how close we are to achieving those goals. First, we want to evaluate our initial situation to see how far we have to go to realize all of our goals. Second, we want to develop and evaluate alternative courses of action (i.e. decisions) expected to help us achieve our goals. Third, a course of action needs to be selected from the alternatives evaluated (typically one that is expected to achieve best the desired goals within constraints imposed on decision makers). Finally, after we have selected a course of action and begun to implement it, we want to monitor our progress toward the stated goals. A detailed discussion of goals and their importance in decision-support systems is included in Nute et al. (2000).

2.2. *Goals as the basis of forestry*

Forestry can be defined as the intervention in ecological processes to meet human needs or goals. Usually the landowner or a representative of a group of landowners articulates the purposes for owning and managing forest land. Forestry practice in general and silviculture in particular are based on the premise that any activity in the forest is intended to meet the goals of the landowner. Indeed, identification of the landowner's objectives is the first step taught to silviculturists in forestry schools (Smith, 1986). Decision-support software intended to help landowners or managers determine appropriate actions must focus on meeting the goals defined by the user or it will not be used.

Because forest managers and landowners are diverse people with diverse goals, any software that is expected to be generally applicable must incorporate design features that make it adaptable to the approach and the goals of many individuals. The NED software includes many features that allow custom design of input screens and reports. Users have an extensive choice among various goals and which ones they want to apply to which parts of their property. However, the system does not yet allow users to define new goals that have not been considered by the developers. This would require each user to determine what conditions must exist in the forest to evaluate whether a goal has been met, and as a result allow a user to redefine basic assumptions about fundamental ecological relationships. While some may desire this capability, the developers have not found a way to provide such freedom without subjecting the system to erroneous results.

3. Individual resource descriptions

3.1. Ecology

3.1.1. Background

NED's ecology goals are designed to promote sustainable resource management for the entire forest resource, not just from a timber perspective. NED incorporates protection of rare and unique genetic, species, habitat, and ecosystem elements, plus ecological issue awareness along with timber, water, visual, and wildlife goals. Ecology resource goals focus on biological diversity and native elements. Landowners may choose to enhance local or regional diversity; promote or maintain a variety of forest types; or protect 'at risk' forest communities such as riparian areas and wetland habitats. Other NED ecology goals allow for active restoration of native species, discouragement of exotics, and acquisition of information on local issues.

3.1.2. Description of goals

Representative ecological goals are to enhance regional biological diversity, gain information on local ecological issues, and protect wetland habitats. Directed to enhance regional biological diversity, NED searches a regional database to identify unique or rare species, habitats, or ecosystems in the region and identify management practices that enhance or establish those unique elements. To help the landowner protect wetlands, NED provides information to help identify whether a wetland is present as well as guidelines for managing wetlands to protect both site and water quality. NED also searches a database on ecological issues for this region to identify programs in which the owner might participate. Each of these goals also may require constraints on how the landowner chooses to manage a unit. For example, if the landowner is managing to enhance regional biological diversity, diversity may be reduced within the unit to provide conditions not found elsewhere in the landscape.

3.2. Timber

3.2.1. Background

Forest users and landowners vary greatly in their view of timber production. Land may be owned primarily as an investment, with the financial returns from timber production being the dominant management objective; or land may be owned for a variety of reasons, of which income from timber production is but one. Timber often is important for reasons other than the financial returns. For example, providing a stable supply of timber products to support local economies and meeting the public's wood product needs may be important on public lands. On private tracts where the landowner does not seek maximum financial returns, timber income still may be desired to cover the costs of managing or holding the land for other purposes.

3.2.2. Description of goals

Because of the variety of attitudes on timber production, timber management goals include a focus on cubic-foot volume, board-foot volume, periodic income, net present value, or allowing natural changes or changes in response to management activities. A representative timber goal within NED is the goal for board-foot production, which implies the following approach: in the absence of other management goals, this choice provides for the regeneration and management of species suitable for high-value products such as sawtimber and veneer. The appropriate silvicultural system, based on the forest types, should be applied using average rotations with thinnings and other intensive treatments to facilitate regeneration and growth as required for sustained production of particular species.

3.3. Visual qualities

3.3.1. Background

The scenic character of forests has long captured the attention of the American public, particularly during this century. Early battles between forestry professionals and national park advocates centered around the legitimacy of forest preservation for noncommodity purposes. By the middle of the 20th century, this struggle had extended to the visual impacts of forest management practices, particularly clearcutting. Anyone considering this tumultuous past might conclude that Americans generally have a strong aesthetic preference for unmanaged forests. However, studies have shown that forest management can either improve natural forest aesthetics or damage it (Hoffman and Palmer, 1996; Hoffman et al., 1996).

3.3.2. Description of goals

The DFC approach adopted by NED provides the user maximum flexibility in describing the visual character of the forest. However, this character is identified through a series of questions that research has shown to represent the silviculturally related themes to which viewers are sensitive. The following are examples of visual goals and how they relate to DFCs:

3.3.2.1. Big trees. For many people, an idealized forest image is dominated by large, stately trees. However, others may be more interested in the patterns and colors characterized by younger trees. NED gives users the opportunity to identify the importance of large trees in their visual preferences.

3.3.2.2. Canopy pattern. One of the forest characteristics about which people's preferences seem to be most varied is the amount of openness or closure in the forest canopy. Some people prefer a dense, closed canopy that gives the impression of a large dim room, others like a more open canopy that allows more light to reach the forest floor, and still others want an opening with no overhead canopy. Similarly, some people desire a single canopy condition to extend throughout a management unit, while others prefer a mix of these effects within the same management unit.

3.4. Water

3.4.1. Background

Forests play an important role in the quantity and quality of surface streams and ground water. The Clean Water Act requires that forest management activities comply with regulations developed at state levels to protect the quality of forest streams. Beyond this mandated protection of water quality, some landowners may have more specific objectives for water resources. For example, managers of municipal watersheds may want to increase low flow volumes by reducing vegetative cover, or forest managers in flood-prone areas may want to minimize changes in peak flows. Others may want to give special consideration to managing wetlands and streamside (riparian) zones or enhancing fish habitat. NED provides several water-quantity and water-quality objectives to address these and other water goals.

3.4.2. Description of goals

Water-quality goals range from simply compliance with requirements for non-point-source pollution control to intensive protection of water resources. The former implies no actions beyond legally mandated activities; whereas the latter implies that added precautions in the form of more rigorous applications of 'Best Management Practices' will be recommended. Examples are applying gravel to all roads open to the public, locating roads and skid trails farther from live streams than might normally be recommended, and mulching and seeding exposed soil at stream crossings as soon as crossing structures are installed and immediately upon their removal.

Water-quantity goals include no specific quantity preferences, increasing water yield, maintaining a minimum flow, or limiting peak flows. In the absence of conflicting management goals, increased yield will imply that a silvicultural system will be chosen to reduce evapotranspiration. For example, species such as softwoods or heavy stocking levels can reduce water yield, particularly during periods of low flow. Thus, if the water-quantity goal is to maintain or increase flow during low flow periods, NED-1 will identify whether there is a risk of flows falling below normal levels under existing conditions.

3.5. Wildlife

3.5.1. Background

Most forest users and landowners enjoy seeing wildlife in their visits to the woods, and some pursue hobbies involving observation of wildlife (such as bird watching). Some are interested in hunting and want to see populations of their favorite game species maintained at levels that optimize their hunting enjoyment. Most people also believe that preserving habitat for a variety of wildlife species is an important goal to be sought in all forested areas, especially public forests.

3.5.2. Description of goals

Wildlife goals in NED are habitat oriented and do not attempt to address population density directly. The user can specify a goal of enhancing the diversity (species richness) of wildlife on a forest property, or select one or more species for which to enhance, maintain, or create habitat. For example, one landowner may wish to increase the abundance of ruffed grouse for hunting. Another may wish to increase the variety of songbirds or amphibians by providing a variety of habitats required by different species.

3.6. Forest health

Forest health is a concept that implies maintenance of forests in a condition that is capable of sustaining human needs. Damage from forest pests usually is considered detrimental to forest health. Yet, pest management practices in forestry too often are an afterthought, resulting in an emphasis on control rather than thoughtful long-term management. Silvicultural prescriptions often are ideal for implementing preventive methods by rendering trees and stands less susceptible to outbreaks and/or less vulnerable to damage. Silvicultural approaches have been identified for several major forest pests, and experience suggests that cultural techniques can be designed to offer potential remedies for lesser-known problems. NED provides information on stress agents that affect the health of the trees within a forest. These agents may include insects, fungi, weather, or people. The program analyzes data on composition of a particular forest and identifies various potential causes of damage, methods to recognize the particular agents, and actions that can be taken to avoid or mitigate damage (Steinman, 1996). Rather than identifying 'pest management' as a goal, maintaining a healthy forest is the goal, and pest management activities are a means to create or maintain the necessary conditions.

4. Input requirements

NED's data requirements are extensive, largely due to the comprehensive and flexible design of the program. Although some of NED's features can operate with little more than tallies of species and diameter, many more cannot. The need to evaluate forests for visual qualities and wildlife habitat provides the largest demand for data collection beyond the traditional, timber-oriented, forestry stand exams. The key elements in the need for additional data are understory conditions, which are critical to both wildlife habitat and visual characteristics. Inventory procedures are adapted from techniques described in Harvey (1994) and Harvey and Finley (1995). Although estimates may be made of size and density of understory plants or down woody material based on an overstory estimate, the mixed forests of the eastern United States are notoriously variable, and there are no reliable models predicting such variables.

The complete input data needs for NED-1 include variables at the management unit, stand within management unit, and plot within stand levels (Fig. 3). Plot-level tallies are required for midstory and overstory trees (greater than 10 feet tall), the shrub layer (woody vegetation 3–10 feet tall), and ground-level vegetation (less than 3 feet). In addition, several variables important to wildlife and visual qualities are collected between plots, such as down woody material and subterranean habitat.

Many variables can be entered by a user at a summary level, thus avoiding the need for a new, detailed inventory, but such practices will reduce reliability. Similarly, if a manager has many similar forest stands and chooses to inventory one and tell the computer that others are just like that one, an analysis can be developed, but its reliability will be only as good as the data.

5. Output capabilities

5.1. General narrative reports

NED-1 provides a standard template for generating a narrative description of each stand or the entire management unit. General reports do not require specified

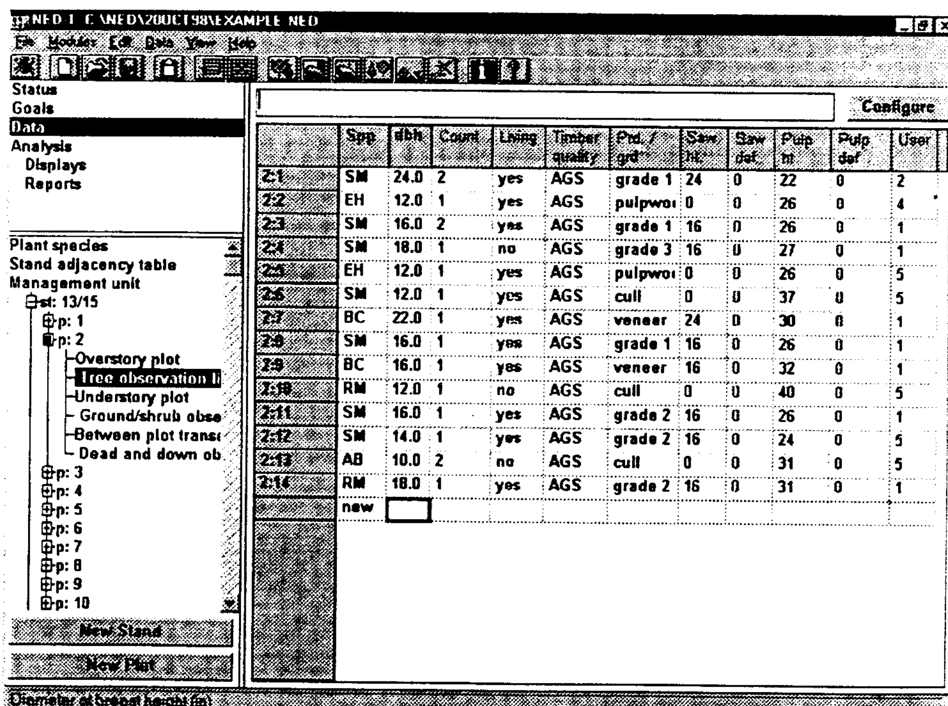

Fig. 3. A typical data entry screen showing the tree observation table for one plot within a stand on the management unit. Note the configure button (upper right), which allows a user to customize the display of variables to be entered.

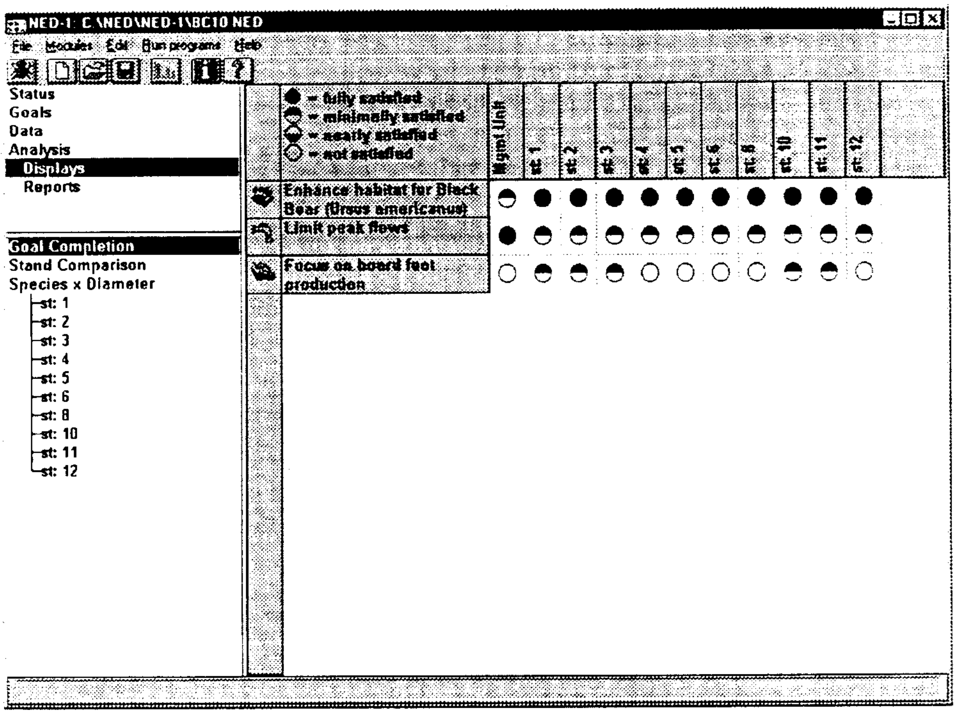

Fig. 4. A NED-1 Goal Completion Display showing a summary evaluation of all stands in a management unit and their contributions to meeting the goals identified by the user.

goals for any resources but are organized around the various resources. A user can request general narrative reports to be displayed on the screen or printed for one resource on one stand, all resources on the entire management unit, or any combination. Each report uses summarized data from the inventory to determine which parts of a potential report are appropriate; the program customizes the output to match the data and the request.

5.2. Goal-oriented narrative reports

Goal-oriented narrative reports provide an evaluation of the management unit or stand based on individual goals identified by the user. The knowledge base within the program correlates the desired conditions implied by the user's selected goals with actual conditions as determined by summarizing input data. Each report then identifies whether particular desired conditions are met and whether the overall goal is satisfied by the current state of the management unit. In addition, several analytical outputs are available in graphical form and are identified as 'displays' rather than 'reports' (Fig. 4). Behind the displays are additional narratives that explain the source of the information.

5.3. *Inventory summary reports*

NED-1 generates summary tables to the screen or a printer in a highly customizable procedure. A user may select one or many specific reports in tabular or graphical form summarized over one stand or an entire management unit. An extensive set of variables can be displayed in the summary tables, usually in a species × diameter format. The diameter-class groupings are fully customizable.

5.4. *Potential species evaluations*

Wildlife habitat conditions can be evaluated in either of two directions. The user can specify a species of interest and determine which of its required or desired conditions are met (and thus the likelihood of its presence), or request an evaluation of existing conditions within the management unit and receive a report describing which of the many possible wildlife species have their habitat requirements met within the area.

6. Technical summary

6.1. *Main program*

The main program of NED-1, which consists of the user interface and data management modules, is written in C++ utilizing the application framework C++/Views (now marketed by Intersolv, Inc. as Allegris Workshop) (Fig. 5). NED-1 runs on the Windows platforms. Three major functions are available to the

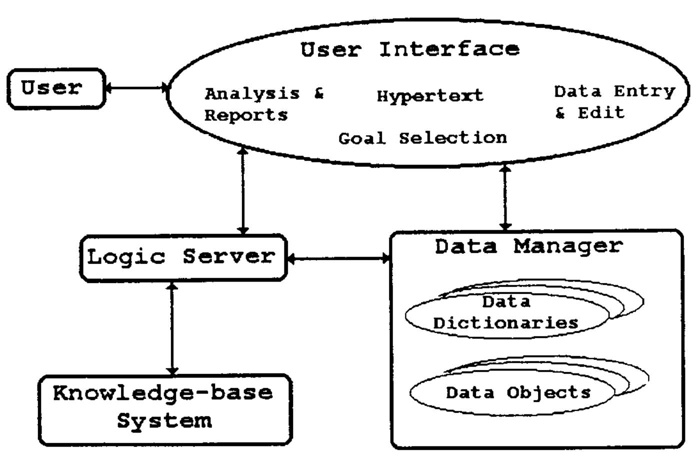

Fig. 5. The major software modules of NED-1. The User Interface and Data Manager are written in C++; the knowledge-based system is written in PROLOG; the Logic Server is written in both C++ and PROLOG.

NED-1 user: goal selection, data entry/edit, and analysis/report generation. Two additional functions, prediction and prescription, will be available in future versions of the program. A hypertext-based help system is included with the program.

A number of the features in NED-1 were designed to increase flexibility and portability. While the current version of NED-1 focuses on the northeastern region of the United States, there is interest in adapting the resulting programs for the southern region and perhaps for other regions. Thus, it was deemed important to design the major elements of the system as replaceable components, and wherever possible, to place elements that are specific to a certain region outside the main body of code so that they can be replaced with equivalent elements specific to another region. A major element in making components replaceable is the choice of an object-oriented programming language, and an attempt to use a clean, object-oriented design for the entire system (Kollasch and Twery, 1995). Although this design was not followed exactly, its influence on the program is clear. Other factors are: (1) placing the rule bases outside the program, (2) using databases and code-generation techniques to ensure concordance between widely disparate parts of the program that must match, and (3) using a report specification language to specify the content and format of NED-1's reports, so that this element also is largely outside the program.

6.1.1. Data manager

The data manager (Fig. 5) functions as a central data repository, receiving data from the input components of goal selection and data entry and serving data to the analysis and report-generation modules. The knowledge-based system module of NED-1 also relies on the data manager as a source of facts and as a potential storage place for inferred results.

A data dictionary approach was used in implementing the data manager. The data dictionary is a form of static metadata that describes each variable in the database and explains how to use it. For instance, a typical dictionary entry holds the name and data type of data, the header to be displayed if the variable is in a column or a row, the format to be used on input and on output of that item, and the context number that will display the associated help screen from the hypertext system. Many data dictionaries are defined in NED-1, each closely associated with the data hierarchies used. For example, there is a data dictionary for management unit variables, one for stand variables, one for plot variables, etc. Each data dictionary is used to create one or several **DataObjects** (Fig. 5). For example, there is one data dictionary for 'Plant species', but there also is a large list of 'Plant species' **DataObjects**, one for each plant species recognized by NED-1. **DataObjects** contain a list of **DataItems**, one for each dictionary entry in the data dictionary. **DataItems** contain the value of the variables as well as a flag indicating the source of the value. Note that the program object names in bold represent C++ class names.

The source field, an item of dynamic data, is attached to every data item in the database. This field stores information from which the program can determine whether the element was entered by the user, computed from other elements in the database, or is a default value. With this information, the program attempts to fill in certain data that the user has not provided. NED-1 is designed to require only a minimum set of absolutely essential variables, and to estimate any necessary variables not entered by the user. Data originally entered by the user are treated as 'more valuable' than data from other sources; in most circumstances, data of higher value cannot be overwritten by data of lower value. Everything the programmer needs to know to use or display a variable is provided in the dictionary and every variable in the program is associated with an entry in a data dictionary. This enables the programmer to automatically generate tables and reports based only on the information in the dictionary. This can save considerable programming effort, because reports and tables can be programmed generically. If a different variable is substituted, the format can be adjusted automatically to display that variable properly.

The data manager is implemented in C++ through the members of the class **MgmtUnitModel** and manages all of the **DataDictionary** and **DataObjects** classes. Any data element in the Ned-1 database can be accessed using one or more of the members *getDisplayString*, *getDataSource*, and *getDataValue*. Because all of these members have the same seven arguments, the programmer can access and traverse the hierarchical data structure to retrieve any piece of data. Because one cannot assume that data are present in every data element, the retrieval procedure typically involves two steps: determining whether data are present, then retrieving the actual value. This may be considered clumsy for the programmer.

Although the data dictionary design allows easy definition of variables through a dictionary entry, the actual retrieval of data is difficult; that is, data manipulation routines are clumsy, and difficult to follow. This trade-off has been accepted by the programming team because variable definition for NED-1 has been a very dynamic process. The NED resource teams are still defining variables that will properly address their needs. When easy variable definition becomes a lower priority, it may be advantageous to redesign the data structure to accommodate simpler, faster data retrieval routines. In anticipation of this, the programming team has encapsulated the data structure within **MgmtUnitModel**. The calls to the public routines will remain the same even if the underlying data structure is modified.

6.1.2. User interface

It is through the user interface that the user accesses the functional elements available in NED-1 (Fig. 5). The current generation of point-and-click graphical user interfaces has achieved a maturity previously unavailable, and an attempt is being made in NED-1 to take advantage of this technology to create a user-friendly environment. With today's tools it is relatively easy to create a sophisticated interface, but it is a challenge to create one that is intuitive to the user. Yet this intuitive character is so important in producing a user-friendly interface that a program can succeed or fail on this element alone.

The major functions in NED-1 are goal selection, data entry, and analysis, which includes the generation and printing of tabular and narrative reports. The hypertext, an additional ancillary function, provides information on using the program and on general forest management issues.

The goal-selection function allows the user to select any combination of 21 management unit level, 18 stand level, and more than 220 wildlife species goals (see previous section on goal selection and development by the NED-1 resource teams). The interface for selecting goals consists of a series of dialog boxes (one for each resource area) and a common Goal List display where the selected goals can be viewed. Selecting goals in NED-1 activates the option to produce a goal-analysis report, which compares the DFCs for the selected goal set with the current stand condition, as defined by the stand data, to determine whether the stand reflects those desired conditions. The user can select a report for either a Stand Goal Analysis or a Management Unit Goal Analysis.

To support efficient evolution of the NED-1 software code, most of the data entry and display screens are generic in nature. These displays are of two types: Data Lists and Data Tables. Data Lists are vertically oriented lists of variables and their values. Data Tables are two-dimensional where the variables are listed as columns and the rows contain individual items (stands, trees, etc.). The cells for the Data Table display the value of the variable for a specific item. A top-level display class was developed to work with the **MgmtUnitModel** class to display and manipulate the data. Subclasses need only define what variables are to be displayed and the top-level display class can display the data, interpret special key strokes, error check user input, and make the necessary calls to **MgmtUnitModel** to store the data.

6.1.3. Report generation

After summarizing the current conditions of the management unit or comparing the current conditions to some DFCs, NED-1 produces a variety of reports. There are several general tabular report formats for which the user must choose the variable that appears in the tables, which potentially produce a diverse set of reports. In addition, there are a series of general narrative reports, one for each of the NED resources of Ecology, Timber, Water, Visual Quality, and Wildlife. NED-1 offers both management unit and stand reports. A dialog box allows the user to select which reports to generate for which stands. A Report List view holds the selected list and allows the user to view them individually or to print one or all of the selected reports.

The most significant reports from the implementation technology point of view are the Stand Goal and Management Unit Goal Analyses. These two reports are the only context in NED-1 where the knowledge-based system capabilities described in the next section are utilized. Future versions also will use knowledge-based systems to generate prescriptions.

All NED-1 reports are produced from specifications stored in a data file external to NED-1. These specifications are written in a programming language — the NED Report Language. This language is similar to a subset of the C programming language but is designed for describing reports. An interpreter for this language is the central element in the report-generation process. This interpreter uses a recursive descent syntax checker with a single token look-ahead. The language is defined by a series of productions, or grammar rules, in which all productions are

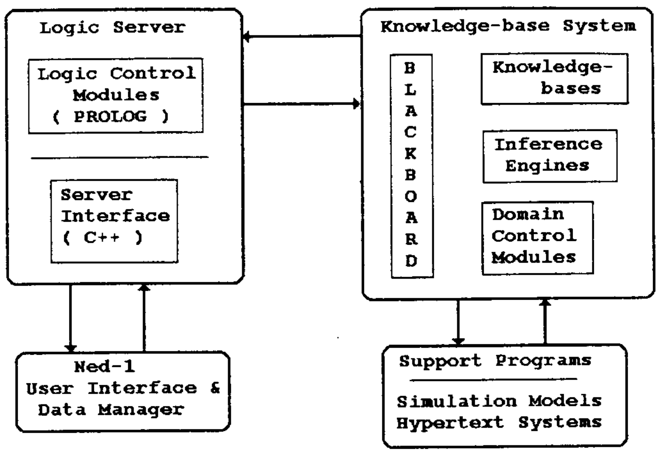

Fig. 6. A top-level diagram of the Logic Server and the knowledge-based system in NED-1 and their communication links with each other and with the NED-1 user interface and data manager.

right-recursive to simplify processing. The language supports a simple computational ability and calls on a library of built-in routines that generate commonly used pieces from which more complex reports can be built.

6.1.4. Hypertext help

User help within NED-1 is supplied by an extensive hypertext-based help facility. The hypertext contains information on: (1) how to use the NED-1 software; (2) what is desired in each field of an input screen; (3) in-depth descriptions of each resource category and their associated goals and DFCs; (4) how to conduct the NED-1 inventory process; and (5) how to interpret the output reports. Further, the metadata contained in the dictionaries for each variable are accessible through the hypertext help system. A section on 'background issues' that is still under development will describe issues such as forest-type definitions and the silvicultural systems used to develop prescriptions for specific goal and resource conditions.

6.2. Knowledge-based system

A decision support system toolkit (DSSTOOLS) written in PROLOG was developed to aid in the management of the knowledge-based modules for NED-1 (Nute et al., 1995; Zhu, 1996) (Fig. 6). The DFCs, developed by large teams of experts based on their intuition, experience, and judgment, represent guidelines or logical rules-of-thumb (Klein and Methlie, 1990), which DSSTOOLS has been built to manage efficiently. DSSTOOLS is a library of reusable PROLOG predicates that extends the PROLOG language by defining new procedures to allow developers to build knowledge-based systems (KBS) quickly and easily. DSSTOOLS is an efficient environment for developing, testing, maintaining, and using groups of such rules collected into knowledge-bases.

Using specific guidelines described by Zhu (1996), the developer can create knowledge bases containing the domain-specific rules and domain control modules which assume control over program execution when they detect appropriate conditions on the blackboard (Fig. 6). DSSTOOLS provides: (1) a blackboard architecture for cross module communication and the routines to maintain it (Englemore and Morgan, 1986); (2) a set of user interface tools that include extensive explanation facilities; and (3) a suite of inference engines that use the knowledge bases to process the knowledge. With DSSTOOLS, the KBS can execute external simulation models, access a hypertext system to provide in-depth explanations, write the logic of the inferencing process to a trace file that the user can later examine, and query the user for instructions or data. Finally, for NED-1, DSSTOOLS has been extended so that the modules can exchange data and instructions with the Logic Server, which acts as the bridge between the C++ side of NED-1 and the PROLOG side of NED-1 (detailed discussion in next section). Detailed presentations of each rule component are beyond the scope of this paper. Interested readers will find a full explanation in Zhu (1996). In addition, DSSTOOLS is in the public domain and the latest copy of the modules can be downloaded free of charge by following the instructions in Rauscher et al. (1996).

The C++ side of NED-1 communicates with the PROLOG side of NED-1 through a software module called a Logic Server (Fig. 6) (Chen, 1996). The client/server model is a paradigm for the interaction between concurrently executing software processes. The client module, in our case the Main Program of NED-1, is proactive and issues requests to the server module, in our case the Logic Server of NED-1. Further explanation of the process can be found in Chen (1996).

7. Outlook for future development

7.1. Integrated prescription development

NED-1 includes analysis of existing conditions both in general and in the context of specified goals. The development of rule bases to identify whether existing conditions meet the requirements of specific goals is nearing completion. Future versions of NED will recommend prescriptions for management activities using the knowledge bases developed from the original resource experts who constructed the goal definitions. The collaborative process the NED development team is using will be crucial in this context, because of the integrated nature of the actions: anything that affects conditions for one resource has the potential to affect all the others.

7.2. Simulation and growth projection

Projection of conditions into the future under various alternative management options is a key element in making future versions of NED useful as planning tools. The initial effort in the NED development process produced NED/SIPS, a stand-level, timber inventory processor and growth simulator (Simpson et al., 1995). That software included a single, DOS-based interface from which a user could run a data set through any of four growth simulators developed by the Forest Service: SILVAH (Marquis and Ernst, 1992), NE-TWIGS (Teck, 1990), FIBER (Solomon et al., 1987), and OAKSIM (Hilt, 1985). Those growth models will be included in future versions of NED, but they will not be sufficient. Their limitations include inadequate handling of small trees and other woody vegetation, which is essential to the modeling of visual conditions and wildlife habitat. The existing simulators also handle poorly, or not at all, any regeneration of trees after removal of existing individuals, so it is necessary to develop a regeneration model that will be able to handle the full extent of possible disturbances to the forest. Work has begun on developing a model management system integrated with NED software to enable inclusion of additional simulation models such as the Forest Vegetation Simulator (FVS) described by Teck et al. (1996). FVS includes several variants of the TWIGS growth model, including NE-TWIGS for the Northeast and SE-TWIGS, calibrated for the southeastern states.

Additional links with other simulation or display models will be made through an interoperability structure being developed using DCOM software (Potter et al., 2000). This structure is designed to facilitate the communication between independently developed programs so that NED may provide the user interface and make use of the analysis and display capabilities of other work, including FVS, FIBER, and the Stand Visualization System (McGaughey, 1998).

7.3. Recreation

NED's approach to recreation management seeks to create environmental conditions that support opportunities for specific experiences. The types of environments that provide optimum opportunities will be somewhat different for tent campers, deer hunters, and mountain bikers. However, little empirical recreation research directly links manageable characteristics of forest sites to recreation opportunities. This is particularly true if one considers that no single forest condition is likely to satisfy all the desired experiences for someone during a recreation outing. Future versions of NED will include the capability to analyze forest landscape patterns in space and time. This capability could be used when modeling recreation DFCs and the effects of management alternatives. For instance, as mountain biking increases in an area, where might displaced hikers go to seek solitude. Another example might be to design a plan to rotate designated back country camping sites every few years to manage long-term environmental impacts. NED might be used to model several alternatives.

7.4. Landscape components

The landscape context is a crucial element in making appropriate land management decisions. For many of the values supplied by forests, the traditional focus of forestry on an individual stand is not valid. Management for wildlife species with large home ranges, for water quality and quantity on full watersheds, and for visual qualities of forests must incorporate information from a broad area with its spatial context intact. Additional information about the multistand context of individual stands can be useful for choosing goals, describing DFCs, and developing prescriptions. NED-1 features the ability to tabulate proportions of various vegetative conditions across the management area, including forest types, age class distribution, size class distribution, and canopy closure classes of the ground layer, shrub layer and canopy layer. These multistand summaries describe the characteristics of the landscape relevant to each resource as part of the resource-specific reports.

The landscape component of NED is envisioned to provide the user with information about landscape characteristics at several scales. The regional and landscape context of the planning unit will be provided by reference to the ecological units of the East, and by directed queries of the Eastwide FIA (USDA Forest Service, Forest Inventory and Analysis Group) database. This information describes the broad-scale setting in which the management unit is located, and may suggest opportunities or constraints on the selection of management goals. For example, if a forest type is poorly represented in the region, it may be desirable to attempt to manage for that species.

Spatial analysis capabilities will be supported by links to geographic information systems (GIS) and other external software. Users without access to spatial analysis software will have limited spatial analysis capability. This capability will depend on the user's identification of the neighbors for each stand in the management unit during data entry. Identification of adjacency will allow calculation of some patch area and adjacency metrics, but will not allow more sophisticated measures such as the amount of core (interior) habitat or proximity measures.

7.5. Social components

Forest management is by definition and by deed a process of social intervention in ecological processes to achieve social goals. Thus, all forestry consists of social and biophysical dimensions. Successful forest management requires in many cases an integrated approach because of the dynamic and reciprocal relationships between social and biophysical structures and functions. This is particularly true in the description of existing, anticipated, and desired conditions (both biophysical and social) and potential cause and effect relationships between management actions and their ability to achieve multiple goals. Particularly important to forest management actions are social constraints — what is economically gainful and socially acceptable — that are expressed through various social institutions and values, such as laws, markets, and political power. Examples of traditional forest management activities and goals that are increasingly sensitive to social context include the use of herbicides, prescribed burning, clearcutting, forest productivity, health and sustainability, recreation, and aesthetics.

NED currently focuses on biophysical data for analysis of existing conditions and silvicultural treatments for management alternatives. We are working to incorporate social science research into NED so that it will include social goals such as community stability; inventory and analysis of existing social conditions; and potential non-silvicultural management strategies. While the development of goals, inventories, and analytic capabilities are important, the incorporation of non-silvicultural management strategies is noteworthy, since many forest management goals may be achieved more effectively through interventions in social systems (tax incentives and subsidies, best management practices, regulations, zoning and limits to access) than in biophysical systems.

The need for such an approach will continue to grow as human populations increase, forest management occurs within a more diverse and fragmented mosaic of land uses and ownerships, and power relations among constituencies for various goals change. For instance, the eastern United States contains a growing mix of urban, suburban, and rural land uses. Nearly 90% of the region is in private ownership, extensive forest cover, and there are increasingly powerful constituencies for forest goods, benefits, and services that have been secondary priorities of traditional forest management. To serve the needs of the people within the context of what is ecologically possible, economically gainful, and socially acceptable, it is important that policy makers and managers have good information from analytic and prescriptive tools such as NED that are both socially and ecologically based.

7.6. *Interoperability*

A key to effective decision support for ecosystem management is interoperability of software systems. Interoperability is the ability of two or more software components to cooperate by exchanging services and data with one another, despite possible heterogeneity in their language, interface, and hardware platform (Wegner, 1996). Interoperable systems provide a software standard that promotes communication between components and provides for the integration of legacy and newly developed software modules. Currently available forest ecosystem management decision support software are independently developed, monolithic systems without open, general purpose communication and control standards that provide interoperability (Potter et al., 2000). These systems use ad hoc, point-to-point integration solutions that are difficult to understand and essentially impossible to expand into a central communication and control architecture. By contrast, interoperability outside the forestry domain has received extensive attention. In particular, the distributed component object model (DCOM) is a mature standard that provides a communication and control backbone for a general-purpose interoperability architecture (Microsoft, 1997). The NED development team is using DCOM to create and test a generic interoperability standard for a forest ecosystem management DSS. This proposed design features language independence, software module extensibility, standardization of user interface management, distributed processing capability, and standardization of methods to deal with legacy software modules (Potter et al., 2000).

8. Discussion

NED attempts to provide a comprehensive set of decision-support tools for forest management for multiple values and purposes. By doing so, we hope to improve the quality of information available to and understood by those who must make forest management decisions. We are not attempting to provide tools for regional or national policy makers, but rather are focusing on a more local context — deciding how best to manage a particular tract of forest. The comprehensiveness is achieved in part through the development and distribution of a variety of different tools, each of which has a specific range of applicability. The goals incorporated into the system's several incarnations provide information that can be used as part of a comprehensive analysis of a management area and may improve the likelihood that a land manager's decisions and subsequent actions will produce the desired results.

NED programs are not designed to provide definitive answers but to shed light on complex problems and encourage the user's own capabilities and judgment. We hope that the NED programs will enable managers to understand the consequences of their planned actions better and to use that information to improve actual conditions. It also should enable improved communication among managers and their clients or constituents about the values that may be traded away to meet higher priority needs.

NED-1 represents the basic programmatic and conceptual platform upon which future versions of NED will be crafted. These would include expanded capabilities such as: (1) projecting current conditions into the future with or without simulated management actions; (2) helping users develop prescription alternatives to move the current conditions closer to desired future conditions; and (3) linking NED to a commercially available, fully tested GIS. Future versions of NED are also planned that will expand the geographic range of application of NED from the northeastern United States to the southern Appalachian Mountains.

The software implementation has been rigorously designed so that it is easy to add or delete variables, modify goals and DFCs, modify input screens for data entry and analysis, modify and add knowledge bases, and modify output reports. This has been accomplished using a data-dictionary approach as the data management backbone of NED-1; by creating generic data-display tables and forms; by creating a generic report-writing language; and by creating a knowledge-based system development toolkit.

Reviews of ecosystem management DSSs show that the current generation of systems vary greatly in the scale at which they operate, the decision analytic procedures they implement, the computer platforms upon which they operate, the way they define the ecosystem management process, etc. While most issues of importance to ecosystem management seem to be addressed with some degree of success by different systems, no single system currently addresses all these issues with even average success (Mowrer, 1997). The current state of the art and science of developing ecosystem management DSSs is this: both the ecosystem management process and the decision support systems being developed to support it are in a state of flux and are not expected to stabilize for some time. In a very real sense, the ecosystem management process and the systems needed to support it are evolving simultaneously, each helping to refine the other in a turbulent, chaotic manner characteristic of juvenile growth and development. The shape and character of the mature ecosystem management DSS we will eventually witness cannot be specified at this time. Thus it is imperative that NED-1 be easily modified in all its functionality so that it can evolve into the mature ecosystem management DSS of the future.

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