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NED-2: A decision support system for integrated forest ecosystem management☆

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Abstract

NED-2 is a Windows-based system designed to improve project-level planning and decision making by providing useful and scientifically sound information to natural resource managers. Resources currently addressed include visual quality, ecology, forest health, timber, water, and wildlife. NED-2 expands on previous versions of NED applications by integrating treatment prescriptions, growth simulation, and alternative comparisons with evaluations of multiple resources across a management unit. The NED-2 system is adaptable for small private holdings, large public properties, or cooperative management across multiple ownerships. NED-2 implements a goal-driven decision process that ensures that all relevant goals are considered; the character and current condition of forestland are known; alternatives to manage the land are designed and tested; the future forest under each alternative is simulated; and the alternative selected achieves the owner's goals. NED-2 is designed to link with

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the NedLite package for field data collection using a handheld PDA, and is constructed to be easy to link to third-party applications. The NED process is being field tested to demonstrate its utility and identify weaknesses. Results of case studies are summarized for two owners, a private individual and the City of Baltimore, Maryland, and its reservoir lands.
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1. Introduction

As natural resource management matures and evolves from a compartmentalized approach to multiple-use management into a more sophisticated approach wherein the interaction among complex ecological and social components must be known and considered, the need for more powerful decision support system (DSS) tools is clear (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.

Decision support systems that are available for forest management in North America are not numerous but do vary greatly in scope and approach. Rauscher (1999) provides an excellent review of the variety available. Mowrer (1997) provides a catalog of systems available, including both full DSSs and other tools that assist in the process of analyzing information for ecosystem management. Some of the more comprehensive DSSs currently available include LMS (McCarter et al., 1998; see also http://research.yale.edu/gisf/lms/lms_tools.html), a comprehensive system incorporating inventory, analysis, and visualization tools; EMDS (Reynolds, 1999; see also http://www.fsl.orst.edu/emds/index.htm), a flexible framework for using knowledge bases to develop ecological assessments at any geographic scale; and the spruce budworm DSS (MacLean et al., 2001), a system designed to focus on forest protection as part of the ecosystem management process.

The NED DSS for ecosystem management is a collection of applications intended to help resource managers develop goals, assess current and future conditions, and produce management plans for sustainable forestry in the eastern United States. NED originally stood for NorthEast Decision model, but since expanding to the South and Midwest, the regional reference has been dropped, and NED is no longer treated as an acronym. The effort is being led by the USDA Forest Service's Northeastern Research Station in cooperation with the Southern Research Station, the University of Georgia, and many other collaborators. 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 objective of this paper is to describe current development efforts on NED-2 and elucidate the unique qualities and benefits of the NED approach to decision support.

The intended users of NED include all who are interested in management of forest land, 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 (Mowrer, 1997), packages that use linear programming techniques. The NED system facilitates translation of general goals into specific and compatible goals and helps a user analyze the tradeoffs among them, allowing the user to develop specific management plans for units of land with these goals. NED-2 does not generate specific recommendations, leaving that decision to the decision makers; it does provide a wealth of information in a variety of output formats so that users may generate and analyze their own alternatives.

Because silviculture often heads the list of tools used by resource managers to achieve their goals, the NED system focuses its analysis at a level that can be implemented through silviculture. 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 also are 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. This information is provided either through the hypertext help files supporting the application or through allowing a forester to experiment with alternative strategies and analyze each option in the light of specific goals. 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 system will be beneficial even to professional natural resource managers.

The development of the NED suite 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 package 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 application 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. Further detail on the development process in earlier years of the NED project can be found in Twery et al. (2000).

The development of a comprehensive system requires considerable time and resources. NED's developers have chosen to release independent packages that implement the NED concept in stages. The initial freestanding applications 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 user base, generated considerable comment, and influenced the design of additional work. Three years of informal distribution of NED-1 (Twery et al., 2000) have provided a strong basis for design and development of NED-2. Concurrent case studies have provided opportunities for in-depth analyses of the interface and the function of the various parts of the system.

2. Goal-focused orientation

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 are defined, there are at least four steps that involve measuring how close achievement of those goals may be. First, evaluate the initial situation to see how different current conditions may be from those needed to realize all goals. Second, develop and evaluate alternative courses of action (i.e., decisions) expected to achieve our goals. Third, select actions from the alternatives evaluated. (Typically, that is the action alternative that is expected to achieve best the desired goals within constraints imposed on decision makers.) Finally, monitor progress toward the stated goals. A detailed discussion of goals and their importance in decision-support systems is presented in Nute et al. (2000).

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). It is reasonable to assume that if a tool does not address the needs of its potential users, it will go unused. Therefore, decision-support systems intended to help landowners or managers determine appropriate actions must focus on meeting the goals defined by the user.

Because forest managers and landowners are diverse people with diverse goals, any system 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 system includes many features that allow custom design of input screens and reports. Users have extensive choices 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.

We present two case studies using NED-1, the previous generation of the system, to illustrate the features that users find helpful and to identify the shortcomings that NED-2 attempts to correct. The features of NED-2 that are necessary to address the needs of users to meet their goals are presented in subsequent sections of this paper: the user interface, the data management system, the plan design module, the goal specification module, the reports module, and links to GIS programs. The paper concludes with discussion of planned enhancements, including more interoperability features, expert prescription development, and visualization capabilities, important additions that we have had to postpone while seeking further resources.

3. Case study implementations

Comprehensive decision support systems are a new development in nonfederal forest management practice in the United States. Few systems have achieved maturity and even fewer have been thoroughly field tested. The NED development team has used an active field-testing component for several years. Through this testing using NED-1, we have been able to focus development efforts for NED-2 in the most beneficial directions. Two field tests are described in the following subsections.

3.1. McKnight property

The 34-ha McKnight property was taken on as a NED case study to examine how small a property makes sense for the NED decision process. This property was purchased by Mrs. Martha McKnight to establish a financially lucrative longleaf pine plantation system. A secondary objective of developing a future housing site around a 1-ha existing pond added a realistic real-estate dimension to this study.

After developing a goal hierarchy, we conducted a NED inventory of the property. The inventory showed that 28 of the 34 ha were in longleaf pine plantation, five in bottomland hardwoods, and the remainder in non-forest condition. With a heavy emphasis on financial performance, effort was focused on performing a variety of benefit-cost analyses using net present value, equivalent annual value, and internal rate of return as the metrics. Longleaf plantations on the McKnight property were established on old-field, former agricultural land, or cutover forest land. Old-field longleaf pine plantations offer very attractive rates of return because of the use of three profit-making enterprises on the same land: (1) collecting government subsidies for approved land use, (2) selling pine straw for mulch, and (3) selling timber (Table 1).

Because the landowner had already established new longleaf pine plantations on 82% of the property and had well defined goals for developing the pond area as a real estate site, we decided that examining multiple scenarios made little sense in this case. The true value of the NED decision process was to organize all known information in an orderly way and prepare detailed financial investment appraisals and a checklist of scheduled management

Table 1
Investment appraisal for longleaf pine plantations

Value estimator	Old-field longleaf	Cutover longleaf
Net present value per ha ($)	2614	1285
Equivalent annual value per ha ($)	104	51
Internal rate of return (%)	80	13.5

Net present value: calculated as cash-flows and expenses discounted to year one. Equivalent annual value: net present value expressed as an annuity over the planning horizon, used to compare investments over unequal time periods. Internal rate of return: the interest rate at which discounted revenues just equal discounted costs.

activities to guide the client in future years. We also know that financial assumptions are notoriously changeable. The NED structure will allow the client to update the investment appraisal at the stand and enterprise level as frequently as is warranted.

3.2. Baltimore city reservoir lands

The City of Baltimore reservoir properties consist of 7118 forested hectares surrounding three primary reservoirs that supply water to 1.8 million people in the metropolitan area. From 2000 to 2002, the Maryland Department of Natural Resources-Forest Service, with the assistance of the USDA Forest Service, developed a comprehensive forest management system for these lands. Explicit programmatic goals and priorities are to: (1) protect and enhance water quality; (2) maintain and restore regional biological diversity; (3) maximize forest habitat value; and (4) provide recreational opportunities. Following a review of the literature and an extensive inventory of all vegetation and physical features, we used a combination of computer-based tools, including ArcView GIS and NED-1, to analyze risks to the long-term sustainability of the ecosystems and to develop and evaluate alternative scenarios for management of the lands.

NED-1 was chosen as the tool to gather, organize, and analyze forest inventory data. Once summarized, NED-1 provided a means to evaluate alternative options and outcomes of forest management prescriptions. In combination with ArcView data layers that included soils, drainage, slope, and external properties, NED allowed examination of a variety of silvicultural alternatives. The detailed, stand-level data in NED-1 provided an easily accessible form of the information necessary to design and evaluate projects at scales appropriate for implementation. Although NED-1 could not perform simulations directly, it was used to analyze conditions generated in a variety of ways, such as other simulators or manual alteration of stand characteristics, as projected by the forest manager. Each alternative prescription designed by the Maryland DNR could be evaluated by examining conditions in similar stands and evaluating the variety of habitat availability and water quality protection, as examples.

Important expected outcomes of adoption of the system, recommended by the Maryland DNR Forest Service as a result of the use of NED-1 in conjunction with other tools, include the development of a three-aged forest; increased structural diversity within forest and aquatic systems; deliberately patterned forest community types to match optimal sites; maintenance of an aggrading forest condition on shallow soils associated with non-point sources of pollution (80–90 year rotations); reduced risk of catastrophic environmental disturbance; specifically designated areas for the development of native plant seed banks and long-term monitoring (control); and a road system reduced to the minimum needed for conservation and protection.

3.3. Lessons learned from the case studies

Many lessons were learned from these case studies. First, it was clear that the NED decision process was practical. The owner could readily understand each step in the process and the reasons for that step. Explicit goals were difficult to develop, but this important step was accomplished through substantial effort. Second, the landowners were impressed by the methodical manner in which the numerous details of managing a large enterprise were organized by the NED process. It is quite typical that landowners lack a good way to organize and use all the information about their property. NED provides this framework. The McKnight case study demonstrated that even if alternative scenarios are not necessary or desirable, there is a huge gain in using the NED decision process to organize information and allow easy updating of analyses as future conditions vary. In the Maryland case, the local foresters ran NED-1 themselves and provided considerable feedback for improvements in usefulness and usability that have been added to NED-2.

The NED team learned that better integration with ArcView and FVS (Teck et al., 1996) was needed. We have improved that integration with NED-2. Scenario design and simulation was awkward during these case studies. We learned and designed a computer assisted method in NED-2, and realized during the inventory process the importance of using a field data recorder in saving time. Consequently, the NED team has developed and tested the NED inventory process on field data recorders.

4. NED-2 design

4.1. NED-2 architecture

NED-2 integrates a sophisticated user interface, databases, simulations, knowledge bases, hypertext documents, geographical information systems, and visualization tools into a single decision support system. We wanted an open system that would allow us to incorporate additional simulations, knowledge bases, and other decision support tools easily. This would not be possible if integration of each component required extensive procedural programming. Instead, we decided to build intelligent agents each of which knew how to use a class of decision support tools. These agents are developed in Prolog, a high-level logic programming language. As an example, the NED-2 simulation agent knows that a growth and yield simulation requires input in a given format, requires control codes to simulate treatments and set stop conditions, and writes output in a specific format.

The central organizing principle for NED-2 is the blackboard (Fig. 1). Unlike object oriented or mediator architectures, agents do not directly invoke each other in a blackboard system. Instead, tasks that need to be done are posted to a blackboard. Blackboard architectures are also more flexible than rigid hierarchical architectures that prevent agents

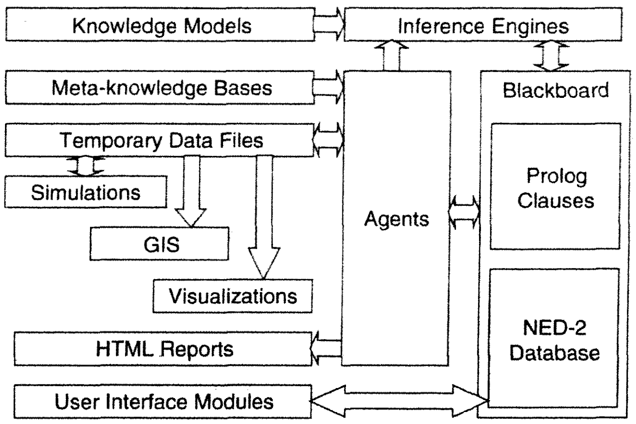

Fig. 1. The NED-2 architecture, a diagram illustrating the relationships among components of the agent-based design using a blackboard for communication between modules.

from accepting assignments from any agents except their immediate supervisors. Using a blackboard architecture, an agent can respond to any agent that can write a request on the blackboard. Discussion of further detail of NED-2 Architecture can be found in Nute et al. (2002, 2003).

4.2. User interface

Users access functional elements available in NED-2 through a user interface. NED-2 is designed to take advantage of available graphical-user-interface, point-and-click 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. Further development of the NED-2 interface will include usability testing to ensure that most users can understand what they see and to enable training materials and programs to provide useful supplements to the material distributed with the system.

The primary new functions in NED-2 are treatment simulation, growth projection, and alternative plan development. These supplement the original major functions in NED-1: goal selection, data entry, and analysis, including the generation and printing of tabular and narrative reports. Hypertext functionality provides information on using the program and on general forest management issues.

4.3. Data management

User data is stored in a Microsoft Access database (hereafter termed Access). An Access database is represented as a single file on a computer. Thus, a NED-2 file is an Access database. Each database represents a single management unit complete with multiple forest stands. NED-2 uses the database to store inventory data collected in the field and data generated from growth simulations. The database also stores alternative treatment plans with detailed prescriptions, selected goals and reports, plant species information, and user preferences. Although a NED-2 database can be viewed in Access, a local installation of NED-2 does not use Access nor does it require Access to be installed. Because NED-2 uses a standard Access file, users familiar with database programming can import data from other database formats or from spreadsheets with a minimum of effort. For electronic data collection, NED currently supports NED-DC, a DOS-based inventory data collection program for portable data recorders, and NedLite, a new application that runs on the Palm Computing platform.

NED's data requirements are extensive, largely due to the comprehensive and flexible design of the program. Although some features of NED 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. 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 can 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 models predicting such variables from tree inventories either do not exist or provide such wide confidence limits as to be of little use (Yanai et al., 1998).

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.

NED was originally designed around a plot layout that included one overstory plot, two understory plots, and two woody-debris transects. In NED-2 the plot layout can be customized to fit the user's needs. Groundcover plots have been added to improve organization of regeneration data, and new inventory variables have been added to support additional reporting requirements. Tally sheets can be printed for manual data entry. Because NED-2 files are in Access database format, import and export are straightforward to users with skills in database manipulation, but NED-2 does not contain any prepackaged import and export routines.

Inventory data are entered and edited using the interface illustrated in Fig. 2. There is a separate screen for each level of data. The data hierarchy is listed in the B-pane (lower left section) by stand. When a selection is made in the B-pane, the corresponding data are displayed in the C-pane (the main work section of the interface). All screens have a "Configure" button that displays a dialog in which the user can select the variables to display, and the order in which they appear. Hypertext pages contain references to the sources, methods of calculation, interdependencies, and other characteristics of each variable.

Detailed inventory and analysis of woody and herbaceous flora requires an extensive list of species. A separate subcomponent of the data management for NED-2 is the plant species database, a list of vascular plant species names and characteristics derived from the USDA NRCS Plants Database. This list is stored in an Access database and is included

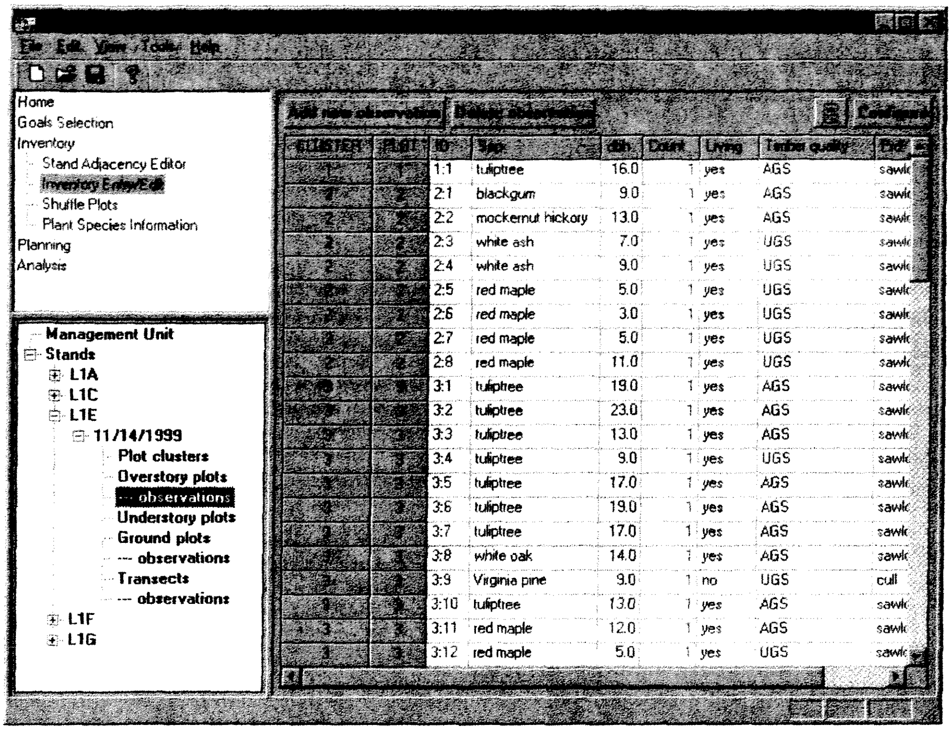

Fig. 2. The NED-2 Inventory entry interface includes configurable data entry screens within an easily grasped hierarchical design.

with NED-2 as a master plants list. Because many species in the master list have incomplete characteristics, NED maintains a sublist of complete species that fulfill reporting requirements. Each NED file contains a copy of the species sublist. A related list of timber species is maintained with volume and pricing information. If desired, users can develop a custom (local) species list with modified plant characteristics. Custom species lists are unique for each NED file, and they can be exported for use in other files.

4.4. Goal selection

In this module, the user selects goals for the management unit or for specific stands. A list of all available predefined NED goals is listed in the C-pane and selected goals are listed in the B-pane (Fig. 3). Goals have been developed by committees of experts in each of the resource specialties addressed by NED. As further resource goals are identified and knowledge of how management can affect conditions, additional goals will be included. Function of the goals module follows the design found to be effective in NED-1, using the same layout as other modules. The user selects goals by highlighting them in the C-pane and copying to the B-pane. The hypertext page for a goal can be displayed by double-clicking

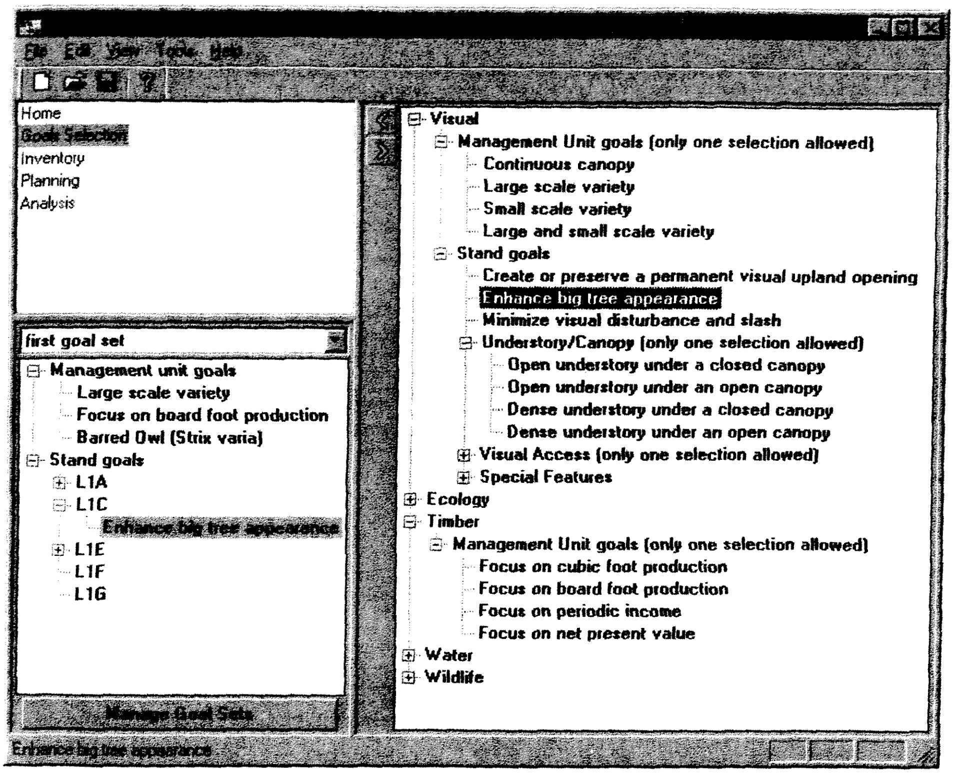

Fig. 3. A sample goals entry screen in NED-2 illustrates the variety of goals available for different resources at stand or management unit scales.

the goal in either pane. Such standardization in interface functionality has been identified as useful by the case study subjects.

5. Alternative plan development

An individual plan in NED-2 consists of specifications of a management unit with inventories of a collection of stands, a specific set of years within the planning horizon, and a specific set of treatments applied to each of the stands within the management unit. Multiple plans can be generated, modified, and compared for evaluation of alternatives, but comparisons must be made between plans with the same beginning (baseline) year and the same length of time.

5.1. Baseline development

Before any plans can be developed, the user must establish a baseline year at which all plans start. This is the stage at which inventories taken in different years can be resolved

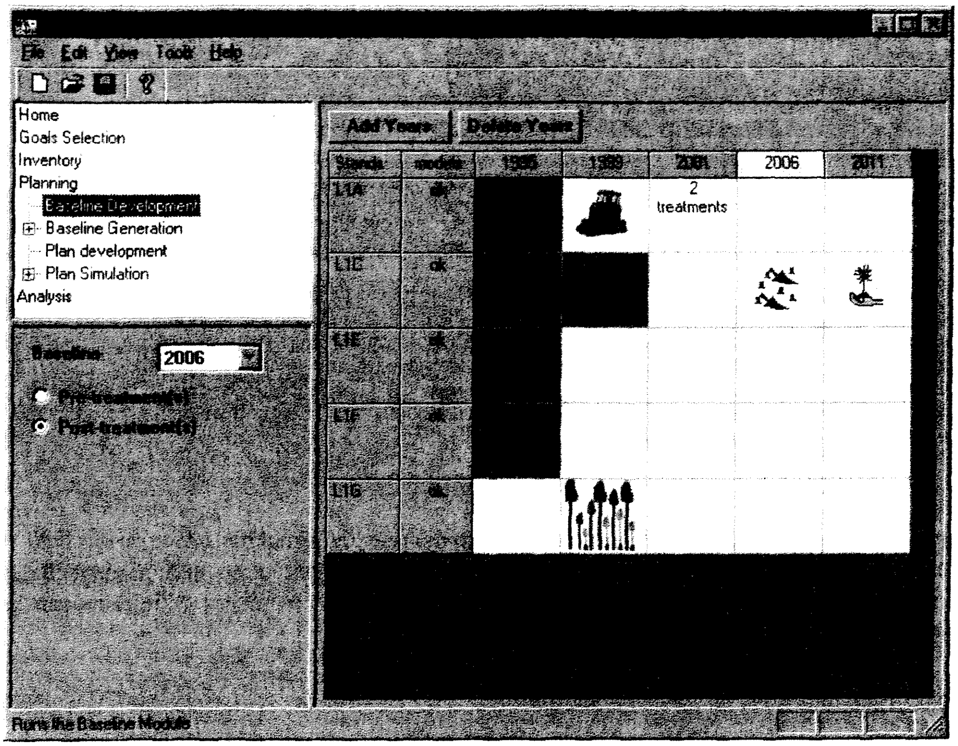

Fig. 4. A sample baseline development screen in NED-2 illustrates the graphical interface and hierarchical organization of selecting and simulating growth to a single, standardized baseline year.

by simulating growth of stands inventoried in earlier years. Simulations are accomplished using a module that provides a seamless interface to a number of simulators, either through FVS or SILVAH, at present. The baseline development submodule also allows the user to specify any treatments that may have taken place on a stand before the baseline year (Fig. 4). Initially the screen will only have years in which an inventory has been taken. The user can add additional years after and between inventory years, but not before the first inventory year. The first valid baseline year is the year of the last inventory.

5.2. Treatment prescription and growth simulation

Treatments in NED-2 are applied using a specially developed interface to FVS, the growth simulator supported nationally by the USDA Forest Service (Teck et al., 1996). NED-2 currently supports the Northeastern variant, based on NE-TWIGS (Teck, 1990), and the Southern variant. Work is continuing to include other growth simulators, including SILVAH (Marquis and Ernst, 1992) and others. Both FVS and SILVAH provide means for a user to specify treatments to apply to individual stands in specified years during a planning and growth cycle (Fig. 5). In NED-2 there are standard and customized treatment libraries,

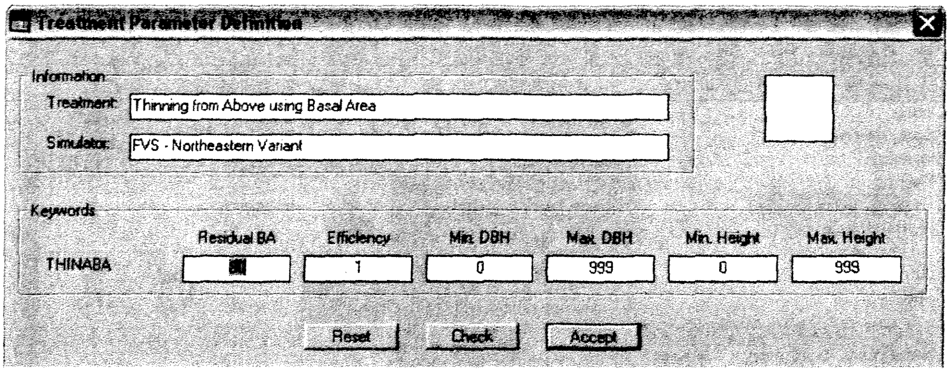

Fig. 5. The treatment parameter definition dialog box in NED-2 illustrates the interface used for specifying user-defined treatment parameters.

and NED-2 generates appropriate commands to the selected simulator which works behind the scenes. NED-2's facility to develop and store customized treatment definitions includes an external treatment knowledge base so that personalized treatment definitions can be shared among separate NED files or by a number of users.

5.3. Plan development and comparison

The plan development screen is much like the baseline screen (Fig. 6). Initially, only the baseline year is displayed. Years can be added after but not before the baseline. Added years show up in all plans. Any year other than the baseline can be deleted. The user adds treatments by double-clicking a cell and selecting from a pick-list of available treatments. Any existing plans can be copied into a new plan, renamed, and altered on one or more stands to generate multiple plans for alternative comparisons.

When several plans have been developed, the user can do a quick comparison using the Plan Comparison table, which displays any user-specified stand-level variable for a selected year for all plans. The values displayed can be before any treatments, after all treatments, or the removal values. Additional detailed reports comparing a user-specified set of alternative management plans over time are also available.

5.4. Landscape components

The landscape context is a crucial element in making appropriate land management decisions. For many values supplied by forests, the traditional focus of forestry on an individual stand is not valid. For example, 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 multi-stand context of individual stands can be useful for choosing goals, describing desired future conditions, and developing prescriptions.

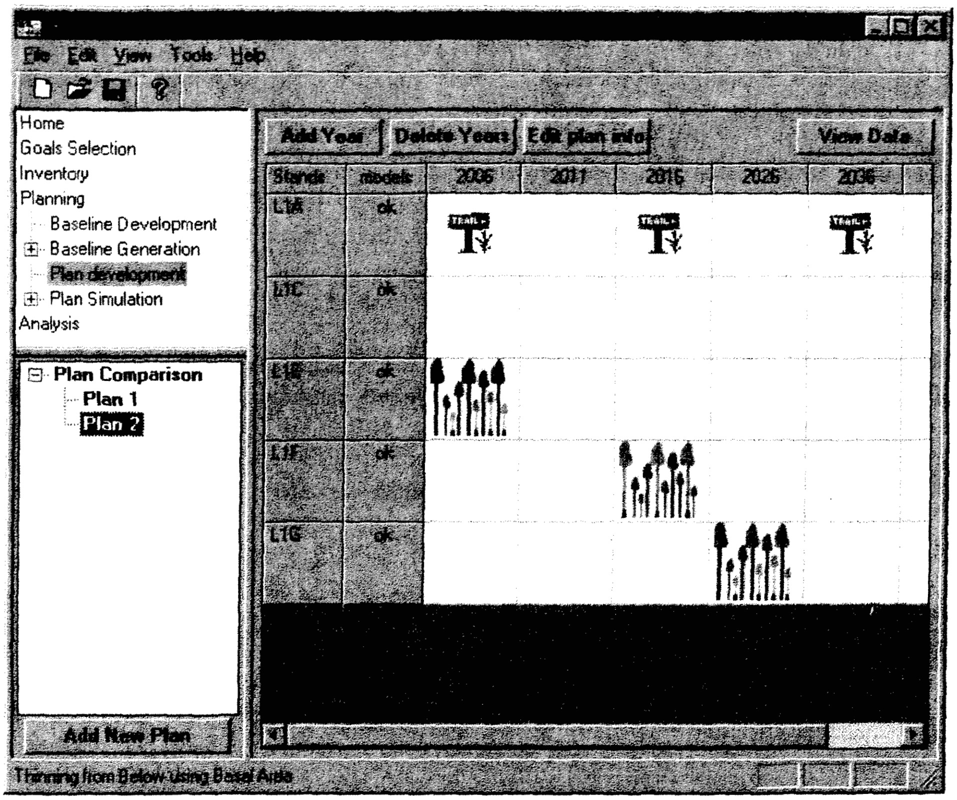

Fig. 6. An example of the plan development interface in NED-2 illustrates the graphical nature of identifying and specifying treatments for each stand and year in each alternative planning scenario developed by the user.

Spatial analysis capabilities in NED-2 are supported by links to the ArcView geographic information system (GIS) and other external packages. Users without access to systems for spatial analysis will have limited spatial analysis capability that depends on identification by the user of the neighbors of each stand in the management unit during data entry. Identification of adjacency allows calculation of some patch area and adjacency metrics, but will not allow more sophisticated measures such as the amount of interior habitat or proximity measures.

6. Output capabilities

6.1. Report generation in NED-2

NED-2 produces a variety of reports, all on specification from the user, at any stage in the process of developing and analyzing plans. The two general types of report generated by

NED-2 are simple data analysis reports and goal analysis reports. Reports are all generated in HTML so that the user can view them in the default browser or import them into a preferred word processor. 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 general narrative reports, one for each of the NED resources of ecology, timber, water, visual quality, and wildlife, whether the user has selected a goal within each resource or not. Reports are available at either the management-unit or stand level, accessible through a standard dialog box that allows a 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 selected reports.

To generate reports, one must make sure that there is a baseline in the loaded database or only inventory data are available. Moreover, if the user wishes to generate goal analysis reports, he or she must ensure that at least one management unit goal is selected. A table of contents report is generated with other requested reports. NED-2 displays the table of contents in the user's default web browser. All reports must specify the year or years and alternative plan for which the report is to be generated.

6.2. *Inventory summary reports*

NED-2 generates summary tables to the screen or a printer by generating HTML files. A user can 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. Diameter-class groupings are fully customizable.

6.3. *Resource descriptions and evaluations*

Use of goals in NED is designed to promote sustainable resource management for the entire forest resource, not just the timber resource. NED incorporates protection of rare and unique genetic, species, habitat, and ecosystem elements, plus awareness of ecological issues 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 address active restoration of native species, discouragement of exotics, and acquisition of information on local issues through identification of species of interest and pointers to further information. Each goal 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. Detailed descriptions of the specific goals developed for NED-1, and incorporated into NED-2, can be found in Twery et al. (2000) and in Twery and Hornbeck (2001).

Wildlife habitat conditions can be evaluated in either of two ways. 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 wildlife species have at least some habitat requirements met within the area. Identification of partial fulfilment of habitat may indicate the need for other management activities or an evaluation of neighboring lands.

NED-2 provides a standard template for generating a narrative description of each stand or the entire management unit. General reports do not require specified 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.

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 includes a set of desired conditions needed to meet each goal. NED-2 then compares the desired conditions with actual conditions based on inventory or simulated 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.

6.4. Current visualization capabilities

Visualization capabilities in the existing NED-2 implementation are strictly through export of data files to SVS (McGaughey, 1997,1998), or EnVision (McGaughey, 2000). The export process is straightforward, because NED-2 generates FVS data formats that in turn can generate SVS files. Further work to link directly to visualization programs is described in Section 7.3.

7. Outlook for future development

7.1. Interoperability

A key to effective decision support for ecosystem management is interoperability of a variety of systems. Interoperability is the ability of two or more 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 standard that promotes communication between components and provides for the integration of legacy and newly developed modules. Currently most available decision support programs for forest ecosystem management are independently developed, monolithic systems without open, general-purpose communication and control standards that provide interoperability (Potter et al., 2000). Such 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 because of their "write once-expand never" design strategy. In addition, point-to-point integration complexity increases exponentially as the number of integrated heterogeneous components increases. By contrast, interoperability outside the forestry domain has received extensive attention. One example, 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 off-the-shelf, third-party programs such as FVS, SILVAH, ArcView, and EnVision, to support NED analyses and the decision making process. The current version of NED-2 incorporates various legacy modules using an agent/wrapper approach (Potter et al., 2000; Nute et al., 2003). The complexity of this approach increases linearly as the number of heterogeneous components increases. Currently, NED-2 is focusing on local interoperability for convenience, but the design is not restricted to a local environment. This design features language independence, module extensibility, standardization of user interface management, distributed processing capability, and standardization of methods to address legacy modules (Potter et al., 2000). The NED developers have experimented successfully with distributed legacy module integration (i.e., modules reside on other machines that are connected via some network such as the Internet).

7.2. *Integrated prescription development*

NED-2 includes analysis of existing conditions both in general and in the context of specified goals. Specific treatment prescriptions currently can be applied and simulated in the treatment module, using FVS. Application of similar treatment specification capability using the SILVAH system of prescription and growth simulation is in development. 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 the others.

7.3. *Visualizations as enhancements to a DSS for forest ecosystem management*

The ability to represent data visually can enhance understanding and facilitate decision making (O'Mara, 1987; Domik, 2000; Bajuk, 1998) by enumerating facts, explaining statistics, and illustrating concepts and relationships (O'Mara, 1987). Forest managers, forest owners, recreationists, and land-use planners all may make decisions based in part on what they see when looking at the forest. Understanding and communicating basic forest stand dynamics can assist these users to appreciate the changes that occur as a result of natural disturbances and human interventions. While tabular or chart formats are well suited for illustrating basic stand attributes, they cannot convey important visual characteristics of stands, for example, form, color, and spatial dimensions.

Visualization can be especially critical in the context of ecosystem management, because principles from numerous resource specialties must be presented (Bergen et al., 1995; Bajuk, 1998; McGaughey, 1998; McQuillan, 1998; Domik, 2000; Bell, 2001; Lange and Bishop, 2001). As NED DSS users develop goals for their properties, visualizations that illustrate changes that are expected to occur over time will provide them with a more complete understanding of how their goals may be realized or that within a particular management scenario, certain goals cannot not be met in the same place at the same time.

Visualizations also may be effective in the communication of the complex concepts and principles of ecosystem management (Bryson, 1997). The work of numerous ecologists has advanced the concept of forest ecosystem management through landscape-level analyses of natural patterns and processes. This concept may be understood within a collaborative group of ecologists and resource managers, but may not be readily understood by a landowner, especially as it may serve as a means to achieve their management goals. An understanding of natural patterns and processes (i.e., scale, intensity and frequency) can tell a landowner the likely changes over certain time scales, and the agents that influence them. Visualizations can illustrate the character of those patterns in space and time for an entire forest landscape. The open blackboard architecture of NED-2 allows developers to provide an understandable interface and supporting programming for access to the combined visualization capabilities of SVS (McGaughey, 1997, 1998), EnVision (McGaughey, 2000) and ArcView. These can generate specific property images and may serve as proxies for understanding other information, such as soils or wildlife values that may not be apparent on the ground (Bell, 2001). Existing versions of NED-1 and NED-2 are capable of linking manually to visualization programs such as SVS and Envision, but easier, more straightforward processes are needed to take advantage of the power of the medium. Ultimately, all of the visualizations would improve NED users' comprehension of ecosystem principles and facilitate comparisons of alternate management scenarios.

8. Synopsis

The NED development effort attempts to provide a comprehensive set of decision-support tools for forest management for multiple values and purposes. With this system, we hope to improve the quality of information available to, and understood by, those who must make forest management decisions. The information NED makes available for analysis includes a variety of variables that help a user evaluate conditions relevant to a variety of goals. NED applications are not designed to provide definitive answers but to shed light on complex problems and encourage the user's own capabilities and judgment. We are not attempting to provide tools for regional or national policy makers, but are focusing on a more local context – deciding how best to manage a particular piece of forest. Comprehensiveness is achieved in part through the development and distribution of a variety of tools, each of which has a specific range of applicability. One key feature is that the goals incorporated into the system's several versions 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. We hope that the NED applications will enable managers to understand the consequences of their planned actions better and to use that information to improve actual conditions. NED also should improve communication among managers and their clients or constituents about tradeoffs that might be required to meet higher-priority needs.

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