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Managing for Visual Goals in the NED-2 Decision Support System for Forest Ecosystems

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Abstract: NED-2 integrates decision support tools for forested ecosystems developed by the NED-2 team with other third-party decision support tools. NED-2 is goal-driven and is designed to help manage for visual, wildlife, and ecological as well as traditional timber goals. Several tools are included to help manage for visual goals. (1) A knowledge based system can perform analysis of visual goals for the management unit. (2) A report generator incorporates the results of the visual goal analysis into detailed reports in HTML format. (3) If a shape file for the management unit is available, the results can also be displayed using ArcGIS. Finally, (4) individual stands can be viewed using the Stand Visualization System. All of these tools can be applied both to inventory data and to simulated data produced using the USDA Forest Service Forest Vegetation Simulator to model alternative treatment plans. The report and visualization tools allow the user to compare different treatment plans in a given year or to compare different years for a single plan. Software agents within NED-2 transparently translate between the internal NED-2 data model and the data formats required by the different decision support tools. This paper describes how the tools for managing visualization goals were developed and how they are used in NED-2.

Keywords: Decision Support Systems, Ecosystem Management, Forest Management.

1. INTRODUCTION

NED-2 is a goal-driven software system running under Microsoft Windows[®] 2000 or Windows XP.¹ It is designed to assist users in developing and evaluating prescriptions (treatment plans) for management units made up of forested stands. The steps in the decision process modeled in NED-2 include entering the inventory for the management unit, selecting management unit goals, developing potential treatment plans for the management unit, simulating the treatment plans, and evaluating the simulated data to determine how well different treatment plans achieve the management goals. In this paper, we will focus on how goals are evaluated and how the results of the goal evaluation are reported to the user. Specifically, we will focus on the methods available in NED-2 for managing visual goals. For

a broad description of the NED-2 decision support system, see [Nute et al., 2004] and [Twery et al., 2005].

In this paper, we will describe the knowledge based system used to evaluate visual goals in NED-2. We will also describe the different tools NED-2 uses to communicate the results of goal analysis to the user. The fundamental method for communicating visual goal analysis is a set of reports in HTML format containing text and tables that summarize the results. The results can also be used to color a map of the management unit in ArcGIS to show which stands meet, barely meet, almost meet, or fail to meet the user's visual goals. Finally, NED-2 can send simulated data to the Stand Visualization System, in which the user can compare visual representations of a stand at different points in time under alternative treatment plans.

2. MANAGING GOALS AND PLANS IN NED-2

In general, goal analysis in NED-2 is accomplished by knowledge based systems that use rules to represent the conditions necessary to satisfy management goals. Goals are established primarily at the level of the management unit,

¹ The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the University of Georgia or the U.S. Department of Agriculture Forest Service of any product or service to the exclusion of others that may be suitable.

although some goals are evaluated only at the stand level. The satisfaction of a goal at the level of the management unit also often depends on the proportion of stands in the management unit that satisfy a related goal at the stand level.

A fundamental concept in the NED-2 data model is the *snapshot*. A snapshot represents a single stand at a particular point in time under a particular treatment plan. We also have snapshots for each stand representing initial inventory. Because inventory may be taken in different years, the user must also establish a *baseline* year, which then serves as the first year for all treatment plans. The baseline year can be the last year at which inventory was taken for the stands in the management unit or any year thereafter. If the baseline year is later than the inventory year for a stand, then NED-2 simulates growth on that stand up to the baseline year. So we also have baseline snapshots representing stands at the baseline year.

Another fundamental concept in the NED-2 data model is the *view*. A view is a picture of the entire management unit at a point in time under a particular treatment plan. Thus, a view is made up of a set of snapshots, one for each stand in the management unit. All the snapshots in a single view will be for the same year and the same plan. Inventory and baseline years also represent views of the management unit that are independent of any treatment plan, even though inventory may not correspond to a single year. Because many goals are conceived primarily at the management unit level, goals in general are analyzed on the entire management unit at a single point in time, and under a single treatment schedule. Consequently, goal analysis can only be performed on the baseline year, or on a view of a treatment plan at a specific year, and the user cannot do a goal analysis on inventory. However, the user can look at summaries of various other kinds of data based on inventory.

Plans are created by specifying treatments at the stand level. Each treatment is entered for a particular year on a particular stand using a special dialog for plan development. Once one or more plans have been defined, the user can request that NED-2 simulate the set of plans. Currently, NED-2 uses the Forest Vegetation Simulator for all growth and treatment simulations [Crookston, 1997]. After one or more plans have been simulated, the user can request goal analysis.

3. VISUAL GOAL ANALYSIS

Visual goals in NED-2 are unusual in that most are set at the stand level rather than at the management unit level. There is a single set of mutually

exclusive goals at the management unit level from which the user can select. These are enhance or encourage (1) continuous canopy, (2) large scale variety, (3) small scale variety, or (4) large and small scale variety. There are rules in NED-2 for each of these goals at both the stand level and the management unit level.

Each rule in NED-2 has two parts. The first part gives the rule name and indicates the *environment* to which the rule belongs and the *inference engine* for which the rule is designed. Rules are divided into environments to make it easier for the goal analysis agent to find the correct rules for a particular goal category when several rule sets are loaded at the same time. Prolog is essentially a backward-chaining inference engine, but we have also designed a forward-chaining inference engine and a backward-chaining inference engine that uses confidence factors, that is, a number that indicates how confident we are that a particular conclusion is correct. We use backward-chaining inference with confidence factors for the visual goal analysis.

The second part of each NED-2 rule includes the actual conclusion and the conditions it depends upon. For the “enhance or encourage continuous canopy” goal, a snapshot (that is, a stand at a point in time under a particular treatment plan) satisfies the goal if the canopy is at least 75% closed; the height of the bottom of the canopy is at least 10 feet; and the canopy is open in at most 10% of the stand.

To evaluate whether the management unit satisfies the continuous canopy goal at a particular view (either at the baseline year or at a later year under a particular treatment plan,) we first collect all the snapshots of individual stands corresponding to the view, and determine which of these satisfy the rule described above. The confidence with which a condition is satisfied is determined by how close the actual value of a parameter is to the target value. If the actual value falls more than 5% beyond the indicated side of the target value, then the snapshot clearly satisfies the condition (confidence that the stand passed the goal is 1.0.) If it falls more than 5% on the wrong side of the target value, then it clearly fails to satisfy the condition (confidence that the stand passed the goal is 0.0.) If the actual value falls within 5% of the target value, then it barely satisfies (confidence is 0.6) or nearly satisfies (confidence is 0.4) the condition, depending on whether it is on the right or wrong side of the target value. We then calculate our confidence that the snapshot passes the goal by combining the confidence values for the conditions. If the conditions are connected by ‘and’ (as in this rule,) we take the least confidence

we have in any of the conditions because we can be no more confident that the stand satisfies two conditions than we are that it satisfies either one of the conditions.) If the conditions are connected by 'or', we take the greatest confidence we have in any of the conditions. For complex rules involving both 'and' and 'or', we combine these methods. The inference engine puts all these intermediate results on the NED-2 blackboard where they are available for the management unit analysis.

The representation of the goal for the management unit in this example is a rather complex rule in raw Prolog. Essentially, it calculates the acreage of the management unit and the acreage of all the snapshots that pass, barely pass, nearly pass, or fail the stand level rule. In this case, if all the stands that pass or barely pass at the stand level comprise at least 75% of the total acreage of the management unit, and if the canopy is open on no more than 10% of the management unit, then the management unit passes the continuous canopy goal. Otherwise, the management unit fails the goal.

There are also two sets of mutually exclusive goals that can be selected for individual stands. The first set includes (1) open understory under a closed canopy, (2) open understory under an open canopy, (3) dense understory under a closed canopy, and (4) dense understory under an open canopy; and the second set includes (1) allow visual access to specified features, and (2) screen specified features from sight. There are rules in NED-2 for each of the first set of goals, but not for the second. This is because the second set of goals cannot be evaluated using the kind of data available in NED-2 and therefore must be evaluated by the user.

There are two additional sets of stand level visual goals. The first set includes (1) create or preserve a permanent visual upland opening, (2) enhance big tree appearance, and (3) minimize visual disturbance and slash. The second set includes (1) feature fall color of trees, shrubs, and ground covers, (2) feature flowers on trees, shrubs, and ground covers, (3) feature nuts, fruits, and berries on trees, shrubs, and ground cover, (4) feature contrasting foliage on trees, and (5) feature contrasting forms of trees. There are rules in NED-2 for each goal in each of these sets of goals.

We will look at just one of the rules for stand level goals, the rule for nuts, fruits and berries. The basic structure of the rule is the same as for the earlier rule, but the body of the rule is more complex, even though only three conditions are involved, because the rule involves both an 'and' and an 'or'. A stand passes the condition if *either*

at least 10% of the basal area is made up of fruiting trees *or* the percentage of the shrub cover that bears fruit plus the percentage of the ground cover that bears fruit, nuts, or berries adds up to 5.

Stand level goals are not evaluated at the management unit level.

4. GOAL REPORTS

The primary method for displaying the results of goal analysis is through a set of reports in HTML format. By default, each set of reports is written to a separate folder in a 'My NED Files' folder created in the user's 'My Documents' folder. Reports are not overwritten unless the user generates a new set of reports for the same NED-2 working file and the same set of views. So reports persist after the NED-2 session and can be accessed outside NED-2. This makes it easy for the user to cut and paste parts of a NED-2 goal report into any other document the user may create.

The user decides whether to generate reports for a single view or for all views, that is, for a single plan in a single year or for all plans and all years. The structure of the reports is rather different in these two cases.

Both single view and plan comparison reports use two frames. A left frame gives identifying information for the set of reports and the date the reports were generated. It also contains links that control the content of the right frame. These links list the different reports that the user has requested. If the user has included visual goals in the set of goals to be analyzed, one of these links will be "Goal Analysis for Visual". When the user clicks on this link, a summary of the visual goal analysis is displayed in the right frame.

The summary visual goal analysis has two parts. The first is a summary of goal analysis at the management unit level. This lists the management unit goals, an analysis of whether the management unit satisfies each goal, and the specific management unit features that contribute to passing or failing each goal. In generating the report, NED-2 uses a template that corresponds to the conditions used to analyze visual goals at the management unit level and inserts values for appropriate variables.

A table that makes up part of the management unit level analysis for the goal 'Create or enhance continuous overhead canopy' for a small management unit with only five stands is shown in the top right of Figure 1. The first column (which does not show up well in the grayscale figure) says

that the status of the management unit is that it does not fully satisfy the goal. The other columns show what percentage of the area of the management unit pass, barely pass, nearly pass, or fail to pass the goal requirements at the stand level. Text in the upper left part of the figure shows that the report is for the Liberty 1 management unit (a sample file distributed with the beta version of NED-2) in the baseline year, and that the report was generated on February 2, 2006.

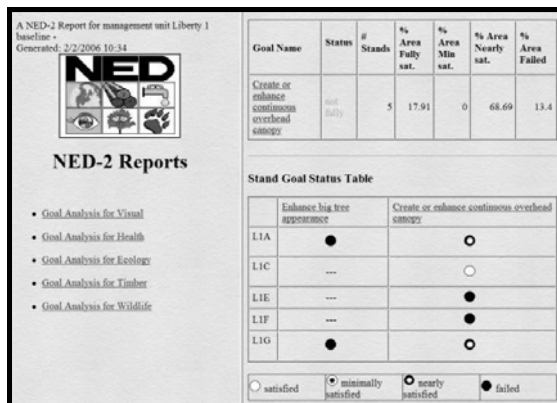


Figure 1. Part of a NED-2 Visual Goal Analysis Summary

The bottom part of the visual goal summary includes a list of stand level goals and a table showing which stands pass or fail each of the visual goals selected for it, including any goals that are also evaluated at the management unit level. We see an example of this part of a visual goal analysis summary report in Figure 1. Each row in the table represents a stand and each column represents a goal. The first column of icons shows results for the goal 'Enhance big tree appearance' and the second shows results for the goal 'Create or enhance continuous overhead canopy.' Notice that 'Enhance big tree appearance' is a stand level goal, and it has only been selected for two stands. A white circle in a cell indicates that the goal is passed by the stand, a white circle with a black center indicates that the stand barely passed, a black circle with a white center indicates that the stand nearly passed, and a black circle indicates that the stand failed the goal.

The list of goals included in this summary that are only evaluated at the stand level (not visible in Figure 1) are also links to more specific reports. These reports give a complete analysis of the rule(s) used to evaluate the stand level goal and a table showing the actual values of the variables used in the goal analysis for each stand (Figure 2.) The representation of the rule used to evaluate a stand level goal is generated by a rule parser and does not use a template as does the summary for the management unit goal analysis. This allows the

NED-2 developer to add new visual goals (or goals in other categories) without building a special template for the corresponding rule. The report writer can generate these stand level goal reports from a generic template together with the rule and the data created during the goal analysis.

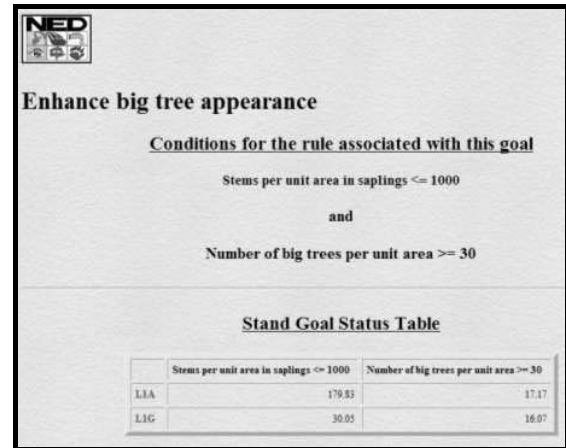


Figure 2. NED-2 visual goal analysis for a specific stand level goal

Plan comparison reports involve more complex summary tables than single view reports. The user can choose whether to represent stands by rows and years by columns, or to represent years by rows and stands by columns. In either case, each row is divided into as many additional rows as there are plans to be compared. So each cell in the table becomes a set of icons showing whether a stand in a certain year passed, barely passed, nearly passed, or failed the goal under each of the user's treatment plans.

With a large number of stands, plans with several years included, or several plans to compare, it can take quite a while to generate plan comparison reports because each goal typically has to be evaluated for each stand, for each year, and for each plan. In addition, results for the stand level tests have to be used to evaluate the goal at the management unit level, and finally all of the results have to be collected and integrated into the HTML report set. It may not be possible to view an entire row of the plan comparison report table on the screen without scrolling when many stands and many years are involved. For smaller management units and plans with only a few years specified, the time needed for the analysis may be reasonable and the report may fit well on the screen. But for larger management units with more years specified in the plans, the user will probably prefer to generate single view plans most of the time.

5. GIS DISPLAY

Another way to view the results of visual goal analysis is by coloring a map of the management unit. This requires ESRI ArcGIS 8.x or 9.x and a shape file for the management unit that uses exactly the same identifiers for the stands in the management unit as are used in NED-2. An advantage of this method over the tables included in the HTML reports is that the user can see the spatial relationships between the stands that do or do not satisfy particular visual goals.

The user requests a GIS display either for a plan or for a year. They then identify the visual goals they wish to display. They may also display goals in other categories or variables such as forest type or basal area. Once the user has identified the plan or year and the goals and variables for GIS display, NED-2 performs the necessary goal analysis and generates a Microsoft Access database with several tables. *Plan_table* includes a list of the layers to be included in the GIS display. There will either be a layer for each year of a single plan, or a layer for each plan in a single year. *Var_table* includes the goals and variables to be included in the display together with their labels, value types (goal, numeric, string,) and their units (ft²/acre, stems/acre, etc.) Finally, there is a table for each layer. This table shows the value for each goal or variable for each stand included in the display.

An ArcGIS project written in Microsoft Visual Basic for Applications (VBA) opens the database created by NED-2. It uses the *Vars_plan* table to create a dialog that allows the user to select a goal or variable for display. The VBA code also merges the tables for the different layers with the user's shape file. When the user selects a goal or variable, the layers in the display are colored accordingly. The user can then move through the different years for a single plan, or the different plans for a single year, and watch how the management unit changes with respect to a given goal or variable.

6. THE STAND VISUALIZATION SYSTEM

One final tool that has been integrated into NED-2 to assist with the management of visual goals is the Stand Visualization System (SVS) (McGaughey 1997). SVS can generate a graphic image of a plot within a stand, showing trees, shrubs, and down material (dead trees on the ground.) NED-2 currently uses SVS only to display standing trees.

To generate its display, SVS needs values for tree height, crown ratio, and maximum crown width for each tree to be displayed. It also needs spatial coordinates for each tree. Users normally do not

enter values for these variables as part of their inventories. However, FVS generates values for tree height, crown ratio, and maximum crown width. So once we grow trees up to the baseline year, this information is available for the baseline and subsequent years.

An SVS utility program converts an FVS tree list into an SVS file. In the process, the utility assigns XY coordinates to each tree in the file. NED-2 uses this utility to create the files SVS uses to generate its displays. However, NED-2 does not retain the FVS tree lists after running a simulation. The data from these lists are stored in a Microsoft Access database. So the NED-2 SVS agent generates a 'dummy' FVS tree list from the stored simulation data and submits this to the SVS utility. We chose this method rather than generating the SVS file directly because, with this approach, we did not need to develop our own routines for assigning spatial coordinates to the trees in the stand.

When the user requests an SVS display, they have the same options as with the GIS display: display all years of a single plan or all plans for a single year. There is, of course, one important difference: while ArcGIS can show all the stands in the management unit at once, SVS is designed to generate a stand level display. So the user must also select the stand to be displayed. After these choices are made, NED-2 creates the dummy FVS tree list, calls the SVS utility to convert this data into an SVS file, and calls SVS to display the file. Once SVS is running, the user can display the different years in a plan in different windows, or display different outcomes for different plans in the same year. Each of these images can be displayed simultaneously in different windows, allowing direct visual comparison. The user can also initiate a new SVS session from within NED-2 without closing the previous SVS session. Therefore, several sessions can be running simultaneously. For example, the user could generate one session showing a stand in all the years using Plan A, and another showing all the years using Plan B. And each of these snapshots can be displayed in its own window at the same time. The only limit on what can be done is the physical size of the monitor and the user's ability to assimilate all the information that is displayed.

7. CONCLUSIONS

Case studies using earlier versions of NED such as the one reported by Rauscher (1997) show that land owners are interested in managing for visual goals and other non-timber goals if they have the tools and the decision processes in place to manage these goals effectively. The NED project

has included tools for managing visual goals since the release of NED-1. However, NED-1 did not provide any methods for simulating treatment plans and did not include either GIS or SVS displays of data. What was available in this first incarnation of NED was analysis of visual goals on inventory data. NED-2, now in beta testing, provides visual goal analysis for any stand at any year in multiple treatment scenarios. In addition, it allows the user to review the results of this analysis through extensive test reports, GIS displays, and SVS displays. This emphasizes the strength of an approach that allows integration of decision tools developed by the NED team, such as the knowledge based systems for visual goal analysis, with powerful third-party decision tools such as FVS, SVS, and ArcGIS.

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