UPDATED PROBE UTILITIES FOR EVALUATION OF FOREST MANAGEMENT USING FORCYTE-11

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The FORCYTE-11 forest yield and trend evaluator model is currently being tested with management gaming and sensitivity analysis. To allow users to more efficiently execute multiple model runs and handle the large amount of output data, a supervisory program (PROBE) has been developed. PROBE assists users during three activities: input data preparation, multiple run execution, and output data analysis. Since first reported at the 6th Bioenergy R&D seminar, the programs for the first two activities have been significantly improved to make them more user-friendly and efficient. In addition, an output data display and file manager has been developed to facilitate the analysis of model results with PROBE.

This output manager has several features which overcome limitations of the standard FORCYTE-11 output. Any output variable of any FORCYTE-11 module run (TREEGROW, PLNTGROW, FORSOILS, MANAFOR) can easily be selected and compared with other variables of the same or other module runs. The menu-driven environment provides both graphical and tabular display of data for comparison and analysis. Finally, several data storage and output options are available, including the ability to archive results in compressed, binary form.

Le modèle d'évaluation du rendement et des tendances des forêts FORCYTE-11 fait actuellement l'objet d'essais avec des programmes de jeux de gestion et des analyses de sensibilité. On a élaboré un programme superviseur (PROBE) afin de permettre aux utilisateurs d'exécuter efficacement plusieurs passages de modélisation et de manipuler les grandes quantités de données de sortie. Le programme PROBE aide les utilisateurs pendant trois types d'activités: la préparation des données, l'exécution de plusieurs passages et l'analyse des données de sortie. Depuis qu'ils ont été signalés pour la première fois au cours du 6e séminaire sur la R et D en bioénergie, les programmes pour les deux premières activités ont fait l'objet d'améliorations considérables qui les ont rendus plus conviviaux et plus efficaces. De plus, un programme de présentation des données de sortie et de gestion des fichiers a été éloboré en vue de faciliter l'analyse des résultats des modélisations avec le programme PROBE.

Le programme de gestion des données de sortie possède plusieurs caractéristiques qui lui permettent de surmonter les limitations imposées obtenues avec le modèle standard FORCYTE-11. Toute varable de sortie obtenue avec tout passage de module FORCYTE-11 (TREEGROW, PLNTGROW, FORSOILS, MANAFOR) peut être facilement choisie et comparée à d'autres variables du même passage ou d'autres passages du module. Le cadre du programme, qui est piloté par menus, permet de présenter les données sous forme graphique ou sous forme de tableaux afin de les comparer et de les analyser. Finalement, plusieurs options permettant de stocker et de restituer les données sont disponibles, dont la capacité d'archiver les résultats sous une forme binaire comprimée.

1 INTRODUCTION

As non-renewable energy sources are inevitably depleted, there is a need to develop renewable ones. Bioenergy, including forest fuels, is becoming more attractive as an alternative energy source, especially when the atmospheric impact of burning fossil fuels is considered.

Forest management strategies for the production of bioenergy have to be evaluated in terms of sustainability and long term environmental consequences. Because of the long time horizon of such evaluations, computer simulation models are appropriate assessment tools. FORCYTE-11 (Kimmins *et al.*, this volume) is an ecosystem simulation model, developed under the ENFOR (Energy from the Forest)

program of Forestry Canada to assess the environmental consequences of intensive forest management for the production of bioenergy.

As a trend evaluator, FORCYTE-11 is best suited for ranking and comparing different management options rather than relying on the absolute predictions. Currently, it is being tested on a variety of tree species (see Grewal *et al.*, Sachs *et al.*, Pike and Meades, this volume). The use of FORCYTE-11 or other ecosystem models to evaluate forest management options requires multiple runs of the model with different initial conditions, management options or calibration parameters. As FORCYTE-11 moves from the development phase into the testing and validation phase, the complexity of setting up multiple module runs has increased greatly, as has the number of data and output files. The supervisor software package PROBE (Apps *et al.* 1988, Kurz *et al.* 1988) has been developed to manage FORCYTE-11 experiments which require a large number of simulation runs.

Since first reported at the 6th Bioenergy R&D Seminar (Kurz *et al.* 1988) PROBE has been enhanced. It now has expanded ability to set up, supervise, and analyze multiple FORCYTE-11 runs in a more user-friendly environment.

This paper describes the PROBE concept approach, and the utility of this approach to evaluating forest management practises with large ecosystem models. It also discusses improvements and new developments with PROBE. Although this paper deals explicitly with FORCYTE-11, the PROBE software can be adapted to work with other simulation models having a similar input/output structure (see Figure 1).

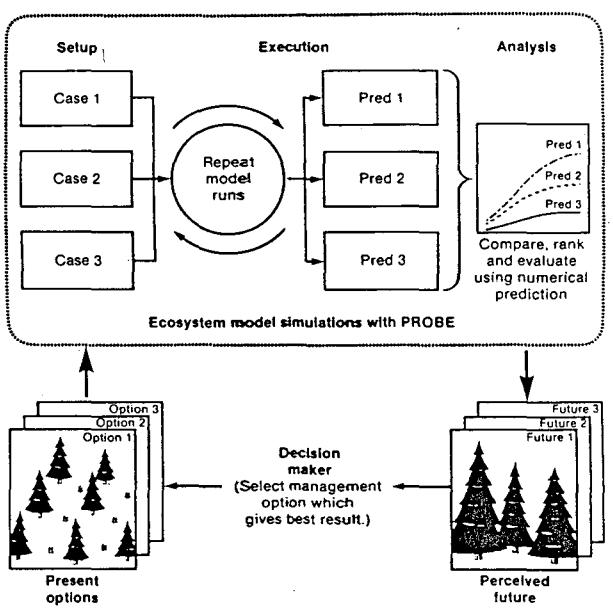

Figure 1: The role of PROBE in the forest management decision process.

2 PROBE CONCEPT

PROBE provides supervisory software which facilitates the use of FORCYTE-11 as a forest management analysis tool. It consists of several programs and associated files which help the user in preparing, executing, and analyzing FORCYTE-11 runs.

Figure 1 shows how PROBE operates within the forest management decision process. It acts as an interface between the user and the technical complexities of running the ecosystem model by providing data editing capabilities, unattended execution of multiple runs and automatic output file production and compression.

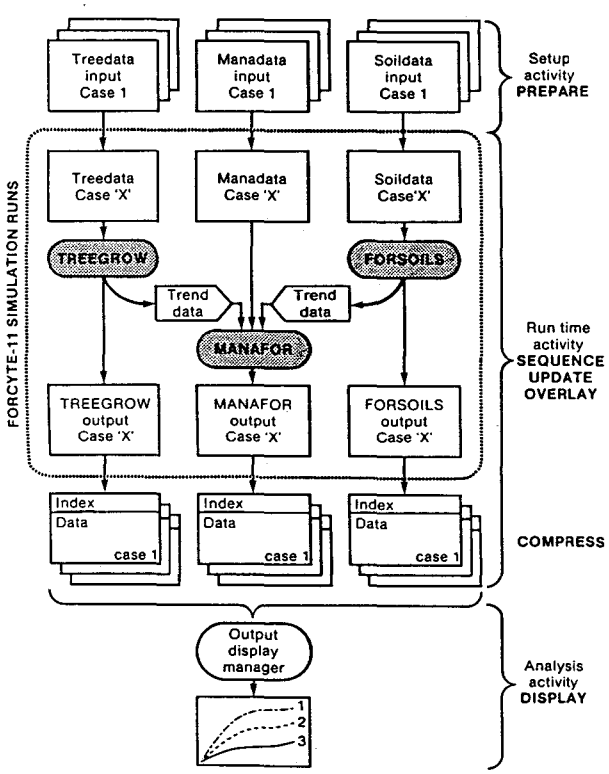

Figure 2: Overview of the FORCYTE-11 model and the PROBE supervisory software.

The PROBE software has features which enhance the operational capabilities of FORCYTE-11. For example, it can be used to set up single FORCYTE-11 run, a sequence of runs (an experiment), and sets of experiments. More importantly, it makes the output results more readily accessible for analysis and interpretation. It allows the user to graph one variable against another while browsing the data and checking for correlations. It also facilitates the selection of data for statistical analysis and graphical or tabular presentation by software external to PROBE.

3 PROBE STRUCTURE AND PROGRAMS

The function of PROBE can be divided into three main activities: data set up, program execution, and data analysis. Each activity is facilitated by specific programs, some of which are activated individually while others are run automatically as part of the execution sequence. These programs, written in Turbo Pascal, are running on IBM-PC compatible machines under the DOS environment.

While the original concept remains the same, there have been significant changes to several PROBE program modules. The following sections summarize improvements since originally reported. More technical descriptions are given in the appropriate user's manuals (Kurz and Apps (1988), MacIsaac and Apps (1989)).

3.1 Set Up Activity

The most important changes to the data set up activity have been extensive modifications and improvements to the interactive program PREPARE (previously called SETUP), which helps the user in the tasks needed to set up multiple FORCYTE-11 runs managed by PROBE.

Using PREPARE, the user can define specific data changes (case overlays) to the original data set (default input files) needed for each program module run. As discussed below in the section on applications, this now allows users to create a database of input options. While preparing the overlays, the original default data files can be displayed for reference and editing; in addition, previously defined case overlays can be edited. Figure 2 is a simplified overview of the FORCYTE-11 model and the PROBE supervisory software and shows how data cases are used as input to FORCYTE-11 program modules. The case descriptions are stored, and at execution time are used as overlays to modify the input data files. With PREPARE, the user can also attach a header section with comments for each output file.

3.2 Run Time Activity

PROBE controls the execution of the FORCYTE-11 program modules and the production of output data files. This process has been significantly improved through the modification of the program SEQUENCE and the addition of the program COMPRESS.

SEQUENCE has been changed to permit the execution of a single FORCYTE-11 program module run (Figure 2), a user-defined sequence of runs (called an experiment) or a set of experiments. The execution sequence is defined in a file which controls the order in which the FORCYTE-11 program modules are run. The file also designates the specific input data file overlay (case) which will be used for input to the specific module. This allows the user to set up an unattended execution of one or more sequences of runs.

Each FORCYTE-11 module produces one or more output files containing simulation results. The available output formats are: tabular summary tables, diagnostic graphs (line printer plots and

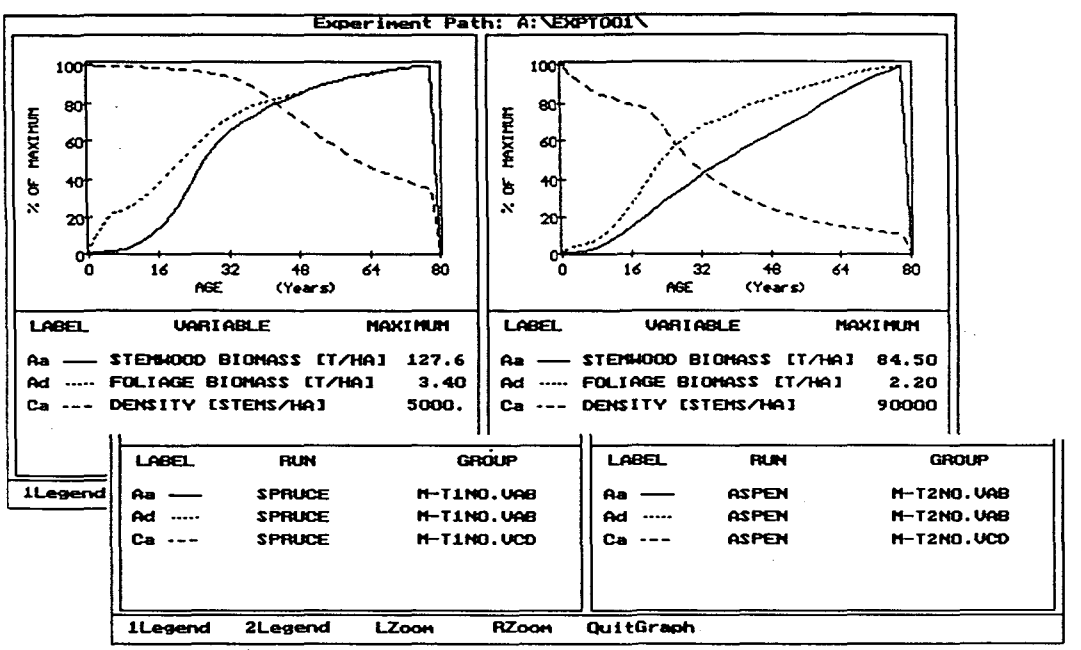

Figure 3: Screen image from program DISPLAY, showing customized output from two FORCYTE-11 runs. The second "pop-up" legend has been superimposed on the first

numerical ASCII files), and numerical ASCII spreadsheet files. However, the FORCYTE-11 output control is "all or nothing", and does not permit selective suppression of output. The output files generated during multiple runs can require large amounts of disk storage space. Furthermore, a direct comparison of variables located in different output files (even of the same format) is not readily possible.

COMPRESS, the second major PROBE program involved in the execution of FORCYTE-11 runs, overcomes the limitations mentioned above. It converts the standard FORCYTE-11 output data to a form which significantly reduces the storage requirements (up to 75%), while permitting faster and more flexible access to it. It performs this magic by converting the regular FORCYTE-11 output into two new files: a small index file which identifies the location of data in the second, binary file. The compressed files have been structured to make them suitable for further data analysis.

3.3 Analysis Activity

The most extensive changes to PROBE have been in support of data analysis. While the graphical display and analysis using the spreadsheet program Symphony (Lotus Development Corp.) was useful for prototype development, its associated computer overhead and relative inflexibility make it unsuitable for use with the greatly expanded data sets provided by the COMPRESS utility. It has been replaced with DISPLAY.

DISPLAY is an interactive program which uses menus and "point-and-pick" routines to efficiently retrieve and analyze the FORCYTE-11 output data. DISPLAY loads the index file information produced by COMPRESS from a user- selected subset of FORCYTE-11 output. It then allows the user to easily and quickly choose, graphically display, and browse through any combination of variables from FORCYTE-11 module runs (TREEGROW, PLNTGROW, FORSOILS, MANAFOR) (Figure 3).

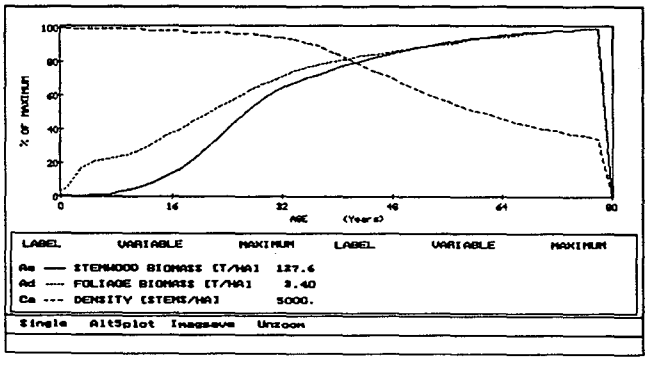

Figure 4: Screen image from program DISPLAY, showing customized zoom graph. The user can also "page through" one plot at a time.

After selecting output for analysis, the user can "page" through several output graphs or "zoom in" on specific graphs (Figure 4), and can also define the combination of variables shown in any graph display. DISPLAY has been designed to show dynamic trends (variables *vs.* time) or to plot relationships between variables (e.g., stand density (stems/ha) *vs.* foliage biomass (t/ha)). It also permits numerical manipulation of the data, for example, changing scaling factors. Once they are displayed, selected graphs can be printed or stored with user annotation for later retrieval.

DISPLAY greatly enhances the usefulness of the original FORCYTE-11 output. As well, this new data display and analysis manager can act as a selector for data to be exported to commercial software such as spreadsheet programs, statistical packages, database systems, and presentation graphics.

4 APPLICATIONS

As illustrated in Figure 1, PROBE provides the flexibility required for a useful decision support tool for forest managers. Although initially designed for use with the FORCYTE series of ecosystem models, PROBE has application as a multiple run management tool for other predictive models. The specific applications of PROBE to FORCYTE-11 are discussed below.

4.1 Database Development and Management

In FORCYTE-11, the initial ecosystem conditions and the forest management activities are defined in input data files. With PROBE, the user can assemble libraries of different ecosystems and management options. For example, nine different management regimes may represent the combination of three levels of fertilization each with three levels of thinning. Using the PROBE program PREPARE, the user defines a file with the default management options and then specifies how each of the nine management regimes (cases 1-9) differs from the default data files. In future simulation runs, each management regime can be referenced simply by its case number, rather than reassembling the desired data each time. Similarly, different initial ecosystem states can be pre-established. There is no limit to the number of cases that can be defined in such libraries of management options or ecosystem conditions.

Because PROBE also manages the output from FORCYTE-11 runs, it can be used to develop libraries of the ecosystem simulation results. These describe ecosystem responses (e.g., growth curves) to different management options.

4.2 Sensitivity Analysis and Management Gaming

Other practical applications for PROBE include sensitivity analysis and management gaming. Sensitivity analysis investigates the response of the forest ecosystem simulation to changes in various input parameters (as in Apps *et al.* 1988). Management gaming may be regarded as a subset of such analysis, in which the run conditions are

specified by management scenarios (see Figure 1). Such analyses often require large numbers of runs. PROBE is being used to prepare and run a factorial simulation experiment with Balsam fir in Newfoundland (Pike and Meades, this volume) with 96 sets of output data: 2 harvest intensities X 4 thinning regimes X 4 fertilization rates X 3 rotation periods. PROBE allows the user to conduct such a large experiment with minimum effort. The data produced by such an experiment are easily compared using DISPLAY. By developing a management options database with PREPARE, the user does not have to run the whole experiment at once. Initial runs can be selected to test various management options, and changes to the data can be made before the main run is executed.

4.3 Evaluating Input Data Requirements

STEMS* is being tested as an input data generator for FORCYTE-11 (Grewal *et al.* this volume). Multiple runs are needed to evaluate the output from STEMS* developed with different biomass equations and PROBE is used to facilitate this analysis. The STEMS* data are incorporated with the FORCYTE-11 input files using data case overlays. DISPLAY allows output from different runs to be compared graphically (Figures 3 and 4).

4.4 Future Directions

A future direction may be to integrate PROBE into an Artificial Intelligence (AI) shell. One approach would be a three tier structure in which ecosystem simulation is performed with FORCYTE-11 or other forest ecosystem model. PROBE would be at the next level, and would set up data cases and manage the multiple runs. At the highest level would be an AI "inference engine" which would help the user organize and query the simulation results which form part of the knowledge base.

As mentioned previously, PROBE can be used to generate a library of ecosystem responses such as growth curves. This may help FORCYTE-11 tie into regional forestry models by allowing the aggregation of stand information to provide whole forest predictions within a GIS framework. COMPRESS provides the proper storage technique; DISPLAY is the tool by which output is assembled and analyzed. DISPLAY utilities could be used to transfer selected data to attribute files for integration with GIS models and regional forestry.

5 CONCLUSIONS

Forest managers are increasingly trying to avoid long-term environmental degradation of forest ecosystems while optimizing returns on their management effort. Various forest management options are best examined by comparing their expected future consequences using a predictive forest simulation model. This task involves setting up the model for a number of different conditions, executing the model for these conditions, generating the appropriate output and, finally, ranking and evaluating the simulated future ecosystem based on the perceived benefit of each. The strength of PROBE is that it supervises and expedites all the steps in this decision-making process. It also provides a framework for integrating large simulation models in other decision support tools such as GIS and AI.

Supervisory software such as PROBE becomes essential if complex ecosystem models like FORCYTE-11 are to be used by forest managers in real-world decision making.

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INTRODUCTION

Forest management strategies for biomass and bioenergy production should be evaluated in terms of sustainability and long-term environmental consequences. Predictive models such as FORCYTE-11 are being increasingly used to perform such evaluations. PROBE helps users to more efficiently examine the predictions and removes some of the technical complexities of running these models.

PROBE STRUCTURE

PROBE consists of a set of programs for IBM-PC compatible machines operating in the DOS environment. Its use with FORCYTE-11 is presented here.

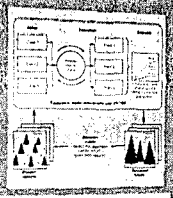


Figure 1. The role of PROBE in the forest management decision process

SET UP ACTIVITY:

- Potential management plans set up as input cases for simulation in MANAFOR.
- Different ecosystem conditions may be specified as cases for simulation in TREEGROW, PLNTGROW, and FORSOILS.
- User can specify single case or complex series of simulations using any of the simulation modules.

RUN TIME ACTIVITY:

- Unattended execution of multiple runs of the simulation model with user-specified input cases.
- Automatic archival of case output predictions in easily-accessed compressed files.

ANALYSIS ACTIVITY:

Menu-driven graphics utility helps the user to evaluate and interpret the simulation results by:

- Rapid browsing of large data files.
- Graphical comparison of all archived data.
- Selection of data for further analysis.

ANALYSIS ACTIVITY: continued

- Graph images saved, with annotated text.

APPLICATIONS

DATABASE DEVELOPMENT:

- Libraries for input cases: ecosystem conditions management options
- Libraries of simulation results.
- Potential application to GIS.
- Development of new calibration data sets (e.g. "STEMS")

SENSITIVITY ANALYSIS:

- Examine model behavior (sensitivity to calibration data).
- Examine understanding of ecosystem processes (sensitivity to process parameters).

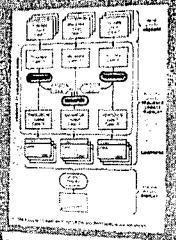
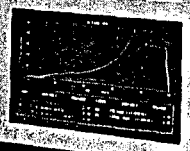


Figure 2. Overview of the FORCYTE-11 model and the PROBE supervisory software



MANAGEMENT "GAMING":

- For given ecosystem, rank management options against perceived results.
- Potential utility for integration within expert systems.
- Potential utility for aggregation of stand information to whole forest level management through GIS.

CONCLUSIONS

Forest management options are best examined by comparing their expected future consequences. PROBE expedites all the steps in this decision-making process. Supervisory software such as PROBE is essential if complex ecosystem models (FORCYTE-11) are to be used by forest managers in real-world decision making.

P1-9

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