THE ROLE AND USE OF MODELS IN DECISION SUPPORT

M.J. Apps and D.A. MacIsaac

1 Introduction

This paper addresses a discussion which was left unresolved at the first Forestry Canada Modelling Working Group Meeting (Ottawa, 1985): the use of basic research models in practical applications. In doing so, components of a larger question - the role of basic research in the decision making process — will be touched upon. The focus of this paper is on temporal dynamics and does not deal explicitly with spatial variation which has been discussed by other researchers in these proceedings.

The approach begins with an examination of differences between research models which are used for understanding (i.e. extend our knowledge of the world around us) and forecasting models that are used in decision support roles (i.e. to support actions to change the future). The role of forecasting models in decision support is briefly examined. An argument in favour of an ecosystem view for stand level predictions will then be given and illustrated with FORCYTE-11. A set of software utilities (PROBE) which codify the main steps for using simulation models in decision support is described. Finally, an example FORCYTE-11 ecosystem simulation is presented, to illustrate the advantages of this approach.

2 Scientific Research and Decision Support System (DSS) Models

Today's society exists in what has been referred to as the information age. Certainly, the information needs of society, as well as the availability of this information, are increasing very rapidly and this has driven an explosive development of electronic data systems to store and manipulate this information. Natural resource managers clearly can, and do, take advantage of these systems but in defining the role of research and models we must be clear on the relative meaning and use of data, facts, knowledge and wisdom in the decision making process. Figure 1, which has been adapted from Drew (1989), presents these levels of understanding in a hierarchical framework. The ultimate role of the decision maker is to exercise wisdom while integrating components from the lower levels.

Most of the questions that managers must face deal with the future outcomes of actions taken today — actions which are often highly technologically oriented and innovative. Current society emphasis is given to assessment of the long-term and large-scale impacts. In some instances (e.g., high yield, short rotation plantations), the managed systems are so beyond our historical experience that we do not have complete experimental data with which to empirically describe the future. Indeed it is a question of more than philosophical interest whether we can, or should, rely on experimental data alone. At least one author (Kimmins 1985) has pointed out that to do so in forestry would lead to the future shock described by Toffler (1970). In this context the role of research, and the challenge to the scientific community, is to find ways to feed the best and latest scientific knowledge into the decision-making process.

Scientists, however, face several traditional barriers in rising to this challenge. In the first place, scientists are generally trained to generate and test hypotheses. Predictions are made for testing their hypotheses rather than for selecting a possible future course of action. This is enhanced by the

Figure 1. Levels of Understanding

DATA - Recorded observations

FACTS - Data which have been verified and validated

INFORMATION - Facts communicated and shared

KNOWLEDGE - Information assembled, distilled, and tested

WISDOM - The judicious exercise of knowledge, using foresight and judgement

Adapted from Drew (1989)

traditionally conservative nature of the scientific approach. Although the really big scientific discoveries are made by seemingly monumental leaps of faith, most scientists prefer to stay on the safer ground provided by hard data. They like to deal with facts, and are not professionally well equipped to deal with opinions, speculation, and "guesstimates". Unfortunately, for many of the critical issues facing resource managers today, all the basic facts are not yet known. However, decisions must, and will, be made. This poses the following conundrum for the scientific community:

> The dilemma of mankind is that all facts are about the past, but decisions must be made for the future where the facts are not yet known.[1]

Professional decision makers also face this conundrum but embrace it as their stock in trade. They are less concerned about being wrong sometimes than with being right more often than wrong. If the facts of the future were known, the decision maker could be replaced by a set of rules (a program or a machine). This is where the wisdom part comes in — part of the decision process must include weighing a number of the alternative future's attributes, some of which may only be guessed at, against each other and against a set of selection criteria. This is an inherently non-linear process in which the successful manager employs a healthy dose of foresight and judgement.

3 Models for Understanding and Models for Forecasting

To try to evaluate how modelling might serve to help resolve the apparent conflict between scientific rigour and decision-making needs, two classes of models are examined: models for understanding and models for forecasting.

---

[1] Quoted in an address by Gordon Baskerville, Dean of Forestry, University of New Brunswick. He attributes it to Pille Binnel.

3.1 Models for Understanding

This class of models forms the basic building blocks of the scientific method. They are used for formulating ideas and for integrating knowledge and facts in a testable concept of the real-world system. Such models are intrinsic expressions of the hypothesis: "the inferred knowledge is a good representation of the real-world system under study". The predictors (also called monitors or output) of such models are testable indicators of the model performance because an underlying principle of the scientific method is to continually test the hypothesis.

In general, only an isolated portion of the total real world is considered, facts collected for this sub-system and the model built to encompass the knowledge that is gleaned from those facts. As such, the data for these models generally come from well controlled experiments — (i.e. the physical subsystem has a well-defined environment and well defined boundaries). These data can be in the form of recorded observations or may be previously established relationships (e.g., knowledge expressed in other models). In this sense, the models can be used to infer new knowledge from other knowledge and observed facts.

The underlying scientific approach is clear: assembly of a system concept, integration in a model of that system, use of the model to make testable predictions and comparison of the predictions against real-world observations. Again, the hypothesis being tested is the system "knowledge" and system concepts expressed by the model. The objective is to make the error term vanish:

$$\text{error} = \{\text{ Predicted Quantity }\} - \{\text{ Observed Quantity }\}$$

Such a vanishing error term is sought not only in a quantitative sense but also in terms of the completeness of the understanding and concepts. We seek to be able to "explain" with arbitrary accuracy (subject to computational and theoretical limitations) as many aspects as we can of what we think is objective reality. The purpose of explanatory models and their output predictions is therefore to make a prediction which can be tested against actual data.

3.2 Models for Forecasting (Predictions for Decision Support)

Forecasting models differ from explanatory models in several important ways, which are described below. The quotation by Baskerville given earlier suggests the importance of this class of models in a DSS. Remembering how the successful manager makes decisions for a future where the facts are not yet known leads to the following codicil which applies to decision support models:

The objective is not to be 100% right - it is just **not** to be 100% wrong.

A good example-by-analogy can be seen in terms of a financial investment. The investment broker (who represents the "model"), forecasts that a particular investment (i.e. management action) will lead to a healthy profit. An investor will probably tolerate being 60% correct, and accepting a modest gain, but will not accept suffering a significant loss. To some extent the investor's confidence in the broker is established by the broker's track record. More generally, however, the wise investor looks at the factors used by the broker in assembling a forecast as well as the broker's track record; the investor uses judgement in accepting a broker's recommendation.

A further piece of insight can be obtained from the investment analogy. Even though brokers will not give any guarantees (and perhaps not even an estimate in the uncertainty of their predictions), their information is of more use to the investor than that provided by analysts who explain with 100% precision the prices of yesterday's stocks, but won't make any guesses about tomorrow's. In Bill Meades' (ForCan, NeFC) words:

> FORESIGHT with some uncertainty is more valuable
> than HINDSIGHT without error!

Models for DSS must be able to compare multiple options. They can't focus on just one solution because if there are no options (choices), then there is no decision to be made and there is no need for the decision-maker, let alone a decision support tool! The job of DSS models is to provide estimates of possible alternatives between which the decision maker can make his choice. The results of such models are used to help select a perceived future — i.e. to support taking current action. (Contrast this with the testing-against-reality use of research model's predictions.)

Obviously, the quantities predicted by such models must meet the application needs of the user. This requires that the model produces estimates to which the user can assign value attributes. Examples of such attributes include profitability, sustainability, wildlife habitat and environmental quality. These reflect the goals and other constraints of the decision process. In other words, the model must permit the user to rank the alternative future outcomes against a set of user-defined criteria and so choose between the alternative current actions.

Such models do not operate with real data because they operate in the time domain of the future. In fact, there may be as much, or more, uncertainty about these future conditions as there is about the correctness of the knowledge base embodied in the model. Put another way, assumptions must be made by the user both about the model itself and the future fact base on which it operates. This fact is often overlooked by both builders and users of forecasting models.

The role of models in the decision-making process is illustrated in Figure 2. The interventions or options (thinning levels 1,2,3) that a forest manager will consider are constrained both by an understanding of the system (including knowledge of new technologies) and by the manager's intuition as to what the future outcomes will be — their perceived benefits. In the example shown, option 1 is a particular thinning regime. The forest manager has some preconceived idea of what the consequence of thinning of some particular spacing is going to be (e.g., fewer but bigger, trees). But there are other options too: for example, thinning could be done at different spacings, the stand could be left alone or herbicides

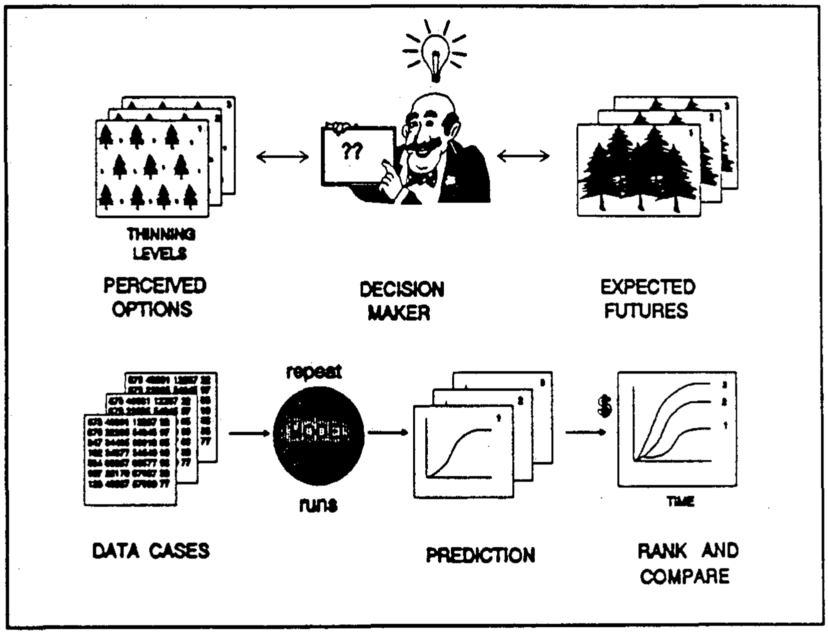


Figure 2 Simulation Models and the Decision Maker.

could be applied to suppress competition. Choosing one from amongst the many involves the comparison of a number of characteristics reflecting the management goals — such as volume of wood, stem size, mean annual increment or cost of treatment. In addition, the manager's options may also be subjected to environmental constraints such as maintaining site productivity or providing suitable wildlife habitat. How then does the forest manager rank the available options given such multiple criteria?

One of the roles of a DSS model is to try to put some numbers to the various alternative futures (encapsulate them mathematically). As shown in Figure 2, the available options are translated into input cases which can in turn be fed into the model. The model is thus used to provide fast-forward views into the possible futures. The predicted quantities relevant to the manager's needs, can be evaluated, compared and ranked for their perceived benefit— i.e. against a selection criteria. It is important to note that the function of the model is merely to support, or to challenge, the forest manager's hunches. It can not make the selection as this generally involves the trading-off of factors and benefits of which the model is ignorant — in other words, the ultimate selection requires the exercise of *wisdom*, generally considered a uniquely human trait.

3.3 Using Explanatory Models for Decision Support

Successful explanatory models can, and are, used as decision support tools. The reasons are very obvious. First of all, they use or encompass existing knowledge. That is, after all, why they are built— they are a statement of how the modeller thinks things work. Secondly, they are also good backwards predictors (i.e. they explain the data). If the data are recent, these models are good at predicting the current reality. Finally, as a corollary, if the future data are assumed to be like those of the past (in other words, if the data domain of relevant experiments up to now is echoed in the future), then they are the best possible forward predictor for peeking into the future. They work as well as they did with the past data—if the assumption of similar conditions is valid.

3.3.1 Pitfalls of Using Explanatory Models as Predictive Tools

1. The management interventions (options) that can be explored are completely constrained by the modeller's paradigm, or world-view. This viewpoint has a very definite impact on whether the explanatory model can be used for a particular predictive application. While perfectly adequate for the purposes for which the model was built (i.e. synthesis of information to generate knowledge), these options may not match the requirements of the resource manager.

   A stand model can be used as a simple example to illustrate this point. If the model has been assembled from stand yield data for a commercial tree species, it may provide an excellent tool for a woodlot manager interested in the expected yield of this species. It is unlikely, however, to include the necessary "levers and switches" that a wildlife manager may need to use the model as an aid in designing an ungulate management plan. This illustrates the different requirements of different management responsibilities — the same object (a forest stand) seen through different windows (manager's paradigm and needs), has different attributes highlighted.[2]

---

[2] It is useful to think of the model as a cartoon of reality - an abstract simplification which focuses on the perceived important factors. The cartoon's abstraction depends on the point the cartoon is trying to make.

This stand model may be used as a further example in which a second coexisting tree species, previously considered a "weed", becomes economically important. A whole new set of management options may be required — options whose effect on the forest may not be reflected in the past data records. Such changes may not have been considered in the original model because they were not part of the modeller's paradigm. One doesn't have to look further than the boreal mixedwood to find concrete examples of this phenomenon.

In addition, researchers (often the architects of models) and managers usually have very different training and have very different job responsibilities. In the exercise of their professional duties, they view the world through different "windows". Even within the narrower universe of the research scientists, widely different windows onto "reality" exist — compare for example the ecologists' description of a given stand with that of a biometrician.

2. The variables which are included in the output predictions may not suit the application needs. An example of this is a biological model that explains well the ecosystem structure and function of the forest. First of all, it is very unlikely that it will have cost and benefit analysis in it, which the woodlot manager of a sawmill company would probably want. Secondly, the temporal scale is likely to be inappropriate for this manager. Even a good explanatory model may not simulate the temporal dynamics that encompass the range that is required for a management model. For example, in stand management, the simulation should be at least one rotation, but an explanatory (or understanding) model, may not have any of that capability. If it does, it may require a Cray super-computer to execute the model simulation over the long time period required.

3. Potentially the most serious pitfall is that, for a given object of study, explanatory and predictive models encompass a different scope. To explain an object or phenomenon, the traditional scientific approach is to focus on the objects and events in space and time that are contained within and below the level of the object being explained. For example, to understand the growth of a single tree, the researcher looks inwards at the tree and its internal processes. The external environment is assumed to be under the control of the researcher (implicitly or explicitly). If the process being modelled requires light or a nutrient source, then it is assumed that those are supplied, and at best, they are represented as an external driving parameter. The system is bounded by an imaginary box that encompasses the phenomenon which is being modelled. Transfers are allowed in, but any processes outside that box are not included.

   On the other hand, if the purpose is to predict the object's behaviour, the system has to be expanded to include all the things that influence that object. To predict a real tree's growth, a representation of the tree's internal processes is still required, although not necessarily to the same level as detail as in an explanatory model. In addition, however, changes in the environment which affect its growth have to be included explicitly. To predict how a tree is going to grow, the effect of changes in supply of resources such as light, nutrients and moisture must be considered. In summary, the difference is that to understand a particular object, we look inwards; to predict we have to look outwards.

   The problem of scope can be further clarified by using the concept of "Levels of Biological Organization and Corresponding Levels of Integration". For example, the level of integration below an organism requires an examination of the objects and events at the organ level. To understand the tree, physiological processes such as transpiration, assimilation of nutrients and translocation of photosynthates have to be considered. If the objective is to understand above that, then we must look outwards.

The question that immediately arises is "What is the appropriate level of integration looking outwards (above the individual or organism)?" This was well answered by Rowe (1961), who stated that the appropriate level of integration above the organism is the ecosystem (the organism and its environment).

4 Ecosystem Models for Stand-Level Predictions

It follows from the above ideas that, in order to forecast the development of a tree species at the forest stand level (i.e. model for predictive purposes), the tree species and its surrounding environment have to be considered. This simple concept means that a management intervention (some action at the forest stand level that affects the individual trees), affects not only the internal processes of the tree species under consideration, but also processes that are taking place throughout the stand (e.g., litter decomposition). This affects the other tree species, understorey plants, soil and the associated ecosystem processes, all of which add up to influence the managed tree species. In other words, management intervention affects more than just the target species and is likely highly non-linear.

Management intervention are the actions that are possible within the system being simulated. This in turn, determines the components and processes that must be included in the ecosystem model. The model defines the scope of the expanded system and is constrained by the modeller's concept of the system. If climatic effects are not in the modeller's paradigm, then temperature and moisture fluctuations caused by climatic change will not be considered.

Unfortunately a paradox arises: ecosystem models tend to be nearly as complex as the systems they are trying to simulate! The ecosystem model FORCYTE-11, which is discussed below, has been accused as being a leading example of this particular phenomenon.[3]

5 The FORCYTE-11 Ecosystem Model

FORCYTE-11 is a complex stand-level ecosystem model that was developed by Hamish Kimmins and Kim Scoullar under contract to Forestry Canada.[4] This model is currently under evaluation at several Forestry Canada centres, including an assessment of its ability to predict medium to long-term consequences of different management practices.

FORCYTE-11 is actually a system of models, as is shown in the structure diagram (Figure 3). The modules "TREEGROW, PLNTGROW, BRYOGROW and FORSOILS" are descriptive growth sub-models which are calibrated with empirical data. They encompass the knowledge ("fact base") of the past. The output from these are input into a simulation program module called "MANAFOR" (MANAgement of the FORest). Several trees as well as understorey plants, mosses and the soil component can be included in a single ecosystem simulation. MANAFOR links the output from these descriptive models by process simulation which explicitly includes nutrient dynamics and light com-

---

[3] The objective in this paper is not to explain, defend or criticize FORCYTE-11, but to use it as an example of ecosystem-level process simulation.

[4] Forestry Canada, NW Region. Scientific Authority: M.J. Apps. This work is supported (in part) by the Federal Panel on Energy R&D (PERD) through the ENFOR (Energy From the Forest) program.

petition within the canopy. In other words, the descriptive past growth records that were encompassed at this ecosystem level are manipulated within MANAFOR. If management interventions (in the MANADATA file) cause changes in the ecosystem from which these data were collected, then it will simulate the change by perturbing the past growth records through competition for light and nutrients in proportion to the changes in conditions. This is done through a "phenomenological look-up" approach in which "empirical rules" calibrated in the setup modules are applied when growth conditions change (Figure 4). This dynamic approach is further explained in Figure 5. The change in a state variable over time (e.g., stemwood biomass) is perturbed by new growth conditions.

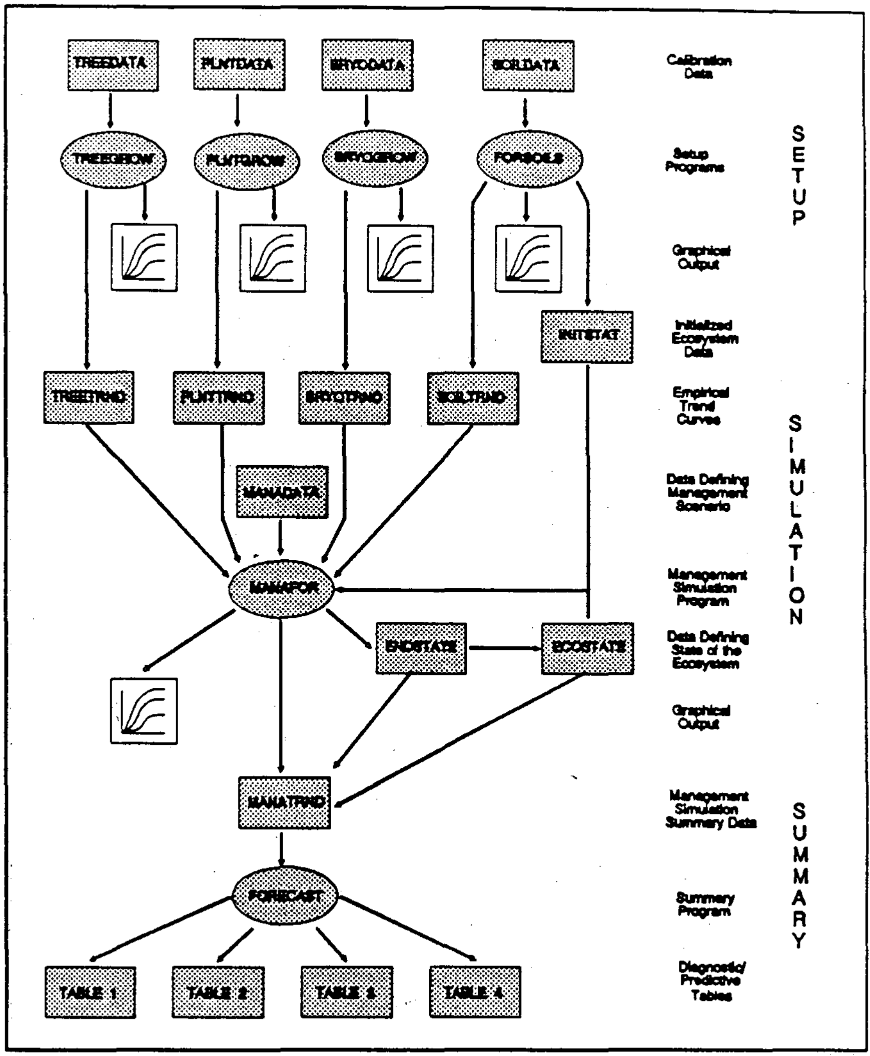


Figure 3 Structure of FORCYTE-11 - Program Modules and I/O Files. (Diagram courtesy of Bruce Pike.)

While temperature effects and moisture competition are two other important determinants of plant growth in ecosystems (for example, they influence stand productivity, species assemblages and litter decomposition rates), they are not simulated within the model (although their effects are implicitly contained within the input data). This is an example of a phenomena mentioned earlier, which is that they were not in the viewpoint (or paradigm) at the time the model was originally constructed. More recently, it has became apparent that these two ecosystem processes should be included in a model of this type, particularly given the possibility of accelerated climate change. The paradigm upon which the original model was based does not allow some of the current questions to be answered.[5]

---

[5] In fairness to Kimmins and Scoullar, temperature and moisture were in their paradigm and their long-term plans were to include them in future model development.

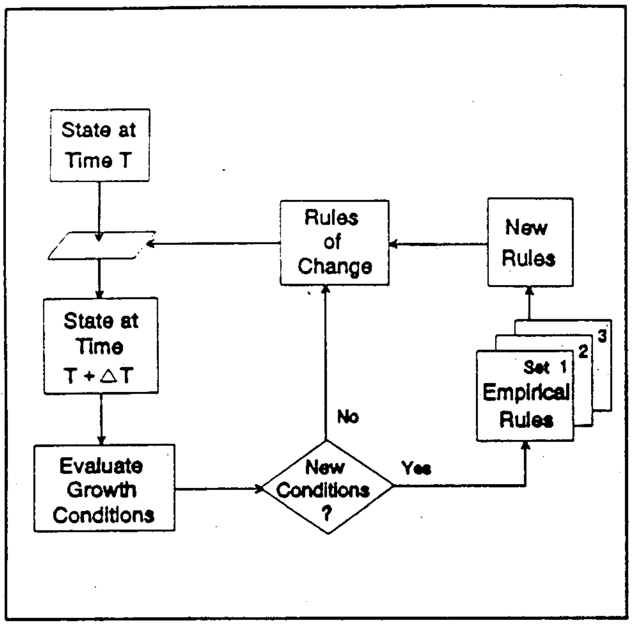


Figure 4 FORCYTE-11 Dynamic Rules of Change

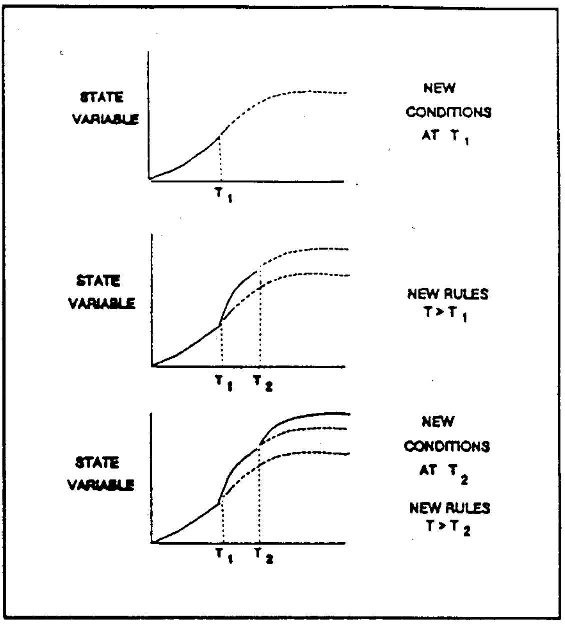


Figure 5 Dynamic Simulation in MANAFOR

6 The Decision Support Process and PROBE.

As shown in Figure 2, the use of ecosystem simulation models in forest management decision-making requires that numerous data cases be set up, multiple models runs be conducted, and the predictive output ranked and compared. With complex models such as FORCYTE-11 this is almost impossible without some computer assistance. To allow users to more efficiently execute multiple model runs and handle the large amount of output data, a supervisory software package (PROBE) has been developed (Apps et al. 1988, Kurz et al. 1988, MacIsaac et al. 1990). PROBE 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.

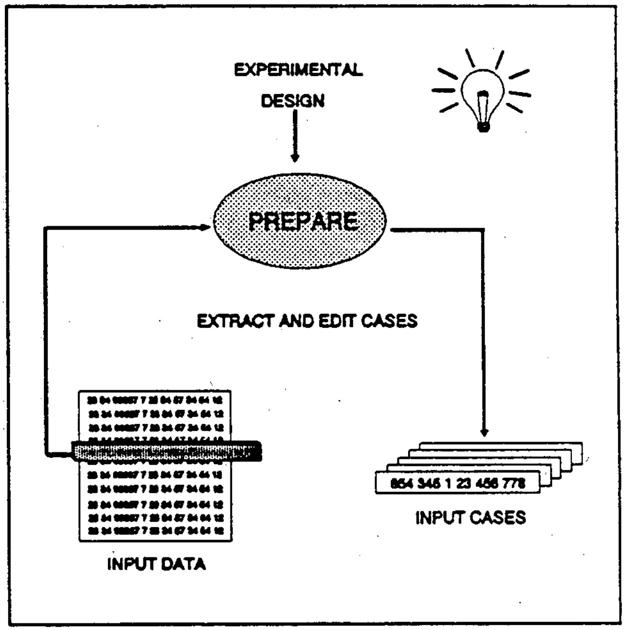


Figure 6 PROBE Set Up Activity

The functions of PROBE can be divided into three main activities: input data preparation, multiple run execution, and output data analysis. Each activity is facilitated by specific programs (PC-compatible, run under DOS) and associated files.

Data Preparation:

Using the utility program PREPARE, the user can define specific data changes (case overlays) to the original data set (default input files) needed for each program module run (Figure 6). This allows users to create a database of input options. The case descriptions are stored, and at execution time are used as overlays to modify the input data files.

Program Execution:

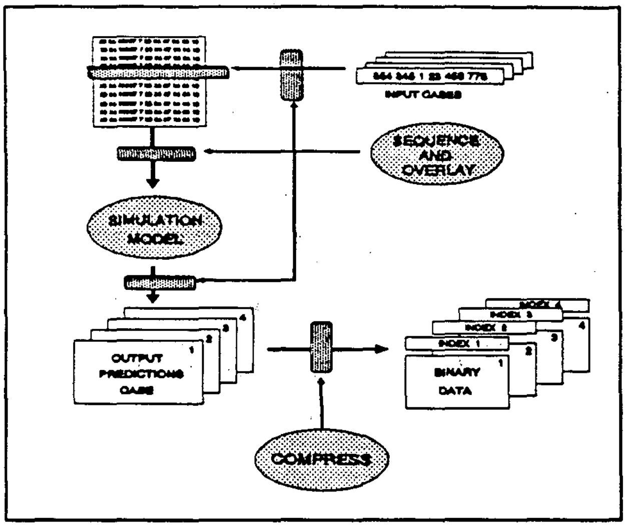


Figure 7 PROBE Run Time Activity

PROBE controls the execution of the FORCYTE-11 program modules and the production of output data files through the programs OVERLAY, SEQUENCE and COMPRESS. SEQUENCE permits the unattended execution of one or more FORCYTE-11 program module runs (an experiment) in a user-defined sequence. The specific input data files for each module run are created with OVERLAY which incorporates the specific case-specific data into default data sets.

COMPRESS 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. This is done 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 (Figure 7). The compressed files have been structured to make them suitable for further data analysis.

Output Data Analysis:

DISPLAY is an interactive program used 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 (Figure 8). It then allows the user to easily and quickly choose, graphically display, browse through and numerically manipulate any combination of variables from FORCYTE-11 module runs. DISPLAY has been designed to show dynamic trends (variables *vs* time) or to plot relationships between variables (e.g., stand density *vs* foliage biomass). It also permits numerical manipulation of the data, for example, changing scaling factors.

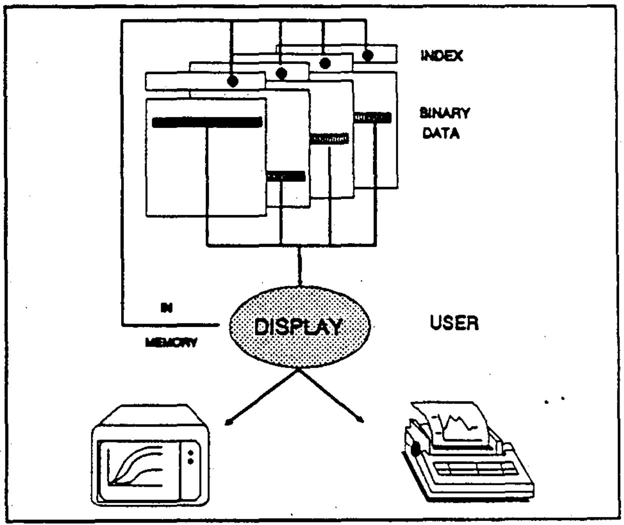


Figure 8 PROBE Analysis Activity - DISPLAY MANAGER

DISPLAY greatly enhances the usefulness of the original FORCYTE-11 output by making the output results more readily accessible for analysis and interpretation. As well, this 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.

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. 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.

The PROBE utilities are being modified for use with any ecosystem simulation model which requires repeat runs with many data files. It can be used for a variety of purposes, including: development and management of "libraries" containing different input data cases (ecosystem and management data) and ecosystem simulation results, sensitivity analysis and management gaming.

7 FORCYTE-11 Simulation Example

For an example of how predictive models embrace both data and process modelling, a simple two-tree ecosystem simulation using FORCYTE-11 is used (with understorey not represented). It consists of a commercial coniferous species and non-commercial nitrogen-fixing deciduous species.[6] The forest manager's mandate is to maximize the return on the investment (i.e., maximizing the conifer yield subject to minimizing costs). The environmental constraint imposed on him, however, is to demonstrate that site fertility can be sustained over multiple rotations. In this example the forest manager has two very simple management options:

1) Eliminate the deciduous species by herbicide treatment at the start of each rotation to remove light competition with the conifer.
2) To obtain benefits of nitrogen input but reduce effects of light competition later in the rotation, let the deciduous species grow for 20 years, then cut it down and leave the slash and stems on the forest floor.

In both cases, the simulation is composed of three 100 year rotations, with the conifer harvested at the end of each rotation (stemwood and branches removed).

The forest manager would be hard pressed to find field data that could allow him to rank between those two alternatives (if such data exist at all). This manager has to somehow compare the future scenarios and make a decision (even if it is not the best one). This can be done by simulating the proposed silvicultural prescriptions using the FORCYTE-11 program MANAFOR. The specific

---

[6] This simulation example is based on a preliminary data set for Douglas fir and red alder (Kimmins et al. 1989a, 1989b). The data have not been verified and confidence has not been determined.

initial stocking and management interventions are defined in the MANADATA file and in case overlays using PREPARE.

7.1 Results

FORCYTE-11 simulation results indicate that at the end of the first rotation, conifer yield (as expressed by stemwood biomass) is slightly better when the competing deciduous species is allowed to grow until year 20 rather than removed at the start of each rotation (Figure 9). This trend is magnified over the next two rotations, so that by the end of the third rotation, the conifer yields when the deciduous species is allowed to grow early in the rotation is approximately 25% better than in the case where it is removed at the start.

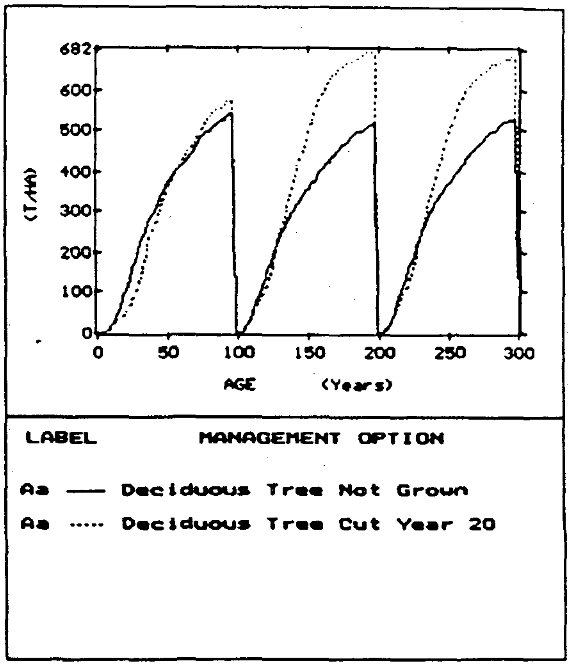


Figure 9 Example Mixedwood (Coniferous and N-fixing Deciduous Species) Simulation With FORCYTE-11. Variable Shown is Stemwood Biomass.

When the conifer is released at year 20 in each rotation, there is an immediate increase in stemwood biomass because there is no longer any competition for light. As well, the portion of the nutrient pool that has been captured by the deciduous species (now contained within the slash) is released as a nutrient "pulse" and is available to the coniferous species. When the deciduous species is used as a "nurse crop" the conifer yield is not only higher, but it increases faster (and MAI peaks at an earlier age). This is believed to be due to site quality improvement associated with the nitrogen-fixation by the deciduous species. From a forester's perspective, it means shorter rotations may be possible.

7.2 FORCYTE-11 Summary

The FORCYTE-11 model illustrates an approach to simulation of the resource competition of light and nutrients at the ecosystem level. The flexibility that this approach uses is very important. "Hard" data can be combined with knowledge and wisdom to try and get a better insight into what might happen in the future. This information is provided to help managers to make decisions for the future. It allows decision makers to explore different options to reinforce or to challenge their hunches. Both the short- and long-term effects of management options can be examined and compared. In this particular example, in both cases, site fertility did not degrade, and in fact, the presence of the nitrogen fixer improved the site fertility over time — something a researcher might have to wait a number of years to prove using a field experiment approach. The approach used by FORCYTE-11 makes it attractive as a potential tool to help in decision support. Whether it will actually is used by forest managers, will depend, in part, on the outcome of the current Forestry Canada evaluation of the model, and the availability of calibrated data sets for the user's area of interest.

8 Conclusions

There are many changes in the factors affecting the Canadian forest industry at present, including: growth in world fibre demand, increased competitiveness to supply the resource, changing public environmental awareness (which lead to constraints on the forest industry) and technical developments in the available silvicultural and harvesting procedures (which allow more sizes and types of materials to be used in manufacturing finished products). These factors, leading to an intensification of management, will require smarter resource management decisions -- ie. require decision makers to be better informed about possible future consequences. Data is required to help in the decision making process but past data may not accurately describe future conditions. Managers may not be able to wait for experimental data to become available and forecasting models, therefore, will be increasingly required to address decision needs. These models, which must predict forest-stand dynamics, should operate at the ecosystem level. They have to encompass more than simply the tree species of interest because of the ecosystem interactions.

The changes described above are going to put pressure on scientists to meet two tasks. Task one is to provide the best possible estimates of the future, even if they have to be built on "mushy" (unproven and speculative) science. The alternative will be to let those decisions be made on the basis of corporate goals or government policy without the benefit of current scientific insight. Forecasting models which incorporate this insight, even if based on expert speculation can be used to assist in the decision making process. This leads, however, to the second task, which is to identify the "mushy" parts and to find ways to replace them with solid scientific foundations. In other words, scientists should state their opinions while being careful to differentiate between speculation and confirmed knowledge. We can take encouragement from the knowledge that our job is not to be 100% right, it is just not to be 100% wrong.

References

Apps, M.J.; Kurz, W.A.; Kimmins, J.P.; Scoullar, K.A. 1988. User friendly applications of the FORCYTE ecosystem model on a microcomputer. Pages 263-269 *in* S.R. Shifley and T.E. Burk, editors. Forest Growth Modeling and Prediction Proc. IUFRO Conference, August 23-27 1987. USDA Tech. Rep. NC-120, Minneapolis, MN.

Drew, T. J. 1990. So the strategies for mixedwood management are... Proc. Northern Mixedwood '89 Symposium, Fort St. John, B.C. Sept 11-14 1989.

Kimmins, J.P. 1985. Future shock in forest yield forecasting: the need for a new approach. Forestry Chronicle **61**(6):503-512.

Kimmins, J.P.; Price, N.; Apps, M.J. 1989a. Red alder. A selected bibliography and compilation of literature data for use in conjunction with the ecosystem management model FORCYTE-11. Unpublished Contract Report, Forestry Canada, Northwest Region, Edmonton, Alberta.

Kimmins, J.P.; Price, N.; Oran, R.; Apps, M.J. 1989b. Douglas fir. A selected bibliography and compilation of literature data for use in conjunction with the ecosystem management model FORCYTE-11. Unpublished Contract Report, Forestry Canada, Northwest Region, Edmonton, Alberta.

Kurz, W.A.; Apps, M.J.; Chan, Y.H. 1988. PROBE: A program to facilitate user-friendly gaming with FORCYTE. Pages 160-164 *in* Granger, C., editor. Proc. Sixth Canadian Bioenergy R&D Seminar, Richmond B.C. Feb 16-18, 1987. BC Research, Vancouver, B.C.

MacIsaac, D.A.; Apps, M.J.; Kurz, W.A. 1990. Updated PROBE utilities for evaluation of forest management using FORCYTE-11. pp 193-198 in E.N. Hogan, editor. Proc. Seventh Canadian Bioenergy R&D Seminar, Ottawa, Ont. April 23-25 1989. Energy Mines and Resources Canada, Ottawa, Ont.

Rowe, J.S. 1961. The level-of-integration concept and ecology. Ecology **42**:420-427.

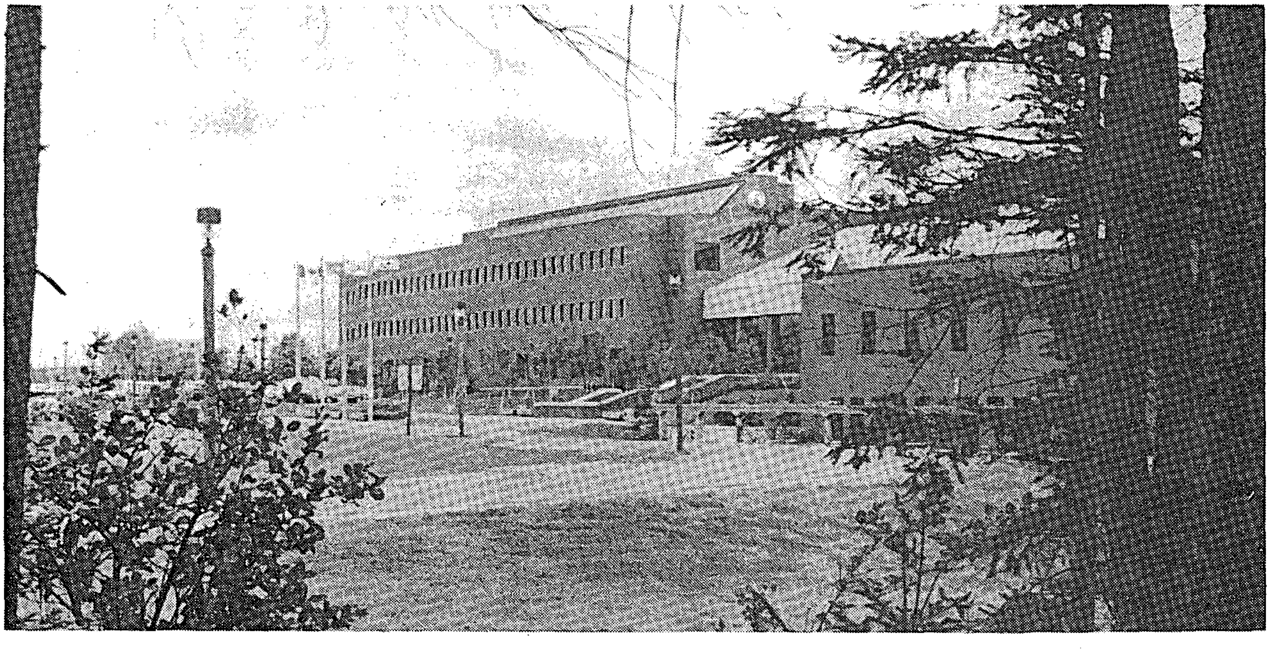
Toffler, A. 1970. Future shock. Random House, New York. 505 pp.

[redacted]

FORESTRY CANADA
MODELLING WORKING GROUP

PROCEEDINGS OF FOURTH MODELLING WORKSHOP

HUGH JOHN FLEMMING FORESTRY CENTRE
FREDERICTON, NEW BRUNSWICK
24-25 OCTOBER 1989



Forestry Canada - Maritimes Region
P.O. Box 4000
Fredericton, New Brunswick
CANADA E3B 5P7

Forestry Canada Forêts Canada

Canada

[redacted]