The SYMFOR Framework for Modelling the Effects of Silviculture on the Growth and Yield of Tropical Forests.

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Abstract. SYMFOR is a software framework allowing forest managers and policy makers to simulate the effects of silvicultural treatments on mixed tropical forests. The framework is designed to use Permanent Sample Plot data and house individual-based, spatially explicit models of silvicultural treatments and ecological processes. The framework and models are presented through a Windows-based User Interface with on-line documentation. The framework represents trees on an individual, spatial basis allowing models to represent practical and theoretical forest management explicitly. This is of particular importance for tropical forests where the high biodiversity makes the forest spatially complex.

In many areas of the tropics, new forest management methods are being implemented without knowledge of likely outcomes. SYMFOR enables trials to be simulated, permitting comparisons between alternative management regimes, and allowing the examination of the likely effects or outcomes resulting from silvicultural treatments. Predictions of yield, forest structure and composition in both the immediate and the long-term are possible using SYMFOR and are essential for informed forest management decision-making. These estimates can be combined with analysis of likely financial, economic and social outcomes to assess the likely sustainability of forest management regimes.

The core structures of the SYMFOR framework allow modellers to add new processes or models using a simple procedure at design time. The choice of models and their associated parameter values are made or loaded at run-time. The user interface handles data input and output, graphical displays and model selection and definition. The core structures of the SYMFOR framework and an overview of the user interface are presented here.

1 Introduction

Forest management involves decision-making that has consequences far into the future. In order to make informed decisions relating to the sustainable use of forest resources, forest managers or decision-makers require knowledge of the state of the forest immediately before management interventions, and predictions for a substantial period into the future. Field trials require at least one cutting cycle (30-50 years) to produce this information. Forest managers, policy and decision-makers cannot wait for field trials to complete one cutting cycle and must rely on statistical analysis and simulation modelling using data from permanent sample plots and static inventory. Forest managers are increasingly being asked to implement new management regimes that do not have recorded precedent in a comparable forest type, and thus they do not have access to information from appropriate field trials. In this case, simulation modelling offers the only approach that can make predictions of likely outcomes (timber yield and forest structure) and to assess the ecological sustainability of management regimes.

Simulation models of tree growth, mortality and the recruitment of young trees into the ecosystem allow the prediction of the changes in ecosystem structure with time. Such models can be combined with models of silvicultural treatments to permit users to evaluate likely outcomes from various forest management regimes. To enable this, a framework to house the models and interact with the users was required. The SYMFOR framework was designed to meet this need and the needs of potential forest management clients for new knowledge (forest managers and policy-makers).

1.1 Design criteria

The clients for the SYMFOR framework and for new knowledge generated by its application to assess forest management practice were determined to be:

National Level

- Forest Managers (Industrial and community scale forest enterprises).
- National and regional policy makers (Government).
- Advisors to forest managers. (Local consultants, NGO's).
- National forest certification bodies.
- Research organisations (including model developers).
- Educational organisations.

Regional and International Level

- International development projects.
- Research organisations.

The SYMFOR framework needed to be able to meet differing requirements from these clients. Forest managers wanted to predict the likely timber production (yield) resulting from particular management strategies, whereas certification bodies are more interested in examining issues relating to sustainability such the future state of the forest and their links to social criteria. Policy-makers need to combine these issues and balance them against other competing land-uses and the need to generate income to finance regional and national development. Forest research organisations were also concerned with biodiversity and habitat loss.

The framework had to be capable of producing output that could be interpreted for all these applications, and yet be simple enough to use that no significant learning curve was required in order to use it. Extensive on-line documentation was required to fully explain the framework, the models within it, its operation and the procedure for obtaining useful results from SYMFOR. A straightforward method for integrating new sub-models was required for model developers.

The needs of the clients meant that a framework was required for models of natural forest behaviour and silviculture that used Permanent Sample Plot (PSP) data, was individual-based and allowed the user to define the silvicultural model at run-time. In addition, it had to present graphical displays, incorporate at least one model of natural forest processes and output data at any stage for further analysis. The framework was required to operate under 32 bit versions of Microsoft Windows™ (Windows 95, 98, ME, NT and 2000).

1.2 Existing model frameworks

Modelling environments such as Stella (High Performance Systems Inc., 1999) or Modelmaker (Cherwell Scientific Ltd., 1999) are suited to model development, but not to the production of user-interfaces required for our clients. At the time of development of the current study, AME (Muetzelfeldt and Taylor, 1997a and 1997b), was not sufficiently developed to be considered for use.

Houllier (1999) describes a framework for modelling silviculture that meets most of the requirements described, but it was not available when the current study began. Young and Muetzelfeldt (1998) produced an early concept of the SYMFOR modelling framework (SYMFOR 2.1) designed to allow the development of forest growth models. Other difficulties were that it required the end user to actually compile the selected model. The user-interface of their system has been taken as a starting point and the name adopted for continuity purposes, but otherwise the system described here is original.

2 The SYMFOR framework

The User Interface (UI) for the SYMFOR framework was written in Microsoft Visual Basic™, and controls all aspects of the interface with the user: selection of data input files, control of data output, selection and definition of the silvicultural and ecological models and graphical displays. The user interface linkes to the SYMFOR Dynamic Link Library (DLL) which was written in Microsoft Visual C^{++}™, and contains the core framework that houses models and their associated data.

2.1 The core framework

2.2.1 Model components

The framework was based on three classes of object:

- swappable function: representing the requirement of the presence of a sub-model;
- module: representing a particular sub-model;

- parameter: representing a constant value required by a particular sub-model. These may have more than one value when a component of a model is calibrated to separately for each species group.

Swappable functions represent the processes that are modelled in the framework. Each swappable function in the framework must have at least one module to satisfy its purpose in a given simulation. A module is a particular algorithm for calculating a value or simulating a process to satisfy a swappable function. There may be several modules for a particular swappable function, but only one may be used in a given model. Alternative modules for a given function may lead to different results as they use different algorithms.

Module parameters are numeric quantities that must remain constant throughout a single simulation. Typically these are coefficients in the model equations or test values in an algorithm that comprises the module. A module may have one or many parameters, or it may have none. The choice of modules and the value of their parameters are set at run-time, allowing consecutive runs to be made using different models. Figure 1 is a schematic diagram showing the formal relationships between swappable functions, modules and parameters.

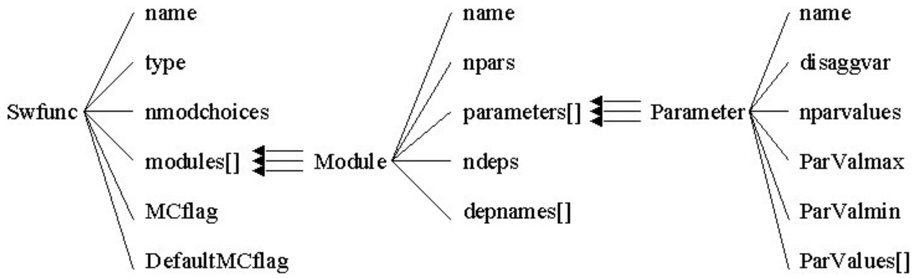

Fig. 1. The swappable function (swfunc), module and parameter classes, and their relationships. Only swfunc objects are declared explicitly in the code, because they contain module objects, which in turn contain parameter objects.

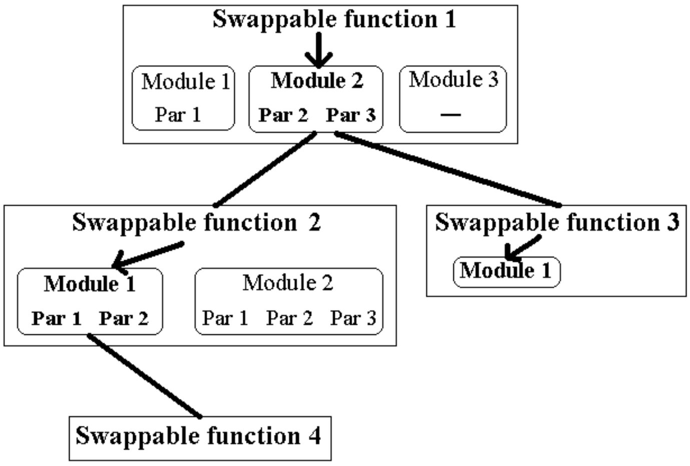

Fig. 2. Schematic diagram indicating the relations between swappable functions, modules and parameters. Parameters are abbreviated to "Par". The relations are only shown in full for swappable functions 1 and 2; for swappable function 3, module 1, the parameters are omitted; the "swappable function 4" label indicates only the requirement of a process external to module 1 of swappable function 2 and does not show a module choice.

The set of possible swappable functions, associated modules and associated parameters is defined at design time (before the code has been compiled). The framework operates on an annual time-step. There are currently six swappable functions that are used every year of simulation in every model:

Management Options swappable functions:

- Harvesting;
- Thinning;
- Clearing strips;

Ecological swappable functions:

- Tree growth;
- Recruitment;
- Mortality.

Depending on the particular module used for each swappable function, further swappable functions may be required. Figure 2 gives an example of the structure built up by the core framework components.

2.1.2 Model definition

Within the framework, a "*model*" is specified by the set of modules that are chosen to fulfil the requirements of the swappable functions, and the values of their parameters. The framework allows the user to save sets of module choices (one module per swappable function) and sets of values of parameters. It is also possible to save a model, defined by the choice of module set and parameter set. The management options and ecological models are separate, so for a simulation the user needs to specify one ecological model and one silvicultural model.

2.1.3 Forest object classes (data)

Data stored by the DLL include information describing the trees and the stand, and quantities that are derived from these data or generated automatically. There are five types of tree objects and three other forest data objects defined in the SYMFOR framework:

Tree Objects:

- *livetree* A normal living tree;
- *fallentree* A tree that died from natural causes other than due to damage;
- *smashedtree* A tree that was killed by damage, either from another tree falling on it, or from logging operations;
- *felledtree* A tree that was logged and extracted from the forest;
- *killedtree* A tree that died from silvicultural thinning techniques (e.g., poisoning);

Other Objects:

- *stand* Describes data relating to the whole stand;
- *skid-trail* The area left when a felled tree has been dragged out of the plot;
- *grid-square* A modelling sub-unit of the area of the plot, normally 10 m by 10 m in size.

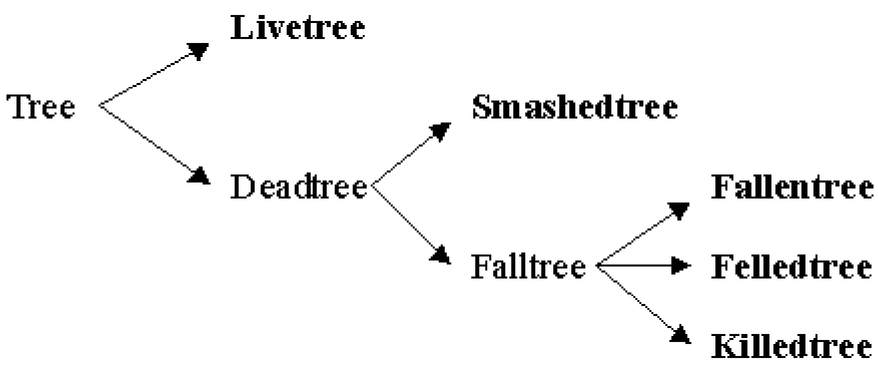

Fig. 3. The class hierarchy of tree objects. The classes that actually have instances are shown in bold.

Figure 3 shows the class hierarchy of tree objects in the SYMFOR framework. A full description of the attributes of each class of objects is given in the SYMFOR on-line documentation (Phillips *et al.*, 1999). "Livetree" data are input to the simulation, and other objects are created during the simulation. Objects within one of the four classifications of dead tree are created as required, and the extra information about their death is stored as attributes for each data object.

There is only one stand per simulation, and so simulating progression in more than one stand requires additional simulations. The grid-squares are typically used to define areas for recruitment using a stochastic approach. Skid-trails are areas of damage that may be created during logging activity. Models and sub-models may use any of these objects, their attributes and functions in their operation.

2.1.4 Functions provided by the core framework

A common problem for most spatially explicit models relates to the effects at the edge of the simulated area. This is particularly obvious for processes such as competition where trees in a simulated stand will experience less competition unless an allowance is made for this "edge effect". In the SYMFOR framework, functions are provided for modules to use to simulate a "wrapped" plot. That is, the east side is mapped onto the west side, and the north side is mapped onto the south side; similarly the corners are mapped to the opposite corner. This method assumes the plot size is larger than the influence of a single tree.

2.2 The User Interface (UI)

The SYMFOR UI is the program that the user executes and then uses to simulate forest activity over a period of time. The UI is used to specify the model, via module choices and parameter values, and to set details for each simulation including the length of simulation period, choice of data files and the specification of output from the simulation. Modules implemented in the SYMFOR framework may contain stochastic components that require several simulations to establish average results. This process is simplified through the provision of a "multiple-run facility" that automates repeated simulations for individual plots and sequential simulations with replicate plots.

The UI contains graphical displays that allow exploratory data analysis of data within the framework as the simulation progresses. The UI can produce graphs of user-specified quantities (such as total stand volume) as a function of simulated time. Histograms can display frequency distributions of data (e.g., the number of trees as a function of DBH) and a map display (see figure 4) can show any of the spatial forest features (including all tree types and damage from tree-fall and a management intervention). Tables can be defined to summarise stand data in the form of a stand table or may alternatively display information in detail, listing all attribute values for each instance of a particular class, for example all "livetree"s.

All settings may be adjusted from within the UI environment, allowing the user to customise the software. The settings that specify the model and display characteristics are stored in text files that can be managed through features allowing editing of saved configurations.

2.2.1 Data input

Data input and output is performed using text files, or via Open Database Connectivity (ODBC) (Microsoft Corporation, 1997) software. ODBC provides a common interface for data between databases. The DLL can use ODBC to read from and write to database tables in many database formats, including Microsoft Access, Excel, dBase IV or FoxPro. The initialisation data table must contain the specified column headings, as stated in the on-line documentation (Phillips *et al*., 1999).

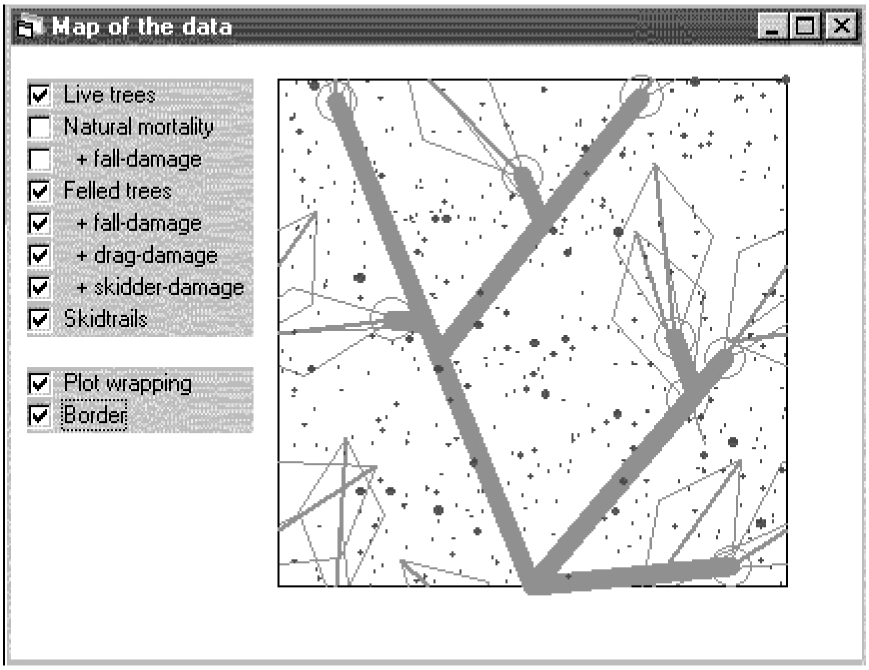

Fig. 4. Showing the “plan view” (from the SYMFOR UI) of the data during a simulation of planned logging. The dots represent trees, the solid grey lines represent skid-trails and the hollow grey shapes represent areas of damage caused by falling trees.

Two input data tables are required: individual tree data and stand data. Trees are specified by their x and y co-ordinates, diameter at breast height (DBH), species or species group number, a unique identifying number and an "utilisation group". This minimal data definition is based on the data that are typically collected from PSPs in Indonesia (Alder and Synott, 1992). The stand data table contains a single row, specifying the minimum and maximum co-ordinate values of the plot, the number of years since the plot was logged and the number of live trees remaining after logging. Data validation is performed following data input, when values are checked against specified limits.

2.2.2 Data output

The user can specify up to 5 output tables, each of which can contain up to 30 columns containing data from forest object attributes or functions. In addition to data describing objects, there are three variables needed for post-simulation data analysis. These specify the reason that data have been output, the identifying number of the simulation and a count of the number of times data have already been output during the current simulation. The data can be output at any one, or more than one, of the following times during simulation:

- At regular time intervals (the interval is selected from an extensive list from 1 year to 50 years);
- Immediately before a management treatment;
- Immediately after a management treatment;
- At the beginning of a simulation;
- At the end of a simulation;
- At a fixed time interval following each logging operation.

The user thus has complete control over the nature, extent and timing of the data output from the simulation. This flexibility allows the user to utilise the detail encompassed by an individual-based spatial model, such as gap dynamics, species composition and regeneration rates, the effect of skid-trails, replanting or strip-clearance and damage zones.

3 Results and Discussion

3.1 Existing SYMFOR models

The default model was deliberately designed to do nothing (there is no growth, no recruitment, etc.), so that users are forced to make an active decision regarding which model to use. An ecological model has been developed based on data from East Kalimantan (Indonesian Borneo) (Phillips *et al*., 2001). There are proposals to make similar models based on data in Guyana, Brazil and Bolivia. As further models are developed within the framework, the need for new modules reduces since previous algorithms may be re-calibrated (the parameters evaluated) for other areas.

Some generic models of common management practices have been included in the framework, and their parameterisation is set as part of particular applications (Susanty and Sardjono, 2000; Suyana and Sukarya, 2000; McLeish and Susanty, 2000).

3.2 Example of framework usage

The implementation of a model is illustrated for the process of tree growth. Tree growth is an essential forest simulation process, and is described by the swappable function "dbhincr" that returns the annual diameter increment for a given tree. There may (for example) be three modules for this swappable function; called "none", "dbhincrIndo" and "dbhincrGuy". Each of these may calculate the diameter increment in a different way, but fulfil the basic requirement of returning a value that the framework uses to increase the diameter for each individual tree. The user may choose between these modules at run-time, changing the way that growth is modelled (usually depending on where the input data is from). Each module may have parameters, and if so these are created at run-time after the user has selected a module. The parameters have default values, but the user may edit them, thus changing the effect of the module. Once a module has been calibrated using data from a forest, the parameter values may be saved, so that they do not need to be re-entered later. The user of the model is advised not to change the parameter values for the ecological model or the module will no longer be a valid model of a real forest.

3.3 Implementation of new models

Models may be changed by changing their component sub-models (module choices, for a given swappable function) or by changing parameter values. End-users are expected to do this for the forest management models contained within the SYMFOR framework. These changes may be made at run-time.

Occasionally it may be found that a required algorithm is not represented in the existing modules within the framework and a new module must be implemented. The modular structure of SYMFOR allows model developers to add alternative modules for an existing swappable function. The new module is added to the source code of the SYMFOR DLL, which is then compiled to be integrated within the framework. This process is fully described in the on-line documentation (Phillips *et al*., 1999) and the SYMFOR code documentation (Phillips, 2000).

It is also possible for developers to add a new swappable function that may complement another part of their model. An example of this could be a "soil" swappable function that returns values for the nutrients available to a tree for its "growth" swappable function. The developer could then test several alternative soil models with the same growth model to identify the sensitive parameters or test nutrient transport theories against observed growth rates. This process is described in the code documentation (Phillips, 2000).

3.4 Silvicultural treatment simulation

Forest managers and policy advisers are not generally expected to produce or calibrate their own ecological models of the natural processes occurring in the forest. Instead they should read the documentation about pre-existing models and parameter within the SYMFOR framework to find one that is valid for their particular forest type. The intervention processes, such as any forest management treatments, are at the discretion of the decision maker, and should be treated as such in the simulation.

Tree species are grouped for silvicultural options separately from the ecological model grouping. There is no a priori reason why a species grouping based on natural tree behaviour should exactly coincide with a grouping defined by merchantability or commercial status, and so they are not coincidental in the framework. The grouping for silvicultural purposes is called "utilisation group", and is entered for each tree in the input data. Many parameters associated with models of silviculture have a value for each utilisation group, which allows the user to define how each group should be managed. Currently up to ten utilisation groups may be used. A very simple grouping could be into two groups: '1' for commercial and '2' for non-commercial, however commercial groupings are often more complicated (related to the economic value of the timber, for example).

3.5 Limitations of the implementation

A "framework" is defined as a; "frame, structure, upon or into which casing or contents can be put" (Sykes, 1982, p390). SYMFOR is a framework for individual-based models of forest processes, both ecological and management. There are, however, restrictions inherent in a framework and it is important to the process of its evaluation that these are identified.

Sub-models may be put into the framework in such a way that together they form a whole model, but they must fit the specified slot and have appropriate connectors. This means they must integrate with the rest of the framework in terms of data handling and parameter value assignment. In addition, they must use individual tree data and interact with the rest of the model on an annual time-step. For these things to be possible, a model developer must edit the source code and have access to a suitable compiler. Instructions of how to go about this are documented in the on-line help pages (Phillips *et al*., 1999) and the SYMFOR code documentation (Phillips, 2000).

Due to the limited data availability for model development and calibration, trees represented in the framework have a minimum DBH of 10 cm. This provides a limit to the modelling of recruitment of new trees and therefore the effects of damage to the forest resulting from management interventions. Should datasets with tree DBH values less than 10 cm become available, the framework could be adapted to use them.

4 Conclusions

The development of SYMFOR has produced a modelling framework that houses models of forest ecology and management, and provides an interface for the end-user. It allows users to switch between comparable components without re-compilation of the program and provides graphical analysis and full data output for subsequent analysis, and so is suitable for application by forest managers and policy advisers.

SYMFOR is a framework for modelling forest development and silviculture designed for use by managers and policy advisers with regard to tropical forests. The SYMFOR framework has been developed for models of managed dipterocarps forests in Indonesia, but can equally be used to develop, test and house models for other locations and forest types. SYMFOR has been used to develop, test and house models, and to perform simulations to test forest management strategies in Indonesia, and thus has so far met the needs of model developers and end-users.

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