

## The SYMFOR framework for individual-based spatial ecological and silvicultural forest models

**P.D. Phillips,  
P.R. van Gardingen  
November 2001**

Centre for the study of Environmental Change and Sustainability (CECS)  
The University of Edinburgh  
John Muir Building  
Mayfield Road  
Edinburgh EH9 3JK  
SCOTLAND  
Tel: +44 131 650 7861  
Fax: +44 131 650 7863  
Email: [symfor@ed.ac.uk](mailto:symfor@ed.ac.uk)

## Summary

---

A software framework, called SYMFOR, is presented that allows 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 houses individual-based, spatially explicit models of many silvicultural treatments. Simulations with the framework utilise a spatial model of the natural forest processes of growth, mortality and seedling recruitment for individual trees. The framework is presented through a sophisticated Windows-based User Interface with a comprehensive on-line documentation.

The fact that the framework represents trees on an individual, spatial basis allows models of silvicultural treatments to explicitly represent practical and theoretical forest management. This is of particular importance for tropical forests, where the effects of disturbance last many decades. In many areas of the tropics, new forest management methods are being implemented without provision for an adequate trial period. SYMFOR enables trials to be simulated, permitting comparisons between alternative treatments, and allowing examination of the likely effects or outcomes resulting from silvicultural treatments. Predictions of yield, sustainability, 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.

Presented here is the design and structure of the framework, a selection of the silvicultural treatment models currently implemented for application in Indonesia and an overview of the user interface. An example is given of a comparison between the simulated effects of two alternative treatments in use in Indonesia, demonstrating the flexibility and realistic representation of the models and framework output.

# Contents

---

<b>Summary</b> .....	<b>ii</b>
<b>Contents</b> .....	<b>iii</b>
<b>1 Introduction</b> .....	<b>1</b>
1.1 Existing models .....	1
1.2 The purpose of the framework .....	1
1.3 Design criteria .....	2
<b>2 The SYMFOR framework</b> .....	<b>3</b>
2.1 Framework design .....	3
2.2 Framework implementation.....	3
<b>3 Model implementation and silvicultural treatments</b> .....	<b>7</b>
3.1 Implementation of new models .....	7
3.2 Silvicultural treatment simulation.....	7
<b>4 Results and Discussion</b> .....	<b>10</b>
4.1 An example .....	10
4.2 Limitations of the implementation.....	15
<b>5 Conclusions</b> .....	<b>16</b>
<b>6 Acknowledgement</b> .....	<b>17</b>
<b>7 References</b> .....	<b>18</b>

# 1 Introduction

---

Forest management involves decision making that has consequences far into the future. Forest managers or decision-makers require knowledge of the state of the forest immediately before and after management interventions, and then predictions for a substantial period into the future, in order to make informed decisions relating to the sustainable use of forest resources. The complex structure and dynamics of tropical forests combined with high species diversity makes it difficult to predict the state of the forest more than a few years into the future. Silvicultural interventions disrupt the natural balance between the processes of growth, in-growth, and mortality and the changes in forest structure and dynamics reflect this.

There is a considerable literature describing the management and silviculture of even-aged forests associated with relatively simple methods for predicting the growth and yield of the forest. An established silvicultural practice, operating in a region that has experienced similar practice for many years, does not demand complex modelling in order to predict the yield at some point in the future, or simulate the forest re-growth. Simulations of forest development are far from simple in virgin tropical forests because of the high species diversity and a range of possible silvicultural options available to the forest manager. Developing countries cannot wait for 30 or 50 years to evaluate the results of silvicultural field trials and the only method for predicting results of these techniques is through forest simulation modelling.

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 a model to simulate silvicultural treatments to permit users to evaluate likely outcomes from forest management.

## 1.1 Existing models

Software that has been developed to simulate the growth of tropical forests includes FORMIX (Huth *et al.*, 1997 and 1998), FORMIND (Köhler and Huth, 1998) and that of Gourlet-Fleury (1998). These programs use differing approaches to address the problems of modelling the development of complex forest systems, but do not simulate silviculture and hence do not meet the requirements of the forest manager or policy maker.

DIPSIM (Kleine and Heuvelop, 1993, and Ong and Kleine, 1996) incorporates a more holistic approach to forest management, in particular for large scale planning and setting the annual allowable cut for management units. Silvicultural techniques are not explicitly represented in DIPSIM, which models different silvicultural techniques through statistical analysis of field trials. For this reason DIPSIM cannot be used to evaluate or predict the results of new silvicultural interventions, and comparison between silvicultural techniques must be made elsewhere.

Young and Muetzelfeldt (1998) produced a modelling framework (SYMFOR) designed to allow the development of forest growth models, however, calibrated models of forest growth and silviculture were not implemented by these authors. Other difficulties were that it required the end user (e.g., a forest manager) 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.

## 1.2 The purpose of the framework

The SYMFOR framework was designed to satisfy several criteria. The design was required to provide a structure in which to develop models of forest dynamics and silvicultural treatments for moist tropical forest systems. More specific limitations were that it should use PSP data for calibration and data input and that the model should represent a stand spatially on an individual-tree basis in order to explicitly model silvicultural treatments. The initial implementation of the framework was developed for use in lowland dipterocarp forests in Indonesia.

The end users were originally defined to be:

- National or regional research organisations in Indonesia, and neighbouring Malaysia;
- The Center for International Forestry Research (CIFOR), Bogor, Indonesia;

- Government officials (e.g. Ministry of Forestry and Estate Crops, Policy), Jakarta, Indonesia;
- Forest Managers (i.e. Indonesian and Malaysian forest concession holders);
- Forest Management Certification bodies such, Lembaga Ekolabel Indonesia (LEI);
- Forestry development (aid) projects, such as the European Union Berau Forest Management Project (BFMP) in East Kalimantan, Indonesia.

The SYMFOR framework needed to be able to meet differing requirements from these user groups. Forest managers wanted to predict the likely production resulting from particular management strategies, whereas certification bodies and policy makers are more interested in examining issues relating to sustainability such the future state of the forest some years after logging. Forest research organisations such as CIFOR and BPK-Samarinda were also concerned with biodiversity and habitat loss. The framework had to be capable of producing output that can 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 reliably. 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.

### 1.3 Design criteria

Processes that influence the state of the forest operate on a continuum of spatial and temporal scales, from competition for light between individual trees up to landscape variations in soil characteristics and climate. Thus the effect of silvicultural treatments on an area of forest cannot be fully captured by a simulation unless the model is explicitly spatial. Permanent Sample Plot (PSP) data often include the spatial location of each tree, as well as their species and size at set measurement intervals, so are ideal for development of and input to spatially explicit forest growth models.

Models of forest behaviour can help to make predictions into the future, but these may be limited by the data resources available for model development and validation for a complex system such as a tropical forest. For this reason some processes within models may not be fully calibrated. As new data sets become available, models should be re-calibrated or possibly re-engineered in order to represent new conditions. Re-evaluation, and re-calibration, may also be necessary when a model developed in one region of forest is applied to another region resulting from different species composition and environment variation that may not be captured in the data.

The evaluation of alternative management strategies using a forest growth simulation model requires the ability to switch between silvicultural treatments. Results from the modelling system can then be used to compare the predicted results of one treatment with another. This requires flexibility of the modelling system, and the ability to contain several sub-models (of silvicultural treatments, for example) that can be selected when the model is run.

With the continual re-development of models and requirement for run-time model definition, it is convenient to use a framework to house model components that does not need to be changed depending on the structure or availability of data. The framework should ideally be modular: that is, sub-processes, such as tree growth and tree mortality, are modelled and implemented independently. New models or sub-models can then be developed and integrated within the framework by combining model components or modules selected by the user. The user-interface of the framework was required to enable the user to select a model, such that multiple models are allowed to exist in parallel within the framework. A complete set of model components is required for a simulation model of the forest.

The programming languages in which the framework was written had to be widely used and accepted in order to guarantee that the framework could still be operational years after its initial development. The languages also had to be industry standards in order that model developers could use them into the future.

## 2 The SYMFOR framework

---

### 2.1 Framework design

The framework was designed to operate under 32 bit versions of Microsoft Windows™ (Windows 95, 98, NT and 2000). The system is constructed in two parts: a user interface (UI) and a dynamic link library (DLL) that contains the model components and handles data input and output and data storage. The earlier modelling system produced by Young and Muetzelfeldt (1998) was used as a starting point in designing the UI in order to maintain continuity for the end users. This decision negated the use of modelling environments such as AME (Muetzelfeldt and Taylor, 1997a and 1997b), Stella (High Performance Systems Inc., 1999) or Modelmaker (Cherwell Scientific Ltd., 1999) for model development.

The purpose of the UI was to provide a simple link between data and models in the DLL and the user. The main function was a graphical interface implemented as a “native” windows-based program. Microsoft Visual Basic (Microsoft corporation, 1998a) programming language was chosen for this purpose because of its speed of development for windows-based applications. The UI also had to include links to the on-line documentation in order to provide the “help” facilities common to Windows-based software.

The DLL was designed to store data describing the stand (state variables) and included functions that set or return data stored in the DLL. The DLL was designed to implement a program structure that allows developers to easily understand and add to existing model options. The main modelling calculations and memory management of the framework take place in the DLL, so Microsoft Visual C++ (Microsoft corporation, 1998b) was chosen as a low-level, computationally fast language. The C++ language allows fully object-oriented programming (Stroustrup, 1997) and dynamic memory allocation, and its functions may be called by Visual Basic routines allowing straightforward communication between the UI and the DLL. To simplify the processes of model development and conceptualisation, the DLL was designed to be object oriented where this was appropriate.

A simple structure was set up for the operation of models within the framework, simulating the essential functions of any model as a sequence of: (1) silvicultural operations, (2) tree growth, (3) recruitment of saplings into the model and (4) mortality of trees.

On-line documentation was developed using Hypertext Mark-up Language (HTML), for use with world-wide-web (WWW) browsers. HTML documentation had the advantage that, without any format conversion, it could be accessed from the WWW as well as from the framework itself.

Visual Basic, C++ and HTML are the most commonly used and accepted computer programming languages for the purposes described above. Their use should guarantee that it is possible to maintain the framework into the future.

### 2.2 Framework implementation

The underlying structure of the framework allows the peripheral components, such as the UI and the data input and output functions to operate and so is described first.

#### Forest object classes

Data stored by the DLL include information describing the trees and the stand used to initialise a simulation, and quantities that are derived from the input data or generated automatically. Data are stored dynamically such that the memory needed to store them is only allocated when necessary and freed immediately after use, thus minimising memory usage. The forest objects that are simulated include 5 classifications of tree and three other forest data 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 poisoning or other silvicultural thinning techniques);
- “stand” (describes data relating to the whole stand);
- “skid-trail” (the gap 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).

A full description of the attributes of each class of objects is given in the SYMFOR on-line documentation (Phillips *et al.*, 1999). Trees are normally specified by their x and y co-ordinates, diameter at breast height (DBH), species or species group number, a unique identifying tag number and a “utilisation group”. This minimal data definition is based on the data that are typically collected from PSPs in Indonesia (Alder and Synott, 1992). “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 more than one simulation. 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.

### Modularity and model structures

Modularity was implemented for the SYMFOR framework using three object classes within the DLL: “swappable function”s, “module”s and “parameter”s. Swappable functions are the processes and sub-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 many modules for a particular swappable function, but only one may be used in a given simulation. 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. This allows consecutive runs to be made using different models, which is a key feature of the SYMFOR framework. Figure 1 is a schematic diagram showing the relations between swappable functions, modules and parameters.

The structure of a model can be 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 are several modules that can return tree growth; called “dbhincr1”, “dbhincr2” up to “dbhincr6” (these represent the different developmental stages of the diameter increment algorithm at present, but in theory could be viable alternatives to each other). Each of these calculates the diameter increment in a different way, but fulfils the basic requirement of returning a value describing the growth of an individual tree. The user can choose between these modules at run-time, changing the way that growth is modelled. 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 (often called “parameterised” in this context, but the process is identical) using data from the forest, the user is advised not to change the parameter values or the module will no longer be a valid model of the real forest.

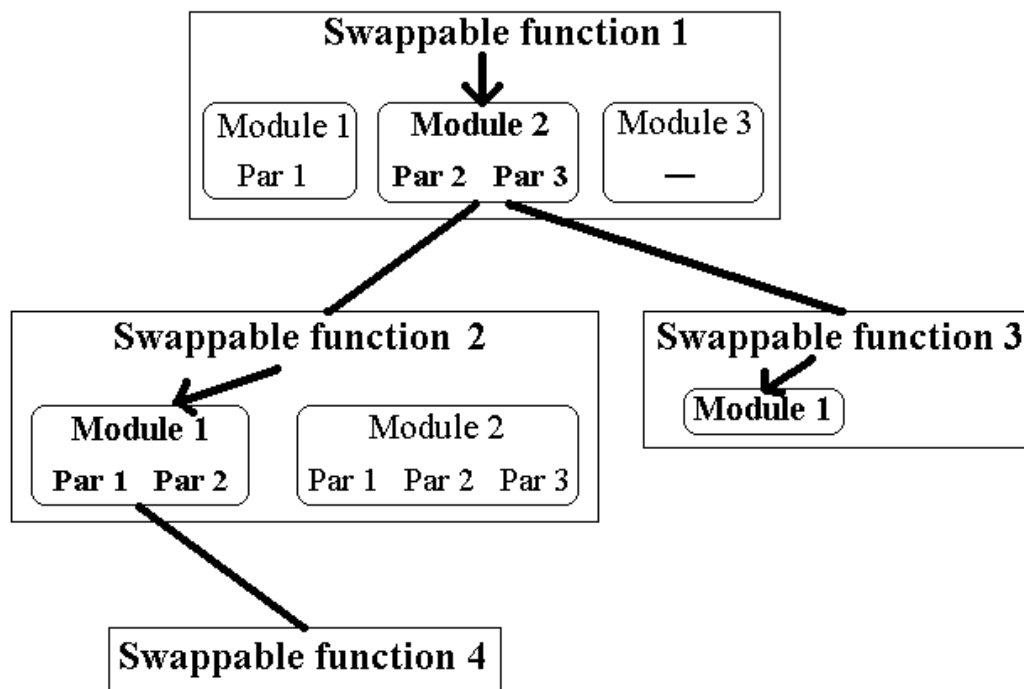


Figure 1: Schematic diagram indicating the relations between swappable functions, modules and parameters. Parameters are abbreviated to “Par”. The relations are only shown in full for swappable functions 1 and 2; for swappable function 3, module 1, the parameters are omitted; the swappable function 4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

### Features of individual-based spatial forest models

Individual-based models of forest dynamics cannot be truly deterministic. Stochastic events such as lightning strike or disease are important, and there may not be sufficient input data to calibrate models that explicitly simulate potentially predictable events such as windfall. The precise state of the forest at some point in the future cannot, therefore, be known with certainty. An approach commonly used to surmount this apparent problem, known as a Monte Carlo method (Fishman, 1995), is to use a random number generator to decide the course of events according to a calculated probability distribution. This means that the results from two apparently identical simulations will not be identical, assuming a different random number seed were used for each run. Typically, in models based on individuals, many aspects will be simulated using a Monte Carlo method, giving many potential sources of variation. The simulation must therefore be repeated several times in order to obtain a mean result with an acceptably small standard error. The variance, however, is not a function of the number of repetitions, but is itself a feature of the system being modelled.

A common aspect of most spatial models relates to the effects at the edge of the simulated area. In the case of a stand of forest this is particularly obvious for processes such as competition: do the trees situated at the edge of the simulated stand experience less competition? In the forest they do not, but in the simulation they will unless an allowance is made for this “edge effect”. In the SYMFOR framework, all spatial comparisons are made using 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.

### 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, initialisation data files, and the selection of data and target files for output. The requirement to repeat simulations in order to gain information concerning the reliability of simulation results is met using a “multiple-run facility” that automates repeated or sequential simulations. This powerful feature allows the user to run SYMFOR overnight, for example, rather than many individual runs each requiring user intervention.

The UI contains graphical displays that allow initial data analysis of both initialisation data and the simulated data as the simulation progresses. The UI can produce graphs of user-defined quantities (such as total felled tree volume) as a function of simulated time. Histograms can show quantities such as the number of trees as a function of DBH) and a map display can show any of the spatial forest features (including all tree types and damage from tree-fall and silvicultural intervention). Tables can be defined to summarise stand data in the form of a customisable “stand table” or to 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.

### Data input and output

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).

The user can specify up to 5 output tables, each of which can contain up to 30 columns containing data from the forest object attributes or functions. In addition to the forest object data, there are three variables that identify the data for the post-simulation data analysis. These specify the reason that particular set of data has been output, the identifying number of the simulation and a count of the number of times data has 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 silvicultural treatment;
- Immediately after a silvicultural treatment;
- At the beginning of a simulation;
- At the end of a simulation;
- At a fixed time interval following each logging operation.

Thus the user has complete control over the nature and extent of the data output from the simulation. This flexibility allows the user to utilise the full 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 Model implementation and silvicultural treatments

---

SYMFOR simulations of the state of a forest over a period of time require several component models. These can be split into two groups, an ecological model describing the growth, recruitment and mortality and a silvicultural model describing any management interventions. Users of the model would generally be expected to change parameters associated with the silvicultural model since that would reflect the decision making of the forest manager. This paper will illustrate the SYMFOR framework with reference to the silvicultural model while the ecological model will be described elsewhere.

### 3.1 Implementation of new models

New models may need to be implemented within the SYMFOR framework in the future. One example could be if an existing model was being adapted a new forest type or silvicultural treatment that is not adequately described by existing modules. In order to change the algorithm used in the calculations it is necessary to either change a SYMFOR module or implement a new module used for a swappable function. 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 properly integrated with the framework. This process is fully described in the on-line documentation (Phillips *et al.*, 1999).

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. Clearly an understanding of the swappable functions already present within SYMFOR is necessary to do this.

### 3.2 Silvicultural treatment simulation

Forest managers and policy makers 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 models and parameter sets already within the SYMFOR framework to find one that is valid for their particular forest type, and use that. The intervention processes, such as any silvicultural treatments or other human interference with the forest, are at the discretion of the decision maker, and should be treated as such in the simulation.

The current version of SYMFOR has silvicultural treatments simulation specified for Indonesian forestry practice, although there is no reason why a developer could not adapt these or add new modules to simulate alternative management methods in other areas. Silvicultural treatments can be applied in the simulation either not at all, once or many times. The simulated time after the start of the run for the first application and the time between subsequent applications are module parameters set by the user. An option exists to use two or more silvicultural treatments in combination, applying them independently in order to combine, for example, selective thinning with conventional harvesting practice.

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 fully define how each group should be used. Up to ten utilisation groups may be defined and 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).

Logging

The main silvicultural management option available to the user is logging. A set of rules, controlled by parameter values allows the framework to decide which trees are to be harvested:

- On the basis of the livetree attribute “utilgrp” (utilisation group), the user can set the minimum tree DBH for the tree to be considered for removal;
- A livetree attribute “quality”, assigned with a uniform random distribution, represents the quality of the stem with respect to merchantability, and a lower limit may be set on this for the tree to be considered for removal;
- A maximum number of trees to be harvested from the simulated stand may be set;
- The maximum timber volume to be extracted (trees are considered in decreasing order of size);
- To specify the selection further, a minimum total timber volume for any trees to be extracted from the stand can be set to represent an economic limit for harvesting.

The user may not specify the individual trees to be removed on a particular simulated logging operation, because of the effects of stochastic simulation as described earlier. The trees that are suitable for logging in one simulation may not be suitable in a repeated simulation with a different random number seed. In addition, the simulated stand should be representative of a much larger area where rules such as those stated above are generally used to define logging strategies.

### Damage caused by logging

In the simulation, trees selected for logging are felled and cause damage to other trees caught in the path of their fall. The swappable function representing damage due to falling trees is considered to be a natural forest process and is subject to calibration with the other ecological models. The user can affect the direction of tree-fall, however, since in practice this is the decision of the tree feller. The user can select a random fall-direction to model un-planned felling, or they may select the angle that the fallen tree makes with the skid-trail used to extract the stem, to simulate planned or directional felling. A simulated area of damage is created to represent damage resulting from activity required to pull the stem into line with the skid-trail. “Livetree”s that are killed by damage in the simulation are re-assigned as “smashedtree”s.

### Damage caused by stem extraction

There are different methods available for extracting the felled stems from the forest, such as skyline logging or dragging by tractor (skidding). Only skidding is currently simulated within SYMFOR.

Different levels of forest management planning can lead to different paths for the skid-trails, depending on whether the tree fellers or the tractor drivers know in advance which trees are to be felled and where the skid-trails should be. This can lead to different levels of damage in the forest. Two options exist for the user to decide how to simulate skid-trail planning:

- The skid-trails are straight and lead from the tree to a point, specified by parameters, on the edge of the simulated stand; or
- The skid-trails form a branched structure where an existing skid-trail may be used to shorten the length of new skid-trails, in reaching the point where the skid-trail leaves the simulated stand.

In both cases, the user can choose the width of the simulated skid-trail, and also the maximum size of trees killed by the skid-trail creation. The latter point is necessary because in practice the tractor driver would normally attempt to avoid damaging large commercial trees in creating the skid-trail, whereas in the simulation this is computationally too expensive and, statistically, the same effect can be achieved by simply leaving the larger trees. Within the simulated skid-trail, all “livetree”s of DBH less than the maximum specified are killed and re-assigned as “smashedtree”s. The skid-trail areas can be used by other modules as areas that have undergone soil compaction, which can affect re-growth.

Two additional features of damage during stem extraction are explicitly represented in SYMFOR: dragging the stem into line with the skid-trail forms a triangle of damage, and in the process of attaching the tractor

winch cable to the stem a circular area of damage is created around the stem. In the simulation, both these areas cause complete loss of trees within the damage area but do not cause soil compaction.

### Strip-clearing and replanting

A strip clearing and replanting silvicultural system known as Tebang Pilih Tanam Jalur (TPTJ) (Departemen Kehutanan RI., 1998) is proposed for use in parts of Indonesia and has been represented in SYMFOR. In addition to the logging options already described, the user can select to clear straight, north-south strips across the plot, removing all trees. The width and separation of the strips are parameters. The user also chooses to plant a selected species, or species group of trees along the centre of each strip, separated by another specified distance. The planted trees only appear in the model after an interval representing the time taken for the trees to reach the minimum diameter represented by the model (this is related to the recruitment module in the natural forest model, currently 10 cm). In addition, the user can select to tend the strip (remove unwanted vegetation, and effectively prohibit re-growth of the forest) for a specified period following clearing.

### Thinning

Selective thinning of the forest is possible by killing trees with poison or felling. Thinning is represented in SYMFOR as an option to follow logging. Trees may be selected for thinning defined by utilisation group, a minimum diameter and maximum stem quality. After thinning, the “livetree”s affected become “killedtree”s in the simulation. Thinning by poisoning is not 100 % successful in practice, and this is represented by a probability of success in the model. Thinning by felling is 100 % successful, and these trees fall and create damage due to falling in the same way as for trees that are felled as part of logging. Trees killed as part of thinning by felling are not removed from the forest, however, so skid-trails and damage associated with dragging the stem are not simulated.

### Replanting

Replanting of particular tree species or species groups within the forest has not yet been attempted in SYMFOR. The simulation of the extra trees appearing in the model is a simple development task, however there is currently insufficient data available to calibrate the natural forest process of seedling survival rate and the time taken to reach the minimum diameter of trees represented in the model.

## 4 Results and Discussion

---

The development of SYMFOR has produced a modelling framework that houses components of forest development (ecological) and silvicultural models. The forest development models will be described elsewhere. The silvicultural models have been described above and explicitly model the aspects of silvicultural treatment that affect the forest. It allows the user to switch between comparable components without re-compilation of the program, and so is suitable for distribution to forest managers and policy-makers.

SYMFOR uses information about individual trees from PSP datasets (usually 1 ha), and so has very many calculations to perform on each simulation timestep. Finite computer processing speed thus effectively limits the representable area of forest, even if the data were available for model initialisation. The combination of data availability and practical computing restrictions limits the area that can be modelled, and this affects the utility of SYMFOR. The variation in number of trees, populations of each species group, size distributions and spatial structure of the forest between individual permanent sample plots in tropical forest is such that many plots are needed to form a realistic representation of a larger area of forest. If such a number of plots are available, then landscape-scale predictions are possible using SYMFOR: if not, SYMFOR is restricted to quantitative comparisons between silvicultural treatments, and qualitative indications of the effect of a particular treatment.

### 4.1 An example

An example of how SYMFOR may be used to compare the long-term effects of two different silvicultural treatments can be shown using the standard Indonesian selective cutting and replanting system known as Tebang Pilih Tanam Indonesia (TPTI) (Departemen Kehutanan R.I., 1993) and an alternative treatment, that implements Reduced Impact Logging (RIL) (Dykstra and Heinrich, 1996, and Elias, 1998).

Essentially the difference between these systems is that system incorporating RIL encompasses an increased element of planning as skid-trail maps are drawn up before felling begins. Skid-trail planning usually results in the reduced overall area of skid-trail created in the forest. Planning also allows directional felling, because the location of the skid-trail is known before the tree is felled. In addition, increased emphasis is placed on minimising damage to the remaining stand. This may lead to the use of a skidding tractor with a narrower blade. Several studies have suggested that RIL techniques are most effective when combined with some form of yield regulation to limit the maximum number of stems or basal area that may be extracted from the forest (Sist *et al.* 1998, van Gardingen *et al.* 1998). Both of these Indonesian studies suggested a limit of eight extracted stems per hectare of primary dipterocarp forest. All of the features described above can be represented within a SYMFOR silvicultural model.

To examine the effects of these differences on simulated yield and damage to the remaining stand, a synthetic PSP dataset (representing 1 ha of forest) was used that was designed to be typical of Indonesian mixed Dipterocarp forests.

For each treatment, the model must be defined. Table 1 shows the swappable functions required and the modules chosen for each swappable function. Table 2 explains the meaning of the parameters used by the chosen modules. For the two simulated silvicultural treatments, the values of the relevant parameters are given in Table 3.

Swappable Function name	Modules for TPTI	Modules for RIL
Treatment	TPTI	RIL
Logqualify	qualify1	qualify1
Logselect	select1	select1
planskidtrails	straight	branched
Felling	undirectional	directional
dragdamage	dragdamage1	dragdamage1
skidprepdamage	skidprepdamage1	skidprepdamage1
Skidtrails	skidtrails1	skidtrails1
skidtraildamage	skidtraildamage1	skidtraildamage1

Table 1: Modules used to represent the swappable functions for simulations of the two silvicultural treatments; TPTI and RIL.

Module	Parameter	Explanation
TPTI, RIL	-	Define the processes in a treatment.
qualify1	dbhcrit	Minimum diameter to qualify for felling.
	qualitylimit	Minimum stem quality for felling.
select1	nlogmax	Maximum number of stems to fell.
	maxextract	Maximum volume of timber to extract.
	minextract	Minimum volume of timber to extract.
straight, branched	accesspointx	X co-ordinate of the skid-trail end-point.
	accesspointy	Y co-ordinate of the skid-trail end-point.
Branched	joinangle	The angle that skid-trail branches meet at.
undirectional	-	Defines felling direction to be random.
directional	cutdirection	Angle (degrees) that the direction of fall makes with the skid-trail.
dragdamage1	-	Defines the area damaged when pulling a stem into line with the skid-trail.
skidprepdamage 1	skidprepradius	The radius of the circle of damage caused in attaching the winch to the stem.
Skidtrails1	skidwidth	The width of the skid-trail.
skidtraildamage1	maxdbhdamage	The maximum diameter tree damaged in skid-trail creation.
	damageprob	The probability of damage to small trees within the skid-trail

Table 2: The parameters and modules used in the example simulation. Complete descriptions are given in the SYMFOR on-line help (Phillips *et al.*, 1999).

Parameter	TPTI	RIL
Dbhcrit	Commercial: 50 cm Non-comm.: 500 cm	Commercial: 50 cm Non-comm.: 500 cm
qualitylimit	0.5	0.5
Nlogmax	600	8
maxextract	500.0	500.0
minextract	0.0	0.0
accesspointx	50.0	50.0
accesspointy	0.0	0.0
Joinangle	n/a	60.0
cutdirection	n/a	150
skidprepradius	5.0	4.0
Skidwidth	5.0	4.0
maxdbhdamage	30.0	30.0
damageprob	1	1

Table 3: Values of the parameters chosen to represent the two silvicultural treatments; TPTI and RIL.

The “plan view” display from the SYMFOR User Interface is shown in Figures 2 and 3. The two images represent different runs of SYMFOR: one with TPTI and the other RIL, both following logging. Clearly evident is the difference in skid-trail design. The unplanned skid-trails of TPTI are represented as straight lines to an “access point” at the edge of the PSP (Fig. 2), whereas the RIL skid-trails form a branched structure (Fig. 3) that in a simple way minimises the overall area affected by skid-trails. For RIL, the skid-trails are narrower than those for TPTI, and the triangles of damage caused by pulling the stem into line with the skid-trail are smaller due to the effects of directional felling. It is clear from the plots that only 8 trees have been felled in the RIL case, compared to 14 for TPTI.

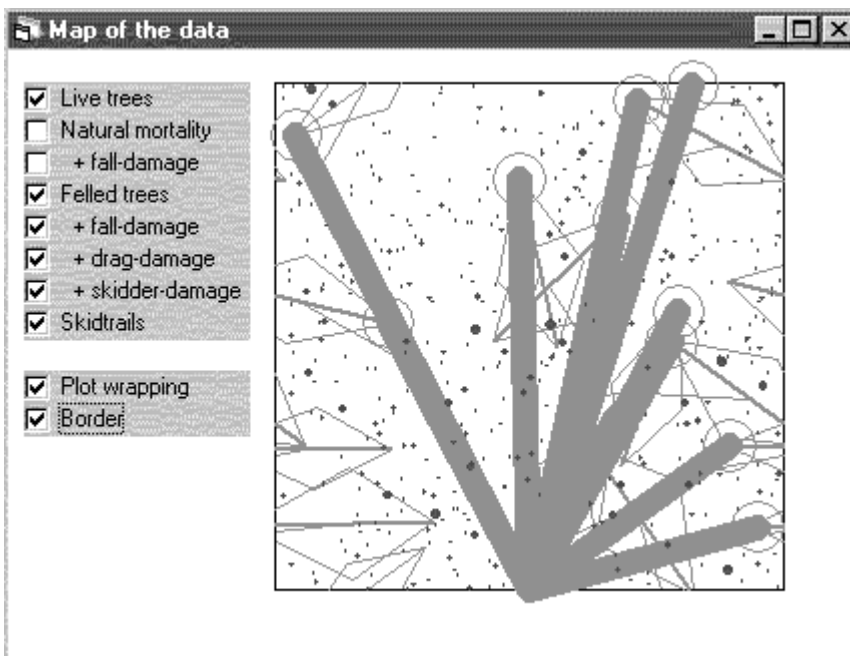


Figure 2: Showing the “plan view” (from the SYMFOR UI) of a single run using the model of the TPTI silvicultural system. The dots represent the living trees and the shaded areas represent the skid-trail paths. The thick lines are the felled trees, and all other lines delimit areas of damage: the trapezoid shapes represent the area under limited damage from the falling action of the felled tree; the triangular shapes are areas that were

damaged when the stem was pulled into line with the skidtrail; and the circles are areas of damage around the base of the stem of the fallen tree where the skidding tractor turns and the stem is attached to the winch cable. The option to display the plot wrapped at the edges, as it is modelled (except for the circular damage), has been selected and is clearly visible. Some of these effects are more clearly seen in figure 3, which shows less damage.

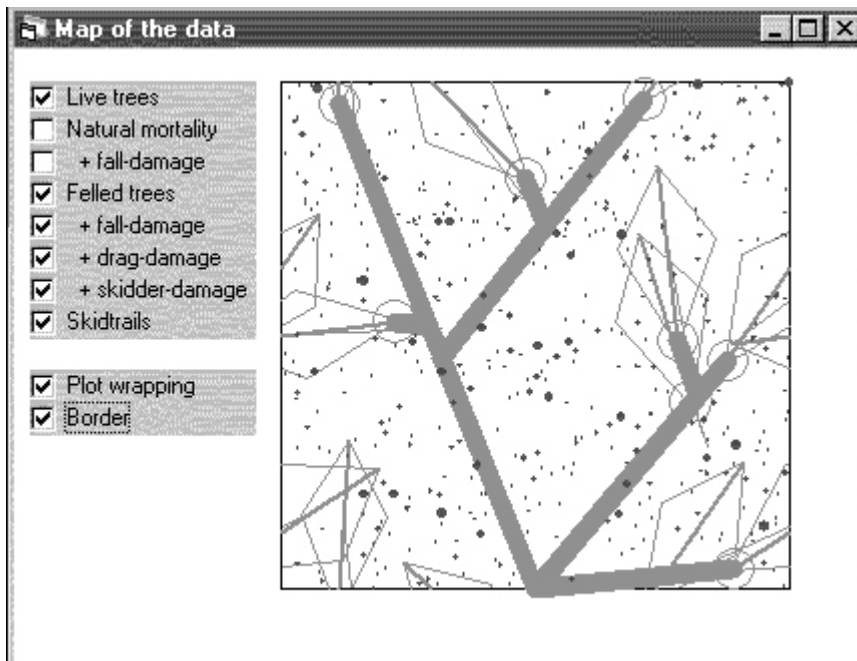


Figure 3: Showing the “plan view” (from the SYMFOR UI) of a single run using the model of the RIL silvicultural system. Other details as for Figure 2.

In order to compare the two treatments quantitatively, it is necessary to perform several runs, repeating the first run of each treatment but changing the initial random number seed. Average values of the resulting quantities, with associated standard errors, can then be evaluated so that the effects of individual stochastic events are removed. The SYMFOR multiple-run facility was used for this purpose, with 10 replicate runs for each scenario. Data describing the felled trees and remaining live trees in the stand were output as a text file for further analysis.

The averaged results of analysis are shown in Tables 4-8. Many quantities could have been calculated from the SYMFOR output, and these particular variables have been chosen as typical of the information required by the forest manager and policy-maker. Table 4 shows some statistics about each silvicultural treatment expressed on the basis of averages per felled tree and per one hectare plot. The simulation results show that the RIL treatment resulted in a reduced damage to the residual stand as specified by the number of trees killed. The RIL treatment had a lower number of trees killed per harvested tree (27 % reduction). The specification for the RIL treatment limited harvesting to a maximum of eight stems per hectare, which, combined with the lower damage per harvested stem, led to a very significant reduction in the number of killed trees per stand (60 %). A similar result was observed for the total area disturbed through the creation of skid-trails. The skid-trail area was 27 % lower in the RIL treatment on an individual tree basis and 60 % lower for the whole stand.



	Per felled tree		Total	
	RIL	TPTI	RIL	TPTI
No. of felled trees	1	1	7.7 ± 0.1	14 ± 0.8
No. of live trees killed	11.3 ± 0.4	15.5 ± 1.1	87 ± 3	217 ± 10
Volume of felled trees (m <sup>3</sup> )	6.9 ± 0.2	5.2 ± 0.1	53.6 ± 2.2	73.5 ± 4.7
Skid-trail area created (% of total plot area)	1.35 ± 0.04	1.87 ± 0.14	10.4 ± 0.3	26.2 ± 1.3

Table 4: Summary of the effects of logging comparing the RIL and TPTI treatments, calculated as an average of 10 replicate runs per plot. Data represent the mean ± 1 standard error.

Table 5 shows statistics describing the living trees in the stand. The pre-logged stand may be compared with the post-treatment stand in both cases. These figures themselves may be used to judge the relative merits of the silvicultural treatments, or alternatively the ecological model within SYMFOR could be used to predict the state of the stand at some point in the future, for example at the end of a proposed cutting cycle. The results from the simulated harvesting show that the RIL treatment retained a higher number of stems following harvesting, resulting in higher volumes for all and commercial species. Some care should be taken in interpreting these results as other simulations have shown that the higher commercial volume is mainly a result of the lower number of harvested stems.

	Pre-logged	Post-RIL	Post-TPTI
Total number of trees	563 ± 3	460 ± 3	343 ± 10
Number of commercial species trees	207 ± 2	166 ± 2	127 ± 4
Total volume of trees (m <sup>3</sup> )	416 ± 5	325 ± 4	252 ± 7
Volume of commercial species trees (m <sup>3</sup> )	260 ± 4	190 ± 3	140 ± 6

Table 5: Number of stems and total volumes of all live trees and live trees of commercial species for the pre-logged stand and the stands following RIL and TPTI treatment. Other details as for Table 4.

Tables 6, 7 and 8 are stand tables representing the stand before logging, after the TPTI has been applied and after the RIL treatment has been applied, respectively. They show the number, sum of basal area and sum of volume of all live trees in the stand as a function of diameter class. Forest managers are generally more familiar with stand tables than with other forms of data presentation, so it can be instructive to summarise the data in this way.

Diameter range	10 ≤ D < 30	30 ≤ D < 50	50 ≤ D < 70	70 ≤ D	All
Pre logging	431.6 ± 2.5	91.3 ± 1.0	27.8 ± 0.6	11.9 ± 0.5	562.6 ± 3.4
TPTI	253.6 ± 8.4	68.9 ± 1.4	14.7 ± 0.6	6.1 ± 0.4	343.4 ± 9.7
RIL	347.0 ± 2.3	83.4 ± 1.0	22.9 ± 0.7	6.6 ± 0.5	459.9 ± 2.5

Table 6: Stand table showing the number of live trees in the stand before logging and after the TPTI and RIL treatments. The different diameter ranges are shown by a range of D (cm). Other details as for Table 4.

Diameter range	10 ≤ D < 30	30 ≤ D < 50	50 ≤ D < 70	70 ≤ D	All
Pre logging	10.3 ± 0.1	10.6 ± 0.1	7.9 ± 0.2	5.9 ± 0.2	34.7 ± 0.4
TPTI	5.9 ± 0.2	8.2 ± 0.2	4.0 ± 0.2	3.1 ± 0.2	21.2 ± 0.6
RIL	8.2 ± 0.1	9.7 ± 0.1	6.3 ± 0.2	3.2 ± 0.3	27.5 ± 0.3

Table 7: Stand table showing the basal-area (m<sup>2</sup>) of live trees in the stand before logging and after the TPTI and RIL treatments. The different diameter ranges are shown by a range of D (cm). Other details as for Table 4.

Diameter range	$10 \leq D < 30$	$30 \leq D < 50$	$50 \leq D < 70$	$70 \leq D$	All
Pre logging	$88.5 \pm 0.7$	$129.0 \pm 1.4$	$110.8 \pm 2.4$	$87.9 \pm 3.6$	$416.2 \pm 4.9$
TPTI	$50.8 \pm 1.8$	$99.5 \pm 2.1$	$55.9 \pm 2.7$	$46.1 \pm 2.8$	$252.3 \pm 7.1$
RIL	$70.7 \pm 0.5$	$117.8 \pm 1.4$	$88.8 \pm 2.8$	$47.2 \pm 3.9$	$324.5 \pm 4.0$

Table 8: Stand table showing the stem volume ( $m^3$ ) of live trees in the stand before logging and after the TPTI and RIL treatments. The different diameter ranges are shown by a range of  $D$  (cm). Other details as for Table 4.

## 4.2 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 natural and silvicultural. 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 timestep. 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).

The choice of tool for developing the framework’s “casing”, the UI, as Microsoft Visual Basic has meant that the software is limited to use on computers that can run 32 bit versions of the Microsoft Windows™ operating systems. For many forest managers and policy makers this is unlikely to be a restriction, however model developers often prefer more traditional software platforms such as UNIX.

Due to the limited data availability for model development, trees represented in the framework have a minimum DBH of 10 cm. Currently this provides a limit to the modelling of recruitment of new trees and therefore the effects of damage to the forest due to silvicultural activity. However, should datasets with tree DBH values less than 10 cm become available, the framework can, with care, be adapted to use them. The time involved in collecting such data is likely to be prohibitive and thus the appropriate approach is likely to be the analysis of data from small subplots established to study seedlings and samplings within existing PSPs. These results could then be incorporated into the main model using the grid-square concept.

Data availability has restricted the modelling of re-planting; a common silvicultural practice in selectively logged forests. A module for this may be added at some point in the future, when data regarding survival rates and the time taken for the seedlings to reach a DBH of 10 cm are available.

## 5 Conclusions

---

SYMFOR is a framework for modelling forest development and silviculture designed for use by managers and policy makers with regard to tropical forests. The current implementation of SYMFOR has been developed and calibrated for use in managed dipterocarps forests in Indonesia. The model has been designed so that it can rapidly be adapted and calibrated for other locations and forest types, given the availability of suitable permanent sample plot data for calibration of model components.

SYMFOR is a Windows-based program with an advanced user-interface that allows run-time module selection and parameter evaluation. Users can change the type and frequency of silviculture practised, and control the details of the silvicultural implementation exactly as they would for a real forest. SYMFOR models represent individual trees including their relative spatial positions, which enables the modelling of silvicultural techniques for which there are no data available concerning the forest re-growth.

The approach used has limitations, and some care should be taken, as with all modelling, that the predictions or comparisons made are valid and that the models within the framework are properly calibrated and tested for the conditions being simulated. However, the advanced user-interface allows forest decision-makers the ability to quantitatively compare management options and to predict the state of the forest at a given point in the future.

The combination of explicit models of silvicultural practices, a model of the natural forest processes and an advanced user-interface forms a new tool for forest management decision making. Other models, using matrix or cohort methods, cannot represent the silvicultural treatments explicitly, so rely on long-term data for their development. SYMFOR is therefore a tool for silvicultural hypothesis testing, designed for use by forest managers and policy makers.

## 6 Acknowledgement

---

The authors gratefully acknowledge the contribution to this project made by colleagues in Indonesia who have helped to specify the structure of the model, provide data and test the resulting framework. The original concept for SYMFOR results from work by Drs R. Muetzelfeldt and A. Young.

## 7 References

---

- Alder, D., Synott, T.J., 1992. Permanent sample plot techniques for mixed tropical forests. Tropical Forestry paper 25, Oxford Forestry Institute, Department of Plant Sciences, University of Oxford, UK.
- Cherwell Scientific Ltd., 1999. Modelmaker overview. [Http://www.cherwell.com/cherwell/products/simulation/modelmaker/overview.htm](http://www.cherwell.com/cherwell/products/simulation/modelmaker/overview.htm).
- Departemen Kehutanan RI., 1993. Pedomannya dan petunjuk teknis Tebang Pilih Tanam Indonesia (TPTI) pada hutan alam daratan. Departemen Kehutanan, Direktorat Jenderal Pengusahaan Hutan, Jakarta, Indonesia.
- Departemen Kehutanan RI., 1998. Selective cutting and strip planting (TPTJ) silvicultural system in management of natural production forest. Departemen Kehutanan, Direktorat Jenderal Pengusahaan Hutan, Jakarta, Indonesia.
- Dykstra, D.P., Heinrich, R., 1996. FAO model code of forest harvesting practice. Food and Agriculture Organisation of the United Nations, Rome, Italy.
- Elias, 1998. Reduced impact timber harvesting in the tropical natural forest in Indonesia. Forest Harvesting Case Study 11, Food and Agriculture Organisation of the United Nations, Rome, Italy.
- Fishman, G.S., 1995. Monte Carlo: concepts, algorithms and applications. Springer, London.
- Gourlet-Fleury, S., 1998. Individual-based spatially explicit modelling of forest stands in French Guiana. In: Laumonier, Y., Proceedings of the EU\_FIMP/INTAG international conference on data management and modelling using remote sensing and GIS for tropical forest land inventory, Jakarta, Indonesia, 473-490.
- High Performance Systems Inc., 1999. Software solutions: Stella 5.1.1. [Http://www.hps-inc.com/edu/stella/stella.htm](http://www.hps-inc.com/edu/stella/stella.htm).
- Huth, A., Ditzer, T., Bossel, H., 1997. Rainforest growth model FORMIX3: a tool for forest management planning towards sustainability. Model development and case study for Deramakot Forest Reserve in Sabah, Malaysia. TOB-series number: TOB FTWF-6/e. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn: 78 S.
- Huth, A., Ditzer, T., Bossel, H., 1998. The rainforest growth model FORMIX3 – model description and analysis of forest growth and logging scenarios for the Deramakot Forest Reserve (Malaysia). Gottinger Beiträger zur land- und Forstwirtschaft in den tropen und subtropen 124. Erich Goltze, Gottingen: 182 S.
- Kleine, M., Heuvelop, J., 1993. A management planning concept for sustained yield of tropical forests in Sabah, Malaysia. Forest Ecol. Manag. 61, 277-297.
- Köhler, P., Huth, A., 1998. The effects of tree species grouping in tropical rainforest modelling: Simulations with the individual-based model FORMIND. Ecol. Model. 109, 301-321.
- McKay, E.N., 1999. Developing user interfaces for Microsoft Windows. Microsoft press, USA.
- Microsoft corporation, 1997. Microsoft ODBC 3.0 software development kit and programmer's reference. Microsoft press, USA.
- Microsoft corporation, 1998a. Microsoft Visual Basic 6.0 reference library. Microsoft press, USA.
- Microsoft corporation, 1998b. Microsoft Visual C++ 6.0 reference library. Microsoft press, USA.
- Muetzelfeldt, R.I. and Taylor, J., 1997a. The suitability of AME for agroforestry modelling. Agroforestry Forum 8(2): 7-9.
- Muetzelfeldt, R.I. and Taylor, J., 1997b. The Agroforestry Modelling Environment. In: Agroforestry Modelling and Research Coordination, Annual Report 1996-97, ODA Forestry Research Programme, Project R5652. NERC/ITE, Edinburgh.
- Ong, R., Kleine, M., 1996. DIPSIM: a dipterocarp forest growth simulation model for Sabah. FRC research papers No. 2, Forestry department, Sabah, Malaysia.

Phillips, P.D., Brash, T., van Gardingen, P.R., 1999. SYMFOR Help Pages.  
<http://meranti.ierm.ed.ac.uk/SYMFOR/Hlp/contents.html>.

Sist, P., Nolan, T., Bertault, J.G., Dykstra, D. (1998). Harvesting intensity versus sustainability in Indonesia. *For. Ecol. Man.* 108:251-260.

Stroustrup, B., 1997. The C++ programming language – third edition. AT&T labs, Murray Hill, New Jersey, USA.

Sykes, J.B., 1982. Oxford English Dictionary. Oxford University Press, Oxford, UK.

Vanclay, J.K., 1994. Modelling forest growth and yield: applications to mixed tropical forests. CAB International, Wallingford, UK.

van Gardingen, P.R., Clearwater, M.J., Nifinluri, T., Effendi, R., Rusmanto, W., Noor, M., Mason, P.A., Ingleby, K., Munro R., (1998). Impacts of logging on the regeneration of lowland dipterocarp forest in Indonesia. *Comm. For. Rev.* 77: 71-82.

Young, A.C., Muetzelfeldt, R.I., 1998. The SYMFOR tropical forest modelling framework. *Commonwealth Forestry Review*, 77, 11-18.