The SYMFOR model of natural forest processes – opening the black box.

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Abstract

SYMFOR is a framework used to simulate the effects of silviculture on the growth and future yield of tropical forests. The framework is made up of models of the natural processes in the forest (ecology) and the management of forest (silviculture)

The ecological model describes the natural forest processes in terms of the behaviour of individual trees, and thus the overall characteristics of the forest. The purpose of the model is to simulate the way that individual trees enter the stand (recruitment), grow and leave the stand (mortality).

The ecological model is made up of components describing the processes of tree growth, natural mortality and recruitment. The growth component predicts the annual diameter increment for an individual tree. The mortality component represents the probability of the death of individual trees. Falling trees then create an area of damage (represented by a kite shape) in which all trees smaller than the falling tree are killed. The recruitment component simulates the ingrowth of trees past the minimum 10 cm diameter threshold of the SYMFOR framework. The ecological model is derived from data to represent real forest processes. It is important to note that the SYMFOR framework does not currently describe some important ecological processes. Examples include the reduced growth rate and enhance mortality associated with extreme events such as *El nĩno*. The reason for this is that there may not be sufficient data available to calibrate the model to respond to such factors. These elements may be implemented in future versions of the model when data are available for calibration

The Forest Management Options model is used to simulate the effects of silviculture and harvesting on the forest. This part of SYMFOR allows the user to define a management system for the forest and for this system to be put into practice within the model.

The ecological and management options models are presented separately to the user. It is expected that most users will only interact with the management options. The growth of real managed forests depends on the interactions between management treatments and the ecology of the forest. SYMFOR accurately represents these interactions. For example, silvicultural activities that alter the structure and composition of the forest such as harvesting or thinning, will influence the ecological model and affect the growth rates of the residual stands.

Introduction

This paper provides a simple introduction to how the SYMFOR framework functions when it simulates the growth of a forest. It is intended for people who are SYMFOR users who want to understand how the ecological model and management options models work. A more complete description of the models will be published elsewhere. More detail describing the mathematical equations underlying the model are available from the online documentation (Online help or available at http://www.symfor.org), which fully document the models.

This document is an output from a project funded through the Forestry Research Programme of the UK Department For International development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.
Project R6915 Forestry Research Programme.

The essentials

Data requirements.

The model uses data from permanent sample plots (PSP) describing every tree in a stand that has a Diameter at Breast Height (DBH) of more than 10 cm. The following information is required for each tree:

- Tree number, a unique identifier;
- Tree position (x and y co-ordinates, in metres);
- Diameter at breast height (DBH) (cm);
- Ecological species group (1-10).
- Commercial species group (1-10).

Procedures are being developed to generate artificial tree position data so that it will be possible to use data from sample plots that do not include tree positions.

Additional and derived data

The ecological model requires additional information to accurately simulate growth. In most cases these data are generated from the original sample plot data.

- Growth-bias. This is an index between 0 and 1 that represents the genetic characteristics of each individual tree. Trees with a growth bias of >0.5 will grow faster and those with a growth bias of <0.5 will grow slower than average.
- Age (years). This is often not available for input, so at the start of the run it is set to zero, and new trees created by the model during a run also start with age zero.

Additional data describing individual trees are generated by the model as it runs, and stored so that the user can output them later. These are documented in the on-line help pages.

Species groups

There are 10 species groups. These are summarised in Table 1, and a complete listing is available from the web-site (http://www.symfor.org). The species groups are used to describe differences in the ecology between trees. For example, trees of species group 1 may grow faster than trees of species group 2. The species were grouped according to their observed behaviour – species whose individuals showed similar characteristics (such as growth rate, or response to canopy opening) were grouped together into one group. Dipterocarps were grouped separately to non-dipterocarps, and trees of unknown species were grouped separately to other trees. A separate grouping of species is used for the management options model.

Each ecological species group has its own growth recruitment and mortality functions. The structure of the equations are the same for all groups, but the constants or coefficients are different. This means that the model predicts different behaviour (e.g. growth rate, recruitment or mortality) for each species group.

Table 1: The characteristics and content summary of each species group.

Group	Name (reference)	Characteristics	Dominant members
1	Fast growing shorea	Large trees, light demanding, very fast growing	*Shorea johorensis*, *S. leprosula*
2	Dipterocarpus	Large trees, shade tolerant, slow growing	*Dipterocarpus*, some *Shorea*
3	Other large dipterocarps	Large trees, shade tolerant, fast growing	*Shorea*, *Parashorea*, *Dryobalanops*
4	Small dipterocarps	Default group for Dipterocarpaceae species	*Hopea*, *Vatica*, some *Shorea*, *Dipterocarpus*
5	Anthocephalus	Small trees, fast growing, highly disturbed forest	*Anthocephalus chinensis*
6	Macaranga	Small trees, light demanding, very fast growing	*Macaranga*
7	Gap small trees	Small trees, recruit in light Areas	*Aglaia*, *Knema*, *Artocarpus*
8	Other small trees	Small trees, default group for non-Dipterocarpaceae species	*Diospyros, Dacryodes*, *Polyalthia*
9	Shade small trees	Small trees, recruit in shady Areas	*Macaranga lowii*, *Gonystylus*, *Madhuca, Kayea*
10	Unknown	"Unknown" species, genus or family identity	Unknown

Timescale and model flow

The model has time-steps of 1 year. This means that SYMFOR performs a series of simulation in sequence, once, each modelled year.

- If the user has set the model to perform a silvicultural activity (for example felling and harvesting) in this year, the Management Options model will perform this at the beginning of the simulated year, before calculating the year's growth.

The sequence of events simulated in the ecological model is as follows:

1. *Growth*: Calculate the diameter increment for each living tree
2. *Mortality*: Decide which living trees die from natural causes this year and determine which other trees (smaller) are killed after being damaged by the falling tree.
3. *Recruitment*: Estimate how many new living trees of each species group come into the stand by growing from less than 10 cm to more than 10 cm.
4. *Age*: At the end of each simulated year, the age of all living trees is increased by one year.

Components of the Ecological Model

This section describes how each component the ecological model works. The paper describes the underlying ecological concepts and some elements of the process of calculation. For a full description of the equations, see the on-line documentation.

The growth model

Individual tree growth, or annual diameter increment, is calculated for each tree. The equation that is used to calculate growth has the same form for all trees which has been calibrated for each species group. This means that, in the same conditions, all trees in a species group behave the same way as each other, but not necessarily the same way as trees in other groups.

For a tree of a particular species group, the growth rate depends on:
- the tree size (DBH);
- an estimate, or index, of the LOCAL competition that the tree is experiencing (using all trees within 5 m of this tree);
- an estimate, or index, of the NON-LOCAL competition that the tree is experiencing (using all trees within 30 m of this tree);
- years since logging. Used to estimate of the amount of organic remains from logging operations that can provide increased nutrients for enhanced rates of tree growth. This is an index formed from the number of years since the plot was logged, and the number of trees left in the plot after logging.

This part of the sub-model is called “deterministic” because it will predict the same growth rate whenever it is given a particular combination of DBH, competition indices and years since logging.

The above factors are all the variables that can be derived from typical PSP data. In a typical dataset they can typically only explain around only about 30 % of the observed (statistical) variation any dataset. This means that that real estimates of growth rate, derived from data may vary significantly from the prediction determined by the deterministic component of the ecological model.

We know that there are many other factors that influence growth that are not described within the deterministic ecological model. For example genetic variation between individual trees of one species, and between different species in each species group. There will also be a response to environmental variation within a plot, for example resulting from soils and topography. This information is not in PSP data sets, so the model cannot use it. These factors have the effect of altering the growth-rate by some amount each year. If a particular tree grows faster than average one year, it will probably grow faster than average the next year too.

This is represented in the model by adding (or subtracting) a small amount to the growth-rate. The amount to add (or subtract) depends on two random numbers – one is produced each year, and the other is the tree’s “growth-bias”. These combine to mean that the growth of a particular tree is biased to be slightly faster (or slower) than the average. The use of random numbers means the model is called “stochastic”.

The recruitment model

Each plot is divided into a network of grid-squares, each 10m by 10m. The recruitment model predicts if new trees will become established in each square for each species group in turn. To do this, it temporarily creates a new tree at a random location within the grid-square. For this tree the model uses a predicted growth rate to calculate a probability of the temporary tree becoming permanent (the faster the tree grows, the more likely it is to be recruited). If the tree is recruited (kept) the DBH is set to 10 cm and the age is set to zero. The growth-bias is selected as a random number.

Trees may not be recruited in areas which are recently created skid-trails. If this occurs, trees are moved to another location within the grid-square. The definition of “recent” depends on the tree species, and varies from 5 years for *Anthocephalus* to 20 years for slow-growing dipterocarps.

The mortality model

The probability of death is calculated for each living tree once a year. The probability is higher for larger trees, and is much higher after a threshold DBH is exceeded (effectively the maximum size that trees are allowed to grow to). This value is compared with a random number to decide if any individual trees actually dies. Another random number is chosen and compared with the probability of falling (43%) to determine if the tree falls down. If it does, a third random number decides the direction of the fall (the "falldirection" data, which is from 0 to 6.28, or –1 for trees that did not fall).

Trees that fall may damage other trees in their path. A kite-shaped area, roughly the dimensions of the falling tree, is used to determine which trees are susceptible to damage. 24 % of trees that are smaller than the falling tree and within the kite-shape are damaged and killed by the falling tree and are converted to "smashedtree" records. Trees that die from damage do not themselves fall.

Other models used for output only

Some quantities are useful for model output, but are not used in the year-to-year running of the model. These include calculations of basal area, and stem volume, which is calculated from DBH by equations determined by Enggelina (1998).

Data used for calibration

This section has been included to allow users to judge whether their forest is likely to be similar to that used to calibrate the model, and so whether the model is valid for use with their data.

The data used for development of this model are PSP data from the Berau region of East Kalimantan (Indonesian Borneo). Lowland mixed dipterocarp forest is predominant in this region. The area is managed natural forest, some parts of which have been selectively logged. The plots were set up by the forestry company PT. Inhutani 1 as part of the STREK project (Bertault and Kadir, 1998) and have been maintained with the help of the European Union funded Berau Forest Management Project since 1996.

A detailed account of the history of the plots, the treatments applied and the data collection is given by Bertault and Kadir (1998), and we have kept this description to a brief summary. The region is at a latitude of 1°-2 ° N and low altitude. The terrain is locally hilly, but generally in a shallow watershed, experiences a rainfall of between 1800-3000 mm per year and low temperature fluctuations between 25 °C and 35 °C. The dry and wet seasons are not extreme, and the relative humidity remains high throughout the year.

There are 72 permanent plots, each a square 1 ha arranged with four adjacent plots arranged in a square blocks of 4 ha. Data from four surveys of the plots were available at the time of analysis, with approximate dates for the surveys being 1991, 1993, 1995 and 1997. Twenty-four hectares of forest were logged in 1980: all other plots were primary forest until experimental treatments were carried out in 1992. Of the 48 ha used for trial silvicultural treatments:

- 12 ha remained as unlogged control plots;
- 12 ha were logged according to the conventional selective logging system as implemented in Indonesia at that time, where all commercial stems with diameter greater than 50 cm were potentially harvested;
- 12 ha were logged using a Reduced Impact Logging (RIL) treatment (Bertault and Sist, 1997, Sist *et al.*, 1998, Sist and Bertault, 1998, Dykstra and Heinrich, 1996, and Elias, 1998) with a cutting diameter lower limit of 50 cm;
- and 12 ha were logged using RIL with a cutting diameter lower limit of 60 cm.

The data available for each tree in each plot and each survey were diameter at breast height (DBH), a numerical code representing species and the co-ordinates of the trees' position. Data for all living trees with a DBH greater than 10 cm were recorded. In-growth (recruitment) and mortality were recorded at each measurement campaign. The data were collated within a database system (Rombouts, 1997) that was used to validate and where possible correct data before use for model calibration. This system was then used to identify the remaining trees with unreliable diameter measurements that were excluded from subsequent analysis, with the exception of the analysis of competition.

Relationship of the Management Options model to the Ecological Model

SYMFOR is a tool which has been designed to simulate the impact of any silvicultural or management activity upon the structure of the forest and its subsequent growth. This makes it necessary that there is an ecological model to grow the forest according to the processes observed in the data, and another model which allows the user to 'manage' the forest in any way he chooses.

Within the Management Options model the user can control the simulation of a range of management activities such as felling cycle, minimum size and species of tree to be harvested, the number of trees to be cut, the direction of felling, and the type and size of skid trails. These activities obviously change the structure and composition of the forest (the size of the trees left and the species composition) and therefore change the way it grows. The Growth model therefore has to look at these changes and alter the forest growth accordingly. For example, if the user decides to fell all trees over 50 cm DBH this will open up the forest canopy and allow more light to penetrate into the forest. The growth model will detect less competition for light amongst the trees still standing and will therefore grow them faster.

The model has been designed so that the user can use the Management Options model to design and test a management system by making small changes to it as he/she goes along. In fact, that is how this tool should be used. Just like a forest manager the user is in control of what is done to the forest. On the other hand the user is encouraged not to change the ecological model as this would change the speed and pattern of forest growth – in the field, forest managers do not control this but can only influence it through their silvicultural and management activities.

Concluding notes

Further information may be obtained from the address at the head of this document, or e-mail or web-site. Please also see the web site to get the latest version of the software, and the status of the software and associated projects.

Acknowledgements

The authors would like to acknowledge the staff of P.T. Inhutani 1, BPK Samarinda and the European Union Berau Forest Management Project for the provision of the data necessary for this work, assistance in data processing and their comments on this manuscript.

This document is an output from a project (R6915 Forestry Research Programme) funded through the Forestry Research Programme of the UK Department For International development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

References and bibliography

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.

Bertault, J.G., Kadir, K., 1998. Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan. Cirad, Montpellier, France.

Bertault, J.G., Sist, P., 1997. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. For. Ecol. Manage., 94, 209-218.

Brokaw, N.V.L., 1985. Gap phase regeneration in a tropical forest. Ecology, 66: 682-687.

Denslow, J.S., 1987. Tropical rain forest gaps and tree diversity. Annual Review of Ecology and Systematics, 18: 431-451.

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.

Enggelina, A., 1998. Volume equations. In: Bertault, J.G. and Kadir, K., (Eds.), Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan. Cirad, Montpellier, France, 127-138.

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.

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 fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn: 78 S.

Kleine, M., Heuveldop, 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.

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., 2000a. SYMFOR Help Pages. http://meranti.ierm.ed.ac.uk/Symfor/Hlp/contents.html.

Phillips, P.D., Yasman, I., Brash, T.E., van Gardingen, P.R., 2000c. Grouping tree species for analysis of forest data in Kalimantan (Indonesian Borneo). For. Ecol. Man., in press.

Rombouts, J., 1997. Data structure of the growth and yield clearing house. Department for International Development, Jakarta, 1-20.

Sist, P., Bertault, J.G., 1998. Reduced impact logging experiments: impact of harvesting intensities and logging techniques on stand damage. In: Bertault, J.G. and Kadir, K., (Eds.), Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan. Cirad, Montpellier, France, 139-161.

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

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

van Gardingen, P.R., Foody, G.M. & Curran, P.J., 1997. Scaling up: From cell to landscape. Society for Experimental Biology, Seminar Series, Cambridge University Press, Cambridge.