The SYMFOR model: A general description.

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Abstract

In this paper we present SYMFOR, a software tool for investigating the effects of forest management. Using SYMFOR, it is possible to compare silvicultural alternatives numerically and scientifically, and thus inform the decisions on forest management and forest policy. It is also an extremely useful tool for education, capturing the ecology of the forest from the data and demonstrating how the interaction of the ecology and the management together affect the forest.

We have used existing datasets from East Kalimantan (Indonesian Borneo) to develop a model of forest growth and the effects of management on the forest, that has been implemented in SYMFOR. This represents the interaction between the natural forest processes and forest management. We have linked the outputs of SYMFOR to financial models, producing economic insight to forest management. A complete sustainability analysis of forest management requires an analysis that includes all social aspects of forest management, which are necessarily linked to natural and financial analyses.

A model of the ecological forest processes is one that determines 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). SYMFOR also has a forest management options model. This part of SYMFOR allows the user to define a management system and for this system to be modelled within SYMFOR. The management options model is presented to the user as separate to the ecological model, but the silvicultural activities will change the structure and composition of the forest and the ecological model will simulate the forest differently in response to this. SYMFOR takes PSP data and projects it through time, with prescribed management interventions. The outputs from SYMFOR can be simply PSP data for some point in the future, or more complex data used by SYMFOR during simulation.

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Introduction

Forests comprise one of the major natural resources in tropical regions, and as such have the potential to contribute enormously to local economies. The balance of priorities, between short-term financial gain and long term economic sustainability, is constantly changing to reflect local and international pressures. Consequently, the policy and methods relating to forest management in the developing countries of the tropics are areas of recurrent criticism and revision. Aspects relevant to forest management are financial, social and natural. Each of these affects the others, although aspects of them may be considered individually.

The individual experience or intuition of forest managers and policy makers is invaluable for obtaining a qualitative understanding of how the natural forest is likely to respond to management, but is unsuitable for use in comparisons of alternative strategies or in making numerical predictions. In general, individual experience is also not available for a particular strategy and forest type, especially in Indonesia, where most selective forestry is still within the first cutting cycle. Logical guesswork is the usual resort in silvicultural decisions, and thus the decisions are based neither on data from the forest or a quantitative, scientific approach.

The Growth and Yield Modelling project, a collaboration between the University of Edinburgh and the Forest Research Institute, Samarinda (Indonesia), set out to develop a science-based tool that could be used to inform tropical forest management decisions. By examining the behaviour of individual trees in a range of conditions and modelling a stand of individuals simultaneously, it would be possible to simulate the overall behaviour of natural forests. This could be used to model any management strategy, even ones that had never been tried before, as long as that strategy did not create conditions in the forest that were outside the range that were used to develop the model. The tool, SYMFOR, could enable forest policy and management decisions to be based on scientific analysis of forest behaviour, rather than logical guesswork or trial and error.

SYMFOR (Silviculture and Yield Modelling for tropical Forests), contains two types of model: models of the natural forest processes of tree growth, mortality and recruitment, and models of the management strategy. Data analysts and forest modellers may be expected to change or recalibrate the models of the natural processes. Forest managers, policy makers and silviculturalists are expected to develop models for their silvicultural strategy options and use existing natural forest models. In this way SYMFOR is a tool for researchers at all levels, and can be used to inform decisions about forest management. This paper describes the model of natural forest processes briefly, and also the forest management options available.

Presented here is a general description of SYMFOR, its operation and data requirements A complete description of the ecological model will be published in late 2000 or early 2001. For the equations used in each part of the model see the online help pages (Phillips *et al.*, 2000a), which document the whole model completely.

The essentials

The ecological model is made up of sub-models of tree growth, natural mortality and recruitment processes. The growth model evaluates annual diameter increment for an individual tree. A “deterministic” part uses tree diameter, local competition (5 m radius), wider competition (30 m radius) and the effect of previous felling to predict expected growth rates. The growth-rate data are not completely explained by the deterministic model, and so factors like genetic variation between individuals, slope position and local soil type are described by the “stochastic” part. The mortality model implements the death of trees using probability. Damage from falling trees is represented by a kite-shaped area in which all trees smaller than the falling tree are killed. The recruitment model uses 10 m by 10 m grid-squares to effect the stochastic recruitment of trees past the 10 cm diameter threshold of the SYMFOR framework. It uses a probability function based on the likely growth-rate of new 10cm trees in each grid-square to decide when a new tree should grow. The whole model is derived from data and does not rely on theories of tree or forest behaviour, but all aspects represent real forest processes.

The model of the natural processes is a description of the ecology of the forest that was captured in the data. It is important to note that any ecology that is not captured in the data cannot be fully captured in the model, because the model must be calibrated from the data. An element of the missing ecology, such as competition for resources, may be implemented in the model and used in the calibration of a quantity that is represented in the data, such as tree growth. In this way the model completely uses the data available, but widens the valid range of use of the model.

Data stored and input

The model uses data about each and every tree that has a Diameter at Breast Height (DBH) of more than 10cm. It stores the following information about each tree:

- Tree number, a unique identifier for labelling only, input;
- species group (1-10), input;
- position (x and y co-ordinates, in metres, normally 0m - 100m), input;
- DBH (cm), input;
- Growth-bias. This is an index between 0 and 1 that represents the genetic pre-disposition of the individual tree to grow faster (>0.5) or slower (<0.5) than average. It is used in a part of the growth model, and is generated automatically when the data is input because the information is not available from the forest.
- 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.

The model calculates many other data 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 on-line (Brash *et al.*, 2000). The process used to generate this grouping is described by Phillips *et al.* (2000b). If species information is available, the trees should be assigned to groups 1-9. Species group 10 is for unidentified tree species, so should be used if species information is not available.

The species groups are important because trees from some species behave in a consistently different way to trees from another species. 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.

There are 10 versions of each equation in the model – one for each species group. The structure of the equation is the same for all groups, but the constants, or coefficients, are different. This means the model predicts different behaviour (e.g. growth rate, or the probability of dying in a particular year) for different species groups, even if everything else about two trees is identical.

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,	*Macaranga*

		very fast growing	
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 the model does a series of things, one after the other, and when it gets to the end it starts again, with a new year. Each year it does the following:

1. Calculate the growth of each living tree this year, and then add the diameter increment to the old diameter, to get the new diameter.
2. Decide which living trees die from natural causes this year, change their data records from indicating that they are alive to show that they died from natural causes, and then decide which trees, if any, are killed by being damaged by the falling tree, and change the records for them as well.
3. Decide how many new living trees come into the model by growing from less than 10cm to more than 10cm this year, decide where they are located, what species they are and create data records for them.
4. At the end of each simulated year, the age of all the trees is increased by 1 year.

If the user has set the model to perform a silvicultural activity (for example logging) in this year, the management options model will perform this at the beginning of the simulated year, before calculating the year's growth.

For these three processes (growth, natural mortality and recruitment) to happen, there must be sub-models for each of them. The sub-models are discussed below.

The ecological model

This section describes how each part, or sub-model, of the whole model work. It does not give equations, but does describe the ecology and some elements of the process of calculation. For a full description, see the on-line documentation.

The growth model

Individual tree growth, or annual diameter increment, is calculated for each tree, each year. The equation that is used to calculate growth has the same form for all trees. From data analysis, we found that the growth rate of trees of a particular species group grew at different rates to those in other groups, so the model has been calibrated differently 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);
- a measure, or index, of the LOCAL competition that the tree is experiencing (using all trees within 5m of this tree);
- a measure, or index, of the NON-LOCAL competition that the tree is experiencing (using all trees within 30m of this tree);
- a measure of the amount of un-natural organic remains from logging operations that can provide increased nutrients for 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.

Because this part of the sub-model gives the same growth every time the same conditions are encountered, it is called "deterministic".

A perfect model is one that can reproduce precisely the same variation within a dataset that is observed in the field. The above factors are all the variables that were found to affect growth rates that can be derived from typical PSP data. They cannot reproduce all the variation in growth rates that are observed, however. In fact they can explain only about 30%. This means that if you take from the real data all trees of a given species group, DBH, local and non-local competition indexes and logging-nutrition index, the model will predict just one value, but the real data will vary quite a bit.

The extra variation is due to factors such as genetic variation between individuals, slight variation between species within a group, and position on a slope (valley, slope or ridge-top. This information is not in PSP data sets, so it cannot be used by the model. The effect it has is to increase (or decrease) 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

The plot area is divided into grid-squares, each 10m by 10m. In each grid-square, in each year, the recruitment model does a test to see whether to introduce a new tree there. To do this for each species group in turn, it temporarily creates a new tree at a random location within the grid-square. For the temporary tree, it predicts its growth rate (using the same model as described above), and uses the 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).

A random number is picked, and compared with the probability to decide if the temporary tree is kept or removed again. If the tree is kept, it's position and species group are as they were in the test, the DBH is set to 10cm and the age is set to zero. The growth-bias is selected as a random number. The tree is then added to the living tree records.

There is one exception to the above rule. If a temporary tree is located on a recently created skid-trail, the tree is not allowed to grow there, and is 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

Each year, for each living tree, the probability of dying is calculated. The probability of dying is higher for larger trees, and is much higher after a threshold DBH (effectively the maximum size that trees are allowed to grow to). All elements of the calculation are different for trees of different species groups.

The probability of dying is compared with a random number to see if the tree actually dies. If it does, it is converted from a living tree record to a "fallentree" record, although it may not actually fall. Another random number is chosen and compared with the probability of falling (43%) to determine if the tree actually falls. 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 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 basal area, which assumes a circular stem cross-section, 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 relative to an origin at one corner of each 1 ha plot. 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.

The management options model

SYMFOR is a tool which has been designed to look at the impact of any silvicultural or management activity upon the structure of the forest and its subsequent growth. This makes it necessary to have 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 they choose.

The management options allow the user to 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 recognises changes in the conditions that the trees experience, and alters the forest growth accordingly. For example, if the user decides to fell all trees over 50cm 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 they go 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

We have presented an introduction to SYMFOR. We have shown that it is a framework that contains a model of the ecological processes that govern tree growth and death, and a series of management options that allow the user to control the forest management model. With PSP data, SYMFOR can then simulate the composition and dynamics of the forest over a period of time. Data may be output that can be used in analyses of yield, silvicultural comparisons or linked to financial models of forest management. In this way, SYMFOR is a tool that can be used to inform decisions relating to forest management.

The models in SYMFOR at present were developed using data from Kalimantan, Indonesia. With suitable datasets, it is possible to calibrate the model for use in other forested regions of the world. There are currently plans to adapt the model for use in other parts of Asia.

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

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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.

Brash, T., Phillips, P.D., van Gardingen 2000. Species groups for use with the SYMFOR modelling framework. http://meranti.ierm.ed.ac.uk/g&y/speciesgroups.htm.

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., 2000b. 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.