Deutscher Tropentag 2000 in Hohenheim
Session: Land Use Planning

Model-based planning and decision making in tropical forest management: An example from Sabah, Malaysia

Hans-Joachim Droste, Reinhold Glauner,
Jochen Heuveldop and Thomas Ditzer

Federal Research Centre for Forestry and Forest Products
Institute for World Forestry
Leuschnerstr. 91, D-21031 Hamburg, Germany
Tel: +49-40-739 62 117, Fax: +49-40-739 62 480, E-mail: droste@holz.uni-hamburg.de

Keywords: growth & yield; tropical rainforest; annual allowable cut; management planning

Introduction

The determination of the annual allowable cut (AAC) is one of the key-issues for sustainable forest management in tropical moist forests. Timber is the most important renewable resource and the main source of income for forest owners. Thus, the determination of the AAC is of striking economic importance. However, due to timber exploitation practices in the past, the derivation of the AAC has also important environmental aspects. To find a balance between economic needs and environmental considerations is the main challenge facing tropical forest management planning today.

Objectives

The objective of our study is to model the development of regenerating lowland dipterocarp forest considering sustainability criteria

1) by simulating growth dynamics on the basis of eco-physiological processes:

- photosynthesis and respiration rates
- competition for light and space
- regeneration and mortality

2) by integrating the spatial distribution of site and stand types:

- topography (slopes)
- forest strata (distribution of big trees)
- exchangeable soil nutrients & plant-available water capacity (site index)

3) to derive the key-parameter for forest management:

- sustainable annual allowable cut (AAC)
- testing different management approaches (scenarios)

Study Area

Deramakot Forest Reserve (DFR) comprises 55,084 ha of heavily logged lowland dipterocarp forest in Sabah, Malaysia (Figure 1).

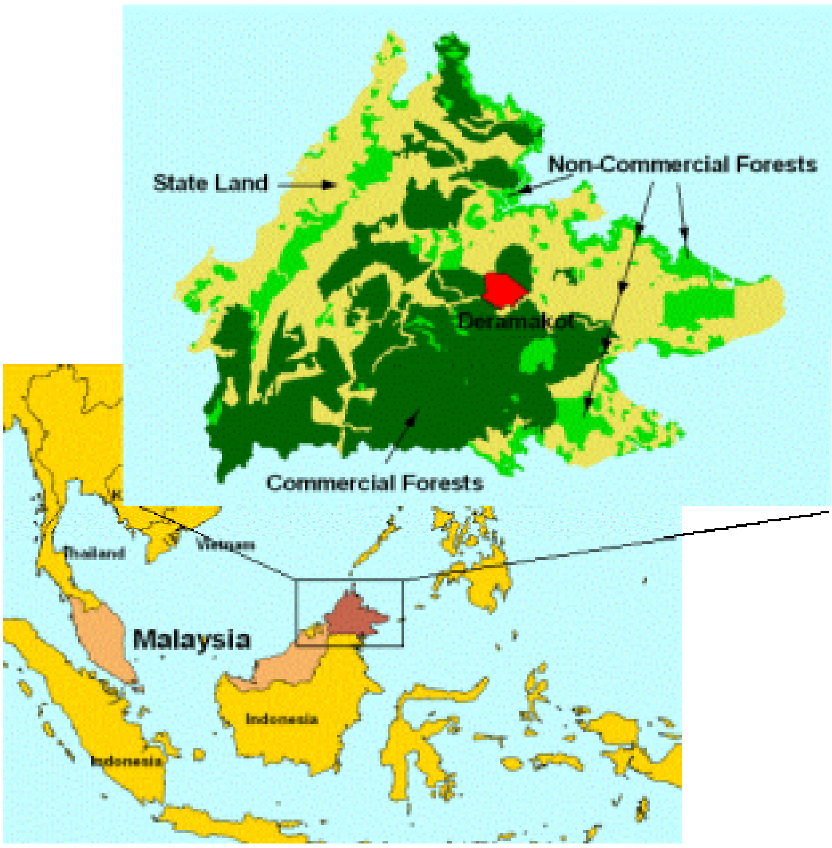


Figure 1: Location of Deramakot Forest Reserve in Sabah and Southeast Asia

The commercial forest reserve is covered by lowland dipterocarp forest dominated by emergent species of *Parashorea tomentella* (Sym.) Meijer (Dipterocarpaceae) and *Eusideroxylon zwageri* Teijsm. & Binn. (Lauraceae) (Fox, 1972). The stands show a total height of up to 50 m. Deramakot is characterised by tertiary sediments on which mainly Acrisols developed. These soils are poor in nutrients, well drained, and easily eroded (Glauner, 2000). The perhumid tropical climate shows no distinct dry season, although dry spells of up to 30 days may occur. The mean annual temperature is 27° C without seasonal variation. Average yearly precipitation is approximately 2,700 mm showing maxima in March and April (Schlensog, 1997).

DFR was at least once selectively logged starting in the late 1950's (Droste et al., 1996). In addition, the forest fires in 1982/83 damaged parts of the area, especially in the south. These disturbances resulted in a high small-scale variation in forest structure (Kilou et al., 1993). Different succession stages are found closely together.

Material and Methods

FORMIX - A process-oriented growth model

FORMIX (Bossel and Krieger, 1991; 1994) is based on earlier work of Kira (1978) and Oikawa (1985) and established the first process-based approach in tropical rain forest modelling. This work was continued by Huth et al. (1998) with the successor model FORMIX 3 and by Ditzer (1999) and Ditzer et al. (1999) with the model FORMIX 3-Q. Several equations describe individual tree growth for different site conditions. The model accurately describes growth using aboveground biomass as the key variable (Koehler et al., 2000b). Tree diversity is aggregated into five species groups (Koehler et al., 2000a). Each group has its own growth characteristics, photosynthesis rates (Eschenbach et al., 1998), and typical mature heights (Droste, 2000). For each species group the model calculates biomass and tree numbers for five distinct canopy layers on spatial patches of 20x20 m (Figure 2).

Although light conditions differ considerably in each layer (Schlensog, 1997), the processes are identical: photoproduction, respiration, shading of lower layers, transitions of trees from lower to higher layers. Photoproduction and respiration rates lead to biomass, diameter, height, and leaf mass growth in each layer. The leaf mass within the layers determines photoproduction of the trees and light conditions in lower layers (competition for light). Mortality of trees is based on field experiences and included as random event. Large dying trees may collapse and create gaps in the forest structure or disintegrate still standing without creating gaps. Preliminary it is assumed that a constant seed bank for all species groups exists to assure continuous seedling establishment. This concept is presently under further investigation (Koehler, 2000; Droste, 2000). The seedlings will start growing, if favourable growth conditions, e.g. gaps, exist.

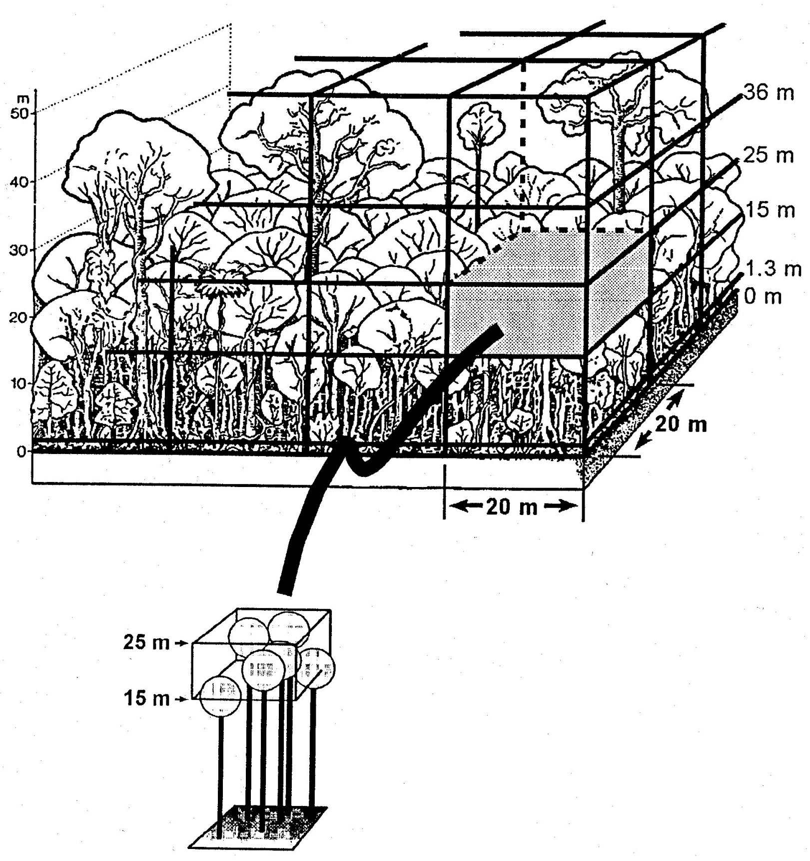


Figure 2: Partitioning lowland dipterocarp forest in five species groups, five canopy layers, and 25 spatial patches of 20x20 m per hectare

Field data analysis and site specific stand types (SSSTs)

Field data for the classification of stand types are provided by Kilou et al. (1993) and additionally for sites and soils by Glauner (2000). The point sampled data are spatially extrapolated for the whole forest reserve using GIS (Foerster et al., 1998). Field data are recorded in a systematic 1x1 km grid during a terrestrial inventory. Trees >10 cm dbh were recorded in

437 combined sample plots (0.01-0.25 ha). At each plot, a site description using standard soil pits was carried out. Site quality classification is based on soil profile descriptions and lab analyses. Soil nutrient stocks (exchangeable Ca, Mg, K) in the upper 50 cm (or to the appearance of a hard or cemented horizon, whichever comes first) and plant-available water capacities were calculated (Glauner, 2000). Based on 1:25,000 black and white aerial photographs, the area was classified into four forest strata based on the number of trees per hectare with crown diameters > 20 m (stratum 1: 0-4, stratum 2: 5-8, stratum 3: 9-16, stratum 4: >16).

GIS analysis

The strata map and the site quality classification were digitally recorded in GIS coverages (ARC/INFO). Topographic maps (1:25,000) with 15 m contour lines were digitised to generate a digital elevation model. After adding peaks and breaklines (Bill, 1996), a triangular irregular network (TIN) following Delauney-triangulation (ESRI, 1992) was derived. Based on the TIN, slopes were grouped in four classes (≤ 5°, 6°-15°, 16°-25°, >25°). As a result of the slope classification, 29% of DFR area exhibit slopes ≤ 5°, 40% slopes of 6-15°, 24% slopes of 16-25°, and 7% slopes >25°.
The average size of continuous areas of one stratum strongly decreases from 911 ha for stratum 1 to 136 ha for stratum 2 to 103 ha for stratum 3 and 101 ha for stratum 4. The strata 1-4 cover 54%, 25%, 13%, and 8% of DFR area respectively. The site quality analyses result in a spatial distribution of sites classified into poor, average, and good quality classes. Approximately 12.7 % of DFR area classified as good, 52.8% as average, and 34.6% as poor. Digital maps depicting the site quality, slope classes, and forest strata are combined to generate a spatial database where the resulting polygons have all features combined. These units of characteristic site conditions and present forest structure (slope-stratum-site) are termed site-specific stand types (SSSTs). The combination of four slope classes, four strata, and three site quality classes leads to the definition of 48 SSSTs (Figure 3). All 48 SSSTs are found in DFR during the field assessment, however, not on each type inventory plots are found. The 48 SSSTs are distributed across DFR in 98,341 continuous patches with an average size of approx. 0.5 ha.

The terrestrial inventory data from all plots falling into each SSST are used to calculate the tree diameter distributions for this specific SSST as input parameters for FORMIX. The inventory data represent only 39 of the 48 possible SSSTs. For each of the missing nine SSSTs the diameter distributions of every SSST with the same site quality and slope class and similar stratum (replacing stratum 4 by 3 and stratum 1 by 2) are used.

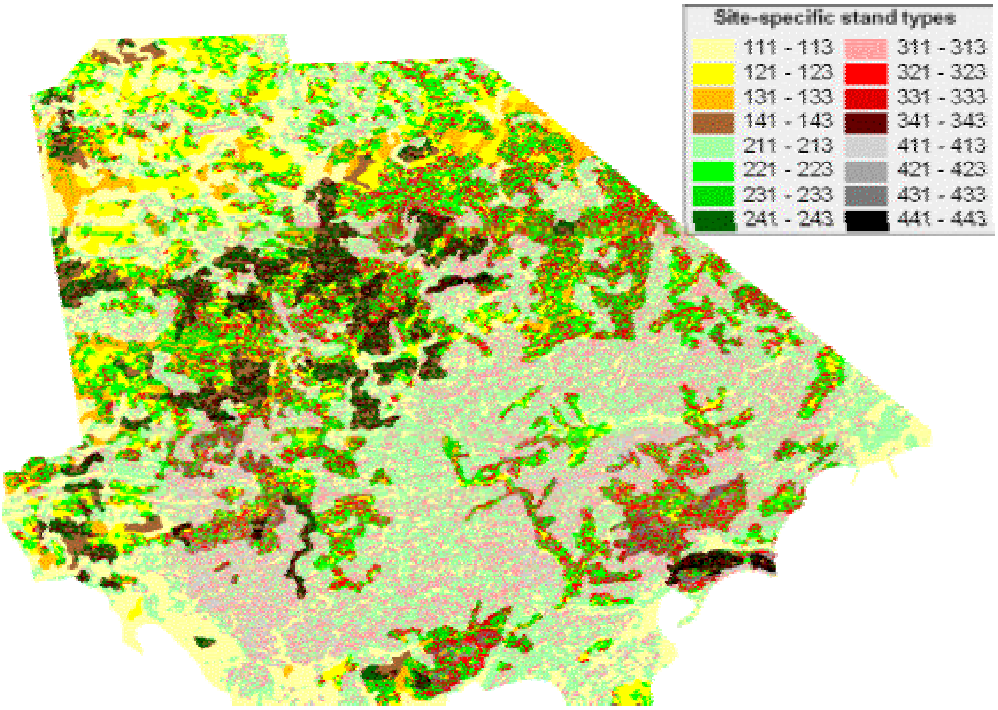


Figure 3: The combination of spatial data layer for four steepness classes with four forest strata and three site quality classes results in 48 site-specific stand types.

Defining scenarios

Based on the SSSTs we simulate the undisturbed development of the forest in DFR. The two SSST-parameters "site quality" and "slope class" characterise the site conditions required by the model. The diameter distribution determined for each SSST in year 0 (1991 inventory) is the starting point of the simulation. Simulations are run for a period of 120 years for each SSSTs. In the model every single SSST is treated as a homogenous 1 ha-stand. We run 10 replications of every model cycle for each SSST to avoid statistic outliers and operate with the mean values in further interpretation. Theoretically, the forest dynamics for 400 years or more could be simulated.

For this paper three management scenarios were defined (two logging and one no logging scenario) and only the silvicultural standards were varied, i.e. the parameters harvesting damage [% of residual stand], number of remaining harvestable trees > 60 cm dbh after harvesting [n ha^{-1}], and minimum number of trees to be harvested [n ha^{-1}].

Table 1: Parameter variation for definition of modelling scenarios

Parameter		Management Scenarios		
		No logging	Logging Scenarios	
			Textbook	Borderline
Harvesting damage	[% of residual stand]	-	20	20
Remaining harvestable trees	[n ha^{-1}]	-	6	3
Minimum economic cut	[n ha^{-1}]	-	5	-

The particular parameters for each scenario are shown in Table 1. For easier recognition the scenarios are named with catchwords as follows: "no logging" where undisturbed regeneration without any harvesting operation is assumed, "textbook" where six seed trees are left in the forest and a minimum economic cut of ≈ 40 m^3 ha^{-1} (≈ 5 trees) is assumed, "borderline" where only three mother trees are left in the forest and economics are neglected (= even a single tree per hectare is harvested). The two logging scenarios correspond to a required pre-harvesting condition of 11 harvestable trees > 60 cm dbh ha^{-1} for the textbook scenario or 4 trees for the borderline scenario respectively. Harvesting damage [% of residual stand] is kept at 20%, assuming that only reduced impact logging techniques are applied.

Model accuracy

A comparison of simulated data with measured data from five permanent sample plots (PSP) in Sabah (Koehler, 2000) revealed that the basal area bias for lowland sites is below 20% and for one hill site approx. 28% (Figure 4). The PSP closest to Deramakot showed a bias of below 10% only (Segaliud Lokan 1). The comparison did not include a site assessment as PSP are not yet mapped. The introduction of the site index concept should lower the bias to even less than 10% for permanent plots. We thus consider the accuracy of FORMIX as appropriate to support medium- to long-term forest management decisions.

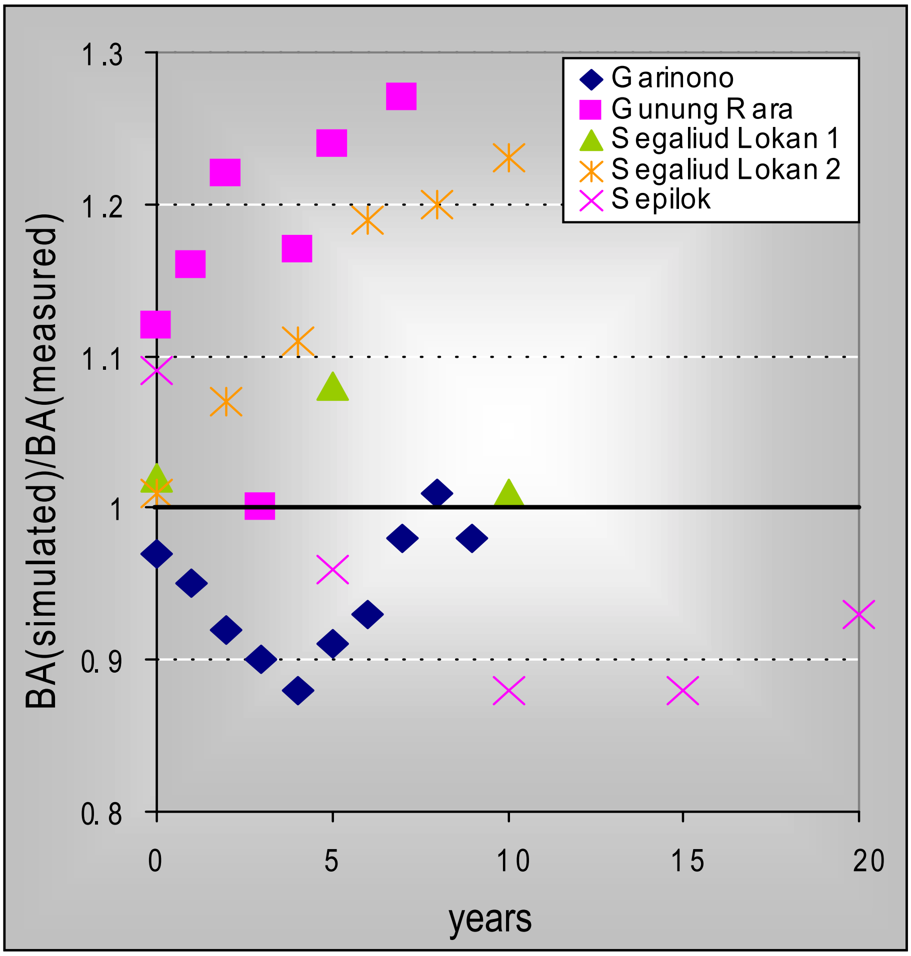


Figure 4: The quotient of Basal Area (simulated) / Basal Area (measured) indicates over- and underestimation of the modelling approach for five Permanent Sample Plots (PSP).
Four lowland sites and one hill site (Gunung Rara) were used for model evaluation.
The sites closest to Deramakot are Segaliud Lokan 1 and 2.

Results and Discussion

Among the many aspects which could be discussed in this paper, we focus on the following management-related aspects:

- Harvesting levels
- Increment pattern
- Volume development
- Increment development

- Stand development
- Spatial pattern
- Sustainability

Harvesting levels

Although Deramakot is heavily logged and partly degraded, harvesting is principally possible under both logging scenarios (textbook and borderline). The possible annual cut for the whole forest management unit amounts to approx. 200 m³ a^{-1} for the textbook scenario and approx. 11,000 m³ a^{-1} for the borderline scenario in the first 10 years. Harvesting levels would rise to 72,000 m³ a^{-1}, respectively to 83,000 m³ a^{-1} in 120 years.

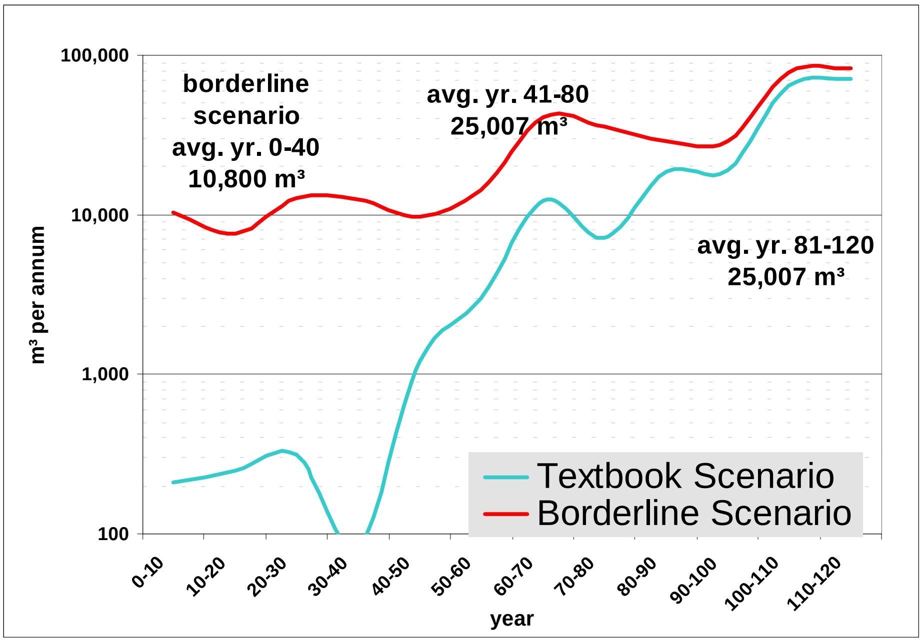


Figure 5: Development of potentially harvestable timber volume in Deramakot over the next 120 years under scenario assumptions (Note: a logarithmic scale for the y-axis was chosen;
the difference of approx. 10,000 m³ a^{-1} remains throughout the whole simulation period)

Increment pattern

The development of the timber increment is a very important aspect in growth and yield planning. When plotting the net increment over the commercial growing stock, a bell-shaped pattern should build up for uneven-aged mixed dipterocarp forests. The curve for Deramakot (Figure 6) allows to determine if more or less increment can be expected during forest rehabilitation. The maximum of the curve corresponds to the desired growing stock level, around which the actual growing stock levels ideally should oscillate (Bick et al., 1998) to obtain maximum increment on the long run. We found good coefficients of correlation between growing stock and net increment for the simulation results (r between 0.69 and 0.88). The maximum increments of the three scenarios vary only about 0.1 m³ ha^{-1} a^{-1} whereas they correspond to considerable different desired commercial growing stock levels. The highest desired growing stock level of ≈ 240 m³ ha^{-1} is computed for the borderline scenario. The maximum for the no logging option corresponds to a growing stock level of ≈ 200 m³ ha^{-1}. Although, especially in the lower growing stock range (≈ 100 m³ ha^{-1} and less), sometimes negative increment values occurred in our simulation results (mortality > growth), the computation of the bell-shaped curve does not allow negative values. We might seek for an appropriate alternative bell-like curve for future correlations.

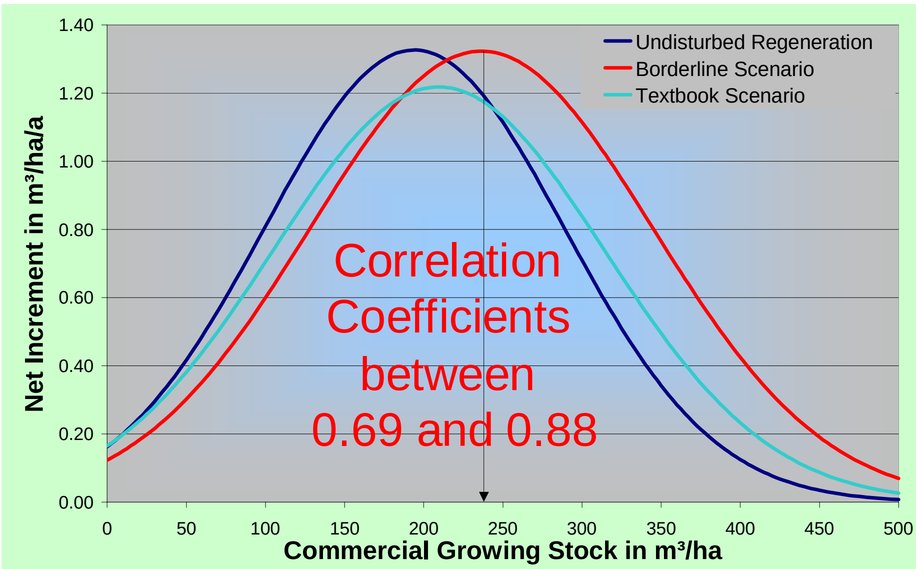


Figure 6: Idealised relationship between commercial growing stock and net (commercial) increment for three management scenarios

Volume development

Another central aspect in forest planning is the parameter "time required until the desired growing stock is achieved", as only then the maximum harvesting levels can be obtained. Especially today this is important, because economic pressure in Sabah is extremely high and harvesting operations cannot be ceased. Our simulations show (Figure 7) that for the no logging scenario it would take some 40 years respectively 65 years under the borderline scenario assumptions to reach a desired commercial growing stock level of ≈ 240 m³ ha^{-1}. Growing stock levels in the no logging scenario pass the desired levels quickly (≈ 55 years) whereas the levels in the borderline scenario oscillate heavily and fall either below or above the desired levels. Only after ≈ 100 years oscillations smoothen out and seem to stabilise. It would be worthwhile to test longer simulation periods.

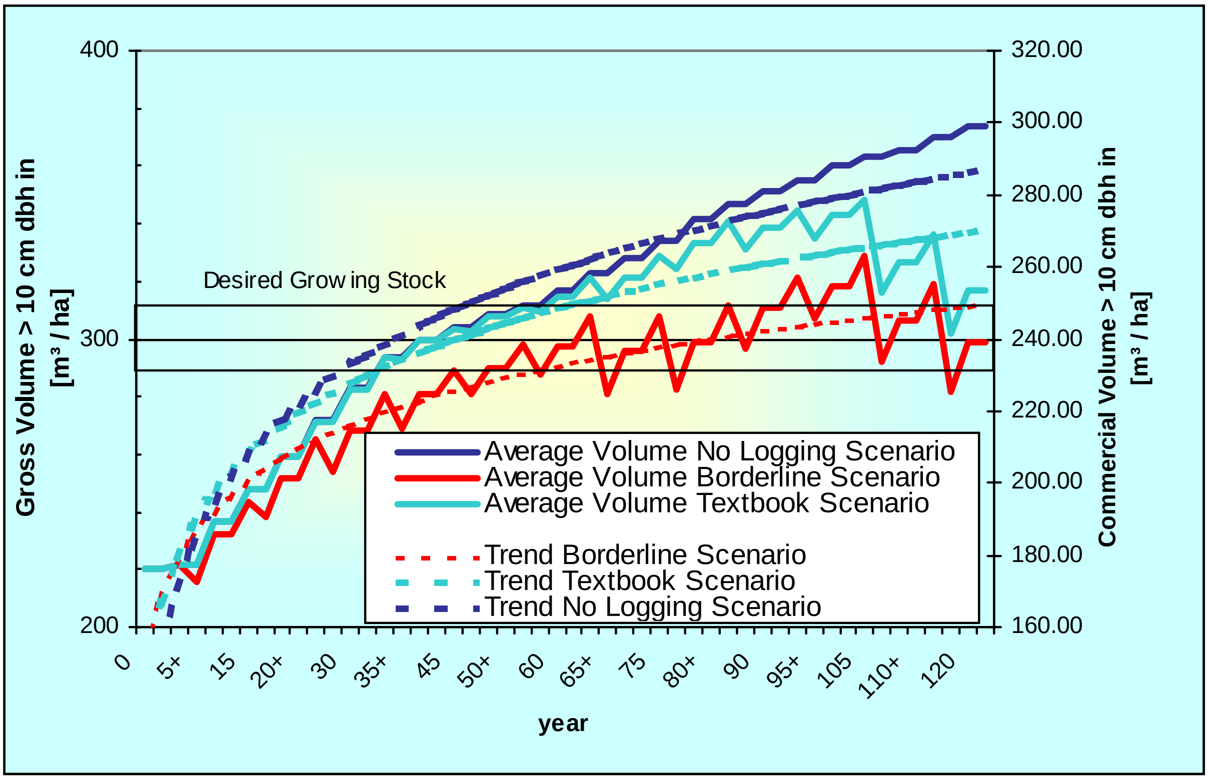


Figure 7: Development of growing stock (gross and commercial) over time for three management scenarios

Increment development

Timber increment is highly correlated with forest structure and site conditions. The heavily degraded and spatially very inhomogeneous forest structure in Deramakot makes the prediction of increment development extremely difficult. With FORMIX it is possible to compute the annual and periodic increment on a forest management unit basis. The simulations for

Deramakot show that increment decreases for ≈ 50 years for all scenarios. Although the absolute figures are different, the trend is surprisingly clear for all scenarios. The lines for the no logging and the textbook options are even very close together. Increment recovers relatively constant beyond 50 years, especially for the logging scenarios. The second drop of the increment around year 100 is caused by the unequal sizes of the working areas. These should be redesigned after 80 years (2 working cycles). This is presently not possible with FORMIX. However, simulation could be halted at 80 years and a new input data set with new working areas could be designed.

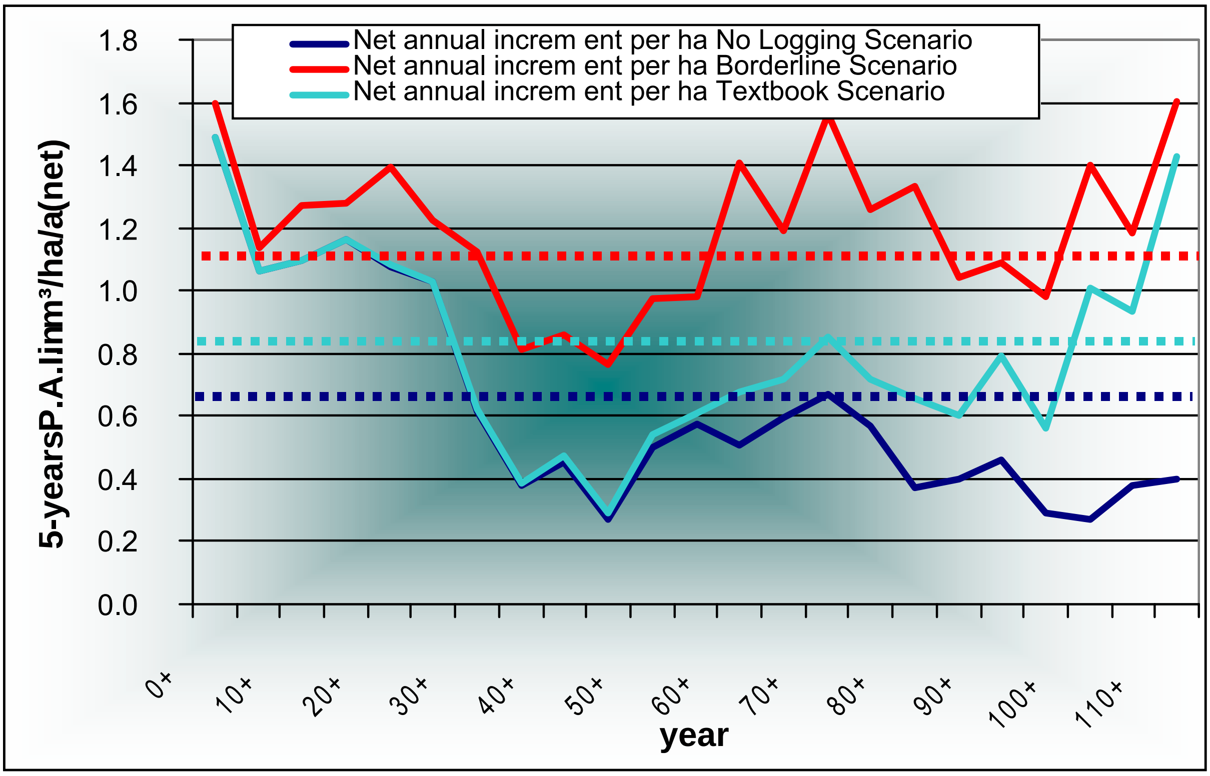


Figure 8: Development of annual increment over the whole simulation period (calculated as mean periodic annual increment P.A.I. of 5-years periods)

Stand development

Timber yields are an important aspect of sustainable forest management. However, to assess sustainability in a holistic sense, many other aspects have to be considered as equally important. There are a number of parameters which could be evaluated using FORMIX. As an example please find below the visualisation possibilities of the stand structure, highlighting the shift in species composition in the borderline scenario (Figure 9). There is a clear increase of pioneer and main canopy species. The number of emergent species decreases. It is also visible that the canopy structure is more open and canopy roughness increases.

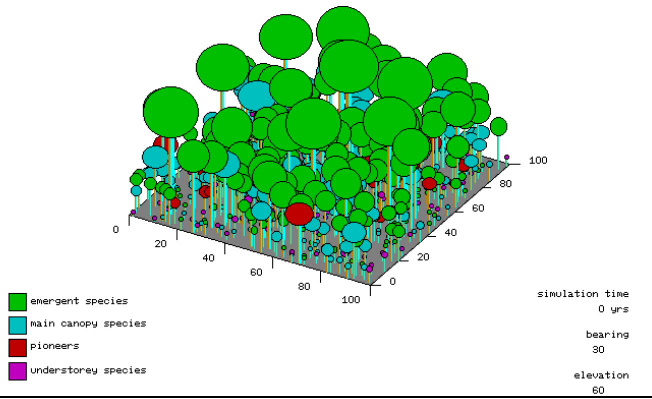
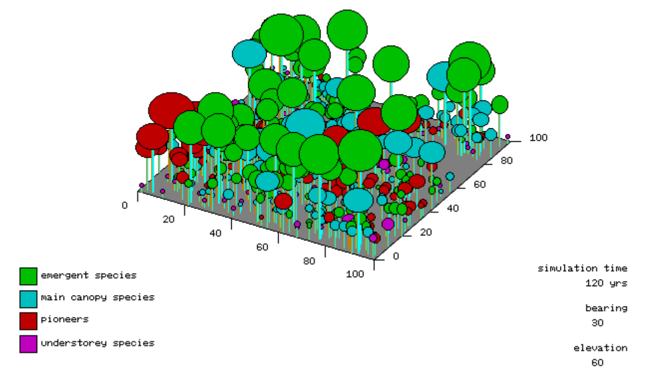
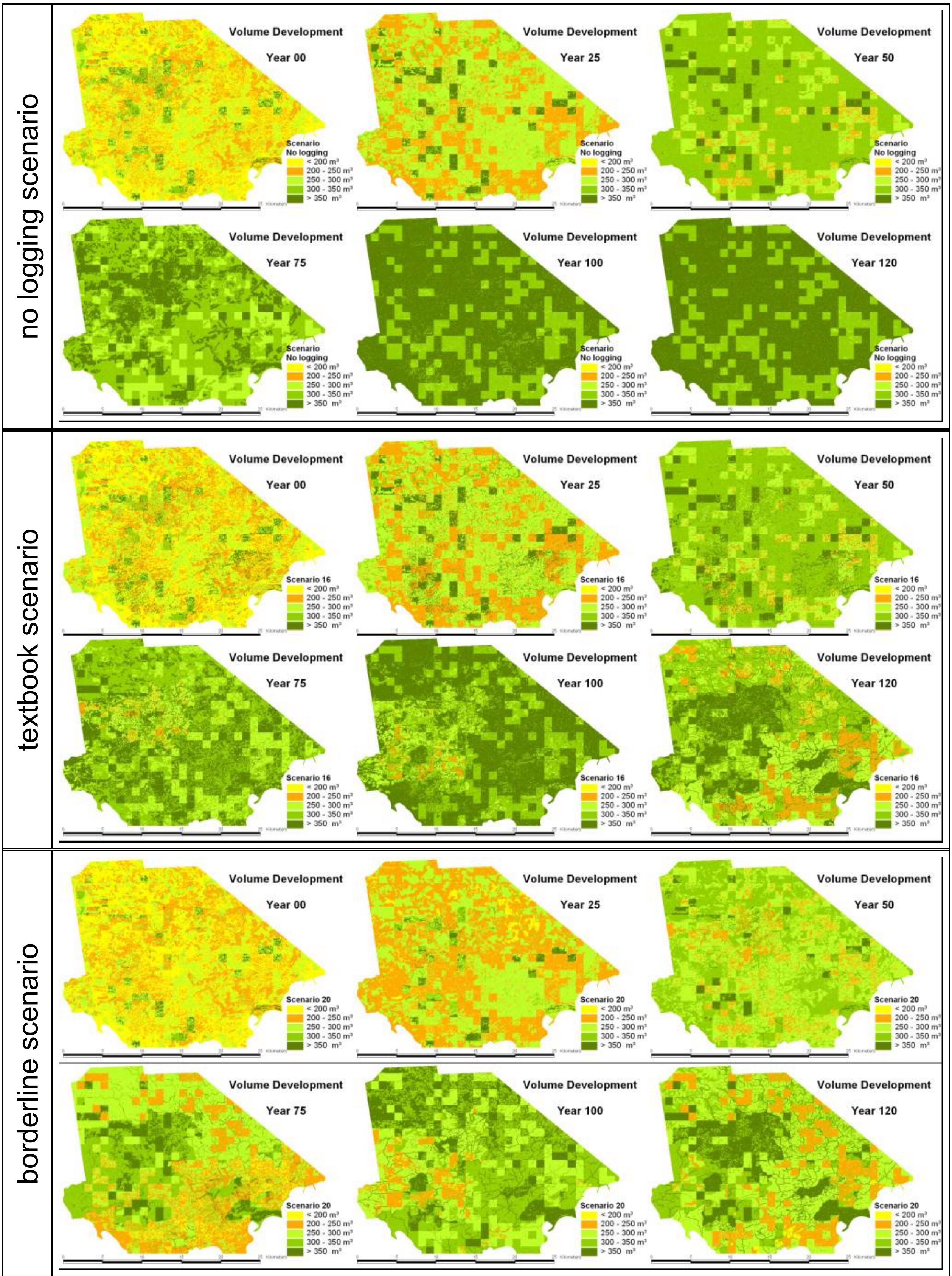
<table>
<tr><td>
</td><td>
</td></tr>
<tr><td>Little disturbed forest stand at year 0 of the simulation</td><td>The same stand at year 120 (borderline scenario)</td></tr>
</table>

Figure 9: Visualisation of stand development (year 0 and year 120) for one stand type and one logging scenario

It is not within the framework of this paper to thoroughly assess if the stand development described above would meet holistic definitions of sustainability. We are fully aware that this scenario would be debatable under certain aspects, e.g. biodiversity. This is one reason why we termed it borderline scenario.

Spatial development

In our approach, the visualisation of the spatial development of forest stands is possible through the combination of a growth model with a GIS database. The example below (Figure 10) shows the volume development for the three management scenarios in 25 years steps in form of a digital map. We have chosen legend colours where darker colours correspond with higher volumes. One can clearly recognise that forest structure is more heterogeneous the stronger the interferences in the forest, i.e. the higher harvesting levels are (size and number of light coloured patches in the borderline scenario). However, it is also clearly assessable that the forest can regain its pristine volume conditions when disturbances by logging would be ceased for 120 years (dominant dark colours in the no log-



Legend: Growing Stock Levels	< 200 m³	200 - 250 m³	250 - 300 m³	300 - 350 m³	> 350 m³

Figure 1: Spatial development of growing stock in Deramakot in steps of 25 years for three management scenarios

ging scenario). The textbook scenario is somewhere in between the two conditions described above. The frequency of areas poor in volume is reduced and more area is found in conditions which are close to pristine forests.

Conclusions

- Logged and degraded forest can recover to conditions which are close to pristine forests if logging is ceased. The time period required for recovery may be 120 years and more.
- Harvesting can be carried out on a sustainable basis even under degraded conditions. However, harvesting levels are very low.
- Harvesting and increment levels in Deramakot vary greatly depending on the set of standards applied. They increase with time when harvesting damages are kept low.
- AAC for Deramakot should be set to >10,000 $m^3 a^{-1}$ for at least 40 years.
- Ecophysiological modelling in a GIS-environment is a promising approach towards comprehensive planning of sustainable forest management.
- Scenario analyses provide sufficient alternatives to meet different levels of sustainability standards.
- Applying growth models in combination with GIS will save planning costs on the long run but requires investments today.

References

Bick, U., Droste, H.-J., Glauner, R., Heuveldop, J., 1998. Assessment and measurement of forestry key parameters for the evaluation of tropical forest management. *Plant Research and Development*, (47/48): 38-61

Bill, R., 1996. Grundlagen der Geo-Informationssysteme. Bd. 2. Heidelberg: Wichmann Verlag, 463 p.

Bossel, H., Krieger, H., 1991. Simulation model of natural tropical forest dynamics. *Ecological Modelling*, (59): 37-71

Bossel, H., Krieger, H., 1994. Simulation of multi-species tropical forest dynamics using a vertically and horizontally structured model. *Forest Ecology and Management*, (69): 123-144

Ditzer, T., 1999. Struktur und Dynamik natuerlicher und bewirtschafteter Dipterocarpaceenwaelder: Eine Fallstudie der Modellbildung und Simulation fuer die Bewirtschaftung natuerlicher Ressourcen unter Unsicherheit. In: Seifert, H.S.H., Vlek, P.L.G., Weidelt, H.-J. (eds.), Goettinger Beitraege zur Land- und Forstwirtschaft in den Tropen und Subtropen, Heft 131. Erich Goltze GmbH, Goettingen, 359 p.

Ditzer, T., Glauner, R., Foerster, M., Koehler, P., Huth, A., 2000. Growth & yield analysis in tropical rain forest: applying the process-based stand growth model FORMIX 3-Q in a GIS-environment (submitted). *Tree Physiology*, (20): 367-381

Droste, H.-J., Glauner, R., Heuveldop, J., 1996. Ein Beispiel nachhaltiger Waldwirtschaft in den Tropen: Deramakot Forest Reserve in Sabah (Malaysia). *Holz-Zentralblatt*, (122)53/54: 893-898

Droste, H.-J., 2000. Die Einsatzmoeglichkeiten eines regionalisierten Waldwachstumsmodells in der forstlichen Planung und Entscheidungsfindung. Dargestellt am Beispiel des Modells FORMIX 3Q (DRAFT). University of Hamburg, Hamburg

Eschenbach, C., Glauner, R., Kleine, M., Kappen, L., 1998. Photosynthesis rates of selected tree species in lowland dipterocarp rainforest of Sabah, Malaysia. Trees, (12): 356-365

ESRI, 1992. Surface Modeling with TIN. User Guide. Redlands

Foerster, M., Glauner, R., Kriebitzsch, W.U., 1998. Modellierung des Waldwachstums von tropischen Regenwaeldern unter Einwirkung von großflaechigen Stoerungen. Arbeitsbericht der Bundesforschungsanstalt fuer Forst- und Holzwirtschaft. Bundesforschungsanstalt fuer Forst- und Holzwirtschaft, Hamburg, 27 p.

Fox, J.E.D., 1972. The natural vegetation of Sabah and natural regeneration of the dipterocarp forest. Department of Forestry and Wood Science University College of North Wales, Bangor

Glauner, R., 2000. The role of soil-and-site science in management planning in managed natural forests. An example from Sabah, Malaysia. Mitteilungen der Bundesforschungsanstalt fuer Forst- und Holzwirtschaft Hamburg No. 197. Max Wiedebusch, Hamburg, 313 p.

Huth, A., Ditzer, T., Bossel, H., 1998. The rain forest growth model FORMIX3. Model description and analysis of forest growth and logging scenarios for the Deramakot Forest Reserve (Malaysia). In: Seifert, H.S.H, Vlek, P.L.G, Weidelt, H.J. (eds.), Goettinger Beitraege zur Land- und Forstwirtschaft in den Tropen und Subtropen. Vol. 124. Erich Goltze, Goettingen, 182 p.

Kilou, P., Lagan, P.M., Glauner, R., Kleine, M., 1993. Medium term forest management planning inventory. Results for Forest Management Unit No.19 - Sandakan. Forestry Department Sabah, Sandakan

Kira, T., 1978. Community architecture and organic matter dynamics in tropical lowland forests of Southeast Asia with special reference to Pasoh Forest, West Malaysia. In: Tomlinson, P.B., Zimmermann, M.H. (eds.), Tropical trees as living systems. Cambridge University Press, Cambridge, 26-30

Koehler, P., 2000. Modelling anthropogeneous impacts on the growth of tropical rainforests using an individual-oriented forest growth model for analyses of logging and fragmentation in three cases studies. University of Kassel, Kassel, 211 p.

Koehler, P., Ditzer, T., Huth, A., 2000a. Concepts for the aggregation of tropical tree species into functional types and the application to Sabah's lowland rain forests. *Journal of Tropical Ecology*, (16)4 (in press)

Koehler, P., Ditzer, T., Ong, R., Huth, A., 2000b. Comparison of measured and modelled growth on permanent plots in Sabah's rain forests. *Forest Ecology and Management*, (in press)

Oikawa, T., 1985. Simulation of forest carbon dynamics based on a dry-matter production model - I. Fundamental model structure of a tropical rainforest ecosystem. *The Botanical Magazine*, (98): 225-238

Schlensog, M., 1997. Experimentelle Untersuchungen des Lichtklimas in Urwaldparzellen Nordborneos. In: Seiffert, H.S.H., Vlek, P.L.G., Weidelt, H.-J. (eds.), Goettinger Beitraege zur Land- und Forstwirtschaft in den Tropen und Subtropen. Vol. 117. Erich Goltze, Goettingen, 151 p.