# A growth model and harvest allocation algorithm for timber and non-timber product management planning in Iwokrama Forest, Guyana

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## Abstract

A model, IwoPlan, is described for planning harvesting and management of timber and non-timber products in the Iwokrama Forest. It includes mapping and geoprocessing components to intersect forest types with management units and apply weighted stand tables from baseline inventory data. Simple growth models based on mean increment and mortality project species stand tables over time. Flexible product specifications can define a variety of timber and non-timber products. A transport network is developed logically from map data and extended by simulation; this is used in allocating harvesting coupes on a last cost, maximum density or least distance basis. Transport routes include roads, rivers, and trails for pack animals. The model calculates costs and prices and provides various financial data including costs, gross and net revenues over time and IRR. The model is considered a useful real-world decision support system in the context of complex multi-product, multi-objective participatory management.

## Introduction

Iwokrama Forest is an area of some 360,000 ha that has been reserved in perpetuity by the Guyana Government under the Iwokrama Act, 1966 for conservation, ecosystem research, and research into sustainable forest management systems. It is located between the Essequibo and Siparuni Rivers, at about 58°30'W and 4°30'N in central Guyana. It is managed by the Iwokrama International Centre for Rain Forest Conservation and Development. Management is considered to be a collaborative process, and there is strong emphasis on the participation of Amerindian communities adjacent to and using the reserve in all aspects of the planning and management process. Detailed background information is available at the organisation's web site http://www.iwokrama.org.

Floristically and botanically, Iwokrama Forest is typical of much of the high forest of Guyana, which has been described in a number of publications (*eg.* Richards, 1952; ter Steege, 1993; Hammond et al, 1996; Zagt, 1997; Thomas, 2001, among others). The dominant species in Iwokrama Forest is Greenheart (*Chlorocardium rodiei*) but Mora (*Mora excelsa*), Wallaba (*Eperua falcata*), Wamara

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(*Swartzia leiocalycina*), Black Kakaralli (*Eschweilera sagottiana*), Baromalli (*Catostemma spp*), Trysil (*Pentaclethra macroloba*) and Crabwood (*Carapa guianensis*) are all very common. Dakama (*Dimorphandra conjugata*) dominates a lower-canopy, simpler forest type that occurs at higher elevations on some 10% of the reserve. Palm forests occur in restricted areas, dominated by Manicole (*Euterpe spp.*) and Kokerite (*Attalea spp.*) palms, together with Wallaba. The entire reserve is forested, although the Dakama formation tends towards a woodland structure. In common with much of Guyana, soil fertility and growth rates are low, and there are possible indications of historic forest fire (Hammond & ter Steege, 1998); cautious and conservative management is therefore clearly a prerequisite for sustainability.

A series of low intensity inventories have been carried out on the reserve, principally between 1997 and 1999, based on 1/10 ha circular plots. In all, 1222 plots were sampled, comprising 0.03% of the reserve. These have been post-stratified using remote sensing and aerial photointerpretation into 9 forest types, whose structure has been confirmed by ordination analysis. Based on this, a zoning exercise was carried out to partition the forest into a totally protected area (Wilderness Preserve, or WP zone), and sustainable use area (SUA). The forest was divided into a series of some 500 stream catchment units. For each unit, benefit equations were used to assign values to a series of timber, non-timber products, conservation, touristic and other values. Optimal allocation of catchment units between the SUA and WP using linear programming were assessed for 77 scenarios with different weightings of benefit equation, in a progessive process to achieve a zoning plan that accorded objectively with maximum benefits, and was also fully acceptable within the consultative process (Iwokrama, 2000).

The SUA comprised ultimately 184,000 ha of forest. This area has to cater for a range of activities which include tourism, timber production, production of canes from lianas, gums and resins, palm leaves for thatching, and a variety of other plant products for medicinal and cosmetic uses. At the present time a planning process is underway to formulate a management plan that provisionally defines locations and management regimes for a number of these products and services.

As part of this process, the model described in this paper was developed. Its purpose is to provide estimates of growth and yield for tree, palm, and liana plant products, to allocate harvesting coupes and estimate transport and processing costs and net revenues for these products, under a variety of scenarios of cost and price structures and possible management regimes.

## Description of the model

#### General features

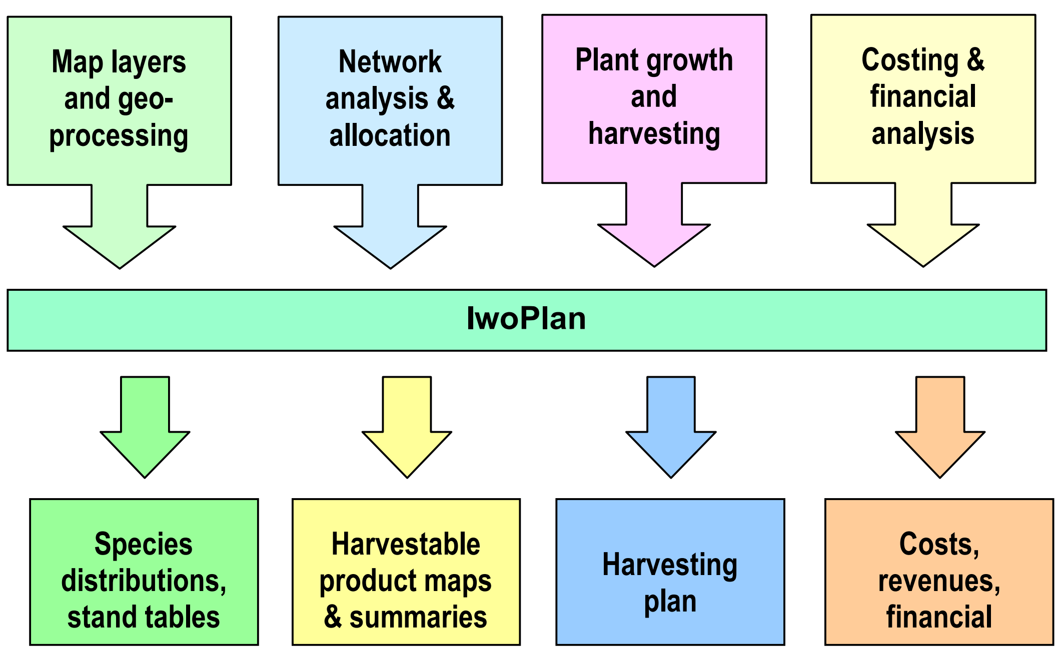
The model is written in Visual Basic 6, and incorporates geoprocessing and mapping functions using the ESRI MapObjects 2 library (see http://www.esri.com/mapobjects for information). The model is called IwoPlan. A schematic diagram is shown overleaf of the models inputs, outputs and main processing modules. These various components will be discussed in this section.

The model in its present form is designed for strategic planning, and uses a 5-year time step. This can be readily changed in future to a 1-year step if more detailed inventory and growth information become available. It is designed to simultaneously manage an open-ended number of products, some of which may be timber volume based, whilst others are allometrically derived from stem numbers, basal area or volume. All transportation is assumed in this version to be to a single base point within the project area.

#### Mapping and geoprocessing

The model requires four map layers as inputs, in the form of ArcView™ shape files. These include the management units, forest types, river system, and pre-

Figure 1 Inputs and outputs of the IwoPlan model



existing roads. An optional border can be supplied and used as a backdrop for maps.

The management units are critical. These could be called forest blocks, compartments, etc. under other systems of nomenclature, and are areas that will be managed as a single entity for practices such as harvesting and silviculture. IwoPlan is indifferent as to the basis of the MUs, but Iwokrama is currently using MUs defined as bordered by streams and watershed lines, that are of the order of 500-1000 ha in size. Where roads exist, these are also used to define MU boundaries.

The forest type layers are derived from remote sensing, photointerpretation or any other source, but critically includes an attribute field with the forest type code that must be linked to the summarised inventory data. The forest type and MU layers are intersected by IwoPlan to form a table of weights for each MU relative to its forest type composition. This process also takes into account buffer zones defined for streams and roads to adjust the area weights.

The stream layer has two important attributes for each stream segment. These are known as Navigability and Bridgeability Index. Navigability is a code from 0 to 2 relative to the size of boat that can be used in that stream. Bridgeability is an index that links to the feasibility and cost of bridge building across the stream. IwoPlan undertakes geoprocessing of the road and stream layers to build a logical internal transport network, as will be described more fully below.

#### Network analysis and harvest allocation

The existing network of roads and rivers is analysed when the model is started, and coded into a logical network of nodes and routes. Each route is characterised by a mode of transport, which may be one of (1) small stream [canoe] (2) large stream [boat] (3) permanent road (4) forest road, (5) trail for pack animal. A secondary analysis is made of the MUs, which defines a network of feasible links between adjacents MUs (*ie* touching polygons) in terms of distance, and number and classes of bridge that would be required.

While the model is running, stands are scheduled for harvesting in each 5-year period according to a number of criteria. A list is first built of candidate MUs, based on:

- <u>Accessibility</u> MUs must be linkable with the existing transport network. This means there should be infrastructure within the MU or within an adjacent MU.
- <u>Felling cycle</u> The felling cycle for the product in question must be respected. Felling may be delayed, but cannot occur sooner than the stipulated cycle.

MUs are then selected sequentially from this list according to one of three possible policies, and a policy modifer. The policies are:

- Lowest unit cost  Unit cost in this context is the total cost of harvesting, extracting and processing the product, including cost of developing any related infrastructure (roads, bridges, etc.) and of maintaining any existing routes required solely for access to this MU, divided by the total quantity of product from the MU.

- Highest product density  This ignores cost considerations, and prioritises MUs according to the density of harvestable product, after any restrictive regulations such as diameter limits and percentage retention have been allowed for.

- Least distance  This prioritises those MUs closest to the base point of the transport network.

Normally, after each MU selection, the list is rebuilt to allow for any infrastructure developed as a result of harvesting a particular MU. This process can be modified so that selections subsequent to the first from this list must satisfy an adjacency constraint, relative to the first MU picked. This forces all MUs harvested in a period to form a contiguous coupe.

The transport network develops dynamically as a simulation proceeds. The simulated network is not intended to be realistic in terms of alignments, but simply to provide a logical framework for constraining and prioritising allocation decisions with regard to MUs. It is also the basis for estimating construction and maintenance costs for permanent infrastructure, including bridges.

Within MUs, a detailed road network is not modelled. These 'internal' roads are local feeder routes which will not be maintained once harvesting ceases. Instead, some simple geometric assumptions are used, which suggest that, approximately, the optimum road density for a given skidding cost, road construction cost and yield can be estimated as:

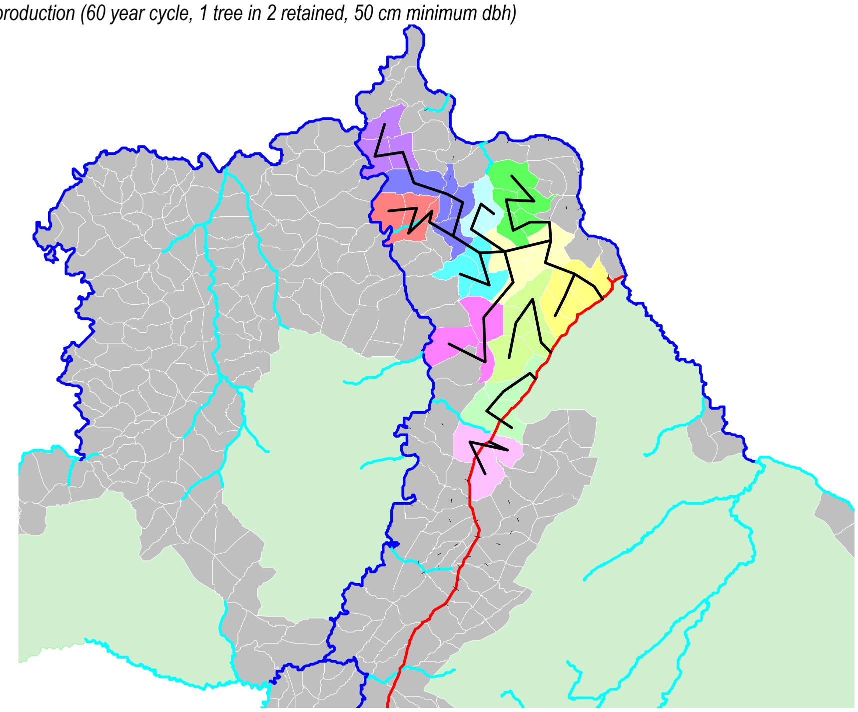
$$L = \sqrt{\frac{S.V}{2R}} \qquad \text{-\{eqn.1\}}$$

where L is roading intensity, in $km/km^2$, S is skidding cost, in $\$/m^3/km^2$, V is yield harvested, in $m^3/km^2$, and R is road construction cost in $\$/km$. This is a slightly simplified function which assumes that haulage cost is small relative to skidding and road construction costs within an MU.

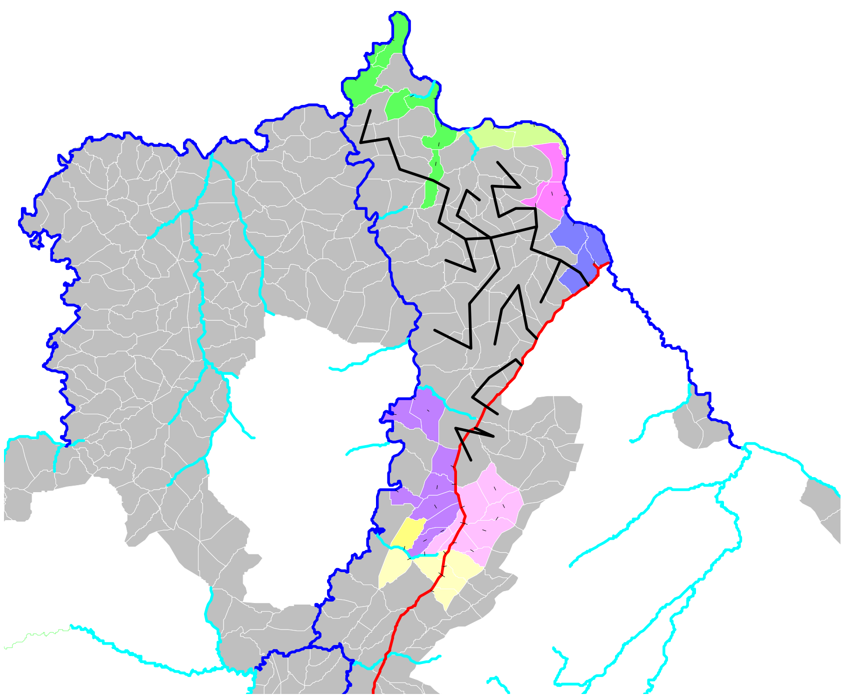
**Figure 2 Felling coupes and infrastructure for extraction of timber and lianas from a simulated IwoPlan scenario**

*Allocation is based on least-cost, consolidated coupes with 60 year cycle for timber and 20 cycle for lianas. White-bounded polygons are management units. Coupes are coloured by year. Grey MUs are unutilised in this scenario. Lime-green areas are wilderness preserve. Solid black lines are simulated roads, dotted lines are simulated trails, blue are rivers, red lines are public roads. The simulation covers 60 years.*

*2(a) Coupes for timber production (60 year cycle, 1 tree in 2 retained, 50 cm minimum dbh)*



*2(b) Coupes for production of lianas (20 year cycle, 1 stem in 2 retained)*



The network model deals with four basic types of route: rivers, pre-existing roads, forest roads and trails. Not all products can move equally along each type of route, and the connections between routes are restricted according to product. Thus mechanized logging is restricted to roads (with the logging operation also building and maintaining roads). Non-timber products and manual/chainsaw logging can use rivers and trails, but it is assumed that when a trail meets road, the road will be used in preference, and the costing is calculated accordingly, including a loading cost at the junction point.

This table of routing and transhipment constraints should be definable externally to the software as a data table, and this may be done in a future version.

Rivers and trails have, like roads, a maintenance cost . Iwokrama's river system contains numerous rapids, and improvement works are required to open navigation during the dry season. Likewise, trails for pack animals have to be kept open, and if used for tourism, improved in various ways.

#### Growth and harvesting models

Inventory data is accepted by IwoPlan as stand table summaries for each forest type. These comprise tree numbers by 10-cm classes for each species sampled. When the model starts it uses the area weights for each forest type with each MU to derive an average stand table for the MU.

Growth modelling uses simple stand projection, based on mean increment rates for species groups, and mean mortality rates (Alder, 1995). The actual rates used are based on PSP data provided by Tropenbos and the Barama Company Ltd, and are described in Alder (2000). This simple scheme is necessary as the inventory data is quite limited, being restricted to key species only. This means that stand density cannot be calculated. The analysis of the data described above also showed that there were few indications of trends of increment with tree size for the most common species.

For non-timber plant products, growth data is very limited. There are some anecdotal suggestions reported (Hoffman, 1997; van Andel, 2000). For example, Hall (2000) reports local knowledge that if only half the stems of Nibbi or Kufa are cut, it will recover within 5 years, but if all are cut, it will die. For palms, the consultant has some experience of data from Costa Rica, where palms are incorporated into the SIRENA model (Alder, 1997), which show little diameter growth for many species (as may be expected from the physiognomy of palms) and mortality rates of about 3% per annum (a half-life of about 23 years). For IwoPlan, this model was adopted for Nibbi, Kufa: an AMR of 3%, and zero diameter increment. This gives a very simple demographic model for the species. For palms, an AMR of 3% was also adopted, with increment of 1 mm/year, as found in Costa Rica, and a maximum size of 30 cm. These are purely assumed models, and need in future to be backed up by research.

The design of IwoPlan is such that all the coding for growth is in one routine. A stand density attribute is calculated (basal area) and could be used as a variable in future models, but is meaningless with present data. Species have a life form attribute, presently either Tree, Liana, or Palm, which can be used to select structurally different types of models if information becomes available. Further and more appropriate types of research are needed to elucidate the growth dynamics of non-tree species.

Harvesting is simulated by reducing the stocking in diameter classes above a stipulated diameter limit in proportion to the harvest intensity in terms of stem numbers. The latter is itself determined from two management rules: The required minimum residual stock, in terms of tree numbers, and the required residual percentage of stems after harvest. These two rules are applied together so that both are respected. Species are grouped for harvesting according to product specifications.

Harvesting is also controlled by felling cycle and target yield. Both of these act at the MU level. Felling cycle restricts the list of MUs eligible for harvesting; whilst target yield is a parameter the model will try to satisfy for each product until there are no more eligible MUs.

#### Costing and financial analysis

The model calculates harvesting, transport and infrastructure development and maintenance costs. Separate cost profiles are entered for timber and for non-timber products. The former are one a per $m^3$ basis; the latter are defined per 'load', which is a rather open-ended concept that may be standardized to a kilogram. The model generate graphs and tables of total and unit costs, cost components, total and net sales revenue, and internal rate of return for the project net income stream.

## An example and conclusions

#### An example with moderate-scale timber and liana harvesting

IwoPlan is designed as a decision-support system. It is flexible with respect to the product specifications, harvesting regimes, cost and prices structures that may be input. These are very much dependent on the particular processing and marketing options to be persued; the model allows feasibility and operational implications to be determined.

An example may illustrate this. It assumes consideration of a medium-scale timber operation, aiming to fell 10,000 $m^3$/yr of Greenheart and other higher-valued species; combined with extraction and marketing of canes (lianas from *Heteropsis* and *Clusia spp*., known locally as Nibbi and Kufa respectively) for furniture manufacture. For the timber trees, harvesting is limited to 50% of stems with a diameter limit of 50 cm dbh, and minimum stock required after felling of 200 trees/$km^2$, with a 60-year felling cycle. For Nibbi and Kufa, harvesting is controlled by requiring that no more than 1 in 2 stems may be removed from each plant.

Figure 2 shows harvesting patterns that result from this scheme after 60 years. The coupes for canes and timber are largely exclusive, although the model does not constrain this. NTPPs can for the most part be moved inexpensively by river, whereas the model constrains mechanized logging to a road-based network.

The model indicates that this scenario would show an internal rate of return of the order of 12%, given an initial capitalization for the logging operation of around $2 million. The operating costs and prices were based on published sources (ITTO, 2001; van der Hout, 1999; van Andel, 2000; GFC, 2000).

#### Conclusions

IwoPlan is a model with broad scope, covering natural forest growth and yield, harvest allocation and financial analysis into a unified framework that can execute within a minute or so on a desktop computer to evaluate outcomes. The model has been designed to use rather simple and limited input data, and can be calibrated from fairly limited information. The inventory data is input as stand tables which can be prepared in a spreadsheet, and can use, for example, historical or published tables. The growth models are simple average increment and mortality rates. These techniques, although crude, are frequently all that is available for natural tropical forest.

The model's design will be elaborated particularly to improve the allocation method and increase the range of policies that may be defined. Allocation at the moment uses simple least cost analysis. This can be improved without great difficulty through a decision tree method that will take into account future efficiencies and benefits of current decisions (*eg*.. bridging a river). These enhancements can be accommodated progressively within the framework of the existing model, whose modular design has proved to be robust and easily extended.

Alternative optimisation methods have also been considered in developing the model, including a genetic algorithm for evolving optimal scenarios, and simulated annealing for a conditioned trial-and-error process (Hughell, 1996). The way in which scenario definition files are processed and stored has been designed with a view to exploring these possibilities in future. However, it does appear that the network analysis and geo-processing approach used within IwoPlan to select and prioritise harvesting units so constrains the decision space that a decision-tree method may be the fastest and most complete optimisation method.

IwoPlan is also an unusual model in that it gives equal priority to non-timber products, and can in fact allow products to be defined in a very flexible way, provided that ultimately they can be allometrically linked to a population of plant stems recognised in the baseline inventory.

IwoPlan is being used within a participatory and consultative process of forest planning and management. The authors believe that forest modelling should be an integral part of forest management, applied in practice in real-world situations and amidst the limitations that are frequently encountered with real-world data. IwoPlan demonstrates the feasibility of this approach for a complex situation in the tropical rain forest.

## Acknowledgments

The development of the IwoPlan model has been financially supported by an International Tropical Timber Organisation project at the Iwokrama International Centre. The Tropenbos Foundation have provided the permanent sample plot data used to develop growth models. The authors would also like to thank the many colleagues and community members at Iwokrama who have contributed in various ways to the basis for this work over the years.

## References

Alder, D (1995) Growth modelling for mixed tropical forests. University of Oxford, *Tropical Forest Papers*, 30, 231 pp.

Alder, D (1997) User's Guide for SIRENA II - A simulation model for the management of natural tropical forests. United Kingdom Department for International Development, June, 1997, unpublished report.

Alder, D (2000) Development of growth models for applications in Guyana. Consultancy Report, DFID/Guyana Forestry Commission Support Project, 39 pp.

GFC (2000) Forestry in Guyana: Quarterly Market Report. Guyana Forestry Commission, December 2000, 25 pp.

Hall, Lorna (2000) Effects of NTFP harvesting on populations of *Manilkara bidentata* and *Heteropsis flexuosa* in central Guyana. M.Sc/Ph.D conversion report. University of West England, Bristol.

Hammond, DS; Gourlet-Fleury, S; ter Steege, H; van der Hout, P; Browen, VK (1996) A compilation of known Guianan timber trees and the significance of their dispersal mode, seed size and taxonomic affinity to tropical rainforest management. *Forest Ecology and Management* 83: 99-116.

Hammond, DS; ter Steege, H (1998) Propensity for fire in Guianan rainforest. *Conservation Biology* 12:944-947.

Hoffman, B (1997) The biology and use of Nibbi, *Heteropsis flexuosa* (Araceae). The source of an aerial root product in Guyana. M.Sc. thesis, Florida International University, Miami.

Hughell, David A (1996) Simulated adaptive management for timber and wildlife under uncertainty. Ph.D thesis, North Carolina State University.

ITTO (2001) Does it cost or does it pay? In: Special edition on reduced impact logging. *Tropical Forest Update* 11(2).

Iwokrama (2000) Zoning of the Iwokrama forest. Iwokrama Working Paper. 46 pp + appendices. (available online from http://www.iwokrama.org).

Richards, PW (1952) *The tropical rain forest.* University of Cambridge Press, 2nd edition 1996, 575 pp.

ter Steege (1993) Patterns in tropical rainforest in Guyana. Ph.D thesis. Tropenbos Foundation, Wageningen.

Thomas, Raquel S (2001) Forest productivity and resource availability in lowland tropical forests in Guyana. *Tropenbos-Guyana Series* 7.

van Andel, TR (2000) Non-timber forest products of the North-West District of Guyana, Part I. *Tropenbos-Guyana Series* 8a.

van der Hout, P (1999) Reduced impact logging in the tropical ran forest of Guyana. *Tropenbos-Guyana Series* 6, 335 pp.

van der Hout, P (2000) Pibiri permanent plots: Objectives, design and database management. *Tropenbos-Guyana Series* 2000-2.

Zagt, RJ (1997) Tree demography in the tropical rain forest of Guyana. *Tropenbos-Guyana Series* 3, 251 pp.