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Evaluation and implications of the CAFOGROM forest growth model

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Executive Summary

This report describes a consultancy to do further work on the CAFOGROM natural forest management model. The main objectives were to make some improvements in the model, to also improve the related data processing program CIMIR, and to undertake a case study with commercial inventory data.

Tests with the existing model suggested growth rates that were too high compared with the permanent sample plots at experimental areas RP11, RP12 and RP14, Tapajós, and RP21 and RP25, Jarí. The patterns of increment and recruitment immediately following harvesting differed also from the plots. Much of the assignment was taken with a careful re-building of the inner structure of the model to get good agreement with the experimental data. This resulted in a new version called CAFOGROM 3, which performs realistically when correctly calibrated.

CAFOGROM 3 is however a tool for the experienced investigator of forest growth and yield, not a commercial computer package. The model functions are exposed to the user, and can be manipulated and adjusted to examine sensitivity and critical responses. Training was given under the assignment in this use of the model as an expert system, to investigate forest dynamics. In the report, examples are given of comparisons with actual data from RP12, RP 11 and RP14. RP12 shows commercial volume growth over 17 years measurement of 0.75 m³/ha/yr; the model accurately reflects this. RP11 shows a much flatter growth curve and little net increment, which the model shows is due mainly to the different species composition. RP12 is richer in faster growing commercial species such as *Didymopanax* and *Jacaranda*.

Studies of existing management regimes based on a 30-year cycle and 45 cm diameter limit showed these were not sustainable without additional controls to limit felling to about 2-3 m²/ha, or 4-6 trees/ha of mature size. Under those conditions, and assuming some use of potential market species, a 30-year cycle would yield sustainably about 25 m³/ha at each harvest. Thinning did not radically affect this result. This is a very preliminary study and CAFOGROM needs to be used to review felling options in more detail.

Future work should bring in data from existing plots in secondary forest. There will also be a need to recalibrate the recruitment functions to operate at a 10-cm dbh limit for commercial use. The model needs to be repackaged it in a more secure form and to allow for the input of suitable commercial inventories. These inventories will require a method of sub-sampling down to 10 cm dbh. A system

based on 400 m² circular plots on a 200 x 200 m grid is suggested, established using 25 m stock survey lines and markers. The inventory data will require the use either of standard species codes from TREMA, or a local list which can be linked via botanical species names.

Linkages to the DENDROGENE project are discussed. The modelling of reproductive biology and gene flow can be done on a static basis initially without requiring growth model components. When these become necessary to establish dynamic population and gene pool changes, there are strategies using available growth data that will allow the problem to be dealt with on a species by species basis. For most likely candidate species, there is a good body of growth and mortality data for life cycle modelling.

| | |
|--|------------|
| Executive Summary | i |
| Contents | iii |
| <i>Abbreviations</i> | <i>iv</i> |
| Introduction | 5 |
| <i>Background</i> | <i>5</i> |
| <i>Terms of reference</i> | <i>5</i> |
| Evaluation of CAFOGROM | 6 |
| <i>Objectives of evaluation</i> | <i>6</i> |
| <i>The EMBRAPA research plots</i> | <i>6</i> |
| <i>Simulation of experiment RP12</i> | <i>7</i> |
| <i>The research plots at Tapajós km 114</i> | <i>8</i> |
| <i>Calibration and sensitivity analysis</i> | <i>10</i> |
| Forest management implications | 11 |
| Database management for the permanent plots | 14 |
| <i>The SFC program</i> | <i>14</i> |
| <i>The role of CIMIR</i> | <i>14</i> |
| <i>TREMA and PSP data</i> | <i>16</i> |
| <i>Programming standards and training</i> | <i>16</i> |
| Future development of growth models | 18 |
| <i>Current status of CAFOGROM</i> | <i>18</i> |
| <i>Application to stock survey data</i> | <i>19</i> |
| <i>Secondary forest</i> | <i>19</i> |
| <i>The DENDROGENE project</i> | <i>19</i> |
| Recommendations and conclusions | 21 |
| <i>Use and role of CAFOGROM</i> | <i>21</i> |
| <i>Further development of the model</i> | <i>21</i> |
| <i>Database recommendations</i> | <i>22</i> |
| <i>Scientific publication</i> | <i>22</i> |
| <i>A perspective</i> | <i>23</i> |
| References | 24 |

Abbreviations

| | |
|---------------|--|
| CAFOGROM..... | CPATU Amazon Forest Growth Model |
| CIMIR | Calculation of Increment Mortality and Recruitment |
| CPATU | Centro de Pesquisa Agropecuaria da Amazonia Oriental |
| Dbh..... | Diameter at breast height (1.3 m). |
| DFID | Department for International Development of the United Kingdom. |
| Excel | <i>Microsoft Excel</i> , version 5. Registered trademark of Microsoft Corporation. |
| EMBRAPA..... | Empresa Brasileira de Pesquisa Agropecuaria |
| PSP | Permanent sample plot. |

Background CAFOGROM is a forest growth model for the natural *Terra Firme* forests of the eastern Amazon. It has been developed under the DFID/EMPRAPA Silviculture Research Project through a series of consultancies by the author which have totalled so far about 6 man-months. The model is intended to assist the rational management of these forests by providing projections of the consequences of forest management practices in terms of future growth, timber yield, and species composition.

The model is based on the concepts of the North Queensland rainforest model (NORM) described by Vanclay (1989). It has evolved through various stages. The original version, CAFOGROM 1, was written in C as an experimental model to test the design concept, using data essentially from EMBRAPA experiments at Tapajós km 67 (Silva *et al*, 1988; Silva, 1989). This version is described in Alder (1995). In 1996, the model was revised to incorporate additional data from the research plots at Tapajós km 114 and Jarí (Silva *et al*, 1994a, 1994b). This involved especially problems of coping with variant species lists and classifications. At the same time, the model was re-written to make it more open in architecture, and more adapted to practical use as a forest planning model. Manuals for this version were written in English and Portuguese (Alder, 1996).

Terms of reference For the present assignment, undertaken between 4th May and 13th June 1998, the consultant's terms of reference were generally specified as: "*Promote the use of CAFOGROM through modification of the programme, training, and case examples*". Attention has been paid especially to testing the model and comparing its accuracy with the reference data from which it is derived. An objective has been to undertake a case study using data from a commercial forest operation supervised by EMBRAPA at Moju. For several reasons which are detailed further in the report, this has not been possible, and instead the case study has focussed on considering some general implications for forest management in eastern Amazonia.

Objectives of evaluation The objectives of the evaluation described in this section are to test the model against real data to confirm, as far as possible, that it provides realistic projections. These tests include detailed side-by-side comparisons between growth on research plots, and simulated growth within the model. They also look at the general behaviour of the model under conditions of long-term projection and more extreme disturbance.

The process of evaluation has not been a linear one. Testing began with version 2 of CAFOGROM, described in Alder (1996). It became apparent that this model could not replicate either the sudden regeneration that occurs following felling, or the associated rapid increase in stand increment. An extensive design of the internal structure of the model was therefore undertaken which has in fact consumed much of the time of this consultancy. The result has been a further revision known as CAFOGROM version 3.

Version 3 behaves well, and as will be seen, replicates most features of stand dynamics. This has however been at the cost of considerable increase in internal complexity. It raises, however, some questions regarding the direction which the development of CAFOGROM should take. These issues are discussed in the concluding section of the report.

The EMBRAPA research plots CAFOGROM is based on a strong base of permanent sample plots established at several research sites in Tapajós forest and at Jarí. The numbers and measurement periods for those plots involved in the CAFOGROM study are detailed in Table 1. There are a various other plots at both sites which have not so far been incorporated in the CAFOGROM functions. These are not listed in the table.

| Location | RP code | Plots | Sample area (ha) | First year | Last year | Measurements |
|--------------|---------|------------|------------------|------------|-----------|--------------|
| Tapajós | 11 | 48 | 12 | 1981 | 1995 | 5 |
| | 12 | 36 | 9 | 1981 | 1997 | 7 |
| | 14 | 12 | 3 | 1983 | 1995 | 4 |
| Jarí | 21 | 36 | 36 | 1984 | 1994 | 5 |
| | 25 | 4 | 4 | 1984 | 1994 | 5 |
| Total | | 136 | 64 | | | |

Table 1 EMBRAPA research plots included in the CAFOGROM analysis

Technical descriptions of these plots will be found in Silva & Lopes (1984), Silva *et al* (1988), Silva (1989), and Silva *et al* (1994a, 1994b). Briefly, the sites can be described as follows:

- RP12, established at Tapajós km 67, comprises 36 plots of ¼ ha each which were logged heavily in 1979, two years before plot establishment. No other treatment has been carried out.
- RP11, established at Tapajós km 114, comprises 36 plots of ¼ ha arranged as three randomized blocks of 12 plots. These were established and measured before logging in 1981, and then heavily logged in 1982. Remeasurement data is so far available up to 1995. The plots were thinned according to an experimental protocol in 1995.
- RP14 is a control block, comprising 12 plots on completely unlogged and untreated forest at Tapajós km 114.
- RP21 is a randomized block logging and thinning experiment at Jarí, with three levels of logging in 1984, and subsequently different thinning treatments in 1995. These plots are of 1-ha design, with a subsample of 10 randomly selected quadrats for smaller trees to 5 cm dbh.
- RP25 is also located at Jarí, and comprises a control block of four unlogged and untreated plots for RP11, established to the same design.

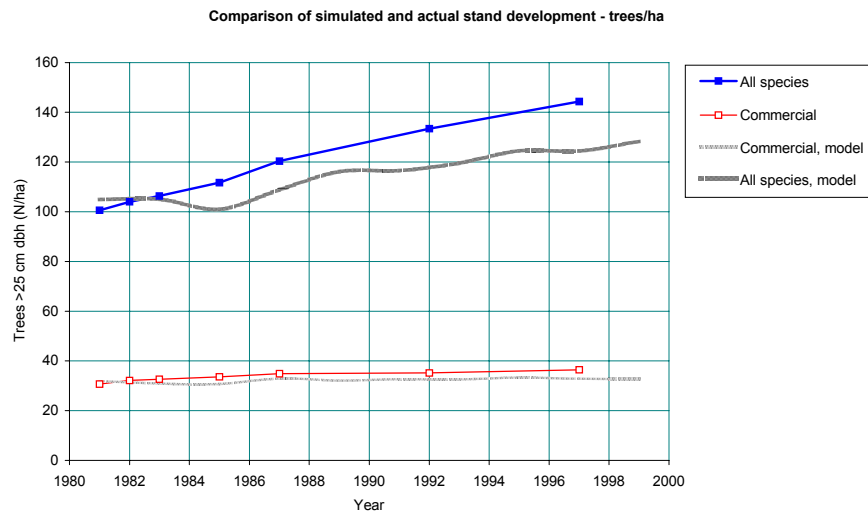


Figure 1 Actual and simulated stockings at tapajos km 67

Simulation of experiment RP12

Actual measurements from the RP12 experiment at Tapajós km 67 were compared with simulated growth from CAFOGROM over the period 1981 to 1997. Figure 1 compares the development of stocking over time between the actual and simulated stands. The lower lines show commercial species, and the upper show all trees, in both cases for stems 25 cm and above.

The performance of the model is reasonably good. For the upper line showing all species the model generally underestimates the number of trees entering the 25 cm+ class. For the commercial species it is quite accurate.

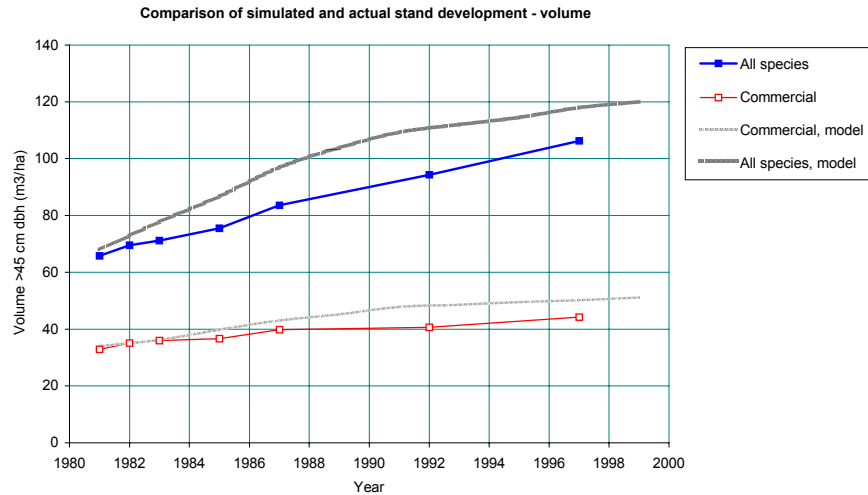


Figure 2 Simulated and actual volumes over time - Tapajos km 67

Figure 2 shows volumes of trees over 45 cm for commercial species and for all species from the RP12 experiment. Interestingly, whereas the model underestimates total tree numbers, it overestimates volumes. This suggests a slight bias in the diameter distribution, with too few trees growing into the 25 cm class, and those that are already in it having too high an increment or too low a mortality. For the commercial volume, as with tree numbers, the model is very accurate.

For the actual plots, it may be noted that the commercial volume gain over 45 cm dbh is 12 m³/ha over 16 years, or an MAI of 0.75 m³/ha per year. This is reasonably typical for natural forest.

These examples are for stands which were logged in 1979, two years before first measurement, at Tapajós km 67. The logging was a typical commercial operation removing about 70 m³/ha (approximately 6 m²/ha basal area).

The research plots at Tapajós km 114

The plots at km 114 represent a shorter measurement series than the RP12 plots, but allow a controlled logging to be tracked by the model and compared against actual data. There are two groups of plots. RP14 comprises a control series of unlogged and untreated plots. This data is most valuable, and gives a useful test of the stability of the model with reference to a fully stocked stand.

Figure 3 compares growth of commercial volume (trees 45cm dbh and over) for the control stand at RP14, and the logged stand at RP11. It will be seen that in both cases, the net volume growth over

the period 1981 to 1995 is very small. This is correctly tracked by the model, although it is not in fact a simple process. There is considerable dynamism within the stand in terms of regeneration and recruitment, diameter growth, and mortality, but these processes essentially balance out.

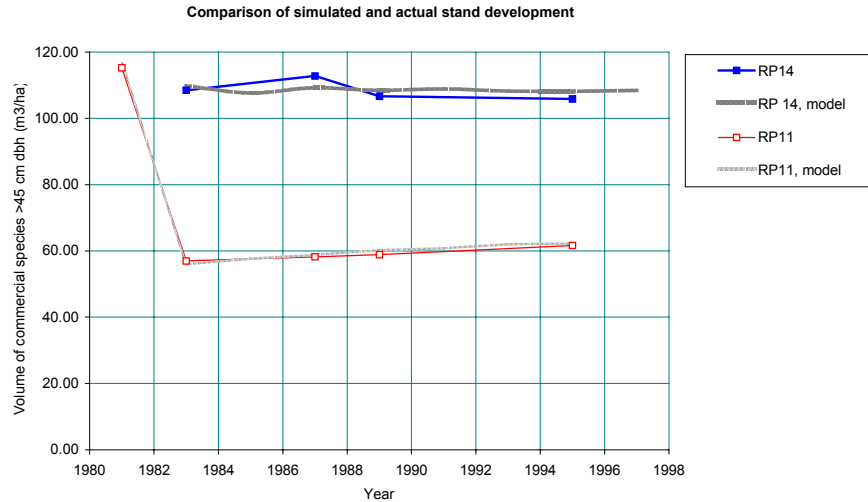
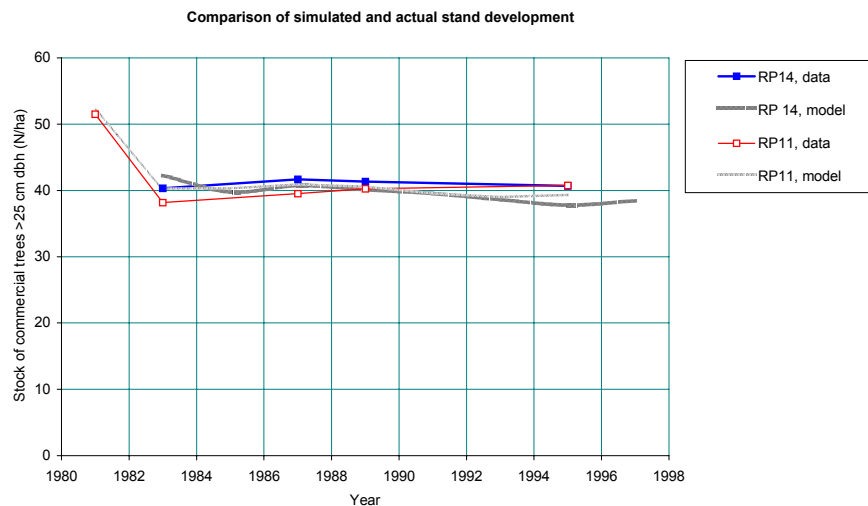


Figure 3 Commercial volume on logged and unlogged experimental stands at km 114, Tapajós

The reduction in volume does not however immediately trigger any rapid response by the residual trees, which appear very much static. There are cohorts of younger trees which establish themselves following logging, and which eventually grow into the commercial volume category, but the model indicates that this requires several decades. The residual stand does show a response, but this is almost exactly cancelled by increased mortality following logging.

Figure 4 Stock of commercial trees over 25 cm dbh on experimental plots at Tapajós km 114



The graph of tree numbers for these experiments is interesting, and is shown in Figure 4. The initial stock on the logged plots (RP11) was somewhat higher than for the control (RP14), so that after

logging, both sets of plots have about 40 commercial trees/ha over 25 cm dbh. Approximately 12 trees/ha were removed in logging.

Calibration and sensitivity analysis These tests show that CAFOGROM replicates growth, stand structure, and the main parameters of stand structure well when it is calibrated correctly.

This short report does not allow these matters to be fully demonstrated, and this will be done in a separate technical paper that is being prepared for publication.

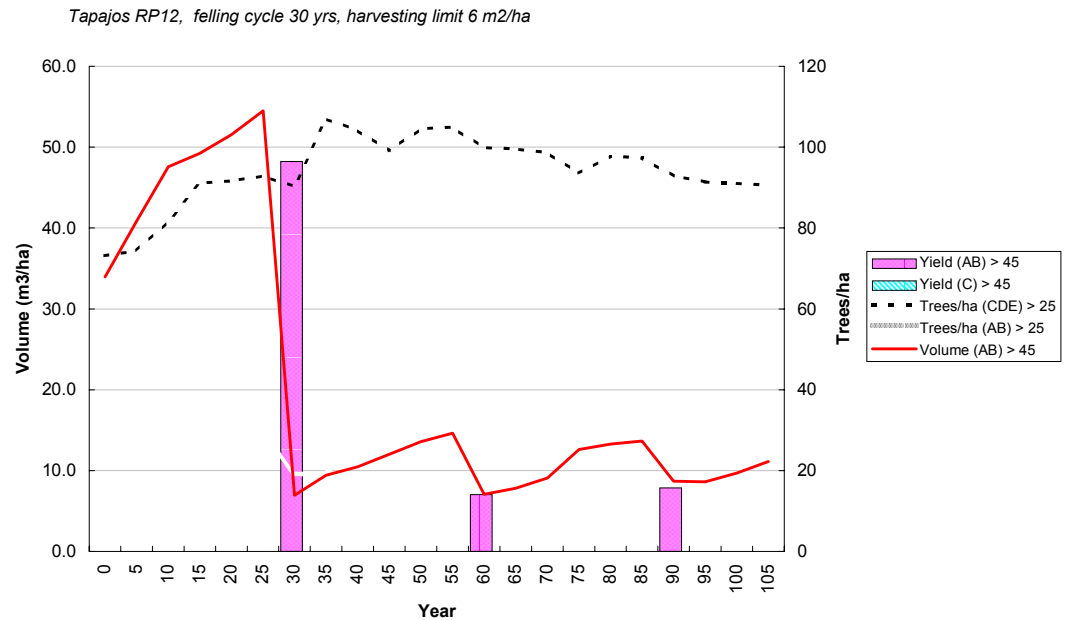
The model can however also produce completely incorrect results when the settings for some parameters are incorrectly adjusted. It is a flexible model which presents the input data in summarized form for the user, and allows some critical functions for growth, mortality, recruitment, and competition to be adjusted. If these settings are not carefully checked, then outputs from the model will be quite misleading.

Forest management implications

This section explores the forest management implications that arise when the calibrated model, as discussed in the preceding section, is applied to a number of common situations, including the sustainability of felling cycles, the effect of thinnings on growth, and annual allowable cut.

A 30-year felling cycle is currently proposed for the *Terra Firme* forests. Examining this scenario for the Tapajos km 67, produces the graph of commercial volumes and tree numbers shown in Figure 5.

Figure 5 A 30-year felling cycle applied to Tapajos km 67



In this graph, the bars are the extracted volume (harvest). The higher solid line shows commercial volume over 45 cm, in m³/ha against the left axis. The higher broken line, and the paler line show tree numbers for stems 25 cm dbh and above. These are read against the right axis.

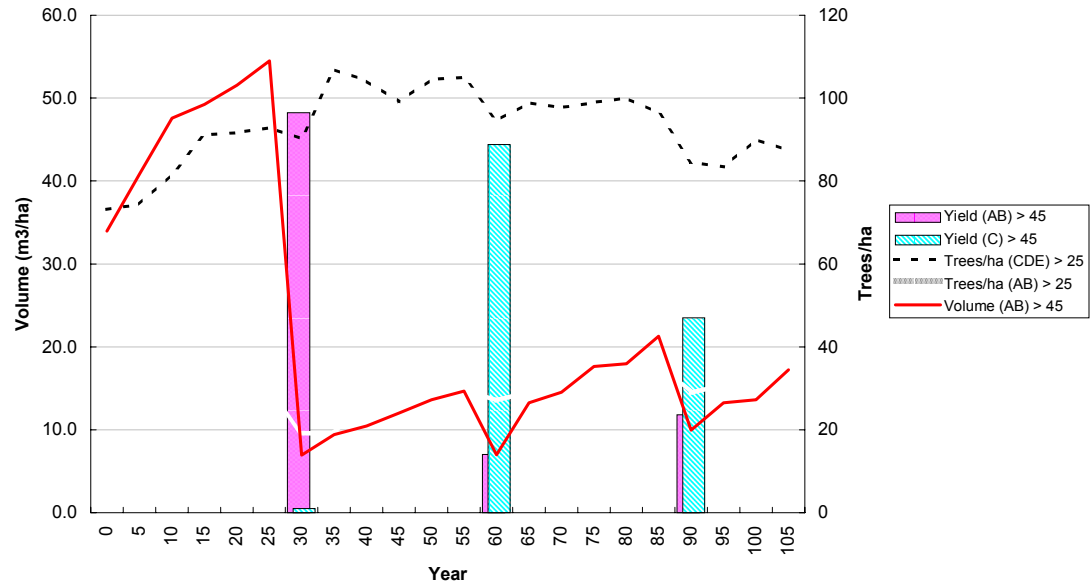
This scenario assumes that all presently commercial trees except those which are defective will be removed over 45 cm dbh. This results in the removal of 48 m³/ha at the first cycle, and 7 and 8 m³/ha respectively at the second and third cycles. It will be noted that this stand was logged immediately prior to the simulated period to a volume of 70 m³/ha. The first cycle therefore represents an MAI of about 1.6 m³/ha/yr; at the second and third cycles, this reduces to less than 0.25 m³/ha/yr. This is a direct result of the destocking of commercial trees without sufficient replacement in the regeneration. The majority of the regeneration following the heavy

fellings are pioneer species such as *Cecropia*, *Inga*, and *Miconia*. Only about 8% comprises *Jacaranda*, which is a commercial pioneer.

If it is assumed that felling can be extended to presently non-commercial species that normally attain large dimensions, then the results shown in Figure 6 are obtained.

Tapajos RP12, felling cycle 30 yrs, harvesting limit 3.6 m²/ha

Figure 6 A scenario with logging of potentially commercial species in the second and third cycles



Here, the first felling is as before. The second felling is made up pre-dominantly of currently non-commercial species, and total production is similar to the first cycle (51 m³/ha). However, at the third cycle, yields are again reduced by de-stocking.

The implications are clear. For a site such as Tapajos km 67, a 30 year felling cycle with uncontrolled logging down to 45 cm dbh is not sustainable.

The net volume growth for commercial species 45 cm and above appears from the model to be about 0.66 m³/ha/yr over 30 years. By limiting removals to this level, then sustainable production should be achieved.

The result is shown in Figure 7. Yields of 27-28 m³/ha on a 30 year cycle are sustainable over 200 years. The harvested species mix must comprise about 66% of currently non-commercial species after the second cycle felling. The fellings remove from 4-6 trees per ha, and are subject to a restriction of 2 m²/ha as the maximum.

Tapajos RP12, felling cycle 30 yrs, harvesting limit 2 m²/ha

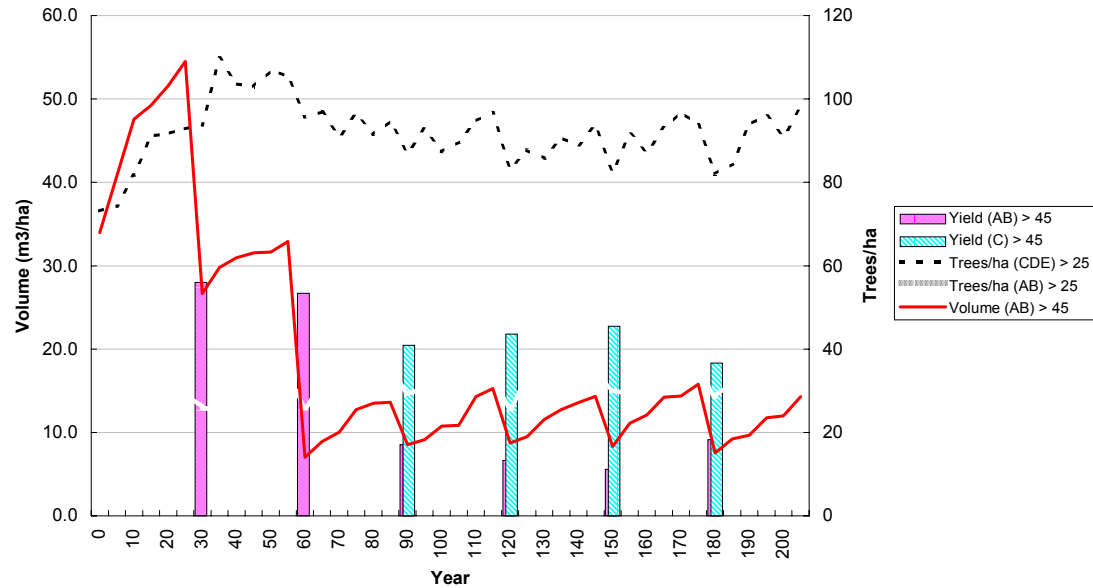


Figure 7 A regime with felling limited to 2 m²/ha projected over 200 years

Can this regime be improved significantly through the application of thinnings or stand treatments? Simulation of a regime of thinning all pioneers species above 20 cm, and also eliminating defective trees left by logging makes no practical difference to the yields. This question does require further exploration, but it is likely that, as with earlier versions of CAFOGROM, the model will indicate on a limited thinning response that does not translate into any substantial improvement in yields.

These results are consistent with those obtained by the author in other countries such as Costa Rica, Mexico, and Papua New Guinea. The average long-term yield of somewhat under 1 m³/ha/yr is also consistent with other published estimates (eg. Dawkins, 1964)..

Database management for the permanent plots

The SFC program SFC is the program originally developed by EMBRAPA to store the PSP data from the various growth and yield experiments. It is written in Clipper under MS-DOS, and functions effectively to allow storage and editing of the data. Through its menu system, a variety of programs can be accessed which perform calculations and produce outputs of stand summaries of volumes, basal areas, mean diameter increments, and tree numbers cross-tabulated by any of the variables measured on the plots.

There is currently a project to update SFC to a more current programming platform. The consultant would recommend that this is based around Visual FoxPro version 6 for Windows. The professional edition of this software allows the programme to be compiled as an EXE file that can be distributed and installed without loading FoxPro.

The consultant also recommends that this revision of SFC should involve a substantial and careful redesign of the user interface and the data storage concepts. A simple translation, retaining existing field names, specifications, design concepts, etc. will represent a missed opportunity to radically improve the utility of the package. This in turn reflects on the access to the data, and ultimately, EMBRAPA's ability to generate publishable science from this considerable information resource.

The role of CIMIR CIMIR is a program written by the author in FoxPro version 2.5 for Windows. It is designed to produce from the SFC data files all the summary information needed by CAFOGROM to fit growth functions. Currently it performs the following operations:

- It merges all the SFC files into a single database called CIMIR, recoding mortality, damage, recruitment, and form into simple binary codes. Each record is tagged with originating experiment code, block and plot in a single identification field. Tree and quadrat numbers are merged into a single field. Diameter is recoded from a character to numeric field. Measurement data is added for each tree. An area weight, reflecting the originating sample plot size, is also added to each record.
- The various species lists used for the different experiments are merged into a single list, and the codes replaced by simple sequential numbers. This combined list is called CIMESP.
- Increments are calculated, and mortality and recruitment codes verified against the sequence of records. Error codes are

inserted for records where increment cannot be calculated, or where it appears excessive or negative.

- A sub-program calculates species mean statistics, which are then used to form species groups by ordination. These species groups are written back into the CIMESP file.
- Increments, mortalities, and recruitment rates are tabulated by species groups according to various classification schemes and output as summary files which can be read by CAFOGROM.
- Basal areas and tree numbers are summarised at the plot level for different canopy classes and for dynamic elements, recruitment, mortality and increment.
- Logging damage is assessed and summarised by size classes and intensities of felling.

These functions are performed in a single step. The program operates in another mode to allow any combination of plots added to the CIMIR database to be selected for use as the starting point for a CAFOGROM simulation. Thus for example, all plots for a particular treatment on RP 25 at Jarí could be selected.

During this assignment, the original version of CIMIR has been revised, with the following changes:

- The user interface has been made less ambiguous. Before, what was essentially a single step process was confused by a menu-style presentation. The program now runs from start to finish in a single operation.
- The species grouping method has been substantially improved. The method now involves a mathematical ordination using five species attributes (commercial status, mean increment, mean mortality, mean dominance, and maximum size).. The groups are labelled with a mnemonic for the most common species, and the output table (SUMGRUP) gives species information.
- A species information database (ESTDESP) is produced which provides various species statistics. Apart from being of general value, this file is the input to the grouping algorithm, whose output file is called SUMGRUP.
- The logging damage and recruitment output tables (DANDEX and INGRESSO) have been changed, to reflect changes in the way these are processed within CAFOGROM.

- The CLASSAB table now includes both stem numbers and basal areas by 20-cm classes for all plots and years.
- The CIMIR database includes a field AWT that allows many types of stand statistic (eg. basal area per ha., volume per ha. by species and/or diameter classes) to be extracted directly using SQL queries, without concern over original plot size or sub-sampling strategies.

CIMIR provides the essential link between CAFOGROM and the PSP data in SFC.

TREMA and PSP data TREMA is being used to store stock survey information and calculate simple inventories. It is a very flexible program that could be adapted to include the functions of SFC. Equally, the various CIMIR sub-programs could operate on files that are maintained and updated by TREMA.

Essentially, what is required is an agreement by all the research groups involved to do this, combined with a commitment of resources for the necessary programming inputs. The problems are mainly those of agreeing standards.

A starting point that would be extremely useful is the adoption of a centralized species list using standard codes. If this is maintained through the EMBRAPA Herbarium, for example, and used in the field by all EMBRAPA research workers, a great deal of duplication and unnecessary work would be eliminated.

A second step, relative to the PSP work, that is also required for the SFC upgrade, is a definition of the output programs needed for PSP data, and standard specifications for the calculations to be performed. This document should be prepared as a systems analysis, and agreed with all parties. It can then be used as a basis for either re-writing SFC, or developing PSP-related modules for use within TREMA.

Programming standards and training EMBRAPA *Amazonia Oriental* needs to adopt a single programming standard for database work and install appropriate software on the network. At the moment, Clipper and various editions of FoxPro are available in very dated versions. All the FoxPro copies the author has seen are English-language editions that pose serious problems for training.

On the network, Microsoft Access is installed, but is as far as the author knows, little used.

It is strongly recommended that:

- FoxPro for Windows in the latest version (6) is installed on the network in a Brazilian Portuguese language edition, and properly configured to allow file sharing, for example.
- Training is offered to research workers on basic Foxpro use, and especially on SQL commands for accessing and summarising data. This should be available within Brazil as short courses.
- SFC, TREMA, and CIMIR adopt this common language standard.

Future development of growth models

Current status of CAFOGROM CAFOGROM now appears to provide a good representation of stand growth. It has been tested against the research plots RP 11, 12, and 14 at Tapajós, and against RP 21 and 25 at Jarí. These cover unlogged, virgin stands, growing over some 12 years, and moderate and heavy logging treatments over 14 -17 years. It can be said that under these conditions, and over these periods of time, the representation of recruitment to 5 cm, of natural and logging-induced mortality, and of increment corresponds closely with sample plot data (see Figures 1-4).

Results from thinning trials at RP11 and RP 21 are not available, and it is likely to be a further 5 years before the model's projected response to thinning can be compared with that observed in reality.

Longer term projections of the model, its use to simulate thinning effects, and its application on sites with different species mixtures remain in the field of extrapolation. Under these conditions, the model's outputs can be regarded as an *expert opinion*, and nothing more.

CAFOGROM still cannot read commercial inventory data and make a direct projection from it. This objective was written into the author's terms of reference but was unachievable for several reasons:

- Initial testing of the existing version 2 against real data showed inadequacies in the model's responses. Most of the time in this consultancy has been spent dealing with these questions and re-programming aspects of the model to obtain realistic responses.
- Existing sets of inventory data do not include a sub-sample down to 5 cm dbh.
- There are significant problems in harmonizing species codes between CAFOGROM and any given inventory data set.

CAFOGROM can therefore be used to examine aspects of forest dynamics and make general statements and test hypotheses, as has been done briefly in this report. It cannot be used in its present form for the management of specific forest stands (other than the experimental plots accessible through CIMIR).

Application to stock survey data There remains the need to use the modelling methods that have been tested to give projections using the sorts of inventories and stock surveys that are being done commercially.

There are two main problem areas:

- *Species coding and occurrence.* Locally, species will occur that may be rare or absent from the original data set. A method is needed to determine parameters for such species based on their general ecology, size distribution, and so on. Species codes from any given inventory will also need to be converted to a standard set.
- *Sampling of trees down to 10 cm.* This is essential for forecasting even over one felling cycle. A possible solution that has been discussed is to place 25 m square regeneration quadrats within the stock survey lines at an intensity of 4 per km of line, with the first plot 100 m from the start of each line. Every eighth line would be sampled. This would give a grid of 200 x 200 m, with one plot of 625 m² for every 4 ha of forest, or a sampling intensity of 1.5%.

The regeneration sampling can be based on even smaller plot units; wide and systematic sample distribution is more important than a large sample area. The author would personally prefer the use of circular plots, of 11.3 m radius (400 m²), established on a 200 m systematic grid. This gives a 1% sample. Within this sample, trees can be measured and identified down to 10 cm dbh. There will typically be about 20 trees per plot. to be measured.

Secondary forest Data from secondary forest experimental plots at Tapajós and Jarí have not so far been included within the CAFOGROM analysis. It is clear that moderately or heavily logged primary forests will tend to assume the regeneration and growth characteristics of these secondary forests, and it is therefore important to extend the analysis to include them at some future time.

The DENDROGENE project Possibilities for an interaction between a growth model and a tropicalised ECOGENE model have been discussed with Berndt Degen and with others at EMBRAPA. Clearly, there are many possibilities and level of input. It depends principally on to what extent the DENDROGENE model is seen to need projections over time.

A very interesting aspect of this from the author's point of view is that of building in to a forest management model three important genetic aspects:

- The possible effect of inbreeding on survival and growth when parent trees become too isolated.
- The dysgenic effects of selection forestry over longer periods of time, as the best and faster growing individuals are removed from the breeding pool.
- The related information on seedling demography and dispersal that will assist in improving modelling of the regeneration process.

Recommendations and conclusions

Use and role of CAFOGROM

CAFOGROM has now been carefully checked against growth from experimental plots at Jarí and Tapajós, and performs sufficiently accurate to give confidence in extrapolations from the model. It can therefore be used to indicate the likely response of *Terra Firme* forests in eastern Amazonia to long-term management. Questions such as sustainable yields, allowable cuts, the efficacy of thinning, the consequences of high-grading, and appropriate felling cycles and girth limits can be examined with the model.

It remains a sensitive and technical model to use, that requires some expertise. Training in these questions has been given to the consultant's counterparts, Natalino M. Silva and Carmo A. Lopes.

The model is also very valuable as a teaching and demonstration tool, to illustrate various aspects of forest structure and dynamics. These include the typical shapes of diameter and basal area distributions, and how they evolve over time; the balance between stand recruitment, increment, and mortality, and how it leads to an equilibrium basal area; the effects of logging and high-grading; the shift in species composition that occurs over time under commercial logging; how mean increment is influenced by species composition, and so on. Many of these facets are relatively little realised even by quite experienced tropical forestry professionals.

The further evolution of the model towards a role similar to that fulfilled by SIRENA in Costa Rica has yet to be completed. At present, the model cannot process commercial inventory data and provide projections from it. To do this requires certain standards in the inventory data supplied to the model. The species codes need to be linked to a list that contains latin names, so that they can be in turn re-coded into the form used by CAFOGROM. The inventory must include a sub-sample down to 10-cm, based on plots on a systematic grid. The inventory results need to be available as raw data files, not as summary stand tables or other processed results.

Aspects of the model will need to be revised to accept this type of data. Recruitment functions will need to be recalibrated based on a 10-cm limit. Appropriate logic will be needed to link the local species list with the CAFOGROM identification codes.

Further development of the model

There is a good deal of data available at EMBRAPA on secondary forest growth which should be included in the rgrowth functions.

There is also a need, as noted above, to re-calibrate recruitment functions to a 10-cm limit, for use with commercial inventories. The author would like to re-write the model in a programming language that can be compiled to an EXE file for speed, security (to prevent unintended modifications), and to permit commercial distribution.

Related to this is the need to provide modules to process commercial inventory data. To test this, suitable data needs to be available, by, for example, conducting a sub-sample within the stock survey areas at Moju.

These various developments can be considered within the next phase of DFID inputs to EMBRAPA.

Database recommendations

The consultant has recommended that EMBRAPA Amazonia Oriental adopt FoxPro as a database standard, and to this end it is recommended that EMBRAPA:

- Purchase and install a properly licensed network-enabled portuguese-language edition of Visual FoxPro 6. The Professional edition is recommended, as it allows compilation of stand-alone programs that can be used on lap-top computers in the field.
- Facilitate short-training courses for research workers, especially those engaged actively in database work, with an emphasis on FoxPro programming and the use of SQL.
- Convert TREMA, CIMIR and SFC to Visual FoxPro versions, preferably in a coordinated fashion and with some consolidation of the overlapping and duplicated functions of these packages, ideally to a single forest data management system. The latter could have significant commercial value if a suitable multilingual design is adopted.

These activities could all be targetted for DFID assistance during the proposed follow-on project.

Scientific publication

A great deal of information has been generated through the work on CAFOGROM that should be published scientifically to ensure its dissemination through international abstracting and library services. The author is currently preparing a joint paper on the technical features of CAFOGROM and the results of its evaluation and testing. This will be submitted within two to three weeks to *Forest Ecology and Management*. Other information that can usefully be published are some of the species statistics contained in the ESTDESP file produced by CIMIR; and results from trials with CAFOGROM of various management regimes, in terms of

implications for sustainable wood production from the Amazonian region.

A perspective Many of the problems in the management of natural tropical forests can be traced to lack of information about growth and yield. This leads to optimistic and glib assumptions by industrialists in order, in effect, to justify or permit timber mining. On the other hand, environmentalists depict the forest as fragile to a degree that it cannot sustain any degree of intervention. Realistic information is essential to rational management and the formulation of moderate policies. Because tropical forests are too complex in their structure to be managed through the simple tools that are appropriate in plantations, computer modelling is necessary. The author contends strongly however that this is not an academic activity. It bears directly on sustainable management, on the maintenance of the fragile environmental web upon which we all depend, and on the use of the forest as a component of the economy, contributing to the alleviation of poverty and the creation of employment. CAFOGROM has, for the Amazonian forests, made an important contribution in this area. Further work is desirable, but even in its present form, it can be applied to improved forest management for general social and environmental benefits.

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