The cohort-empirical modelling strategy and its application to forest management for Tapajós Forest, Pará, Brazilian Amazon

Denis ALDER[1]
José Natalino M. SILVA[2]
João Olegário Pereira DE CARVALHO[2]
Jose DO CARMO LOPES[3]
Ademir R. RUSCHEL[3]

[1] Consultant in Forest Biometrics
9, Stansfield Close
Oxford
United Kingdom

[2] Universidade Federal Rural da Amazônia
Avenida Presidente Tancredo Neves 2501
CEP: 66.077-901
Belém, Pará
Brasil

[3] EMBRAPA
Amazônia Oriental
Traversa Dr. Enéas Pinheiro
CEP 66095-100
Caixa Postal 48
Belém, Pará
Brazil

General view of Permanent Sample Plot, showing point of measurement (POM) marked with paint normally at 1.3 m.
Photograph J. Olegario & P. de Carvalho.

D. Alder, J. N. M. Silva,
J. O. P. de Carvalho,
J. do Carmo Lopes, A. R. Ruschel

RÉSUMÉ

LA STRATÉGIE DE MODÉLISATION EMPIRIQUE « COHORT » ET SON APPLICATION POUR L'AMÉNAGEMENT DE LA FORÊT DE TAPAJÓS, PARÁ, AMAZONIE BRÉSILIENNE

La stratégie de modélisation empirique est ici revue et présentée ainsi que son application à l'Amazonie orientale. Le modèle de croissance Cafogrom élaboré au cours de la période 1994-1998 a pu être testé grâce aux récentes mesures de 2003 et 2007 en Forêt nationale de Tapajós dans deux zones expérimentales dénommées km67 et km114 au long de l'autoroute BR 163 reliant Santarém à Cuiabá. Le modèle montre un accroissement annuel de la forêt avec un écart annuel de moins de 15 % au cours de la période 1981-2007 sur le km67 et avec la même précision sur km114, un site moins productif, mais avec un biais accru de sous-estimation d'environ 32 % en 26 ans. L'accroissement moyen annuel du volume des arbres de plus de 50 cm de diamètre (DBH) a été de 2,2 m^3/ha/an en 26 ans, dont 1,2 m^3/ha/an (54 %) pour les essences commerciales. Les parcelles étudiées sur le site km114, le moins productif, ont eu un accroissement moyen de 1,07 m^3/ha/an au cours de vingt ans couvrant la période 1983-2003. En considérant les règles du gouvernement brésilien dont l'intensité maximale d'exploitation est de 30 m^3/ha avec une rotation de passage en coupe de 35 ans (0,86 m^3/ha/an), la viabilité de ce régime conservateur est confirmée à condition que l'exploitation comprenne une gamme variée d'espèces commerciales. La stratégie de mise à jour de Cafogrom est détaillée, elle devra être réécrite sous la forme d'une application en langage Python dans le cadre contextuel Myrlin/Fmt (www.myrlin.org, www.eofmt.com).

Mots-clés : stratégie, modèle de croissance, gestion forestière, forêt de Tapajós, Amazonie.

ABSTRACT

THE COHORT-EMPIRICAL MODELLING STRATEGY AND ITS APPLICATION TO FOREST MANAGEMENT FOR TAPAJÓS FOREST, PARÁ, BRAZILIAN AMAZON

The cohort-empirical modelling strategy is reviewed and its application to the Eastern Amazon described. The growth model Cafogrom, developed over the period 1994-1998 is tested against recent measurements from 2003 and 2007 on Tapajós National Forest km67 and km114 experimental areas along the highway BR 163 Santarém-Cuiabá. The model represents growth with less than 15% annual deviation over the period 1981-2007 on km67 and similar accuracy on km114, a less productive site, but with an accrued bias to underestimation of about 32% over 26 years. Actual net mean annual increment of volume on trees over 50 cm of diameter (DBH) was 2.2 m^3/ha/year over 26 years, of which 1.2 m^3/ha/year (54%) were on commercial species. The logged plots on the less productive km114 site has shown a net increment of 1.07 m^3/ha/year from 1983-2003 (20 years). Modelling of Brazilian Forest Management regulations of 30 m3/ha allowable cut on a 35 year felling cycle (0.86 m^3/ha/year) has confirmed the sustainability of this conservative regime, provided harvesting included a broad range of commercial species. The strategy for updating Cafogrom is described, which is likely to be re-written as a Python application within the Myrlin/Fmt framework (www.myrlin.org, www.eofmt.com).

Keywords: strategy, growth model, forest management, Tapajós Forest, Amazon.

RESUMO

A ESTRATÉGIA DE MODELAGEM EMPÍRICA "COHORT" E SUA APLICAÇÃO PARA A GESTÃO DA FLORESTA DO TAPAJÓS, PARÁ, AMAZÔNIA BRASILEIRA

No presente trabalho se revisa a estratégia de modelagem empírica usando "cohort" e se descreve sua aplicação na Amazônia oriental. O modelo de crescimento Cafogrom, desenvolvido no período de 1994-1998, foi testado com dados recentes, de 2003 e 2007 na Floresta Nacional do Tapajós, nas áreas experimentais do km67 e km114 da rodovia BR 163 Santarém-Cuiabá. O modelo retrata o crescimento da floresta com desvio anual menor que 15% no período 1981-2007 no km67 e precisão similar no km114, uma área menos produtiva, porém como uma forte tendência de subestimação de aproximadamente 32% em 26 anos. O incremento médio anual líquido do volume das árvores com diâmetro (DAP) a partir de 50 cm no km67 foi 2,2 m^3/ha/ano no período de 26 anos, dos quais 1,2 m^3/ha/ano (54%) foi de espécies comerciais. As parcelas exploradas no site com menor produção no Km 114 apresentaram um incremento líquido de 1,07 m^3/ha/ano no período de 1983-2003 (20 anos). Aplicando a regulamentação do Governo Brasileiro de intensidade máxima de exploração de 30 m^3/ha em ciclo de corte de 35 anos (0,86 m^3/ha/ano) confirmou-se a sustentabilidade desse regime conservador, desde que a exploração inclua uma gama variada de espécies comerciais. A estratégia de atualização do Cafogrom é descrita, a qual deverá ser reescrita como uma aplicação em linguagem Python dentro da estrutura do aplicativo Myrlin/Fmt (www.myrlin.org, www.eofmt.com).

Palavras chave: estratégia, modelo de crescimento, gestão florestal, floresta do Tapajós, Amazônia.

Measurements are made aligned with the top of the paint mark.
On this tree, the POM is above convergence of buttress.
Photograph J. Olegario & P. de Carvalho.

Introduction

The cohort-empirical modelling strategy was explicitly defined by VANCLAY (1989) for the North Queensland Forest model, though it has its oldest usage in the FORSIM model of GIBSON *et al.* (1969), who had the idea that instead of moving trees from diameter class to diameter class as was done in classical stand models and in matrix models (USHER, 1966), the size class medians themselves should be updated by the growth functions, without changing the trees they represented. VANCLAY (1989) introduced several other ideas particularly needed for tropical mixed forest models: That cohorts should represent size classes of species groups with similar growth models, that tree numbers in the cohort should be reduced by mortality, that recruitment be represented by the addition of new cohorts, that cohorts might be split to represent the division of trees into low and high increment subgroups, that cohorts might be merged if their characteristics become similar, and that the cohort list might be represented computationally as a dynamic data structure.

In Brazil, SILVA (1989) had applied the Standpro model (KOFOD, 1982; KORSGAARD, 1982) to the evaluation and interpretation of experiments established in Tapajós National Forest. Standpro model was a classical diameter class projection model written in Fortran. In 1994, this work was updated with new measurements, and at that time the modelling strategy of VANCLAY (1989) was adopted for the CAFOGROM model, which was written in C (ALDER, 1994, 1995). With new PSP measurements in 1996 and 1998, the Cafogrom model was again updated, and also re-written in VBA for Excel, as a more accessible formulation of the program (ALDER, 1996a & 1998a). Variants of this model were also written for Costa Rica (the Sirena model; ALDER, 1996b), Papua New Guinea (Pinform; ALDER, 1998b) and Guyana (Gemform; ALDER, 2001) among others. ALDER & SILVA (2000) describe the validation of the most recent version of the Cafogrom model (version 3.4), and give a detailed description of all the growth functions used, for diameter increment, mortality, recruitment, competition index and stand density, and logging damage. That paper also describes the plot data from Tapajós and Jarí used in developing the model. The treatment and growth of these plots have also been described by SILVA & UHL (1992) and SILVA *et al.* (1995 & 1996).

Re-measurements and comparisons with Cafogrom projections

Cafogrom version 3.4 (ALDER & SILVA, 2000) was developed using data available up to 1998. Recent measurements allow for comparisons between model projections and actual data that is independent of any calibration process and give an interesting quality assurance relative to the model.

The data used in these comparisons are from permanent sample plots (PSPs) established at km67 (2°53'S, 54°55'W) and km114 (3°18'S, 54°56'W) in Tapajós National Forest. The km67 plots have been measured 8 times over the period 1981-2007. These plots were initially logged in 1979 and not treated silviculturally. The logging specified the removal of 16 trees per ha from 38 commercial species, amounting to approximately 75 m^3/ha. There are 36 plots, each of ¼-ha (50 x 50 m) on which all trees with a Diameter at Breast Height (DBH) down to 5 cm were measured (SILVA, 1989).

The km114 plots were arranged as an experiment with different silvicultural treatments. However, these plots were damaged by severe forest fire in 1997, and from the original 48 treated and 12 control plots, only 35 treated and 6 control plots survived to be re-measured in 2003. These plots were of the same size and measurement system as at km67 (¼-ha, trees over 5 cm dbh measured). The treated plots were measured 6 times from 1981-2003 (before first treatment in 1981, other measurements after treatment, and the control plots (not treated) from 1983-2003.

Figure 1 shows actual growth data from 1981 to 2007 for the Tapajós km 67 PSPs. During this 26 years period, volume increment was 2.2 m^3/ha/yr on a residual volume of 53 m3/ha above 50 cm DBH. Of this, approximately 54% is estimated to be commercial (1.2 m^3/ha/yr). The actual plot data, shown as thin grey lines, shows the great variation that occurs from plot to plot, both in initial condition, and in growth. As the plots are relatively small for tropical forest (¼-ha), the presence or absence of a few large trees can lead to great variation.

The red line[1] on figure 1 shows the result of a simulation using a stand constructed as the average of the size and species distributions of the individual plots. This starts some 10% higher than the blue line[2] which represents the average volumes of the individual plots (as volume and diameter have different sample distributions, their means are not the same). The simulation tracks the average of the plots well, but with a slightly lower slope. Increment for the simulation over the 26 years period is 1.5 m^3/ha/yr of all species, or 0.8 m^3/ha/yr commercial.

Figure 2 shows the mean volume of the experimental blocks at km114. Each block and the control originally included 12 PSPs. Block 1 was harvested in a way similar to km67, with a minimum diameter of 45 cm DBH and some 90 m^3/ha removed over the whole area, though the effect at the level of a ¼-ha plot was very variable. Blocks 2-4 were subject to a lighter harvesting nominally, with a 55 cm minimum DBH, and were additionally treated with arboricides post harvest to reduce basal areas of non-commercial species by 30%, 50% and 70% respectively. The control block was left without harvesting or treatment, as primary forest.

Figure 2 shows the average volumes for each treatment. These lines are each the means of 12 plots, and the variation is considerable, giving an overall picture similar to figure 1, with little discernible tendency between treatments. The variation is due to the combination of highly variable initial conditions for each plot, and the variable effect of treatment as it was applied on top of that.

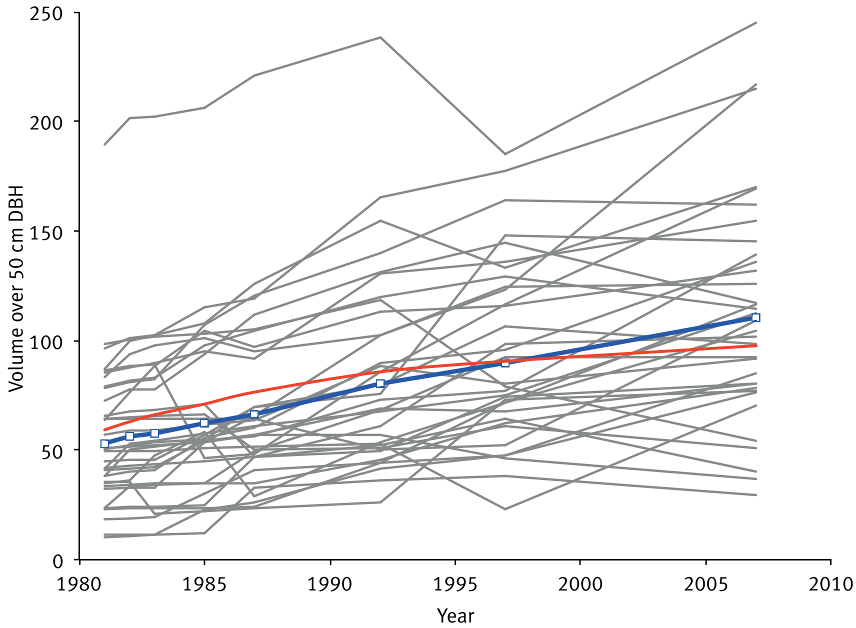

Figure 1.
Actual and simulated volumes for Tapajós km67 PSPs.
Mean of Actual Plot Volumes 50 cm+ — Individual Plots —
Simulated Volume 45 cm+ — .

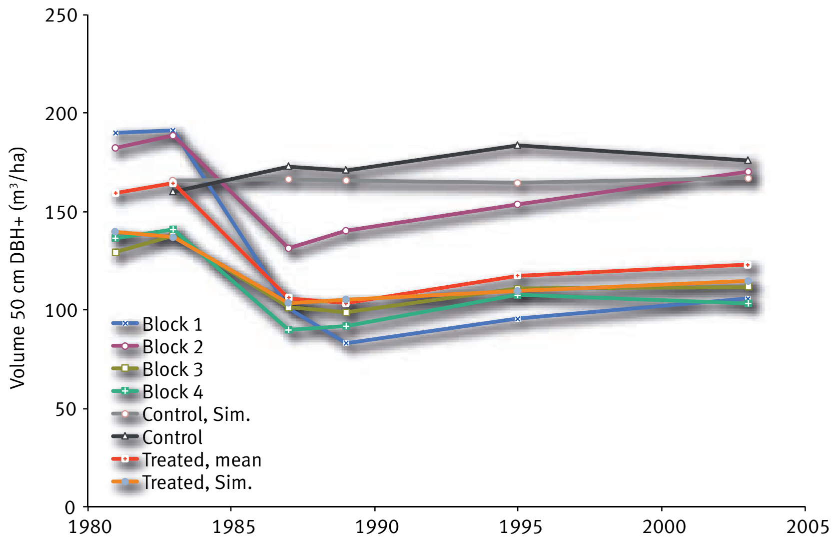

Figure 2.
Actual and simulated volumes for Tapajós km114 PSPs.
See text for a description of the treatments.

Two simulations are made for comparison. One, shown as the cross-hatched thick red line, simulates the mean composition of blocks 1-4, subject to a simulated felling with a diameter limit of 55 cm DBH and intensity equivalent to the mean of that observed. This can be compared to the thin dotted line which is the actual mean of the four treatment blocks.

These stands show quite a low increment compared with the km67 plots. The mean increment of the blocks was 1.07 m^3/ha/yr over 16 years from 1987 to 2003, whilst the simulation predicted an increment of 0.72 m^3/ha/yr over the same period.

The control, untreated block, has a mean growth over its whole measurement period (20 years) of 0.16 m^3/ha/yr, with the simulation of the control being in almost exact equilibrium, with net growth of 0.01 m^3/ha/yr.

[1] Red Line: In monochrome, it can be seen as the line of medium bold thickness, without data markers.
[2] Blue Line: In monochrome, the thickest line, with square data markers.

Sustainability of forest management regulations

Brazilian Forest Management Regulations require that mechanically-harvested mixed tropical forests must be managed on the basis of an allowable cut of 30 m^3/ha over a 35 years felling cycle, or 0.86 m^3/ha/year. An alternative regulation is in place for forests under community management which do not use mechanical timber extraction, which allows for a 10 year felling cycle and removal of 10 m^3/ha, or an allowable cut of 1 m^3/ha/year.

The simulations shown here examine the sustainability of the mechanised harvesting regulation for allowable cut and felling cycle (30 m^3/ha over a 35 years cycle), with respect to the two forest areas discussed in the last section, being Tapajós km67 and Tapajos km114. These two are compared as they appear to represent sites of comparatively high and low productivity, as measured by net long-term growth.

Figure 3 shows the result of simulated harvesting of km67 plots using a broad definition of commercial species comprising 91% of the initial post-harvest volume over 50 cm in 1981. Species are classified in the species list into categories A-E, with A and B being fully commercial, C being marginally commercial, with D and E species being non-commercial based on size, form or technical criteria, or restricted by conservation considerations. The broad definition of commercial species includes categories A-C, whilst the narrower group comprises the market preferred A-B groups. With the broadly defined harvestable species base, production of 30 m^3/ha every 35 years is sustainable over 3 cycles (which includes implicitly a 4^{th} cycle, being the initial harvest immediately before the start of the simulation).

In figure 3, the first harvest is taken at 33 years after the start of the simulation, as this stand had been exploited 2 years prior to the inventory date, in 1979. This amounts to an initial 35 years cycle, with subsequent cycles being of the same duration.

Figure 4 shows the same results for the management of the Tapajos km114 control plots, which is previously unlogged forest. It will be recalled from figure 2 that the growth curve for this plot is flat, indicating an equilibrium situation. Figure 4 shows that with harvesting of 30 m^3/ha on a 35 years cycle, this site also gives a sustained yield.

However, this picture of sustainability depends on using a broad range of species, or perhaps harvesting different species at different cycles. If there is concentration on a narrower range of current, fully commercial species (categories A and B within the Cafogrom species list), then the volumes of those species above 50 cm DBH no longer fully recovers between 35 years cycles, as shown figure 5. The species harvested in this case represent about 50% of the initial stock.

It can be seen that, whilst the harvesting can be maintained for 3 felling cycles, at the fourth cycle, yield of these most commercial species will decline. In reality, this is not a bad result, as it is unlikely the market for species will be the same, 80 years hence, as it is now, whilst all the simulations show that, on both sites, stand overall stocking and basal area recover fully between cycles.

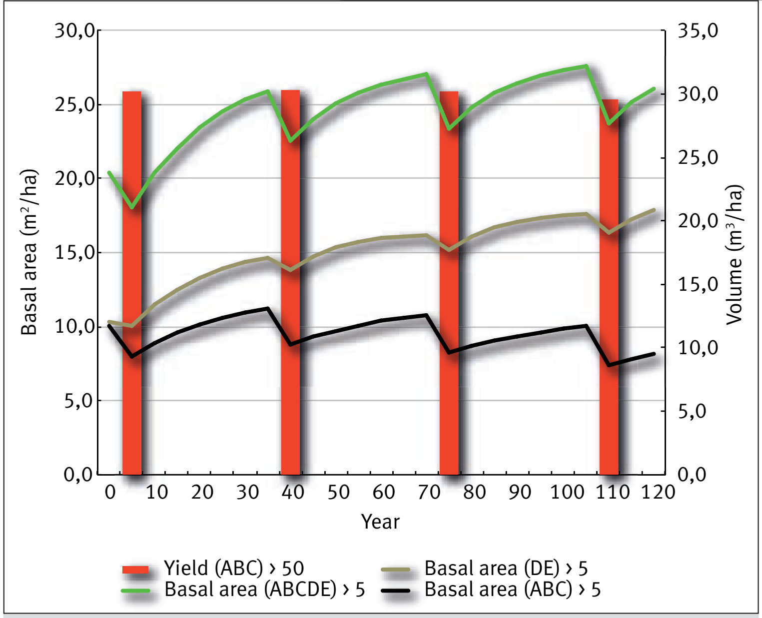

Figure 3.
Simulated harvesting at Tapajós km67 over 3 cycles with a broad base of commercial species. The chart is pasted directly from CAFOGROM. A harvesting limit of 2.2 m^2/ha basal area is c. 30 m^3/ha volume.

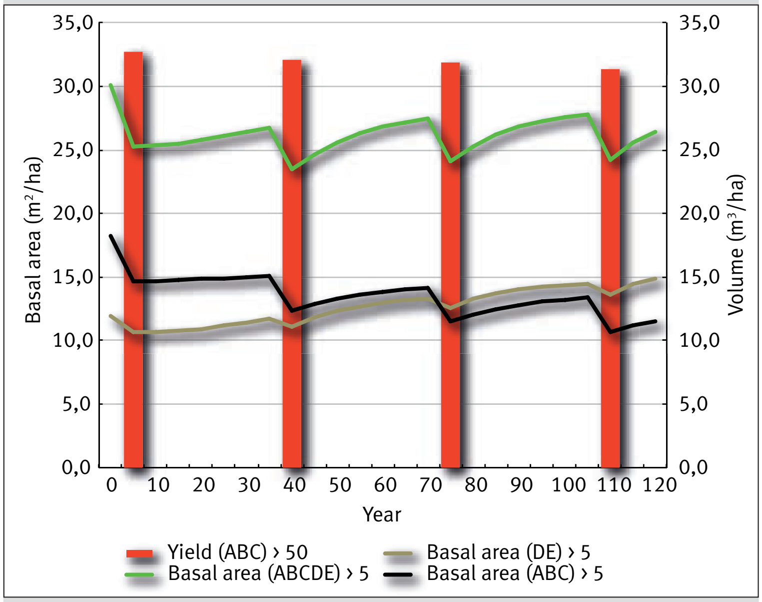

Figure 4.
Simulated harvesting at Tapajós km114 over 4 cycles with a broad base of commercial species. The chart is pasted directly from CAFOGROM. A harvesting limit of 2.2 m^2/ha basal area is c. 30 m^3/ha volume.

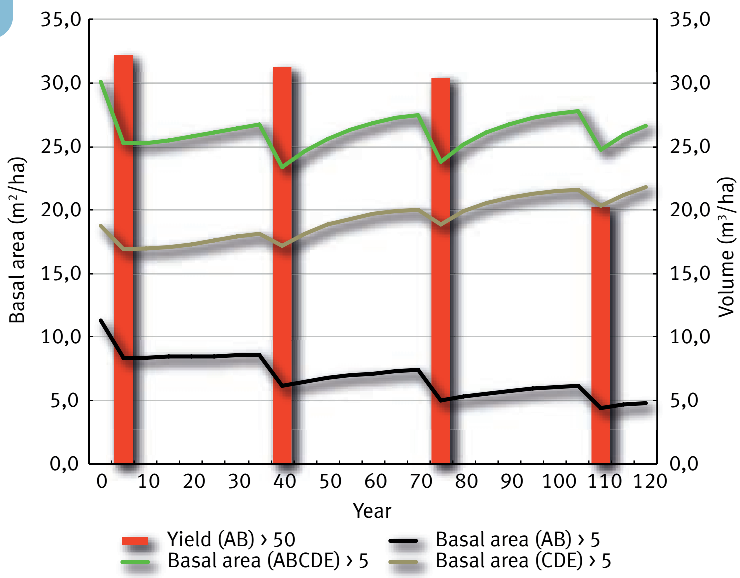

Figure 5.
Simulated harvesting at Tapajós km114 over 4 cycles with a limited base of commercial species. The chart is pasted directly from CAFOGROM. A harvesting limit of 2.2 m^2/ha basal area is c. 30 m^3/ha volume.

Discussion

Cafogrom, based on calibration with data available up to 1998, represents actual growth on new plot measurements from 2003 and 2008 quite well, with less than 15% deviation in estimated volume on these new measurements. It is however tending to underestimate growth, and it is likely on longer term projections that the deviation will grow.

Whilst sustainability is indicated with the broad definition of commercial species using the simple criteria of volume and basal area, many would argue that this does not sufficiently indicate ecological sustainability (GAYOT & SIST, 2004; PUTZ *et al.*, 2008, 2012; SIST & NASCIMENTO FERREIRA, 2007). Accordingly, while CAFOGROM can indicate the simplest and most classical form of sustainability, in terms of technical volumes, it is not sensitive to the many factors in complex tropical forest that can reduce future yields.

A process is underway to recalibrate the model using the latest data. However, it is clear that some improvements are needed at a practical level:

The existing VBA code is for the 1997 version of Microsoft Excel. Many of the user interface objects are now deprecated. Although they still run, maintenance and modification is very problematic.

The model operates only on species groups. This creates problems in the specification of different commercial species and difficulties and confusion when communicating model outputs with practical users. An alternative strategy is to operate on species, although the models for each species will still be for groups.

The model operates on aggregate stand data (inventory summaries, in effect). Because there is much variation from plot to plot or within stand mosaics, separate simulations of each plot or mosaic element are likely to be more accurate.

The model is to some extent self-calibrating, but requires complex file formats that are generated by a FoxPro pre-processor program, Cimir. As FoxPro is now effectively obsolete and unsupported, this aspect of the system needs to be re-written.

Altogether, a simplification of some aspects, and enhancement of others indicates that a complete re-write of the program is needed. It is likely that this will be done in Python language using the QT interface, aligned with the Myrlin concept for simplified forest modelling (WRIGHT & ALDER, 2000; ALDER *et al.*, 2002; www.myrlin.org), and embedded in the Forest Management Toolkit (www.eofmt.com) to allow a remote sensing and GIS element to be integrated with the processing of inventory plots and representation of the forest mosaic. At the same time, the various functional modules for growth, mortality, competition, recruitment and logging damage will be exposed as plug-in elements, to encourage collaborative working and enhancement of the model.

However, these updates do not detract from the flexibility and robustness of the basic cohort-empirical approach to tropical forest modelling. Although less sophisticated than single tree and process-driven modelling, it is an approach that is well able to deliver practical forest management models for planning and certification.

Large trees with extended buttresses are marked and measured using ladders.
Photograph J. Olegario & P. de Carvalho.

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