INTERNATIONAL TROPICAL TIMBER ORGANIZATION
Project PD 162/91 - Papua New Guinea

Intensification of growth and yield studies in previously logged forest

ITTO

PINFORM : A growth model for lowland tropical forest in Papua New Guinea

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The ITTO project has established 72 PSPs, of which 70 are in lowland tropical forest, and 2 in sub-montane formations. All plots have been remeasured over at least 2 years interval. A major objective of the project has been development of a growth model to inform forest management decisions.

This report describes the model, called PINFORM (PNG/ITTO Natural Forest Model). It covers the design and growth functions, a user's guide, performance testing, and some management implications from the model.

The model is a single-stand simulator. The forest is described by cohorts whose growth, mortality and recruitment are directly based on empirical functions from the PSPs. Mortality and growth use mean rates for functional species groups. The groups combine species with similar growth rates and maximum size. Average diameter increment is used, modifed by a stand density index depending on basal area. A site factor called growth index also modifies increment. Mortality varies only between sound and defective trees within species groups. Recruitment depends on basal area 5 years before, with a weighting factor between pioneer and non-pioneer species depending on disturbance. For logging damage, a function is borrowed from Costa Rica. Fire response and the re-colonization of clearings are based on assumed models that give qualitatively satisfactory results.

In operation, the model is a typical Windows program, with pull-down menus and dialog boxes to set parameters, run the model, and view various outputs. It runs under and requires Microsoft Excel version 5 or higher, and is written in Visual Basic for Applications. The model includes special functions to convert FIPS inventory data. The user can select different initial inventory files, define a harvesting regime, and run the model to see the effect. Site factors, diameter classes, and species groups can be varied. Harvesting can be based on a fixed cycle or felling at a specified basal area. Intensity of harvest can be controlled by minimum diameter limit, percentage basal area felled, or volume/ha harvested. Simulations can run upto 200 years. Graphical outputs include a basal area dynamics graph showing basal area gains and losses, area under clearings (non-forest), and tree numbers above a user-specified dbh limit; stand structure diagrams of basal area or tree numbers by size classes for a given year; volumes by species groups over time; volumes actually harvested at each cycle; and a graph to compare results from successive simulation runs. Each type of graph is supported by an underlying table. All graphs and tables can be printed or copied to other packages using Windows cut and paste techniques.

Tests on model performance show that without logging it tends to a basal area limit of about 35 m^2/ha under a variety of circumstances. At the limit, both increment and mortality are active but in balance. Q-ratios for disturbed stands tend to oscillate and converge to stable values of about 3 with 20-cm classes. Basal area classes tend to approximately equal distribution. Growth rates of recovering forest total about 1.75 m3/ha, and are sensitive to growth index. The volume maximum occurs much later than the basal area limit, at perhaps 170 years, whereas BA limit occurs at about 70 years. Heavy felling results in a pioneer population that rises in number for 20-30 years then dies away.

Various management regimes, initial stand conditions, site factors, logging methods, and fire regimes were tested to derive general indicators. It is found that felling cycle is not a good method of ensuring sustainability. Longer cycles result in heavier fellings and higher losses in damage. In general best results are obtained by regulating volume felled. Over a wide range of felling cycles, an annual allowable cut of 0.55 m^3/ha/yr can be sustained on average sites, falling to 0.35 m^3/ha/yr on the poorer sites, or rising to 0.75 m^3/ha/yr on the best. AAC is not very sensitive to starting conditions (initial stand structure) provided a sufficient stock is present at the first felling (around 25 m^2/ha or more). However, AAC is quite sensitive to logging method. Frequent fires are not compatible with sustainable production forestry under natural regeneration. In practise a controlled AAC appears feasible with lower-cost but effective monitoring methods. A regime with a 20-year felling cycle and AAC of 0.5 m3/ha/yr could be widely adopted once suitable controls have been field tested and given statutory support.

Additional field work is needed to develop local logging damage functions, new volume equations, to correlate site and growth index, and to study fire and grass dynamics in re-growth of forest clearings. A follow-on ITTO project could permit these and further improvement of the model with a longer time series of PSP data.

A 2-day workshop was given to offer training to some 10 individuals from FRI and the Forest Authority in the use of the model. Installation kits for the model are available on diskette.

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Disclaimer

Abbreviations

AAC .... Maximum annual allowable cut.
Dbh .... Diameter at breast height (1.3 m).
Excel .... *Microsoft Excel*. A registered trademark of Microsoft
                       Corporation.
FIPS .... Forest Inventory Programming System
FIMS .... Forest Inventory Mapping System
FMA .... Forest Management Authority
FRI .... Forest Research Institute
GTZ .... Gesellschaft für Technische Zusammenwerke
ITTO .... International Tropical Timber Organization
JICA .... Japanese International Cooperation Agency
PERSYST .... Permanent Plot System
PINFORM......... PNG/ITTO Natural Forest Model
PNG .... Papua New Guinea
PSP .... Permanent sample plot.
VBA .... Visual Basic for Applications. *Visual Basic* is a
                       registered trademark of Microsoft Corporation.

Typographic and other conventions

Text typed in *Arial 10 point italics* refers to wording on PINFORM
menus, dialog forms or outputs. Figures reproduced directly from
PINFORM show the PINFORM figure number (1-6) in bold
immediately above, as part of the figure. The figure number used
in this report is always shown in the left margin as part of the
caption. This document is printed using Book Antiqua, Impact
and Arial fonts available with Microsoft Windows 95 and is
formatted for A4 paper.

Background The ITTO project *Intensification of growth and yield studies in previously logged forest* started in 1992 and has to date resulted in the establishment and remeasurement of 72 permanent sample plots widely distributed throughout Papua New Guinea. Romijn (1994c) describes the plot design and measurement procedures. A fundamental aim of the project has been to develop a simulation model of tropical forest growth and yield which can be used to inform thinking about forest management practices (Oavika, 1994). To that end, the present author was employed by ITTO to complete the analysis of the plot data and produce a working model. His earlier reports have described the steps taken so far in that direction. In July 1997, he prepared a number of programs for data analysis, and completed preliminary work on diameter increment functions, and species grouping (Alder, 1997a). He also instigated a work programme by the project staff at FRI to eliminate a number of errors from the database that had become apparent through cross-checking of successive measurements.

In November 1997, further work was undertaken. An ordination analysis of plots and species was undertaken to determine whether there were major discontinuities in the forest types represented. It was concluded that with the exception of two plots in *Nothofagus* forest in the Southern Highlands, all the PSPs could be regarded as having rather similar floristic composition characteristic of the lowland tropical forests of PNG. The increment models were also evaluated in more detail with respect to species, density dependent effects, and site effects, and a final model achieved. These details were reported in Alder (1997d), which also included a user's guide to the data analysis programs.

The present report covers a further two months work, during February and March 1998. It concludes the development and testing of the model, and gives some examples of its application to forest management, especially in terms of general implications for felling cycle and annual allowable cut.

The model as a practical tool Growth models for natural forest management should not be regarded as ivory-tower projects. They are simply a computational framework for pulling together the complex information on tree growth, recruitment and mortality that is required to correctly describe a natural tropical forest. Forests of this type are too complex for their potential yield to be evaluated by any simple graphical method, such as could be used for plantations. Consequently, a computer model becomes indispensible.

Practical use of models in tropical forest management were first described by Korsgaard (1984) in Sarawak. His model was also evaluated for Brazil by Silva (1989). Vanclay (1989) developed a more flexible and sophisticated approach, the so-called cohort model, for the North Queensland rainforests. The present author has developed several related models based on Vanclay's concepts, for application in Costa Rica, Brazil and Mexico (Alder, 1996a, 1996b, 1997b, 1997c).

The model developed for Papua New Guinea has been called PINFORM, which is an acronym for PNG/ITTO Natural Forest Model. It is written in VBA to run under Excel 5 or Excel 97. In the section on *Growth Functions and Design* of this report, the technical basis of the model is described. The following section, *Program Operation*, is a user's guide to the model. *Performance Evaluation* describes the testing of the model to verify that its performance is as realistic as possible, given the limitations of the data and other constraints on the project. Finally, the *Management Implications* of the model are considered.

Workshops and training   A workshop on the use of PINFORM was held on 27-28th March 1998 at FRI, Lae. This involved a presentation of the model, a description of the background, and discussion of its implications. This was followed by some 8 hours of practical use of the model by about 10 participants, including two from the PNG Forest Authority, one from JICA, and the remainder from FRI and the ITTO project staff.

A somewhat briefer seminar on the model was also given to the Association of Foresters of PNG on 21st March 1998.

Several one-to-one sessions have also been given to ITTO staff members on the use of the model with special reference to the updating of the growth functions as new data becomes available.

General model structure   The block diagram in Figure 1 gives a simplified schematic of the PINFORM model. A menu bar at the top of the screen is the logical starting point for program operations. Full details of the menu system are given in Figure 10 on page 15. The menu allows program options to be set via dialog screens, and also selects various model outputs for examination. One menu command executes the model itself, to simulate the growth of a forest stand over a period of time.

As shown in Figure 1, the model first initializes itself, by reading the various settings contained on the dialog screens, and resetting all graphs, tables, and internal variables. It then reads inventory data from an external file, which defines the initial state of the forest to be simulated.

After these initial processes, the program enters a loop of repeated operations over time. These simulate, in step, the main processes of forest dynamics, including tree growth, mortality, and recruitment. Under conditions determined by the user, the program simulates harvesting or thinning of the stand. Specialized routines manage the cohort list that describes the forest, and calculate quantities such as tree numbers, basal areas and volumes for the various outputs graphs and tables. This sequence of operations is repeated until the time limit set by the user has been reached.

On completion of a run, control returns to the menu, allowing the ouputs to be examined, and inputs to be modified for further trials.

Species codes, groups and models   Earlier reports have discussed the method of analysing species data from the PSPs to form species groups (Alder, 1997a, d). A FoxPro program called SPPORD summaries mean increment of non-defective trees, and calculates the 90% point of the diameter distribution. A related Excel spreadsheet, called SPPORD.XLS can process the output file from the Foxpro program to form species groups by ordination.

These groups are designated by single letter codes A-Z. There are 21 groups, whose representation on the ordination diagram is shown in Figure 2. The large majority of trees fall into the groups A-G, which comprise the main sequence. Above this lies a series of faster growing groups, using the letters P-V, and a group of extreme ephemeral pioneers, group X. Below the main sequence lie species which are typically slow growing, including some trees which attain large dimensions.

Menu bar

Run dialog
initiates
execution

Dialogs
to set options

Get parameters .... **Initialize**
from dialog sheets   graphs,
                         tables etc.

Display
graphs,
tables

Inventory
data input

*Figure 1 Block diagram
of the PINFORM model*

**Time
loop**

End
return to
menu

Growth
diameter
increment

Mortality

Repeat for next
5-year time step

Recruitment

**Harvest-
ing due?** —Yes▶ **Harvesting** ▶ **Damage**

**Thinning
due?** —Yes▶ **Thinning**

Compress
cohort list

Analysis
for output
graphs etc.
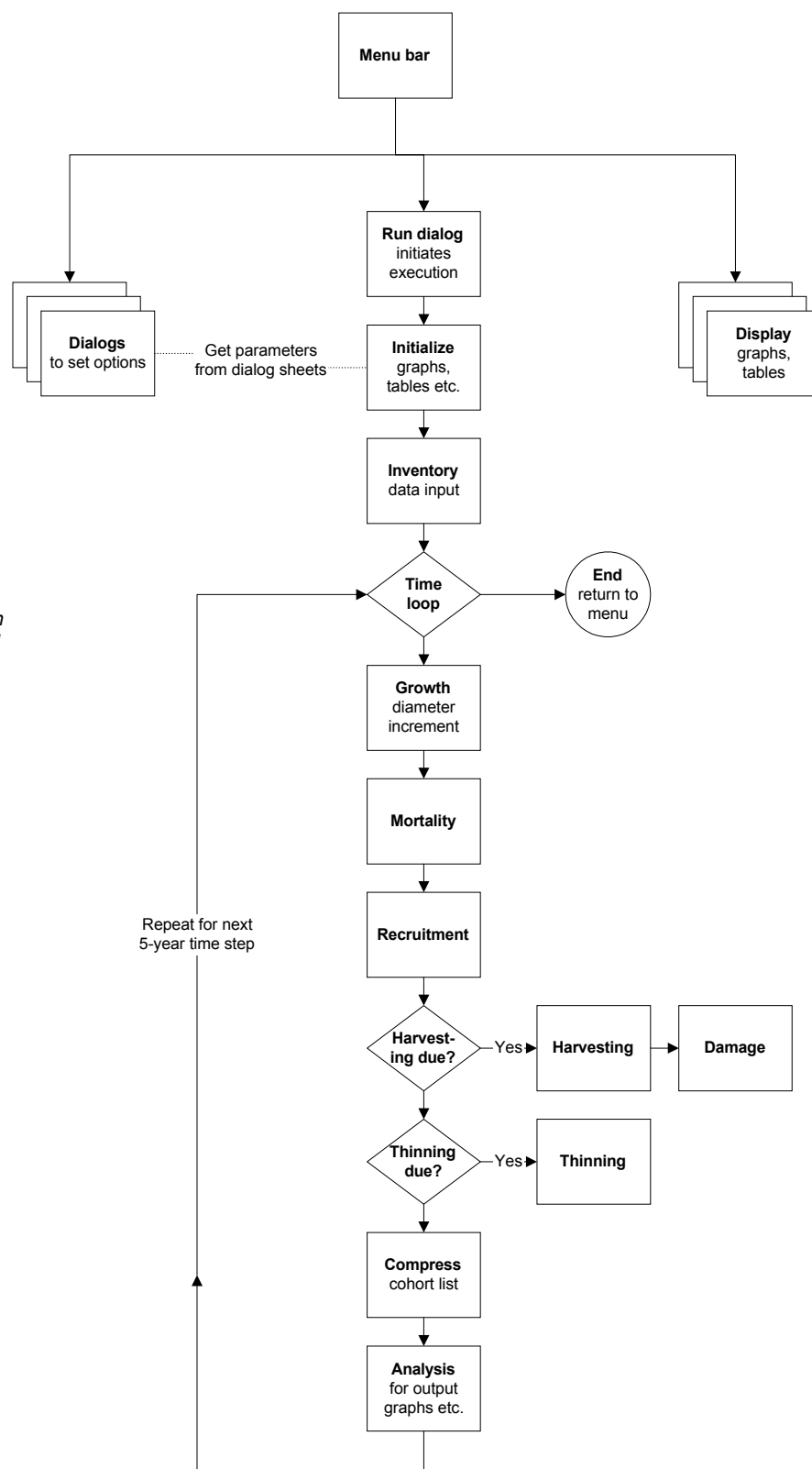
Figure 2 Species models, with mean increment and typical size
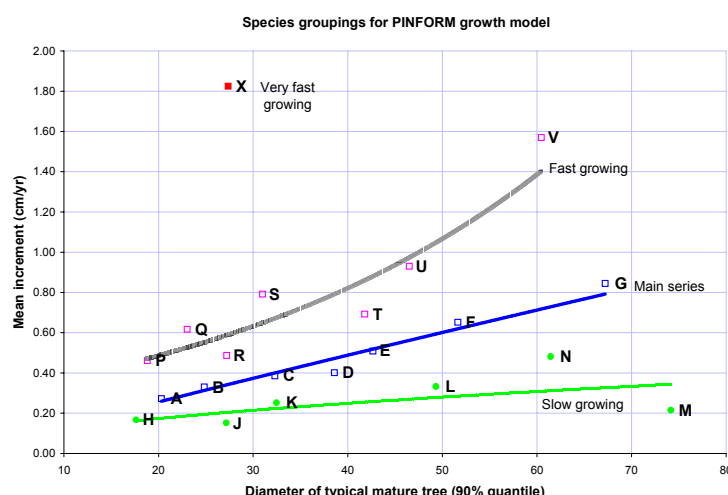
These species groups are used internally to decide which growth model to apply for a particular species. However, for forest management purposes, a separate series of groups are defined. To avoid confusion, the growth model groups are called *species models*, whilst the normal commercial and management groups, are referred to as *management groups*. As far as PINFORM is concerned, the allocation of a species to a species model and management group depends on the codes entered in the internal species list. This can be edited manually. It is however a direct copy of the database file SPECLIST from the PERSYST system (Romijn, 1994b). Species which are found in the inventory data but have no entry in the species list are always assigned to the last management group, and to a growth model derived from pooled data for all species.

A dialog accessible from the menu bar allows the management groups to be re-named or re-ordered. Their code numbers determine the priority in which groups are selected for harvesting, and which are commercial or non-commercial.

All the model outputs are based on the management groups, as are harvesting and treatment prescriptions. The species models are however referred to in the following discussions, and form the basis of the internal simulation of growth, mortality and recruitment.

Increment, mortality, and maximum size

The key species-based growth models are summarised from the PSP data by a single FoxPro program called MODELS. The output, a database file of the same name, can be imported directly into PINFORM, using Windows cut and paste techniques. Table 1 shows this data, reproduced directly from PINFORM.

For each species model, the two left hand columns show the number of sound or defective sample trees. Defective trees

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include those with very poor crown form, broken top, or notes indicating dieback, decay, or damage. This information is shown mainly for reference, and to assess the reliability of the mortality estimates. It will be seen that the groups vary greatly in the number of trees they contain.

The bottom line of the table, identified by a # in the left column, is an overall average for all the data. The penultimate line, marked ?, contains data from species occurring on the PSPs but not found in the SPECLIST file. Overall, it can be seen that there are 21,799 sound trees, and 1,282 defective ones in the sample. Trees which do not constitute either reliable increment or mortality records are omitted from this count and the parameter estimates.

Average species increment is represented by two figures, in the fourth and fifth columns of Table 1. These give the mean increments respectively of the 50% slower and 50% faster growing trees for the group.

Mortality rates are shown separately for sound and defective trees in the sixth and seventh columns. The rates for defective trees are mostly unreliable, and are zero where there is no data (ie. no dead trees in that category). This column is not used directly, except for the overall average on the last line.

The eighth column shows the 99% point of the diameter distribution, as an indicator of maximum tree size.

The final column lists the most common species in the group, in order of abundance. This list includes the species which make up at least two-thirds of the group basal area.

The stand density function The mean diameter increments are modified in each growth cycle according to stand basal area. The form of this multiplier function is shown in Figure 3. The multiplier is derived by calculating the mean basal area increment of a plot from the species composition and mean increment only, to derive an estimate of plot increment BAI*. The ratio of actual basal area increment BAI over BAI* is then plotted against stand basal area. The equation gives a multiplier in the increment function that can be used to compensate for changes in stand density.

Table 1 Table of species growth models reproduced from PINFORM

Model group	Trees sampled Sound	Defect	Diam. incr. (cm/yr) lower 50%	upper 50%	Annual mortality % Sound	Defect	Dmax 99%	Typical species in order, comprising first 66% of basal area in group
A	356	19	0.097	0.436	0.71%	0.00%	30	Timonius, Cleistanthus, Mammea veimaurensis
B	2108	109	0.123	0.564	1.25%	4.32%	44	Myristica, Polyalthia, Gonystylus macrophyllus, Medusanthera
C	2146	100	0.139	0.621	1.09%	4.53%	52	Horsfieldia, Garcinia, Chisocheton, Aglaia
D	4027	234	0.154	0.653	1.23%	4.01%	59	Syzygium, Canarium, Planchonella
E	4359	243	0.175	0.809	1.34%	5.11%	68	Ficus, Cryptocarya, Pimeleodendron amboinicum, Calophyllum, Celtis, Litsea
F	2669	155	0.214	1.011	0.80%	2.83%	76	Pometia pinnata, Terminalia, Dillenia, Pterocarpus indicus, Euodia
G	325	30	0.286	1.314	0.76%	0.00%	110	Vitex, Spondias cytherea, Nothofagus
H	162	16	0.052	0.285	0.80%	6.22%	33	Osmoxyllon novoguineensis, Zygogynum, Aralia, Ryparosa javanica
J	144	18	0.047	0.345	2.30%	3.71%	45	Cnesmocarpon discoloroides, Mallotus, Steganthera, Xanthophyllum papuanum, Oreocallis wickhamii
K	850	54	0.088	0.420	0.88%	2.97%	51	Maniltoa, Diospyros, Parastemon versteeghii
L	396	5	0.109	0.513	0.84%	0.00%	71	Vatica rassak, Vitex cofassus, Gmelina moluccana, Ilex
M	53	3	0.096	0.417	0.85%	0.00%	125	Alstonia scholaris, Aglaia sapindina, Alstonia brassii
N	180	5	0.186	0.842	1.69%	0.00%	100	Teijsmanniodendron, Neonauclea, Pterygota horsfieldii, Endospermum meddulosum
P	467	54	0.172	0.716	0.73%	2.99%	41	Gnetum gnemon, Astronia, Dendrocnide, Erythrospermum
Q	608	49	0.196	0.927	3.25%	10.51%	43	Macaranga, Ziziphus, Macaranga aleuritoides
R	655	27	0.170	0.793	2.21%	9.35%	44	Microcos, Prunus
S	245	16	0.302	1.285	1.81%	0.00%	51	Elaeocarpus, Duabanga moluccana, Alphitonia
T	442	33	0.282	0.990	1.33%	2.79%	65	Anisoptera thurifera, Cerbera floribunda, Galbulimima belgraveana, Merrilliodendron
U	278	20	0.315	1.466	0.95%	2.98%	72	Artocarpus, Anthocephalus chinensis, Tristiropsis, Hibiscus
V	68	6	0.332	2.169	2.58%	8.31%	120	Elmerrillia, Hernandia, Ailanthus integrifolia
X	119	5	0.720	2.788	5.10%	29.36%	47	Trichospermum burretii, Trichospermum, Trema
?	1142	81	0.137	0.623	2.92%	10.37%	54	Unknown species
#	21799	1282	0.156	0.769	1.35%	4.67%	66	All species combined
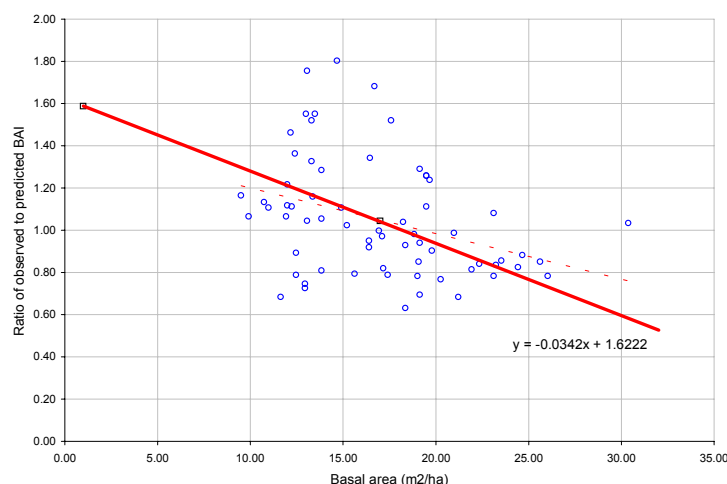
The dotted line in Figure 3 shows the regression. The solid line is a curve located by eye to give a slightly stronger density dependent effect. The slope of this curve determines the maximum basal area that a stand will reach, which with the hand fitted curve shown is about 35 m²/ha.

Site effects on increment

The unexplained variation in Figure 3 is partially related to site. The PSPs are mostly located in pairs, or in a few cases in groups of three or four. It is obvious from inspection that the deviations from the mean increment line tend to be correlated for pairs and groups. Statistical analysis shows also highly significant differences at the provincial level. Using the province as a stratification for site, the growth indices shown in Figure 4 are found. Growth index is here defined as a multiplier for mean tree increment that depends on site. A growth index of 1 (100%) represents the overall average site factor for all plots.

Figure 4 Average growth index for PSPs grouped by provinces
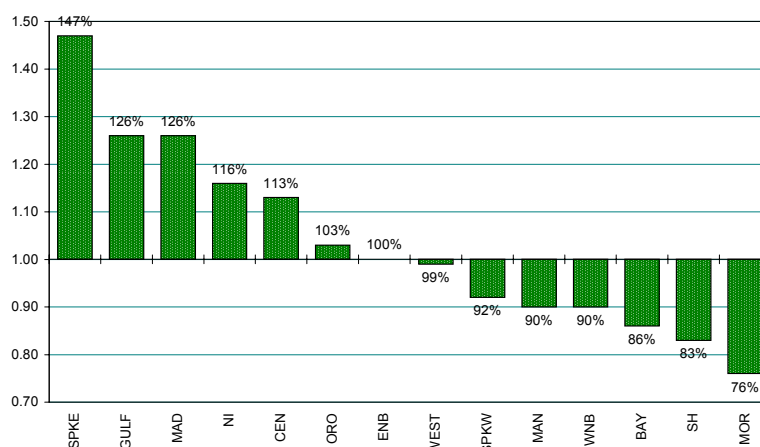
The detailed analysis relating to the calculation of the growth indices is presented in an earlier report (Alder, 1997d). Although the figures are presented at provincial level, the differences between plots are probably due primarily to variations in water regime and soil fertility. This is a useful field

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for future study. In the PINFORM model, the growth index can be set by the user over a range from 70% to 130%.

Recruitment Total recruitment is predicted in the model as the basal area of recruits over a period, based on the initial basal area, as shown in Figure 5 below. In this graph, each point is one PSP. The basal area is that taken at the first measurement. The recruitment is the basal area of all new trees occurring over the entire measurement period (2-5 years), converted to an annual value by dividing by the measurement period. A linear regression with an R^2 of 11% is shown as the dotted line. The solid line is an assumed exponential function which tends to a recruitment of 0.8 m²/ha/yr as the stand basal area approaches zero, and closely approximates a linear function over the range of the data.
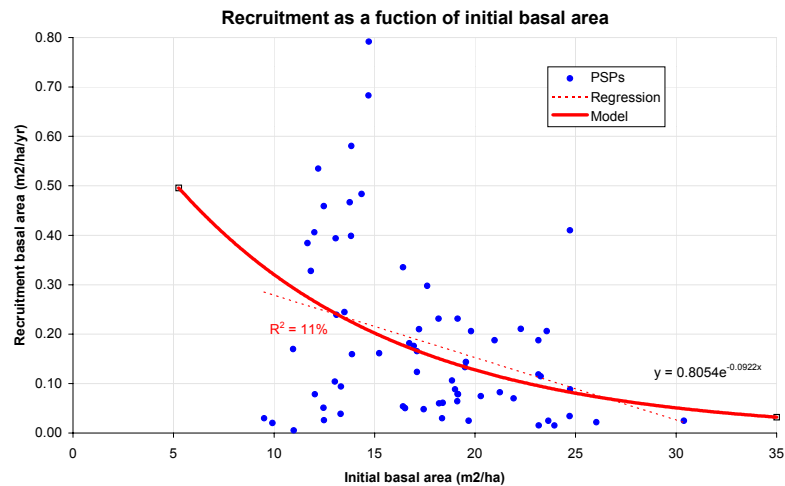
Figure 5 Recruitment as a function of initial basal area

Recruitment as a fuction of initial basal area

Legend: • PSPs; ---- Regression; —— Model

$R^2 = 11\%$

$y = 0.8054e^{-0.0922x}$

Y-axis: Recruitment basal area (m2/ha/yr)
X-axis: Initial basal area (m2/ha)

To convert recruit basal area into a number of recruits, a second function relates recruit basal area and numbers, and implicitly defines mean recruit size. This is shown in Figure 6 below. Each point on this graph shows the recruit basal areas and numbers for one PSP. The dotted line shows the relationship that would occur if the mean recruit dbh were 13.5 cm. The solid line is a logarithmic regression with R^2 of 96%, and is the function used in PINFORM. The equation is shown on the graph.

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Recruitments basal area and tree numbers

$$y = 61.452x^{0.8676}$$
$$R^2 = 0.9659$$

Figure 6 Recruit numbers as a function of recruit basal area
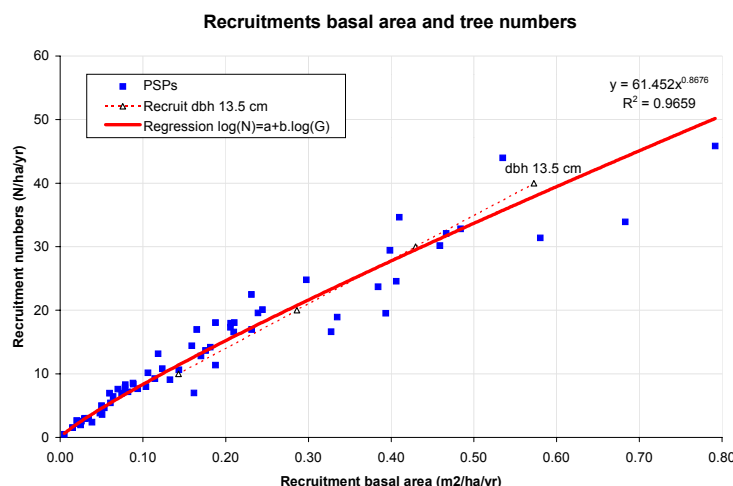
The final part of the recruitment function gives the proportion of recruits occurring as pioneer species, as shown in Figure 7. This data is weak compared with similar work the author has done elsewhere (Alder, 1995:175), reflecting the short measurement period and similiar histories of the plots (all were logged prior to measurement), but nonetheless shows a signficant tendency for higher proportions of pioneers to occur at higher recuitment levels. These in turn will be associated in general with more disturbed sites.

Proportion of recruits as pioneers, with level of recruitment

$$y = 0.791x^{0.5475}$$
$$R^2 = 20\%$$

Figure 7 Proportion of recruits as pioneer species
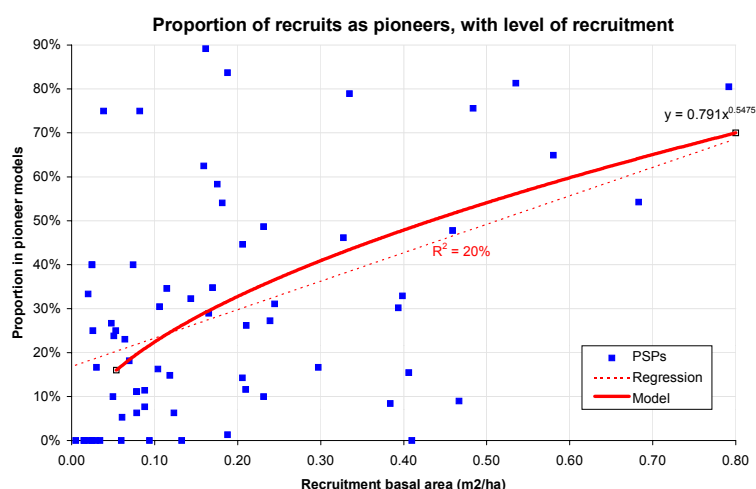
Species distribution of recruitment   The model uses the foregoing functions to determine the general levels and characteristics of recruits, and to allocate these between pioneer and non-pioneer species. The actual species distribution is based on the inventory data supplied to PINFORM. This is analysed to weight species occurrence at each growth cycle by basal area in two lists: Pioneer and non-pioneer.   Total numbers are then allocated to individual species in proportion to these weights. This has the effect of:

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- Requiring the presence of parent trees before a species can reproduce, and ensuring that regeneration will reflect the species occurring in the overstorey.

- Separating pioneer and non-pioneer species in terms of weighting, so that pioneers can occur at high densities after clearing even if they are a rare component before felling.

- At the same time, allowing for species differences between localities in both pioneer and non-pioneer components.

- Natural succession will be reflected in the non-reproduction of pioneers under closed canopies.

- Artificial creaming of species will result in their diminished reproduction, and consequent disappearance from future crops.

There are many features of natural regeneration that are not included. The distinction between pioneers and non-pioneers is too crude. There is a large group of species which require some disturbance but are not true pioneers (non-pioneer light demanders, or NPLDs). CAFOGROM modelled this group (Alder, 1995:175, 1996b), but the data available in PNG is too limited at present to justify this step. There is also a need to review the species groups in conjunction with available ecological information (eg. Cameron & Vigus, 1995).

Logging damage As far as the author is aware, there are no logging damage studies in PNG that can be used to directly calibrate this aspect of PINFORM. He has used as a basis a study in Costa Rica that was used in the SIRENA 2 model. This form of this function is shown in Figure 8.

Each point on this graph represents average data from a number of plots laid in a harvested area. Six different areas representing a range of logging intensities were assessed. The lines are logarithmic curves fitted through the points by regression. The data are plotted on log-log scales.

The heavier, solid line, gives the areas destroyed completely as skid trails, felling gaps, and landings. The lighter line shows the percentage of residual trees significantly damaged (broken crowns, swathes of bark stripped off, buttresses broken).

Figure 8 Logging damage functions based on the CODEFORSA study in Costa Rica
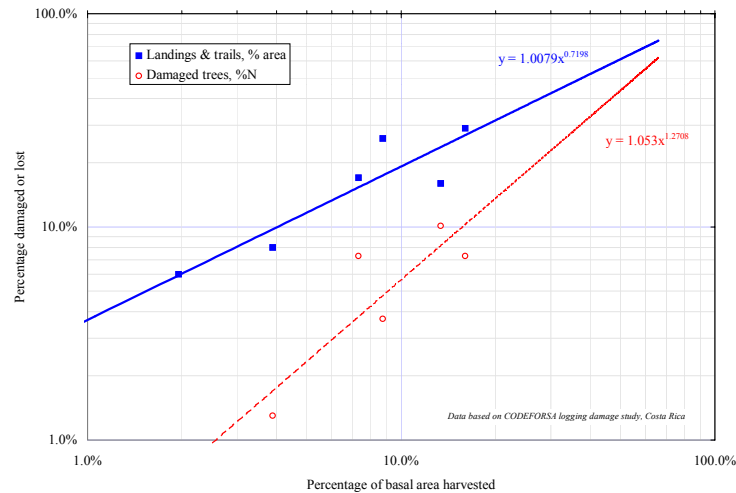
The functions are consistent with other studies (eg. Kobayashi, 1992), but also may be taken as representing optimal technique, as the extraction was done with agricultural tractors and winch, the forests were stock mapped before hand, and care was applied in felling direction and location of trails.

PINFORM provides for sensitivity analysis of logging functions. Three levels can be selected, described as *Low Impact, Normal,* and *High Impact.* User defined multipliers can be attached to the *Normal* and *High Impact* levels.

Fire damage and clearings

The lowland forests of PNG are often popularly described as rainforest. However, few foresters would agree with this description. They are a drier type of forest, subject to periodic fire, and readily converted to savannah where fires become frequent, as in proximity to settlements. It is clearly important that PINFORM reflects this reality, as it is a critical factor of forest management.

There is little direct data on this subject. The author has introduced some assumed elements into the model that allow sensitivity analysis with respect to the fire regime and its interaction with logging. These elements are as follows:

- Areas cleared as a result of logging recover at an annual rate determined by a *Site Recovery Factor.* Only recovering areas experience regeneration, and these only receive seedlings from the pioneer list. This is intended to model the inhibiting effect of grasses on regeneration, and the fact that grass areas are invaded by trees mainly at the edges.

- The site recovery factor is retarded by a fire severity multiplier.

- Fire also effects mortality rates in standing trees, again by a severity multiplier.

- Recruitment is effected by fire as a power function, so that under severe fire regimes, recruitment is almost completely inhibited. This reflects the fact that the shrub layer in a forest is almost totally destroyed or absent with annual burning.

The multipliers used have been calibrated to give behaviour that corresponds to normal growth with a fire regime of periodic severe fires, retarded growth with more frequent fires, and a progressive disappearance of forest cover with annual burning. These factors interact with logging through the recovery process related to clearings. A logged forest is more sensitive to conversion to grassland.

Model coefficients   Model coefficients can be adjusted by the user, but it is recommended that this is only done on the basis of careful empirical analysis. Arbitrary adjustments to coefficients will result in erratic model behaviour and misleading projections. Figure 9 shows the standard values in the model, corresponding to the various functions discussed above.

Figure 9 PINFORM dialog used to set stand model coefficients

Tree volume equation   PINFORM does not model or calculate tree heights, and cannot therefore use the standard double entry volume equations for indigenous trees. It uses a simple single entry equation of the form:

$$V = 1.116\ k\mathrm{D}^{2.4762}$$

where k is 0.00007854 and D is tree dbh. This equation is taken from PERSYST (Romijn, 1994b) but is original attribution is unknown. A comparison with other single entry equations from Ghana, Costa Rica and Brazil shows that it lies slightly above the lowest of these, for Costa Rica, but is below the other two. Using this equation to calculate results from some FIPS inventory data instead of the double entry equations used by FIPS gave very similar results. The equation certainly does not overestimate volumes, as there is evidence that FIPS volumes are themselves underestimates due to bias in the ocular method of height estimation.

Installation and start up of PINFORM

PINFORM is distributed with some demonstration files as a self-extracting archive. The distribution disk contains a README file with installation intructions. The working program will normally be called PINFORM.XLT.

Excel 5 or Excel 97 must be properly installed for PINFORM to run. It has been tested with both these systems, under Windows 3.11 and Windows 95.

The program can be started by clicking on the PINFORM.XLT file name from the Windows Explorer or File Manager. More conveniently if it is to be used frequently, an icon can be set up to start the program. An icon file PINFORM.ICO will be found on the diskette that can be used for this purpose.

The main menu

As soon as the program starts, the Excel menu will be replaced by the PINFORM menu bar. The complete list of available choices are shown in Figure 10. There are three main headings: *Forest management, Model outputs,* and *Control*.

The *Forest management* menu brings up a list of sub-headings as shown in the figure. These are concerned with basic settings for a model run. The *Inventory* option sets the file that is used as the basis for a simulation. The *Harvesting* and *Thinning* menus set forest management options such as felling cycle. The *Site factors* option allows different site quality, fire regime, and logging methods to be compared. The *Diameter classes* menu sets class widths and and lower bounds used in the various output tables and graphs. The *Species list* and *Species groups* menus allow various aspects of species naming and grouping to be controlled. The *Models* menu sets the underlying coefficients used by the growth model. The *Stand table* menu produces a stand table by species that is directly comparable with FIPS output, to check baseline data being used by the model. The *FIPS files* menu allows for checking and conversion of FIPS inventory data so that it can be used by PINFORM.

The *Model outputs* menu simply displays the various graphs or tables produced during a simulation run. The *Control* menu has options to initiate a simulation run, to print displayed graphs or tables, to save the model with all current settings and data, to exit and return to Windows, to set headings for printed outputs, and to adjust the size of graphics.

```
Forest Management ─────── Model outputs ─────── Control

      Inventory              Basal area dynamics         Run

      Harvesting             Basal area by size          Print
                             classes

      Thinning               Tree numbers by size        Save
                             classes

      Site Factors           Standing volumes            Quit

      Diameter classes       Volumes harvested           Front cover

      Species list           Comparison of runs          Maintenance

      Species groups              View                        Access code

      Models                      Options                     Excel

          General                                             Monitor

          Tree growth        Tables for graphs               Toolkit

      Stand table                Basal area dynamics          Protection

                                 Basal area by size      Page headings
                                 classes
      FIPS files
                                 Tree numbers by size    Zoom
          Specification          classes

          Convert data           Standing volumes

          Check data             Volumes harvested

                                 Comparison of runs
```

Figure 10 The menu system for PINFORM

The menu system works in the same way as all other Windows menus, with selections being made by clicking with the mouse. Hot keys are also designated on the menu by underline characters and can be used in combination with the Alt key to access the menu. With one or two exceptions, the menu selections either display a dialog box that allows further options to be set and operations to be executed, or they simply display a worksheet or graph with model parameters or results.

Basic use of the model The basic use of PINFORM requires setting the inventory and harvesting options via the *Inventory* and *Harvest* menus. The model is then run with the *Control/Run* menu, and the various graphs examined to assess:

- Indicators of sustainability
- Average yields
- Composition of outputs

Harvesting options can be modified to improve sustainability or yield.

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Setting inventory files The *Inventory* menu brings up a dialog box which will appear as shown in Figure 11.
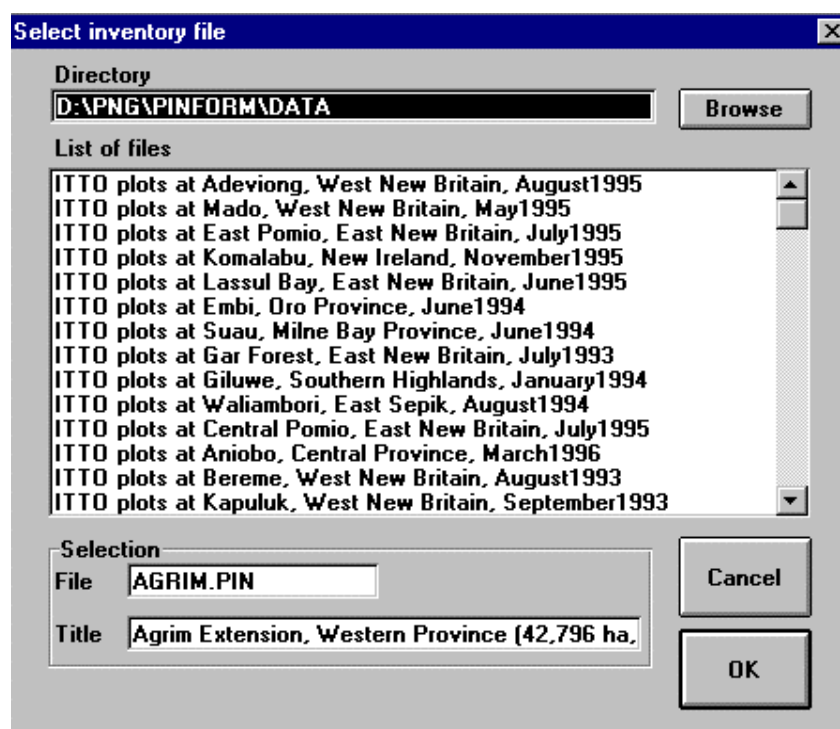
Figure 11 Dialog to set an inventory file

The valid PINFORM inventory files will be listed in the central window by their title. When one is selected by clicking it, the file name and title will appear in the bottom part labelled *Selection*. If the directory at the top appears incorrect, it can be changed by clicking the Browse button. A standard Windows file finder box will appear, through which the user can navigate to the disk and directory of choice. Any file in the target directory can be clicked to close the finder dialog box: any valid PINFORM inventory files will then be listed by title.
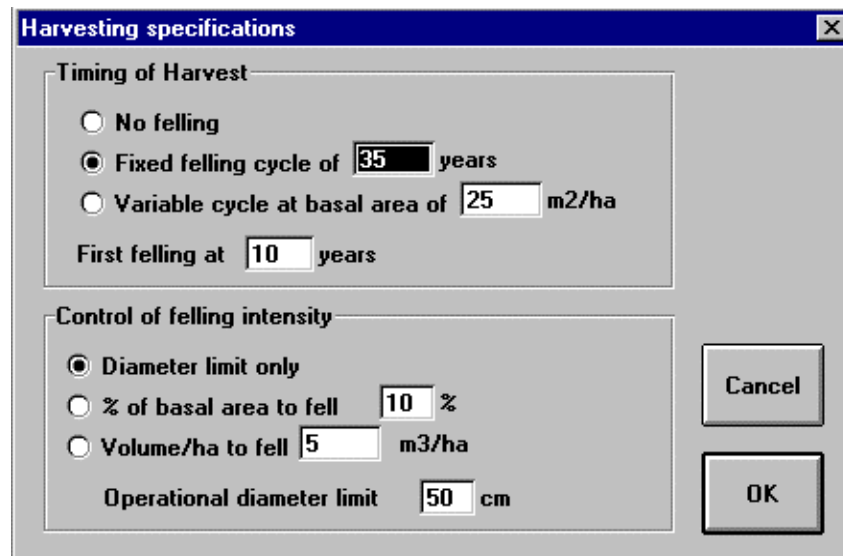
PINFORM inventory files have an extension PIN and use a special format. The demonstration edition of PINFORM includes as samples the first measurement from the ITTO PSPs converted to PIN format. The PSPs are mostly in pairs, and are grouped within the files by localities.

PINFORM inventory files can also be created from the FIPS data files used by the PNG Forest Authority for its normal inventory operations.

Once a file has been selected, the *OK* button is clicked to return to the PINFORM menu system.

Harvesting options The *Harvesting* menu allows options such as the felling cycle and diameter limit to be set. The dialog box appears as shown in Figure 12.

Figure 12 Dialog to set harvesting options

The timing of the harvest can be controlled by three alternatives:

- *No felling*: In this case, the inventory data supplied will be grown by the model without felling. This is useful for comparison purposes, or for analyses related to conservation issues. It also illustrates some basic aspects of forest dynamics.

- *Fixed felling cycle*: This is the conventional option. The felling cycle to be used is entered in the adjacent box.

- *Variable felling cycle*: This allows the stand to be felled when it reaches a certain level of stocking in terms of basal area. It can be used to explore questions of appropriate felling cycles without resorting to extensive trial and error.

The first harvest performed by the model is done in the year set in the box labelled *First felling at …. years*.

The intensity of felling can be controlled by one of three methods:

- *Diameter limit only:* In this case, all commercial trees are felled which are above the diameter specified in the *operational diameter limit* box.

- *Basal area %*: A percentage of the basal area to be removed can be specified. This will still respect the diameter limit and commercial criteria, but not more than the specified percentage will be removed.

- *Volume/ha*: A fixed volume is removed, although again, diameter limits and commercial criteria are respected.

In all cases, only trees belonging to commercial species groups are felled, and then only trees which are non-defective.

When felling is controlled by basal area % or volume, then the specified volume or basal area must be available from the commercial trees before the operation starts. Otherwise it is delayed until the next time period (normally 5 years), and may be delayed further if the volume or basal area still cannot be attained. This is designed to avoid an unrealistic situation where the forest is continually being nibbled for very small volumes.

However, when only the diameter limit control is used, the model will repeatedly carry out very small harvests if the felling cycle allows it.

Running a simulation The *Run* menu brings up a dialog box as shown in Figure 13.

Figure 13 The Run dialog

This gives the time limit for the simulation, shown in the example as 100 years, and allows a line on the *comparisons graph* to be selected and labelled. Clicking the *Start* button begins the simulation. Clicking *Cancel* reverts to the menu without running the model.

The graph that is displayed at the time the *Run* option is selected will remain visible during the simulation. If no graph is displayed, then the graph of basal area dynamics is shown by default.

During the simulation run, the current simulated year is shown on the status bar. There is an initialization phase, usually of about 15 seconds, before the run starts whilst PINFORM reads the inventory data and re-sets graphs and tables from a previous run.

The *Esc* key can be pressed during a simulation run to cancel it and return to the menu.

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Model outputs   PINFORM generates six different graphs during a simulation run. Each of these is backed by a corresponding table. Various examples of the graphs are shown in the section on management implications, and are referred to in the explanation below. The graphs are made visible in each case by the menu choice with the corresponding name.

1. *Basal area dynamics*: This graph shows basal area on the left axis and time as the ordinate (see Figure 20). A bar is shown for standing basal area of sound trees and of defective or damaged trees. Growth and recruitment are shown on top of these. Below the zero axis are shown deductions from basal area: mortality, harvesting, and logging damage. A solid line shows numbers of trees above a user-specified diameter limit. This relates to the right-hand axis. A lighter solid line shows the area of forest which is unstocked (clearings or grass areas) as a percentage, also on the right axis.

2. *Basal area by size classes*: This graph shows forest structure during one time period as a diagram of basal area by size class, with the bars sub-divided by species groups (see for example, Figure 25). *Double-clicking on the graph brings up a year selector dialog* as shown in Figure 14, which allows the year in view to be changed.

Figure 14 Year selector dialog
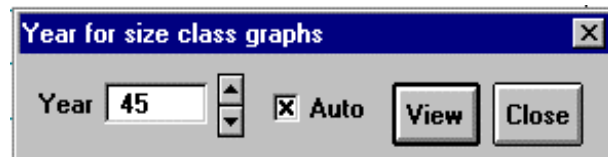
In this dialog, the year to be viewed is entered in the *Year* field, either directly or by clicking the spinner with the mouse. The graph will update to that year when the *View* button is clicked. Checking the Auto box causes the graph to update automatically in 5-year steps as spinner is clicked. This is convenient for stepping through a time sequence, but is very slow when jumping over a large period. In that case the *Auto* box should be cleared and the *View* button used to update the graph..

3. *Tree numbers by size classes*: This shows tree numbers by size classes and species groups for one simulation period (see for example, Figure 22). As with the equivalent basal area diagram, double clicking on the graph brings up a year selector dialog as in Figure 14.

4. *Standing volumes*: Standing volumes are shown over time, sub-divided into species groups. The diameter limit above which volume is shown is defined by the *Diameter classes* menu.

5. *Volumes harvested*: This graph shows volume yields for each felling, with the species groups and the year. It shows only extracted volume, and therefore necessarily excludes defective trees, non-commercial species, and volume below the operational diameter limit.

6. *Comparison of runs*: This graph shows a single volume line over time for each simulation run (see for example, Figure 26). It allows performance under different management regimes to be compared directly. The volume shown can either be total volume above a diameter limit, equivalent to the standing volumes graph; or commercial volume, based on non-defective commercial species above the operational diameter. This latter therefore corresponds to the volumes shown on the *Volumes harvested* graph.

The tables which contain the data shown on the graphs can be viewed by using the *Tables for graphs* menu, and selecting the appropriate sub-menu, each with the same name as the graph.

These tables are not elaborately formatted, but if they need to be reproduced, then can easily be exported to another Excel spreadsheet or to a word processor and formatted as required for presentation.

Exporting graphs and tables   Graphs and tables can be exported for publication puposes, or to enable further ananlysis in another spreadsheet. This can be done using Windows cut and paste technique. For a graph, select the background, and then use *ctrl+C* to copy it. In the target application, it can usually be pasted in either as an Excel object using *Ctrl+V*, or using the *Paste Special* options as a Windows metafile or picture.

For a table, select the cells required using the mouse, and then copy them with *ctrl+C*. They can be pasted into another Excel spreadsheet using *ctrl+V*. In a word processor, they are usually better pasted in Rich Text Format as a table, using the *Paste Special* option.

Graphs and tables can be printed in PINFORM using the *Print* menu under *Control*. This prints whatever table or graph is visible on the screen.

Diameter class options   The diameter classes used on graphs and tables can be set by the menu choice *Diameter classes*. This dialog also allows the lower diameter limit for volume graphs to be defined, and the lower diameter limit for the tree numbers line that appears on the *Basal area dynamics* figure. The dialog appears as shown in Figure 15.

Figure 15 Dialog to set diameter class values for graphs

In the example, diameter classes will be 10-29, 30-49, 50-69, 70-89, and 90+ cm. Volumes are shown above 50 cm, and tree numbers above 30 cm.

Note that changes to these classes do not take effect until the next time a simulation is run. The current graphs and tables will not be immediately updated.

Site factors and sensitivity analysis   Species show a range of growth rates on different plots, as shown in Figure 4, which appear to be due to site differences. The *Site factors* menu brings up a dialog that allows the growth index to be adjusted up or down 30% from a standard value of 100%, which represents the average for all sample plots.

Figure 16 Dialog box for setting site factors

Three severities of fire regime can be compared for sensitivity analysis. They are *Normal, Frequent,* and *Severe*. The *Normal* fire regime corresponds to that observed on the plots. The *Frequent* regime assumes higher mortality, especially of small trees, and slower recovery of cleared areas. This would correspond to a situation such as that experienced over an El Niño period within closed forest, with more frequent and severe forest fires than normal. The *Severe* regime is intended to emulate the effects of

annual uncontrolled burning, as may occur at the forest margins. In this scenario, mortality is substantially increased, and recruitment very much depressed.

In the same way, three levels of logging impact can be compared. The baseline functions shown in Figure 8 are for *Low Impact* logging. This involves using agricultural tractors with winches, and careful skid trail and felling direction planning in conjunction with stock and topographic maps. The *Normal* regime for PNG, with limited control and the use of heavier tracked vehicles, assumes 50% higher rates of damage than for the baseline function. The *High Impact* option doubles the damage associated with low impact felling, and would correspond to the use of D8 or D9 specification tracked vehicles, and complete indifference by the operators to questions of damage to the residual stand.

These options allow the sensitivity of results to assumptions about site, fire risk, and logging methods to be tested. For standard use of the model, the *Growth Index* should be 100%, and the other options set to *Normal*.

Viewing and modifying the species list

The *Species list* menu option displays the species list used by PINFORM. This gives the mnemonic code for the species, its MEP group, the growth model group, botanical and common names, the FIPS code number, and the user's management group allocated within PINFORM.

This worksheet is normally protected and cannot be edited. However, the *Protection* function under the *Maintenance* menu will switch off this protection temporarily, allowing any column to be edited. This facility requires password access, as changes to the species list will affect the way the model works.

The most common changes that may need to be made are to the *Group* number in the right hand column. This number is between 1 and 6, and corresponds to one of the management groups listed on the *Species groups* dialog discussed below. It can be modifed to assign species to a different group.

The species list can be printed using the *Print* menu function. It can also be copied in whole or part be selecting cells with the mouse or *Shift+arrow* keys, and then using *ctrl+C* to copy the selection to the Windows clipboard.

Species groups

The *Species groups* menu allows the names of species groups to be edited, their commercial priority to be changed, and the set of commercial groups to be defined. The dialog box appears as shown below.

22

Figure 17 Dialog to modify species groups
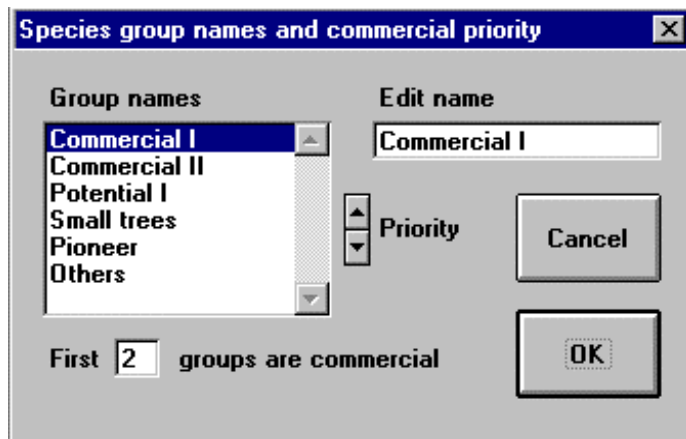
In this dialog, six group names will be shown, which correspond to the group codes one to six in the last column of the species list. The selected name will appear in the *Edit name* box. It can be edited here, and the list will be automatically be updated.

The order of groups from top down reflects their commercial priority. The spinner labelled *Priority* can be clicked to move a selected group up or down. This changes its commercial importance. The priorities influence how felling is performed, as the logging always takes all the higher priority species before the lower ones. If there are limits on volume or basal area to be harvested, then lower priority species, although commercial, may not be harvested. This is designed to reflect the realities of timber operations, in which higher valued species will normally be felled before the lower valued ones.

When priorities are changed, the groups in the species list will actually be renumbered automatically to reflect the new order.

Not all the groups are commercial. The box at the bottom designates which are considered commercial groups. Not more than 5 commercial groups can be specified; at least the last group must always be treated as non-commercial. Only commercial species will be harvested.

When a species occurs in the data which is not in the species list, it will always be treated as belonging to the sixth group.

Compiling an initial stand table The menu selection *Stand table* displays a table for the current inventory data file, showing tree numbers, basal area and volumes by species. The species are listed in order of their volume above 50 cm dbh. The highest volume species are listed first. The right hand column shows the percentage of volume above 50 cm dbh accounted for by the species. Two size classes

are shown: Trees 20-50 cm, and trees above 50 cm. All species are listed individually until a limit of 95% of the cumulative volume is reached. A summary line is given at the bottom for all species.

The format of this table is practically identical to the stand table produced by FIPS, and it can be directly compared. However, it should be noted that the volume equation used by PINFORM is the single-entry, diameter only, equation given on page 13, whereas FIPS uses both diameter and height. Furthermore, when FIPS data is converted to a PIN file, as discussed below, there will be small changes in the tree number and basal area figures as the individual tree measurements are merged into 1-cm classes. Hence the figures from FIPS and PINFORM, although very similar, will not be identical to the last decimal place.

The stand table is usually updated when a new file is assigned via the *Inventory* menu. In this case, when the stand table is viewed, a message appears requesting that the table should be updated. Clicking the *OK* button will allow this to be done.

If the inventory file has not apparently changed, then the stand table is not updated when it is viewed. However, the updating can be forced by double-clicking on the sheet with the mouse.

Converting FIPS data   The forest inventory system used by the Forest Authority at present is called FIPS. PINFORM has the facility to read and convert FIPS data files. There are three sub menus relating to this, found under the *FIPS files* menu. They are as follows:

Specification   Sets the file names and locations for the input and output files, and some parameters relating to the inventory plots.
Convert data   Starts the data conversion process.
Check data   Flags diameters that seem excessively large in the input data file and allows the file to be corrected and saved from Excel.

The *Specification* menu produces the dialog form shown in Figure 18. The input file name can be selected using a typical Windows file open dialog by pressing the *Browse* button, or it can be typed directly into the *Input path and file* field.   The FIPS file names will be .DBF files with a name starting FD, and with digits representing province, project and block numbers.

Figure 18 Specification dialog for FIPS data conversion

The ouput file name can be selected from the corresponding *Browse* button, which gives a typical Windows *Save As* dialog to set the disk, directory, and allow a file name to be selected or typed in. Alternatively, the full output file name and path can be typed in directly to the box. This is a file with a .PIN extension.

The project title must be typed in. This is saved as the first line of the .PIN file.

The inventory design for linear strip sampling with FIPS is standard, and the settings shown need not normally be changed unless circular plots or some other variant design have been used. The first box shows the smallest diameter measured on the main sample. The second shows the smallest diameter on the sub-sample. The third gives the ratio of sub-sample area over main-sample area.

For example, the normal FIPS system is to use a 20 m wide strip to measure all trees over 50 cm, and an inner strip of 10 m to measure all trees over 20 cm.

The final box with the Q-ratio for interpolation is designed to allow PINFORM to fill in the missing data that it needs between 20 and 10 cm. FIPS inventories normally only measure down to 20 cm. The interpolation is made by taking each tree occurring in the range 20-30 cm, deducting 10 cm from its diameter, multiplying its assumed stocking by the Q ratio given (eg. 1.5), and adding it to the output file. This gives trees in the 10-20 cm class whose species composition exactly reflects the 20-30 cm class, but which are 1.5 times more numerous.

The longer term projections of PINFORM are quite sensitive to the stocking in the 10-20 cm class. A Q-ratio of 1.5 seems appropriate.

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The FIPS conversion process has been tested with strip sample data as described above. It has not been tested with the circular plot design that has been used from time to time.

After the specification has been set and the dialog closed, the *Convert data* and *Check data* operations can be run. It is recommended that normally the check function is run first. This searches for diameters in excess of 200 cm. These usually represent typing errors for small tree diameters, or sometime mixing of diameter and species code data. The bad figures are flagged in red.

At the end, the FIPS file is left open in Excel. It can be scrolled through and edited. Double-clicking on the sheet saves it via a *Save As* dialog. Usually the original file name and directory should not be altered.

A programming bug associated with this process is that the PINFORM menus remain active and visible, but will not function whilst the FIPS file is open. Any attept to use any PINFORM function results in a system error message. The solution is to double-click on the sheet and close the FIPS file before attempting to access the PINFORM menu.

The *Convert data* function actually generates the output file designated in the specification dialog. Whilst this is in process, the FIPS file is open and scrolls through on the sheet. If a diameter is encountered over 200 cm, a warning appears. Clicking the *OK* button continues the conversion, including the aberrant diameter in the output file. The *Cancel* button halts the conversion.

The *Cancel* button at the time of writing however leaves the FIPS file open, and incapacitates the PINFORM menus. The *Ctrl-Tab* keys should be pressed re-display the last PINFORM graph or sheet, before any menu function will work[1].

Program control functions The *Control* menu gives access to a number of functions controlling program operation. These are as follows:

Run   This executes a simulation, as described on page 18.

Print   This allows whatever is currently displayed to be printed. A standard Windows printer control dialog appears, allowing various settings to be changed, including the printer itself. For tables, selected cells can be printed on their own, without printing all the data.

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[1] This problem has been fixed on version 1.24d. If you are using 1.24c, contact the author by email on D-ALDER@EUROBELL.CO.UK for an update.

Save   This allows the current state of PINFORM to be saved either with the original name (PINFORM.XLT) or under a new name, with a default .XLS extension.

Quit   Closes the program and returns control to Windows.

Front Cover   Displays the PINFORM front cover. The button marked » at the top left restarts the programme. This can be useful to clear some types of error.

Maintenance   These functions are inaccessible unless an *Access code* is entered. They allow for various operations of interest to the programmer.

Page headings This shows a dialog box that allows the top left, centre and bottom left headings to be set for all printed outputs. When executed, this function may take 30-60 seconds to update all worksheets in the model.

Zoom   This sizes graphics so that they properly fill the screen.

Errors and problems   This documentation relates to version 1.24c of the program. The last letter of the version number is usually updated as programming bugs are identified and fixed. However, as there are time constraints on the programmer's efforts, it is likely that version 1.24c will remain in use for some time.

Program errors of various kinds may occur whilst running PINFORM. Figure 19 below shows a typical example as it would be seen running the model under Excel 5. The user should normally select the *End* button in response to the error. Selecting either *Debug* or *Goto* results in exposure of the program code to the user, with possible further side effects arising from unintended modes of operation or alterations to the program.
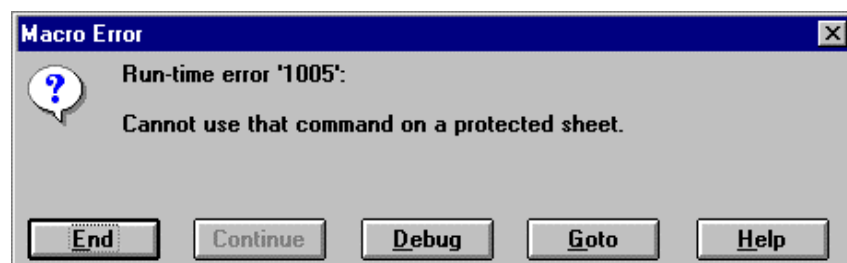

Figure 19 Macro error dialog in Excel 5

After selecting *End*, the PINFORM menu should still be visible. Try to identify the source of the error from one the following possibilities:

1. *Protected sheet errors*: Working with PINFORM via Excel, or accessing sheets via the sheet tabs rather than the menus, can

result in the sheet protection being out of phase with the logic of the program. To correct this, view each of the 6 graphs on the *Model outputs* menu in turn. This will reset protection to its normal operation and clear this error. This error may occur when PINFORM is first installed. It may also happen if execution is interrupted with the *Esc* key during the initialization phase of a simulation.

2. *File and device errors*: Messages indicating *Device unavailable, File not found* etc. may occur when PINFORM is first installed and run without selecting an inventory file. They may also arise on network systems when a network drive is not online. The error can be cleared by using the *Inventory* option to set a file. This will always bring up a file dialog box if a specified device or directory does not exist on your system.

3. *Models and coefficients*: Check that the screens shown under the *Models General* or *Models Tree Growth* menus correspond to those shown in Figure 9 and Table 1. PINFORM dos not check that the user has supplied sensible values for these coefficients, so experimental changes may have drastic side effects.

4. *Menu does not work during FIPS conversion:* As noted on page 26, the PINFORM menus are inoperative while a FIPS file is visible on the screen. Try one of the following to resume normal operation:
   - *Double-click on the sheet*. This may bring up a dialog box allowing it to be saved or closed.
   - *Use Ctrl+Tab* to switch to the last used sheet from PINFORM (usually the front cover or a graph). The menus will then operate normally.

5. *Errors following species group changes:* Species group codes on the species list can be edited, but must be in the range 1-6. Other values may cause messages such as *Division by zero*, *Array bounds*, etc.

6. *Errors relating to objects, methods, or properties*: Error messages such as *Object not found* or *.... does not have a .... method* may occur when something such as a data series, axis, title, etc. has been deleted from a graph by the user. In normal use in PINFORM, graphics sheets are protected to avoid this problem. However, the determined user may by-pass this protection by accident or by design. Deleting anything from a graphic sheet will cause problems for the program that can only be resolved by reverting to the original distribution copy of PINFORM.

If all else fails, quit from the program without saving by using the *Alt+F4* key. Respond *No* when invited to save changes.

Restart using either the previous copy of PINFORM, or the distribution copy in the compressed file PIN124C.EXE.

If the program is not reponding at all, use *Ctrl+Alt+Del* to force the program to shut down.

If troubled by persistent errors or operating problems, contact the author at D-ALDER@EUROBELL.CO.UK.

Introduction PINFORM has been developed on the basis of growth data measured over a period of some two to five years. It is applied, as the section on Management Implications will show, to consider questions of forest management over periods of fifty years or more. How reliable can it be when used in this way?

The approach taken to testing the model is to consider how well the model reflects what is generally known about natural forest structure, behaviour and growth. It is considered that the model should conform to accepted knowledge if it is to be considered reasonably reliable. At the same time the structure of the model should not force such conformity. For example, it should produce realistic Q-ratios between successive diameter classes without there being any internal control or mechanism that forces specific Q values. In other words, the complex diagnostic features of model validity should as far as possible be emergent properties arising from the interaction of simple empirical functions.

The testing process occurred in parallel with the model development and conditioned it. However, it was interesting that complex approaches, and the introduction of elaborate assumptions, generally resulted in a deterioration of the behaviour of the model. The rather simple structure that exists proved to be more successful and reliable than more complex hypotheses.

Figure 20 Test simulation of unlogged forest over 200 years

Figure 1 : Dynamic analysis of basal area
Agrim Extension, Western Province (42,796 ha, 1989)

30
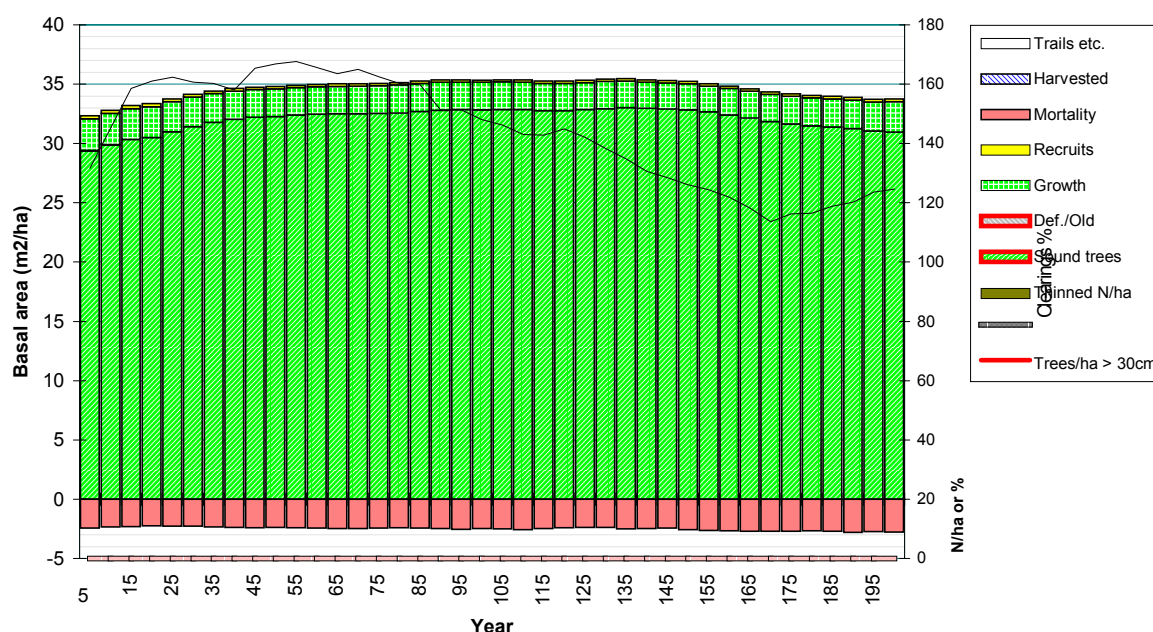
The first test considers the behaviour of the model under conditions of long-term forest growth without harvesting.

Figure 20 above shows the result with the basal area dynamics graph reproduced from PINFORM. The initial stand was from inventory data in a previously unlogged forest. The stand has a starting basal area of about 30 m²/ha, which fluctuates gently over time up to about 33 m²/ha before falling again to near the starting state. Numbers of trees above 30 cm dbh (red line) fluctuate more strongly on a slow cycle with a periodicity of about 160 years. Numbers vary between an initial 130/ha to a maximum of 170, and a minimum of about 110. After 200 years they are close to the initial value.

Basal area increment and mortality are in a close balance, but both are quite dynamic. Larger trees are actively dying, and recruitment and growth are continuously taking place.

This conforms to what is known of undisturbed tropical forest dynamics. Recruitment and growth remain active processes, whilst overall basal areas tend to be relatively constant at somewhere between 30 and 40 m²/ha, sometimes with periods of decline.

Figure 21 Basal area recovery of a heavily logged stand

Figure 1 : Dynamic analysis of basal area
ITTO plots at Kapuluk, West New Britain, September1993
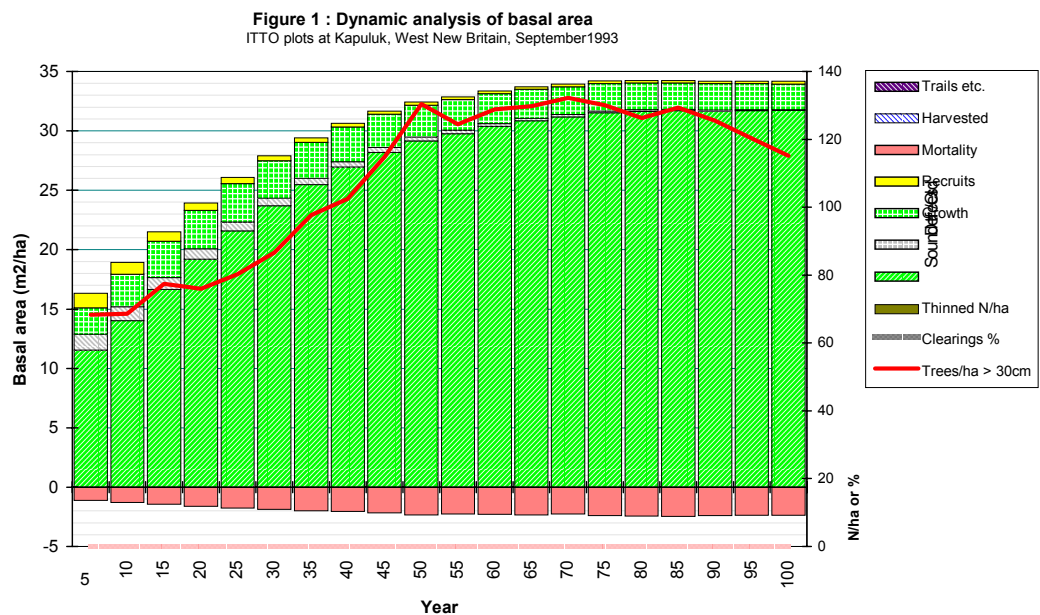
Figure 21 shows the recovery of one of the more heavily logged group of ITTO plots, at Kapuluk in West New Britain. From a basal area of about 12 m²/ha in 1993, the stand recovers to a basal area of about 33 m²/ha over some 75 years. Tree numbers similarly rise from about 70/ha over 30 cm dbh after logging to some 130 after 70 years.

What is very striking about this test is the similarity of the equilibrium results to those seen from the long-term projections

of the unlogged forest at Agrim. Both stands have equilibrium
stocks of about 33 m²/ha and tree numbers over 30 cm of about
120-130/ha. It should be emphasised again that there is nothing
in the model that directly constrains either statistic to these
limits.

Tree numbers by size classes

The diagram of tree numbers by 20-cm size classes is shown in
Figure 22 for the Kapuluk plots used in the previous example.
This is the initial condition of the stand, immediately after
logging, and before any applied growth projection by the
simulator.

Figure 3 : Stocking by size classes
ITTO plots at Kapuluk, West New Britain, September1993   Year 0

Figure 22 Initial diameter class distribution for logged plots at Kapuluk

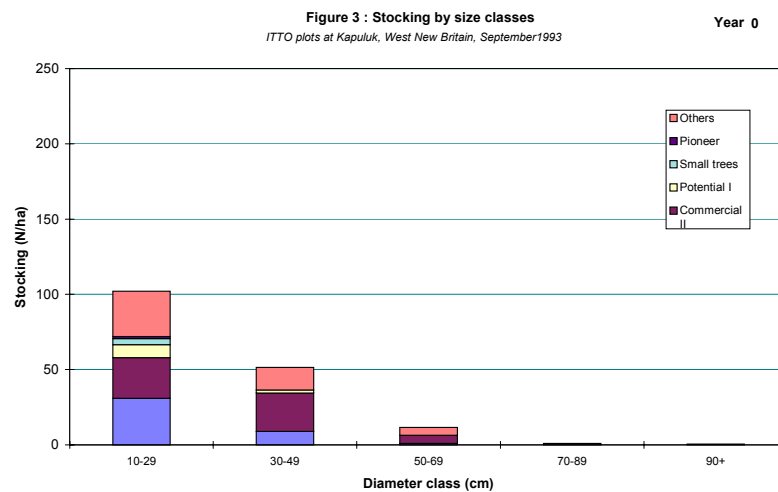This shows the very low stocking of the stand, with a complete
absence of trees over 70 cm dbh. After 10 years, the model
projects considerable regeneration and recruitment into the
lowest diameter class (10-30 cm). This stage is shown in

Figure 3 : Stocking by size classes
ITTO plots at Kapuluk, West New Britain, September1993   Year 10

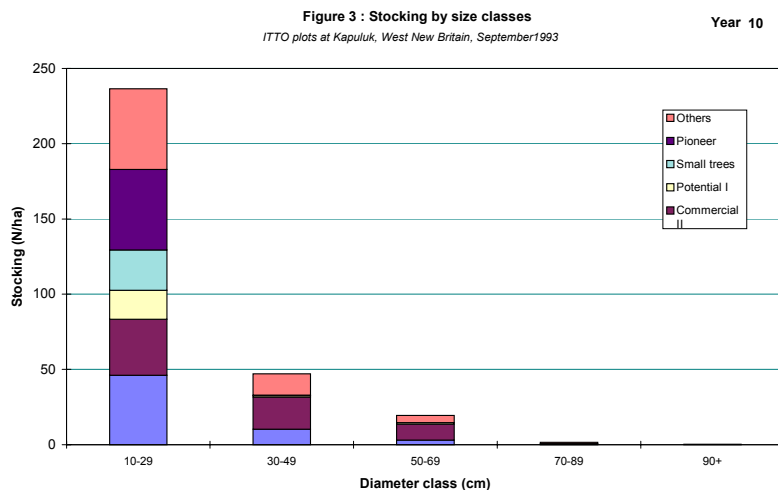*Figure 23 Simulated diameter distribution after 10 years on Kapuluk plots*

Figure 23. A substantial part of this projected recruitment is
made up of pioneer species, which can be seen as the second
colour from the top in the left-hand bar of Figure 23. Further
projection shows total numbers of trees continuing to increase
until year 30, after which it declines and the appearance of the

stand table becomes more normal. The Q-ratios between the 20-cm diameter classes can be plotted over time, as shown in
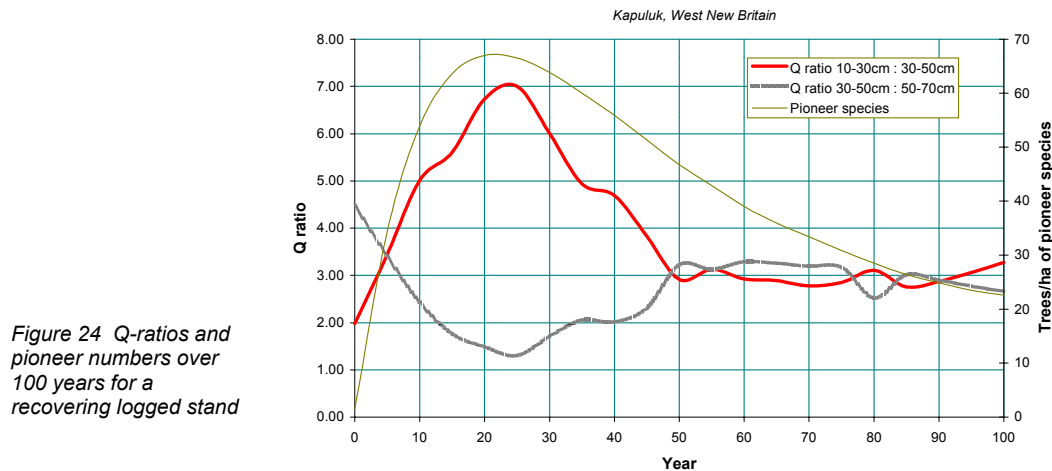

Kapuluk, West New Britain

Figure 24. In this, the Q-ratio between the 10-30 cm and 30-50 cm classes continues to increase until the 25th year after logging, after which it declines. Conversely, the ratio between the larger classes drops.   Both return to an equilibrium Q-ratio of about 3. The numbers of pioneers rises sharply, and then drops gradually as they cease to occur as recruits and gradually die out.

This behaviour appears to reflect quite well what may be expected to happen. Relatively constant Q-ratios between classes are a feature of forests towards the equilbrium state, as recruitment, growth and mortality achieve a balance. Constant Q-ratios are a direct mathematical consequence of relatively fixed growth and mortality rates, and PINFORM will necessarily tend in that direction because of the simple functions used. The value of 3 that appears to emerge is quite typical for natural tropical forests, and is a fair prediction for the model given that its input data is all based on heavily disturbed stands.

The rapid increase and subsequent decline in the pioneer population is also as may be expected. It is probable that the rate of decline is too slow. This aspect of the model may be improved through a more careful definition of species groups, as well as additional data.

Basal areas by size class The diagram of basal areas by size classes is another way of examining stand structure that is generally more informative than the tree numbers over diameter graph. Figure 25 shows this view of structure for the two series of plots previously discussed. The top pair of graphs show the data from the Agrim inventory as measured, on the left, and after 100 years of undisturbed growth, on the right.

Figure 2 : Basal area by diameter classes
Agrim Extension, Western Province (42,796 ha, 1989)
Year 0

Figure 2 : Basal area by diameter classes
Agrim Extension, Western Province (42,796 ha, 1989)
Year 100

Figure 2 : Basal area by diameter classes
ITTO plots at Kapuluk, West New Britain, September1993
Year 0

Figure 2 : Basal area by diameter classes
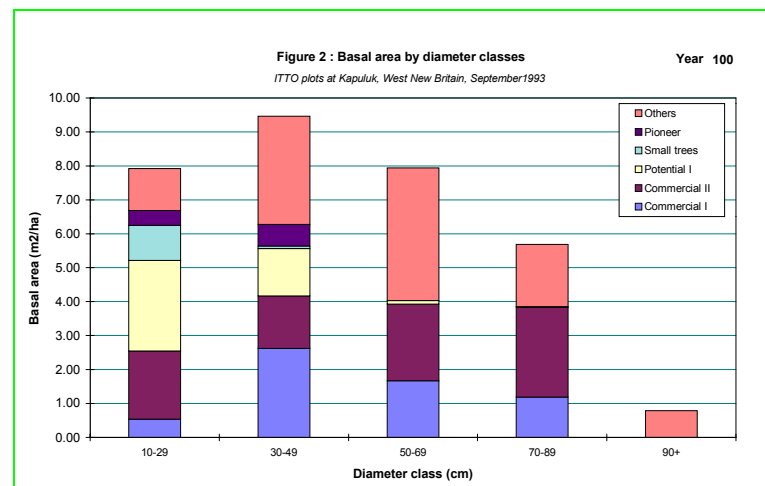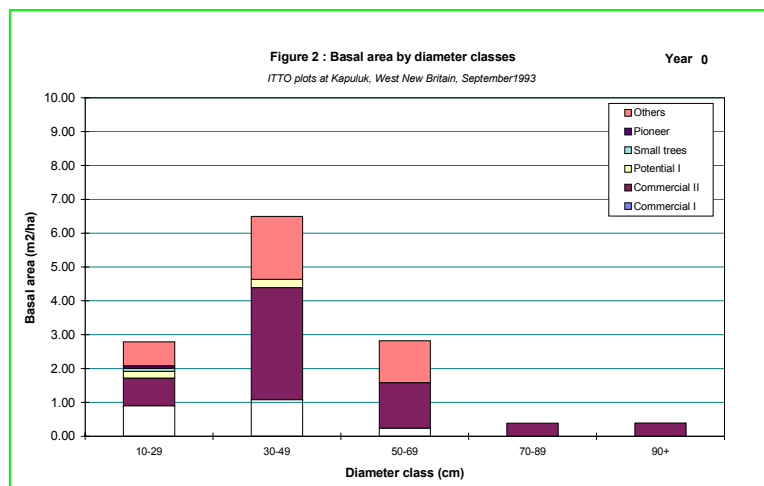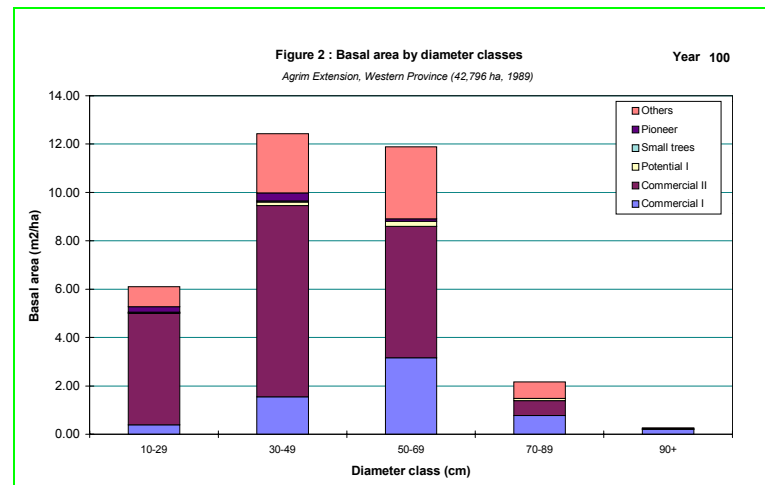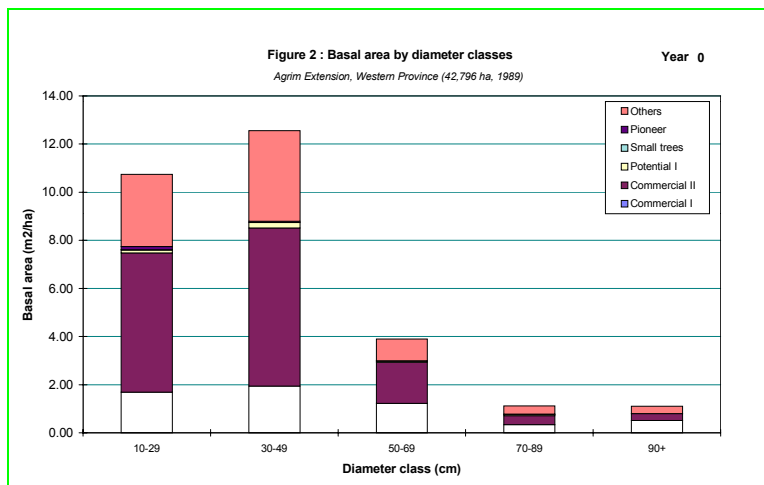*ITTO plots at Kapuluk, West New Britain, September1993*
Year 100

Figure 25 Stand structure diagrams for unlogged and logged stands over 100 years

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The bottom pair of graphs are for the ITTO plots at Kapuluk, which were heavily logged immediately prior to plot establishment.

A common feature of this type of graph is the relatively even distribution of basal area between the lower size classes. As the stand develops, the higher classes tend to increase in basal area until they are of similar magnitude to the lower ones. The initial graph for Agrim Extension (top left, Figure 25) shows similar basal areas in the two lower classes. After 100 years projected growth, the 50-70 cm class comes up to the same level, whilst the first class is somewhat lower due to a decline in regeneration on this fully stocked stand.

The bottom right graph, for Kapuluk immediately after logging, shows considerably depleted stocking. Substantial regeneration occurs, as noted previously, over the next 20 years. At the end of the 100 year projection period, this has resulted in a relatively even distribution of basal areas between classes.

These graphs demonstrate two features of the models performance:

- After a period of growth, basal area is neither excessively concentrated nor excessively depleted in any one size class.

- The classes tend to fill from the left in a relatively even manner, as is commonly observed in natural forest inventory data.

As with the tree numbers graphs, these analyses tend to create confidence that the model does not produce unrealistic stand structures, either in modelling undisturbed forest, or in the recovery of heavily logged stands.

Volume growth Comparing volume statistics between forests of different regions of the world is less certain than basal area because of the variations in definition and volume equations used. The volume equations in PNG appear to be toward the lower end of the spectrum the author has examined, and this should be borne in mind when comparing volumes per ha with those from other areas.

Figure 26 shows projected volume growth on two stands and for two lower dbh limits. The Agrim stands were unlogged, and show relatively static projected bole volumes over 20 cm dbh over a 200 year period of about 200 m3/ha. Over the same period, volume above 50 cm dbh rises slowly, appearing to level off at about 150 m3/ha.

Figure 6 : Comparison of simulation runs

Legend:
- Agrim, 20cm+
- Agrim, 50cm+
- Kapuluk, 20 cm+
- Kapuluk, 50cm+

Figure 26   Volume growth on unlogged and recovering logged stands
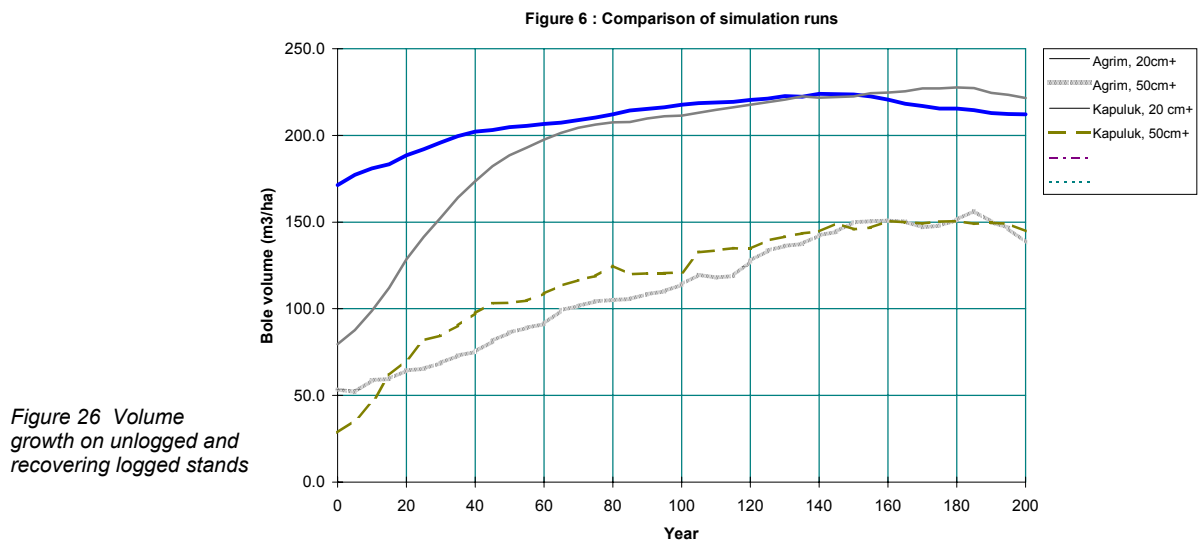
The Kapuluk stands, as previously discussed, were heavily logged immediately prior to measurement (year 0). The bole volume above 20 cm dbh recovers rapidly from 80 to 190 m³/ha over a 50 year period (2.2 m³/ha/yr). Volume over 50 cm dbh grows from 30 to 105 m³/ha over the same period (1.5 m³/ha/yr). These figures are consistent with net volume growth on logged tropical forest elsewhere, and represent reasonable projections.

The gradually increasing volumes on the old growth stands at Agrim show mean annual increments over the first 50 year period of 0.66 m³/ha/yr, whether measured to either 20 or 50 cm dbh. This indicates that the volume growth is occurring through the accretion of larger trees, whilst volumes in the size range 20-50 cm do not change very much. In fact the common occurrence of light-demanding species such *Pometia pinnata* in these forests demonstrates that they are probably cyclically disturbed by major catastrophes such as fire. As such, the Agrim forest is probably not completely at equilibrium, and this slow growth in volume is reasonable.

For both the disturbed and undisturbed forest, volume production at all sizes levels off completely after 150 years, and standing volumes may decline gently or fluctuate in a slow cycle over long periods.

Simulation of felling   A simulated felling on the old growth Agrim forest data can be compared with some aspects of logged Kapuluk plots to see how similar the actual and projected fellings are.

The result of this comparison is shown in Figure 27. The simulated felling on the Agrim area has been adjusted to remove 15 m3/ha, giving a stand with post-logging stock equivalent to the logged Kapuluk plots.

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Figure 6 : Comparison of simulation runs
ITTO plots at Kapuluk, West New Britain, September1993

Figure 27 Projected recovery of stands after actual and simulated felling
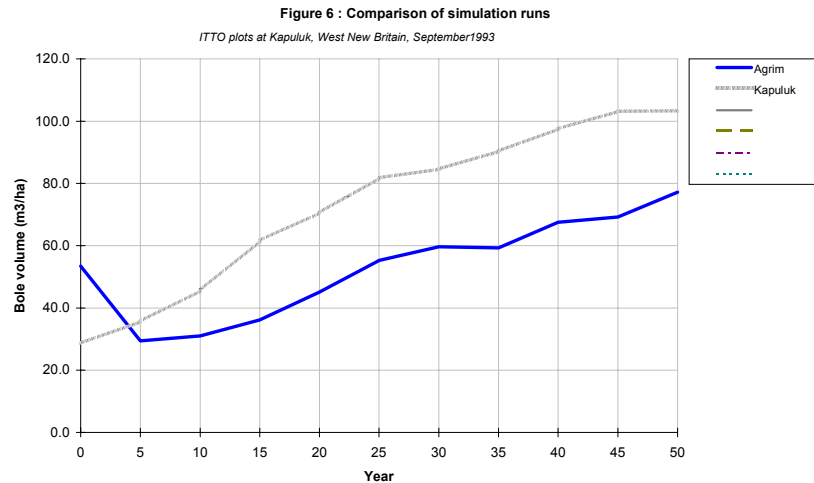
The stands show roughly similar recovery paths, although there are differences between them in species composition. The Kapuluk plot shows a steeper recovery curve, indicating a higher accrual of volume over 50 cm dbh. However, this does not necessarily mean faster tree increments; it can simply be a consequence of a greater stock of advance growth.

Figure 2 : Basal area by diameter classes   **Year 15**
Agrim Extension, Western Province (42,796 ha, 1989)

Figure 28 Stand structure 10 years after actual and simulated logging

Figure 2 : Basal area by diameter classes   **Year 10**
ITTO plots at Kapuluk, West New Britain, September1993
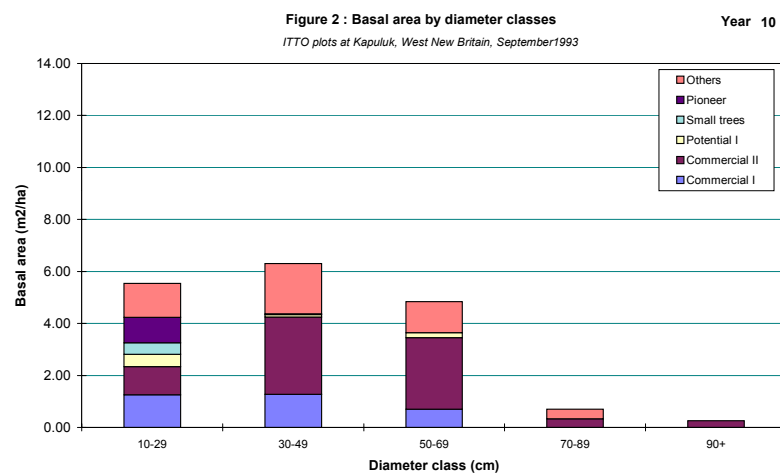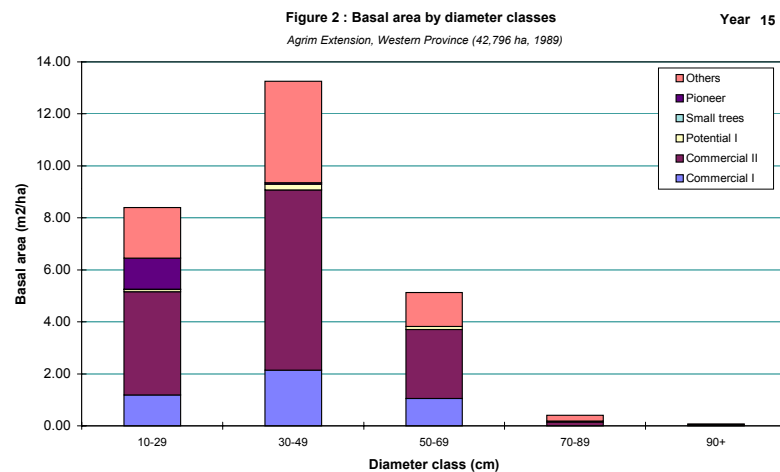
For the purposes of testing simulated felling, these comparisons are adequate. The composition of species removed in the actual

and simulated logging appear similar. Both concentrate harvesting on the most valuable commercial species and leave the less valuable ones. Both have a similar impact on the diameter distribution.

Tests with alternative increment models

Various different types of function for growth, mortality and recuitment have been tested during the course of model development (Alder, 1997d). For example, it is observable that crown position has a correlation with increment. However, including crown position in the model involved the problem of deciding how tree crown positions should be allocated. After various trials, it was found that simple assumptions did not work well, and a crown position increment model was actually less effective than the basal area multiplier for growth shown in Figure 3.

However, it is likely that as further measurements are made, the basic models will be improved. One of the most sensitive areas relates to recruitment, which can strongly condition the stocking of the stand at the next felling cycle. For most of the existing plots, the period since felling is too short to see the full post-logging reaction.

Clearings and fire interactions

PINFORM provides levels of intensity for the fire regime, and for variations in the logging method. It also shows the percentage area of the forest which appear to be clearings. It should be emphasised that these aspects of the model are speculative and are designed to meet two needs:

- Sensitivity analysis, to determine the importance of fire and logging controls to forest yield.
- To emphasise the fact that PNG lowland forests are ecologically fragile when mis-managed, and can be transformed into non-forest plagioclimaxes. These are most commonly grasslands, but also may be Giant Ginger, climber tangles, etc.

Figure 29 Collapse of forest ecosystem due to over-logging and fire

Figure 1 : Dynamic analysis of basal area
Agrim Extension, Western Province (42,796 ha, 1989)

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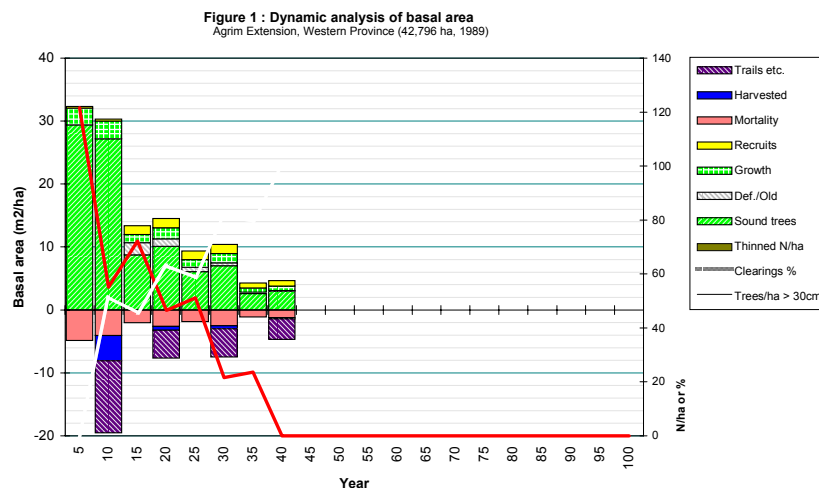
The coefficients used to control the effects of fire and the formation of clearings were adjusted by trial and error. Experimentation will show that with the normal fire regime (occasional severe fires), the forest will always recover. However, a combination of frequent logging and a frequent fire regime can cause the ecosystem to collapse to a plagioclimax. The severe fire regime, which corresponds to annual burning of the understorey, always leads ultimately to a collapse of the forest ecosystem as grasses invade and inhibit regeneration.

Figure 29 shows an example of such a regime. The unlogged Agrim forest was used as a basis, with a 10-year felling cycle down to 50 cm diameter, and the *Frequent* fire regime option (see page 21). Some 30 years after the start of logging, the forest cover has disappeared completely.

This is clearly an important area for further research in PNG. Plagioclimax communities occur widely, especially grasslands. Recovery on the logged plots that the author has visited is clearly slow in the gaps and clearings, with grasses becoming established. The ITTO PSPs will allow these processes of formation and recovery of clearings to be monitored over time, especially with some improvements in the site recording methods.

Evaluation of model performance The model appears to reflect well the structural and dynamic features of natural tropical forests as they may be described qualitatively. It does this both with undisturbed and heavily logged stands. The quantitative parameters such as maximum basal area, Q-ratios, basal areas by diameter classes, and volume production and mean annual increment also appear to agree well with general expectations.

Comparability of long-term projections with the structure of old growth stands is good. Generally, the model appears able to fill a useful niche in suggesting how the forest may respond dynamically to management.

However, there are still considerable gaps and uncertainties. Further mathematical analysis of how whole stand increment depends on numbers of trees in different size classes will improve understanding. Recruitment behaviour in particular needs further information, as it is quite a sensitive aspect of the model in terms of increment rates and future species composition. Site effects need to be studied in much more detail.

Felling cycle and logging intensity

During the course of both the testing of PINFORM, and the workshop that has been given on its use, numerous trials have been made based on different plots and felling regimes. These lead to two related conclusions:

- A simple felling cycle of 35 years with a 50 cm diameter limit results in an initial felling that is excessively heavy. Subsequent cycles have much lower yields, and the initial post-logging period shows substantial stand damage and risk of initiating a cycle of stand degradation. See Figure 30 and Figure 31.

Figure 1 : Dynamic analysis of basal area
ITTO plots at Adeviong, West New Britain, August1995

Figure 30 A 35-year cycle and 50 cm limit results in excessively heavy logging

Figure 5 : Yields per cutting cycle
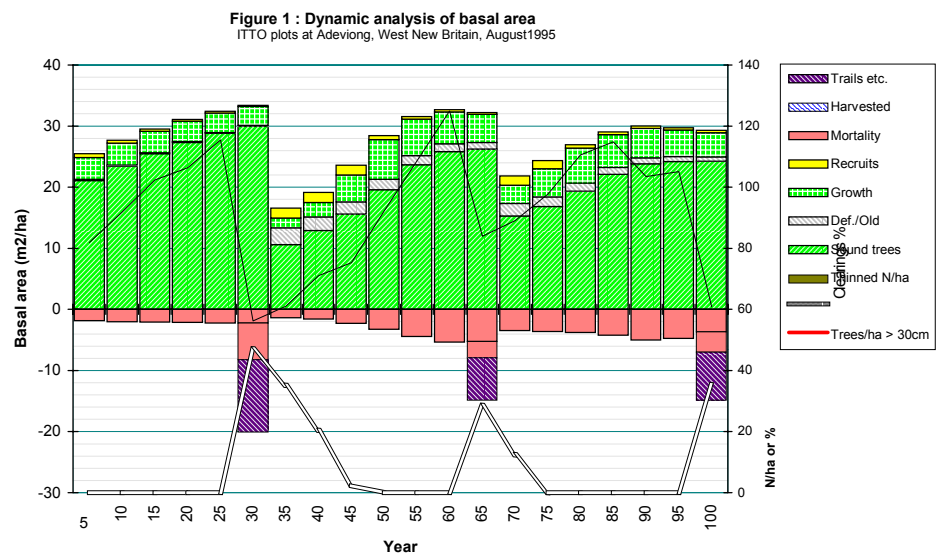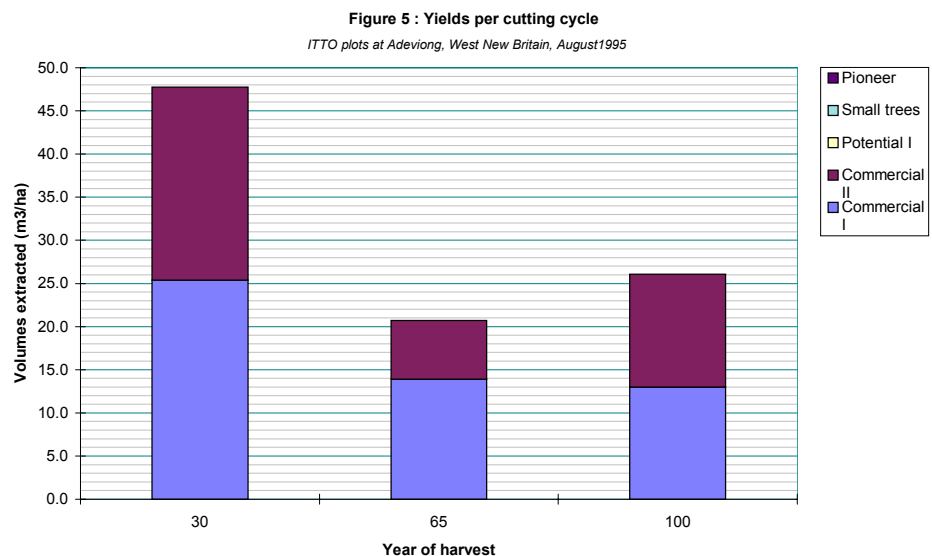*ITTO plots at Adeviong, West New Britain, August1995*

Figure 31 With felling to a 50 cm limit, there is an initial heavy felling, followed by subsequent yields near to 20 m3/ha/cycle

- Stronger control on felling intensity allows much more stable and sustainable forest management. This control can be achieved through a 65-cm minimum dbh on a 35 year cycle (Figure 32), or by limiting the volume cut to less than 0.5 m³/ha/yr. With a 20-year cycle, controlling the harvest at 10 m³/ha gives similar results to the 35 year cycle with a yield of 18 m³/ha. In both cases this is 0.5 m³/ha/yr (Figure 33).

Figure 1 : Dynamic analysis of basal area
ITTO plots at Adeviong, West New Britain, August1995

Figure 32 A 65-cm minimum dbh and 35 year cycle gives a stable, well structured stand at sustained yield

Figure 6 : Comparison of simulation runs
ITTO plots at Adeviong, West New Britain, August1995
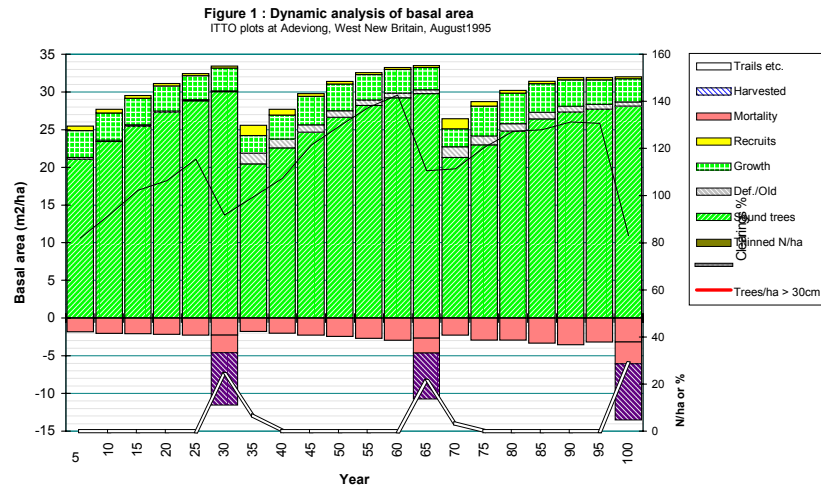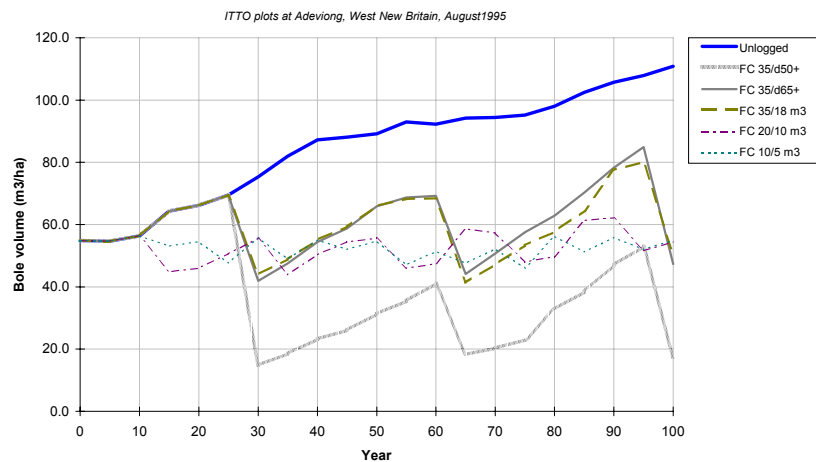
Figure 33 Regimes with 65 cm dbh limit or AAC of 0.4 m3/ha/yr are sustainable

Figure 33 also shows a regime with a 10-year felling cycle and allowable cut of 5 m³/ha. This is equally sustainable.

Site sensitivity   The above results are obtained with a growth index of 100%, or the average for all the ITTO plots. The sustainable AAC, or maximum annual allowable cut, depends directly on the growth index, but again appears relatively independent of felling cycle. Figure 34 shows how this is done with PINFORM. A basic 20-year felling cycle is used, and run with growth indices 80%, 100%, and 120%. By trial and error, the allowable cut is adjusted so that the standing volume above 50 cm dbh remains relatively constant over time immediately before each felling. The AAC is the periodic allowable cut divided by the felling cycle.

Figure 6 : Comparison of simulation runs

ITTO plots at Adeviong, West New Britain, August1995

Figure 34 AAC adjusted for 3 growth indices to give sustainable yields on a 20-year felling cycle
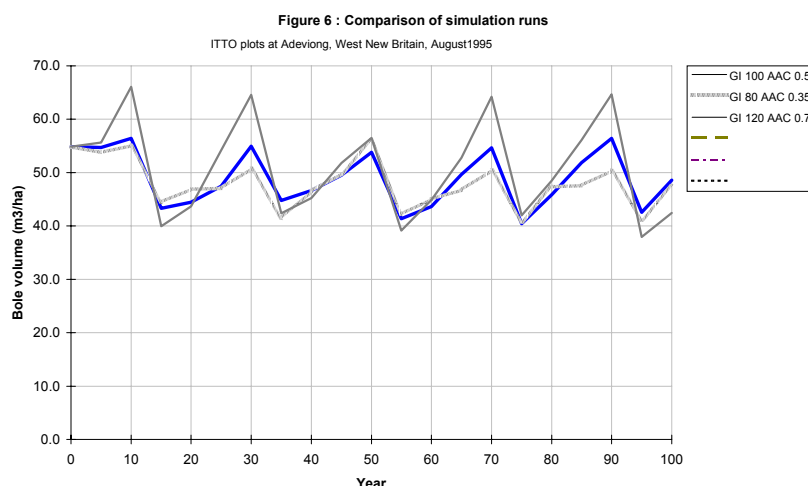
The AACs corresponding to the growth indices obtained in this way have a linear relation, as shown in the table.

Table 2 Growth index and AAC

Growth index	AAC m^3/ha/yr	Cut on 20-yr cycle, m^3/ha	Cut on 35-yr cycle, m^3/ha
80	0.35	7	12
100	0.55	11	19
120	0.75	15	26

It should be noted that this exercise has been carried out for only one group of rather typical plots at Adeviong, West New Britain. This is dominated by the species *Homalium spp.*, *Ficus spp.*, *Pometia pinnata, Canarium spp., Dysoxylum spp.* and *Syzygium spp.*, and was chosen as being very typical of the forests types found among the ITTO plots.

The site sensitivity of AAC emphasises the importance of identifying environmental correlates for the Growth Index.

Sensitivity to initial conditions Figure 35 shows the application of an AAC of 0.5 m^3/ha/yr to six different localities. These represent an arbitrary mixture of initial stand conditions, although all had been logged in the 5-year period prior to the start of the simulation. In all cases, the projections are sustainable at this level if a growth index of 100% is assumed.

This indicates that the AAC is not especially sensitive to the initial condition of the stand. However, it does appear that stands with basal areas below 25 m^2/ha should be allowed a respite to recover to at least that stocking before being scheduled for logging.

Figure 6 : Comparison of simulation runs

Figure 35 AAC of 0.5 m³/ha/yr applied to 6 different stands on a 20-year felling cycle
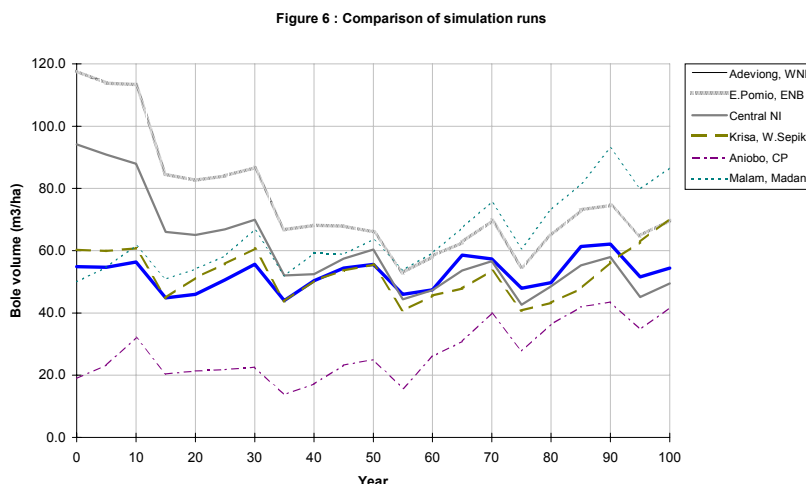
Sensitivity to logging damage

PINFORM provides three levels of logging damage. There is a base-line *Low Impact* model, corresponding to the use of tractors or smaller rubber-tyred skidders. An intermediate *Normal* model gives 50% higher levels of area and tree damage, and is assumed to be equivalent to typical uncontrolled logging in PNG. A *High Impact* function, perhaps equivalent to the careless use of D8 or D9-type tracked vehicles, provides for double the impact of the baseline functions. For all the examples above, the *Normal* function has been used. They are thus not predicated on especially careful logging technique.

Figure 36 compares the influence of these three levels of logging, using the rather typical Adeviong plots as an example.

Figure 6 : Comparison of simulation runs

ITTO plots at Adeviong, West New Britain, August1995

Figure 36 Effect of logging method on volumes over 50 cm dbh, with a 20-year cycle and AAC of 0.5 m3/ha/yr
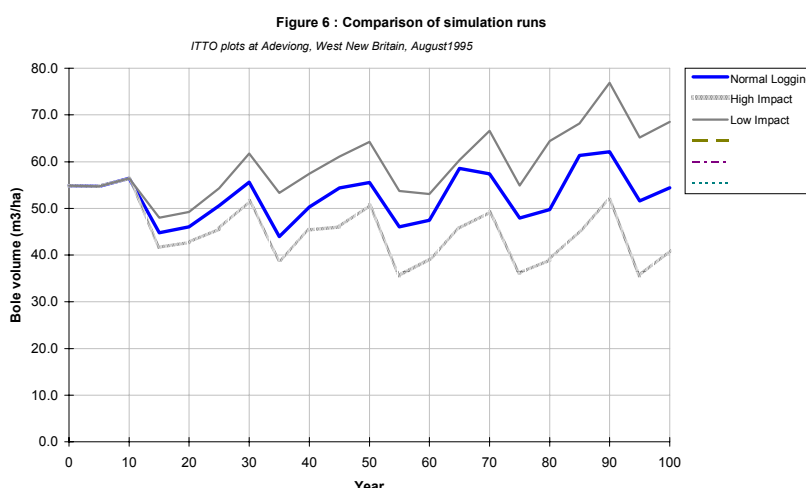
It is clear that the higher impact logging can only be sustained by reducing the AAC, whilst conversely, adoption of a low-impact method would allow a slightly higher AAC.

There is a need to establish logging damage functions appropriate for PNG, and a research proposal is being prepared for presentation to ITTO regarding this. However, comparisons

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with available global data suggest that the *Normal* function is very unlikely to be an underestimate of damage levels, and the influence of logging damage on the PINFORM projections tends therefore to be conservative, in the sense that damage is likely to be over-estimated.

The influence of fire on sustainability

Both yields and sustainability are very sensitive to the fire regime. PINFORM allows three levels of fire impact to be compared. The *Normal* regime (see page 21) imposes no special factors on the basic growth functions, which operate directly as captured from the ITTO plots. It will be noted that this includes only measurements made before the onset of the 1997-98 El Niño season and its associated severe fires and drought.

Figure 1 : Dynamic analysis of basal area
ITTO plots at Adeviong, West New Britain, August 1995

Figure 37 Frequent fires result in a gradual decline in forest stock when managed with an AAC of 0.5 m3/ha/yr
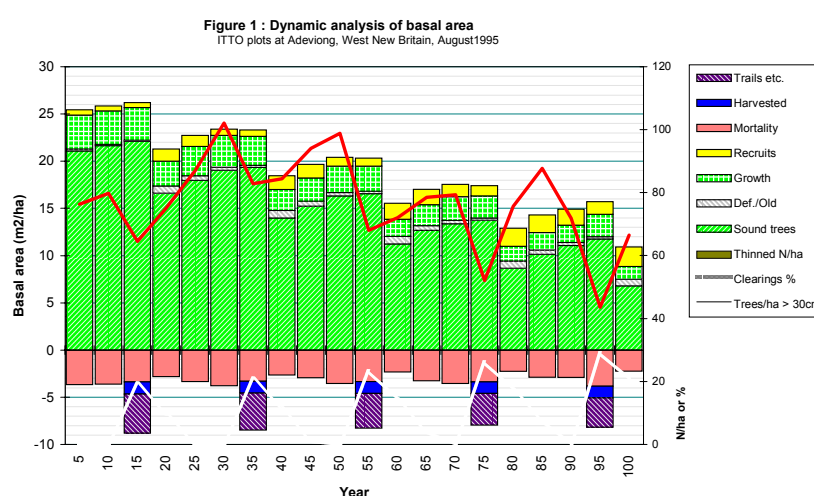
The *Frequent* regime would be associated with regular fires of moderate intensity, at least once every 5 years, and assumes higher mortality, lower recruitment, and lower recovery rates for clearings back to forest. This fire regime, applied to the Adeviong plots managed on a 20-year felling cycle and AAC of 0.5 m³/ha/yr, results in a clearly non-sustainable yield (Figure 37).

The modelling of fire effects in PINFORM is conjectural at present. However, it is clear that yields and sustainability are very sensitive to processes that impede recruitment. Because fire tends to selectively kill seedlings, and also encourages grasses which are antagonistic to tree regeneration, it has a very severe impact when it occurs frequently and at moderate intensities. Occasional hot fires, which are a normal part of the ecology of many tropical forests, have a different effect. They encourage regeneration of key pioneer species[1], but do not occur frequently enough to destroy the understorey and permit grass invasion.

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[1]These include important economic species such as *Swietenia* Mahogany in the Americas, Iroko (*Milicia excelsa*) in West Africa and many Dipterocarps including *Anisoptera thurifera* in PNG.

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Of course, hot fires also devastate the overstorey trees, and can cause large commercial losses.

The interaction of fire and logging is also critical. Logging creates clearings where grasses can become established, and may be a key factor in encouraging savannization. The presence of clearings may in itself transform the fire regime from one of periodic hot fires, to annual understorey burning. This will then catastrophically transform the forest to grassland. These dynamics need to be explored in PNG through further research, and incorporated in future versions of the model. The existing model has the program logic for this, but lacks calibrated functions.

Summary of forest management implications
There is no indication from the model that felling cycle is a critical parameter of forest management. The model shows that stands can be managed on cycles of 20 years, or even perhaps shorter periods.

The critical factor is the regulation of felling intensity. This needs to be kept to fairly low levels in order to avoid excessive collateral damage during logging.

For the average conditions which exist in PNG, *enforcement* of a *maximum* annual allowable cut of 0.5 m^3/ha/yr would result in sustainable management. On a 20 year cycle, this implies limiting felling to a maximum of 10 m^3/ha. On a 35 year cycle, it is equivalent to a maximum of 17.5 m^3/ha.

An alternative to the use of AAC is to raise diameter limits to a minimum of 65 cm dbh. This gives a similar result.

In either case, the critical issues are the method of monitoring and enforcement. Merely promulgating a minimum diameter limit or AAC from a desk is meaningless. Effective and realistic methods for prescribing, monitoring and enforcing felling controls require extensive discussion and field testing, and cannot be considered in this report.

The appropriate AAC for sustainable management is relatively insensitive to stand structure, but is sensitive to site (growth index), logging method, and especially, to fire regime. More research is needed into site factors and fire regimes in the lowland forest areas of PNG if the model is to be applied in a fully effective manner. There is also a need to calibrate the logging damage functions with a suitably designed trial.

Review   In this report, the design, growth functions, operation, testing
and implications of the PINFORM model have been presented.
The model is a cohort model, based on simple average growth
and mortality rates for functional groups of species. The groups
are derived statistically for species of similar growth rate and
maximum size. Increment is modified by a stand density
multiplier derived from basal area, and a growth index derived
from residual analysis for groups of plots. Mortality rates differ
between sound and defective trees in each species group.
Recruitment depends on stand density 5 years earlier, and varies
in species composition depending on the degree of disturbance.
These functions are empirically derived from the 72 ITTO
permanent sample plots whose establishment and measurement
have formed the core activity of the project since 1992.

The section on program operation has explained how to use the
model. It is a Windows program, operating with Microsoft
Excel, version 5 or higher. The user interface is driven by pull
down menus and dialog boxes in the usual Windows style. The
outputs from the model comprise graphs or tables, and can be
readily pasted into other Windows applications for report
writing. The model can work with data prepared for the FIPS
inventory program used by the PNG Forest Authority. It is also
provided with some 30 prepared files based on the initial
measurements of the ITTO PSPs, which can be used to explore
some of the varieties of lowland forest behaviour under
management.

Tests on the model show that it performs well in general terms,
and shows the main features of mixed tropical forest structure
and dynamics. The forecast production levels are within
expected limits.

The report has explored the models implications with respect to
felling cycle, yields, site effects, logging methods, and fire
impact.

Future developments   Use of the PINFORM model should provide some thought-
provoking insights into the best way to manage PNG's lowland
tropical forests. It will be improved and modified as further
data becomes available, to become a more reliable tool for forest
management.

In its present form it is a single-stand simulator. A future
evolution that can be envisaged is to develop a concession
management model that can analyse and project the spatial
characteristics of a set of inventory data as a multitude of stands,
whilst seeking to satisfy constraints such as the use of coupes of
equal annual volume.

PINFORM does not include in its present form any module to take account of options for planting or re-stocking. In a follow-on project, this could be addressed, in combination with more detailed studies of the natural restocking that is occurring on landings and other cleared areas on the existing plots. The model will then be able to show the extent to which artificial re-stocking can influence stand development and yield.

The ITTO project will continue until the end of 1998, acquiring a final year's measurements, and tidying the database so that it can be offered as a resource to research workers in PNG. The various analytical programs written by the author should be of major assistance in this area. There will hopefully be a follow-on project, that will allow the PSPs established so far to be maintained for a further 5 years. Preliminary proposals for such a project stress the need to do more work on site evaluation, fire effects, and logging damage. There is also a need for the development of new volume equations of known origin and sampling characteristics.

Implications for forest management PINFORM itself shows that uncontrolled fellings on a 35 year cycle with a 50 cm dbh limit are excessively destructive in their impact, and give yields that are not strictly sustainable. The principle problem is the intensity of felling that results when there is no method of regulating the cut.

Various options exist and need to be discussed on how such regulation can be formulated, monitored, and enforced. It appears from the simulations that with such a regime, a shorter felling cycle is entirely feasible and safe. This would have significant economic, social, and political advantages. The model suggests that an Annual Allowable Cut of 0. 5 m^3/ha/yr overall should represent the upper permitted limit of felling, although this figure is site sensitive. With a 20-year cycle, this implies cutting 10 m^3/ha on each felling coupe. In each year, 1/20th of the concession area would be felled. A low cost but viable monitoring system would use satellite imagery to track felling areas (combined as necessary with aircraft or ground inspections), and log measurement returns to control volumes extracted. Fines or more serious penalties could be imposed for exceeding either the volume or area limits.

Conclusion The fundamental purpose of this report is to provide a reference for users of PINFORM. It has not been the author's intention to try and offer prescriptive guidance on forest management in PNG. The model itself synthesises and extrapolates a useful body of growth and yield data, and necessarily leads to certain general conclusions, which have been discussed in the report.

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