

# **CAFOGROM.XLS: A simulation model for natural tropical forest management**

User's guide and technical reference manual

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This document has been prepared for the *Centro de Pesquisa Agroflorestal da Amazonia Oriental* (CPATU), Belém, Brazil under contract through the United Kingdom Overseas Development Administration. Oxford, September 1996.

## Executive Summary

CAFOGROM.XLS is a simulation model for natural tropical forests in northern Brazil. It is based on an earlier design written in C, but modified and extended to run under Visual Basic for Excel. The design concepts are closely related to the SIRENA model developed for Costa Rica. This publication provides a reference information guide for users of the model.

A design feature of CAFOGROM.XLS is the access of the non-programmer to model parameterization via a graphical and regression-based interface, that fits models of diameter increment, tree mortality, crown class, felling damage, recruitment, and stand basal area increment and mortality directly to tabulated data. A supporting program, CIMIR, creates these data tables directly from the permanent sample plot data base of CPATU. CIMIR is designed to be adapted easily to different PSP systems, making the combined CIMIR/CAFOGROM system relatively generic for mixed natural forest management. CIMIR requires *Microsoft FoxPro for Windows 2.6* or higher, whilst CAFOGROM.XLS needs *Microsoft Excel version 5* or higher.

The model uses a flexible scheme of species groups and classes to define the application of management options. Input data is summarised by groups of species defined externally. These can be regrouped into 4 classes for management definition. For output presentation, one or more classes can be selected by size limits for plotting.

Harvesting is defined by felling cycle or minimum basal area or both together. Both act as constraints on felling. Felling is also controlled by limiting the basal area to be removed, and the minimum diameter of selected species classes. Felling can be prioritized to the largest trees, or alternatively to smaller trees above the diameter limits, leaving the largest as seed trees. The model distinguishes damaged and healthy trees, and does not fell trees which are damaged or defined as non-commercial.

Silvicultural treatment in the model implies removing unwanted trees (thinning). These may be defined by species class and minimum size, and may be limited to only damaged or malformed trees in a class. Total removals may be limited by basal area. Thinning is applied as specified number of years after felling.

Outputs from the model comprise four graphs with associated tables, any of which may be printed or copied to Windows-compatible programs for publication or re-analysis. The first graph gives components of basal area including standing trees, damage, recruitment, increment, mortality, thinned and harvested trees. The second graph shows volumes by four user-defined categories comprising species classes and size limits. A third graph compares the first-defined volume category between successive simulation runs. The final graph gives basal areas by size classes, and is useful for defining thinning and harvesting prescriptions and also for testing the accuracy of the model.

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## Typographic conventions

The following conventions have been adopted to distinguish program messages, menu texts, and symbolic names:

- SMALL CAPITALS are used for symbolic names such as file names, names of worksheet tabs, and variable names.
- **Bold Arial** 10 pt font is used for main menu items and for buttons on dialog forms.
- *Arial 10 pt Italic* is used for second-level menu items and for program messages and texts.
- Arial 10 pt underlined is used for third-level menu items.

## Introduction

### ***The CAFOGROM.XLS model***

CAFOGROM.XLS is a computer simulation model for the growth of natural tropical forests. It is based on empirical functions for projecting the development of size cohorts, organized by species groups, and considers the processes of diameter growth, or increment, tree mortality and recruitment. Cohorts are also differentiated between healthy and damaged trees, and between the upper canopy and understorey.

The empirical functions are fitted within the model from summary data imported from permanent sample plot (PSP) data. An associated program called CIMIR, also documented in this manual, prepares the raw PSP data for analysis.

CAFOGROM has evolved from an original model written in the C programming language during 1994, and documented in Alder (1995). That version was designed to run under the MS-DOS operating system, and used fixed, pre-analysed functions. It was suitable as a demonstration tool for ideas of modelling and tropical forest management, but did not have the flexibility needed for more practical use as a planning tool.

Subsequently, the ideas in the first version of CAFOGROM were embodied in a new model called SIRENA (*Simulacion del Rendimiento de Bosque Natural* in Spanish) which was written for use in Costa Rica. This model had to be used for supporting the documentation of forest management plans with projections of growth and yield, and incorporated a number of features specific to that institutional environment. It also introduced the use of Visual Basic for Excel (VBE), instead of C, as the programming platform. This had the advantages of easier programming and complete compatibility with Microsoft Windows. The latter makes the inclusion of outputs from the model in documentation very easy, either in tabular or graphical form.

The experience from the development of SIRENA was incorporated into a new version of CAFOGROM also written in VBE. In addition, further evolutionary steps were taken to improve the usefulness of the model:

- A multilingual structure was imposed on all texts, menus and outputs. This allows the user interface to be switched between English and Portuguese by a simple menu choice. Additional languages can be included with very limited re-programming.
- The growth functions are fitted within the model to standard data tables. This allows the model to be easily transported to new forest areas, or for existing data sets to be readily updated.
- An interface program was written (CIMIR) which carries out required standardization and summarization of raw PSP data sets. This further simplifies the process of updating or localizing growth functions.

### ***The CIMIR data analysis program***

CIMIR (calculation of increment, mortality and recruitment) is a program that provides an interface between the growth model and the database of raw PSP data. It is written in Microsoft FoxPro for Windows. CIMIR is designed to work with data from CPATU's SFC system for storing permanent plot data. However, most of the program is quite general, and it should be readily possible to adapt CIMIR to work with the PSP databases of other institutions.

This manual includes a full description of the use of CIMIR and its input and output file structures.

### ***Prerequisites for using CAFOGROM***

A computer running Microsoft Windows 3.1, Windows 95 or a fully compatible operating system is required, typically with at least 8 MB of memory and a 486DX66 or better processor. Microsoft FoxPro version 2.6 for Windows (standard edition) is needed to run CIMIR. Microsoft Excel version 5 is needed to run CAFOGROM.XLS.

Both CIMIR and CAFOGROM require that the user has a good understanding of forestry concepts and terminology, especially with respect to growth and yield studies. A knowledge of natural tropical forest management is needed, together with an understanding of regression analysis concepts. Some background in using Windows and Excel is necessary and is assumed for this documentation.

The model requires an extensive base of PSP data from natural tropical forest, covering a range of sites and disturbance conditions, if it is to be parameterized effectively. The CIMIR program is designed to operate with data from the SFC system of CPATU, and will need to be reconfigured if used with PSP management systems other than SFC.

A limited set of demonstration data for CAFOGROM is available on the distribution diskette. This is designed for teaching forest management concepts and for learning the use of CAFOGROM. The demonstration data does not relate to any real forest or location. It should not be used as a basis for formulating policies towards natural tropical forest management and is intended only for training purposes.

### ***Installation of the model***

A directory should be set up on a local hard disk (typically drive C:) called \CIMIR, and the following files copied across from the distribution diskette:

CAFOGROM.XLS .....	The CAFOGROM model with pre-configured growth functions for the demonstration data
DEMOPAT1.CIV .....	Demonstration data from an imaginary logged-over tropical forest
DEMOPAT2.CIV .....	Demonstration data from an imaginary unlogged tropical forest
CIMIR.PRG .....	The CIMIR source program in FoxPro
CIMMNU.DBF .....	The CIMIR menu system in English and Portuguese
CIMMNU.CDX .....	The associated index file
CIMMSG.DBF .....	Miscellaneous texts and messages in English and Portuguese
CIMMSG.CDX .....	The associated index file
SPREP.FRT .....	Report format for printing species list from CIMIR
SPREP.FRX .....	An associated file for the report form

The model and the CIMIR program should then be ready for use. Clicking on the file CAFOGROM.XLS from the Windows 3.1 File Manager or Windows 95 Explorer will start the CAFOGROM with demonstration data and models ready to run, provided that Microsoft Excel 5 has been installed on the system.

CIMIR can be started from Microsoft FoxPro, as discussed on page 4. However, it needs a base of SFC data accessible on a local or network drive in order to operate. This data is not supplied with the demonstration disk.



## Using the CIMIR data interface program

### **CIMIR and SFC**

The SFC program (*Sistema de Inventário Florestal Continuo*) has been written by CPATU for the storage and management of data from permanent sample plots. The protocols for plot establishment and measurement are documented in Silva and Lopes (1984) and in Korsgaard (1993). Korsgaard also developed a number of analytical programs for PSP data, and the latest version of SFC.

The latest version of SFC is written in Clipper, which is an XBASE-type language. The files in which data are stored are all DBF-compatible.

CIMIR was developed for expediency in another XBASE language, Microsoft FoxPro, with the view that its code could be relatively easily modified by CPATU's programmers to offer complete integration within the SFC menu system if required. In this case, CIMIR would disappear as a separate program, but its functions would be accessed through the SFC menu. However, at the present time, CIMIR operates as a separate program which must be started from within Microsoft FoxPro under Windows.

It should be noted that CIMIR does not update or alter the SFC files in any way. It simply reads from them, making conversions and calculations to produce a new database, called CIMIR.DBF, and a consolidated species list, CIMESP.DBF. All subsequent analyses are then performed on the CIMIR.DBF file. This means that adapting CIMIR to PSP data management systems other than SFC is relatively straightforward, and once done, all other aspects of the CIMIR-CAFOGROM system can be used unchanged.

### **Starting CIMIR**

The system should be in Windows, and Foxpro started by clicking on the appropriate icon.

A command window will appear, in which the instructions:

```
SET DEFAULT TO C:\CIMIR  
DO CIMIR
```

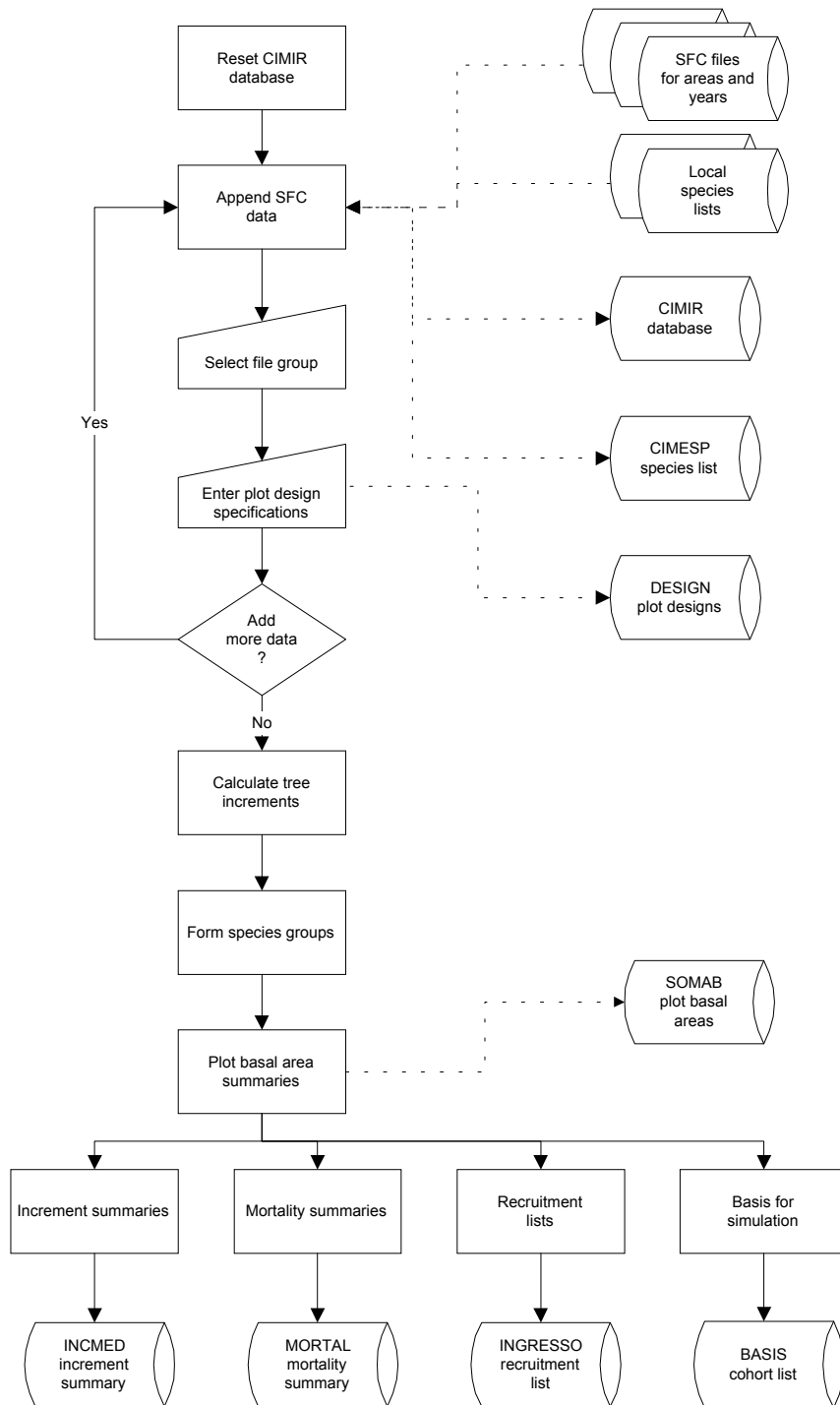
should be typed. The underlined portion of the command should be modified if a different directory is used for the CIMIR program and files.

A blank window will appear with a simple menu bar from which selections can be made by the mouse. Table 1 shows the menu bars available and their associated functions. A general flowchart of the operations performed by the program via the various menu choices is shown in Figure 1.

**Table 1 The CIMIR menu system**

<b>Menu bar</b>	<b>Sub menu</b>	<b>Description</b>
<b>Data</b>	Reset CIMIR database Append SFC data Calculate increments Form species groups Print species list Convert from SDF to DBF data	<p><i>Functions relating to the initial conversion of the data</i></p> <p><i>Clears the tree database and prepares it for input.</i></p> <p><i>Adds new SFC data files from a selected locality.</i></p> <p><i>Adds increments and sets the mortality and recruitment flags depending on the status of the tree. Fills in the error code.</i></p> <p><i>Automatically forms species groups based on typical size, mean growth rate, and commercial status of the tree</i></p> <p><i>Prints a consolidated species list sorted by groups, with statistics on the numbers of trees observed for each species and group.</i></p> <p><i>Re-converts SFCfiles which are in SDF format back to DBF files.</i></p>
<b>Tables</b>	Basal areas Increment Mortality Recruitment Stand structure Basis for simulation	<p><i>Generates the SOMAB output file</i></p> <p><i>Generates the INCMED output file</i></p> <p><i>Generates the MORTAL output file</i></p> <p><i>Generates the INGRESSO output file</i></p> <p><i>Generates the CLASSAB output file</i></p> <p><i>Generates the BASIS output file</i></p>
<b>View</b>	Tree data Species list Basal area summary Increment table Mortality table Recruitment lists Stand structure table Design table Progress summary	<p><i>All the selections under this menu view databases as BROWSE tables in a read only mode. To interpret the column headings, the user should refer to Appendix A.</i></p> <p><i>This shows operations completed since the last initialization, and can be used for reference if losing track of progress.</i></p>
<b>Control</b>	Exit Translate	<p><i>Reverts to the FoxPro command Window and closes CIMIR.</i></p> <p><i>Changes from English to Portuguese text or vice versa.</i></p>

**Figure 1 Flowchart of operations carried out by CIMIR**



## Preparing the CIMIR database

The data to be used as a basis for a growth modelling project is extracted from the SFC files and reformatted into a database called CIMIR.DBF. The first step in this operation is to select the menu choice *Reset CIMIR database* from the **Data** menu bar. This produces a warning message: *Will overwrite CIMIR files! Press ESC to cancel.* At this point, the ESC key will cancel the operation. Pressing any other key or clicking the mouse will allow the program to continue. If the CIMIR.DBF file does not exist, it is created in the same directory as the CIMIR program. If it already exists, then it is cleared of current data.

Following this step, data can be added from selected SFC files. Normally, all data available should be added, provided that it has been error checked and is reasonably free from the inevitable errors that occur in permanent plot work. It should be noted that CIMIR is not an error checking program and high levels of error can significantly distort growth and mortality functions.

Data is added via the menu choice **Data Append SFC data**. When this is selected, a standard Windows open file dialog appears, filtered to show files corresponding to the template AV0????.??. This matches the file nomenclature used for the SFC database. By selecting different drives and directories, it is possible to search for the location of the SFC files anywhere on the system. Once a list of corresponding AV... files is seen, selecting and clicking on one will add to the database all files with the same location code. The AV... file names are constructed according to the following template:

AV0aaaa.yy1

where aaaa is the location code. For example, 1202 designates Tapajos km67, 1401 the control plots at Tapajos km114, and so on. The yy designator indicates the year of measurement. Thus clicking the mouse on any file with the code 1202 will add all measurement years for Tapajos km67 to the system.

Once a set of AV files has been selected, then a second open file dialog box appears, to select the corresponding species list. CIMIR will display for this purpose all .DBF files in the same directory as the AV files. The user is responsible for selecting the file which is the correct species list corresponding to the AV files chosen. If the wrong file is selected, subsequent analyses may be seriously distorted, as incorrect species codes may be applied.

After selecting the species list, a dialog box appears which allows the user to fill in the following information:

<b>Location</b>	Text, up to 20 characters, describing the location of the plots
<b>Area code</b>	This is a 4 digit code, shown as extracted from the name of the AV files selected.
<b>Plot area</b>	Plot area in hectares.
<b>Minimum diameter</b>	The smallest diameter specified for measurement on the whole plot
<b>Subplot area</b>	The area of a subplot, if any. If there are no sub-plots, this can be zero.
<b>Minimum diameter</b>	The smallest diameter specified for measurement on the subplot.
<b>Species list file</b>	The name of the selected species list file.

Two buttons appear on this screen: **OK** and **Cancel**. The **OK** button will continue processing. The **Cancel** button will terminate the operation without adding anything to the CIMIR database.

It should be noted that if the plot or sub-plot sizes are entered incorrectly, all subsequent data will be in error. The data entered on this screen are stored in a file called DESIGN.DBF. It can be reviewed via the menu choices **View Design table** (see Table 1).

Only the major sub-plot in a sample plot design can be processed via CIMIR. If there are two levels of subplot within a main plot, then the inner subplot data will be ignored.

Once the **OK** button has been pressed, CIMIR will start to convert the data from the SFC format into CIMIR.DBF. As it does this, the status bar at the bottom of the screen shows the current file being processed and the record number.

After adding data for one area code, the **Data Append SFC data** menu will normally be used again to add the data for all other localities in the SFC system in turn.

In Appendix A, the structures of all the CIMIR files are shown, including CIMIR.DBF and the species list, CIMESP.DBF. The species list is a consolidation of the separate lists from each locality, which uses a standardised code (IDESP) generated internally. CIMIR.DBF conforms to the standards for year-per-record (YPR) files described in Alder(1995). Each record has attached to it a unique plot identification code, tree number, and year of measurement. This allows the records to be sorted and indexed for analyses of increment and mortality that are carried out in the subsequent stages of CIMIR. The complex codes for the status of the tree used in the SFC system are simplified to the essentials useful for constructing the models required by CAFOGROM, and are mostly coded as logical fields (true or false). An error code is attached to the record, which is 0 for valid data, and non-zero for bad measurements. Only the valid data is used for constructing data summaries output to CAFOGROM.

The menu choice **Data Convert from SDF to DBF data** can be used as a utility function prior to appending data, to convert AV files which have been archived or copied in the SDF format back into a .DBF format. Generally, SDF files are used for processing by FORTRAN programs and statistical packages. This utility function should not normally be needed.

### **Calculation of increment**

The data as added to CIMIR does not include increments, which are calculated separately once all the files have been added. The menu bar **Data calculate increments** starts this process. Three types of time-dependent data are filled in during processing. The diameter increment field INCD is calculated for each year as the mean annual diameter increment between the current and next record for a tree. For the last measurement in a series on one tree, the increment is recorded as zero, but the error code field ERRC is set to 3, indicating an unusable measurement.

Mortality is filled in on the basis of two possible criteria. If the tree is recorded as dead or fallen, it is treated as dead by CIMIR. Also, if a tree disappears before the end of a measurement series for the plot, a dummy record is inserted for the next year of

measurement showing the tree as dead, and copying data from the previous record for diameter and other aspects of tree status. Mortality is recorded by setting the MORT field to TRUE.

Recruitment is detected when a tree appears in the measurement series after the first measurement on the plot. In this case, the RECR field is set to TRUE.

It should be clear therefore that mortality and recruitment cannot be detected on the first measurement on a plot, and relate always to an event during the preceding measurement interval. Increment on the other hand is calculated forwards, and is thus unknown for the last measurement on a tree. This is flagged accordingly and not used in increment summaries.

Increment can in principle be calculated either forwards or backwards in time. Forward calculation is used because the regressions for increment are designed as *predictive* models, to estimate future increment. Using historical (past) increment as the basis for such regressions might be a biased procedure if the process is significantly non-linear.

Adding new data after increments have been calculated invalidates the increment, mortality and recruitment fields of the CIMIR database. The program controls this using internal flags to record the progress of work, and will block subsequent operations with an appropriate error message if work has not been done in the correct sequence.

### **Formation of species groups**

A feature of research into natural tropical forest is the very large number of species involved. Typically, there may be 500-600 species in a given locality of a few hectares. Many of the species will be represented as only one or two individuals. Effective growth studies thus require some strategy for grouping species.

CIMIR groups species by a two-way classification based on largest observed size, and mean increment. The maximum size observed is indicated by a letter, and the mean increment class by a digit. In addition species which have been recorded as commercial in *any* local species list are suffixed by a + code. Species always recorded as non-commercial are suffixed by -. The codes used for grouping species thus take the form A2+, B3-, and so on. Table 2 shows the codes used.

The size and increment classes used are non-linear to reflect the typically exponential distribution of species by size and mean increment. Small, slow growing species are most common, with the largest, fastest growing species being the least frequent.

The codes are added to the consolidated species list CIMESP.DBF as the field GRUP. In principle, alternative grouping methods can be applied for use within CAFOGROM by over-writing the GRUP field with codes developed according to other criteria by an external program. It is likely also that later releases of CIMIR will provide for more flexible tools in this respect. In all cases however, the final prefix should be reserved to indicate economic status. The first two characters can be any combination of two letters or a letter and a number.

Particular species which are well represented in the data and of great commercial or ecological significance can also be selected manually by editing the `GRUP` field manually, using the `BROWSE` function from FoxPro.

**Table 2 Coding system used by CIMIR for species groups**

<b>Indicator</b>	<b>Description</b>
<i>Tree size code</i>	
A	Largest 1% of population over 90 cm diameter
B	Largest 1% of population over 60 cm but less than 90 cm.
C	Trees occur over 30 cm diameter, but less than 1% are over 60 cm.
D	No trees are observed over 30 cm diameter.
P	Palms
X	No diameter data - typical size unknown
<i>Mean increment code</i>	
0	No increment data available
1	Mean growth rates less than 2 mm/year
2	Mean growth rates 2-4 mm/year
3	Mean growth rate 4-8 mm/year
4	Mean growth rate 8 mm /year or more
<i>Commercial status</i>	
+	Recorded as commercial in one or more local species lists
-	Not recorded as commercial in any species list

The menu function **Data Form species groups** initiates the species grouping process. No user inputs are required during this process.

Once species groups have been allocated, the consolidated species list can be printed, organized by species groups, by selecting the menu function **Data Print species list**. A preview of the list is shown first on the screen. This can be scrolled and zoomed using standard Foxpro report preview functions. The list shows the species group, internal code number, botanical name, and number of observed trees for each species. It is summarized and ordered by species groups.

After closing the Preview screen, a message *Print report? (ESC to cancel)* will appear. Clicking the mouse or pressing any key except ESC causes the report to be printed.

It should be noted that the internal species codes are for reference purposes when examining `CIMIR.DBF` only, *and should never be used as a basis for field recording*. This is because they may change if the `CIMIR.DBF` file is rebuilt using different local lists or if the same local lists are appended in a different sequence to the database.

### **Generating CIMIR output tables**

The various functions under the **Tables** menu of CIMIR should be used in the sequence listed on the menu (see Table 1) to produce the output tables required as inputs to define growth models in CAFOGROM.

The menu selection **Tables Basal areas** causes the files `SOMAB.DBF`, `SOMAB.CDX` and `SOMAB.CIM` to be generated. The structure of `SOMAB.DBF` is shown in Appendix A. It gives the components of stand basal area for each plot and year of measurement. The file

SOMAB.CDX is an index file, created and used by FoxPro, but not needed by other programs. The SOMAB.CIM file has the same data columns as SOMAB.DBF, but is stored as a text file, with the fields separated by commas, and each record on a new line. This format is the fastest way to read data into a VBE program, and is used by CAFOGROM. The data stored in SOMAB is used in the model to develop functions for stand basal area increment, logging damage, general recruitment levels, and basal area distribution between understorey and canopy trees.

The menu selection **Tables Increment** causes the files INCMED.DBF, INCMED.CDX and INCMED.CIM to be generated. The INCMED files contain information on mean increment by species group, size class, and canopy class. The structure of the files is as shown in Appendix A. INCMED.CIM is used by CAFOGROM for the individual tree increment models. The other files are used internally by CIMIR, and are available for analysis of growth functions externally to CAFOGROM via Excel or a statistical package.

The menu selections **Tables Mortality** and **Tables Recruitment** cause the generation, respectively, of .DBF, .CDX and .CIM files MORTAL and INGRESSO, with the structures and contents shown in Appendix A. These provide information to CAFOGROM on mortality rates and the distribution of recruitment by species groups.

The above four menu selections must be used in sequence to generate the set of files needed by CAFOGROM for model parameterization. The menu choice **Tables Stand structure** differs in that no .CIM file is generated, and the CLASSAB.DBF file is not necessary for running CAFOGROM. Its purpose is to provide a breakdown of stand basal area by size classes over time that can be used to validate CAFOGROM by comparisons between model outputs and actual data.

### ***Defining a set of plots to be used as a basis for simulation***

As well as requiring data for the definition of empirical models, CAFOGROM also needs summary data to describe the forest stands that are to form the basis for projections. These can be selected from sets of permanent plots at their first measurement for the purposes of model testing and development, and for general evaluation of stand management options. CIMIR provides this facility via the **Tables Basis for simulation** menu selection.

When this menu bar is selected, a screen appears as shown in Figure 2. The plots to be included in the basis are selected from the left-hand box by clicking with the mouse. They will be added to the list in the right-hand box. Selections can be reversed by clicking on a plot in the right hand box.

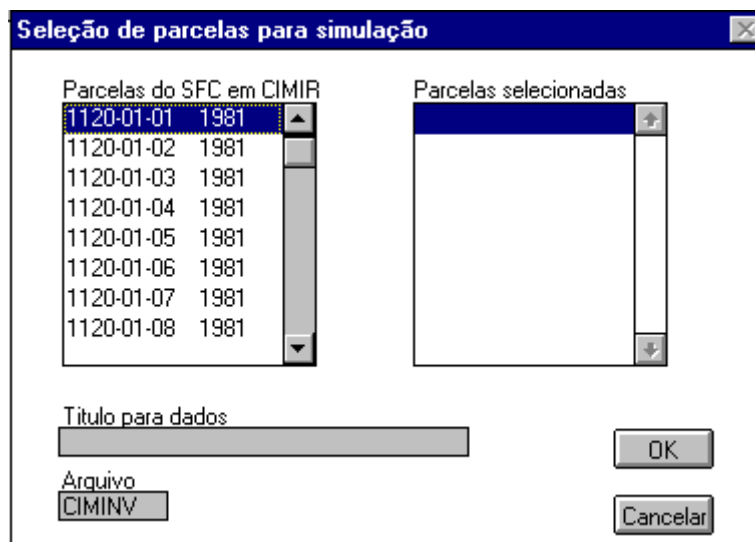
A title for the data set should be entered where shown, and a filename of upto 8 characters given. The data will be saved as that file name with the extension .CIV appended when the **OK** button is pressed.

The format for the basis file is a text file with values separated by commas. The first line is the title of the data, enclosed in double quotation marks. Second and subsequent lines give values for each cohort in the stand to be simulated. Cohorts typically can be summarised from inventory data by compiling the data by CIMIR species groups and 1-cm size classes. For each class a per hectare tally of trees is required. Cohorts are



compiled separately for damaged/malformed trees and good trees. There are thus 4 items per line, each separated by commas, comprising in order: Species group, mean number per ha., mean diameter of the cohort, and a zero or one for good or defective trees respectively.

**Figure 2 CIMIR dialog screen for selection of plots as a basis for simulation**



### **Viewing CIMIR output and control tables**

The various output tables generated by CIMIR, as well as the tree data in CIMIR.DBF and the species list CIMESP.DBF, can be viewed by using the various options on the **View** menu bar, as listed in Table 1. This brings up, for each particular table, a browse screen with column headings based on field names. The field names are described in Appendix A for each table.

The *Design table* and *Progress summary* may be noted as special purpose tables. The design table lists the size, location and diameter limits for each sample plot. The progress summary shows the various processing stages that have been completed, and can be used to check that each necessary operation has been carried out.

### **Exiting from CIMIR**

CIMIR is terminated by using the menu selection **Control exit**. This brings control back to the FoxPro command window. Typing the command `QUIT` will close FoxPro.

### **Switching between Portuguese and English versions**

The menu selection **Control Translate** changes all text from the current to the alternate language, which in the version described here are English and Portuguese. This can be done at any time without interfering the operation of the system. Texts for all menus and messages in the system are contained in the database files CIMMNU.DBF and CIMMSG.DBF. Editing these files allows the program to be configured for other languages.

## CAFOGROM basics and model parameterization

### **General design of the model**

CAFOGROM.XLS is written as an Excel workbook, and comprises a number of sheets which may contain Visual Basic program code (modules), tabulated data (worksheets), graphs (charts), or screen forms (dialogs). Appendix B lists the sheets found in the model together with a description of their function.

When the workbook is loaded, either by clicking on the CAFOGROM.XLS file from the file manager, or by opening it from within Excel, then the program code starts automatically. The Excel menus and toolbars are replaced by the CAFOGROM menu, and a simple title sheet appears. Program functions are controlled from this menu system.

In using the model, work will naturally fall into two stages:

1. *Growth model parameterization.* This involves operations under the **Models** menu bar. Data tables created by CIMIR are loaded, graphs, tables and regressions produced, and where appropriate adjustments are carried out. Once model parameters have been set in this way, they do not need to be changed unless new PSP data is added to the database, or the model is applied to a different data set. All details of the parameters will be saved when exiting from CAFOGROM.XLS to Windows or Excel.
2. *Running simulations.* This involves setting forest management options, executing the model, and examining the various output graphs and tables. The latter can be printed or copied, via the Windows clipboard, into other documents for publication or further analysis.

Readers who are interested in the technical aspects of the growth model design will find the key program code on the module sheet *Simulator*. This corresponds very much to the general cohort model design described in Alder (1995: 97-100), and closely follows the original C version of CAFOGROM.

### **The menu system**

The first two levels of the CAFOGROM menu system are shown in Table 3. Several of the choices have a third level of options, typically to show either tabular or graphical forms of data. There are four menu items arranged horizontally on the screen giving access to the main groups of functions. **Models** accesses operations related to fitting and documenting growth functions. Data can be imported and filtered to select groups of plots or measurement years. Regressions are fitted automatically and displayed on the graphs. Graphs and underlying tables can be printed or copied as needed.

**Forest management** includes a series of dialog screens which allow the user to define the options for forest management. **View outputs** shows simulation results in graphical or tabular form. **Control** accesses a variety of functions, including running the model, switching languages, saving the current status of the model, and exiting to Excel or Windows.

**Table 3 First and second levels of the CAFOGROM menu system**

<b>Menu bar</b>	<b>Menu item</b>	<b>Description</b>
<b>Models</b>	Increment	<i>Import and display data for tree increment models for each species group by crown and size classes. Models can be adjusted manually for ill-conditioned data.</i>
	Mortality	<i>Import and display tree mortality rate data by species groups for canopy, understorey and damaged trees. Adjusts weak data by using class means.</i>
	Recruitment	<i>Import and display recruitment data. Shows table of recruitment rates by species groups and disturbance classes. Fits basal area recruitment model, with optional filtering of data by plot codes and years.</i>
	Crown class	<i>Imports and displays data on proportions of understorey trees by basal area. Fits model, and allows data filtering by plot code and year.</i>
	Logging damage	<i>Imports and displays data on logging damage and mortality following logging. Fits model, and allows data filtering by plot code and year.</i>
	Basal area dynamics	<i>Imports and displays data on stand basal area increment. Fits model, and allows data filtering by plot code and year.</i>
<b>Forest management</b>	Forest basis	<i>Dialog screen to allow selection of a forest stand to be used as the basis for subsequent simulation runs.</i>
	Species groups	<i>Dialog screen to define groups of species for forest management and reporting purposes within the model.</i>
	Silvicultural treatment	<i>Dialog screen to define the timing and intensity of silvicultural treatments</i>
	Harvesting	<i>Dialog screen to define the felling cycle, constraints on basal area to remove, protection criteria, and diameter limits.</i>
	Volume definitions	<i>Dialog screen to define lower diameter limits for volumes for graphical outputs.</i>
	Clear comparisons	<i>Resets the table and graph which compare successive simulations.</i>
	Time limit	<i>Defines the time limit for simulations.</i>
<b>View outputs</b>	Basal areas	<i>Shows the graph or underlying tabulated data for basal area development simulated over time, broken down into standing BA, damaged trees, recruits, growth, mortality, extraction, and treated BA.</i>
	Volumes	<i>Shows the graph or underlying tabulated data for standing and harvested volumes by size groups.</i>
	Comparisons	<i>Shows the graph or underlying tabulated data for standing volume in the first defined group for sets of successive simulations.</i>
	BA by size class	<i>Shows the graph or underlying tabulated data for standing basal area development over time, by 20 cm size classes.</i>
	Print	<i>Prints any currently displayed table or graph, and allows setting of printer options.</i>
<b>Control</b>	Start simulation	<i>Starts a simulation with currently defined options and models.</i>
	Exit Cafogrom	<i>Exits to either Excel or Windows.</i>
	System functions	<i>Special functions to re-size graphs (zoom), to re-start the model after an error, or to save its current status.</i>
	Select language	<i>Switches menus, captions and messages between English and Portuguese.</i>

## Tree diameter increment functions

CAFOGROM uses a quadratic regression in the form:

$$\Delta d = \alpha + \beta_1 \cdot d + \beta_2 \cdot d^2 \quad \{\text{eqn. 1}\}$$

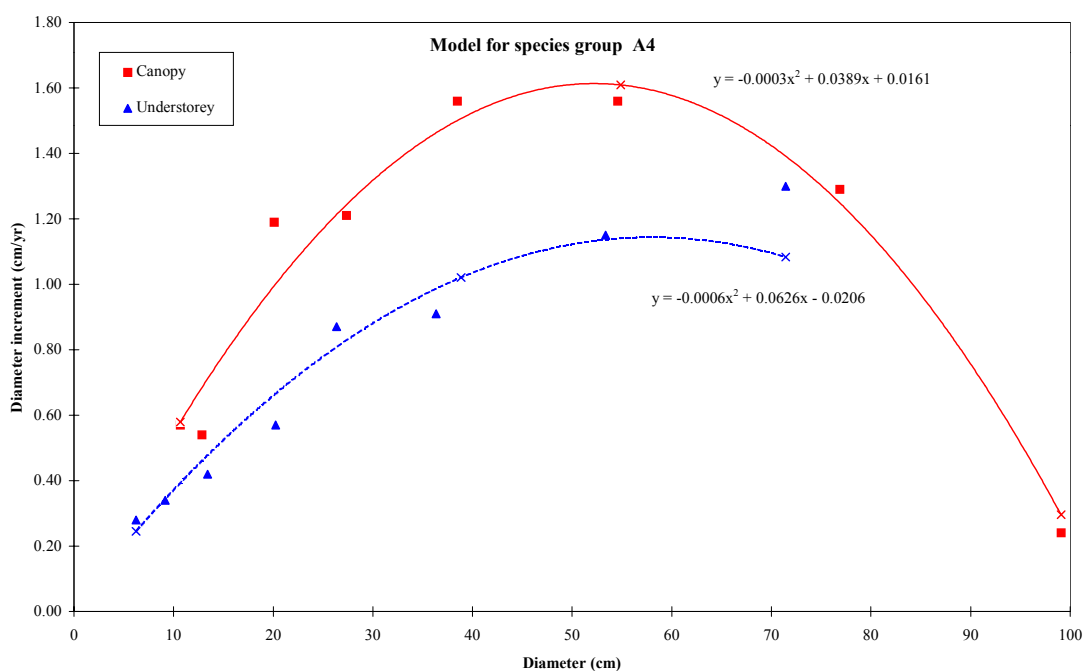
to predict tree diameter increment. In this equation  $\Delta d$  is diameter increment, in  $\text{cm yr}^{-1}$ , and  $d$  is diameter, in cm. The  $\alpha$  and  $\beta_i$  are regression coefficients, with different models fitted to each species group and to understorey or canopy trees. The **Models Increment** menu is used to fit and display these models. Because data is often sparse, leading to models of erratic shape, it is possible to manually adjust the shape of the function using the mouse on the graph, and then save the coefficients for the adjusted model instead of the fitted one.

The menu selection **Models Increment** leads to four sub menus:

**New data** Imports new data by reading the CIMIR output file INCMED.CIM into the workbook. A dialog screen appears asking for confirmation of the data input. When this is accepted by clicking the **ok** button, the data will be updated. If the working directory for the data files is undefined, an open file dialog appears. This should be navigated to locate the \*.CIM files.

**Graphs** Displays the increment graph for a species group. The group shown will be determined by the position of the cursor in the table of growth models. This is set in the **Models** sub-menu, as described below. Figure 3 shows the typical appearance of a diameter increment function. Both lines are concave with respect to the x-axis, originating close to zero, and bending again to zero with values in the range 100-200 cm diameter. A maximum

**Figure 3 Graph of diameter increment function for one species group in CAFOGROM**



increment occurs in the mid-diameter range. The increment function for understorey trees is substantially below that for canopy trees. The trend line is fitted by weighted regression to classified data, with weighting function of  $\log(n)$ , where  $n$  is the number of data points in each class

On each trend line there are three control points, marked by x. These points can be selected by mouse and moved to adjust the trend line when the data is ill-conditioned. This is necessary especially when the line is convex with respect to the  $x$ -axis. It should then be adjusted to a reasonable concave shape.

Update This function is used when the graph shape has been adjusted manually, as described above. It overwrites the original coefficient values, fitted statistically to the data, with coefficients for the adjusted increment model.

Models This function displays the table of coefficients for all the species groups, as shown in Figure 4 below. The columns  $N_a$  and  $N_c$  give the total number of trees and the number of classes (data points) in each regression.  $R^2$  values are not calculated as the data is classified and the regression weighted.

When the cursor is positioned on a row in the table, and Graphs selected from the **Models Increment** menu, then the graph displayed will be for that model. Abnormal functions can be noted by examining the signs and magnitudes of the regressions. The  $\alpha$  coefficient should be close to zero,  $\beta_1$  should be positive, and  $\beta_2$  should be negative. If this is not the case, the graph should be viewed and if necessary adjusted.

**Figure 4 Table of tree increment coefficients in CAFOGROM**

	A	B	C	D	E	F	G	H	I	J	K
<b>1</b>	<b>Increment models</b>	<b>Canopy trees</b>					<b>Understorey trees</b>				
<b>2</b>	<b>Model</b>	<b>Na</b>	<b>Nc</b>	$\alpha$	$\beta_1$	$\beta_2$	<b>Na</b>	<b>Nc</b>	$\alpha$	$\beta_1$	$\beta_2$
<b>3</b>	A1	34	6	0.10976	0.00276	-0.00002	39	5	0.10020	0.00260	-0.00004
<b>4</b>	A2	3010	18	0.20483	0.01309	-0.00013	2703	16	0.07779	0.01387	-0.00021
<b>5</b>	A3	529	18	0.27992	0.01956	-0.00016	484	15	0.18464	0.01443	-0.00019
<b>6</b>	A4	368	8	-0.02059	0.06260	-0.00060	359	8	0.01606	0.03887	-0.00034
<b>7</b>	B1	1126	16	0.10978	0.00820	-0.00010	1999	15	0.10365	0.00843	-0.00021
<b>8</b>	B2	5343	16	0.11729	0.01438	-0.00018	7837	17	0.11160	0.01282	-0.00024
<b>9</b>	B3	2134	15	0.32609	0.03520	-0.00045	3398	16	0.19365	0.03466	-0.00069
<b>10</b>	B4	28	10	0.30106	0.05779	-0.00066	37	5	0.31468	0.02314	-0.00030
<b>11</b>	C1	3917	13	0.08605	0.01326	-0.00024	21422	14	0.02682	0.01684	-0.00043
<b>12</b>	C2	4668	15	0.21233	0.02127	-0.00038	21414	16	0.11636	0.03000	-0.00089
<b>13</b>	C3	2858	13	0.23169	0.06915	-0.00136	10217	14	0.07450	0.07807	-0.00213
<b>14</b>	C4	1463	9	1.41307	0.01943	-0.00063	2676	9	0.50656	0.02459	-0.00049
<b>15</b>	D1	591	7	0.08792	0.01586	-0.00056	11363	10	0.01145	0.01716	-0.00065
<b>16</b>	D2	311	7	0.02762	0.03634	-0.00113	1561	10	0.03470	0.04176	-0.00161
<b>17</b>	D3	41	6	0.02556	0.13899	-0.00478	113	10	0.18498	0.05760	-0.00217
<b>18</b>	D4	17	4	0.31841	0.15859	-0.00554	76	5	0.15078	0.14735	-0.00496
<b>19</b>	X0	2911	8	0.13918	0.01302	-0.00016	9892	9	0.12242	0.01428	-0.00038

### **Tree mortality models**

Annual mortality rates (AMR) are calculated in CIMIR for each species group, and separately for damaged or malformed trees, understory trees, and canopy trees. This table of rates is read in to CAFOGROM with the menu selection **Models mortality**. There are two sub-menus:

- New data This imports the mortality data from the CIMIR file MORTAL.CIM. A dialog box appears to confirm updating of the data in CAFOGROM. After input, data relating to trees with less than 100 observations is shaded grey, and a second dialog box appears to ask whether these weak estimates are to be over-written with class means. The worksheet containing the mortality rates will be displayed as soon as the New data sub-menu is selected, and appears as shown in Figure 5.
- View table This simply shows the table of mortality rates, without updating or modifying the data.

**Figure 5 Table of mortality rates in CAFOGROM**

Species group	Annual Mortality Rate %			No. trees in sample		
	Damaged	Understorey	Canopy	Damaged	Understorey	Canopy
A0	3.90	3.79	1.62	-	-	4
A1	3.90	3.79	1.62	7	40	35
A2	3.44	2.55	0.73	783	2,645	2,973
A3	2.30	2.83	1.81	331	394	377
A4	3.90	4.65	3.32	62	355	361
B1	2.23	2.15	0.86	472	1,977	1,108
B2	1.85	2.21	1.33	4,484	5,986	4,348
B3	3.81	2.88	1.92	657	3,348	2,110
B4	3.90	3.79	1.62	1	37	28
C0	3.90	3.79	1.62	-	1	-
C1	4.23	3.49	1.35	3,944	20,809	3,657
C2	5.47	4.51	1.94	2,926	20,989	4,422
C3	5.86	3.96	2.74	1,246	10,073	2,741
C4	9.30	9.52	1.63	135	2,703	1,436
D0	3.90	3.79	1.62	-	4	-
D1	4.84	3.74	1.60	1,332	10,955	527
D2	5.75	3.29	1.65	209	1,530	299
D3	3.90	3.26	1.62	28	109	39
D4	3.90	3.79	1.62	5	74	17

### **Stand recruitment levels and species allocation**

Recruitment in CAFOGROM is controlled by two kinds of model. At the stand level, the total basal area of recruits is calculated by a function relating recruitment basal area to stand basal area. This is referred to as the *general recruitment model*. General recruitment is then allocated to species groups, and to commercial and non-commercial components of each species group, via a table of recruitment proportions that depends on *disturbance class*.

The disturbance class is defined in terms of recruitment basal area. If recruitment is less than 0.3 m<sup>2</sup>/ha/yr then this is class 1. If it is 0.3 m<sup>2</sup>/ha/yr or more, but less than 0.7 m<sup>2</sup>/ha/yr, then it is class 2. When recruitment is greater than 0.7 m<sup>2</sup>/ha/yr, then it is class 3.

Recruitment models are set up in CAFOGROM via the menu selection **Models recruitment**. This gives access to four sub-menu choices:

Recruitment list This displays the recruitment list. A dialog box will ask if new data is to be imported. Responding **Yes** will update the table from the CIMIR file INGRESSO.CIM. Responding **No** will leave the table displayed without further action. The appearance of this table is shown in Figure 6.

New data This imports the basal area data for the general recruitment model. A dialog box will ask for confirmation of the action, and the data will be left shown as in Figure 7.

Filter data This option displays the same data as above, as shown in Figure 7. At the top of the first two columns, arrows will be seen denoting the Excel *Filter* function. These can allow plots to be selected by plot number and/or by year for inclusion in the general recruitment model. When the arrow is clicked, a list of values to select appears in a drop-down menu. Selecting

**Figure 6 Part of the recruitment list imported into CAFOGROM from CIMIR**

	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>	<b>F</b>	<b>G</b>
<b>1</b>		<b>Proportion of recruits %</b>			<b>Mean diameter of recruits, cm</b>		
<b>2</b>	<b>Species group</b>	<i>Regeneration class</i>			<i>Regeneration class</i>		
<b>3</b>		<b>1</b>	<b>2</b>	<b>3</b>	<b>1</b>	<b>2</b>	<b>3</b>
<b>4</b>	A1+		0.02			21.90	
<b>5</b>	A2+	2.11	1.40	1.08	7.88	9.34	9.78
<b>6</b>	A3+	0.53	1.06	1.27	10.75	7.41	8.06
<b>7</b>	A3-	0.74	0.20	0.24	6.06	9.58	12.05
<b>8</b>	A4+	1.09	1.64	2.59	5.89	6.36	7.22
<b>9</b>	B1+	1.83	1.53	1.57	5.65	6.77	7.03
<b>10</b>	B1-	0.39	0.17	0.16	6.48	6.55	5.90
<b>11</b>	B2+	4.39	4.63	6.82	7.37	8.32	7.55
<b>12</b>	B2-	4.00	2.67	1.83	7.42	9.54	8.93
<b>13</b>	B3+	2.00	2.90	2.48	7.28	7.99	7.64
<b>14</b>	B3-	0.07	0.20	0.73	21.65	8.82	9.00
<b>15</b>	B4+			0.02			26.80
<b>16</b>	C1+	6.32	4.77	4.07	6.41	6.52	7.08
<b>17</b>	C1-	13.73	11.43	8.59	6.11	6.66	6.09

**Figure 7 Part of worksheet showing recruitment basal area data in CAFOGROM**

<i>Data for general recruitment model</i>			
Plot	Year	Basal area (m2/ha)	
		<i>Standing</i>	<i>Recruits</i>
1120-01-01	1983	22.25	0.41
1120-01-01	1987	24.99	0.75
1120-01-01	1989	23.61	0.20
1120-01-02	1983	23.05	0.25
1120-01-02	1987	25.84	0.66
1120-01-02	1989	26.96	0.16
1120-01-03	1983	28.56	0.20
1120-01-03	1987	31.15	0.65
1120-01-03	1989	31.76	0.29
1120-01-04	1983	23.25	0.18
1120-01-04	1987	26.11	2.75
1120-01-04	1989	25.68	0.38
1120-01-05	1983	19.77	0.16
1120-01-05	1987	21.93	1.46

one of these will limit the data to only rows containing that value. For example, data for a single year can be selected. Also in the drop down list will be seen the word *All* and *Custom*. Selecting *All* cancels the filtering process, displaying all data unless there are filters active in another column. Selecting *Custom* will display a dialog box which allows logical combinations and wildcards to be used to construct more complex filters. For example, it is useful to select plots for a particular locality. Opening the filter by clicking the arrow, clicking *Custom*, and then entering 2\* will select all plots whose area code begins with 2. Entering 1401\* would select all plots starting with area code 1401.

Filtering is a standard Excel function described in the Microsoft documentation and in the help system. The user is referred to that for further examples and information.

View graph

This option will display a graph of the recruitment basal area plotted against standing basal area, together with a regression model in the form:

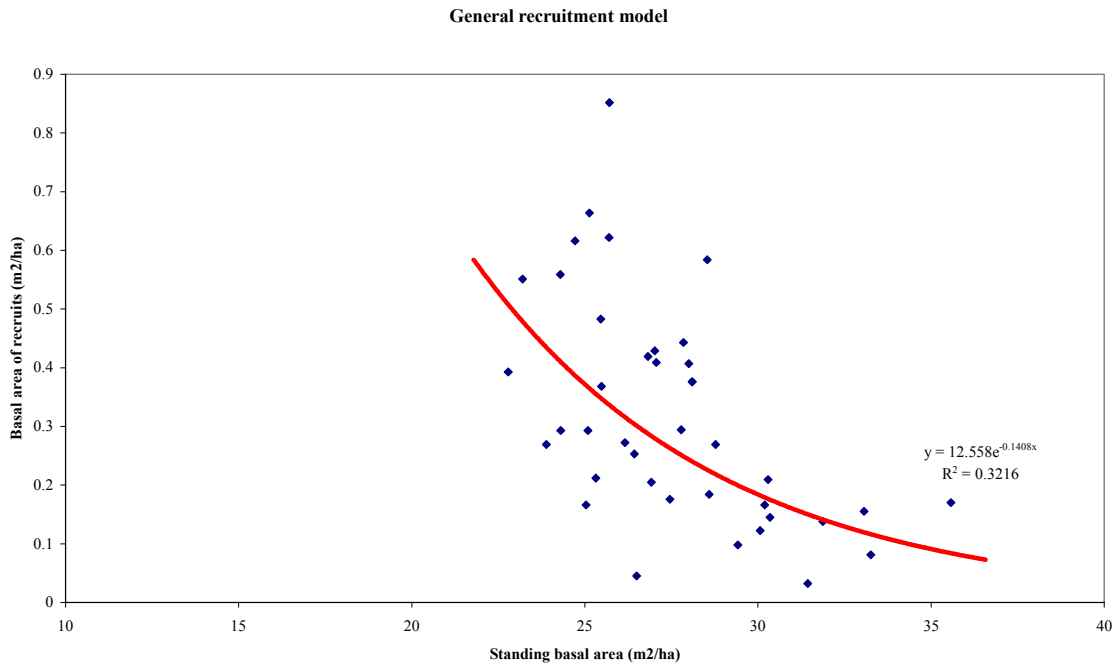
$$RBA = \alpha \cdot \exp(-\beta \cdot SBA) \quad \{\text{eqn. 2}\}$$

where *RBA* is the recruitment basal area, and *SBA* is the standing basal area. The  $\alpha$  coefficient indicates the annual recruitment expected at zero basal area, and  $\beta$  represents a slope factor.

The data in this graph will reflect the current filtering conditions. The model coefficients shown will be those used within subsequent simulations. Thus, changing the filter conditions will change the progress of a simulation.



**Figure 8 Graph of the general recruitment model, showing data selected by filter**



### **Crown class allocation of trees**

Trees are allocated to crown classes on the basis of standing basal area. Two crown classes are considered in the model: *Understorey trees*, including those of intermediate or sub-canopy status, and *canopy trees*, including emergents. The proportion of understorey as a component of basal area is given by the function:

$$UBA = \beta \cdot \ln(SBA) - \alpha \quad \text{\{eqn. 3\}}$$

where *UBA* is understorey basal area, and *SBA* is standing basal area, both in m<sup>2</sup>/ha. Negative values of understorey basal area are given by this equation when standing basal area is below  $\alpha/\beta$ , and are assumed to be zero in the model.

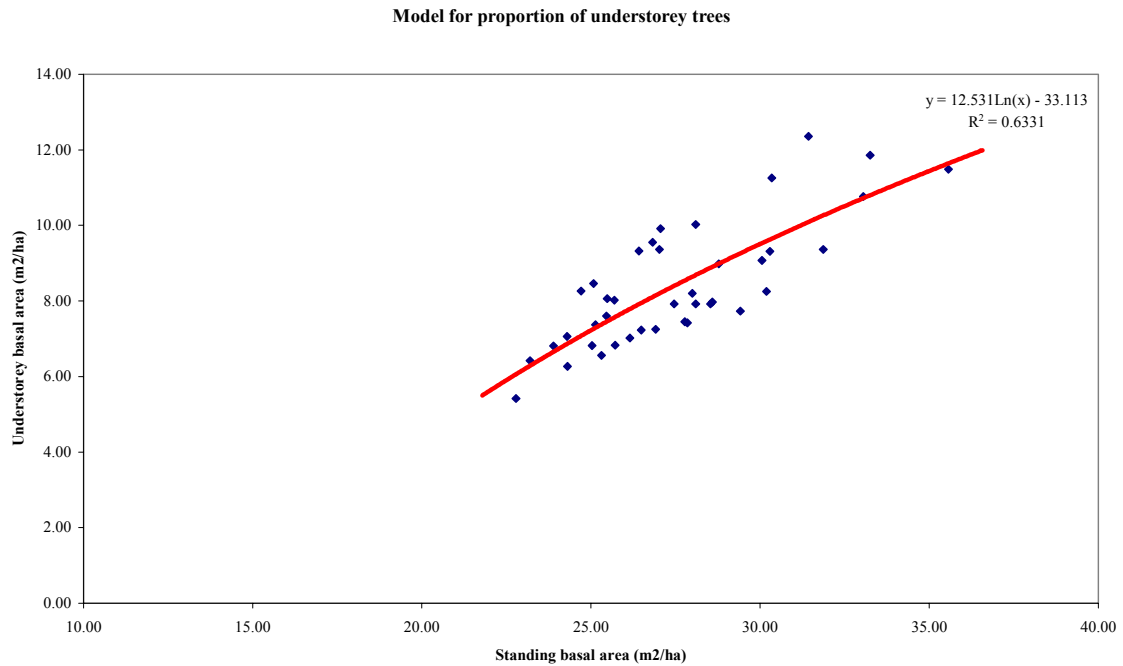
The menu **Models crown class** has three options:

New data This displays a worksheet with columns for plot, year, standing and understorey basal area, and adds new data from the CIMIR file SOMAB.CIM.

Filter data This applies filtering conditions to the data, as discussed on page 18. Groups of plots or measurement years can be selected or excluded from the model.

View graph This displays the data and fitted regression model as a graph, as shown in Figure 9

**Figure 9 Understorey basal area model with regression data**



### **Logging damage**

Logging damage is modelled in CAFOGROM by relating severe tree damage and direct mortality following logging to the absolute basal area extracted. The damaged trees are tracked as separate cohorts to the healthy ones, and have higher subsequent mortality. They can also be treated by silvicultural treatment independently of the healthy stock.

Both logging mortality and damage are indicated by equations with the form:

$$DBA = \alpha \cdot HBA^\beta \quad \{\text{eqn. 4}\}$$

where *DBA* is the basal area of damaged or dead trees, and *HBA* is the basal area extracted in harvesting.  $\alpha$  and  $\beta$  are regression coefficients.

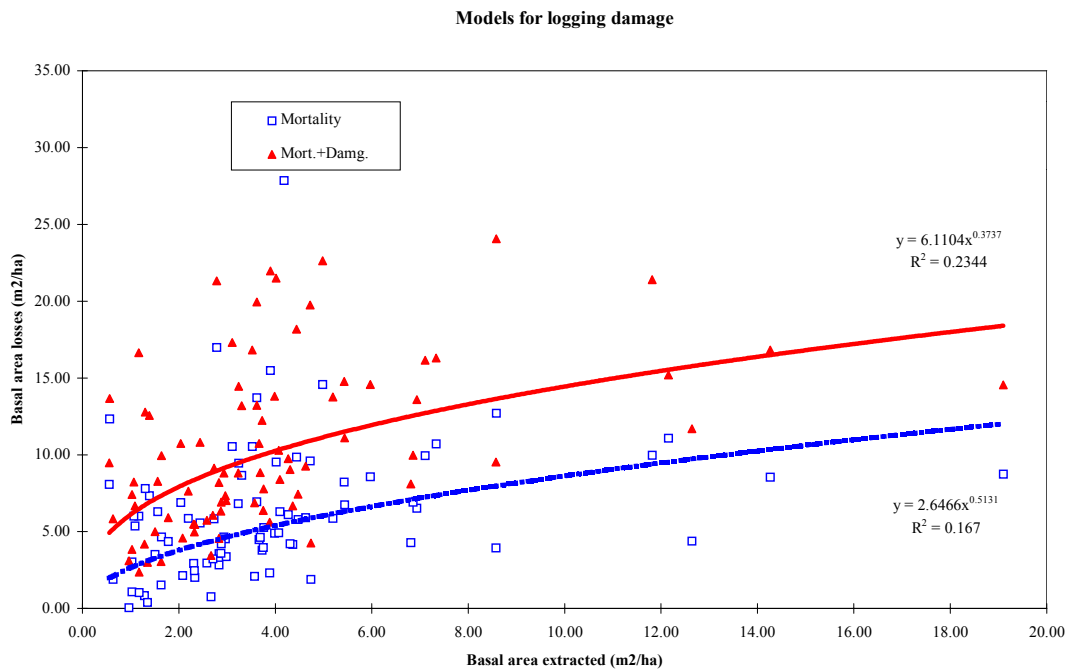
The menu **Models logging damage** has three options:

New data This displays a worksheet with columns for plot, year, harvested, killed, and damaged+killed basal areas. A dialog box allows the worksheet to be updated from the CIMIR file SOMAB.CIM.

Filter data This applies filtering conditions to the data, as discussed on page 18. Groups of plots or measurement years can be selected or excluded from the model.

View graph This displays the data and fitted regression model as a graph, as shown in Figure 10

**Figure 10 Logging damage and mortality models following harvesting**



***Limiting stand basal area increment***

It is a common problem of simple growth models built from individual tree increments that they tend to overestimate growth for stands at high densities. To provide some control for this effect, CAFOGROM, in common with the SIRENA model, uses a function of stand basal area increment to constrain total increment.

The menu **Models basal area dynamics** has three options which are used to set up the whole stand increment model:

New data This displays a worksheet with columns for plot, year, standing basal area, and increment and mortality basal areas. A dialog box allows the worksheet to be updated by importing basal area increment data from the CIMIR file SOMAB.CIM.

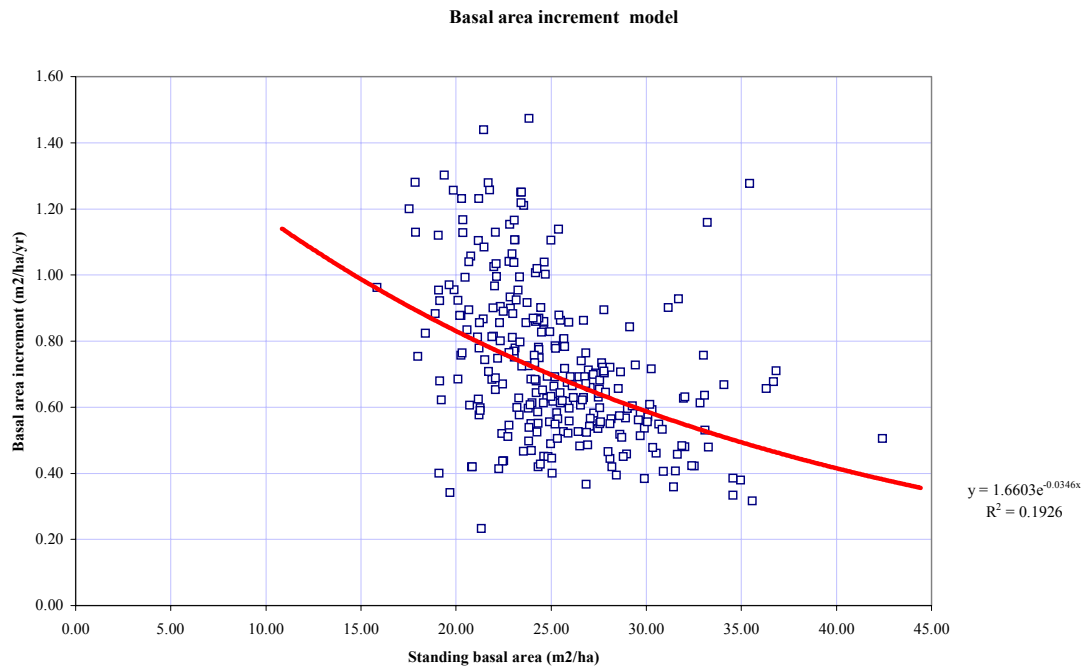
Filter data This applies filtering conditions to the data, as discussed on page 18. Groups of plots or measurement years can be selected or excluded from the model.

View graph This displays the data and fitted regression model as a graph, as shown in Figure 11.

The regression function fitted is:

$$BAI = \alpha \cdot \exp(-\beta \cdot SBA) \quad \{\text{eqn. 5}\}$$

**Figure 11 The stand basal area increment model in CAFOGROM**



where  $SBA$  is standing basal area,  $SBAI$  is basal area increment per annum, and  $\alpha$ ,  $\beta$  are coefficients. This model tends to the increment value  $\alpha$  as stand basal area approaches zero. In the example illustrated stand basal area increment would be about  $1.6 \text{ m}^2/\text{ha}/\text{yr}$  at low densities, and would tend to about  $0.5 \text{ m}^2/\text{ha}/\text{yr}$  at the highest densities observed (35-40  $\text{m}^2/\text{ha}$ ).

In the model, individual tree increments are applied to the largest canopy trees first, progressing to the smaller in the cohort list. If the limiting basal area increment for the stand is reached, then no more increment is added.

If increment is added to all canopy trees without reaching the limit, then the program progresses through the understorey tree list, again from largest to smallest.

No increment is added to trees marked as severely damaged.

This scheme for controlling and adding increment evolved from several possibilities during testing of the program to give the most realistic distribution of size classes over long term projections.

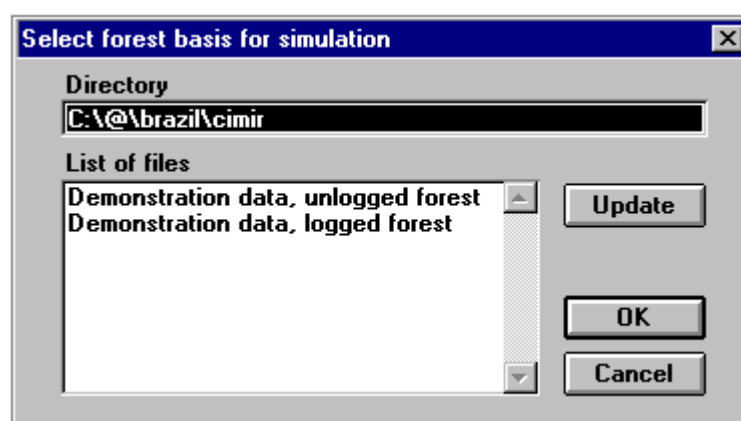
## Forest management options

### ***The forest basis for simulation***

The *forest basis* is the stand which is to be used as the basis for simulation trials. It does not define the growth models, but only the initial stock of the forest at the beginning of the simulation.

Forest basis data is stored in files with the extension .civ. These can be created by CIMIR from subsets of the permanent plot data at the first measurement, as described on page 11.

**Figure 12** Dialog screen to select the forest stand to be used as a basis for simulation



Alternatively, these files can be compiled directly from forest inventory data for simulations of specific forest areas.

The menu choice **Forest management** *Forest basis* brings up a dialog screen as shown in Figure 12 which allows the chosen file to be opened. The directory which contains the .civ files is entered in the *Directory* box. The **Update** button searches that directory and lists the title lines for each .civ file found. Selecting a line and clicking the **Ok** button will make that file the active basis. The title line will appear on subsequent graphs and tables from the model. The **Cancel** button exits from the screen without changing current settings.

### ***Species groups and classes***

The individual species groups that CAFOGROM will recognise depends on the codes found in the data processed under the various **Models** menus. It is important that each group should have a defined model for increment, mortality and recruitment.

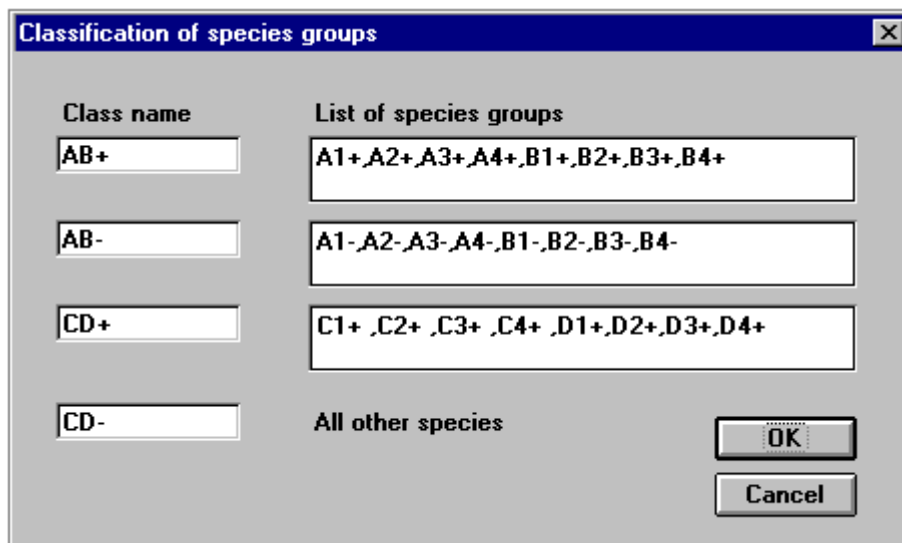
If a species group code occurs in the forest basis file that does not have a defined growth model, then it will default to the last model listed under the **Models** *increment* models menu function (see page 16).

The individual species groups used within the growth model are too numerous to be convenient for defining silvicultural treatments, harvesting options, or outputs from the model. The menu function **Forest management Species groups** allows these individual groups to be re-grouped into 4 broader classes that form the basis for specifying stand treatments, harvesting controls, and the presentation of outputs from the model. These super-groups are referred to as *species classes*.

When the menu choice **Forest management Species groups** is made, a dialog screen appears as shown in Figure 13. Each row defines the members of one of the species classes. The left-hand box, headed *Class name*, gives a short title for the graph. The right-hand box lists the species groups that are members of the class. It will be noted that for the last row, the members of the class do not have to be explicitly listed. Any groups not specified elsewhere will be in this class. The entries should be separated by commas. The + or - designators for commercial and non-commercial species should always be included with the group. There is no validity check on the entries in the list, and bad entries will be ignored. If a species group is assigned to two different classes, it will be treated as occurring in the higher class in the list. If a group name is mis-spelt on entry so that it cannot be recognised, then it will be treated as occurring in the last class.

The **Ok** button will save the defined groups. The **Cancel** button exits without saving the

Figure 13 Dialog screen for the classification of species groups



group definitions. However it is not possible to restore any edits made to the lists, and the **Cancel** button is therefore of limited effectiveness.

The way in which the species groups are used on the various dialog screens and outputs is summarised in Table 4.

**Table 4 Summary of usages for species class codes**

<b>Function</b>	<b>Usage of species classes</b>
<i>Definition</i>	4 species classes are defined under the <b>Forest management Species groups</b> menu. For the first three, the group codes to be included are listed explicitly. The last class is a default, including any groups not listed explicitly.
<i>Outputs</i>	On the graph given by <b>View outputs Volumes</b> , the 4 categories of volume defined under <b>Forest management Volume definitions</b> are given. Each consists of a species class name, in any order, and the minimum diameter for trees to be included in that volume category. On the comparisons graph produced by <b>View outputs Comparisons</b> , the first defined volume from the screen <i>Volume definitions</i> is used for each line from successive simulation runs.
<i>Harvesting</i>	The species classes for those species to be harvested are listed on the screen for <b>Forest management Harvesting</b> , together with applicable diameter limits.
<i>Silviculture</i>	The species classes for those species to be thinned are listed on the screen for <b>Forest management Silvicultural treatment</b> , together with applicable diameter limits.

### **Silvicultural treatment options**

Silvicultural treatment in this model is taken to imply the culling of unwanted trees, by girdling or herbicide treatment. The unwanted trees are usually certain categories of non-commercial species which tend to suppress the growth of more valuable trees, and commercial trees that have been severely damaged by logging or natural causes. These trees are defined as *relicts* in that they will always be left by commercial logging. In reality, treatment is often applied on the basis of spatial criteria: The distance and size of the tree crown relative to a desirable subject tree. Rules for this type of thinning cannot be applied in a non-spatial model. CAFOGROM is limited to defining treatment in terms of the species class, the minimum size to be removed, and whether the trees are relicts or not.

The menu selection **Forest management silvicultural treatment** brings up the dialog box shown in Figure 14. The box labelled *Interval between felling and treatment* gives the time that should elapse between harvesting and treatment. The *basal area to be removed* specifies an upper limit on basal area to be removed. This is taken in combination with the diameter limits. Thinning starts from the largest trees eligible downwards until either the diameter limit for that class is encountered, or the basal area limit for the stand is reached. The *Minimum diameter* boxes give the smallest tree that is to be felled. If the box labelled *Only treat malformed trees* is checked, then only the damaged or malformed trees in the species class will be eligible for thinning. Species classes which are not to be treated should not be listed.

If no treatment is to be done at all, then the *No silvicultural treatment* box should be checked. In this case, the simulation model ignores the various options given and does no treatment.

Figure 14 Dialog screen for the specification of silvicultural treatments

Class of species	Minimum diameter	Only treat malformed trees
AB+	20	<input type="checkbox"/>
AB-	20	<input type="checkbox"/>
CD+	20	<input type="checkbox"/>
CD-	20	<input type="checkbox"/>

The **Ok** button will save the defined options and make them effective for subsequent simulation runs. The **Cancel** button exits without saving the options definitions.

### Harvesting options

Logging or harvesting of trees is controlled by a number of options that are set from the dialog screen shown in Figure 15. This appears after selecting the menu choice **Forest management Harvesting**.

The frequency of harvesting can be controlled by a felling cycle, or by a minimum basal area to be achieved before entry to the stand is allowed. The box labelled *Minimum interval between harvesting* gives the felling cycle. If this is zero, as in the example shown, then

Figure 15 Dialog screen to specify harvesting options

Class of species	Minimum diameter
AB+	60
AB-	60
CD+	60



the timing of felling is determined by stand basal area, set in the box *Minimum basal area before harvesting*. The *Basal area limit for extraction* determines the maximum basal area that may be removed during the harvesting operation. In the example shown, not more than 5 m<sup>2</sup>/ha may be removed. Coupled with a basal area limit of 30 m<sup>2</sup>/ha, this implies a extracting about 15-20% of the stand volume (16.6% of basal area).

The box *First harvest from start of simulation* gives the number of years that pass before any harvesting is done. After the first harvest, the timing of fellings will be controlled either by the felling cycle, or by the basal area.

Diameter limits on species classes are set in the *Minimum diameter* boxes. In no case will trees be felled smaller than these diameters. The check box *Fell largest trees first* determines how harvesting is prioritized in cases where the basal area limits on extraction are a constraint. If only some of the trees above the minimum diameter can be felled within the basal area extraction limit, then larger trees will be given priority if this box is checked. Otherwise, the trees closer to the minimum diameter limit will be felled, and the larger trees will be left as seed trees and for protection. Severely damaged or malformed trees are always left during harvesting. If they are to be felled, this must be specified as a silvicultural treatment.

If the *No harvesting* box is checked, then the stand will not be harvested at any time during the simulation, and any other options on this screen will be ignored. The **Ok** button will save the defined options. The **Cancel** button exits without saving the options definitions.

### **Volume limits for reporting**

Tree volumes are calculated from volume equations entered into the subroutine *VolEqn* on the module sheet *Simulator*. The current form of this equation is:

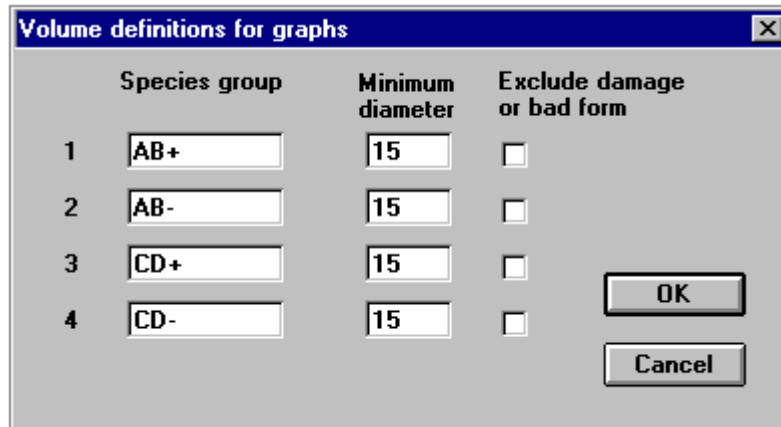
$$V = 0.0004866 D^{2.1809} \quad \{\text{eqn. 6}\}$$

where  $V$  is the commercial volume of the stem, in m<sup>3</sup>, and  $D$  is the diameter at 1.3 m or above buttress. This is the volume equation for Tapajos Forest for trees over 45 cm, derived from Silva (1989). Future releases of CAFOGROM will allow the volume equation to be entered directly by the user or to be fitted to tabulated data.

For reporting output from the model, different minimum diameters may apply to species groups, or to the stand as a whole. The menu selection **Forest management Volume definitions** brings up the screen shown in Figure 16. This allows a minimum diameter to be specified for the commercial volume. It also allows trees with severe damage or bad form to be excluded from the reported volumes.

In the example shown, volume will be calculated to include boles of trees down to 15 cm diameter, and will include both good and malformed trees.

Figure 16 Dialog screen to specify minimum diameters for volumes displayed on graphs



## Running simulation trials

### **Starting a run**

Once the model parameters have been set, and the forest management options defined, the simulation model can be run. This is done from the menu choice **Control Start simulation**. A dialog box will appear requesting a short title for the run. This title is added to graph titles and used as a line label on the comparisons graph, and should be kept as short as possible.

While the simulation is running, the status line at the bottom of the screen will show the current simulated year. It is recommended that one of the output graphs is selected for viewing before starting the run, as this also shows progress of the simulation in a dynamic fashion.

### **Setting the time limit and time step**

The time limit for simulations is set from the menu choice **Forest management time limit**. This brings up a dialog box to enter a time limit. The default, set when the program is started, is 100 years.

The simulator runs on a time step that is given by the program constant YIP, which is defined in a statement near the top of the SIMULATOR module. The definition is in a statement of the form:

```
PUBLIC CONST YIP AS SINGLE = 5#
```

By changing the value 5 to, for example, 2, the program time step will be altered from 5 years to 2 years. The program must be restarted using the **Control System function Restart** menu selection after making this change. It is recommended that a period of between 2 and 5 years is used.

## Output graphs and tables

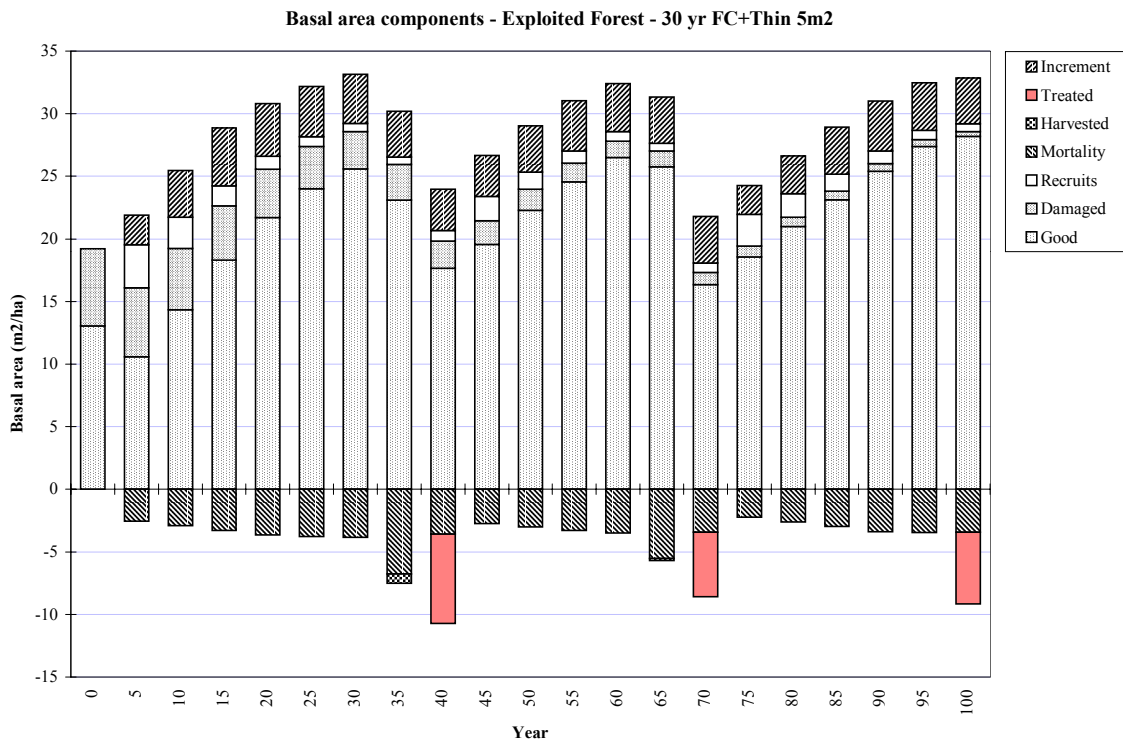
### Basal area components

The menu selection **View outputs Basal areas** offers two sub-menu items. The first, Graph, displays the diagram shown in Figure 17 below. This can be viewed before the start of the simulation, and will develop dynamically over time as the run proceeds. For each simulation period (5 years in the example shown), this graph gives total basal area down to a limit determined by the PSP design of the data supplied to the model. Standing basal area of good and damaged/malformed trees existing at the start of the period are shown immediately above the axis. Added to these are the basal area due to new recruits, and the growth of the standing trees. Below the axis are shown negative components of growth, including losses from mortality, removals in harvesting, and losses due to trees culled during silvicultural treatment.

A second sub-menu, Table, shows the underlying data for the graph. Both the graph and the data can be selected, copied, and pasted into other applications using conventional Windows methods, either for further analysis or for publication.

The graph produced by a simulation run will remain unchanged until a new run is started. The title to the graph is composed of three components which apply to all the the figures under the **View outputs** menu. The left hand part describes the type of graph (*Basal area components*). The central part gives the title for the data set (*Exploited forest*), and the right hand part is taken from the short title for the simulation run (*30 yr FC + Thin 5m<sup>2</sup>*). The title can be selected and edited for presentation purposes.

**Figure 17 Simulation outputs : Graph of basal area components over time**

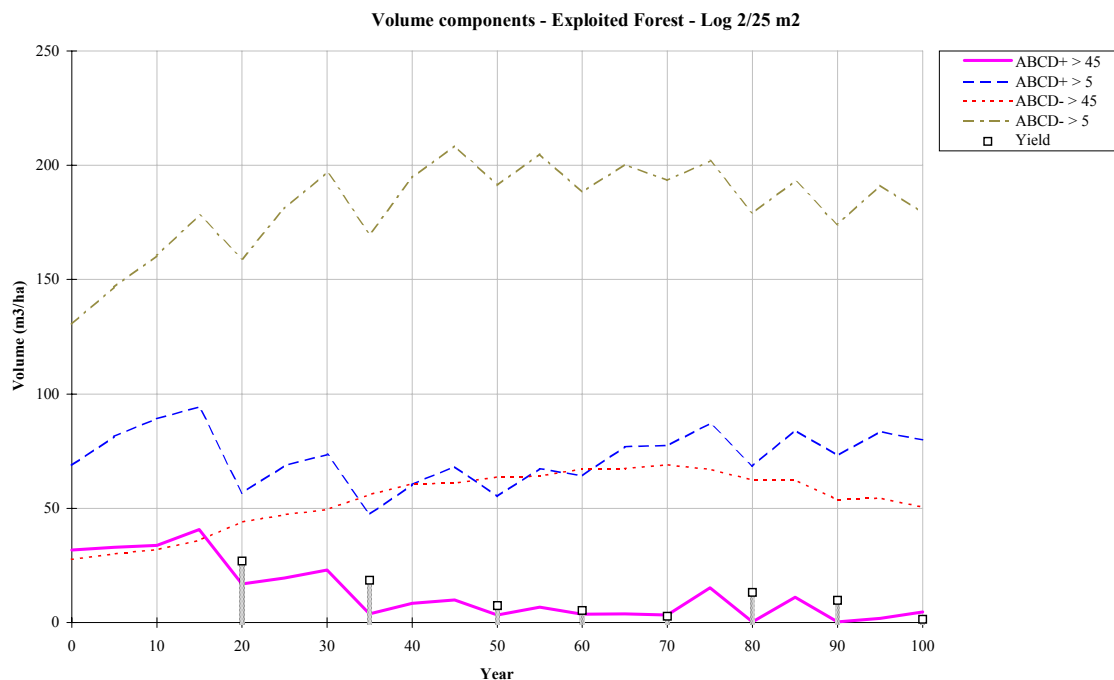


## Standing and harvested volumes

A diagram of standing and harvested volumes is given by the menu selection **View outputs Volumes Graph**. An example is shown in Figure 18 below. The underlying data for this graph can be seen with the menu selection **View outputs Volumes Table**. As with other output graphs, this can be selected before the simulation run is started, and will develop dynamically during processing. Alternatively, at the end of the simulation run, the various graphs can be viewed and printed in turn.

The graph always shows data series for five items. Four lines represent the four

**Figure 18 Simulation outputs : Graph of standing volumes for selected species classes and size limits**



categories of standing volumes defined by the **Forest management volume definitions** menu choice (see page 29). The vertical bars and square symbol show the volumes actually extracted. These are positioned at the end of the period in which the harvesting takes place. For example, if harvesting is specified for year 15, the output volume will be shown in year 20. The model assumes harvesting takes place continuously over the time step, and shows the accrued value at the end of the interval.

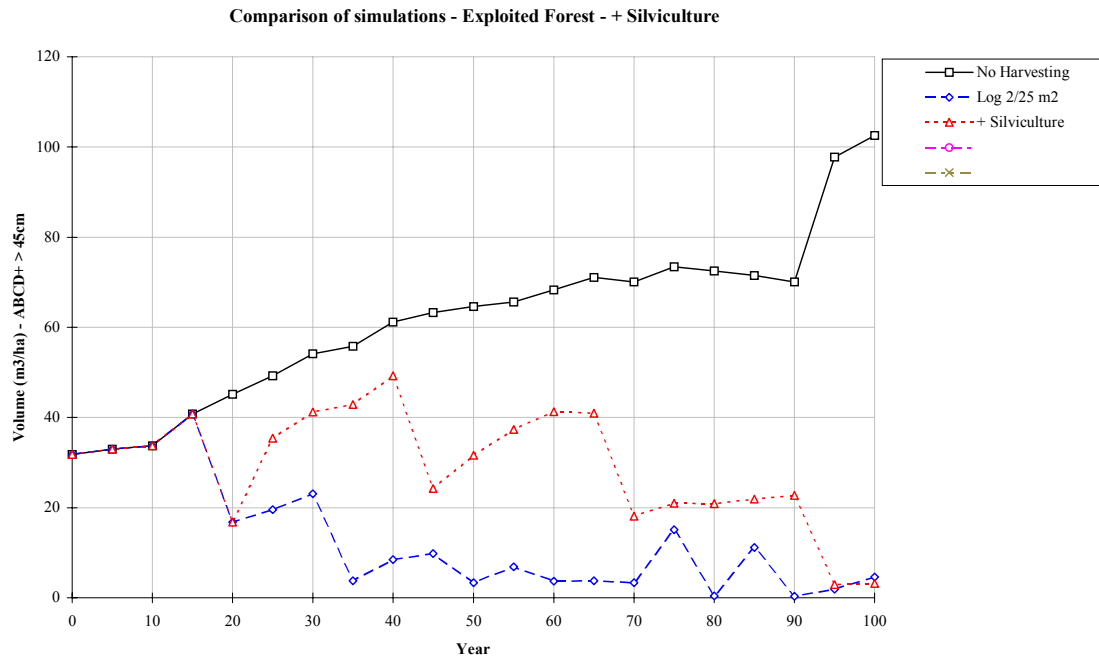
## Comparison of volumes between simulations

The menu selection **View outputs Comparisons Graph** shows a graph that compares successive simulation runs. Up to five runs can be compared. Each run produces a single line, corresponding to the first defined volume in the **Forest management volume definitions** dialog (page 29). The symbols for the lines are assigned automatically, and a legend uses the short title for each simulation as a label for the lines. An example is shown in Figure 19.

The successive runs can be chosen to contrast successive features of interest, either using different forest bases with the same management options, or different silviculture and harvesting options. It is also possible to run identical data and management scenarios but

with different size limits selected. Sensitivity tests on the model can be carried out by changing aspects of the parameterization under the various **Models** sub-menus, and then

**Figure 19 Simulation outputs : Graph comparing successive simulations runs**



re-running the simulation.

In the example shown, three regimes are compared for a forest heavily exploited before the start of the simulation. The first is without harvesting. The second is for extraction under basal area control of 2 m<sup>2</sup>/ha when the stand attains 25 m<sup>2</sup>/ha or more, giving approximately a 10 year felling cycle. The third regime uses the same specification for harvesting, but with thinning of up to 5 m<sup>2</sup>/ha of the largest non-commercial stems. The volumes shown in all cases are for commercial species over 45 cm diameter.

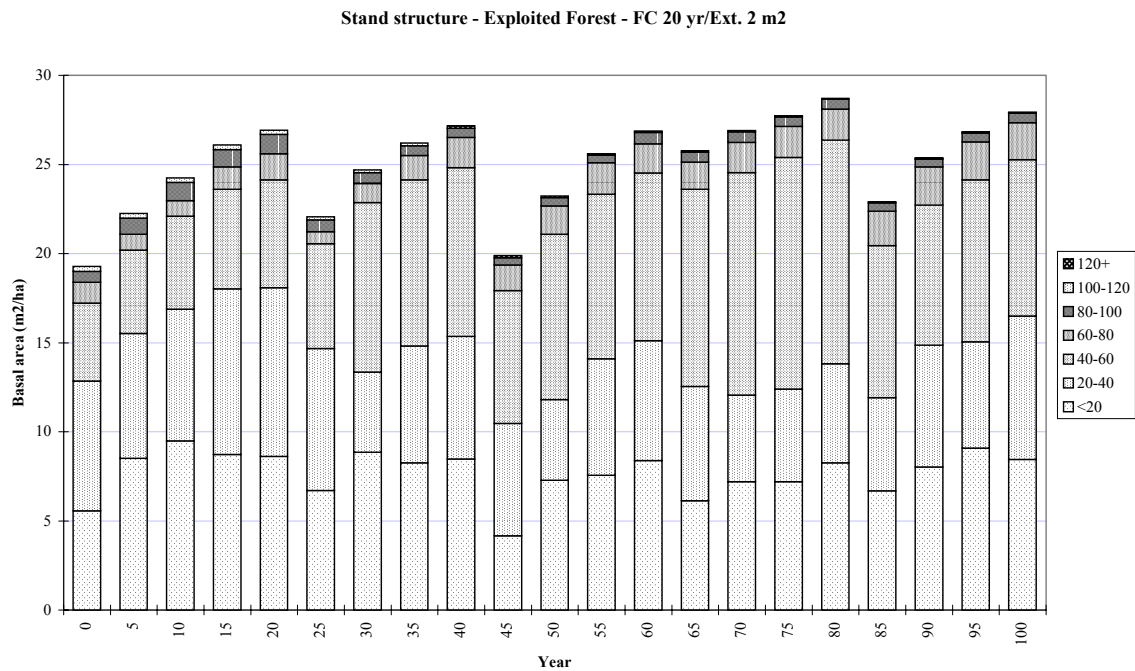
The title generated by the system for the comparisons graph is rarely appropriate and will normally need to be edited for publication or presentation purposes. As with other output graphs, it summarises the type of graph, the name of the data set, and the run title for the most recent simulation. The title can be edited by selecting it with the mouse and typing in new text. The edited version will be over-written when the model is re-run, so this should be done immediately before copying or printing the desired version.

The comparisons graph is cleared when starting CAFOGROM either directly from Excel or Windows, or via the **Control System functions Restart** menu. The **Forest management Clear comparisons** menu also clears the comparisons graph without affecting any other aspect of the model. A maximum of five lines are shown on the graph, so the sixth run in a series will over-write the first legend entry and line, the seventh run the second line, and so on.

### Stand structure: Basal area by size classes

The menu selection **View outputs BA by size class Graph** shows a graph of the distribution of basal area by size classes over time. This provides a sensitive test of the validity of the model by comparison with real size distribution data. It can also be used in planning the specifications for harvesting and thinning treatments under basal area control, by showing the sizes of trees that would be affected by different levels of extraction or treatment. The example shown is for a forest operated under a 20 year felling cycle.

**Figure 20 Simulation outputs : Graph of basal area by size classes**



## Control functions

### ***Exiting to Excel and Windows***

CAFOGROM can be terminated by leaving either to Excel or to Windows. The menu choice **Control Exit Cafogrom** offers two sub-menus: to Excel or to Windows. The appropriate selection invokes the indicated action.

When exiting the model to Windows, its current status is always saved. Exiting to Excel does not cause a save operation, but Excel will request this when leaving to Windows. The model can be re-started manually from Excel by running the AUTO\_OPEN macro from the **Tools macro** menu.

### ***Printing, copying and sizing outputs***

Any displayed chart or worksheet can be printed by viewing it, and then selecting **View outputs print**. This will bring up the standard Excel print dialog box which allows various facets of printer use to be customized. The printer, paper size, and header or footer titles can be modified as required. It is also possible to print a selected part of a worksheet or graph. However, *do not* select the *Entire workbook* option, as the output produced will run to several hundred pages of program code, data listings, and other unwanted items.

Charts and worksheets can be copied to the Windows clipboard for importation into word processors or other programs. For a chart, select the outside margin of the chart with the mouse, and then copy it to the clipboard with CTRL+C. For a worksheet, select the desired area of the table before pressing CTRL+C.

When importing graphs and tables into *Microsoft Word*, it is recommended that pasting is done using the **Edit Paste special** menu, and selecting *Picture* format. This gives a better result than importing the item as an Excel object.

When charts are viewed in the model, they may not be properly sized for the screen. This can be corrected by selecting the outer margin of the chart with the mouse and then using the **Control System functions zoom** menu. The latter may be repeated if the desired effect is not achieved at the first use, as the function acts as a toggle between enlarged and normal views of the graph.

Selecting a part of a graph and then zooming in on it can be useful for reading fine detail such as some of the equations on the graphs under the **Models** menu.

### ***Error conditions and program restarts***

A number of conditions may cause CAFOGROM to crash. These include internal, as yet unidentified bugs, the setting of inappropriate models, or use of inappropriate data. Also, if graphs are edited in Excel and objects deleted from them, or the type of graph changed, the program will probably not be able to function.

When the program crashes a screen appears with the error type and number, such as for example *Error 91 : Object not found*. The **End** button should be selected on this screen to close the program. The CAFOGROM menu choice **Control System functions re-start** then re-starts the model.

Note that the program *must be re-started* after an error. If menu selections are made after selecting **End** from the error window, many program variables will be undefined and the program will not function.

After a re-start, a number of items will be reset to default values:

- The selection of a forest basis file will need to be made, and will be requested when the model is first run.
- The simulation time will be reset to 100 years.
- The comparisons graph will be cleared.
- Worksheet tabs will be re-hidden if they have been switched on.

For help or more information on error conditions, I can be contacted by fax or E-mail on:

Fax:           00 44 1865 60780  
E-mail:       d-alder@zynet.mail.co.uk

To assist in providing diagnostic information it is helpful when the error screen appears to press the **Debug** instead of the **End** button, and then to copy the entire screen to the clipboard. This can then be attached to an E-mail as a Word document, or printed and sent via fax.

The **Control System functions** menu functions Show tabs and Edit worksheet are designed for development purposes and for debugging. Show tabs displays normal worksheet tabs and allows movement between worksheets other than by the CAFOGROM menu selections. It also enables access to a number of hidden sheets such as the program modules. Edit worksheet releases protection on a sheet and allows objects and data to be modified. *Neither of these functions should be used casually.* Both are revoked when re-start is selected.

### ***Saving the current model status***

CAFOGROM is always saved when exiting to Windows. This process involves over-writing the CAFOGROM.XLS file with a new version that includes all current models, data, graphs, options, and so on. *It is very important* to keep a secure backup of CAFOGROM.XLS in a directory other than the working directory in case the system is saved in an unworkable state.

The model can also be explicitly saved in its current state via the menu selection **Control System functions** save.



### ***Switching between language versions***

CAFOGROM contains menu texts, table and graph captions and dialog messages in English and Portuguese. By selecting the appropriate language from the **Control Select language** menu, a translation process will be invoked. Translation also re-starts the model, so some conditions will be reset by this choice.

## CAFOGROM limitations and developments

### *Limitations of the model*

CAFOGROM places responsibility for supplying growth data and developing suitable growth models on the user. The various functions supplied under the **Models** menu automatically fit models to data, but suitable filtering conditions need to be selected and adjustments made.

If inappropriate or inadequate data is supplied, or the filtering conditions and adjustments not made in the best way, then the basic models may give quite inaccurate results.

The forest basis data should also be compatible with the fitted models in some degree, from similar forest types and species mixtures.

### *Further developments*

CAFOGROM is likely to have the following features added in future versions:

- A diagram and table showing basal areas by species groups and size categories for the current time period.
- A more flexible basal area increment/mortality model to define limiting increment and mortality. This would replace the current graph and functions under the **Models basal area dynamics** menu.

Options for total run time, time step, and cohort width resolution are likely to be placed on a single dialog screen, instead of the latter two being modified in the program code as at present.

- A field to enter the title for the comparisons graph will be added to a screen to reset comparisons, instead of using the generated title for the current run.
- More options on species grouping are likely to be added to CIMIR.
- Error handling and robustness of the model will continue to be improved.

For current information and versions of the model, or for general discussions concerning its use, contact me at the addresses given on page 35.

Denis Alder  
Oxford  
September 1996.

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## Appendix A : Field definitions in CIMIR files

Table	Field	Type	Description
CIMIR	IDPARC	C 10	Plot identity, constructed as area-block-plot
	IDARV	C 6	Tree identity, constructed as quadrat-tree
	ANMED	C 4	Year of measurement
	IDESP	N 4	Internal species code
	DAP	N 5.1	Mean diameter, cm
	INCD	N 5.2	Mean increment cm/yr
	CORT	L 1	TRUE if only a cut stump was recorded
	MORT	L 1	TRUE if the tree was dead or fallen
	RECR	L 1	TRUE if the tree is a recruit
	TRAT	L 1	TRUE if the tree has been poisoned or ring-barked
	ILC	N 1	Crown illumination class
	DANO	L 1	TRUE if the tree has severe damage
	FRM	L 1	TRUE if the tree has no commercial log due to bad form
	FCL	N 1	Forest class (gap phase)
ERRC	N 1	Error code for increment. 0=valid increment.	
CIMESP	IDESP	N 4	Internal species code
	GRUP	C 3	Species group code
	GENSPP	C 9	Genus-species code. 5 letters of genus + 4 letters of species
	NOMESP	C 30	Botanical name
	NARV	N 6	Number of trees of this species observed
	LOCALCODE	C 8	Code in the SFC species list last read
	COMERC	L 1	TRUE if classified commercial in any SFC species list
DESIGN	LOCATION	C 20	Plot location in text
	ACODE	C 4	Area code for the location
	PSIZE1	N 5.2	Plot size in ha.
	DMIN1	N 4.1	Smallest diameter measured on the whole plot.
	PSIZE2	N 5.2	Sub-plot size in ha.
	DMIN2	N 4.1	Smallest diameter measured on the sub-plot
	SPLIST	C 12	Local SFC species list file name
SOMAB	IDPARC	C 10	Plot identification, Area-block-plot
	ANO	N 4	Year
	INTMD	N 2	Measurement interval from the last measurement
	SBA	N 7.3	Basal area, m <sup>2</sup> /ha of undamaged trees of good form
	DBA	N 7.3	BA of damaged trees
	FBA	N 7.3	BA of malformed trees
	UBA	N 7.3	BA of understorey trees
	RBA	N 7.3	BA of recruits adjusted to annual basis, m <sup>2</sup> /ha/yr
	SBAT	N 7.3	Total live basal area
	SBAI	N 7.3	BA increment on live trees, m <sup>2</sup> /ha/yr, excluding recruitment
	MBA	N 7.3	BA of mortality, adjusted to annual basis, m <sup>2</sup> /ha/yr
	HBA	N 7.3	Harvested BA, cut stumps using last measured diameter
KBA	N 7.3	BA of all trees recorded as treated (alive or dead)	
INCMED	GRUP	C 3	Species group
	NDC	N 2	Diameter class index (used only for sorting - classes are unequal)
	SBQ	N 1	Canopy class. 0=canopy, 1=understorey
	DMED	N 16.2	Mean diameter of class, cm
	MEDINC	N 16.2	Mean increment of class, cm/yr
	NT	N 10	Number of trees in the class
	SSD	N 27.4	Raw increment sum of squares of deviations from the mean

<b>Table</b>	<b>Field</b>	<b>Type</b>	<b>Description</b>
MORTAL	GRUP	C 3	<i>Species group</i>
	NAVDANO	N 6	<i>Number of damaged trees observed (alive and dead)</i>
	RMADANO	N 7.3	<i>Annual mortality rate % of damaged trees</i>
	NAVSBQ	N 6	<i>Number of understorey trees observed</i>
	RMASBQ	N 7.3	<i>AMR% of understorey trees</i>
	NAVBASE	N 6	<i>Number of undamaged, canopy trees observed</i>
	RMABASE	N 7.3	<i>AMR% undamaged, canopy trees</i>
INGRESSO	NRC	N 1	<i>Recruitment class, 1&lt;0.3 m<sup>2</sup>/ha/yr, 3&gt;0.7 m<sup>2</sup>/ha/yr, 2=others</i>
	GRUP	C 3	<i>Species group</i>
	NAVHA	N 12.3	<i>Percentage of total recruitment numbers in that class</i>
	DMED	N 12.2	<i>Mean diameter of recruits</i>
CLASSAB	IDPARC	C 10	<i>Plot identification, Area-block-plot</i>
	ANO	N 4	<i>Year</i>
	BA1	N 7.3	<i>Basal area, m<sup>2</sup>/ha, for trees less than 20 cm</i>
	BA2	N 7.3	<i>BA, trees 20-39 cm</i>
	BA3	N 7.3	<i>BA, trees 40-59 cm</i>
	BA4	N 7.3	<i>BA, trees 60-79 cm</i>
	BA5	N 7.3	<i>BA, trees 80-99 cm</i>
	BA6	N 7.3	<i>BA, trees 100-119 cm</i>
	BA7	N 7.3	<i>BA, trees 120 cm or larger</i>

## Append B : Workbook structure in CAFOGROM.XLS

The worksheets listed below are in the order in which they occur in the CAFOGROM.XLS workbook.

Sheet	Type	Description
FrontCover	Worksheet	Main title page for the model, shown on start-up
DanoGraf	Chart	Graph of logging damage models and data
DanoData	Worksheet	Data for logging damage model
DanoProg	Module	Programs relating to logging damage analysis
BAMlgraf	Chart	Graph of stand basal area increment models and data
BAMldata	Worksheet	Stand basal area increment data
BAMlprog	Module	Programs relating to stand basal area increment analysis
IngList	Worksheet	Recruitment frequencies by species groups
IngData	Worksheet	Recruitment basal area data
IngGraf	Chart	Graph of recruitment data with fitted model
IngProg	Module	Programs for recruitment model analysis
UsData	Worksheet	Data for the understory basal area model
UsGraf	Chart	Graph of understorey basal area data and model
UsProg	Module	Programs for the analysis of understorey data
MortModl	Worksheet	Mortality rate data
MortProg	Module	Programs for mortality rate analysis
IncModl	Worksheet	Table of increment model coefficients
IncGraf	Chart	Graph of increments with canopy and understorey models
IncData	Worksheet	Increment data for the currently viewed species group
IncProg	Module	Programs for diameter increment model analysis
MenuText	Worksheet	Bilingual texts and control information for the menu system
SetGraph	Module	Program to redefine all graph and table captions by language
Menu	Module	Initialization and utility programs for the user interface
BAsizeG	Chart	Graph of simulated basal areas by size class over time
BAsizeT	Worksheet	Tabulated data for the above graph
BAgraf	Chart	Graph of basal area components over time
BAtable	Worksheet	Tabulated data for the above graph
CompGraf	Chart	Graph comparing volumes between simulation runs
CompTable	Worksheet	Tabulated data for the above graph
VolGraf	Chart	Graph of volumes by groups over time
VolTable	Worksheet	Tabulated data for the above graph
Simulator	Module	Main simulation program
Texts	Worksheet	Bilingual texts for captions and messages
ForBasis	Dialog	Screen for inputting simulation basis options
SilvOpt	Dialog	Screen for inputting silvicultural treatment options
HarvOpt	Dialog	Screen for inputting harvesting options
GrupOpt	Dialog	Screen for inputting species group options
VolOpt	Dialog	Screen for inputting size limits for volumes on graph
Dialogs	Module	Programs to organize dialog boxes and translate captions