

SIRENA

*A simulation model for tropical forest management in
Northern Costa Rica*

User's Guide and Technical Notes

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Executive Summary

SIRENA is a simulation model of natural tropical forest in northern Costa Rica. It is based on the analysis of 32.75 ha of permanent plots, some of 1 ha and some of ¼-ha design, established and measured by CODEFORSA and Portico. The model is programmed in Visual Basic for Excel and is a Microsoft Windows compatible system. It accepts inventory data from a variety of sources, provided all species are measured, with sampling or sub-sampling down to 10cm. Only diameter, species, and plot number are needed.

Harvesting can be specified in the model by felling cycle or under basal area control. Diameter limits and volume retention can be given by species groups or set quickly to the legal standard of 60 cm with 40% retention by volume. Species groups are defined from commercial codes applicable to either CODEFORSA or Portico, or by user-defined categories involving mixtures of basic growth models. Silvicultural treatment can be specified as an initial operation or within the felling cycle, and as a basal area reduction by species groups.

Outputs are in the form of graphs and tables, which can be selected by menu as alternative 'views' of forest structure and composition over time. A basal area graph shows components of growth, mortality, recruitment, harvesting, logging damage, and treatment. A volume graph gives commercial volumes above the diameter limit specified, standing and removed in harvesting. Stand structure is shown as basal areas by size classes and species groups. This graph can be stepped through time. A comparison graph can be set to plot volumes for successive runs of the model. These volumes may be any selected group, and above any defined tree diameter. A basic management table is produced which gives stem numbers, basal areas, volumes, increments, and extracted volume on a single output. All the outputs can be printed or selected and copied to other documents within the Windows operating system.

The report documents the use of the program and also describes the underlying analysis. 17 species groups were formed from ordination based on mean increment and largest tree size. Tree increment was modelled using a power function of tree basal area increment on tree basal area, adjusted for the proportion of zero increments. Mortality was derived as group averages. Recruitment proportions were averaged by groups for two distinct forest types, distinguished by the presence or absence of the *Vochysia/Dipteryx* association. *Carapa*-rich forests generally lack *Vochysia* and have a different regeneration mix. These models were applied to cohorts which were grown and adjusted quantitatively over 2-year time periods. Stand density effects were controlled via a basal area sub-model which defined basal area increment, mortality and recruitment as functions of standing basal area. Individual species growth was limited to the overall stand values and apportioned in a fashion biased by size, with larger trees growing preferentially, and smaller trees dying under conditions of limiting basal area. Logging damage functions were derived from a CODEFORSA study on six forests with low-impact logging. Gaps and trails were modelled by reduction in small tree stockings. Severely damaged residuals of all sizes were assumed to die.

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Abbreviations and symbols

CATIE.....	Centro Agronomico Tropical de Investigación y Enseñanza
CODEFORSA.....	Comisión para el <u>D</u> esarrollo <u>F</u> orestal de <u>S</u> an Carlos
ITCR	Instituto Tecnológico de Costa Rica
ODA	United Kingdom Overseas Development Administration
Portico	Tecnoforest del Norte SA.
SIRENA	<u>S</u> imulacion del <u>r</u> endimiento de bosque <u>n</u> atural

*.....Indicates SIRENA menu choices

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Introduction

SIRENA is an acronym for *Simulación del Rendimiento de Bosque Natural*. It is a simulation model for natural tropical forest management in the northern region of Costa Rica. It has been developed as part of the ODA project for integrated forest management being undertaken in cooperation with CODEFORSA.

SIRENA is based on the CAFOGROM model developed for the Brazilian Amazon¹. However, the original model has been completely reworked in order to adapt to differences in the data available. At the same time, the model has been re-written in Visual Basic for Excel, rather than in C as in the case of CAFOGROM. Although it remains a complex program, it is hoped this will provide an easier learning curve for students of forest modelling techniques. It also provides for a better user interface, compatible with Microsoft Windows, Excel and Word in all respects.

This document provides in a condensed format a user's guide to the program, and a technical description of the data analysis undertaken to develop model functions.

User's guide to SIRENA

Starting the program

SIRENA is contained in the file SIRENA.XLS, which is an Excel workbook file. It can be started by clicking on the file name within the Windows file manager, or by opening the file from Excel. In either case, the simulation program starts automatically, replacing the standard Excel menus and toolbars with those of SIRENA.

When the program is started, it will normally 'remember' options and datasets loaded in the preceding run, so that it is not necessary, for example, to read in forest data on each occasion, but only when a new forest is being studied.

However, certain aspects of the program are reset as default values when the program is started, or when **Función*Re-inicializar* is selected from the menu. These defaults are shown below:

Default values on starting the program or re-initialization

Length of simulation	40 years
Harvesting	None
Treatment.....	None
Species groups.....	Undefined
Inventory data.....	As carried over from last simulation

¹ Alder (1995) Growth Modelling for Mixed Tropical Forests. Department of Plant Sciences, University of Oxford, Tropical Forestry Paper 30. See pages 165-176.

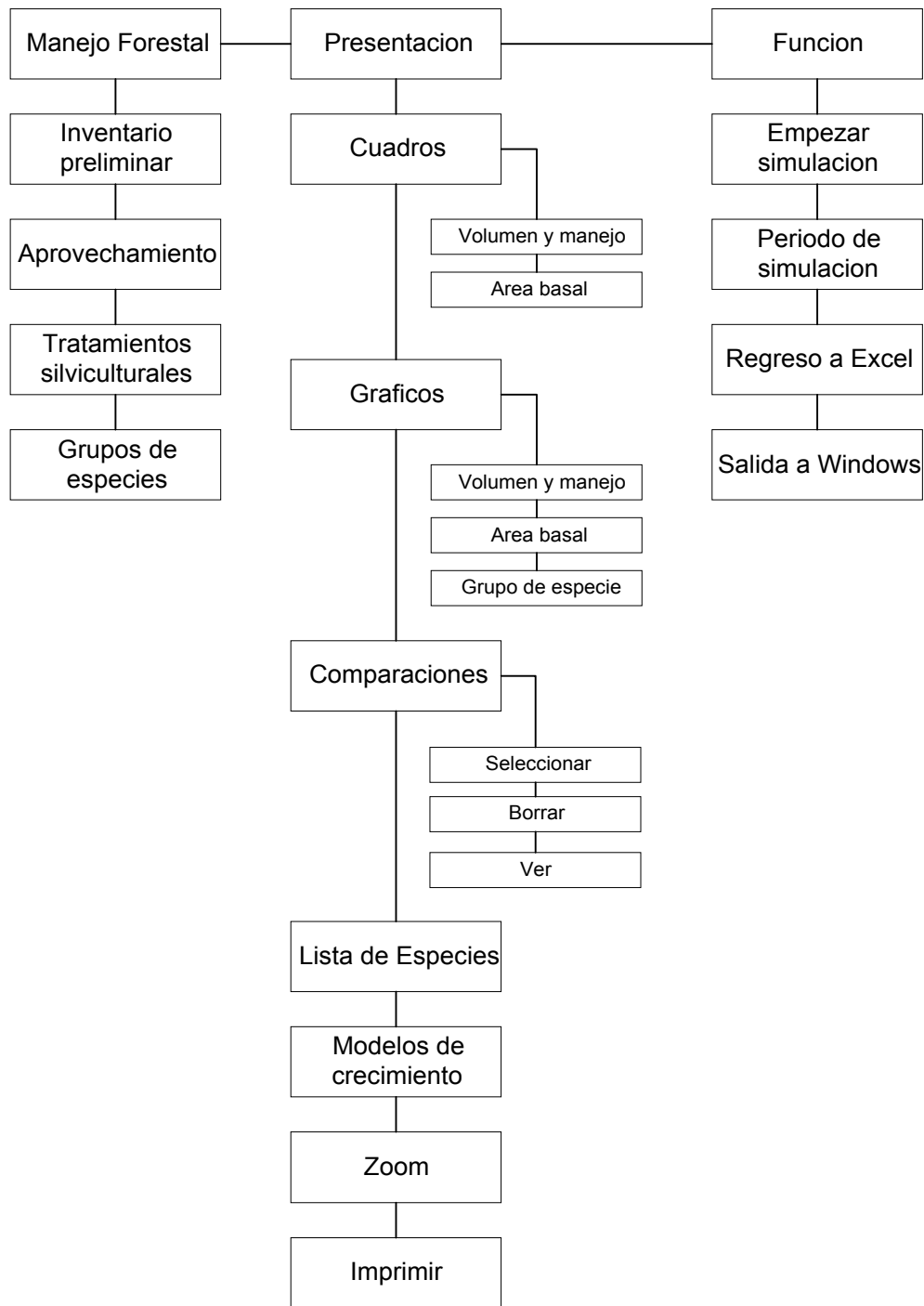


Figure 1 The SIRENA menu system

When the program starts, the SIRENA menu system is displayed. The complete set of menu options are shown in Figure 1.

Forest management options (*Manejo forestal)

Setting the forest inventory basis (*Inventario preliminar)

To provide SIRENA with information about the forest to be simulated, a file of forest inventory data must be read in. This need only be done once, as the summarised inventory data is then stored in the SIRENA.XLS file until a new file is input.

The forest inventory data must satisfy the following conditions:

- All species should be measured down to 10 cm on a main plot or sub-plot.
- The species codes should be according to the *CODEFORSA* or *Portico* species lists.

A variety of different types and formats of inventory file can be processed.

Figure 2 Inventory data options screen (*Inventario preliminar)

Figure 2 shows the screen form which appears when the menu selection **Inventario preliminar* is made. The various fields which should be completed are as follows:

<i>Nombre de bosque:</i>	This is a title which appears at the top of any printed output.
<i>Area:</i>	This gives the effective forest area. In this version of <i>SIRENA</i> no use is made of the area information.
<i>Sistema de codigos:</i>	A pull down list offers a choice of <i>CODEFORSA</i> or <i>Portico</i> species codes. This relates to the species numbering system used in the data.
<i>Archivo:</i>	The file name, with extension, containing the inventory data.
<i>Tipo:</i>	A pull-down list of recognisable file types, including DBF(dBase/FoxPro), WQ1 (Quattro files), WK1 (Lotus 123), XLS (Excel worksheet), and TXT (text format using values separated by commas).

<i>Directorio:</i>	The directory where the file may be found.
<i>No. de parcela:</i>	The column in the data which contains plot number or plot identification. Changes in the value of this field are used to count plots. It may not be blank (lines with a blank plot identification are ignored).
<i>Código:</i>	The column in the data containing the species code.
<i>Diámetro:</i>	The column number containing tree diameters.
<i>Primera fila de datos:</i>	The first row in the datafile that contains valid inventory data. This allows any preliminary text information in the file to be skipped.
<i>Area - Parcela:</i>	The area of the main inventory plot, in ha.
<i>DAP min. - Parcela:</i>	The smallest tree measured on the main plot.
<i>Area - Sub Parcela:</i>	The area of subplots on the main inventory plot, in ha.
<i>DAP min. - Sub Parcela:</i>	The smallest tree measured on the sub-plot.

The example shown in Figure 2 is for a typical CODEFORSA inventory extracted from the PLANMAN inventory file.

The relevant column and starting row information can be seen for any inventory file by opening the file in Excel and reviewing which columns are used for plot number, species code, and diameter.

The buttons at the top right of the screen form control program action once the parameters have been filled in. If *Cancelar* is pressed, no data will be read, and the parameter entries will be forgotten, with the screen reverting to its initial values.

When *Aceptar* is pressed (the usual option) then SIRENA will attempt to open the data file. If it does not succeed (due to a wrong file name or a clash in file access on the network), then an error occurs. The user should select *End* to revert to normal operation of SIRENA. If the file is opened successfully and the formatting information is correct, then the inventory file will be seen briefly on the screen in Excel worksheet format, after which SIRENA will revert to displaying the underlying screen without further messages. This shows that the data has been read correctly.

If the wrong columns have been specified in the data, results will be unpredictable. The system may fail. In this case, select **Función *Re-inicializar* to restart. Alternatively, the data may be read, but appear somewhat bizarre on the initial graphs and tables. This could happen for example, if the height column was specified instead of diameter.

Setting the species groups (Grupos de especies*)**

Although the menu item **Grupos de especies* is at the bottom of the **Manejo forestal* menu, it is logically the next operation that should be performed after reading inventory data. This menu option should always be entered and explicitly selected after:

- Starting the program from Windows or Excel
- Re-initializing the program via the **Re-inicializar* menu selection

If this is not done and the species groups are undefined, the program will fail. In that case, use **Re-inicializar* to restart.

The screen form for definition of species groups is shown in Figure 3.

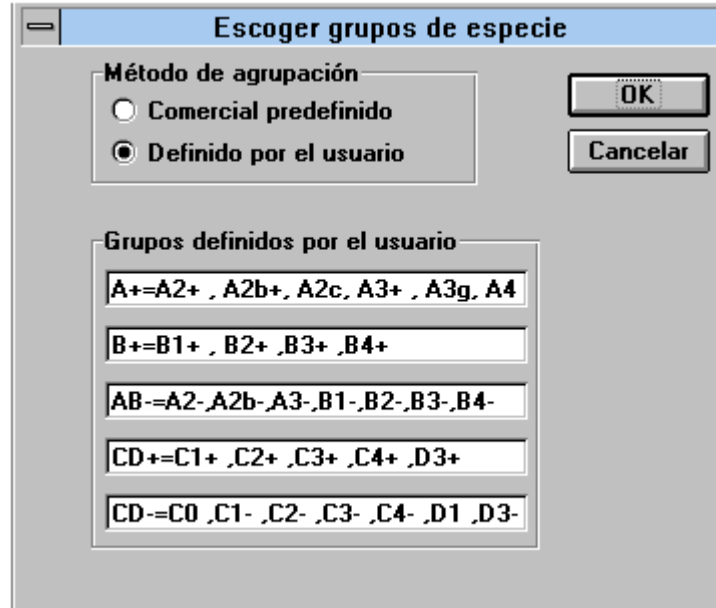


Figure 3 Selection of species groups(* *Grupos de especies*)

The method of grouping may be either with the predefined commercial groups (*comercial predefinido*) or by combinations of basic model groups selected by the user (*definido por el usuario*).

If pre-defined commercial groups are selected, then one of the species group columns in the species list is selected, based on the type of species coding system in the inventory data.

For the user-defined groups, up to 5 groups may be defined. These control how the output is summarised in the graphs. The general syntax is:

name=group list

The name can be any text, but as it appears on the graph legends, it should not be too long or the graph formatting will be distorted.

The group list must use one of the symbols relating to species groups. These groups combine information about tree size and growth rate. Table 1 shows the groups identifiers recognised by SIRENA.

Mod- elo	Typical species	Increment model			Mortality %/yr	DiamMax (cm)	Recruitment \geq 10 cm		
		% zero	α	β			+A4	-A4	Comm %
A2	Tabebuia	18.9	1.829	0.476	3.4%	160	1.3%	0.7%	93%
A2b	Inga, Pterocarpus, Ficus	24.3	1.722	0.503	3.5%	160	3.9%	6.9%	20%
A2c	Caesalpinia	13.8	1.673	0.486	1.8%	160	0.2%	6.4%	100%
A3	Dalmanella, Luehea	14.7	2.422	0.468	2.4%	160	1.4%	5.6%	60%
A3g	Pentaclethra	12.2	3.304	0.417	3.4%	160	1.1%	20.0%	99%
A4	Vochysia, Dipteryx	9.1	1.913	0.533	2.8%	160	5.0%	0.0%	100%
B1	Eleocharis, Guarea, Licania, Dendro	34.4	2.922	0.384	3.5%	80	9.7%	5.4%	41%
B2	Qualea, Pouteria, unknowns	18.9	1.169	0.559	4.2%	80	35.7%	14.4%	76%
B3	Virola, Vatairea, Pithecellobium	15.3	2.244	0.477	3.9%	80	12.1%	5.8%	37%
B4	Goethalia, Sclerobium	33.9	1.620	0.611	5.3%	80	4.8%	13.2%	100%
C0	Welfia	67.0	23.465	0.013	3.5%	40	4.0%	0.3%	0%
C1	Hippotis, Socatea, Ferdinand	30.5	2.508	0.402	3.3%	40	8.8%	2.0%	17%
C2	Protium, Miconia	16.6	0.847	0.621	3.2%	40	7.4%	4.2%	35%
C3	Tapiria, Trichilia, Mabuetia	11.8	5.234	0.342	3.9%	40	2.9%	4.2%	58%
C4	Eschweilera, Xylopia	29.1	2.335	0.527	0.8%	40	0.6%	0.1%	100%
D1	Astrocaryum	97.7	0.279	0.876	2.6%	20	0.6%	7.0%	0%

Table 1 Growth model groups and parameters used in SIRENA

The groups can be suffixed by the notations + and - to indicate only commercial and non-commercial components.

Thus in the example shown, the A+ group comprises all large commercial species. B+ includes medium sized commercial trees. AB- consists of large and medium sized non-commercial species. CD+ and CD- are respectively commercial and non-commercial small trees.

Some groups comprise only a small number of species. For example A2c consists only of *Carapa* species, A2g is only *Pentaclethra*, and A4 is only *Vochysia* and *Dipteryx*. This reflects the large numbers of trees in these genera on the permanent sample plots, allowing them to be analysed individually or as small groups. Other groups are mostly diverse and comprise numerous species. In SIRENA, the species list can be viewed from the menu to see exactly which species are in each group. This is discussed on page 15 ff.

The groups were formed on the basis of tree size and growth rate. The letter indicates trees of decreasing maximum size, and the number increasing growth rate. A third letter is added (eg. A2c) where special factors allowed the formation of a distinct sub-group.

Setting options for harvesting (**Aprovechamiento*)

The screen which appears when the menu choice **Manejo forestal*Aprovechamiento* is selected is shown in Figure 4 below. This allows the various options for harvesting to be set. The check box controls on this screen have differing levels of priority and will override settings of lower priority.

Grupo de especies	Diámetro mínimo, cm	Volumen remanente %
A+	60	60
B+	60	60
AB-	60	60
CD+	60	60
CD-		100

Figure 4 Screen for setting harvesting options

The check box *Simulacion sin aprovech.* (Simulation without harvesting) has the highest priority. If checked, all other options on the screen are ignored, and the model will run without doing any harvesting. This is designed to allow a quick baseline study of how the forest could develop.

The box labelled *Control por area basal* determines the timing of fellings. If this box is cleared, then felling will be done in accordance with the felling cycle periods. If the box is checked, then timing will depend on stand basal area.

The checkbox *Aprovechamiento estándar* controls size limits and the retention %. If the box is checked, then legal limits on felling are applied to all commercial species. These are a minimum diameter of 60 cm, and a retention of 40% of the volume for each species.

If this box is cleared, then the felling limits will be controlled by the values set for each individual species group. Note that if a group is given a retention volume of 100%, then it will not be harvested, even if commercial. On the other hand, non-commercial species according to the CODEFORSA/Portico codings will never be harvested, even if a volume limit is set for them. Non-commercial groups need be given a retention of 100% only for clarity and documentation purposes.

To change the commercial/non-commercial status of a species, it is necessary to edit the code numbers in the species list and then re-read the inventory data.

The timing of harvesting is controlled by the boxes for *Ciclo de corta* and *Primera corta*. The *Primera corta* entry determines the number of years after the start of the simulation that the first cut is taken. After that, further harvests are taken at an interval determined by the *Ciclo de corta*. All times are rounded to the nearest 2 years, as the model works in 2-year time steps.

However, if basal area control is selected by checking the box *Control por area basal*, then the felling cycle and first cut figures are ignored, and the timing of felling depends only on stand basal area. The forest will be harvested whenever the basal area exceeds the limit given in the *Cortar en*. The volume removed is limited by the basal area to be harvested, given in the *Extraccion* box. Fellings under basal area control respect the diameter limits and retention percentages which have been set. The largest trees are cut first, until all available volume in a particular category is removed or until the basal area limit for harvesting is reached.

Options for silvicultural treatment (*Tratamientos silviculturales)

Silvicultural treatments are specified by selecting the menu choice **Tratamientos silviculturales*. This brings up the screen form shown in Figure 5.

This screen has two check boxes to control the timing of treatment. The box *Tratamiento inicial* indicates that an initial treatment should be at a time from the start of the simula-

tion indicated by the box *Año para inicio tratamiento*. This treatment will be undertaken at the indicated time whether or not the stand is harvested.

Grupo de especies	AB % a reducir
A+	10
B+	10
AB-	50
CD+	20
CD-	50

Figure 5 Option screen for silvicultural treatments

The box *Tratamiento en ciclo*, when checked, signifies a repeated silvicultural treatment in each felling cycle, whose date is indicated by the box labelled *Nº años despues del aprovechamiento*.

The intensity of treatment is indicated by the percentage of basal area to be removed in each species group.

If no treatment is required, both check boxes should be left clear.

Displaying output (*Presentacion)

Several types of outputs are produced by SIRENA. These can be displayed before a simulation starts, and seen to develop dynamically as the program runs. Alternatively, the user can switch between the different tables at the end of the run. The species list and growth models tables do not change during a run, but may be edited to alter program operation, and can be printed for reference. The model is a fully Windows-compatible program, and output can be selected with the mouse and copied to the clipboard using CTRL+C. The clipboard copies can then be included in reports. Copies taken in this way are also Excel objects, and can be grafted into other Excel worksheets as graphs and tables. All outputs can also be printed using the **Imprimir* menu. The following sections describe the types of outputs in the same order that they appear under the menu **Presentacion*.

The forest management table (**Volumen y manejo*)

The forest management table is designed to give a summary of essential information about the stand and the yields that can be expected in each felling cycle. An example is shown in Table 2. The first three columns give the trees/ha in three diameter classes as an indicator of stand structure. The basal area column is designed to assist management and treatment decisions using basal area, and give total basal area above 10cm diameter, the percentage of commercial species, and the percentage removed in any specified treatments.

Año	No. Arboles/ha			Area basal > 10cm diam.			Volumen del rodel			Incremento		Volumen
	10-30	30-60	60+	Actuel	%Com.	%Trat.	Com.	> DMin	Total	IAA	IMA	Extraida
	N/ha			m2/ha	%	%	m3/ha			m3/ha/an		m3/ha
0	233	109	21	30.6	91.6%		192.7	74.0	209.1			
2	230	101	20	30.7	91.7%		194.6	79.6	211.0	0.93	0.93	
4	173	91	9	21.1	89.5%		126.2	29.2	140.7			51.5
6	189	92	10	21.8	89.5%		131.1	32.3	146.2	2.44	2.44	
8	196	98	11	22.5	89.5%		136.0	36.9	151.7	2.44	2.44	
10	204	99	12	23.2	89.5%		140.7	39.8	157.1	2.37	2.42	
12	214	93	16	23.9	89.6%		145.4	48.9	162.3	2.35	2.40	
14	180	82	8	17.8	87.2%		102.8	20.1	118.3			34.4
16	208	83	10	18.7	87.3%		108.2	23.1	124.5	2.69	2.69	
18	234	79	12	19.6	87.4%		113.6	26.7	130.6	2.72	2.70	
20	254	77	14	20.5	87.5%		119.0	31.0	136.8	2.71	2.70	
22	269	74	15	21.3	87.6%		124.4	34.4	143.0	2.71	2.70	
24	227	68	9	17.0	85.2%		94.6	14.5	112.4			24.6
26	258	66	11	17.9	85.3%		100.3	17.8	118.9	2.83	2.83	
28	284	63	14	18.9	85.5%		106.1	23.1	125.7	2.90	2.86	
30	301	63	14	19.8	85.5%		111.5	25.1	132.1	2.71	2.81	
32	312	61	19	20.7	85.6%		116.9	34.0	138.6	2.73	2.79	
34	259	54	12	16.2	82.6%		86.7	14.2	107.2			24.6
36	292	54	12	17.2	82.9%		92.4	15.3	113.9	2.87	2.87	
38	318	50	16	18.1	83.2%		97.9	23.9	120.3	2.73	2.80	
40	335	51	18	19.0	83.6%		103.6	29.7	126.6	2.85	2.82	

Table 2 Volume and management table produced by SIRENA

The volumes shown are:

- Commercial volumes of all trees above 10cm.
- Commercial volumes of all trees above the specified diameter limits for harvesting (which may vary between species groups, but are 60cm for the standard option).
- Total volume above 10cm of all species.

Increments given are in terms of commercial volumes over 10cm diameter. IAA is the current annual increment, and IMA the mean annual increment relative to the last harvesting operation.

The volume actually removed in harvesting is given in the last column.

All figures are given on a per hectare basis.

Graph of harvested volume (*Graficos *Volumen y manejo)

The graph of harvested volumes is based on the standing commercial volumes above the diameter limit, shown as the solid line, and the volumes actually harvested, shown as the vertical bar. The graph appears as shown in Figure 6 below.

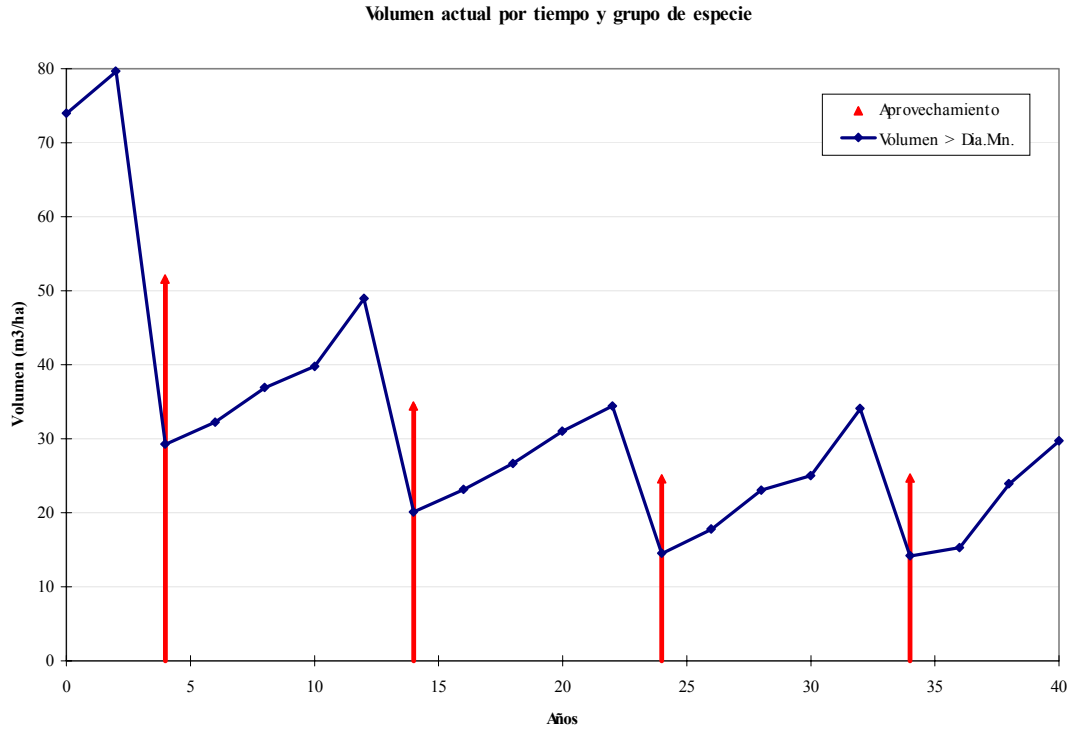


Figure 6 Graph of commercial volumes standing and harvested

The basal area graph (*Graficos *Area basal)

The basal area graph shows the components of increment, mortality, recruitment, harvesting, felling damage and stand treatment which cause changes in stand basal area over time. An example of the graph is shown in Figure 7. Normally it will be seen that basal area increment and mortality are of similar magnitude, becoming equal as the stand approaches a basal area of about 35 m²/ha. Recruitment is small until the basal area is reduced by harvesting or treatment, when heavy regeneration occurs. Harvesting induces logging damage, which is of about equal magnitude to the basal area extracted. Treatment is not shown in this example, but will also appear as a negative item.

This graph is produced directly from the basal area table, which can be viewed by the menu selection *Cuadros *Area basal.

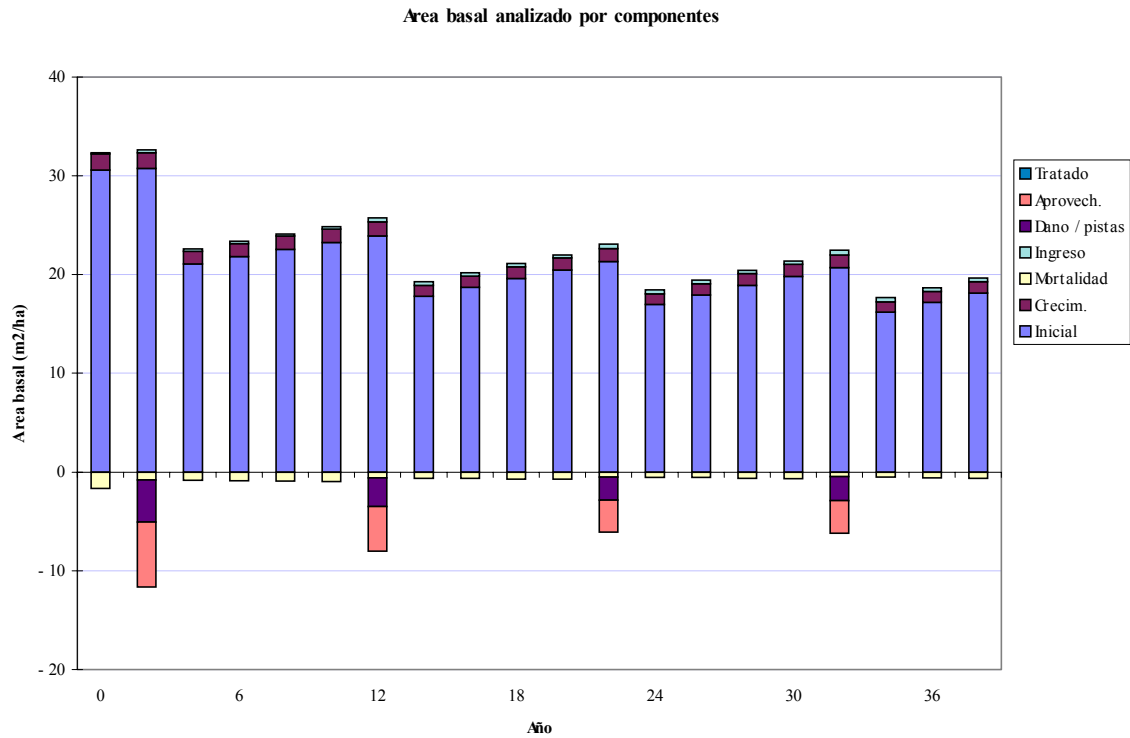


Figure 7 Graph of basal area components

Graph of stand structure by species groups (Graficos *Grupo de especie*)**

The stand structure diagram gives basal areas by three size classes (10-30, 30-60 and 60+ cm) and by the species groups defined before the run commences. It is useful in determining the components of most value in the stand, and for observing the effects of harvesting and treatment on the species composition of basal area. In this context it is useful to consider that percentages by volume and by basal area will be approximately the same.

The graph develops dynamically as the program is run, and can be viewed changing with each time period. After the run is completed, two buttons showing up and down arrows allow stand structure in each period to be reviewed. Clicking the buttons quickly steps the graph through a single 2-year period forwards or backwards. Holding the button down will move to the first or last simulation period in a single step.

Area basal por clase diamétrica y grupo de especie

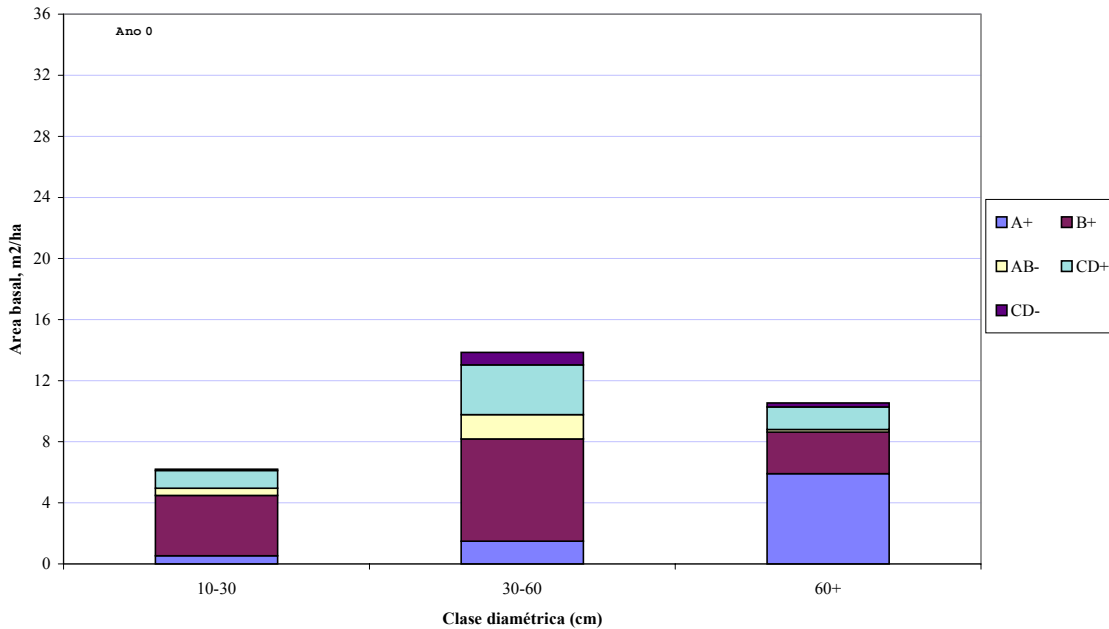


Figure 8 Graph of stand structure by size classes and species groups

Making comparisons between successive simulation runs (*Comparaciones)

It is useful to compare the results of successive runs on a single graph. This can be done with the menu option **Comparaciones*. The parameter compared is the volume for a specified group greater than a given size limit. The lines for each run can be labelled separately for documentation purposes.

Graphs are defined initially with the sub-menu choice **Comparaciones* **Seleccionar*. This brings up the screen form shown in Figure 9. For each run (shown as *Vuelta #*), a species group can be selected from the pull down list. The volumes calculated will be those of trees exceeding the diameter limit given by the *>Diámetro* field. The *texto* field defines a label that appears in the graph legend. The check box *Hacer comparaciones* must be set for a comparison to be done with the current run.

The dialog box titled "Comparación de Simulaciones" is for "Vuelta 4". It contains the following fields and controls:

- Grupo:** A dropdown menu showing "A+".
- > Diámetro:** A text input field containing "60".
- Texto:** A text input field containing "Control AB".
- Buttons:** "Aceptar" and "Cancelar".
- Checkbox:** "Hacer comparaciones" is checked.

Figure 9 Screen form to define comparisons graph

The comparison option should be set before starting the simulation. For each successive run, the legend title indicated by *texto* should be modified to indicate the run options. However, no error results if it is not changed.

Viewing the comparisons graph (**Comparaciones *Ver*)

The comparisons graph is viewed by selecting **Comparaciones *Ver*. Figure 10 shows an example which compares 3 runs. The top line in the legend is a standard felling (60cm/40%) on a 10-year cycle. The second is a similar felling but with a retention of 60% instead of 40%. The last line uses the same felling rules, but with basal area control limiting extraction to 4 m²/ha whenever basal area is 25 m²/ha or more.

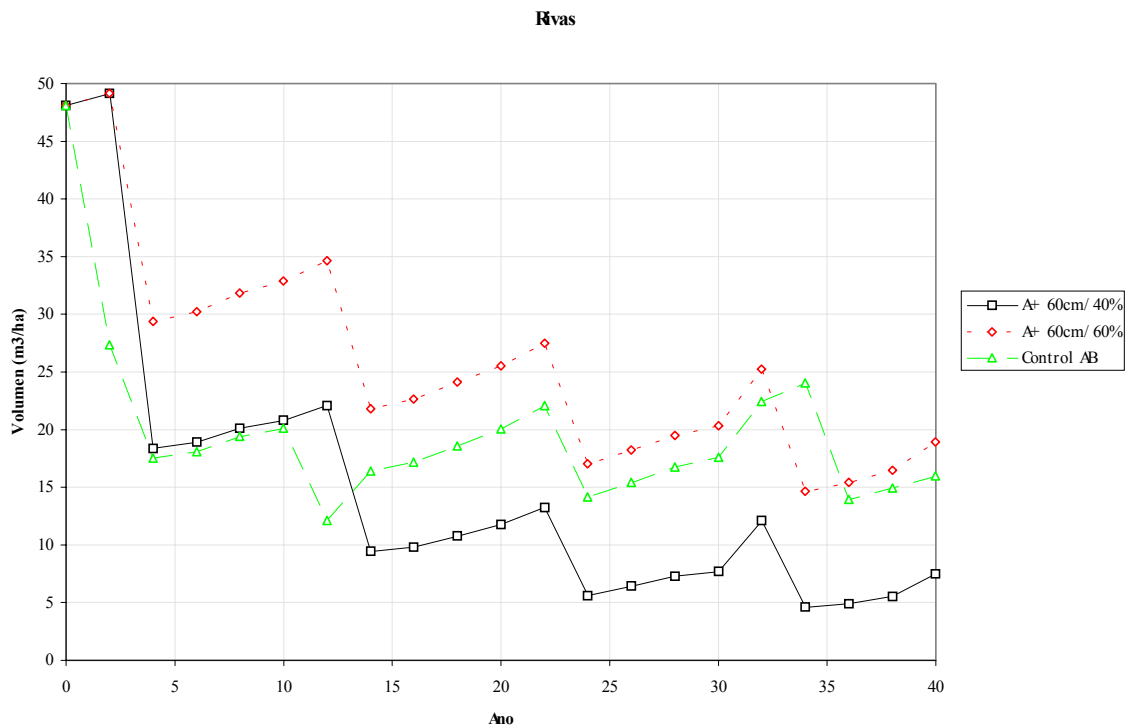


Figure 10 Comparisons graph showing results from 3 successive simulation runs

Some restrictions exist on viewing the graph in the present version of SIRENA:

- If the *texto* field of the options screen is blank, then the comparisons graph cannot be viewed.
- If the graph is on screen when the options for comparisons are set, it may be left on screen while the simulation is run. However, if another graph or table is in view, when the options are set, then the comparisons graph cannot be viewed until after the run is completed.

A message box in the form *No hay vuelta #* will appear when attempting to view the graph under these restrictions. Ensure the *texto* field has been set to non-blank text and

run the simulation as normal whilst viewing another graph or table. Then switch to the comparisons graph at the end of the run.

If a run fails in the middle of a series of comparisons then it is unlikely to be possible to view the comparisons graph. Clear the graph using the **Comparaciones *Borrar* option and try again.*

Viewing and editing the species list (**Lista de Especies*)

The species list is viewed using the menu selection **Lista de Especies*. The list can be printed in part or entirely, or sections of it can be saved to the clipboard for use in other documents. The list may also be edited, but care is required for those columns which effect the operation of SIRENA. An extract from the list is shown in Table 3.

Gen.spp	Modelo crecim.	CODA-	PORT-	Nombre científico	Comercial		Vol. Eqn.
		FORSA	ICO		CODA.	PORT.	
Cal.*	A2		2615	<i>Callophyllum sp</i>		2	
Cal.acu	A2		6404	<i>Callicarpa acuminata</i>		4	
Cal.bra	A2	61	2601	<i>Callophyllum brasiliense</i>	3	2	4
Cal.can	A2	33		<i>Calycophyllum candidissimum</i>	3		4
Cal.cos	A2	258	2801	<i>Calatola costaricensis</i>	5	4	4
Cei.pen	A2	81	0801	<i>Ceiba pentandra</i>	4	2	4
Con.ere	A2	354		<i>Conocarpus erecta</i>	4		3
Con.ple	A2	353		<i>Conceveiba pleiostemona</i>	5		4
Con.xal	A2	355		<i>Conostegia xalapensis</i>	5		4
Pri.cop	A2	38	1107	<i>Prioria copaifera</i>	3	2	3
Sac.*	A2	334		<i>Sacoglottis sp</i>	4		4
Sac.tri	A2	60	2704	<i>Sacoglottis trichogyna</i>	3	2	4
Spo.mom	A2	150	0201	<i>Spondias mombin</i>	4	4	4
Spo.pur	A2	219		<i>Spondias purpurea</i>	5		4
Spo.rad	A2	404	0202	<i>Spondias radkolferi</i>	5	4	4
Tab.amy	A2		0406	<i>Tabernaemontana amyodalif</i>		4	
Tab.arb	A2		0407	<i>Tabernaemontana arborea</i>		4	
Tab.chr	A2	28		<i>Tabebuia chrysantha</i>	1		4
Tab.gua	A2	209	0703	<i>Tabebuia guayacan</i>	1	2	4
Tab.och	A2	408		<i>Tabebuia ochracea</i>	4		4
Tab.pal	A2	183		<i>Tabebuia palmi</i>	3		4
Tab.ros	A2	57	0704	<i>Tabebuia rosea</i>	3	2	4
Fic.*	A2b	128		<i>Ficus spp</i>	4		4
Fic.bre	A2b		3910	<i>Ficus brevibracteata</i>		4	
Fic.cos	A2b		3928	<i>Ficus costaricana</i>		4	

Table 3 Section of the species list, as viewed with **Lista de Especies*

The columns *Gen.spp* and *Nombre científico* have no effect on the model and can be edited freely. The growth model column, headed *Modelo*, indicates which growth model the species is assigned to. Two columns of species codes are shown, for CODEFORSA and Portico. If these are changed, it will effect how inventory files are interpreted. The column for commercial groups for either CODEFORSA or Portico can be altered to change the grouping and commercial status. In the CODEFORSA column, a code of 5

* These restrictions are likely to be removed in later releases of SIRENA. They relate to a bug that appears to exist in Excel when trying to delete a SERIES object that references an empty RANGE.

indicates non-commercial species, whilst for Portico, a code of 4 indicates non-commercial. If values higher than 5 or 4 are entered in these respective lists, then an error will occur when the program is run. The final column shows the volume equation number. This is not used by the model.

The table of growth models (Modelos de crecimiento*)**

The table of growth models can be viewed and edited by selecting **Modelos de crecimiento* from the menu. It appears much as in Table 1, although the latter has been slightly edited. The models can be revised through re-analysis of the data, and indeed by changing the species group codes in the species list (column 2), the grouping system could be completely revised. However it is suggested that for normal use, this table should not be altered.

Scaling graphs to the viewscreen (Zoom*)**

The zoom function brings a selected area of the graph to fill the screen. It is intended primarily for bringing the display to normal size if operations have been carried out in Excel that have changed the scaling factor. The graph background should be selected by clicking on the edge, and then **Zoom* selected. The graph will then fill the viewing screen.

Printing graphs and tables (Imprimir*)**

The screen currently being viewed can be printed by pressing **Imprimir*. For graphs, this is all that is required. For tables, an area of the table must be selected before printing. This is to prevent inadvertently printing large numbers of pages, from for example, the species list.

Problems can be experienced with the printer configuration which need to be resolved in Excel. The setup options should be compatible with the printer and port in use, and a graphics resolution selected which does not cause memory problems in the printer.

General program control (Funcion*)**

The simulation model is started, using current parameters, by selecting **Empezar simulación*. During the simulation run, the status bar at the bottom of the screen shows the current year.

The simulation runs for 40 years by default. The period can be changed by selecting **Periodo de simulación*. A box appears requesting the total simulation period.

Following an error condition, it is usually better to completely restart the program, as some variables may be in undefined states. This can be achieved with **Re-inicializar*.

The user can go to Excel with **Regreso a Excel*. This is blocked by a password filter to prevent casual alterations to the program and worksheets that might prevent the model from running.

Normal exit from the model to Windows is via the menu choice **Salida a Windows*.

Technical Notes

These notes give a brief description of analyses undertaken to develop the functions for SIRENA.

Sources of data

The functions and analyses in the model were based on data from 26 1-ha plots and 27 ¼-ha plots. The table shows the distribution between CODEFORSA and Portico sites.

CODEFORSA

- 9 x 1-ha plots, 3-5 years growth on 9 sites
- 27 x ¼-ha plots, 2-3 years growth on 3 sites

Portico

- 17 x 1-ha plots, 2-3 years growth on 5 sites

Total area of the plots was 32.75 ha. All the plots had only one re-measurement available at the time of analysis.

Formation of species groups

The formation of species groups was severely constrained by the time available for the study and the groups that have been formed and used in the model should be reviewed and re-analysed when resources are available. The method involved a classification into \log_2 classes of mean increment and tree size. After this, *ad hoc* adjustments were made where sufficient data existed.

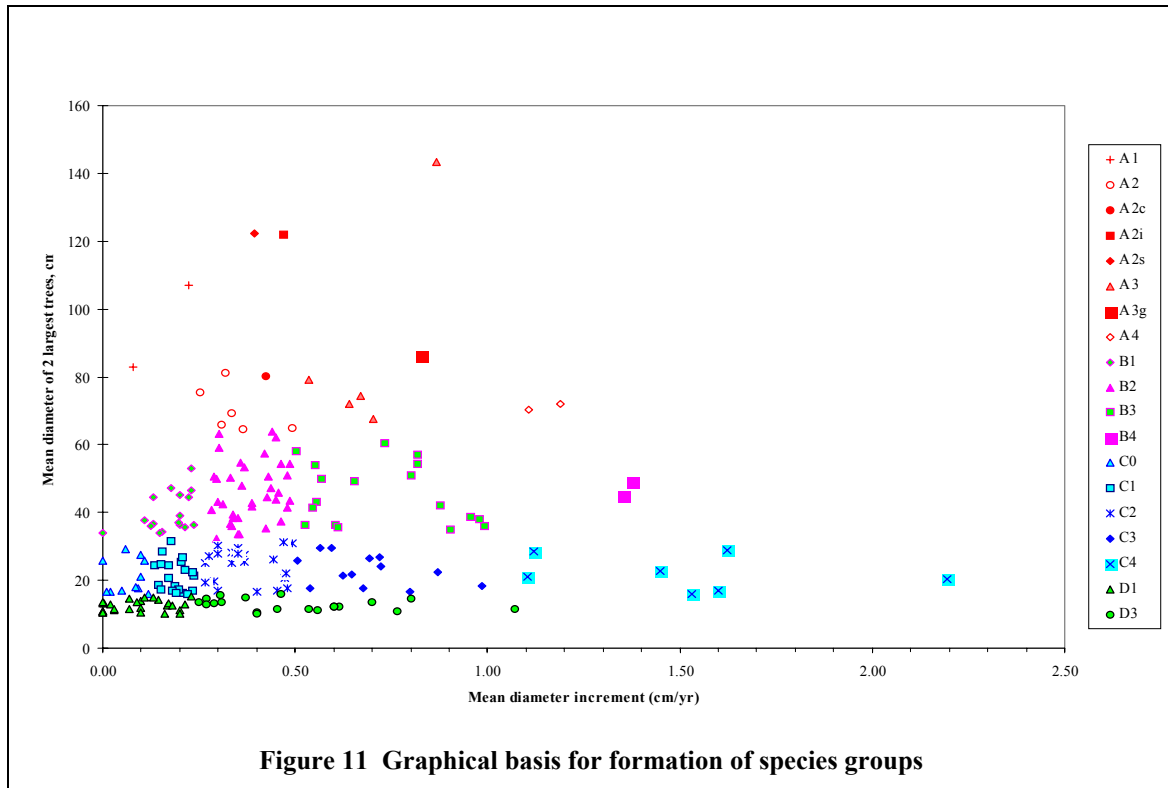


Figure 11 Graphical basis for formation of species groups

Tree increment functions

Because of the short measurement period, many trees showed zero increments. For the non-zero increments, a regression was fitted in the form:

$$\Delta g^* = \alpha g^\beta$$

where:

- Δg^* is tree basal area increment in cm^2/yr of trees showing positive increment
- g is tree basal area in cm^2
- α, β are coefficients fitted by regression

Mean increments were calculated in the model from:

$$\Delta g = (1 - P_0) \cdot \Delta g^*$$

where P_0 is the proportion of trees showing zero increment.

Figure 12 shows how the regression appears for one group (A2c), comprising *Carapa* species. Table 1 on page 6 gives the coefficients for all the species groups, as well as the P_0 value.

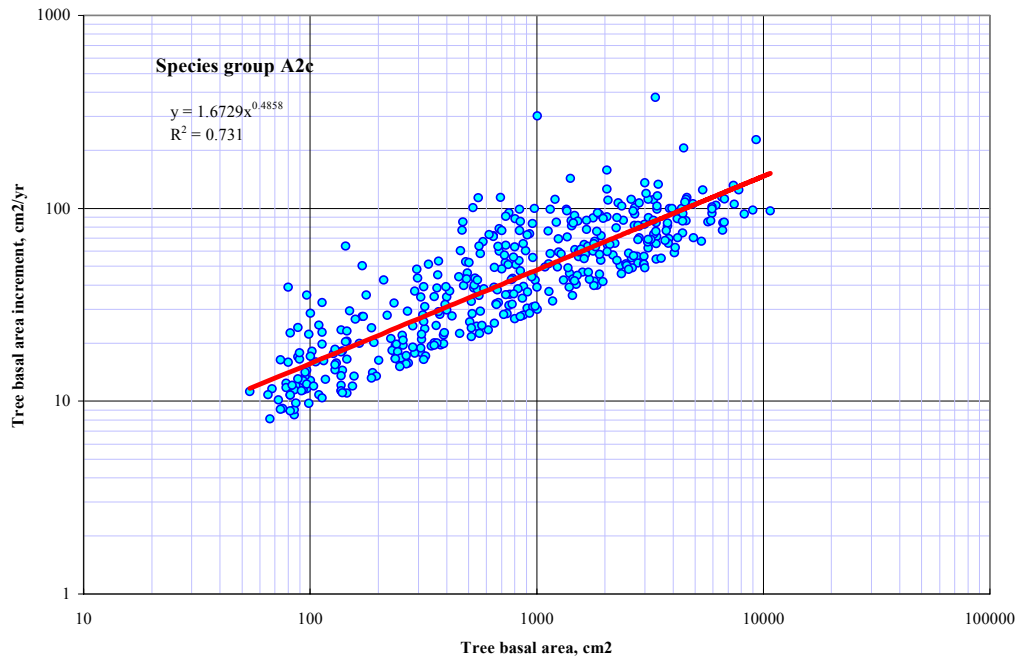


Figure 12 Tree increments and fitted regression for group A2c (*Carapa*)

Mortality rates

Mortality rates for each species groups were calculated as simple averages, and are shown in Table 1. During the simulation process, these species group averages are modified in two ways:

- Stand mortality is limited by a stand basal area function
- The smallest trees die first, until the stand mortality limit is reached, applying the species group rates to each size class.

Mortality also occurs following logging, in accordance with the logging damage functions.

Recruitment rates

Recruitment showed distinctively different patterns in the forests with and without the *Vochysia/Dipteryx* group (A4). A4 occurs on less dense stands, in terms of basal area, and is strongly disassociated with *Carapa*. When A4 is present, A2c is almost entirely absent.

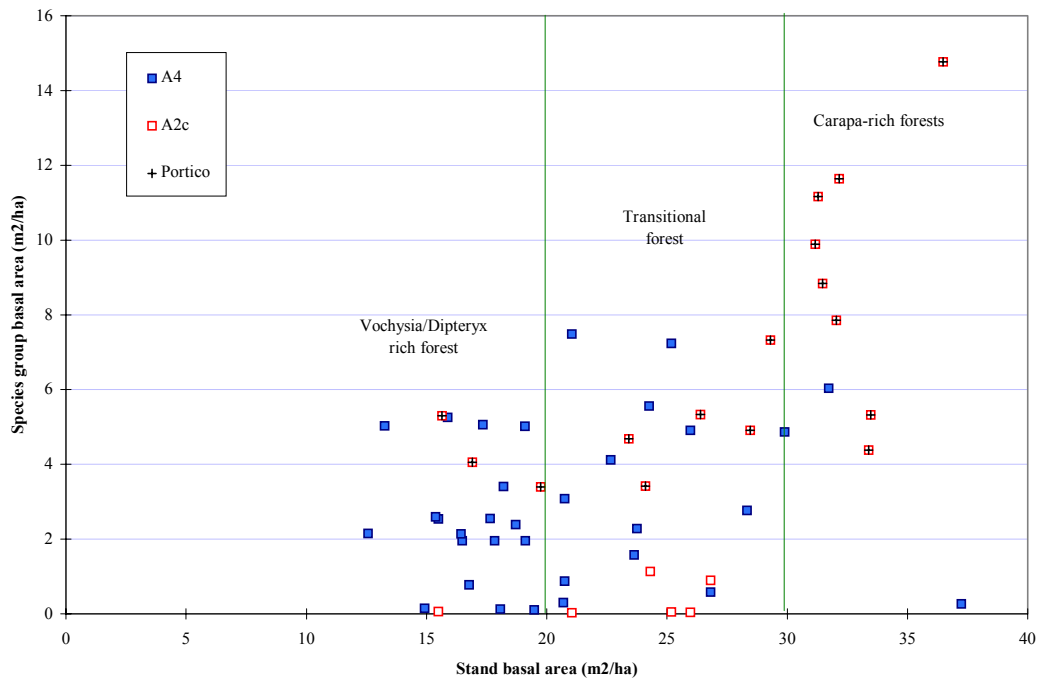


Figure 13 *Vochysia/Dipteryx* (A4) and *Carapa* (A2c) distribution with stand density

This was used to form two regeneration groups, as shown in Table 1 under the A4+ and A4- columns. When inventory data is read by the model, it checks whether there is more than 1% of A4 in the basal area. If there is, it assigns it to the A4+ group. Otherwise, it uses the A4- regeneration type.

The recruitment percentages by species are also allocated to commercial and non-commercial fractions, based on averages observed on the permanent plots. This is shown as the last column on Table 1.

As with mortality, the overall level of recruitment is determined by the recruitment basal area which is calculated as a function of stand density. Recruitment is generated in the model in the following steps:

- Recruitment basal area is calculated as a function of stand basal area.
- The total number of recruits is determined by assigning this basal area to the appropriate number of 10-cm trees.
- This number is allocated proportionately to each group according to either the A4+ or A4- lists, based on the originally assessed forest type.
- Within each group, sub-cohorts are formed proportionately of commercial and non-commercial species components.

The stand basal area model

A stand basal area model was developed for SIRENA to provide density-dependent feedback in mortality, recruitment and increment. In CAFOGROM these features were provided by crown-class dependent functions, but in the present case, crown class data was not available, and an alternative approach was needed.

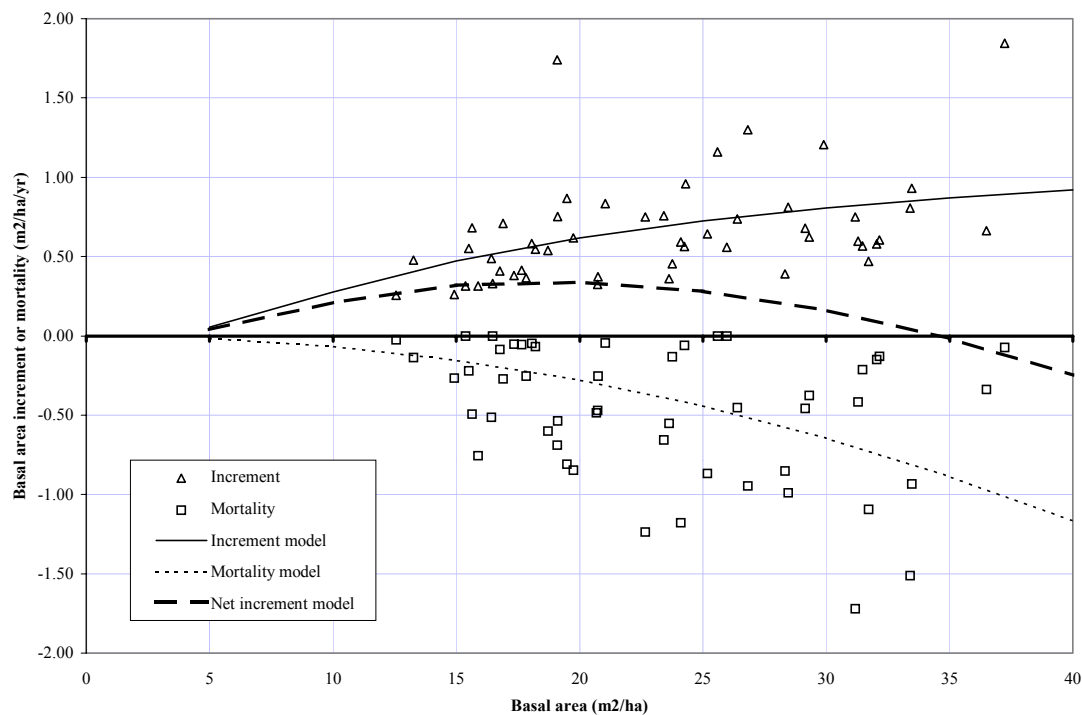


Figure 14 Basal area increment and mortality models with plot data

Figure 14 shows the functions developed. The top line gives basal area increment as a function of basal area. The lower line gives mortality. The central line is the net increment function, which shows a maximum at about 20 m²/ha, and is zero at 35 m²/ha. The equations representing these functions are shown as the top two entries in Table 4.

		A	b
Increment	$Ae^{-b/G}$	1.372	16
Mortality	AG^b	0.000567	2.067
Recruitment	Ae^{-bG}	2.0528	-0.0994

Table 4 Equations in the basal area model

Recruitment was analysed in a similar way, plotting the basal area of recruits against stand basal area at the beginning of the period, and dividing by the growth interval. The data and the regression line are shown in Figure 15.

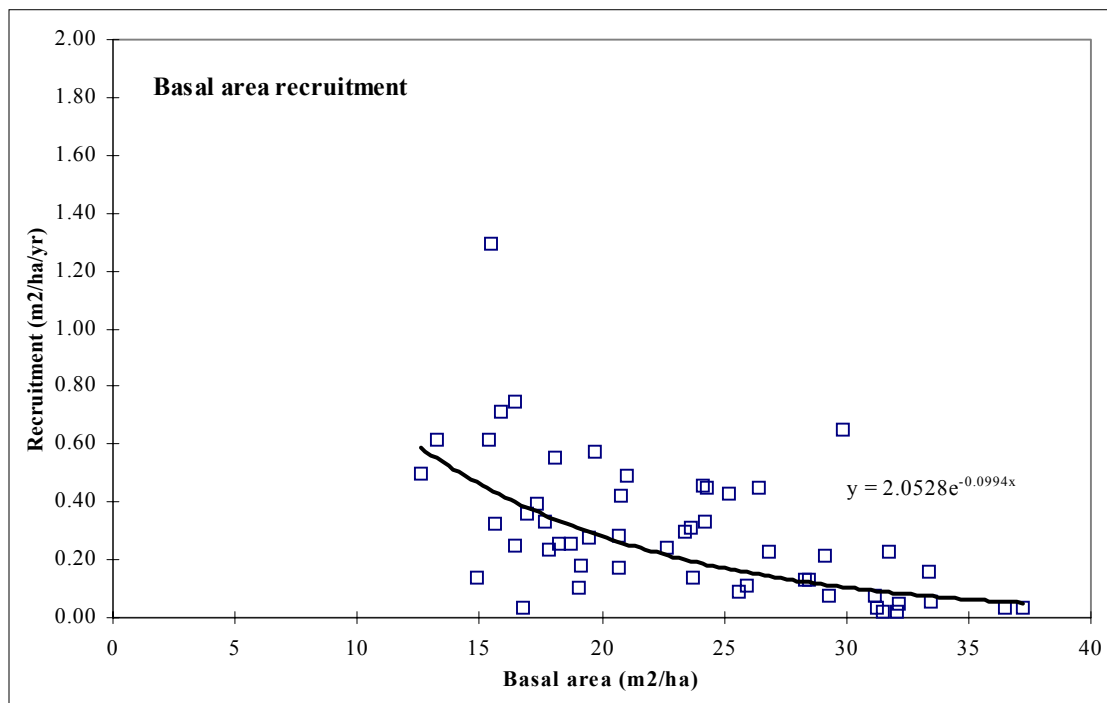


Figure 15 The basal area of recruits as a function of basal area

Logging damage

A study of logging damage was carried out at CODEFORSA by James Gordon in the last quarter of 1995. The data from this was used as the basis for the logging damage functions in the model. Six forests were logged at a range of intensities, and area damage in skid trails, gaps and roads recorded. Tree damage was also classified by severity and size class. For the growth model, this data was regrouped to define a single figure for area damage by trails and gaps, and a second figure giving percentage of tree numbers severely damaged. Logging intensity was defined as basal area removed relative to basal area before logging.

The graph (Figure 16) shows the data obtained and the functions fitted. Linear, exponential, and logarithmic models all fit the data, but give different effects on extrapolation. The logarithmic model used gives intermediate extrapolations. The exponential function tends to over-exaggerate the effects of heavy logging, while linear extrapolation gives low figures that might excessively encourage short-cycle harvesting.

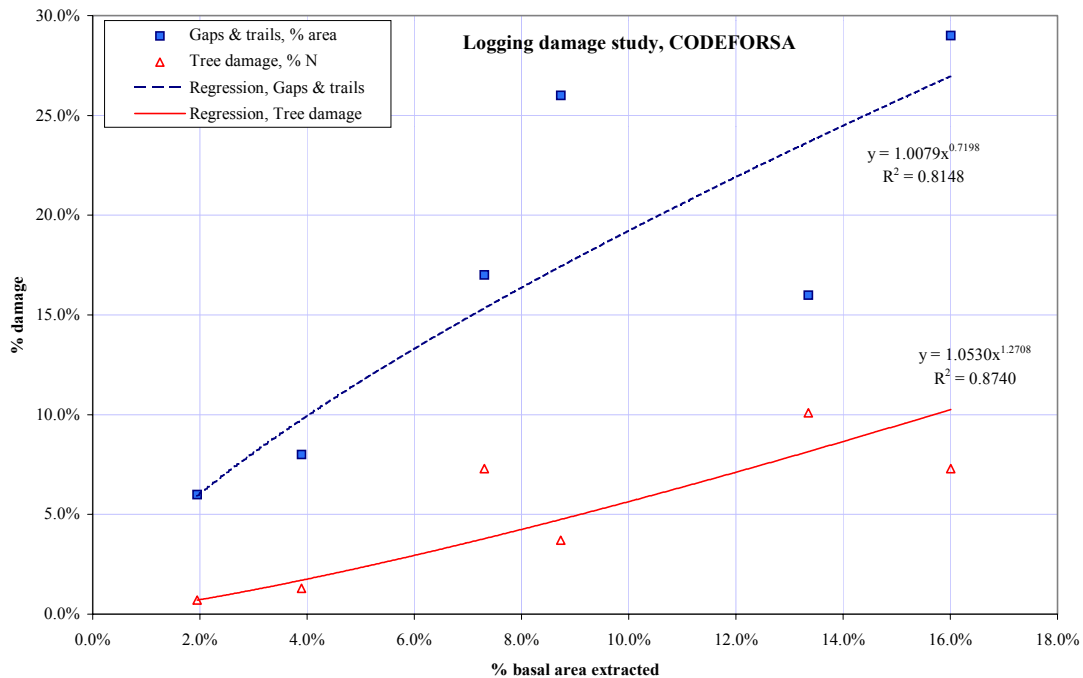


Figure 16 Gaps, skid trails and tree damage as functions of logging intensity

The coefficients for the functions are shown in Table 5. In the model, logging damage is calculated by adding the total basal area extracted, to obtain logging intensity. Area damage is assumed to affect only trees below 20cm, larger trees being avoided by tractor operators. These trees are reduced in stocking in proportion to the calculated damage.

	A	b
Gaps & trails, % area	1.0079	0.720
Trees damaged, %N	1.053	1.271
Model: $Y=AX^b$ $X=\%$ basal area extracted		

Table 5 Equations for components of logging damage

Tree damage is assumed to affect all size classes equally, and is applied as a stocking reduction to the percentage calculated from the equation.

More information on logging damage would help to determine the most appropriate type of function to use. More refined analysis is possible with the existing data, but was not undertaken due to time constraints. It would also be desirable to follow up the survival and growth of a set of moderately and severely damaged trees. In the model the assumption is that severe damage leads to immediate death, whilst moderate damage has no effect. However, in practice moderately damaged trees may become relicts of poor form and growth. Experimental data on this would be useful and important.

Conclusions and recommendations

Application of the model

SIRENA can be applied to sets of inventory data from forests managed by CODEFORSA or Portico to determine what management regimes are likely to give sustainable production. A degree of common sense needs to be applied in assessing model projections, which represent best estimates on the basis of limited data and knowledge, and should not be conceived otherwise. Like all estimates and projections, results are likely to be revised as new data becomes available, functions are re-analysed, and knowledge is improved.

The model indicates the primary importance of felling damage in determining next cycle yields. Measures to reduce logging damage are likely to have direct economic and environmental benefits. Increased knowledge of logging damage effects can also be considered a research priority.

The model is not fully responsive to site and forest type variations, and this must be borne in mind when considering low-fertility areas, secondary forests on grasslands and other major variations from the original data sets.

Revision and improvement

Some aspects of SIRENA could have been improved in the context of currently available data if more time had been available for development and analysis. These are:

- *The influence and treatment of relict trees left after felling.* Static data from post-harvest inventories allows some analysis of this situation. Intermediate degrees of logging damage, currently ignored in the model, could be associated with a process of stem damage and decay leading to relict formation. This is a topic of obvious concern to forest managers.
- *Enhancements to the modelling of recruitment to reflect ecological succession.* During the consultancy information became available on the ecological guilds of many species, but too late to be incorporated in the analysis. Generally, there was insufficient time to thoroughly analyse available regeneration and recruitment data and the model is therefore somewhat static in these respects.
- *Improvements in specification of species groups.* The present system is cumbersome and does not map very well on to management needs. It would be better if the model gave a stand table in terms of local names on reading data, and allowed reporting groups to be formed from lists of local names. The groups themselves should be re-organized on the basis of available ecological guilds.

Permanent plot procedures at CODEFORSA

The standards of measurement of the CODEFORSA plots appear good. It is recommended however that some changes are made to measurement standards and to data processing methods. These are as follows:

- *Extend the remeasurement period to 3-5 years.* Annual or bi-annual measurements are not very useful. A 5-year interval is very suitable if the needs of plot maintenance permit it. If there is a danger of tree markings being lost in this time, then a shorter period can be used. However, measurements should always be taken immediately before and after treatments or harvesting to assess losses, damage, and to identify trees treated or harvested.
- *Include crown and stem codes in the measurement procedure.* Increment correlates strongly with crown illumination. Crown form is also an indicator of increment and of relict trees. Stem form codes indicate relicts. These subjective indicators do not take long to assess in the field. Since they do not change rapidly with time, they can usefully be applied retroactively in the analysis of existing data.
- *Standardize plot size to either 1-ha or ¼-ha units.* It is dangerous to analyse basal area and other spatial phenomena from different sized plots, and ultimately may not be possible. Both types of units could be combined if the larger plots were sub-divided into ¼-ha for measurement purposes. The smaller plot size has some advantages as a more convenient work-unit for one day, which can reduce logistic costs. If the ¼-ha unit is adopted as a standard, then existing 1-ha plots should be redemarcated as 4 × ¼-ha plots when next measured.
- *A data entry and basic analysis system is needed.* Existing data needs to be converted into a format more suitable for analysis. Much time was spent manipulating and harmonizing the variant Quattro worksheets. The Portico system provides a good model for a basic file structure and organization. The computer program, working with this structure, should manage data entry and editing, check measurements for consistency, provide lists for re-measurement, and do some basic analysis of increment, mortality and recruitment rates by species, species groups, and plots.

Numbers and continuity of permanent plots

Permanent plots do not become truly reliable as indicators of forest dynamics until 10-20 years data are available. This is because, in tropical forests, the age of trees is not known, and many mistaken assumptions can be made on the basis of analysing short-run data. It is therefore more important to maintain a small number of plots over a long period than to continually turn over the base of permanent plots after 3-5 years measurement.

Resources available determine the number of plots that can be maintained. Efficiency can be improved through adopting a longer re-measurement period.

In the ideal world, the author would like to see one permanent plot of 1-ha (or 4 × ¼-ha plots) on each managed forest unit of 50-100 ha. However, realistically, costs are likely to prevent this. It would be interesting if incentives could be devised for forest owners to support the establishment and maintenance of plots on their properties, perhaps in association with certification schemes.

Generally, it is desirable for plots to cover as many forest types as possible. If secondary forest on abandoned pastures are likely to become significant, this type of forest should be sampled from early in the successional cycle.

The author would strongly recommend that CODEFORSA do not abandon any existing plots, but continue to measure them at more extended periods if there are constraints on funding.

Linkages and cooperation with ITCR and CATIE

The author is involved in initiatives with ITCR, under the current ODA project, and under different auspices, with CATIE, to continue the development of growth models in Costa Rica. Hopefully, a culture can be developed whereby:

- Species lists, codes, ecological, forest type, and growth information are exchanged and standardized.
- Modelling strategies are explored and focussed towards generally standardized solutions at the forest management level.
- Software for permanent sample plot management and analysis is shared and standardized.
- Cooperative research projects are undertaken between private sector organizations such as CODEFORSA and Portico, and institutions such as ITCR and CATIE, perhaps in association with research studentships.

This process cannot be forced, but may develop through meetings and workshops, which should initially be simply aimed at presenting results, but which may evolve to a more proactive cooperative process. The advantages will be simply the avoidance of a good deal of repetitive re-invention of the same software, or re-analysis of similar data. It will allow an efficient focussing of limited resources on a complex problem.

Conclusion

SIRENA represents a useful addition to the software used by CODEFORSA for developing forest management plans. It allows a rational estimate to be made of the sustainability of particular harvesting options. It also makes use of and justifies the continuation of CODEFORSA's permanent sample plot programme. In the broader context of Costa Rica, it provides an example of a tropical forest model that may be used as a basis for training and development by institutions such as CATIE and ITCR. There are few examples in the world of growth models being actively used in the management of mixed tropical forest; SIRENA places Costa Rica in a prominent position in this aspect of forest management.

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Ciudad Quesada
March 26, 1996/October 11, 2002

