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Revised: 02-Nov-2021

*Report on a consultancy to the*

## **Quintana Roo Forest Management Project**

*on behalf of the*

Department for International Development of the United Kingdom

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## Executive Summary

Some 1240 permanent sample plots have been established in Quintana Roo by forest ejido communities. These plots are of a circular design, being 500 m<sup>2</sup> in area. The DFID Quintana Roo Forest Management Project has sponsored the remeasurement and data processing on some of these plots. The consultant was invited to analyse the data and develop a growth model to assist forest management.

It was found that 197 plots had been remeasured and the data entered on the computer. Measurements spanned 4 years, either from 1991-1995 on the ejidos of Petcacab, Avila Camacho, and Los Divorciados, or 1993-1997 on Nohbec. Increments were calculated for all represented species. Species were grouped into similar growth patterns by cluster analysis, and statistics for 16 growth models elaborated. The data lacked indicators for mortality, logging damage or harvesting, and this aspect of the model had to be estimated. Furthermore, the increments observed seemed excessively low compared with other analyses. It was concluded that at plot establishment, the point of height measurement had not been carefully controlled, and many trees were measured below the regulation height of 1.3 m.

Nonetheless, by applying correction factors based on expected stand behaviour, a useable model was developed and demonstrated at a workshop of forest technicians. This model, called MOSQUIRO (*Modelo para manejo sostenible de las selvas de Quintana Roo*), is based on the Costa Rican SIRENA model developed by the consultant, and is closely similar. It is written in Microsoft Excel, and is an open system that can be readily adapted or modified in future. Local staff were able to adapt ejido inventory data and make projections for their own stands using the model during the workshop. The present document includes a user's guide to the model.

It was recommended on the basis of the analysis that DFID continue to support the PSP work. Principle needs are for centralised management of data archival and processing, as much data has been lost and error correction is impossible without original forms. It is also necessary to adapt existing software to code tree numbers and mortality codes into the data base. A specific list of mortality codes is given, and a field training exercise is needed, coordinated with changes in the data processing system, to ensure their proper use.

It was not felt that plot size or design should be revised. The plots are small by the standards of tropical high forest, but the *Selva mediana* of Quintana Roo comprises small densely thicketed trees, and use of large plots would over-sample locally. The basal area distribution of the plots was similar to those for ¼-ha plots in tropical high forest in Costa Rica and Brazil.

It was also noted during the analysis that the volume functions used in Quintana Roo are obsolete and biased for small trees, and of a form that commits inventory crews to height measurement of every tree. Dramatic savings in inventory costs are possible through modernization of these procedures. A desk study was recommended in the first instance to present details and biometric particulars of this proposal in a fashion that would be convincing to forest engineers of the state and federal forest management organs, as well as to the ejido technicians and Civil Societies themselves.

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## Abbreviations

CAFOGROM.....	CPATU Amazon Forest Growth Model
DFID.....	Department for International Development of the United Kingdom
Excel.....	<i>Microsoft Excel</i> , version 5. Registered trademark of Microsoft Corporation.
MOSQIRO.....	<i>Modelo para manejo sostenible de las selvas de Quintana Roo</i>
POM.....	Point of measurement
PSP.....	Permanent sample plot
SIRENA.....	<i>Simulación del rendimiento de bosque natural</i>
VBA.....	Visual Basic for Applications. <i>Visual Basic</i> is a registered trademark of Microsoft Corporation

## Disclaimer

This work is the solely responsibility of its author, and does not represent the formal view, opinion, or official position of any other body, including the Department for International Development. Its recommendations and conclusions are those of the author, offered as a basis for further discussion and elaboration.

## Introduction

### **Background**

Since 1991, a process of establishing permanent sample plots (PSPs) has been continuing in the forest ejidos of Quintana Roo. Sanchez Román (1993) describes the procedures, the objectives, and data processing system to store the data print various basic reports and analyses. At the time of writing, it is estimated that approximately 1240 such plots have been established.

The plots were seen as essential to sustained yield management of the forests. Their role is to provide information on increment and the dynamic response of the forest over time. Without them, rational decisions about felling cycles, girth limits, and allowable cut cannot be made.

However, between the establishment of the plots and their effective utilization for forest management there has been something of a gap. As will be noted, basic office procedures to archive the field forms do not seem to be in place, and many original forms may in fact be lost. Neither data processing nor remeasurement and maintenance have been on-going functions; they have been funded in an *ad hoc* manner from time to time, and there is no permanent organization or office to support the activity of managing or using the PSPs.

DFID (formerly ODA) became involved with the start of the Quintana Roo Forest Management Project. The present consultant was contracted to develop a growth and yield model based on the PSPs which could be used for forest management decisions and analysis.

The current assignment, undertaken between 11th September and 18th October 1997 is the second of two. The first three week contract covered the development of a modelling framework, during January 1997. At the same time, the project supported the remeasurement of plots and data entry and checking in Mexico. The majority of this data was provided via the internet to the consultant in the UK for assessment and review prior to departure for Mexico to commence the current assignment.

### **Objectives**

The present mission aimed to use such data as was available to produce a model that could project forest growth and yield under a variety of management options. The time available for this task was relatively limited, and the objectives were accordingly confined to:

- Basic data analysis
- Completion of the model
- Installation at the project offices
- A training workshop of one day in the use of the model

## Analysis of PSP data

### *General limitations*

#### **Design**

The PSPs established on the ejidos under the *Plan Piloto Forestal* are described by Sanchez Román (1993). They are circular plots of 500 m<sup>2</sup> (12.6 m radius), laid down in partial systematic designs with individual plots on a grid 2000 x 500 m<sup>1</sup>. The standards of measurement have changed over the years, with different methods for assessing regeneration. However, for the purposes of the present study, two different groups can be recognised:

- (i) The plots measured from 1991 to 1994 on *Avila Camacho*, *Petcacab*, and *Los Divorciados* ejidos. On these plots, trees were not numbered and the point of measurement was unmarked. At the first measurement, only trees above 15 cm diameter were measured. At the second measurement, trees 10 cm and above were included.
- (ii) On *Nohbec* ejido plots were established in 1993 and remeasured in February-April 1997. The design was improved slightly, with individual trees being marked with nails and tags. The point of measurement is said to be 5 cm above the nail. All trees over 10 cm were measured on both occasions.

#### **Parameters measured**

For all trees on the plots, species, diameter, and merchantable height are recorded, together with crown position, stem form, and health. These measurements were made in the field on all plots, as far as the author is aware, but were not completely present in the database analysed. For reasons of time, height measurements were not available for the *Nohbec* plots.

Crown position was assessed on a 3 point scale for the plots the 1991 measurements, and subsequently on Dawkins 5 point scale. This is not a problem as crown position does not change rapidly and later observations can be applied to earlier records.

No formal system exists for coding mortality. On the field forms, the disappearance of a tree, its death or harvesting are usually noted clearly in long-hand. However, these observations was not coded into the database. Consequently and very importantly, *it has not been possible to estimate harvesting impacts, logging damage or natural mortality rates* from the plots. This is a serious issue that needs to be corrected in future measurements.

#### **Data management and processing**

Probably due to lack of proper funding and central control, data processing is not well organized. In particular, the consultant has not been able to find the location of the majority of the original measurement forms. There is a substantial gap in time and space between the field measurement process and data entry and checking. It is clear that there are errors in the

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<sup>1</sup> The author has verified this arrangement only on *Petcacab*. The spacing of plots may differ on other ejidos. All are however partial systematic arrangements using a sub-sample of inventory plots.

database which need to be checked against forms and if necessary on the ground. There is also the problem of entering mortality and harvesting observations from the original sheets, and of verifying precise dates of measurement.

The consultant will recommend that the QRFMP take direct responsibility for remeasuring plots, and ensure that data is entered in Chetumal with the close involvement of the responsible field officer, and that copies of field forms are retained by the project for cross checking purposes.

### **Number and distribution of PSPs**

#### **PSPs established**

The following table provided by E. Ramirez Segura shows PSPs established since 1991 using the 500 m<sup>2</sup> circular design within the standard inventory sampling lines.

<i>Sociedad Civil</i>	Ejido	Year Est.	No. PSPs
Sociedad de Productores Forestales Ejidales de Q.R..	Tres Garantias	1994	180
	Los Divorciados	1991	32
	Avila Camacho	1991	25
	Nohbec	1993	150
	Nohbec	1994	280
	Petcacab	1991	83
	P. de la Noria Pte.	1991	57
Organizacion de Ejidos Productores Forestales de la Zona Maya	Xpichil	1994	180
	Tres Reyes	1994	80
Sociedad de Pueblos Indigenas Forestales de Q.R. "Tumben Cuxtal"	San Isidro Pte.	1994	173
Reserva Yum Balam	Chiquila San	1994	101
	Angelo		
<b>Total</b>			<b>1240</b>

**Table 1 List of PSPs established, by ejido**

The status of many of these plots is very vague. The whereabouts of the original forms could not be established with certainty, and there is some probability that much original measurement data may be lost. This would be very unfortunate, given the substantial effort and funds expended on their establishment.

#### **PSPs remeasured and processed**

The plots which have definitely been remeasured and for which data was provided to the author for analysis are as shown in Table 1.

**Table 2 Remeasurement data available for PSPs**

<b>Ejido</b>	<b>Period</b>	<b>No. PSPs</b>
<i>Nohbec</i>	1993-97	106
<i>Petcacab</i>	1991-95	58
<i>Avila Camacho</i>	1991-95	25
<i>Los Divorciados</i>	1991-95	8
<b>Total</b>		<b>197</b>

The database also includes the 1991 measurements for an additional 25 plots for Los Divorciados, but with no second measurement.

The total of 197 plots amounts to some 5195 remeasured tree records. The total area measured is 9.85 ha. The ejidos are located in close proximity some 100 km north of Chetumal. Thus the results described here relate specifically to that zone and should be extrapolated elsewhere with a degree of caution.

### ***Diameter increments and species groups***

#### **Grouping of species by ordination**

Mean diameter increments and diameter distributions were calculated for all species using programs written in VBA. Species were then grouped using an ordination of mean diameter increment on maximum observed diameter (Alder, 1995). The groups were determined statistically using *k-means* ordination analysis with the package STATISTICA. The resulting distribution of increments and tree sizes are shown in Figure 1.

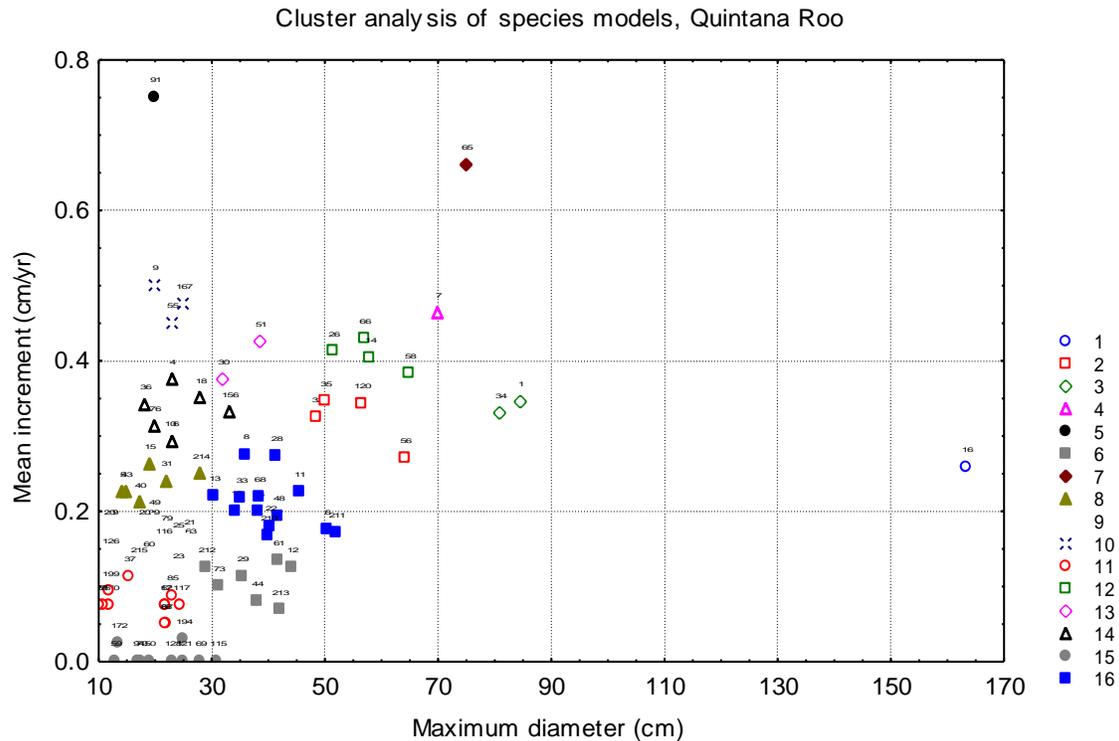
Each point represents a mean value for one species<sup>1</sup>. In some cases, there may be only one tree in the sample. The logic of this method is that there may be assumed to be a relation between mean increment, maximum tree size, and mortality rate, and this ordination provides a direct and robust method for ordinating species by groups of similar increment and mortality rate.

The numbers shown against the individual points are the species code from the list. These are given in Appendix A for the species found in the PSP data, together with their assigned groups. The consultant used only local names throughout the analysis. Although some botanical name information is available from different lists, these have not been formally associated with the PSP coding system, and there are known to be many synonyms for local names in use. It is likely that in some cases, one species code may represent several distinct species; conversely, some names and codes may be synonymous.

The group numbers shown were revised slightly on the basis of inspection. It was found that each species in groups 10 and 5 were represented by a single tree only. These weak observations were merged with group 14. The number 5 was reallocated for Ramon (56) which was separated from the other species in group 12 as it is very numerous and was somewhat distant from the cluster centre. Group 10 was reallocated to Botan (194), which is a common palm which was assigned statistically to group 15.

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<sup>1</sup> As identified by local name. See following paragraph.



**Figure 1 Grouping species by ordination of mean dominant increment on largest diameter**

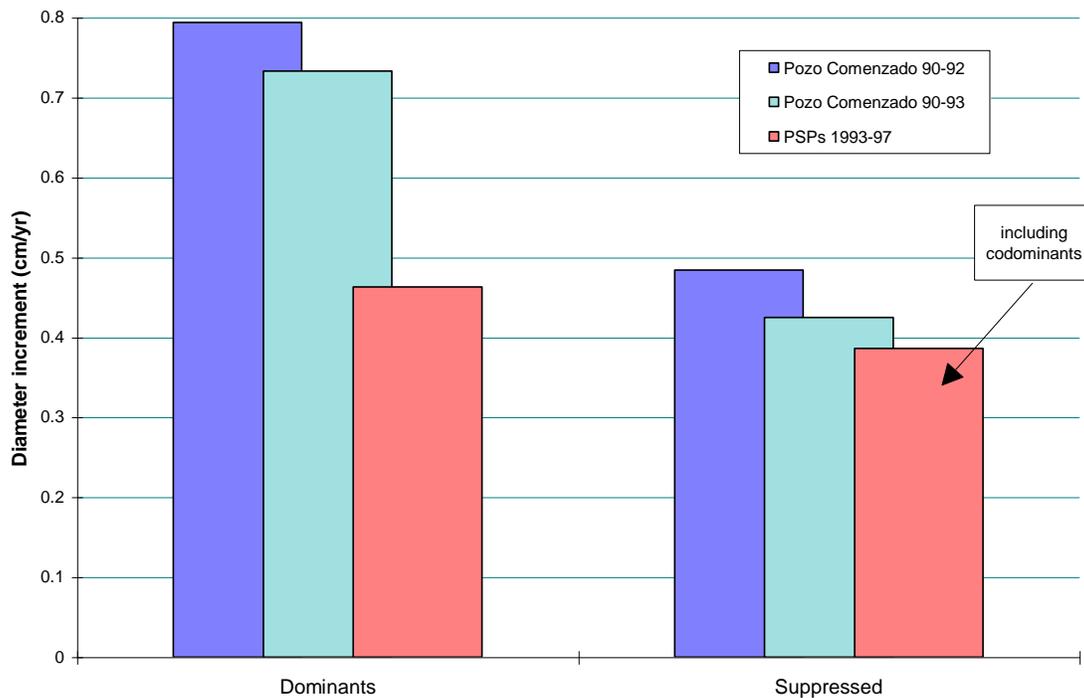
Having assigned the groups by this method, mean increments were re-calculated for the groups. The results are summarised in Table 2. This shows for each group the principle species, the abundance in terms of basal area %, the mean increments for dominant and emergent trees, or for sub-dominant and suppressed trees, the frequency distribution by 10-cm size classes, and the diameter of the largest tree in the group.

**Comparison with other increment measurements**

In examining the increments shown in Table 3, it can be seen that those for Caoba are lower than expected. Ramírez & Sanchez (1992, 1993) reported increments from the *Pozo Comenzado* plot in Nohbec of the order of 0.8 cm/yr, as against means of around 0.4 cm/yr in Table 3. A direct comparison is shown in Figure 2.

**Table 3 Abundance, mean increment, frequency distributions and largest diameter for species groups**

<b>Species groups</b>		<b>Abund.</b>	<b>Diameter increment, cm/yr</b>				<b>Frequency distribution by diameter classes</b>					<b>Dmax</b>
No.	Typical species	BA%	<i>Dom.</i>	<i>Nt</i>	<i>Sub.</i>	<i>Nt</i>	15-24	25-34	35-44	45-54	55 +	cm
1	<i>Chicozapote</i>	18.7%	0.258	78	0.217	134	23%	30%	20%	16%	11%	163
2	<i>Kaniste, Kitamche</i>	4.0%	0.328	47	0.153	93	62%	32%	4%	2%		50
3	<i>Amapola, Katalox</i>	7.6%	0.339	42	0.201	91	48%	28%	13%	4%	7%	85
4	<i>Caoba</i>	4.9%	0.463	48	0.386	27	25%	28%	28%	15%	5%	70
5	<i>Ramon</i>	9.5%	0.271	114	0.202	94	41%	36%	13%	8%	2%	64
6	<i>Tabaquillo, Chakte Kok, Palo de Sol + 4</i>	11.4%	0.118	87	0.102	501	77%	19%	4%			44
7	<i>Tzalam</i>	4.4%	0.660	61	0.323	25	45%	29%	12%	9%	4%	75
8	<i>Kanatsin, Majahua + 3</i>	0.6%	0.243	18	0.088	29	86%	14%				28
9	<i>Elemuy, Perez Kuch, Chobenche, + 10</i>	1.0%	0.143	21	0.144	99	94%	6%				26
10	<i>Botan</i>	2.4%	0.030	65	-0.011	190	99%	1%				25
11	<i>Kekenche, Limonaria, Ekjule, + 8</i>	0.7%	0.068	7	0.137	107	100%					25
12	<i>Chechen, Sac Chaka, Yaaxnik, Higo</i>	12.9%	0.402	164	0.268	258	64%	26%	6%	3%	1%	65
13	<i>Pimienta, Jobo</i>	2.1%	0.360	28	0.155	104	72%	24%	3%		1%	57
14	<i>Laurel, Silit, Bob + 7</i>	0.8%	0.368	18	0.089	57	82%	18%				33
15	<i>Anal, Huano, Dzidzilche + 6</i>	0.4%	0.000	2	-0.028	25	81%	19%				31
16	<i>Chaka, Zapotillo, Pasaak, Tastab, Copal +8</i>	18.4%	0.214	224	0.166	665	75%	19%	5%	0%		52



**Figure 2 Comparison of Caoba increments from different measurements**

Various possible explanations for the large difference in mean increments can be considered.

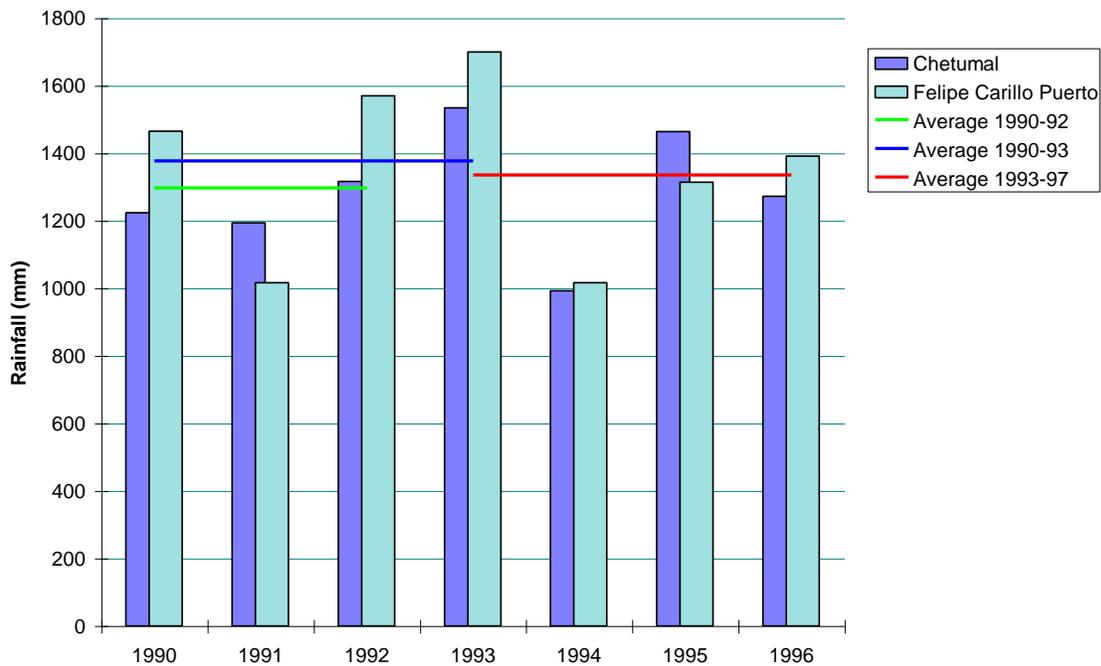
- *The dates given for the first measurement may be substantially in error.* This does not seem to be the case from recorded data and recollection, but given the absence of original dated measurement forms, it remains a possibility. However, the stated dates would need to be at least one year out, and this seems most unlikely.
- *There are large sites differences between Pozo Comenzado and other areas.* This also does not seem likely. The Nohbec measurements show the same low values as other sites, and include plots close to Pozo Comenzado. The Smithsonian measurements (see below) show the same effect and are in many cases on the same PSPs.
- *Rainfall was substantially lower over the 1993-1997 period* which predominates in the PSP data than the 1990-93 period for the Pozo Comenzado data. This possibility is contradicted by rainfall records (Figure 3) which show similar average precipitation over the period.
- *The change from calipers to tapes may have biased measurements.* Normally, diameter tapes measure the convex hull of a tree cross section. Estimated diameters will be slightly larger on average than caliper measurements. Thus, this effect would have the reverse effect and would tend to exaggerate increments.
- *The height of the point of measurement (POM) was systematically underestimated at the first measurement.* This appears to be the only remaining probable cause. At the first measurement strict control over the POM was not exercised, and it was not marked on the trees.

It will require further measurements of the PSPs to clear this matter up. Measurements made on some PSPs in Nohbec under a Smithsonian Institute contract<sup>1</sup> during 1994 are consistent with the higher increments in the Ramírez & Sanchez (1992, 1993) reports. The author was able to compare these with Nohbec measurements on the same PSPs over the period 1993-1997 and found generally higher increments on several species. This remains consistent with problems over the initial point of measurement.

It must therefore be assumed that the general increments shown in Table 3 are probably too low. This is clear from the overall behaviour of MOSQIRO, and is compensated for in the model by providing a general (and user-adjustable) multiplier factor of 25% on the average increments determined from analysis.

Once additional re-measurements are available, it will be possible to calculate an average correction factor, so that data from the first measurement will still be of some value.

**Figure 3 Average rainfall over different measurement periods**



<sup>1</sup> Data provided by Felipe Sanchez Román, personal communication, 1997.

**Tree volume equations**

**Standard equations**

There are five standard equations used in Quintana Roo, developed during the period when MIQRO operated concessions in the state. These equations all have the form:

$$V = a + b \cdot D^2 \cdot H \quad \text{\{eqn. 1\}}$$

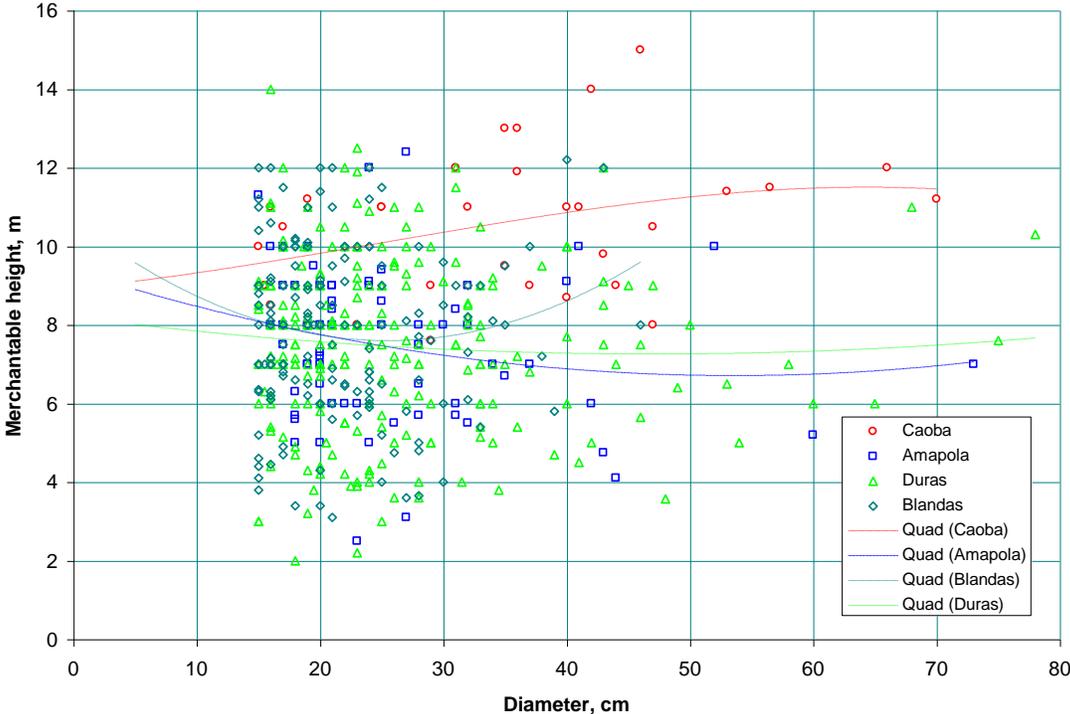
where V is bole volume in m<sup>3</sup>, D is tree diameter at 1.3 m in cm, and H is the height of the bole. The coefficients for the equations are shown in Table 4.

Equation	Species/Group	a	b
1	CEDRO	0.07055	0.000047705
2	BLANDAS	0.01247	0.000047554
3	DURAS	0.00842	0.000050894
4	AMAPOLA	0.03139	0.000038954
5	CAOBA	0.01711	0.000041591

**Table 4 Standard volume equation coefficients**

These equations cannot be used directly in a simulation model such as MOSQIRO because they require a measurement of commercial height, which is unknown in the model. The possibilities

**Figure 4 Height-Merchantable diameter relationships on PSPs**



for developing a volume equation based solely on tree diameter were therefore examined.

### Height/diameter relationships

Figure 4 shows merchantable height against diameter for the volume groups for trees from PSPs on Petcacab, Los Divorciados and Avila Camacho. The Nohbec data was not included as heights had not been entered in the database at the time of this analysis.

The relationship between diameter and height is very weak. Only Caoba shows a consistent trend with height. In general, it appears that by the time trees have reached 15 cm diameter, they have reached a final commercial height. This tends to suggest that a volume-diameter model based on a constant form-height should be a reasonable approximation for area estimates of volume.

### Volume equations based on diameter

For use within the MOSQIRO model, equations were developed to calculate volume from diameter only, without the use of merchantable height as in the standard equations. From inspection of Figure 4, it was concluded that two equations would suffice: One for Caoba, and the other for all other species. The volumes calculated from the standard equations were plotted against diameter for the sample trees from the PSPs. A regression was fitted with the form:

$$V = a.D^2 + b.D \quad \text{\{eqn. 2\}}$$

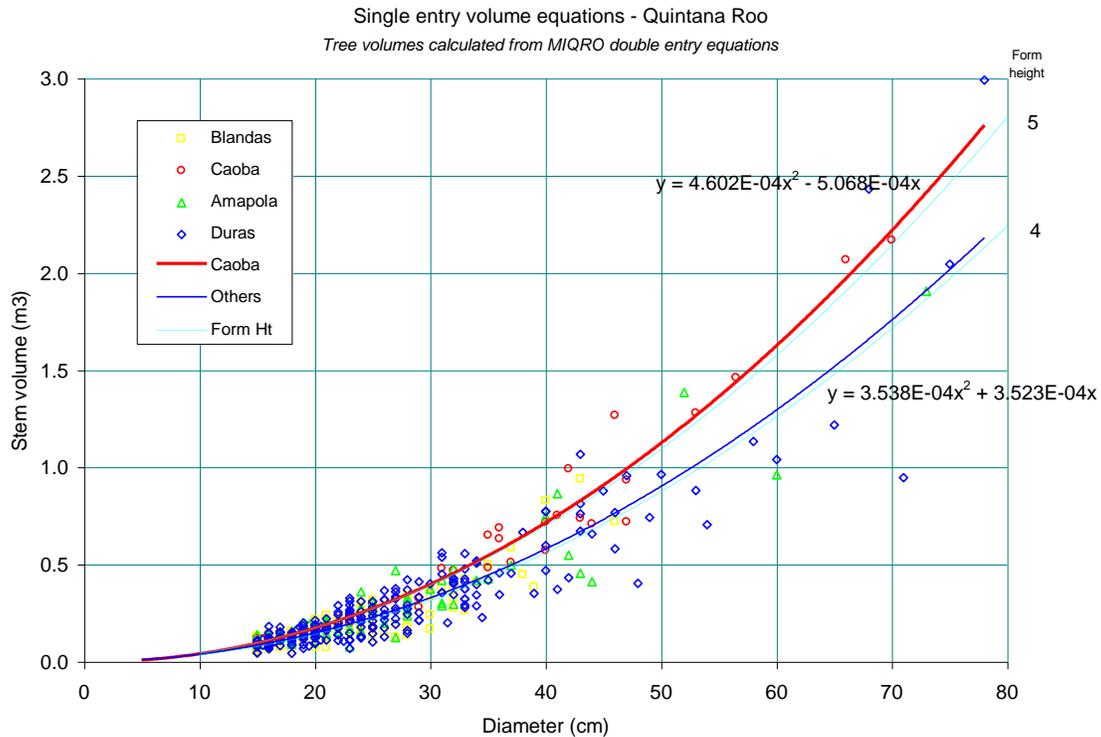


Figure 5 Diameter-based volume equations used in MOSQIRO

The fitted regressions for this model are shown on Figure 5. For comparison, the simple form-height models based on the equation:

$$V = F_h \cdot G \quad \text{\{eqn. 3\}}$$

are shown. In the above equation,  $G$  is tree or stand basal area in  $m^2$ , and  $V$  is bole volume in  $m^3$ .  $F_h$  is *form height* in  $m$ , or the height of a cylinder with equivalent volume to that of the tree. The ratio of form height to merchantable height is the form factor of the stem. The Caoba model closely approximates a constant form height of 5 m, while that for other species is close to the form height of 4 m.

These approximations provide a good basis for estimating stand volume from basal area. In general, it can be said that stand volume is 4 times basal area. The stand volume of Caoba is 5 times the basal area of Caoba.

### **Efficiency of height measurement in inventory**

At present, on both inventory plots and permanent sample plots, all trees are measured for height using telescopic poles. This procedure uses approximately 60% of the time spent on an inventory plot, based on anecdotal observations. The error component due to the volume equation can be calculated in an inventory, and compared with the error due to spatial sampling. It will generally be found to be very small, due to the large number of sample trees. The relative difference between a single entry equation based on diameter only, and a double entry equation based on diameter and height will be found to be small, compared with other factors influencing the precision of the inventory. On the other hand, height measurement constitutes a large part of the cost of the inventory.

It is the consultant's observation that:

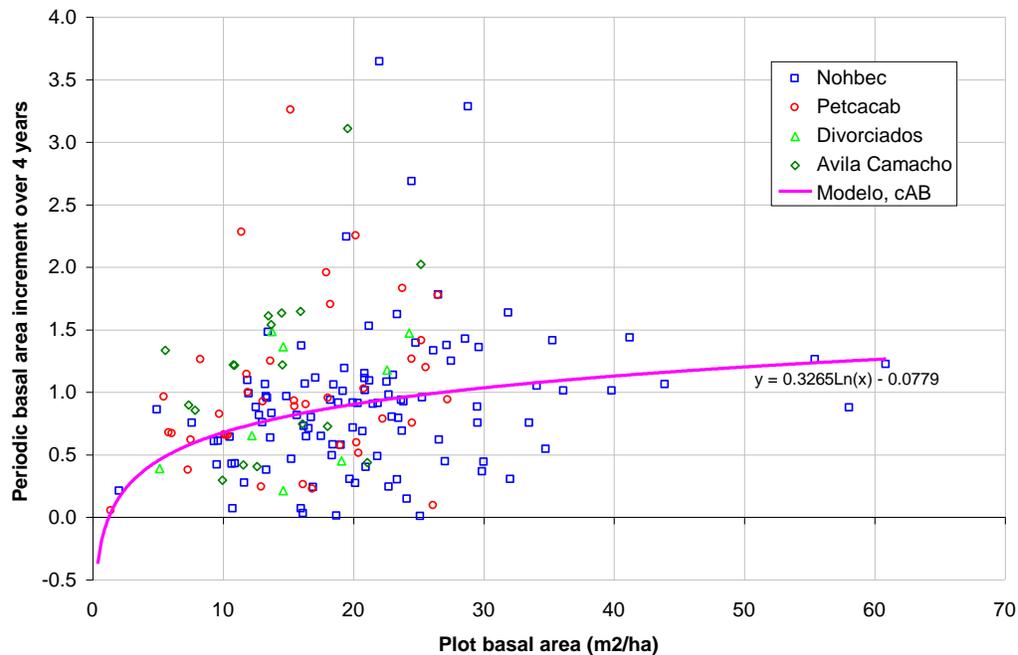
- (i) Use of a double-entry volume equation for forest inventory is probably unnecessary.
- (ii) The cost savings through using a single-entry equation would be substantial.

The precise effect of the different methods can be estimated through a consideration of the equations involved, typical sample sizes, and error factors associated with the volume equations. A desk study of this would be a valuable exercise that would probably support the points made above, and show that inventory procedures could be significantly simplified and substantial economies made.

## Stand basal area and volume increment

### Basal area increment

The basal area and basal area increment were calculated for all trees over 15 cm for the entire set of available data. These results were plotted as shown in Figure 2. There do not appear to be any substantial differences between the ejidos, and for the model, a logarithmic function similar to that shown was fitted to the data over 10-cm diameter for Nohbec only.



**Figure 6 Basal area growth over 4 years on PSPs**

The pattern of basal area increment is complex and requires more detailed study than the brief period allotted under this assignment. There are variations in increment depending on stocking, and also probably site variations, which may be accounted for by production classes. It may be possible to correlate production classes with various qualitative indicators for the plots, such as soil type and depth, or the presence of indicator species. It is also necessary to analyse basal area increment in terms of size class distribution.

The periodic basal area increment over 4 years is more or less equivalent to annual volume increment, given as noted that mean form height is close to 4 m. Thus the vertical axis in Figure 6 can also be read as *Bole volume increment (m3/ha/yr) for trees over 15 cm diameter*.

### Volume increment and allowable cut

Although the primary purpose of this study is to develop a dynamic model for the *Selva mediana* forests of Quintana Roo, the PSPs can be used directly as a source of management information about increment. There is much confusion about what constitutes increment in a natural forest, and how it may be equated to allowable cut. In principle, the author considers that both

recruitment and mortality should enter the equation, and that only increment on the commercial component of the stand is relevant. In the present case, the mortality is unknown, and the figures presented are those for gross increment without including recruitment. They can be regarded as giving a first approximation of allowable cut, or sustainable yield.

Volume increment is given for trees over 25 cm. This includes mainly commercial volume (35 cm+) and the *Reservas* that will become commercial over a 25 year period. The mean increment is 0.527 m<sup>3</sup>/ha/yr. Much of this is potentially commercial, on these larger size trees. The figure of 0.25 m<sup>3</sup>/ha/yr generally adopted as a state-level annual allowable cut seems reasonable on these forest types. This figure can be contrasted with the 4 m<sup>3</sup>/ha/yr mean annual increment that is easily achievable on plantations of Caoba.

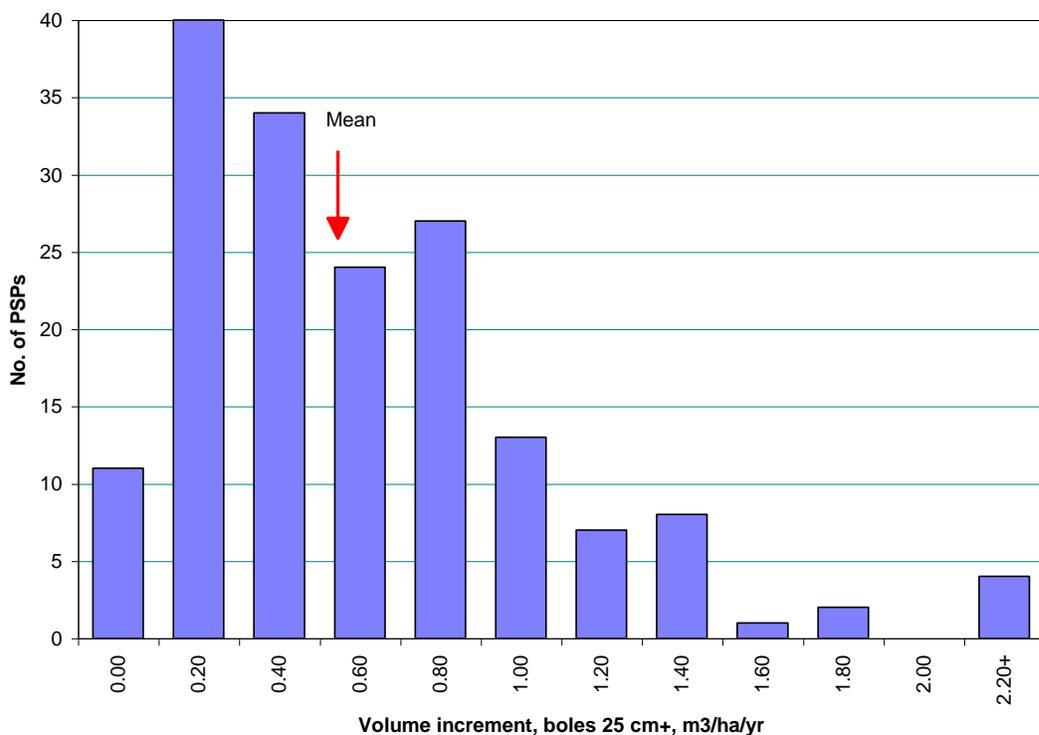
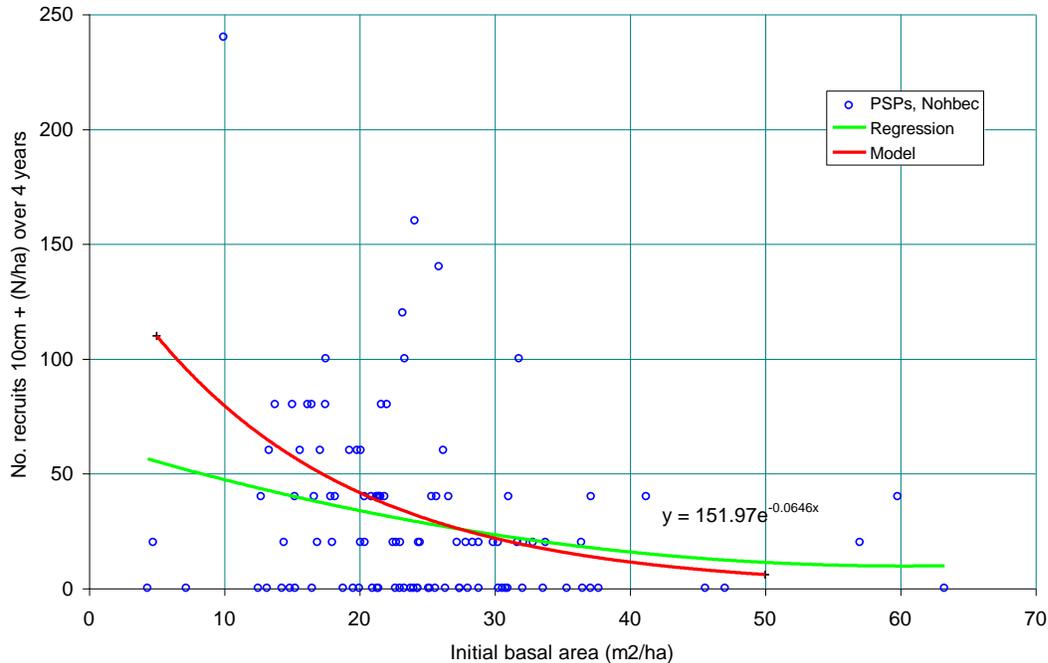


Figure 7 Frequency distribution of volume increments over 25 cm dbh on PSPs

## Recruitment

### Overall recruitment

Overall recruitment levels can be estimated directly from the PSPs. Because the model was being built to operate to a minimum diameter limit of 10 cm, only the Nohbec PSPs were suitable for this analysis. The other PSPs were measured to a minimum limit of 15 cm at the first measurement, although the second measurement was to 10 cm.



**Figure 8 Recruitment over 4 years versus initial basal area**

The graph shows the regression model, and an exponential model adjusted to give a good performance of the overall model. Work on other projects has shown that the recruitment function is sensitive to the period elapsed since disturbance, and the degree of disturbance. It would be desirable to partition the data by various site factors to examine these influences, but the number of plots is too small to permit this at the moment.

The small plot size results in a number of zero values, and this approach, which has been developed based on experience with larger plots in Brazil and Costa Rica, may not be the best type of analysis for Quintana Roo. There is considerable information on the regeneration sub-plots of the PSPs which has yet to be analysed, and may provide better indicators of recruitment rates.

### **Species distribution of recruits**

The overall levels of recruitment need to be allocated to species in the functioning model. This was done by preparing lists of recruits for 3 densities of stand: Below 20 m<sup>2</sup>/ha, 20-30 m<sup>2</sup>/ha, and above 30 m<sup>2</sup>/ha. These lists are expressed as percentages of total recruitment.

## Mortality estimates

### Average mortality rates

Average mortality rates were estimated from the largest diameter tree and mean increment under the assumptions of uniform increment and mortality rates. Both these assumptions are very questionable, and these mortality rates provide nothing more than *guesstimates* of appropriate figures. They do appear to be of an appropriate magnitude compared with the author's experience in mature high forest, but when applied without adjustment within MOSQIRO, result in negative increment. Therefore it must be assumed that these figures are too high for larger trees, given the dynamic and relatively young state of the *Selva mediana*. After experimenting with the model, it was found that applying a multiplier factor of 1/3 gave estimates of mortality that were appropriate at the whole stand level.

It will be appreciated therefore how important it is that this information should be entered in the database. There are usually long-hand notes on the field sheets about dead trees, damage, felled trees, and so on. Better procedures should be adopted in future, as detailed in the **Recommendations**, to record types of mortality or tree loss as coded notes (Alder & Synnott, 1992).

### Density-dependent mortality

Growth in forest stands is strongly density limited. The classical expression of this is the Reineke Line (Reineke, 1933), which is a form of the general ecological 3/2 Power Law. In the absence of empirical mortality data, a limiting function based on the Reineke Line was used to

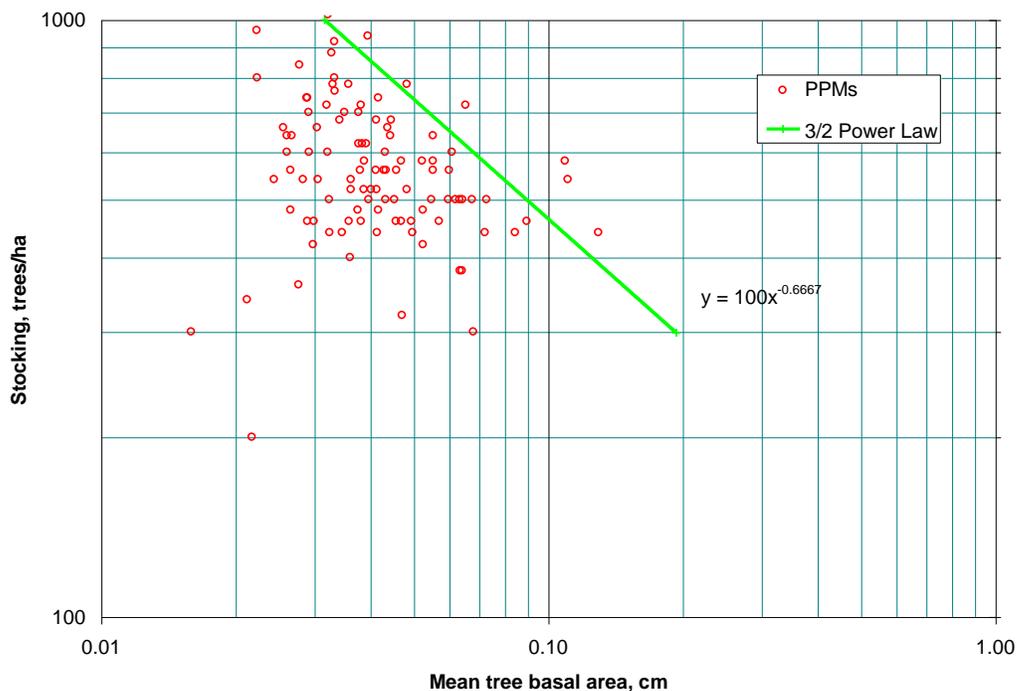


Figure 9 Reineke Line used to infer density-dependent mortality

apply mortality when stocking reached limiting levels. Figure 9 shows the sample plot data together with the assumed limiting density line.

### ***Felling damage***

The effects of felling damage are an important influence on growth and future yields. Damage occurs at three levels:

- Direct destruction and clearing of trees on *bacadiers*, skid trails and in felling gaps. This is referred to as *area damage*. The percentage of area damage gives a figure in which *all tree stocking is destroyed*.
- Residual standing trees with more or less severe damage to branch or bole. Depending on species and severity of damage, this will lead to decay, loss of increment and death. This is referred to as tree damage, and is measured crudely as the percentage of trees over 10 cm which show severe crown breakage or bark abrasion.
- Undamaged trees which die following logging as a result of physiological stress. In long terms studies this can be estimated from the higher residual mortality on undamaged trees after logging. The effect is quite significant and can equal mortality on obviously damaged trees.

Various authors have published studies of felling damage (see Alder, 1995 or Vanclay, 1994 for citations supporting the above points).

There is some information on areas of skid trails and *bacadiers*<sup>1</sup> under the project, but this does not seem to have been written up in a formal way that is useful for model development. The consultant also did not have sufficient time under this study to examine this data. In order to provide some figures for the MOSQIRO model, the data and functions from SIRENA in Costa Rica have been used. This is based on careful logging with light tractors, and should be reasonably similar to that applicable in Quintana Roo.

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<sup>1</sup> i.e. log loading bays or landings.

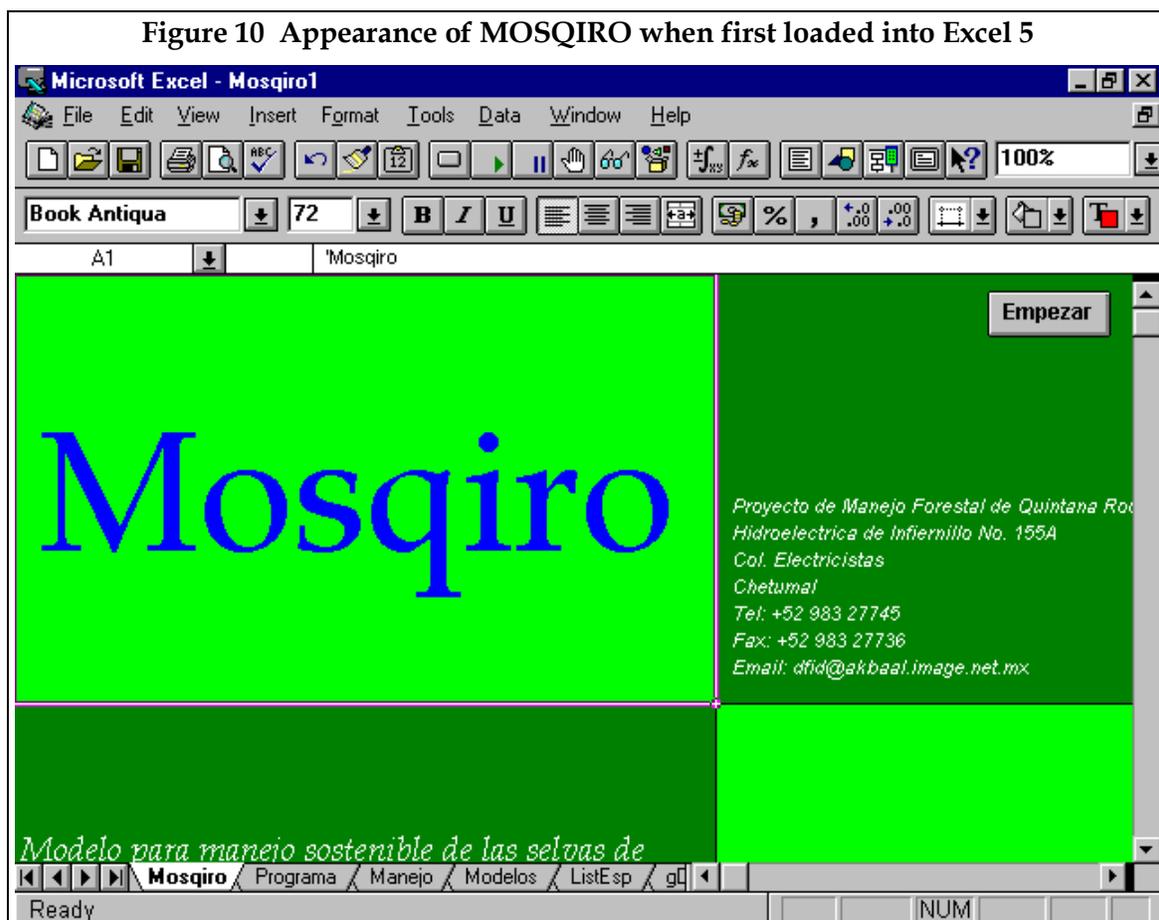
## The MOSQIRO growth model

### General structure

The MOSQIRO model embodies the functions discussed in the preceding section into an integrated model of forest stand development. It is very similar to the CAFOGROM and SIRENA models developed for Brazil and Costa Rica under other UK-supported projects.

MOSQIRO is an Excel 5 workbook which comprises a number of different elements, including the program in Visual Basic, dialogsheets, worksheets, and graphs. In the default condition in which the model is distributed, only a limited number of these elements are visible to the user. The remainder are hidden to protect them from inadvertent alteration. All the protected elements of the model can however be made visible and modified *using a password that is the same as the name of the sheet*. This should not be done for normal use, but is necessary if the model is to be modified or developed further.

MOSQIRO is also distributed as a *template file*, with extension .XLT. This provides a further level of protection. When the worksheet is saved, it will be automatically saved under a different name, with the extension .XLS. This becomes a working copy of the model, which users should re-load in future if they wish to maintain the parameters that they have set up. However, should they inadvertently delete or modify some vital part of the model so that it no



longer runs properly, they can re-load the original MOSQIRO.XLT file.

Figure 10 shows how the Excel screen looks when MOSQIRO is first loaded. If the green caption screen with the tag *Mosqiro* is not the active sheet, the tag should be clicked with the mouse to bring it to the front. The various buttons at the top of the screen may vary depending on how Excel is configured.

The model is started by clicking the button labelled **empezar**. At this point the various buttons and menus, sheet tags etc. should disappear to be replaced by the MOSQIRO menu.

**Table 5 The MOSQIRO menu system**

<b>Menu</b>	<b>Bar</b>	<b>Description</b>
<b>Parametros</b>	Inventario	<i>Brings up a dialog to set the file name and plot size details for the inventory data describing the forest to be simulated.</i>
	Opciones	<i>Brings up a dialog for general model options, such as the run time, title, diameter classes for graphs, and minimum diameter for volume calculation.</i>
	Aprovechamiento	<i>Brings up a dialog for general options for harvesting: Felling cycle and year of initial felling.</i>
	Manejo	<i>Displays a user-editable worksheet listing user-defined species groups, their minimum felling diameter, the percentage retention above the limit, and species to be used for replanting bacadillas and trails.</i>
	Modelos	<i>Displays a user-editable worksheet giving growth model parameters, which may be adjusted or updated by the user.</i>
	Especies	<i>Displays a user-editable worksheet listing species, inventory and PSP codes, growth models, and user-defined groups to which a species is assigned.</i>
<b>Gráficos</b>	Dinamicos	<i>Displays a graph showing dynamics of basal area over time: Standing stock, growth, mortality, recruitment, harvesting, damage.</i>
	Area Basal	<i>Displays a graph showing basal area by diameter classes and species groups. Control buttons on the graph allow this to step forwards or backwards over time after the model has been run.</i>
	No. Arboles	<i>Displays a graph showing tree numbers by diameter classes and species groups. Control buttons on the graph allow this to step forwards or backwards over time after the model has been run.</i>
	Volumen	<i>Displays a graph showing standing volume above a user-specified diameter limit by species groups over time.</i>
	Rendimiento	<i>Displays a graph showing volumes actually harvested, by species groups, for each felling.</i>
<b>Ejecutar</b>	Pasar	<i>Runs the model with current settings, updating graphs.</i>
	Salir	<i>Exits from the model to Excel.</i>
	Zoom	<i>Adjusts the size of graphics to fill the display properly.</i>
	Imprimir	<i>Sends the current graph or worksheet to the printer.</i>

### **Menu system**

The menu which appears when the model is running has three main entries, horizontally arranged. Each of these when selected with the mouse brings down a sub-menu, with the entries shown in Table 5. Selecting the sub-menu item starts the appropriate program function.

## Model parameters and options

### Inventory data for the forest to be simulated

The *Parametros/Inventario* menu choice brings up a dialog box as shown in Figure 11. This allows the following details to be set:

- Name of the file containing the inventory data.
- Plot size, in m<sup>2</sup>.
- Sub-plot size, in m<sup>2</sup>, if any. This can be blank if the plot is not sub-sampled.
- The minimum diameter for measurement on the main plot, in cm.
- The system of codes to be used. This may be either the standard PSP codes, or the standard inventory codes. These codes are selected from two different columns in the species list, as discussed further on page 23.

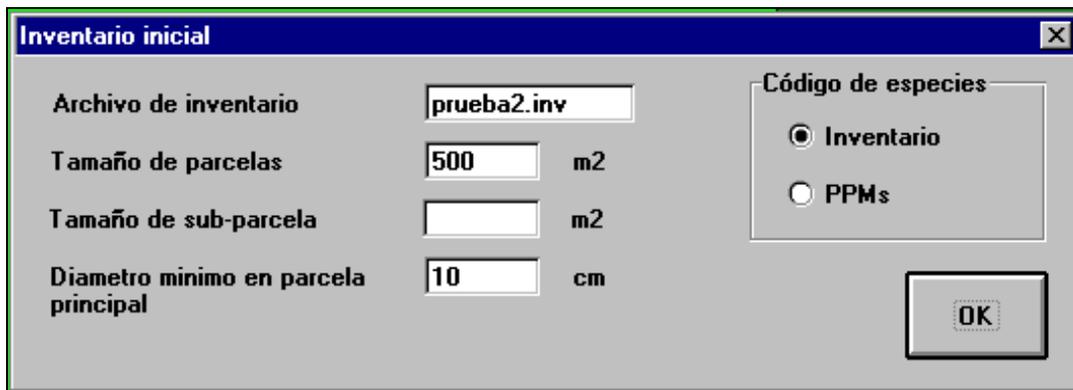


Figure 11 Dialog box defining inventory file and plot size details

This dialog, like others in MOSQIRO, is not active. No processing is done when the OK button is clicked. The options are simply stored until the model is run.

When the model is executed from the *Ejecutar/Pasar* menu., it will look for the specified inventory file in the current Windows directory. If it is not found, then a system dialog box will appear which allows a different file and directory to be selected.

The inventory data is stored in a text file, which should be given the extension .INV. The format of this file is as follows:

- The first line may contain any arbitrary information, usually a description of the data. It is not read by the program and is skipped over.
- Second and subsequent lines consist of tree measurements, and should include:
  - Line number
  - Plot number
  - Species code
  - Tree diameter

The tree data items are all numeric, and should be comma separated. The species codes must correspond to those in the species list.

## General model options

The menu selection *Parametros/Opciones* is used to set general options controlling the simulation. The dialog shown in Figure 12 will appear, from which the following settings can be made:

- *A general title.* This will appear as a centred heading on printed outputs, but is only updated when the box labelled *Actualizar titulos...*, at the foot of the dialog, is checked.
- *Simulation period.* This determines how many years the model will run for. MOSQIRO runs in 5-year steps, and any figure given will be rounded to the nearest 5-year period.
- *Diameter classes.* This governs the diameter classes used on the graphs of basal area and stem numbers by size class. The smallest class should not be less than 10 cm.
- *Volume minimum diameter.* This determines the smallest tree included in volume calculation for the graph of volumes over time. A setting below 10-cm is meaningless within the model and is not recommended.
- *Updating of printed headings.* When graphs are printed, the standard Excel header and footer are replaced by settings from MOSQIRO giving version number, date, filename, and the user's general title. On slow computers, this updating can be an irritating process that is not necessary for casual printings. Clearing this box will skip over the updating process.
- *Principal graph.* When the model is run, either of the two graphs which show data over time may be shown: The graph of basal area dynamics, or the graph of standing volumes. Selecting the appropriate option button determines which is displayed.

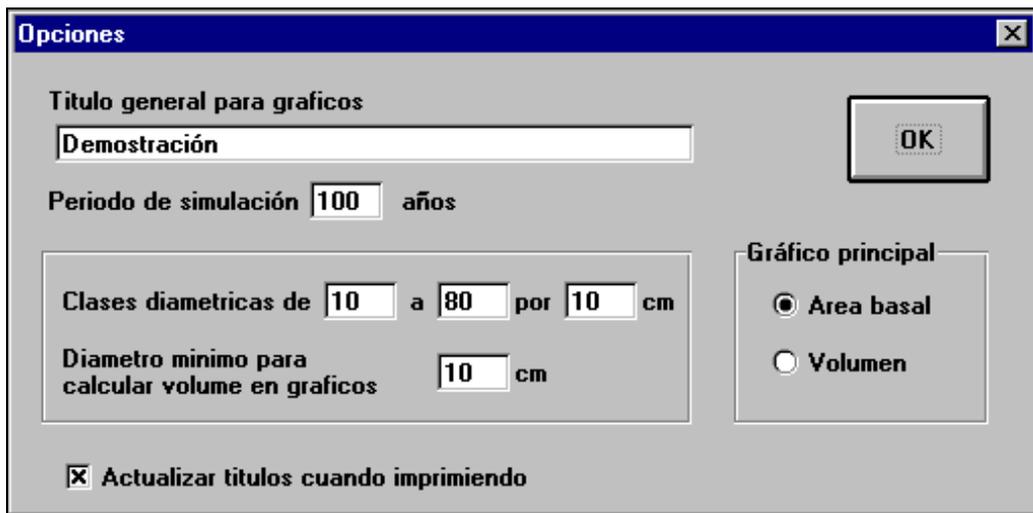


Figure 12 Dialog to set general options for MOSQIRO

## Felling cycle and timing of first harvest

When the menu *Parametros/Aprovechamiento* is selected, then the dialog shown in Figure 13 appears. This allows the felling cycle and the year of first harvest to be set. If the box marked *Sin aprovechamiento* is checked, then no harvesting is done.

Both the felling cycle and the year of first felling will be rounded to the nearest 5-year period. If the year of first felling is zero or blank, then the first felling is done at the end of one felling

cycle, not in year zero. This is because in the model, year 0 data is always shown exactly as given in the inventory file, before any simulation routines (including harvesting) are applied.

Other felling options such as diameter limits and percentage retention, are controlled via the *Manejo* menu at the species group level.

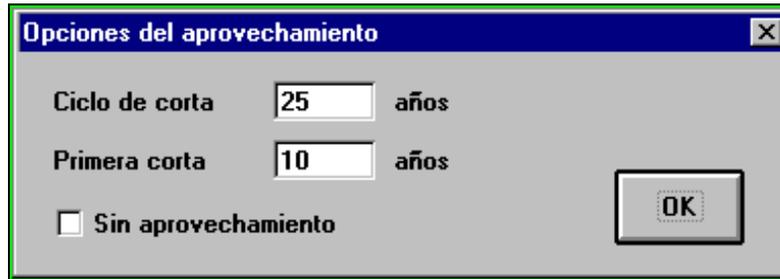


Figure 13 Dialog for setting harvesting options

### Forest management at the species level

Minimum diameters for felling, and species to be planted in clearings, trails and bacadillas, are controlled via the *Parametros/Manejo* menu. This brings up the worksheet shown in Figure 14. The headings and formats in this worksheet are protected, but the data can be edited by the user to control in more detail how the forest is managed.

<i>Especificaciones de manejo forestal por grupos de especies</i>					
<b>Código</b>	<b>Grupo de especies</b>	<b>Diámetro mínimo</b>	<b>% Restantes</b>	<b>Plantaciones</b>	
<i>en lista</i>	<i>nombre para gráficos</i>	<i>para cortar</i>	<i>semilleros etc.</i>	<i>Codigo</i>	<i>N/ha</i>
P	Caoba	55	10	7	1000
A	Amapola	35	50		
H	Chicozapote	35	100		
S	Sac Chaka	35	50		
B	Blandas	35	50		
C	Comerciales	35	50		
P	Potenciales	35	50		
R	Ramon	35	50		

Figure 14 Worksheet to set diameter limits, retention %, and planting specifications by species groups

A number of species groups can be defined. Each species group can have a different felling diameter limit and percentage retention. Each is also shown separately on the output graphs, and labelled with the group name given.

The letter codes are used to link the groups with the species list. In the species list, each species having a particular letter code will be assigned to that group. The use of one-letter codes limits the number of possible groups to 26.

No trees of a given species group will be felled below the specified minimum diameter. Above the minimum, a percentage of trees will be left after felling. This percentage should be adjusted to realistically reflect:

- *Market demand.* Groups with weak demand as timber, or species used for non-timber products such as Chicozapote, will have a high percentage retention. Species with a heavy demand, such as Caoba, will have a low retention percentage unless constrained by silvicultural or conservation factors.
- *Defective trees.* A percentage of trees will be unusable due to defect. MOSQUIRO (unlike CAFOGROM or SIRENA 2) does not model defect, and it is necessary to be able to leave a certain percentage of trees after felling in accordance with typical defect levels.
- *Silvicultural and conservation factors.* It may be desired to leave a certain percentage of the stock of large trees as seed sources or for conservation reasons.

One or more species may be specified for planting in felling gaps, trails and bacadillas. MOSQUIRO uses the total area calculated by the area damage function for planting, and does not allow a subdivision of the types of affected areas. The density per ha of plantings in the cleared areas should be given. The species code used should correspond to the coding system selected for reading the inventory file.

### Model coefficients

The menu selection *Parametros/Modelos* brings up the worksheet shown in Figure 16. This gives the parameters for all the growth models used in MOSQUIRO. *It is recommended that the user does not modify these coefficients until they have a good understanding of the use and behaviour of the model.*

There are three boxes on the worksheet. Under the heading *Modelos general* are coefficients for

Figure 16 Worksheet defining model coefficients

1. Modelos general										
				$\alpha$	$\beta$	<b>Multiplicadores</b>				
				0.0399	0.0771	Crecimiento	1.25			
				32.00	0.0004	Mortalidad	0.33			
				1.0530	1.2708	Ingresos	1.00			
				1.0079	0.7198					
2. Modelos de especies										
Características	Modelo #	Especies típicas del grupo	No. Arb. en muestra	AB %	IncDiam (cm/an)		Mortal. (%/an)		Vol. ecu.	Dmax cm
Arboles grandes de dosel superior	1	Chicozapote	212	19%	0.258		8.0%		2	163
	3	Amapola, Katalox	133	8%	0.339		1.9%		2	85
	7	Tzalam	86	4%	0.660		3.8%		2	75
	4	Caoba	75	5%	0.463		2.8%		1	70
	12	Chechen, Sac Chaka, Yaaxnik, Higo	422	13%	0.402		3.7%		2	65
Arboles medianos de dosel inferior		Ramon	208	10%	0.271		2.2%		2	64
	13	Pimienta, Jobo	132	2%	0.360		3.1%		2	57
	16	Chaka, Zapotillo, Pasaak, Tastab, Copal +8	889	18%	0.214		2.8%		2	52
	2	Kaniste, Kitamche	140	4%	0.328		3.2%		2	50
Arboles pequeños de sotobosque	6	Tabaquillo, Chakte Kok, Palo de Sol + 4	588	11%	0.118		1.7%		2	44
	14	Laurel, Silli, Bob + 7	75	1%	0.368		4.7%		2	33
	15	Anal, Huano, Dzidziche + 6	27	0%	0.068		1.3%		2	31
	9	Kanatsin, Majahua + 3	47	1%	0.243		3.3%		2	28
Palmas	8	Elemuy, Perez Kuch, Chobenche, + 10	120	1%	0.143		2.6%		2	26
	11	Kekenche, Limonaria, Ekjule, + 8	114	1%	0.068		1.3%		2	25
	10	Botan	255	2%	0.030		0.7%		0	25

stand models, and multipliers that can be used to adjust the performance of the model. Under *Modelos de especies* are the coefficients related to the model groups which are given on the species list. There is no limit in the program to the number of models that can be used, and the list shown can be shortened or extended as may be needed.

At the moment, the columns for understorey increment and mortality are blank. This is to allow space for a more sophisticated development of the model functions as new data becomes available. This initial version of MOSQUIRO uses only average increments, which are adjusted by the stand density growth functions.

### **The species list**

The menu selection *Parametros/Especies* brings up the species list shown in Figure 15. The columns of this table are as follows:

- A. Code for the species used in the PSP data.
- B. Name of the species.
- C. The model number, corresponding to an entry in the species models table (see Figure 16)
  - . If no number is given ( a blank or non-numeric entry), then the model for that species will default to 16. By reference to Figure 1, the reader will see that this is a group for species of medium size and growth rate.
- D. The user-defined groups for forest management and output. These entries can be edited to create new groups. A letter should be given, and a corresponding entry made in the table shown in Figure 14. Several species may have the same letter. If the entry is not a letter in the range A-Z, or is blank, then the species will be grouped under *Other species* in the output graphs, and cannot be selected for felling or management under the *Parametros/Manejo* table.
- E. The species code used in standard inventory files. Note that under the *Parametros/Inventario* dialog shown in Figure 11, the *Código de especies* option determines whether column A or column E is used to decode species numbers when reading the data file. If the option *Inventario* is selected, the column E code will be used. If the PPM option is chosen, then the species numbers in column A will be used. If a species code is found when reading the data which does not exist in column E (or A if selected), then that species is treated as an *Other species* in the output graphs, and as model 16 for growth analysis.

### **Graphical and other outputs**

## Basal area dynamics

The graph of basal area dynamics is viewed by selecting the menu option *Gráficos/Dinamicos*. It will also appear by default when the model is running if selected from the *Parametros/Opciones* screen (Figure 12). The graph appears as shown in Figure 17. For each 5-year period, it shows periodic increment, recruitment and mortality in basal area, as well as the standing stock at the start of the 5 year period. When harvesting is done, it shows the basal area extracted, and basal area losses through area and tree damage.

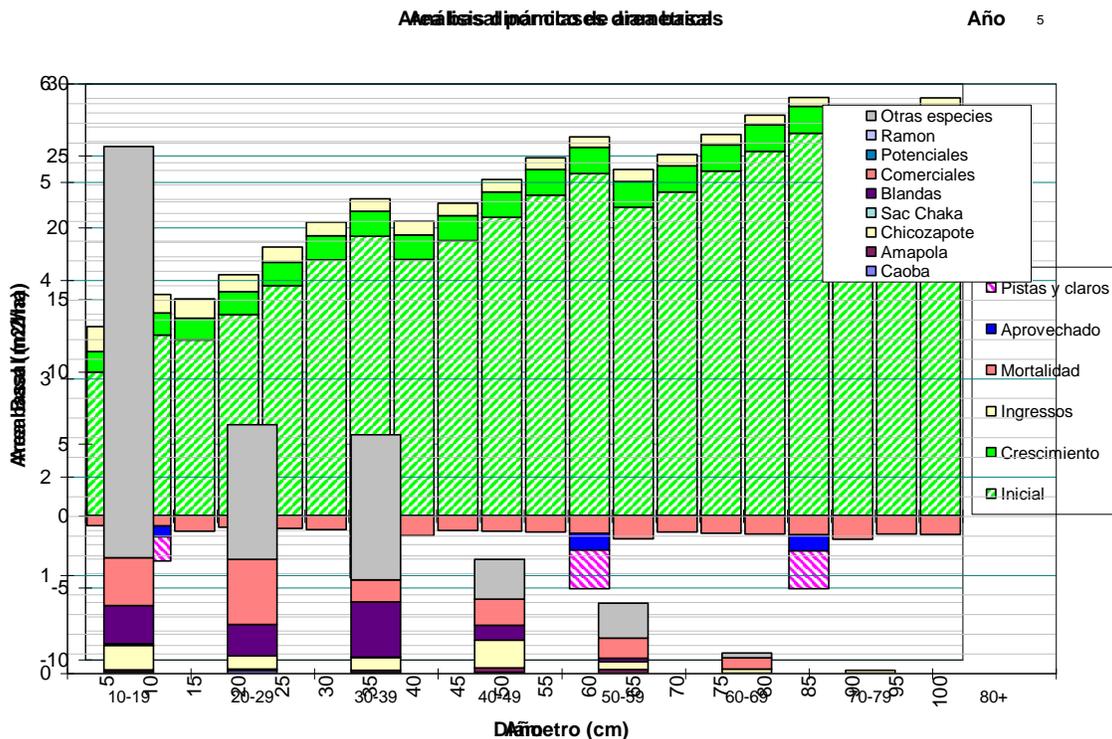
## Basal areas by size classes

The menu selection *Gráficos/Area Basal* will display a graph similar to that shown in Figure 18 after the model has run. It cannot be viewed while the model is running. This graph shows the structure of the stand at the indicated year in terms of basal area by diameter classes and species groups.

The graph has four control buttons which can be used to view stand structure at different time periods. The button functions are as follows:

- |< This shows stand structure in year zero.
- < This steps back one period from the current display to show structure in the preceding 5-year period.
- > This steps forward one period from the current display to show structure in the next 5-year period.
- >| This shows stand structure at the end of the simulation.

Figure 18 Graph of basal area dynamics in the stand and species groups



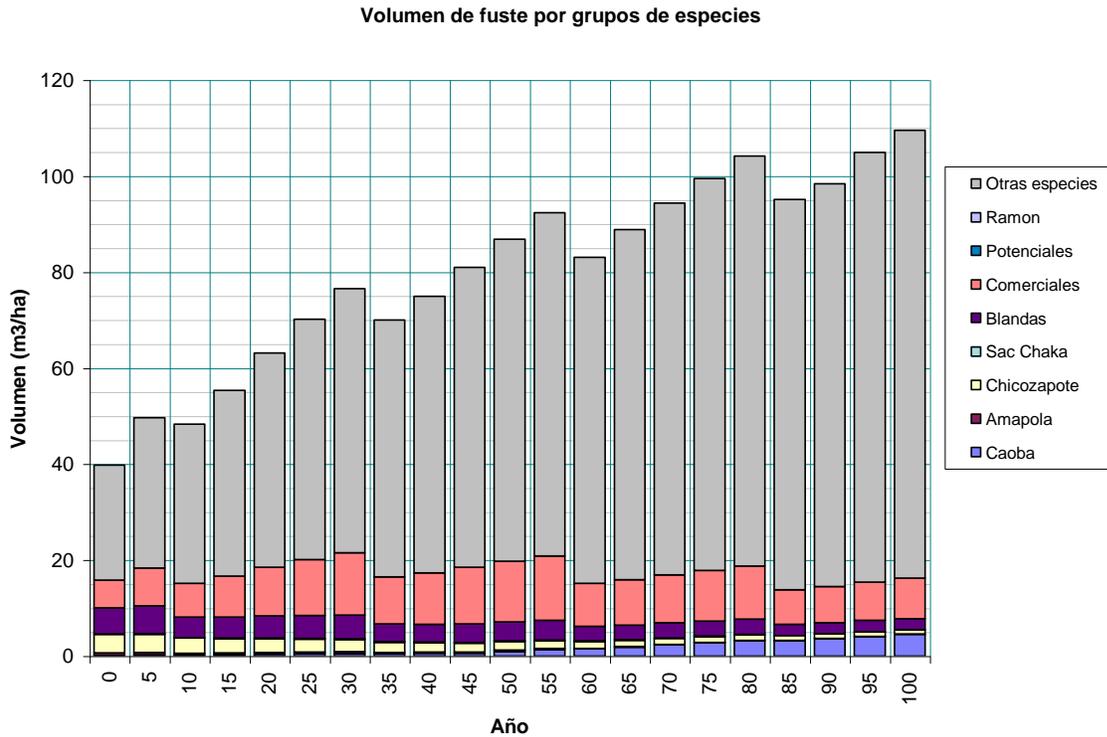
### Tree numbers by size classes

The menu selection *Gráficos/No. Arboles* brings up a graph with the same characteristics and functions as the basal area/stand structure graph, but showing number of trees/ha rather than basal area.

### Standing volumes

A graph of standing volumes by species groups over time can be viewed with the menu selection *Gráficos/Volumen*. This graph can also be viewed while the model is running if selected from the *Parametros/Opciones* dialog. It appears as shown in Figure 19. The volumes shown are bole volumes for trees above the minimum diameter for volume graphs, as defined on the *Opciones* dialog (see page 20).

**Figure 19 Graph of standing volume over time by species groups**

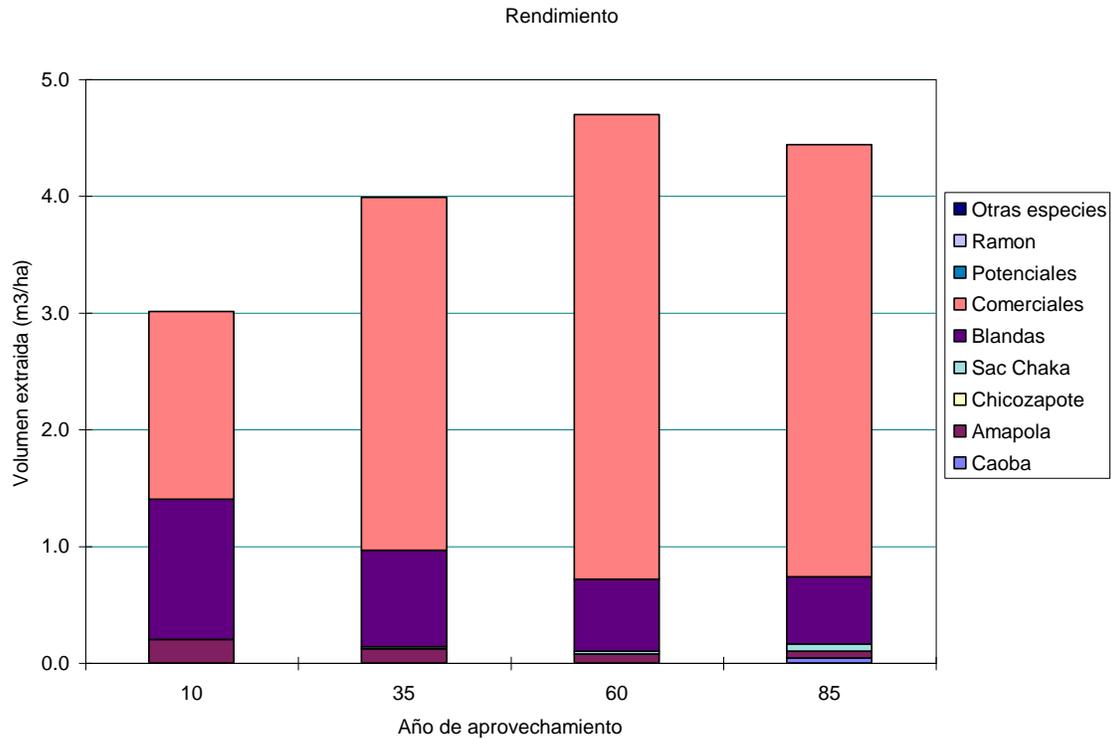


### Harvested volumes

A graph of volumes actually extracted at each felling cycle can be viewed with the menu option *Gráficos/Rendimiento*. An example is shown in Figure 20.

### Viewing tabulated outputs

Underlying each of the graphs described in the preceding section is a table of figures generated by the model. For certain purposes, such as the comparison of different simulation options, or



**Figure 20 Graph of harvested volumes**

an economic evaluation of management alternatives, it may be desirable to copy these figures into other Excel workbooks.

Table 6 shows the sheet names for each graph and underlying worksheet. The worksheets are normally hidden in the distribution copy of MOSQUIRO, but can be viewed if required by:

- Unprotecting the structure of the model (with the password *Mosqiro*).
- Using the Excel menu option *Format/Sheet/Unhide*<sup>1</sup> to expose the required sheet.

The tables are not formatted for presentation. It is recommended that user's do not attempt to format them, as they are erased and rewritten whenever the model is run. To produce copies of the tables for printing or display, it is recommended that they are copied to another Excel workbook, and edited there.

**Table 6 Worksheet and chart names corresponding to graphs**

Graph	Chart name	Worksheet name
<i>Dinamicos</i>	gDinAB	cDinAb
<i>Area Basal</i>	gABxD	cABxD
<i>No. Arboles</i>	gNxD	cNxD
<i>Volumen</i>	gVol	cVol
<i>Rendimiento</i>	gRend	cRend

<sup>1</sup> In the English version of Excel 5.

## **Executable functions**

### **Running the model**

The menu selection *Ejecutar/Pasar* runs the model with currently defined parameters. While the model is running, either the graph of basal area dynamics or standing volumes will be displayed. These show the development of the forest over time.

When the model begins to execute, it reads the various options that have been set, the species list, inventory data file, and management options. It is at this point that any serious errors or inconsistencies in the parameters may cause an error message, not when the parameters are entered. Following such an error, the run will be cancelled, and it is necessary to go to the parameter screen and make an appropriate correction. An example of such an error would be failure to give a plot size.

Once the run is finished, then graphs other than the default can be viewed. Pressing the Esc key while the model is executing causes the run to be cancelled.

### **Exiting to Excel**

The menu selection *Ejecutar/Salir* will resume normal operation in Excel<sup>1</sup>. In this mode, it is possible to save the model with current settings, or to view and modify elements of the model using standard Excel operations.

Note carefully however that even small changes to the structure of the model may prevent it from operating normally. It is necessary always to experiment with a copy of the program, and to develop a good understanding of how Excel objects and methods function within Visual Basic if it is desired to modify the model in any way. To limit the chances of inadvertent changes, MOSQIRO is distributed as a template XLT file. Saving this file always creates a copy with the extension XLS. The original XLT file will be available for recovery if mistakes are made.

### **The Zoom function**

Under the *Ejecutar* menu will be found the *Zoom* function. This is used to adjust the size of graphic images or displayed worksheets. The selected part of a graph or worksheet will be expanded to fill the screen when Zoom is selected.

### **Printing graphs and worksheets**

The currently displayed graph or worksheet will be printed to the Windows printer when the *Imprimir* menu bar is clicked. Changes to the printer setup can be made from Excel, or from Windows for general printer setup. Specific parts of a graph can be modified by selecting them and clicking the right mouse button. This allows access to functions to change the colour or shading of histogram bars, for example.

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<sup>1</sup>. Note however that MOSQIRO will not restore non-standard tool bars in its present version when reverting to the Excel menu. The *Standard* and *Formatting* toolbars are restored.

## Recommendations and conclusions

### *Support for PSP work*

#### **Standards for plot measurement**

Although the consultant has had some concern about the small size of the PSPs, the analysis made here shows that this is adequate, and it is not recommended that any change is made to the general procedures or plot design.

It is however very important that mortality is correctly coded. The author suggests the following numeric codes are adopted:

- 0 or blank.....Healthy, normal tree
- 11 .....Alive but moribund. Dieback on branches and/or substantial decay in the stem.
- 12 .....Defoliated, apparently dead. Tree appears to be dead, but without obvious damage or decay. A machete cut to the stem shows live wood.
- 13 .....Severely burnt, defoliated or with dead foliage. Severely burnt trees will sometimes recover and may appear live at the next enumeration.
- 21 .....Dead standing tree. The tree is clearly dead, but standing. Bark is exfoliating showing dry wood, and branches may be beginning to fall.
- 22 .....Dead, partially or wholly fallen, but without major logging or wind damage.
- 23 .....Dead, fallen and partially decayed.
- 31 .....Logging or wind damage, but some branches remain, and tree is not pushed from vertical.
- 32 .....Broken top through storm or logging damage, but may have fresh epicormic sprouting. No crown branches left intact.
- 33 .....Tree pushed from vertical or partially fallen, possibly with other crown damage, but still alive.
- 34 .....Tree completely destroyed, fallen or pushed to the ground, or crushed by machinery. There may be vertical epicormic shoots from the fallen stem.
- 41 .....A cut stump is found where the tree should be.
- 42 .....Fallen tree with evidence of hand or machine felling: Axe or saw cuts.
- 51 .....The tree has completely disappeared. There is no evidence as to the cause.

Using these codes allows both the fact and the probable causes of mortality to be established. A training exercise is needed with appropriately designed forms to ensure the codes are properly applied in the field.

The consultant would also prefer to see the point of measurement clearly painted on trees. This is a little time consuming, but ensures accurate remeasurement.

### **Field forms, data entry and processing**

The management of the field sheets and the data entry process is the area where the PSP programme has shown the greatest weakness. As noted earlier, Sanchez Román (1993) describes clearly data processing methods and has well-designed field forms for remeasurement. These have not been used in practice probably because the initial measurement data was never processed or was lost..

DFID can play a role in improving procedures in this area. There are human factors at work, in the form of rivalries among professionals involved in the PSP programme, and the need is clearly for leadership, based on a single Forest Engineer or equivalent appointed to manage the PSP programme with the support of the involved Civil Societies and ejido councils. This professional needs to attend to and control the following aspects:

- Location, and copying of all original measurement forms, and their proper archival and storage in a suspension filing system.
- Design of field forms and data entry procedures. Existing procedures are good, but need modification to allow for storage of tree numbers and mortality codes.
- Scheduling of remeasurements, and printing of remeasurement forms to ensure field crews have a list of previous measurements.
- Logistics and management of the field aspects of remeasurement.
- Control of data entry, ensuring plot data is entered immediately after collection, so that checks can be run and queries dealt with directly whilst the field staff are still available and have a good recollection of the work.
- Direct check measurements where queries cannot be resolved in the office.

DFID can facilitate this appointment by providing office and physical facilities, possibly a salary supplement, and a non-controversial and unaffiliated organizational linkage that will encourage the cooperation of the ejidos. DFID can also give financial and material support to some aspects of the field work.

### **Further data analysis**

The present analysis is very provisional. Information on mortality rates and logging damage needs to be acquired. There are doubts about the reliability of increment measurements. There is a need, quite simply, for much more data than has been available, regardless of the question of quality.

There are professionals in Mexico, some already well known In Quintana Roo, who are well able to replicate and extend the work described here, and to continue to develop forest

modelling tools. As far as possible, the consultant would recommend the involvement of local professionals in future rounds of analysis.

### **Height measurement on inventory plots**

As discussed on page 11, height measurement on inventory plots can probably be shown by statistical analysis to be unnecessary, given the development of suitable volume equations. There would be considerable saving in inventory costs, as the process of height measurement may consume some 60% of the time spent on a plot. The telescopic height poles are also heavy, and slow down travel time between plots. The consultant recommends a short study to evaluate the statistical aspects of this question in a way that will be convincing to various stakeholders in the inventory process in Quintana Roo, and to make a presentation of the findings.

This study should also define procedures and forms for developing new volume equations. This work would be undertaken with DFID assistance if the findings were accepted.

### **Conclusion**

The MOSQIRO model provides a working tool for forest management in Quintana Roo. At this stage it is very provisional, due to the limited data available. However, it provides a complete and accessible system which can be developed further by biometrics specialists in Mexico as may be necessary. In its present form it provides a clear indication of how forest structure and species distribution will develop, subject to various possible regimes of harvesting.

The PSP work needs to be continued in Quintana Roo. The original concepts were very good, and as with other aspects of forest management in the region, were unusual in their cooperative and community based origins. There are some weaknesses however. The most important ones have been the failure to control measurement height properly on the first occasion, insufficient emphasis and clarity on the subject of mortality and damage coding, and weak management of the data and field forms, which may have led to some data being lost.

DFID can facilitate improved work at relatively low cost, by encouraging centralised control (under mutual agreement) of the field and office aspects of the work, and providing the necessary material and logistic support. This would be a most valuable and catalytic contribution to sustainable forest management in an important region of sub-humid tropical forest.

Denis Alder  
2 November, 2021

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## Appendix A: Species statistics from PSP analysis

Species name	code	Abundance		Diam. increment, cm/yr			Diameter distribution by cm classes					Dmax cm	Model	
		BA%	Cum%	Dom.	Nt	Sub.	Nt	15-24	25-34	35-44	45-54			55 +
CHICOZAPOTE	16	19%	19%	0.258	78	0.217	134	23%	30%	20%	16%	11%	163	1
RAMON	56	10%	28%	0.271	114	0.202	94	41%	36%	13%	8%	2%	64	5
AMAPOLA	1	6%	34%	0.345	26	0.218	81	47%	27%	16%	5%	6%	85	3
CAOBA	7	5%	39%	0.463	48	0.386	27	25%	28%	28%	15%	5%	70	4
CHAKA	11	5%	44%	0.225	60	0.137	113	71%	21%	6%	1%		46	16
CHAKTE-KOK	12	5%	49%	0.124	46	0.109	111	57%	34%	9%			44	6
TZALAM	65	4%	53%	0.660	61	0.323	25	45%	29%	12%	9%	4%	75	7
CHECHEN	14	4%	58%	0.404	49	0.293	78	60%	34%	4%		3%	58	12
SAC CHAKA	58	4%	62%	0.383	69	0.201	108	72%	21%	3%	2%	1%	65	12
TABAQUILLO	61	4%	66%	0.135	21	0.067	266	91%	9%	1%			42	6
ZAPOTILLO	68	4%	70%	0.219	8	0.169	334	85%	14%	1%			38	16
YAAXNIK	66	4%	74%	0.430	44	0.341	62	59%	24%	11%	5%	1%	57	12
KANISTE	32	3%	77%	0.325	40	0.159	84	63%	31%	5%	1%		49	2
PASAAK	48	3%	80%	0.193	33	0.214	37	52%	37%	11%			42	16
BOTAN	194	2%	82%	0.030	65	-0.011	190	99%	1%				25	10
TASTAB	64	2%	84%	0.199	45	0.147	48	79%	20%	1%			38	16
PALO DE SOL	44	2%	86%	0.080	5	0.172	105	83%	15%	1%			38	6
JABIN	28	1%	87%	0.273	26	0.175	18	65%	26%	9%			41	16
KATALOX	34	1%	89%	0.330	16	0.060	10	52%	33%			14%	81	3
OTROS	120	1%	90%	0.343	21	0.127	54	74%	21%	3%		3%	57	13
BOOP	6	1%	91%	0.175	10	0.045	11	70%	10%	15%	5%		50	16
COPAL	19	1%	92%	0.200	6	0.193	57	97%	3%				34	16
NARANJILLO	213	1%	92%	0.069	8	0.189	14	60%	27%	13%			42	6
KITAMCHE	35	1%	93%	0.346	7	0.100	9	57%	36%		7%		50	2
HIGO	26	1%	93%	0.412	2	0.352	10	50%	20%	20%	10%		52	12
CAPULIN	211	1%	94%	0.172	8	0.264	11	81%	13%		6%		52	16
PIMIENTA	51	1%	94%	0.425	5	0.171	42	68%	26%	5%			39	13
KASKAAT	33	0%	95%	0.217	13	0.117	14	83%	11%	6%			35	16
GUAYA	22	0%	95%	0.180	5	0.127	10	60%	30%	10%			40	16
JOBO	30	0%	95%	0.375	2	0.262	8	67%	33%				32	13
CHAKTE-VIGA	13	0%	96%	0.220	5	0.575	3	57%	43%				30	16
PALO ROSA	210	0%	96%	0.167	3	0.166	8	71%	14%	14%			40	16
GUAYABILLO	23	0%	96%	0.117	6	-0.055	5	100%					24	9
KANATSIN	31	0%	96%	0.240	12	0.000	9	100%					22	8
BOB	156	0%	97%	0.331	4	0.114	7	33%	67%				33	14
PALO CHILILLO	214	0%	97%	0.250	3	0.000	3	33%	67%				28	8
EKJULE	117	0%	97%			0.075	22	100%					25	11
KEKENCHE	86	0%	97%	0.050	1	0.155	40	100%					22	11
GUAYACOX	25	0%	97%	0.158	3	0.394	8	100%					24	9
YAITI	67	0%	98%	0.050	2	0.200	10	100%					22	11
HUANO	69	0%	98%			-0.011	7	86%	14%				28	15
JOBILLO	29	0%	98%	0.112	4	0.075	2	75%		25%			35	6
DZIDZILCHE	115	0%	98%			-0.096	7	75%	25%				31	15
HUACAX	212	0%	98%	0.125	2	0.150	3	50%	50%				29	6
SILIL	106	0%	98%	0.293	6	0.120	5	100%					23	14
TAMAY	63	0%	98%	0.150	3	0.131	4	60%	40%				26	9
CARACOLILLO	8	0%	98%	0.275	2	0.050	1	50%		50%			36	16
GRANADILLO	21	0%	99%	0.162	2	0.063	2	75%	25%				26	9
CHOBENCHE	116	0%	99%	0.150	2	0.155	15	100%					21	9
PEREZ KUCH	49	0%	99%			0.189	18	100%					20	9
LAUREL	36	0%	99%	0.342	3	0.134	35	100%					18	14
CILILLON	18	0%	99%	0.350	1	-1.600	2	67%	33%				28	14
CHI-CHE	15	0%	99%	0.263	2	-0.125	3	100%					19	8
TUSIKCHE	85	0%	99%	0.088	2	0.850	1	100%					23	11
BOBCHICHE	4	0%	99%			0.375	4	100%					23	14
MAJAHUA	40	0%	99%			0.211	11	100%					17	8

Species name	code	Abundance		Diam. increment, cm/yr				Diameter distribution by cm classes					Dmax cm	Model	
		BA%	Cum%	Dom.	Nt	Sub.	Nt	15-24	25-34	35-44	45-54	55 +			
TADSI	62	0%	99%	0.075	1	0.147	9	100%						22	11
HUILOTE	215	0%	99%			0.125	16	100%						17	9
ROBLE	55	0%	100%	0.450	1	0.025	2	100%						23	14
XUUL	73	0%	100%	0.100	1				100%					31	6
TOYUB	79	0%	100%			0.167	6	100%						22	9
SUBIN	60	0%	100%	0.133	3	0.100	1	100%						19	9
SIPCHE	121	0%	100%	0.000	1				100%					25	15
KOLOL	167	0%	100%	0.475	1				100%					25	14
OKNOM	128	0%	100%	0.000	1			100%						23	15
CHINTOK	17	0%	100%	0.075	1			100%						22	11
CEDRO	9	0%	100%	0.500	1			100%						20	14
CULINSIS	91	0%	100%	0.750	1			100%						20	14
YUUY	76	0%	100%			0.313	2	100%						20	14
MACULIS	39	0%	100%	0.175	1	0.025	1	100%						20	9
PICH	50	0%	100%			0.000	1	100%						19	15
ELEMUY	20	0%	100%	0.175	1	0.071	20	100%						18	9
SAC-YAB	70	0%	100%			-0.025	1	100%						18	15
SAC-USICNE	94	0%	100%			0.000	1	100%						17	15
LIMONARIA	37	0%	100%			0.113	18	100%						15	11
BOJON	5	0%	100%	0.225	1	0.150	1							14	8
NANCE	43	0%	100%			0.225	2							15	8
RUDA	57	0%	100%			0.075	1							10	11
SIRICOTE	59	0%	100%			-0.038	2							13	15
AKIX	126	0%	100%			0.137	2							12	9
SACITZE	170	0%	100%			0.075	1							12	11
ANAL	172	0%	100%			0.025	6							14	15
CHILAR	199	0%	100%			0.094	4							12	11
ISINCHE	206	0%	100%			0.075	1							11	11
PALO	209	0%	100%			0.175	1							12	9
CHACHALACA															