Sustainable Forest Management Plan For The Chiquibul Forest Reserve 2018 - 2022

Bull Ridge Limited
License No: LTFL 03/06

Prepared by:
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List of Abbreviations

AAC	-	Annual Allowable Cut
ACC	-	Annual Cutting Compartment (annual coupe)
AMR	-	Annual Mortality Rate
APO	-	Annual Plan of Operations
BF	-	Board foot measure
BRL	-	Bull Ridge Ltd
CAR	-	Caracol Archaeological Reserve
CAT	-	Caterpillar Inc. machinery (tractor) company
CCS	-	Chiquibul Cave System
CFJEU	-	Chiquibul Forest Joint Enforcement Unit
CFO	-	Chief Forest Officer
CFR	-	Chiquibul Forest Reserve
CITES	-	Convention on International Trade in Endangered Species
CNP	-	Chiquibul National Park
COC	-	Chain of Custody
CONAP	-	Consejo Nacional de Áreas Protegidas (Guatemalan National Council for Protected Areas)
D95	-	95% point on the cumulative diameter distribution
Dbh	-	Diameter at breast height (1.3 m above ground level)
DEM	-	Digital Elevation Model
Dinc	-	Mean Annual Diameter Increment
DOS	-	Directorate of Overseas Surveys
DSM	-	Digital Surface Model
FCD	-	Friends for Conservation and Development (NGO)
FD	-	Forest Department (Belize)
FNPV	-	Fundación Naturaleza Para la Vida (Foundation Nature For Life, Petén, Guatemala)
FORMNET	-	Forest Monitoring Network of Belize
FPMP	-	Forest Planning and Management Project (UK and Belize)
FSC	-	Forest Stewardship Council
GPS	-	Global Positioning System
GYM	-	General Yield Model
HCVF	-	High Conservation Value Forest
IA	-	The Institute of Archaeology
LCRS	-	Las Cuevas Research Station
LTFL	-	Long-Term Forest License

LULCF	-	Land Use and Land Use Change and Forestry (emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities)
MAI	-	Mean Annual Increment
MaxCD	-	Maximum Cutting Diameter Limit
MCDL	-	Minimum Cutting Diameter Limit
MDI	-	Minimum Diameter Inventoried
MLC	-	Maximum Likelihood Classifier
NAD27	-	North American Datum of 1927 (geodetic reference system)
NDVI	-	Normalized Difference Vegetation Index
NTFP	-	Non-Timber Forest Product
PHA	-	Post-Harvest Audit
PSP	-	Permanent Sample Plot
PVG	-	Provisional Vegetation Group
RIL	-	Reduced Impact Logging (method)
RME	-	Reliable Minimum Estimate (statistical analysis)
SFMP	-	Sustainable Forest Management Plan
T95	-	Time taken by a tree to grow to its species' D95 diameter
UNEP	-	United Nations Environmental Program
UNESCO	-	United Nations Educational, Scientific and Cultural Organization
UTM	-	Universal Transverse Mercator coordinate system
WCMC	-	World Conservation Monitoring Centre

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1 EXECUTIVE SUMMARY

1.1 Background to the plan

1.1.1 Chiquibul Forest Reserve

This Sustainable Forest Management Plan exhibits the background and current status of the Chiquibul Forest Reserve, its timber stocking and sustained yield forecast, and Bull Ridge Ltd.'s planning of forest operations for the period 2018-2022. Bull Ridge Ltd.'s long-term forest license (LTFL 03/06) applies to the Chiquibul Forest Reserve (CFR). When gazetted in 1956 the total area of the Forest Reserve was estimated at 714 square miles (184,926 ha), of which 330 square miles (85,470 ha) was classified as protection forest. The size of the Forest Reserve was considerably reduced in 1991 when the major part of the area was re-designated as a National Park (approximately 107,605 ha). New boundaries were recommended shortly after in 1994, which were subsequently gazetted in 1995. The area of the Forest Reserve is now 59,822 hectares, Chiquibul National Park 106,838 ha and the Caracol Archaeological Reserve 10,339 ha.

Bull Ridge Ltd. (BRL) has exclusive rights to all primary hardwood, secondary hardwood and pine trees in the license area and is entitled to fell and remove all trees identified for felling under the SFMP and designated for felling under a current APO. BRL has long-term tenure and use rights through this license with duration of 40 years, commencing on the 28th September 2006 and ending on 27th September 2046; with an option to extend for a further 40-yr. period.

1.1.2 Physical characteristics of the reserve

The CFR lies on part of the Maya Mountains sloping westwards and northwards from the Main Divide and is bounded on the north by the Macal River; and on the east, south, and west sides by the Chiquibul National Park (CNP). The central and western part of the forest reserve is mostly covered by a capping of karstic limestone, except for the San Pastor Pine ridge which is on an area underlain by sandstone and slate. Exposures of igneous rocks occur to the area east of the Raspaculo River and Monkey Tail branch and south of the Rio Ceibo Grande. As a consequence, the valleys of tributaries of the upper Macal River and the lower Raspaculo branch tend to be steep sided and there slopes of more than 25° are frequently encountered. The topography on the karstic limestone capping is very different. This limestone plateau has weathered to give cone or tower shaped hills, while drainage is mainly subterranean. Between these hills the terrain usually slopes gently or moderately, and slopes of less than 10° are common. The Chiquibul Cave System, the longest and largest known network of caves in Central America, is partly situated in this limestone plateau.

The soils of the Chiquibul reflect its geology; in the central and western part of the reserve the soils tend to be basic (karstic) and by tropical soil standards, relatively fertile. The eastern part of the reserve for the most part lacks the capping of karstic limestone typical of the plane. Dropping away from the main divide of the Maya Mountains are steep and precipitous ridges on sedimentary and volcanic rocks. There soils tend to be weathered, acidic (siliceous) and poor in nutrients.

Precipitation in the CFR is variable but there is a general north to south gradient, with the south of the area receiving considerably more rainfall than the north. The broad pattern of climate through the year consists of a dry season starting in January or February and ending in May or June followed by wetter months (except for a 'little dry' which sometimes occurs in August). Tropical storms and hurricanes can occur between September and December and numerous storms and hurricanes have affected Belize over the past 100 years. Six of those have affected the Chiquibul; hurricane Hattie in 1961 being the most noteworthy for its devastating impact on the forest canopy.

The vegetation varies from semi-deciduous forest in the drier north to evergreen tropical forests in the wetter south and pine savannah on the sandstone and slate of San Pastor Pine ridge. Penn *et al*. (2004) classify the majority of the forest coverage as deciduous forest in the north-western and western part, followed by semi-evergreen forest in the south-eastern part and evergreen forest in the southern part.

1.1.3 History of human activity

Mayan civilisation

At the time of the ancient Maya civilisation, circa A.D. 200 - 925, the limestone area of the Chiquibul forest was inhabited. It is evident that large areas were cleared for cultivation during this period as indicated by terracing of the gently sloping ground between the steep limestone hills. These terraces still survive, often with the retaining walls still visible. Ruins of dwellings still remain on raised mounds and many hilltops.

Timber exploitation

Chiquibul was not penetrated for exploitation of its timber until the 20th century when a railway was built southwards from Vaca Falls along the Vaca plateau towards Chiquibul. Beyond that point truck passes were opened up for extraction to the railhead. By 1955 the logging operations had penetrated south beyond Resumidero, close to present southern boundary of the reserve. In 1956 the Chiquibul forest was gazette as a Forest Reserve and came under one long-term licence with an allowable annual cut of 240,000 ft^3 for mahogany and cedar. After hurricane Hattie excessive salvage logging depleted the timber stock that had survived the devastation havocked by the hurricane and logging of the two prime species reached an annual yield of 330,000 ft^3 in 1962. Salvage logging continued until 1964 and the license was revised with a reduced allowable yield. Average annual production fell to 130,000 ft^3 for mahogany and cedar for the period 1965-1976. A third long-term licence was issued in 1977 but stocks of mahogany and cedar had become depleted to that extent that the average annual cut for mahogany and cedar was reduced to only 14,000 ft^3 by the time this licence expired in 1987. The actual cut was apparently only 12% of the allowable cut suggesting that little exploitable timber remained and a moratorium was put in place for the next 10 years.

Sustainable forest management

A new forest management system was introduced in 1994 during the Forest Planning and Management Project (Bird, 1998) based on the concept of area control. The size of the annual coupe was determined on the basis of a cutting cycle of 40 years, using general estimates of growth and mortality (Alder, 1993). Based on this 40-year cycle, the production forest area was divided into eighty compartments of approximately 500 ha each, of which two would be allowed to be harvested every year (Bird, 1998). No fixed annual allowable yield was set but a 'local' allowable yield was determined for each individual annual coupe based on a pre-harvest stock survey. Crop trees were to be selected and reserve trees to be retained in such a way that would allow for the same timber harvest in 40 years' time, while at least 10 seed trees for each individual species were to be retained per km^2. The stock survey aimed to determine a timber yield that could be sustained for at least two felling cycles (Bird, 1998). In terms of the present yield, the potential crop trees are to be identified as the number of merchantable trees less the number of seed trees which need to be retained. In terms of the future yield, the number of reserve trees is discounted by 40%, the assumed cumulative mortality over the felling cycle of 40 years. The number of potential crop trees for each species is then adjusted, where necessary, so that the present yield does not exceed the expected yield at the next felling cycle.

Between 2006 and 2016, Bull Ridge Limited harvested 16 compartments covering in total 8,226 ha according to this system. In 2017, two compartments are being harvested with a total area of 965 ha; by the end of 2017, resulting in a total area harvested by BRL of 9,191 ha. Then, 11,044 ha will have been harvested since the start of the present cutting cycle in 1997; or 26% of the production forest as defined by the FPMP management plan. Actual timber extraction records are only available since 2015 when the company introduced a chain of custody system. However, the Annual Plans of Operation (APO) give an indication of the size of the yearly harvests. Between 2009 and 2017 the company has been selecting 1,595 trees per year for harvest on average equivalent to a volume of 2,448 m^3 (86,435 ft^3) over an average annual cutting area of 919 ha. On average, 777 mahogany trees have been selected for harvest each year equivalent to a volume of 1,285 m^3 (45,373 ft^3).

In comparison with the first long-term licence issued in 1956 for which an annual allowable yield of 240,000 ft^3 was set for mahogany and cedar, BRL's forest management practice denotes a drastic reduction in annual yield. The currently available mahogany stock indicates that the species has had the ability to recover after being over-exploited for over 30 years and the devastation havocked by hurricane Hattie. On the other hand, it must be noted that the devastating impact of hurricane Hatti followed by wild fires, probably has provoked the prodigious mahogany regeneration which resulted in the current adequate stock.

Year	Compartment	Gross (net) area (ha)	Mahogany			Other species		
			Crop trees		Residual trees	Crop trees		Residual trees
			No.	Vol (m^3)	No.	No.	Vol (m^3)	No.
2007/08	59 & 60	1,000	754	1,182	2,385	1,010	1,696	2,438
2009	34 & 35	951	571	859	1,946	1,622	1,672	4,865
2010	81	829	628	924	1,851	1,391	1,316	4,085
2011	52 & 53	1,000	942	1,193	2,829	213	364	963
2013	45	446	591	900	1,643	711	805	1,488
2014	61 & 62	1,000	814	1,285	1,894	319	339	1,206
2015	3, 9, 10 & 15	2,000 (1,163)	1,109	2,171	2,489	480	1,099	1,695
2016	19 & 20	1,000 (794)	743	1,302	2,078	809	1,489	4,241
2017	4 & 11	965 (870)	840	1,749	6,808	805	1,685	4,174
TOTAL		9,190	6992	11,565	23,923	7,360	10,465	25,155

The annual harvests conducted by BRL fulfil the established criteria for sustainable forest management in Belize with just 1.6 trees felled per hectare of which only 0.8 trees are mahogany. A substantial number of reserved, preserved and seed trees are retained every year; as many as 5.3 trees of all harvested species per hectare and 2.6 mahogany trees per hectare, on average. In other words, for each mahogany tree being harvested 3.4 trees (≥ 30 cm dbh) are being retained. Similarly, for each tree of the other harvested species 3.4 trees are retained.

Illegal incursions

There are various threats to the Chiquibul Forest. These threats range from agricultural activities, fires, illegal logging, wildlife depletion and looting of cultural artefacts to vandalism by desecrating both cultural and geological assets. Nearly all threats are linked to illegal incursions by Guatemalan villagers.

Illegal logging In the Chiquibul Forest was first detected in 2006. By March 2008, a joint forces patrol documented that illegal logging was escalating and a logging trail network was evident. By 2010, joint patrols reported frequent and persistent illegal logging activities. All extraction of illegal timber was of a trans-boundary nature, namely from Guatemala. The area impacted by illegal logging has shown an increase of 2.5 times from 2010 to 2015 but appears to have reached a saturation point in 2014.

1.2 Forest resource management

1.2.1 Forest organisation

When the redefined boundaries of the CFR were gazette in 1995, controlled timber harvesting was to occur over 41,423 ha (69% of the area). The San Pastor Pine ridge and surrounding broken ridge were excluded from the management area at the time. The remainder of the reserve was designated as protection forest. At a later stage the San Pastor Pine ridge and the broken ridge surrounding and interlacing the San Pastor Pine ridge were added to the production forest, resulting in a production forest area of 42,024 ha.

While developing this SFMP the topography of the CFR was re-examined and it was concluded that the compartments situate to the east of the Monkey Tail River gorge are difficult to access and to work. Similarly, the south-eastern corner of the reserve between the gorge of the Chiquibul River and an unnamed tributary is difficult to access. Further adjustments are proposed in order to incorporate the recommendations of the Chiquibul Cave System Management Plan (Meerman & Moore, 2010), changing the designation to tourism within a buffer zone along the Chiquibul River downstream of the Natural Arch, and to rationalise the boundaries of the 'mining' areas in the southwestern corner of the reserve. The proposed changes in working cycle areas are shown below.

Working circle	**previously**		**proposed**	
	area (ha)	**percentage of total area**	**area (ha)**	**percentage of total area**
Hardwood	42,097	70.4%	35,751	59.8%
Pine	1,001	1.7%	1,001	1.7%
Protection	15,225	25.5%	20,481	34.2%
Tourism	200	0.3%	945	1.6%
Mining	1,081	1.8%	1,426	2.4%
Research	216	0.4%	216	0.4%

Several compartments have already been logged since the start of the present felling cycle in 1997. A total of 21 out of 81 compartments will have been logged by the end of 2017. The redefined zonation of the CFR resulted in the foregoing of a part of one already logged compartment, implying that that 70% of the reserve is still available for logging during the present felling cycle.

1.2.2 Inventory of forest resources

General forest inventory (2011/14)

The first major forest inventory was performed during 1969-1971 in an area that is now predominantly within the Chiquibul National Park (Johnson & Chaffey, 1973). This inventory showed that, at the time, the reserve was nearly completely depleted of its prime species mahogany and cedar in 1969 with less than 1 tree ≥ 50 cm dbh for every 7 hectares or a mere 150 trees for a present day annual cutting compartment. A reliable minimum volume estimate was found of only 28 m^3 mahogany and 113 m^3 cedar per 1,000 ha (Alder, 1993). It is clear that this was sufficient reason for imposing the moratorium on logging in the reserve until 1996. Nevertheless, regeneration of both mahogany and cedar although not abundant appeared adequate. In 1969, the reserve was still in the early stages of recovery from Hurricane Hattie which may explain the low stocking of mahogany and cedar, but other species nargusta and sapodilla showed adequate mature stocking. It is probable that the low stocking of mahogany and cedar in 1969 did not in as much resulted from the impact of hurricane Hattie, but rather from decades of overexploitation and, particularly, excessive salvage cuts during 1962-1964.

A second general forest inventory was started out in the Chiquibul Forest Reserve on behalf of BRL during April and May 2011 in order to guide the development of this management plan, but was not completed until December 2014 due to unforeseen delays. Unfortunately, the sampling design was not implemented consistently with trees in the size class 10-25 cm dbh being sampled at different levels. This erratic implementation of the sampling design considerably reduces the confidence in the estimates for this size class 10-25 cm dbh and hence prevents any proper assessment of the regeneration potential of mahogany in particular.

Comparison of the 2011/14 inventory with the inventory of Johnson & Chaffey of 1969 suggests that mahogany made a strong recovery after the species had been as good as annihilated in 1969. As a matter of fact all species of interest to BRL showed a strong increase in stem density in all size classes, except for cedar and sapodilla. This is not surprising because most species except for sapodilla and santa maria are light-demanding species.

According to the general inventory the prime species make up to 1.4% of all trees ≥ 10 cm dbh, elite species 5.5%, select species 20.8% and unclassified species 72.4%. It is indicated that the following merchantable tree species in the CFR are the most common: sillion, nargusta and hogplum with all over 20 trees/ha ≥ 10 cm dbh, followed by white gumbolimbo, mylady, salmwood, wild grape, sapodilla, fiddlewood and white breadnut with all over 10 trees/ha ≥ 10 cm dbh.

In terms of mature trees (≥ 50 cm dbh) the prime species constituted 11.0% of the total tree density [1.5 trees/ha ≥ 50 cm dbh], elite species 3.8% [0.5 trees/ha], select species 43.9% [5.8 trees/ha] and unclassified species 41.3% [5.5 trees/ha]. Nargusta was the most common species among the trees of mature size [1.7 trees/ha ≥ 50 cm dbh], followed by sillion with 1.4 trees/ha [10.8%], sapodilla with 1.3 trees/ha [9.8%], mahogany with 1.1 trees/ha [8.2%] and hogplum with 0.7 trees/ha [5.6%]. Cedar, barbajolote and santa maria had lower densities; less than 0.4 trees/ha.

Roundwood to sawn lumber volume conversion

In the analysis of the general inventory, gross standing tree volumes were estimated using volume equations developed by Denis Alder (1992a). Relationships between the tree diameter (dbh) and the gross standing volume, the APO volume, the net extracted volume (sawmill input) and recovered volume (sawmill output) were determined using BRL's chain of custody records of the 2016 harvest.

The BRL chain of custody data reveals that the volume calculated in the APO using the equation prescribed by the Forest Department corresponds closely to the sawmill input volume in case of mahogany. The application of the FD prescribed equations hence generates adequate results and should be maintained. This cannot be said about the official conversion factor to estimate BF sawn lumber from m³ roundwood. The Forest Department recently reduced the conversion factor from 212 to 169 BF/m³ (APO volume). The actual conversion factor (2016 harvest) appears to be 240 BF/m³ (222-252 BF/m³ depending on the tree diameter) in case of mahogany sawn lumber.

The estimated standing volumes emanating from the general inventory were converted into net extractable volumes (sawmill input) and sawn lumber (sawmill output) based on linear regression models for mahogany, cedar and nargusta. The theoretical annually available sawmill lumber output based on the density of trees ≥50 cm dbh is estimated at c. 400,000 BF (minimum c. 290,000 BF) for mahogany, c. 180,000 BF (minimum c. 46,000 BF) for cedar, c. 150,000 BF (minimum c. 87,000 BF) for barbajolote, c. 1,000,000 BF (minimum c. 610,000 BF) for nargusta, c. 680,000 (minimum c. 480,000 BF) for sapodilla and c. 50,000 BF (minimum c. 23,000 BF) for santa maria. The estimates for nargusta and sapodilla are not very trustworthy due to suspicious general inventory estimates. Not all trees above 50 cm dbh can be harvested because trees ≥90 cm dbh may not be harvested, seed trees must be retained and a variable number of trees above the MCDL have to be retained depending on the density of 'future' trees to guarantee a 'sustainable' harvest volume at the subsequent harvest. See table below for details on estimated standing volumes.

Trees ≥50 cm dbh	Annual cutting area: 1,000 ha						
	Gross Volume (m^3)	SE of mean Gross Volume (%)	RME* Gross Volume (m^3)	Sawmill input (ft^3)	RME Sawmill input (ft^3)	Sawmill output (BF)	RME Sawmill output (BF)
Mahogany	2,890	15%	2,158	59,022	42,693	404,287	289,653
Cedar	1,205	39%	431	26,638	9,359	180,473	45,781
Barbajolote	1,053	24%	643	21,710	12,885	151,157	86,679
Nargusta	6,932	17%	5,025	151,793	89,000	1,031,564	611,767
Sapodilla	4,695	16%	3,454	96,038	68,918	677,971	477,241
Santa maria	369	33%	169	7,630	3,413	51,611	22,781

*RME = Reliable Minimum Estimates at probability p=0.95

Comparison with stock surveys 2009-17

Comparison of the outcome of the 2011/14 general forest inventory with the findings of Johnson and Chaffey (1973) and the outcomes of stock surveys over the period 2009-17 casts serious doubts on the reliability of the general inventory. This not only applies to the size class 10-25 cm dbh which was sampled at different levels. In addition, erratic implementation probably varied by species and no clear patterns could be discerned to indicate which species was sampled at which level. Yet, not only are the stem densities in the size class 10-25 cm dbh much higher according to the general inventory than according to the stock surveys, stem densities in the size class ≥30 cm dbh seem also inflated for barbajolote, nargusta, santa maria and sapodilla. Only the stem densities of cedar seem to be in line with the stock surveys for the size class ≥30 cm dbh. The stem densities of mahogany are also in line with the exception of the size class 30-40 cm dbh which seems to be overestimated.

The stem densities of mature trees (dbh ≥50 cm dbh) do not differ significantly for mahogany, cedar, barbajolote, santa maria and rosewood, but this does not apply to nargusta or sapodilla; both species have considerably less mature trees in the stock surveys than indicated by the general inventory. At least, the general inventory suggests that BRL is targeting common, well distributed species with substantial harvestable volumes. Mahogany is well represented and distributed and does not appear to be threatened appreciably because of the low proportion of trees that may be cut. Cedar and barbajolote have lower but adequate standing volumes, while volumes of santa maria and rosewood appear be of no more than marginal commercial interest. BRL may consider exploring the market potential of white breadnut and black cabbage bark, given the observation that these species show acceptable standing volumes.

Pre-harvest inventory

The pre-harvest inventory has three principal objectives: to identify the potential crop trees for the current harvest; to identify potential crop trees for the next harvest and to identify seed trees to guarantee sufficient regeneration in the longer term. The stock survey methodology follows the established protocol of dividing the compartment into transects 100 m wide and surveying all trees of the target species above the minimum inventory diameter within the compartments forming the annual cutting area. Each tree is assessed for species, diameter, crown height, form class, crown position and crown form and degree of vine infestation. Potential crop trees, seed trees and future trees are also mapped and measured. All trees over the MCDL are tagged with flagging tape and labelled with a sequential number which is painted onto the stem. Seed trees are selected afterwards based on crown position and crown form.

Post-harvest audit

A post-harvest audit is performed within 2 months after the close of logging operations in collaboration with the Forest Department to assess compliance with the approved APO and assess forest damage.

1.2.3 Silvicultural system

The silvicultural system for the Chiquibul Forest Reserve is based on the following ecological and silvicultural objectives, principles and strategies in accordance with the stipulations by the Forest Department:

1. **Silvicultural Goal**: Prepare the forest for the next stand initiating event (hurricane).
2. **Silvicultural Principle**: Multiple yields may be attainable before the stand reaches a minimum stocking threshold below which stem density may be too low to withstand annual mortality plus mortality caused by the next stand initiating event such that sufficient stems survive to allow for regeneration and stand replenishment. This threshold is termed the "restocking threshold".
3. **Silvicultural Strategy**: Determine a yield that the population can sustain at least twice before reaching the restocking threshold.
4. **Restocking threshold**: Prime and Rosewood: >=50 evenly distributed stems per square km that are >=25 cm DBH; Other species groups: >=20 evenly distributed stems per square km that are >=25 cm DBH.
5. **Ecological Goal**: Maintain or improve forest structure, forest resilience and species distribution.
6. **Ecological Principle**: The larger the tree the more it contributes to resiliency of the population through better survival and seeding.
7. **Ecological Strategy:** Leave all trees >=90 cm DBH. Future relative forest structure should shadow present relative forest structure.

The regeneration method in the CFR relies on natural regeneration. In this respect, it is understood that the species of interest vary in their ecological guild as expressed by their seed dispersal mode, light conditions for seedling establishment and growth, and wood density.

Mahogany, cedar and other light demanding species such as barbajolote and nargusta do not regenerate well under an intact canopy, supposedly even one heavily disturbed by logging, in sufficient numbers to replace the stocking in the harvestable diameter classes. However, the species apparently regenerates profusely following hurricane disturbance, which may induce a heavy fire load and therefore be succeeded by wide spread wild fires, especially during the often intensely dry period between February and May. The general inventory shows that, 53 years after hurricane Hattie, mid-sized mahogany trees are especially abundant.

Poor regeneration of mahogany after harvesting only shows the inherent conflict between impacts of harvesting or management, and the longer term distribution of species and age-classes within the forest. Higher intensity logging will create more light, improving regeneration, but increasing disturbance. Single tree selective logging as advocated in Belize will allow less light, reducing regeneration, but causing less disturbance. There may therefore be inherent trade-offs between the objectives of reducing short term environmental impact, and the longer term environmental objective of regeneration.

1.2.4 Yield regulation and production

Annual allowable cut and length of felling cycle

The annual allowable cut (AAC) should ideally constitute the volumes which can be sustainably removed over an indefinite period, taking into account all aspects of stand dynamics, environmental and social considerations. Generally, the amount of timber that a forest or stand can yield on a periodic basis is equal to the volume accrual that has accumulated between periods. The sustainable yield of a stand is therefore determined by present and future stocking, the length of the cutting cycle, and growth and mortality.

In 1994, a 40-yr. cutting cycle was defined for the CFR based on preliminary work by Alder (1992a) who asserted that if, as a rule of thumb, 0.5 cm/yr. increment would apply, then all trees in the size range 40-60 cm would grow to mature size (60+ cm) over a 40 year period. With a presumed 1.5% annual mortality, only 55% of the trees would survive; the remainder would die. Consequently the ratio of tree numbers in the 40-60 cm class to those in the 60+ cm class must be greater than 1/0.55 or 1.8 if there is to be sufficient stock in the lower class to replace all the mature stock.

General Yield Model

The General Yield Model was introduced by the Forest Department in 2015 to regulate yield and is mandatory in the preparation of the APO. The model grows individual trees through time, based on size-dependent growth rates applied in 5-year increments, and removes trees based on a fixed mortality rate over the full length of the cutting cycle. The model produces an estimated population at either year 25 or year 40, thereby allowing the estimation of accrual in terms of size class densities in between the present and future populations.

The sustainable yield of the forest is then determined as follows: up to 80% of the trees (strictly applied to each 5-cm size class) may be removed through harvesting as long as the same potential yield can be achieved in another 25 or 40 years' time, *i.e.* over 2 cutting cycles. If the same yield cannot be achieved, the level of the harvest should be reduced using lower cutting intensities, until the present and future yields balance. However, a minimum threshold applies to the residual stocking which must not be less than 500 trees ≥ 25 cm dbh per 1,000 hectares for the prime species and rosewood and 200 trees ≥ 25 cm dbh per 1,000 hectares for other species. This applies to the residual stocking following both the present and successive harvest. Furthermore, a maximum diameter cutting limit of 90 cm dbh applies, with the exception of prime species for which an 80 cm limit is being introduced this year and a 50 cm limit for rosewood.

In practice the intention is to sustain both the yield and the (mature) population structure. The latter assumes that the size class distribution equals an age-class distribution which is obviously not the case in natural uneven-aged mixed forest. In reality, each size class will contain trees of different ages, growing at largely different rates.

The principal thought behind the limited cutting intensity, the maximum cutting diameter and the minimum stocking threshold is that certain resilience must be built into the residual population structure in order for it to sustain a (presumably inevitable) future hurricane with sufficient intact mature stems to allow for regeneration and stand replacement. In this respect, the Forestry Department makes the following assumptions:

1) larger mahogany trees have more extensive root systems, bigger buttresses and more mass than smaller trees and are assumed to be too heavy to be easily toppled or broken by strong winds;
2) large trees are generally better seed producers and dispersers (height, wind, crown volume);
3) the size threshold here that defines 'large' is typically 50 cm dbh.

Special consideration is given to large trees ≥90 cm dbh, on account of their scarcity in the CFR, resilience and importance in maintaining upper canopy structure. All trees ≥90 cm must therefore be excluded from crop selection.

Critical appraisal of the General Yield Model (GYM)

An appraisal was carried out of the parameters used in the General Yield Model (GYM). Diameter increment rates were assessed on the basis of 10 PSPs that were established in the CFR in the period 1992-1994 during the Forest Planning and Management Project. A few plots were re-measured between 2010 and 2012 as part of the FORMNET-B project (Cho *et al.* 2013). For each tree that was still alive at its last census the periodic annual diameter increment was determined over the period between the first and last census in which it was included.

The GYM makes use of species groups; prime, elite and select. These species groups are primarily based on the value of the species and not so much on the ecological guild or wood density of the species. A species' ecological guild would indicate whether a species is e.g. light-demanding or shade-bearing and its seed dispersal mechanism. Wood density is a good indicator of the diameter growth rate of a species at maturity. Mahogany, cedar, barbajolote and nargusta are all light-demanding species; while sapodilla and santa maria are shade-tolerant species. Barbajolote, nargusta and santa maria have similar wood densities and can be expected to have similar growth rates at maturity. Sapodilla has a higher wood density which would place this species in a different group.

The diameter increment rates in the CFR PSPs suggest that the GYM underestimates growth rates for mahogany, cedar, nargusta and santa maria, while the growth rate for sapodilla seems to be overestimated. The mahogany and cedar increment rates are probably 150% of the rates used in the GYM for prime species. The increment rate of nargusta and santa maria are probably 130% and 150%, respectively, of the rates used in the GYM for select species, while the increment rate for sapodilla increment rate is probably only 40% of the rates used in the GYM. There were insufficient PSP data on barbajolote and rosewood to contest or confirm the GYM function for elite species. Higher increment rates imply higher sustainable yields and lower cumulative mortality.

Modelling future structure of the stand table and the ultimate timber yield is at least as sensitive to mortality as it is to mean tree increment, and probably more so. The GYM model uses annual mortality rates for the species group that are constant throughout the life of a tree. The GYM simplifies the impact of mortality by applying the compounded annual mortality rate at the end of the full felling cycle. This implies that the GYM ignores the fact that actual mortality depends on the diameter increment rate and the size class for which that increment rate applies. Trees in higher size classes grow faster and would pass through a fixed (5-cm) size class more rapidly than a slower growing small tree would through a size class of the same width. In that sense, the GYM overestimates mortality among the larger trees and underestimates mortality among smaller ones, resulting in a different size class distribution after completion of the present felling cycle than is obtained if a classical method like stand table projection is used whereby mortality is applied at each 5-yr increment depending on the time of passage through a size class.

The constant mortality rates that are used in the GYM appear low for the prime and elite species and high for the select species. Moreover, the species grouping based on timber values ignores the differences in population dynamics of the species of interest. Species-specific annual mortality rates would actually be needed. A simple approach to estimating annual mortality, as proposed by Alder *et al*. (2002), was used which is based on the 95% point on the cumulative diameter distribution (D95) and the time taken by a tree to grow to this D95 diameter (T95), which in turn is calculated by dividing D95 by the mean diameter increment (Dinc).

Two approaches were used in estimating D95 and Dinc. The first approach estimates D95 from stand tables produced from the general inventory and Dinc from the CFR PSP data. The second approach estimated D95 from the average stand table of the APO stock surveys 2009-2017. Dinc is estimated by applying the respective GYM function. Annual mortality rates for mahogany are thus estimated at 2.5%-2.7%, cedar 2.2%-2.5%, barbajolote 0.7%-1.5%, rosewood 3.2%-4.4%, nargusta 1.3%-1.7%, santa maria 1.6%-1.8% and sapodilla 0.7%-1.4%.

The simple approach to estimating annual mortality shows that the GYM applies relatively low annual mortality rates for mahogany, cedar and rosewood, while mortality rates in GYM for nargusta and sapodilla are relatively high. Mahogany and cedar populations in the CFR are still in the recovery phase after years of overharvesting and hurricane damage, implying that most trees are comparatively young and that few large trees occur. This inherently results in a low D95 and T95, as indeed observed. Logically, the model needs a high mortality rate to explain the encountered size class distribution, which would only be true if the observed population structure would remain stable from this point in time onwards.

Simple stand table projection using the GYM parameters results in a marginal difference in the stocking at the next cut after a cutting cycle of 40 years. Because the same allowable cut was used in both models the residual stocking did not differ. However, the accrual in number of stems 55-90 cm dbh is higher than produced by the GYM because of the incorrect application of annual mortality in the GYM. If also the diameter increment rates of the CFR PSPs are used, in addition to the correction for the flawed mortality computation in the GYM, accrual becomes significantly greater.

Bird (1998) and several other authors suggest to predict the growth rate of future crop trees based on the faster growing trees because those trees are the ones that are most likely to survive until the tree reaches a mature size. Several authors therefore recommend using the upper quartile instead of the mean of a distribution of growth rates for a certain size class. This proposition is supported by the big difference in stocking of mid-size and mature mahogany in 1969 according to Johnson and Chaffey and the current abundance of mahogany in the size class ≥50 cm dbh. It is generally assumed that the current harvestable mahogany stock originated as a result of hurricane Hattie in 1961. Inherently, the present harvestable stock is no older than 56 years, implying that all currently harvestable trees must have attained a mean annual increment of 1 cm/yr. or more.

A second stand table projection model was constructed to measure the effect of predicting future stand development based on the upper quartile increment values for each diameter class instead of mean values. The stand table projection, using the upper quartile increment rates, also results in a marginal difference in the total stocking at the next cut after a cutting cycle of 40 years. However, the accrual in number of stems 55-90 cm dbh is much greater when using the upper quartile increment rates.

This basically means that a much greater number of residual trees 55-90 cm dbh are likely to be relinquished as crop trees than indicated by the GYM. Another key difference between the three results is that the number of stems that will surpass the 90 cm maximum diameter limit before the next cut will be much higher than suggested by the GYM.

The conclusion is that the GYM is unnecessarily dissipates potentially harvestable trees. This can be reversed by either rescinding the maximum 80% cutting intensity for every diameter class or shortening the cutting cycle.

Calculation of cutting cycle and annual allowable cut

Appropriate cutting cycle

Mahogany is the main commercial species and is abundant in the mid-size class in the Chiquibul forest. It therefore makes sense to base the length of the cutting cycle on the population structure of mahogany and apply this to the other secondary hardwoods as well.

Until recently, a 40-year felling cycle has been adopted for the CFR on the basis of various considerations described by Bird (1998). Also recently, the Forest Department introduced the option to select a 25-year felling cycle. In theory, compartments may be managed under different felling cycles but this poses serious problems when organizing forest management of the reserve over two felling cycles. Given a prior decision as to possible felling cycles, it is possible to apply a simple spreadsheet method to show how the CFR can be managed to give a sustainable yield from growth rate and mortality data (Alder, 1992b). Given a current harvestable size class is 55-90 cm dbh, this class is split into a mature class and an over-sized class based on their mean diameter increment differences. Given a 40-year felling cycle, the size class that will form the next cut in 40 years would then be 30-55 cm dbh based on the average growth rate of this class. Similarly, the second next cut in 80 years would be formed by the trees that are presently in the class 15-30 cm dbh. By compiling inventory per 1 km² data into these size classes one obtains an impression of the yields per 1 km² of trees that will be available in the present and successive felling cycles.

A survival rate is applied to the present stocking to produce a final stocking at the time of harvest. No trees above 90 cm may be cut. Those are therefore ignored in the table. The maximum cutting intensity of 80% is applied to each size class; both in the present and over-sized class. The allowable minimum total stocking is 50 trees ≥ 25 cm dbh per 1 km², of which at least 25 trees must be ≥ 50 cm dbh. Once the sustainable yield is set at 80% of the currently mature (55-75 cm) and over-sized trees (75-90 cm), all other data relating to trees harvested, retained, and accrued from previous stocks are calculated depending on this entry. The results are shown in the table below.

Felling cycle	+80 yrs.	+40 yrs.	Present	OverSize
Present diameter class (cm)	15-30	30-55	55-75	75-90
Initial stocking (N/km²)	131	273	80	6
Survival %	57.0%	75.5%	100%	100%
Final stocking (N/km²)	75	206	80	6
Accrual from last cycle	113	13	NA	NA
Total stocking (N/km²)	188	219	80	6
Harvest	69	69	64	5
Retained trees (N/km²)	119	150	16	1

Consistent application of the current yield per 1 km² in number of trees means that the cutting intensity will be just 32% (69÷219) at the next cut and 37% (69÷188) at the second next cut. Apparently, the current maximum cutting intensity can easily be maintained; even after two full felling cycles. This is not surprising given the current stand structure of mahogany with relatively few trees of harvestable size and an abundance trees in the 25-55 cm class.

It also shows that capping the harvest at 80% is not necessary from a sustained yield point of view. The relatively high abundance of trees in the 25-55 cm is a guarantee that the size class 55-75 cm will be restocked adequately during the felling cycle. If we set the sustainable yield at 100% of the currently mature (55-75 cm) and over-sized trees (75-90 cm), the sustainable yield is increased to 86 trees per 1 km². Consistent application of this cutting level at succeeding cuts appears fully sustainable because the cutting intensity would remain below the current 80% threshold at the next cut and second next cut.

The same procedure was applied to estimate sustained yield per 1 km² of mahogany in the CFR with a 25-year felling cycle. Below the pattern of stock survey data per 1 km² for mahogany forest is shown grouped into classes of variable size, corresponding to their mean diameter increment rates.

Felling cycle	+75 yrs.	+50 yrs.	+25 yrs.	Present	OverSize
Present diameter class (cm)	15-25	25-40	40-55	55-70	70-90
Initial stocking (N/km²)	79	167	158	73	12
Survival %	59.0%	70.4%	83.9%	100%	100%
Final stocking (N/km²)	47	118	132	73	12
Accrual from last cycle	81	65	14	NA	NA
Total stocking (N/km²)	128	183	146	73	12
Harvest	68	68	68	58	10
Retained trees (N/km²)	60	115	78	15	2

The initial maximum cutting intensity is again set at 80% in each size class as required by the FD; both in the present and over-sized class. This cutting level can be maintained for four successive cuts over a period of 75 years compared to three successive cuts over a period of 80 years with a 40-yr. cycle. Successive application of the current maximum cut of 68 trees per km² results in cutting intensities of 47% (68÷146) at the second cut, 37% (68÷183) at the third cut and 53% at the fourth cut. The number of retained trees ≥ 50 cm dbh stays above 50 trees per km² at each of the cuts.

With a 25-yr. cycle 107 trees in the size class 15-55 cm would be lost due to natural mortality over a period of 75 years against 123 trees over a period of 80 years with a 40-yr. cycle. Over a period of 75 years, the total harvest will consist of 272 trees with a 25-yr. cycle, while 207 trees will be harvested in total over a period of 80 years with a 40-yr. cycle.

A 25-year cycle is thus preferred from a silvicultural point of view because better use is made of the forest's productive capacity and the, possibly temporary, abundance of mahogany trees in the midsize class (25-50 cm dbh).

BRL proposes to change to a 25-yr felling cycle for three reasons:

1. The production forest area is adjusted downward to 35,751 ha – of which 10,633 ha has been logged during the present felling cycle – due to inaccessibility of the forest, previously classified as production forest, along and beyond the Raspaculo River and Monkey Tail Rivers, incorporation of the recommendations of the Chiquibul Cave System Management Plan and rationalisation of the boundaries of mining areas. BRL will run out of production forest at the current harvest rate of 1,000 ha per year due to this adjusted production forest area.

2. The Forest Department reduced the maximum cutting diameter from 100 cm dbh to 90 cm dbh in 2015 and is planning to reduce this limit further to 80 cm dbh. As diameter increment rates of 1 cm/yr. or more for mahogany canopy trees are quite credible, application of a 40-yr. felling cycle would imply that many reserve trees will surpass the 90(80)-cm limit before the scheduled year for the next harvest. Hence, with a 40-yr felling cycle, the harvest of many trees will be forgone.
3. With the present diameter class frequency distribution of mahogany a ‘sustained’ yield can be maintained for at least four successive cuts over a period of 75 years with a 25-yr. cycle against three successive cuts over a period of 80 years with a 40-yr. cycle. A 25-yr. felling cycle will suffer less loss of production due to natural mortality and will produce a higher total yield over a period of 80 years.

Annual allowable cut

Although BRL could assert that higher diameter increment rates should be applied for e.g. mahogany, it would be futile because the allowable yield must ultimately be based on the obligatory GYM parameters.

Stand table projection as described by Alder (1995) and a 25-year cutting cycle are used to estimate the annual allowable cut. The parameters in the stand table projection model are taken from the General Yield Model including all pertinent harvesting restrictions that were in force at the time of writing this FMP. Initial diameter class distributions are taken from the 2009-17 stock surveys because confidence in the results of the general inventory is low. Recruitment into the 10-15 cm diameter class is ignored mainly because no reliable information is available about mahogany recruitment after present sustained yield logging. The results of the stand table projections for an annual cutting area of 1,000 ha are summarized below:

Stand table projection 25-year felling cycle (1,000 ha)									
Species	DBH class	present cycle				+25 years			
		Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
mahogany	10-55	4,252			4,252	1,971			1,971
	55-90	860	80.0%	687	173	1,730	41.1%	687	1,043
	≥90	18			18	18			18
	Total	**5,130**		**687**	**4,443**	**3,719**		**687**	**3,032**
cedar	10-60	799			799	384			384
	60-90	194	67.6%	130	64	333	38.8%	130	203
	≥90	12			12	12			12
	Total	**1,005**		**130**	**875**	**729**		**130**	**599**
barba-jolote	25-50	77			77	26			26
	50-90	106	20.5%	21	85	125	17.4%	22	103
	≥90	16			16	18			18
	Total	**199**		**21**	**178**	**169**		**22**	**147**
rosewood	20-35	491			491	33			33
	35-70	270	44.1%	113	157	582	21.1%	113	469
	≥70	0			0	0			0
	Total	**761**		**113**	**648**	**615**		**113**	**502**
nargusta	25-50	897			897	345			345
	50-90	410	67.9%	268	142	361	72.5%	268	93
	≥90	13			13	9			9
	Total	**1,320**		**268**	**1,052**	**715**		**268**	**447**
santa maria	25-50	401			401	166			166
	50-90	83	80.0%	65	18	119	45.5%	65	54
	≥90	1			1	1			1
	Total	**485**		**65**	**420**	**286**		**65**	**221**
sapodilla	25-50	500			500	178			178
	50-90	303	56.4%	165	139	254	66.5%	166	88
	≥90	18			18	13			13
	Total	**821**		**165**	**657**	**445**		**166**	**279**

Stand table projection model were also constructed based on the size class distribution found with the general inventory. Sustained yields of mahogany and cedar appear somewhat lower but yields of barbajolote, nargusta, santa maria and sapodilla are much higher according to the general inventory. The huge differences in the estimates for the latter four species back the serious concerns about the reliability of the general inventory.

Stand table projection 25-year felling cycle (1,000 ha)									
		present cycle				+25 years			
Species	DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
mahogany	10-55	7,151			7,151	4,267			4,267
	55-90	612	80.0%	490	122	1,815	25.7%	490	1,325
	≥90	35			18	33			33
	Total	**7,798**		**490**	**7,308**	**6,115**		**490**	**5,625**
cedar	10-60	1,063			1,063	622			622
	60-90	169	67.6%	114	55	309	38.8%	114	195
	≥90	111			111	97			97
	Total	**1,343**		**114**	**1,229**	**1,028**		**114**	**914**
barba-jolote	10-50	1,622			1,622	1,201			1,201
	50-90	336	76.8%	258	78	375	69.6%	258	117
	≥90	258			258	244			244
	Total	**2,216**		**258**	**1,958**	**1,820**		**258**	**1,562**
rosewood	10-35	316			316	98			98
	35-70	53	0.0%		53	255	0.0%		255
	≥70	0			0	0			0
	Total	**369**			**369**	**353**			**353**
nargusta	10-50	4,835			4,835	4,838			4,838
	50-90	1,480	68.9%	1,023	460	1,278	80.0%	1,023	255
	≥90	535			535	377			377
	Total	**6,850**		**1,023**	**5,830**	**6,493**		**1,023**	**5,470**
santa maria	10-50	5,243			5,243	3,347			3,347
	50-90	156	80.0%	123	33	225	43.7%	123	102
	≥90	5			5	5			5
	Total	**5,404**		**123**	**5,281**	**3,577**		**123**	**3,454**
sapodilla	10-50	5,612			5,612	3,264			3,264
	50-90	1,096	59.6%	655	441	818	79.9%	654	164
	≥90	266			266	197			197
	Total	**6,974**		**655**	**6,319**	**4,279**		**654**	**3,625**

Division of the forest into annual harvesting units

The production forest area was initially set at 41,423 ha and broken down into 80 cutting blocks known as compartments, generally measuring 500 ha each, whose boundaries basically follow the UTM grid system (Bird, 1998). BRL proposes in this management plan to reduce the production forest area to 35,751 ha. The compartments as established by Bird in 1994 will be maintained, although some of them will be reduced in size. After the adjustment of the production forest area 76 compartments remain with an average area of 470 ha. A 25-yr. felling cycle implies that the annual cutting area should equal 1,430 hectares, equivalent to three compartments.

A challenge in changing the felling cycle before the cycle has been completed is that the two cycles will have to be merged in such a way that the felling cycle of already harvested compartments is maintained while ensuring that harvestable cutting areas remain available in any and every year of the cycle. During the present felling cycle 15 compartments with a total area of 7,668 ha have been cut on the basis of a 40-yr felling cycle and 6 compartments with a total area of 2,965 ha based on a 25-yr cycle. This means that a transition period is required during which the two different cycles have to be merged. The transition process will only be completed in 2056 when the last compartment that was harvested based on a 40-yr cycle will have completed its felling cycle. The next 20 years, 2018-2037, new, unlogged compartments will be harvested. In 2037, the first compartment for which the yield was regulated according to the 40-yr. cycles is earmarked to be harvested a second time. From 2040, the first compartments for which the yield was regulated according to the 40-yr. cycles are to be harvested a second time. Due to the variation in cutting cycle not every year compartments are available to cut for a second time. This means that some yet unlogged compartments must be reserved to fill in years where no compartment is available for a second cut. In principle, 55 unlogged compartments are available which should be divided over the years when no compartments qualify for a second cut, implying that only two compartments can be cut per year until 2030.

Ten compartments have been shortlisted for the period 2018-2022 on the basis of the distribution of mature mahogany trees across the reserve according to the general inventory. BRL will carry out a 10% strip sample consisting of two 10-m wide strips running the entire length of the compartments (north to south) to verify the mahogany stocking in the shortlisted compartments in the table below.

Year	Compartment nos.	Area (ha)
2018	16, 17	981
2019	12, 13	1,000
2020	24, 25	1,073
2021	32, 33	1,098
2022	39, 44	1,000

BRL also intends to carry out diagnostic sampling in the compartments that were felled according to a 40-yr cycle between 1997 and 2011 (compartments 34, 35, 38, 58, 59 and 60) to assess the stand development in those compartments. There are indications that mahogany is growing (much) faster in diameter than the 0.5 cm/yr. on which the 40-yr. cycle was based. The objective of the diagnostic survey is to assess the feasibility to shorten the cutting cycle to 25 years, while maintaining adherence to the restrictions imposed in the GYM. This may lead to a shorter transition from the 40-yr. to 25-yr. cycle. Nevertheless, no changes are foreseen for the duration of this management plan; i.e. 2018-2022.

Schedule of timber production

The annual hardwood production from the CFR is estimated by way of stand table projection on the basis of the average stock surveys results over the period 2009-2017 and BRL's roundwood to sawn lumber conversion rates of 2016. Harvesting normally takes place between February and May.

Timber species	Roundwood volume (ft^3)	Roundwood volume (m^3)	Sawn lumber produced (BF)
mahogany	40,902	1,158	266,138
nargusta	14,359	407	101,874
sapodilla	9,755	276	71,142
cedar	8,237	233	49,681
santa maria	3,870	110	28,223
rosewood	2,721	77	10,069
barbajolote	1,025	29	6,223

The projected annual timber on the basis of the general inventory would generate much higher volumes of nargusta and sapodilla (4 times higher for both species), barbajolote (14 times higher) and santa maria (2 times). Timber production estimates for cedar and mahogany are somewhat lower according to the general inventory; respectively 8% and 12% lower. However, confidence in the general inventory estimates is lower than the estimates on the basis of the eight most recent annual stock surveys. The inconsistent implementation of the sampling level of the smallest size class, suggests that the inventory was poorly supervised. Therefore, there are also reservations regarding the estimates of the larger size classes and more value is attached to the estimated timber production on the basis of past stock surveys.

As a general conclusion, mahogany, nargusta and sapodilla must be regarded as the main species. Production of steady supplies of cedar and santa maria seem possible but at limited levels. Production of barbajolote and rosewood remains unpredictable and any production of these species should be regarded as a bonus only.

1.2.5 Markets and utilization

BRL's sawmill produces mainly rough sawn lumber of mahogany, cedar, barbajolote, rosewood, nargusta, santa maria, and sapodilla. Mahogany, cedar and rosewood primarily for export to the USA and barbajolote, nargusta and santa maria mostly for the domestic market although some nargusta was recently exported as well. On the basis of the actual lumber production figures of 2015-16 the annual production of export grade (Sel & Btr and COM 1-2) mahogany is estimated at 186,500 BF and of export grade cedar at 49,000 BF, of which 125,000 BF mahogany and 33,000 BF cedar may be exported. The remaining lumber (including grade COM 3-4) 141,000 BF mahogany and 17,000 BF cedar will be sold to local buyers.

Marketing including demands and constraints

Mahogany has been listed on CITES Appendix II since 2002. A CITES Appendix II listing requires that exports must be accompanied by a CITES export permit, which is issued by the Forest Department in the capacity of National CITES Management Authority on the basis of a annually determined national export quota. All species of rosewood under the genus *Dalbergia* are protected under CITES Appendix II since 2nd January 2017. The listing of *Dalbergia* is annotated to indicate that the all parts and derivatives are included, except: a) leaves, flowers, pollen, fruits, and seeds; and b) non-commercial exports of a maximum total weight of 10 kg per shipment. Interestingly, *Dalbergia* spp. originating and exported from Mexico are covered by the annotation that only logs, sawn wood, veneer sheets and plywood are included; i.e. finished and semi-finished rosewood products may still be exported from Mexico without a CITES permit.

The export of mahogany is limited to 67% of the APO estimate of produced lumber. The national export quota is determined by the FD based on BRL's APO and APO's of other mahogany exporters. The APO's traditionally have been using a conversion factor of 212 to estimate BF sawn lumber from m^3 roundwood. Effective from January 2017, the conversion factor has been reduced to 169 by the Forest Department. However, the actual conversion rate rather amounts to 240 BF/m^3, while 70% of the sawn lumber (mahogany) is of export grade (Select or better or COM 1-2). The current APO conversion factor yields on average 70.5% of the true recovery, resulting in a CITES export quota of just 47.3% (67% x 70.5%) of the true sawn lumber output.

Constraints

- The local mahogany market situation is difficult due to unfair competition by other suppliers; competition is unfair because mahogany is supplied from short-term license areas and illegal sources (reserves and parks), both having much lower production cost; e.g. no cost for forest management (pre-harvest inventory, preparation of APO and SFMP, etc.)
- The export quota and imposed conversion rates limit potential trade (export)
- Sustained yield of mahogany is probably higher than the yield estimated by the GYM
- Calculation of export quota depends on timely submission of APO's of other companies that harvest mahogany for export (not necessarily exported by the roundwood producer) as well, leading to delays in issuing export permits. This entails the risk that buyers may become sceptical about BRL; buyers become suspicious that material might be illegal or otherwise unavailable, because an export permit is not being granted with delay.

- FD procedures regarding quota and sustained yield are fluid; e.g. rules governing APO's, conversion factors, diameter increment equations, cutting diameter limits, etc. have been updated frequently without notice within the past three years.

Opportunities

- Resort construction boom; in order to maintain a 'green' image resorts may demand timber sourced form properly managed forest
- Demand for mahogany export remains huge, but due to supply limitations prices are under pressure. Supply limitations have urged buyers to seek alternatives for American mahogany (*Swietenia*), resorting to African mahoganies (*Khaya*, *Entandrophragma*), plantation grown American mahogany (Africa) and other species in the mahogany family Meliaceae, which are widely available at lower prices.
- BRL considers exploring opportunities to have its forest management FSC certified; BRL will take a stepwise approach in FSC certification, commencing with exploring options for FSC COC certification.

1.2.6 Monitoring and research

The CFR has been an important area for scientific research. The Las Cuevas Research Station, which is located in the middle of the CFR, has been operating since 1995 to document the biodiversity of the Chiquibul Forest and contribute practical knowledge to Belize's sustainable development and conservation. Priorities include understanding the maintenance and structure of the forest, evaluating human and natural impacts on the forest and linking science with conservation policy.

A number of PSPs have been established in the CFR in the early 1990s; the majority forming part of Neil Bird's (1998) logging experiment. The plots now form part of the FORMNET-B network. BRL supports this mutually beneficial research. In addition, PSPs were established on behalf of BRL in the 2008, 2009, and 2010 annual cutting compartments. BRL intends to re-measure those PSPs during the duration of the SFMP.

1.2.7 Factors which influence management

There are several bio-physical factors which may influence management. These include fire, wind (hurricanes) and mahogany and cedar shoot borer attacks. Fire normally is no serious threat in the CFR because of the high precipitation and high humidity levels. Selective single-tree forest exploitation does not result in high enough fuel loads to increase the propensity for fire during the dry season (February – May). Hurricanes may lead to high fuel loads and an increase of the propensity to fire.

The Chiquibul Forest area offers various opportunities for resource use, including timber operations, nature tourism, research, NTFPs. At present, tourism is very limited because of poor access (Chiquibul Cave System) and security concerns (Guatemalan incursions). Important other resource use is allowed entrance by the road that provides access to the Caracol archaeological site, which branches of the Chiquibul Road at Tapir Camp; Las Cuevas, there is good communication with FCD who informs BRL when there are researchers active in and around Las Cuevas. Due to the single entry point to the Chiquibul Forest at Guacamallo Bridge (Tapir Camp barrier) and multiple resource users FCD recommends managing of the Chiquibul Forest as a single multi-zone unit. To achieve this, a functional multi-stakeholder governance and management structure should be put in place for the Chiquibul National Park and the Chiquibul Forest Reserve. Considerations underlying the ideal scenario include among others:

- Management of the Chiquibul Forest Reserve cannot be done in isolation; for ecological and practical reasons, management of the CFR must in fact be integrated with that of the Chiquibul Forest.
- There are numerous stakeholders within the Chiquibul Forest, and therefore management needs to be inclusive in order to take into account the interests of the various stakeholders
- Currently FCD, the co-manager of both the CNP and the Chiquibul Cave system has no income generating activities, such as entry and user fees, but only grant funding.

BRL confers with FCD and other stakeholders such as the Tourist Association and the Belize Defence Force concerning the division of roles in the management of the Chiquibul Forest.

1.2.8 Security

The main threat to the forest resources in the Chiquibul Forest is the illegal felling of trees by Guatemalan trespassers. In recent years this threat has increased and has spread into the Reserve along the western boundary with the National Park. The Forest Department does not maintain a steady presence in this area, and only the NGO Friends for Conservation and Development (FCD) routinely patrol the area. In conjunction with the Company, FCD has established a Chiquibul Advisory Panel to advocate for better protection of the Chiquibul forest, inclusive of the National Park. A higher number of FCD rangers and security forces in the Chiquibul Forest mean more law enforcement patrols within the illegal logging hotspots in the Chiquibul, helping to reduce the illicit activity. Although the Company would like to do more about the security issues, it is understood that the matter is one of national security and is outside the hands of the Company. In the meantime, partnership with FCD is the most viable option for working towards the security of the reserve.

1.2.9 Other subjects covered

The Sustainable Forest Management Plan further describes rules, regulations and procedures governing timber harvesting operations, roading operations, and environmental conservation measures

BRL is neither engaged in extracting Non-Timber Forest Products nor in the Management for Payment for Environmental Services or any other goods besides timber.

2 COMPANY PROFILE

In 2006, Bull Ridge Limited was granted a long-term forest logging license (LTFL 03/06) for the approximate 40,000 hectares of hardwood production forest in the Chiquibul Forest Reserve. Nevertheless, actual logging operations initiated until the year 2013. A later amendment to the license resulted in the inclusion of the pine production forest of the San Pastor Pine Ridge and the associated 'broken ridge' hard wood forest surrounding the Mountain Pine Ridge Forest Reserve. With this addition, the company obtained exclusive timber rights to all the production forest within the Chiquibul Forest Reserve.

Bull Ridge Ltd. received its name from the amalgamation of Chiquibul and Mountain Pine Ridge, where Bull Ridge Ltd.'s sister company, Pine Lumber Co. Ltd. operates. Bull Ridge Ltd. currently employs at least 20 full time staff, but the workload of the operations pertaining to the license is shared among staff of both sister companies.

Logging operations are conducted sustainably in compliance with a multi-year Sustainable Forest Management Plan and consecutive Annual Plans of Operations. The Annual Plan of Operations, which is submitted and approved by the Forest Department, is the core which guides the company's operations every year.

3 BASIC RESOURCE DATA

3.1 Legal status of the management area

Bull Ridge Ltd.'s license applies to the production forests within the Chiquibul Forest Reserve, as defined from time to time by regulations, the current area of which is more particularly described in Statutory Instrument No. 54 of 1995. The boundaries of the Chiquibul Forest Reserve may be varied from time to time to exclude lands therefrom, and the licence area excludes all lands, presently or in the future, held under lease or granted.

The Chiquibul Forest Reserve was first gazetted under Statutory Instrument No. 55 of 1956. When gazetted for the first time the total area of the Forest Reserve was estimated at 714 square miles (184,926 ha), of which 330 square miles (85,470 ha) [46%] was classified as protection forest (Forest Department, 1956; in Bird, 1998). The size of the Forest Reserve was considerably reduced in 1991 when the major part of the area was re-designated as a National Park (approximately 107,605 ha) under Statutory Instrument No. 166 of 1991. This change was not based upon any detailed assessment of the area, and so in 1994 a further revision of the boundaries, using environmental, biodiversity and land-use criteria, was carried out (Bird, 1998). On the basis of this work new boundaries were recommended and these were subsequently gazetted under Statutory Instruments Nos. 54 and 55 of 1995.

Currently, the Chiquibul Forest covers an area of 176,999 ha (437,376 acres) comprising the Chiquibul National Park (106,838 ha), the Caracol Archaeological Reserve (10,339 ha) and the Chiquibul Forest Reserve (59,822 ha).

Bull Ridge Co. Ltd. of Mile 61 George Price Highway is licensed, subject to the provisions of the Forests Act in force at any time during the currency of this licence whether enacted prior to or subsequent to the granting thereof and any rules and regulations made there under and in force at any time during the currency of its licence whether enacted prior to or subsequent to the granting thereof and to the conditions expressed in its license, to cut and remove any species of primary hardwood, secondary hardwood or pine trees and to carry out such activities as are necessary for the maximum protection, optimum regeneration, general improvement and sustainable management of the timber and other forest resources and environmental goods and services within the tract of land hereinafter described and in accordance with this Sustainable Forest Management Plan. Specifically, Bull Ridge Co. Ltd.:

- is entitled to fell and remove all trees identified for felling under the SFMP and designated for felling under a current APO.

- has exclusive rights to all primary hardwood, secondary hardwood and pine trees in the license area and no other timber harvesting license whatsoever shall be granted in the license area unless it is granted with the full consent of Bull Ridge Co. Ltd.
- has the right to establish and operate logging camps, office buildings and wood-processing facilities at locations in the licence area agreed to by the Chief Forest Officer and entitled to clear forest growth for the establishment of these sites, as designated for felling under a current APO.
- has the right of free access within the license area, subject to the conditions of this license.
- has first right to any licence to harvest any non-timber forest produce (excluding germplasm) within the license area in accordance with the terms and conditions of such licence, where the issuance of such is deemed conducive to good forest management.

With the prior approval of the Chief Forest Officer, Bull Ridge Co. Ltd. can construct and operate logging roads and barquadiers (log landings) and in accordance with specifications given to it by the Forest Department. The right to skid and haul logs and to transport timber as well as drive heavy vehicles on any forest roads within and outside the license area or within the license area may be withdrawn by a Forest Officer during periods of bad weather.

This license is personal to Bull Ridge Co. Ltd. and may not be transferred by Bull Ridge Co. Ltd. to any third party other than with the prior approval of the Minister responsible for forestry, obtained in accordance with the procedure provided for in the Forest Rules or any amendment thereto.

Bull Ridge Co. Ltd.'s license is initially for 40 years duration, commenced on the 28th September 2006 and will end on 27th September 2046. The option exists to extend the duration of this license for a single, further 40-year period.

There are no other organizations, villages, communities or individual who have any legally defined, officially or traditionally recognized or claimed rights or practices which affect the area, the forest or its resources such as fuel wood, fruits, fodder, grazing of livestock, fishing, hunting, cultivation or permanent or temporary residence. Only a mining Company resides at the extreme south-western tip of the forest reserve where gold is panned from the alluvial fan of the Rio Ceibo Chico. Mining areas are administered by the Geology and Petroleum Department.

The Chiquibul Forest Joint Enforcement Unit (CFJEU) comprising of the Belize Defence Force, Police and Friends for Conservation and Development (FCD) rangers provides a robust patrolling system to combat and contain (trans-boundary) illegal activities in the Chiquibul Forest. Bull Ridge Co. Ltd provides a conservation post to the CFJEU. Friends for Conservation and Development (FCD) signed a co-management agreement with the Forest Department to manage the Chiquibul National Park and in 2008 a co-management agreement with the Institute of Archaeology was made to manage the Chiquibul Cave System.

Las Cuevas Research Station (LCRS) is located in the heart of the Chiquibul Forest Reserve. Since 1994 LCRS has promoted biological, botanical, wildlife, climatic, and archaeological research and education. LCRS provides a range of opportunities for avid researchers, naturalists, environmentalists, and students who seek to conduct biodiversity research, and interest in the protection of this Maya forest through science and natural resource based efforts. LCRS is co-managed by Friends for Conservation and Development and the Government of Belize.

The Chiquibul Cave System is partly situated within the boundaries of the Chiquibul Forest Reserve. Jurisdiction over the Chiquibul Cave falls under the Institute of Archaeology, which has not only jurisdiction over declared Archaeological Reserves such as the Caracol Archaeological Reserve, but also over any Cultural and/or Historical site in Belize as provided by the National Institute of Culture and History Act, Chapter 331 of 2000 (Revised 2003) of the Laws of Belize. In 2008, The Institute of Archaeology entered into a co-management agreement for the Chiquibul Cave System with Friends of Conservation and Development (FCD).

3.2 Geographic location of the management area

The Chiquibul Forest Reserve is located within the central mountainous region of Belize known as the Maya Mountains and consists of all that piece or parcel of land in the Cayo District comprising approximately 59,818 hectares (147,810 acres) bounded on the north by the Macal River; and on the east, south, and west sides by the Chiquibul National Park (see Figure 1). Except for the natural boundary to the north formed by the Macal River, the border of the forest reserve is demarcated by straight arbitrary lines.

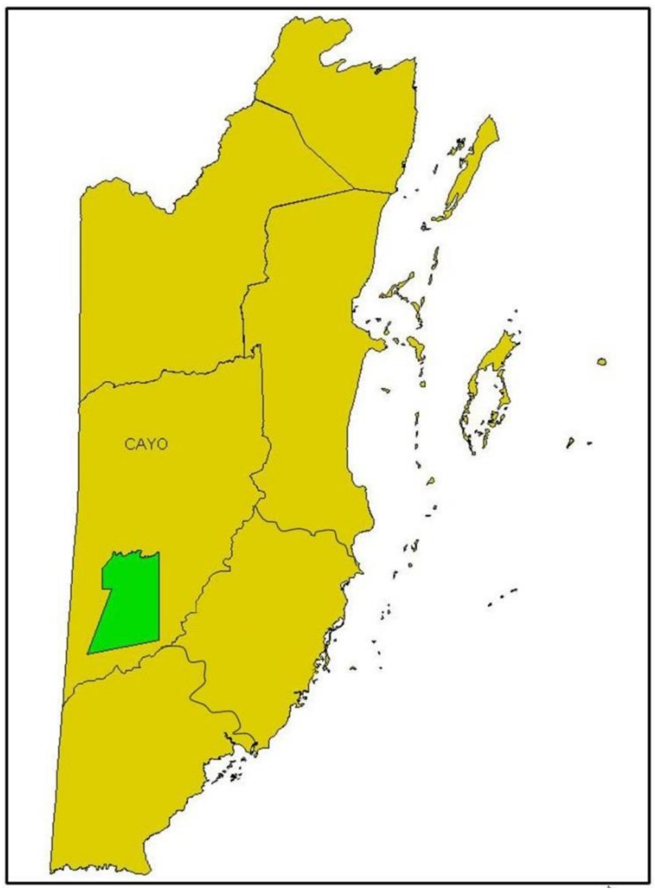


Figure 1 Location of the Chiquibul Forest Reserve in the Cayo District, Belize

3.3 Description of the boundaries of the forest license

The Chiquibul Forest Reserve boundaries are described as follows:

Commencing at the Guacamallo Bridge crossing the Macal River, having the scaled UTM co-ordinates of 1,865,550 North and 282,750 East (Geographic Coordinate System: GCS North American 1927 and Projected Coordinate System: NAD27 UTM Zone 16N); thence in a general southern direction along the Chiquibul road for an approximate distance of 2,450 metres to the Caracol/Millionario junction, having the scaled UTM co-ordinates of 1,863,400 North and 282,100 East; thence south west for an approximate distance of 4,650 metres to a point having the scaled UTM co-ordinates of 1,860,000 North and 279,000 East; thence south for an approximate distance of 7,000 metres to a point having the scaled UTM co-ordinates of 1,853,000 North and 279,000 East; thence east for an approximate distance of 3,000 metres to a point having the scaled UTM co-ordinates of 1,853,000 North and 282,000 East; thence south-west for an approximate distance of 23,500 metres to a point having the scaled UTM co-ordinates of 1,830,900 North and 273,900 East; thence north-east for an approximate distance of 24,500 metres to a point having the scaled UTM co-ordinates of 1,835,650 North and 298,000 East; thence north for an approximate distance of 29,800 metres to a point on the Macal River having the scaled UTM co-ordinates of 1,865,350 North and 298,000 East; thence west following the Macal River to the point of commencement.

Bull Ridge Co. Ltd. has sole responsibility for ensuring that appropriate boundary markers and/or signs are put in place and maintained on the ground to clearly demarcate the licence area boundaries, especially where such boundaries coincide with publicly active areas. The determination of alignments for boundary markers and positions for signs is achieved through a cooperative effort with the Forest Department. License boundaries to the east, west and south coincide with boundaries of the Chiquibul National Park. Protected areas inside, adjacent to or around the license area are clearly marked on the license map and on the ground. With regards to demarcating protected areas on the ground, demarcation of boundaries is achieved through a cooperative effort between the Forest Department, Bull Ridge Co. Ltd. and the Friends for Conservation and Development (FCD) (Co-manager Chiquibul National Park). There is no entry into protected areas for timber exploitation nor is any road through any protected area traversed or will be opened.

3.4 Physical characteristics of the area

The DOS topographic maps which reference the Chiquibul Forest Reserve are sheets number 28, 29, 33 and 34 last revised in the early 1990’s using aerial photography from the late 1980’s (Figure 2 below).

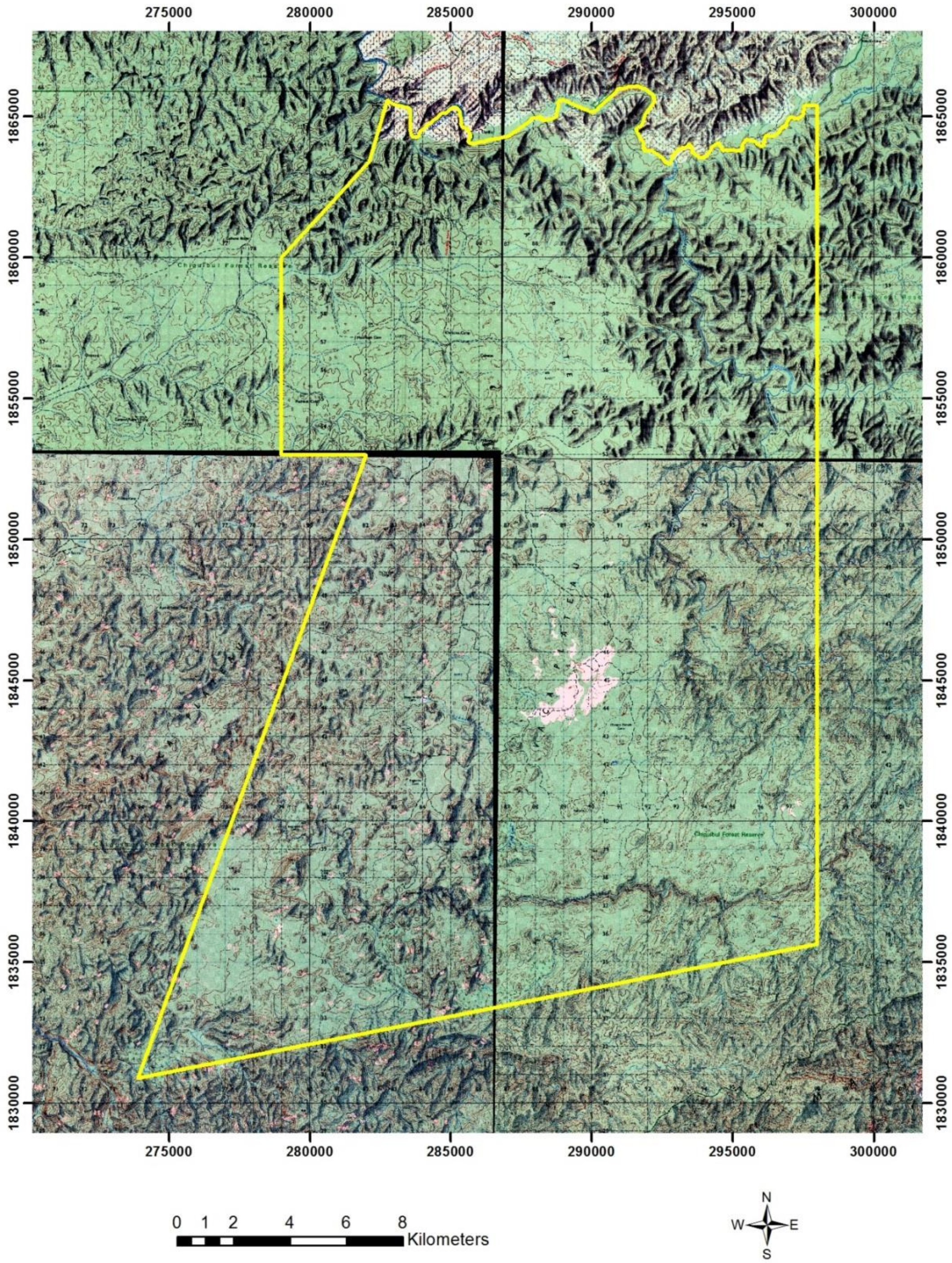


Figure 2 Topographic map of the Chiquibul Forest Reserve (topographic map sheets 28, 29, 33 and 34)

3.4.1 Topography and hydrology

Topography

The Chiquibul Forest Reserve lies on part of the Maya Mountains sloping westwards and northwards from the Main Divide. The slopes drop from about 900 m (2,955 ft.) elevation at the higher points on the Main Divide down to about 370 m (1,215 ft.) on the Macal River.

The valleys of tributaries of the upper Macal River and the lower Raspaculo branch tend to be steep sided and there slopes of more than 25° are frequently encountered. From about 8 km (5 mi) upstream from its junction with the Monkey Tail branch the Raspaculo branch runs through a wide gorge some 180 m (590 ft.) to 270 m (885 ft.) deep (Figures 3 & 4). In the catchments of some of the upper tributaries of the Raspaculo branch the rocks have been eroded to give gently to moderately undulating terrain forming a large basin. Slopes of more than 25° are unusual there. (Johnson & Chaffey, 1973)

The topography on the karstic limestone capping covering most of the western half of the Reserve is very different. This limestone plateau has weathered to give cone or tower shaped hills. Between these hills the terrain usually slopes gently or moderately, and slopes of less than 10° are common. Those areas together with the lower slopes of the hills have been extensively terraced at the time of the ancient Maya civilisation. The hillsides tend to vary sharply in degree of slope. Steep slopes of more than 25° are often encountered (Figures 3 & 4). Exposures of bare rock are often found on the steep slopes and sheer cliffs occur. (Johnson & Chaffey, 1973)

Hydrology

The geology has a conspicuous effect on the drainage pattern.

The entire Chiquibul Forest forms part of the Belize River Watershed. But within that are 2 main sub-drainage systems formed by the Macal and the Mopan (with the Chiquibul River as the main tributary). The division between the 2 sub-watersheds splits the Chiquibul Forest roughly in two. Notable is the difference between surface drainage patterns between the two sub-watersheds. In the Macal sub-watershed, there exists abundant surface drainage (small streams), while the Mopan sub-watershed has a large subterranean component. The Mopan sub-watershed itself needs to be divided to a next level including the Mopan-East Watershed, the Chiquibul Watershed, and the Rio Ceibo Watershed (Meerman & Moore 2010).

The bedrock in the eastern part of the Chiquibul Forest Reserve is mainly impervious slate, shale or sandstone. The drainage is on the surface and its pattern is rectangular sub-dendritic. This refers mainly to the catchments of the Macal River and its main tributary the Raspaculo branch. Only the extreme south-eastern and southern parts drain into the Chiquibul branch and

Rio Ceibo Grande. The rivers are shallow with rapids and waterfalls and are not suitable for floating out logs. The Vaca Falls on the Macal River, approximately 15 km (9.5 mi) downstream from the Reserve boundary presents an impassable barrier for log floating. (Johnson & Chaffey, 1973)

The central and western part of the forest reserve is mostly covered by a capping of karstic limestone in which the drainage is mainly subterranean. Where small surface streams occur on the limestone, such as Zaiden creek or Grano de Oro creek, they tend soon to disappear underground. The limestone is honeycombed with sinkholes and caves. Subterranean streams occur in caves, as at Las Cuevas. The Chiquibul branch is the only surface river of size in the limestone area. It has evidently cut down to a layer of impervious rock. At Puente Natural it runs beneath a natural limestone bridge. About 6 km (3.5 mi) farther on the river runs underground in a cave at Resumidero. It continues westwards, as evidenced by reappearances where the tunnel roof has collapsed, and is presumed to join the Mopan (or western branch of the Belize River) in Guatemala. There are 'aguadas' or water holes on the surface of the limestone. These are found in depressions where a layer of impervious rock or the plugging of sinkholes by clay prevents the downward percolation of water. All but the largest waterholes dry up in a prolonged dry season. (Johnson & Chaffey, 1973)

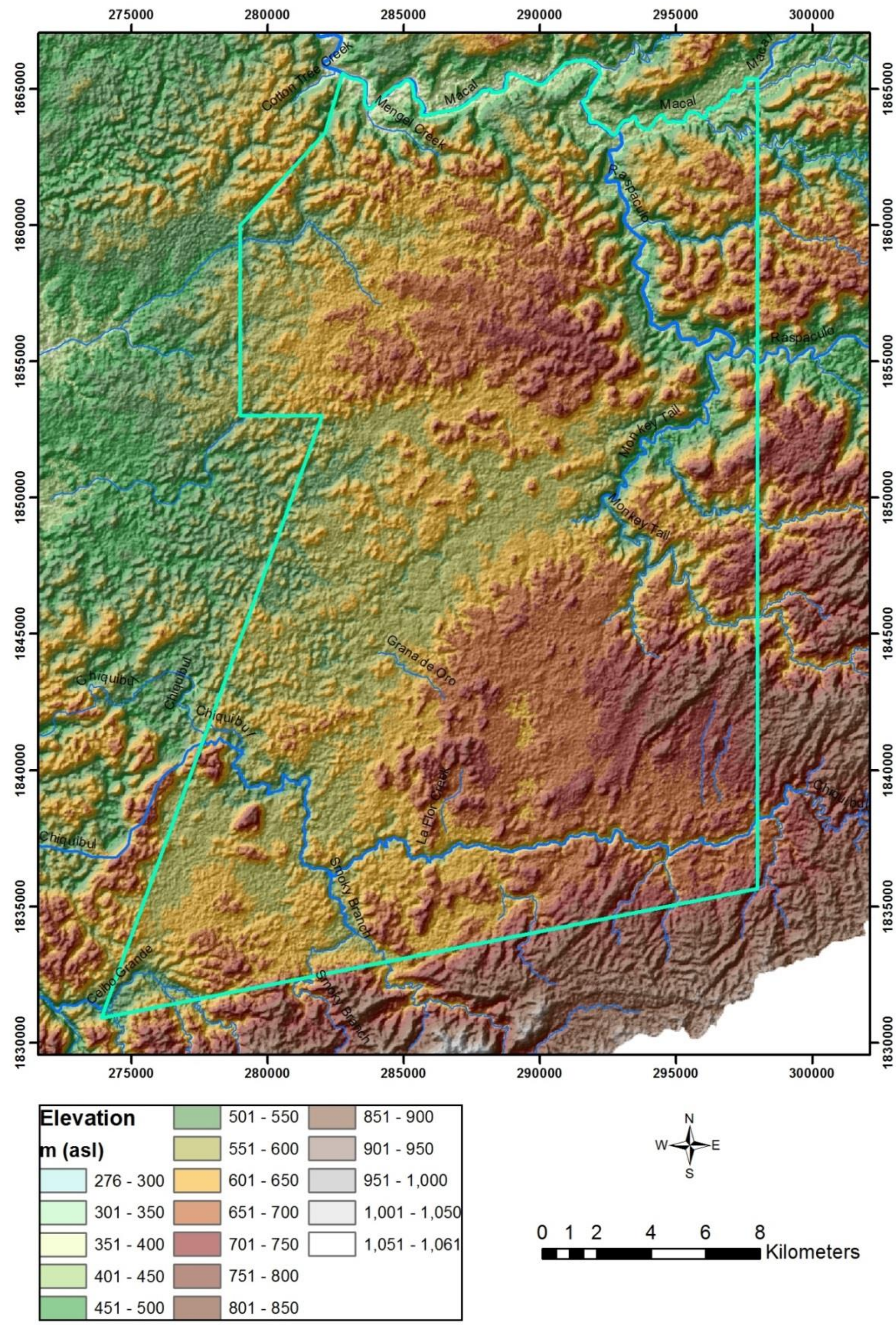


Figure 3 Elevation and hydrology map of the Chiquibul Forest Reserve

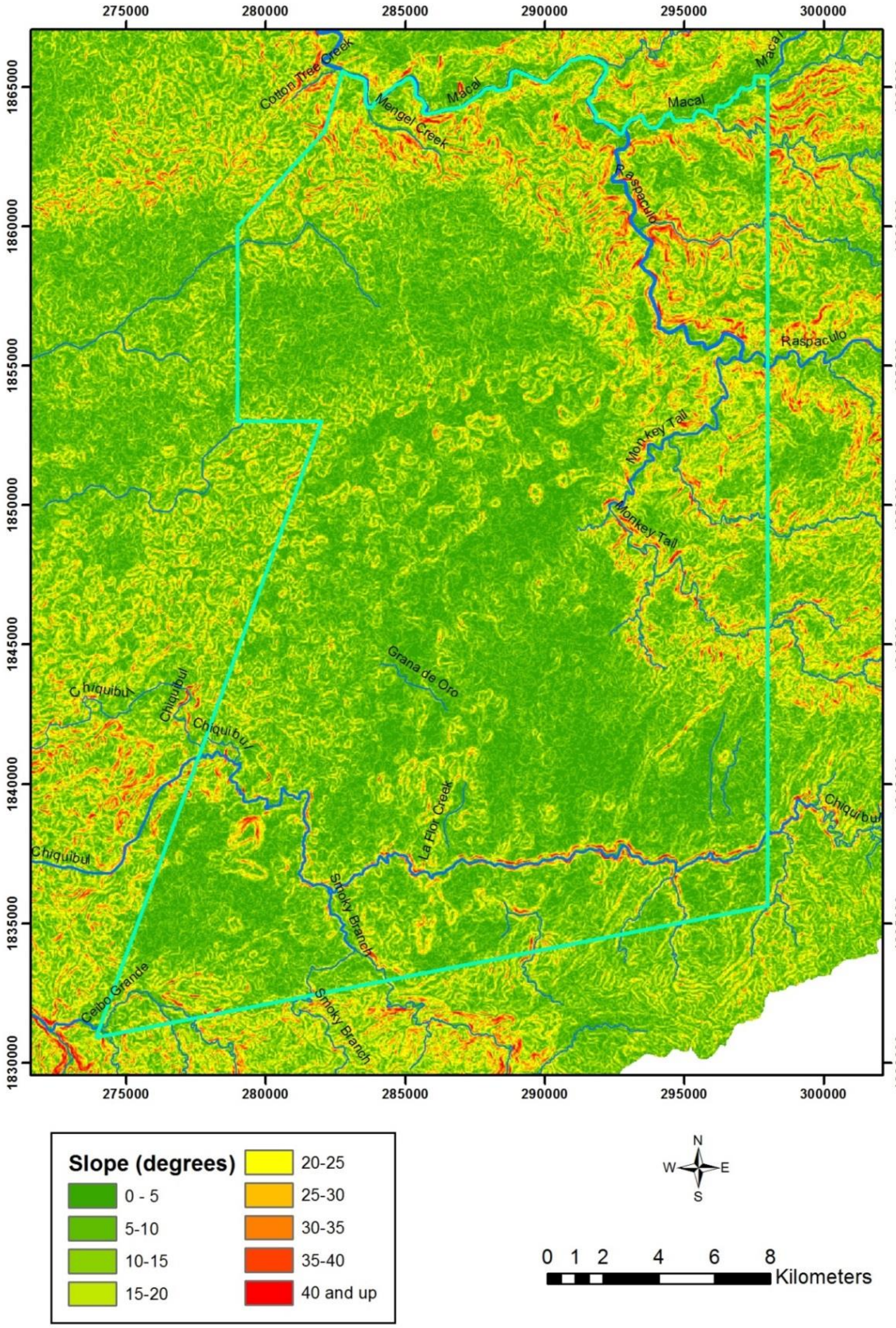


Figure 4 **Slope map of the Chiquibul Forest Reserve**

3.4.2 Geology and soils

Geology

The Chiquibul Forest Reserve lies on the western side of the up-faulted block of Palaeozoic rocks which forms the Maya Mountain massif. The rocks are mainly hard, ancient sandstones, slates and shales often metamorphosed. During the late Cretaceous, abundant and widespread limestone sediments were deposited over all but the highest outcrops (Bateson & Hall, 1977). Subsequent uplift during the Pliocene has resulted in a relatively flat land surface with scattered limestone hills. Exposures of igneous rocks are common in the Maya Mountains, with large areas occurring in the Mountain Pine Ridge region. The remaining limestone deposits are now mainly confined to the area west of the Raspaculo River and Monkey Tail branch and north of the Rio Ceibo Grande except for the area south-east of the junction of the Raspaculo and Macal Rivers. This means that the entire Forest Reserve is underlain by this limestone cap, except for the San Pastor Pine ridge (and broken ridge) which is on an area underlain by sandstone and slate.

The consequence of this limestone cap is a karstic terrain, or one filled with underground rivers, sinkholes and egg-box type hills with deep valleys. The karst geomorphic cycle is well advanced, as indicated by the exposure of karst tunnels, caves, and natural bridges along the surface drainage of the Chiquibul Branch. The hills are now well weathered and have been shaped into ridges and fairly deeply incised valleys by the rivers.

Soils

The principal factors influencing soil types in the Chiquibul Forest Reserve are the presence of underlying limestone, topographical variation, and anthropogenic factors. Soils present in the upland limestone zones are often very thin (less than 5 cm in depth) (Furley & Newey, 1979; Penn & Furley, 1999), while in areas of gentler relief the soils are deeper (often greater than 60 cm depth) and have a higher percentage of clay. In general, the soils of the reserve have been classified into the 'Xpicilha Hills with plains' land system (King et al., 1992). Most of the Chiquibul forest falls into the 'undulating plain' class, zones of 'high Karst', and finally 'siliceous plain with low Karst' (Murray, 1999).

The soils of the Chiquibul reflect the geology, where the soils are on limestone, the soils tend to be basic and by tropical soil standards, relatively fertile. On the other hand, over the steeper limestone hills, the soils have been classified by Wright (1959) as skeletal. Meaning that they are very shallow and that bedrock is protruding on many places. On the meta-sediments and volcanic deposits to the east and south, more acid soils are found. These soils tend to be very weathered, acidic and poor in nutrients. On top of that they tend to be on very steep slopes as well and the soils, in many cases can be classified skeletal as well. (Salas & Meerman, 2008)

In the central and western part of the reserve the soils are dominated by the karstic limestone which forms the underlying rock through most of the area. The Cabro set of shallow stony clays occur in the areas of more rugged limestone hills and the Chacalte sets of clays or stony clays in the areas of less rugged limestone. Of lesser extent are the Cumbre clays and sandy clay loams, on hard limestone and siliceous limestone conglomerate respectively, in the south near the Chiquibul branch river. The Chiquibul clays and sandy loams and gravelly sandy loams occur on Santa Rosa shales, quartzites and sandstones but occupy only a small area close to the Chiquibul branch river. The soils of the San Pastor Pine Ridge are named the Granodoro set and are gravelly loamy sands derived from acid quartzite and sandstone rocks of the Santa Rosa series. Fringing the San Pastor Pine Ridge are Ossory silty clay loams derived from alluvium, the Curassow silty clay loams derived from Santa Rosa shale and Machiquila sandy loam derived from San Rosa shale and colluvium. (Johnson & Chaffey, 1973)

The Cabro set of clays on rugged limestone cover is found on the steep hillsides the depth of the soil is frequently only 50 to 100 mm (2 to 4 in). Outcrops of bare rock are frequent as are deeper pockets of soil. At the time of the ancient Maya civilisation much of this area was populated and cultivated. Much of the gently sloping ground between the steep limestone hills was terraced by the Mayas and these terraces, usually 30-100 cm (12-39 in) high, still survive, often with the retaining walls still visible. It has been postulated that the terraces are silt traps rather than hand raised works, and that the valleys were enriched by trapping of soil washed down from the steep hillsides as a result of removal of the vegetation. Wright *et al.* (1959) recommended that these steep hillsides be protected. The Chacalte set of clays is found on less rugged limestone. On flatter land patches of fairly fertile soil occur, which are more water-retentive than those on the slopes. (From Johnson & Chaffey, 1973)

The Granodoro set form the soils of the San Pastor Pine Ridge. They are gravelly, loamy sands. They are infertile and the vegetation type they support is a Pine Ridge of *Pinus patula* Schiede and Deppe ssp. *tecunumanii* (Eguiluz and Perry) Styles. With protection from fire there has developed a dense undergrowth mainly of fern, tiger bush *(Dicranopteris pectinata* (Willd.) Underw.). By contrast the Ossory silty clay loams, Curassow silty clay loams and Machiquila sandy loams surrounding the Pine Ridge are more fertile and support a vegetation type with abundant mahogany. (From Johnson & Chaffey, 1973)

The eastern part of the reserve for the most part lacks the capping of karstic limestone typical of the plane. Dropping away from the main divide of the Maya Mountains are steep and precipitous ridges on sedimentary rocks and volcanics of the Santa Rosa Series. The soil sets are described as the Raspacula set with stony clay loam and rocky and stony sandy loams on Santa Rosa shale and sandstone, the Cockscomb set of stony and bouldery sandy loam, rocky sandy loam and stony sandy clay loam with rocky sandy clay loam on Santa Rosa sandstone and quartzite, and the Chapayal set with stony sandy clay loam and rocky sandy clay loam on Santa Rosa shale. On steep slopes these soils are shallow, only 25-150 mm (1-16 in) deep and very susceptible to erosion. (From Johnson & Chaffey, 1973)

Occupying slightly lower elevations are the Curassow set of soils, mainly on steeply dissected terrain. The gravelly clay and clay of the set form shallow soils over Santa Rosa shale on moderately steep slopes. Wright *et al*. (1959) warned that these soils should be kept under vegetation cover as a protection against the severe erosion which would occur if they were farmed or harvested. The silty clay loam areas of the Curassow are situated remotely in the upper basin of the Raspaculo branch and the Monkey Tail branch. Soils of the Ossory and Chiquibul sets are mostly hill soils only 100-127 mm (4-5 in) thick, overlying quartzite, sandstone and shales on steep slopes. There is danger of erosion with these soils and these areas should be kept under protection forest. (From Johnson & Chaffey, 1973)

3.4.3 Climate

The broad pattern of climate through the year consists of a dry season starting in January or February and ending in May or June followed by wetter months (except for a 'little dry' which sometimes occurs in August). Temperatures are cooler at the start of the year but rise through the dry season reaching a peak in May. They remain high through the wetter summer months until September when they decline to cooler levels again. Particularly in the cooler months from September to February, cold fronts from the northern higher latitudes reach as far south as Belize and beyond. They bring cold weather lasting for a few days and often heavy rainfall. Belize lies within the range of tropical cyclones. These can occur in the tropical northern part of the Atlantic Ocean and in the Caribbean Sea in any month of the year but are most common from July to November. Torrential rainfall over a considerable area is a common feature of these cyclones. They vary greatly in intensity. Meteorological records from within the Forest Reserve are confined to figures for rainfall at Millionario for the years 1956-1959. The nearest stations with fuller records which may be taken as indicative of Chiquibul's climate are Douglas D' Silva Station and Cooma Cairn Lookout in the Mountain Pine Ridge Forest Reserve. (From Johnson & Chaffey, 1973)

Rainfall

Belize has a subtropical climate with marked wet and dry seasons. Rainfall is variable but there is a general north to south rainfall gradient, with the south of the area receiving considerably more rainfall than the north. There is a general lack of climatological data for the Chiquibul

Reserve. Information on climatic factors is limited to 1956–59 records from Millionario and recent data from the nearby Las Cuevas Research Station. The former suggests precipitation in the region of 1500 mm per annum for the northern part of the area (Johnson & Chaffey, 1973), but with considerable annual variation. The climate appears to be heavily influenced by the topographical heterogeneity of the Maya Mountains (Penn & Furley, 1999). The predominantly moist easterly trade winds are forced to rise as they pass over the Maya Mountains, increasing rainfall across the region. Hilltops are shrouded in mist or dew overnight and precipitation can be localized to individual valleys or the whole of the Greater Maya Mountains. This, coupled with the variable dry and wet seasons, tropical storms and occasional hurricanes, makes the climatic variation across the study area considerable and unpredictable. (Penn *et al*. 2004)

Long term rainfall data from Cooma Cairn (1958-1980) in the Mountain Pine Ridge show an annual mean of 1,950 mm of rainfall with a 4 month dry season from February to May. Data from Douglas D'Silva Forest Station (1949-1980) just north of Chiquibul show an annual mean of 1,680 mm of rainfall with a 4.5 month dry season from January to mid-May. Data from Millionario (1956-1959) give a mean annual rainfall of 1,480 mm. In contrast, over the main divide in the Columbia River Forest Reserve (1959-1964), the annual mean rainfall is 3,012 mm with a 2.5 month dry season. A little further south in Punta Gorda (1935-2009), the annual mean rainfall is 3,860 mm with a 2 month dry season. It is therefore believed that rainfall increases from north to south in the Chiquibul Forest Reserve (Johnson and Chaffey, 1973). However, the weather appears to be heavily influenced by the topographical heterogeneity of the Maya Mountains (Penn & Furley, 1999). The predominantly moist easterly trade winds are forced to rise as they pass over the Maya Mountains, increasing rainfall across the region. It is not certain if rainfall decreases again once the warm air has passed over the Maya Mountains into the lower lying Chiquibul Forest Reserve. This, coupled with the variable dry and wet seasons, tropical storms and occasional hurricanes, makes the climatic variation across the Chiquibul Forest Reserve considerable and unpredictable (Penn *et al*., 2004)

Temperature

Temperature data are available for Douglas D'Silva Forest Station and Cooma Cairn Lookout on the Mountain Pine Ridge but not for Millionario within the Forest Reserve or for Columbia Forest Station to the south of it. At Douglas D'Silva the mean annual maximum recorded is 29°C and the mean annual minimum is 19°C.

Temperatures are not uniform through the year. They are lowest in January and February when the lowest minima of 6°C (43°F) were recorded. It becomes warmer as the dry season sets in and progresses, the highest maxima of 39°C (102°F) being recorded at Douglas D'Silva in April and May. Monthly mean maximum temperatures over 30°C (86°F) are sustained from April to

August at Douglas D'Silva. Thereafter there is a progressive cooling from September to the end of the year. (Johnson and Chaffey, 1973).

Relative humidity

The mean monthly relative humidity at Douglas D'Silva in the period 1965-70 varied between 70% (May) and 90% (January), with an annual mean of 82%. Corresponding figures for Cooma Cairn over the same period are 72% (May), 92% (January) and 83% annual mean. Where there is a closed forest community in Chiquibul Forest Reserve the relative humidity is probably higher than at the stations at Douglas D'Silva or Cooma Cairn. (Johnson and Chaffey, 1973).

Wind

In the period November - April tropical easterly Trade Winds predominate. At the beginning of this period cold fronts originating from the interior of the North American continent push southwards, modifying rapidly when crossing the Gulf of Mexico and becoming laden with moisture. The easterly Trade Winds generally intensify after April. In the period May - October, a southerly wind may also develop and the rainy season begins. The rains are essentially associated with disturbances in the broad easterly wind current. Tropical cyclones develop over the tropical Atlantic Ocean and Caribbean Sea mainly in the period July to October. Air circulations with sustained wind speeds up to 60 km/h (38 mi/h or 33 kn) are called tropical depressions. Cyclones with sustained wind speeds in the range 60-120 km/h (40-75 mi/h, 34-63 kn) are called tropical storms. Those with sustained surface wind speeds of 120 km/h (75 mi/h, 64 kn) or more are called hurricanes. The speed of the maximum winds near the centre of the cyclone has been estimated at more than 320 km/h (200 mi/h, 175 kn) in well-developed hurricanes. From 1889 to 2016, 31 tropical storms and 22 hurricanes are known to have affected Belize (Belize National Meteorological Service). Severe hurricanes with winds of up to 320 km/h (200 mi/h) are of great importance to forestry because of the damage done to the vegetation. Hurricanes affecting the Chiquibul in the past 100 years (Meerman & Moore, 2010) are listed below:

- Unnamed 1918: 45 mph (?)
- Anna 1961: 45 mph
- Hattie 1961: 160 mph
- Fifi 1974: 115 mph
- Greta 1978: 135 mph
- Earl 2016: 75 mph

It should be noted that although the Chiquibul is on the leeward side of the Maya Mountains the impact from hurricanes is still substantial.

3.4.4 Special features (cultural sites, etc.)

Archaeological Sites

At least the limestone area of Chiquibul forest was inhabited at the time of the ancient Maya civilisation, circa A.D. 200 - 925. It is evident that large areas were cleared for cultivation during this period as indicated by widespread terracing of the gentler slopes between the limestone hills still in evidence today. Much of the gently sloping ground between the steep limestone hills was terraced by the Mayas and these terraces, usually 30-100 cm (12-39 in) high, still survive, often with the retaining walls still visible. It has been postulated that the terraces are silt traps rather than hand raised works, and that the valleys were enriched by trapping of soil washed down from the steep hillsides as a result of removal of the vegetation. Ruins of dwellings still remain on raised mounds and many hilltops. The collapse of the classic Maya civilisation occurred in the period A.D. 800 - A.D. 925 (Thompson, 1966) and the ceremonial centres were abandoned. At some time the population declined and habitation in the Chiquibul area ceased. Cultivated area reverted to forest. It is assumed that the forest remained relatively undisturbed by man for several centuries up until recent times. (Johnson and Chaffey, 1973).

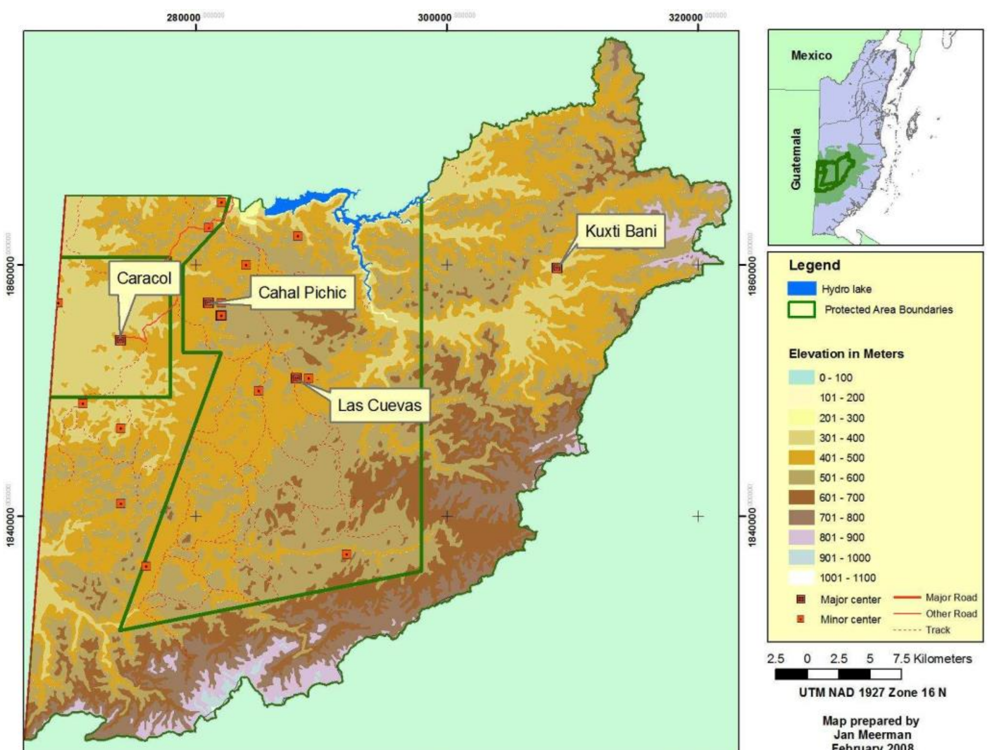


Figure 5 Major and minor centres of archaeological significance in the Chiquibul (Source: Salas & Meerman, 2008)

The Chiquibul Forest, like most places in Belize, is bestrewn with archaeological sites. Of the known archaeological sites in the Chiquibul forest, the most well-known are those at Caracol, as well as the archaeological features within the Las Cuevas site located next to the Las Cuevas Research Station in the centre of the Chiquibul Forest Reserve. Caracol, which is administered by the Institute of Archaeology, is a major tourism destination. Most of the major and minor centres of archaeological significance that have been mapped in the Chiquibul Forest are located within the Caracol Archaeological Reserve (CAR) and the northern and central part of the Chiquibul Forest Reserve, with a few sites in the western Chiquibul National Park south of the CAR. With the exception of the Cush Tabani site, no sites have been mapped in the southern and eastern CNP (see Figure 5 above). This does not mean that archaeological sites are not located in this area (Salas & Meerman, 2008).

Chiquibul Cave System and Natural Arch

The Chiquibul Cave System, the longest and largest known network of caves in Central America, is partly situated within the boundaries of the Chiquibul Forest Reserve (see Figure 6). This huge cave system is the underground passage of the Chiquibul River. The system consists of four big caves and numerous sinkholes. These caverns are known as Kabal, Tunkul, Cebada, and Xibalba. The Chiquibul Cave proper, the surrounding sinkholes and the Natural Arch all have been identified as forming the Chiquibul Cave System. (Meerman & Moore, 2009).

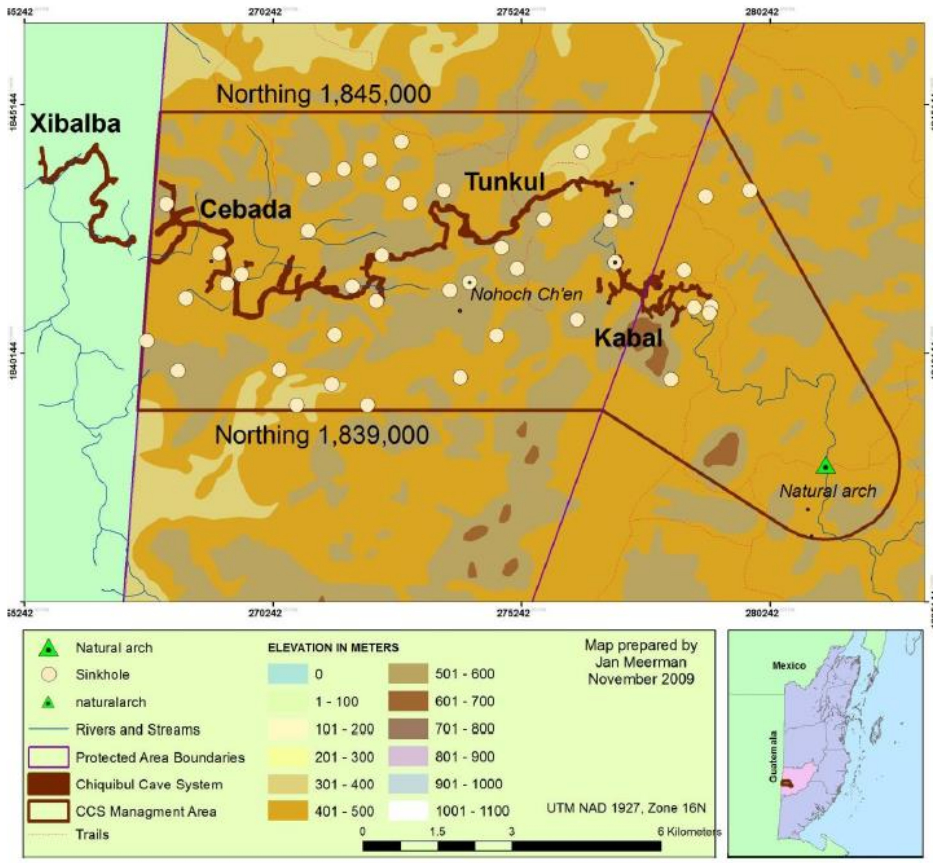


Figure 6 Detail of Chiquibul Cave System Management Area (Meerman & Moore 2010)

The Chiquibul System's Kabal cavern, which consists of a series of large, former stream passages that intersect the underground Chiquibul River in one passage for about 150 m, is situated on the border of the Chiquibul Forest Reserve with the western part of the Chiquibul National Park. Passages in the cave are generally 10-60 m wide and 10-30 m high. The Natural Arch is a potential tourism feature.

FCD has no management mandate for the Chiquibul Forest Reserve although the latter contains part of the CCS as well as the Natural Arch. The CCS is not a declared protected area in itself (even though, as a cave, it is automatically protected within the IA mandate), and there is no delineated boundary.

Meerman & Moore's (2010) Chiquibul Cave System management plan promotes the modification of the Sustainable Forest Management Plan for the Chiquibul Forest Reserve to prevent future (incompatible with watershed function) logging within a 1.5 km buffer of the Chiquibul Branch beginning at the Natural Arch (area zoned for Tourism) and to develop a tourism development plan with the Kabal section of the Chiquibul Cave and the Natural Arch as main attractions.

3.5 Description of the vegetation types

3.5.1 Vegetation Classification

At a regional scale, the vegetation and climate of Belize, as classified by the Holdridge *et al*. (1971) life zone system, falls into subtropical moist forest and subtropical wet forest (rainforest), with the latter mainly in the south of the country and over the upper slopes of the Maya Mountains. This general classification has been reinforced by Bailey's (1996) work, in which he determined that Belize was located in the humid tropical domain and specifically in the rainforest division. (Penn *et al*. 2004)

Holdridge's classification depends on the possession of fairly detailed meteorological data for temperature and rainfall for its application. Lack of meteorological data from Chiquibul Forest Reserve, apart from figures for rainfall at Millionario for 3 ½ years, precludes precise application of this classification. However it can be said that the Maya Mountain area in which the Forest Reserve lies is probably on the transition between Holdridge's Tropical Dry Forest, Tropical Moist Forest and Subtropical Moist Forest Life Zones. (Johnson and Chaffey, 1973).

There is also the classification of Beard (1944). Beard's classification is based on an examination of the structure of the vegetation, for example the numbers of tiers of tree species in a forest and which tiers have a continuous canopy. This classification partly depends on having undisturbed vegetation to examine. That is largely not the case with Chiquibul forest whose structure has over large areas been modified by man's disturbance, or has recently been destroyed by hurricane Hattie in 1961. In an undisturbed state the forest would probably fall into Beard's Semi-Evergreen Seasonal Forest in the wetter south and Deciduous Seasonal Forest in the drier north. (Johnson and Chaffey, 1973).

Recently, Penn *et* al. (2004) recognized six broad vegetation zones for the Greater Maya Mountains based on analysis of satellite imagery and the vegetation classifications above (see Figure 7):

- (i) savannahs (pine and grass);
- (ii) highly disturbed tropical forests;
- (iii) semi-deciduous tropical forests;
- (iv) semi-evergreen tropical forests;
- (v) evergreen tropical forests;
- (vi) mangroves and swamps.

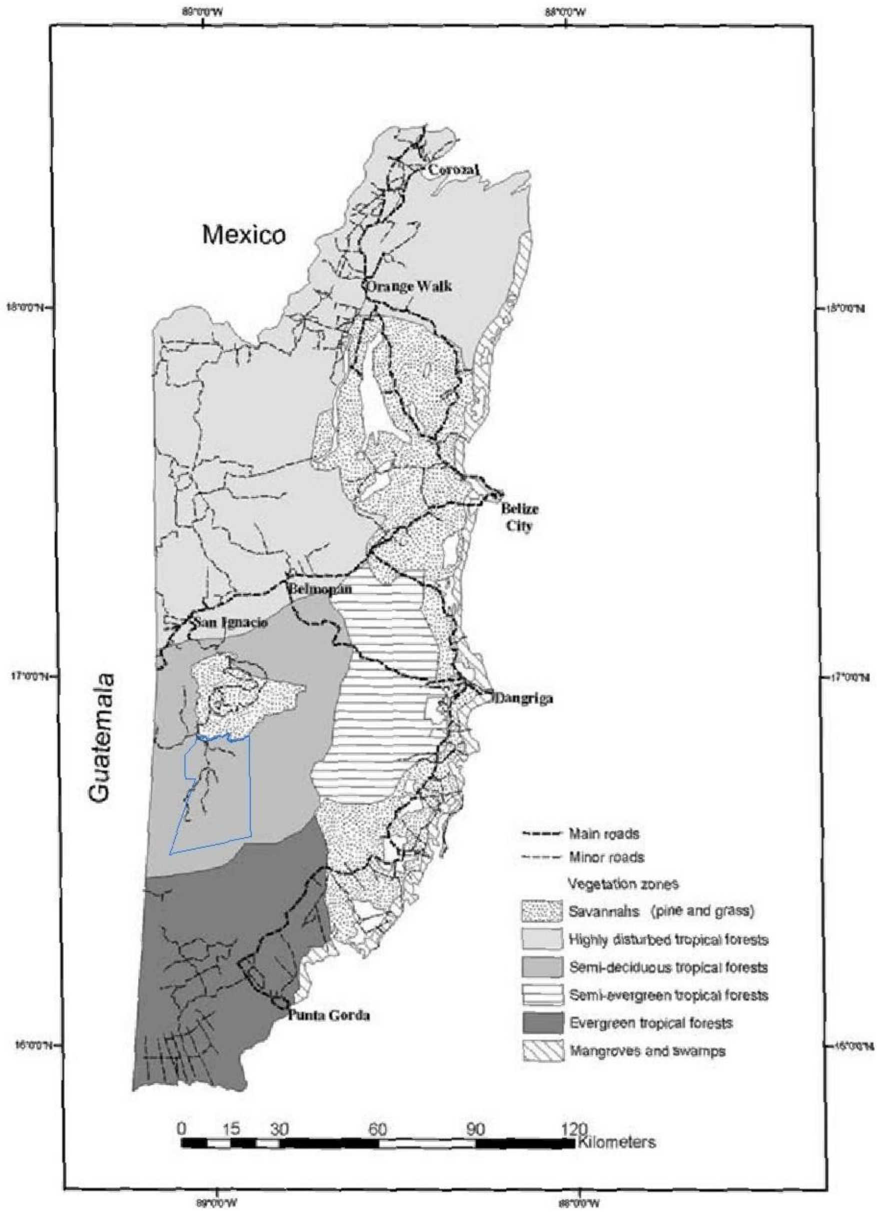


Figure 7 General vegetation map of Belize by Penn et al. (2004) with the Chiquibul Forest Reserve in blue outline

This general and simplified broad classification gives an overview of the Belizean land-cover but is of insufficient detail to reflect the diversity of vegetation in the Chiquibul Forest Reserve, which is located in an area associated with semi-deciduous to evergreen tropical forests and pine savannahs.

3.5.2 Vegetation assessments

Wright et al. (1959)

Three vegetation surveys are of importance for the Chiquibul Forest Reserve: the surveys of Lundell (1940), Wright *et al*. (1959), and Iremonger & Brokaw (1995). The studies by Lundell (1940) and by Wright *et al*. (1959) have concentrated on field survey methods to characterize vegetation classes. In 1959, Wright *et al*. published a detailed and highly regarded vegetation map of Belize. It is based on extensive field observations made around 1950, at which time Wright was carrying out a land-use and agricultural potential survey for what was then British Honduras. The classification was based mainly on relationships between soil and vegetation. He divided the whole of Belize into 34 different vegetation types, some of which were further subdivided. For example, 'Broadleaf Forests Rich in Lime-Loving Species' was divided into eight different subzones depending on canopy height and whether they represented seasonal or semi-evergreen forest. For the Chiquibul Forest, Wright *et al*. (1959) split the area into nine subclasses, consisting of evergreen, semi-deciduous or deciduous forest (see Figure 8). Today this vegetation classification remains one of the main sources of information on land cover within Belize and has stood the passage of time admirably. (Penn *et al*. 2004)

In 1995 Iremonger and Brokaw produced a vegetation classification for Belize that is hierarchical, based on physiognomic structure, using Landsat TM data and detailed sampling especially in northwest Belize (Rio Bravo Conservation – Management Area). The vegetation zones identified broadly correspond to those of Wright's classification but the authors expand the classes in some areas and collapse the older groupings in others, particularly for the Chiquibul forest. They identified 51 classes across Belize, which included 36 forest classes, nine scrub and six herbaceous classes (Brokaw, 2001). They identified seven classes within the bounds of the Chiquibul Forest. (Penn *et al*. 2004)

Penn et al. (2004)

Penn *et al*. (2004) used remote sensing data and GIS techniques to classify and map different vegetation classifications at different scales, from the local to regional, thereby enabling detailed spatial delimitation of each specific vegetation class. Their vegetation classification was based on IRS 1C LISS multispectral data collected during May 1999. They produced a normalized difference vegetation index (NDVI), which discriminates between different types of vegetation by using band combinations and divisions to produce an image based on greenness (i.e. differences in chlorophyll concentrations). The NDVI image with other sources of ancillary data, including a digital elevation model (DEM) derived from 1:50,000 topography maps, and land cover maps from Wright *et al*. (1959) and Iremonger & Brokaw (1995), provided information for defining and fine tuning the choice of training areas (image pixels of similar reflectance values) used within the Maximum Likelihood Classifier (MLC). Subsequently, Penn *et al*. (2004) classified the satellite image using a supervised MLC, where information from field sources and known maps of the area (Wright *et al*., 1959) were utilized to delimit/identify specific locations. The classification was checked for its accuracy using matrices and field comparisons within known areas around Las Cuevas. The vegetation classification of their study area, which includes the Vaca Plateau, Maya Mountains, Bladen Nature Reserve and southern part of the Mountain Pine Ridge, is hierarchical in structure and is loosely based on the United Nations Environmental Program (UNEP) World Conservation Monitoring Centre (WCMC) forest programme 26 forest type classification. All classes are tropical, with the 32 principal classes belonging to four major vegetation groups. These are defined as:

Broadleaf	Tropical broadleaf forest.
Savannah	Grasslands, usually with dense woody thickets, orchards and pine woodlands.
Riparian	Periodically flooded forest along rivers with a distinct herbaceous component.
Scrubland	Short stature and without a continuous canopy (due to natural or human disturbance).

Each group was further subdivided into specific classes using information collected in the field. This included data on dominance, species presence or absence, canopy height, highest per cent tree species cover/canopy size within the class, soil types and altitude. Where possible they subdivided classes based on the percentage deciduous component of the canopy (calculated by aerial extent and species presence or absence).

Evergreen	0–20% deciduous.
Semi-evergreen	21–50% deciduous.
Semi-deciduous	51–70% deciduous.
Deciduous	> 71% deciduous.

Annex I Table 76 summarizes the presence of classes and degree of equivalencies with the classifications of Wright *et al*. (1959) and Iremonger & Brokaw (1995). The classes correspond primarily to geological features and the soils derived from different parent materials, but hydrology also plays a significant part, determined to a large extent by topography. The classes occurring in the Chiquibul Forest Reserve are described below (from Penn *et al*. 2004):

Broadleaf: Class 1, Deciduous forest

This class is the first major one encountered on crossing the Guacamallo Bridge and rising into the hills of the Chiquibul forest. It is characterized by sapodilla (*Manilkara zapota* (L.) P. Royen), fiddlewood (*Vitex gaumeri* Greenm.), quamwood (*Schizolobium parahyba* (Vell.) S.F. Blake), white poisonwood (*Sebastiania tuerckheimiana* (Pax & K. Hoffm.) Lundell), chiquebul

(*Manilkara chicle* (Pittier) Gilly), mahogany (*Swietenia macrophylla* King), hogplum (*Spondias mombin* L.) and white copal (*Protium copal* (Schltdl.& Cham.) Engl). It is more or less equivalent

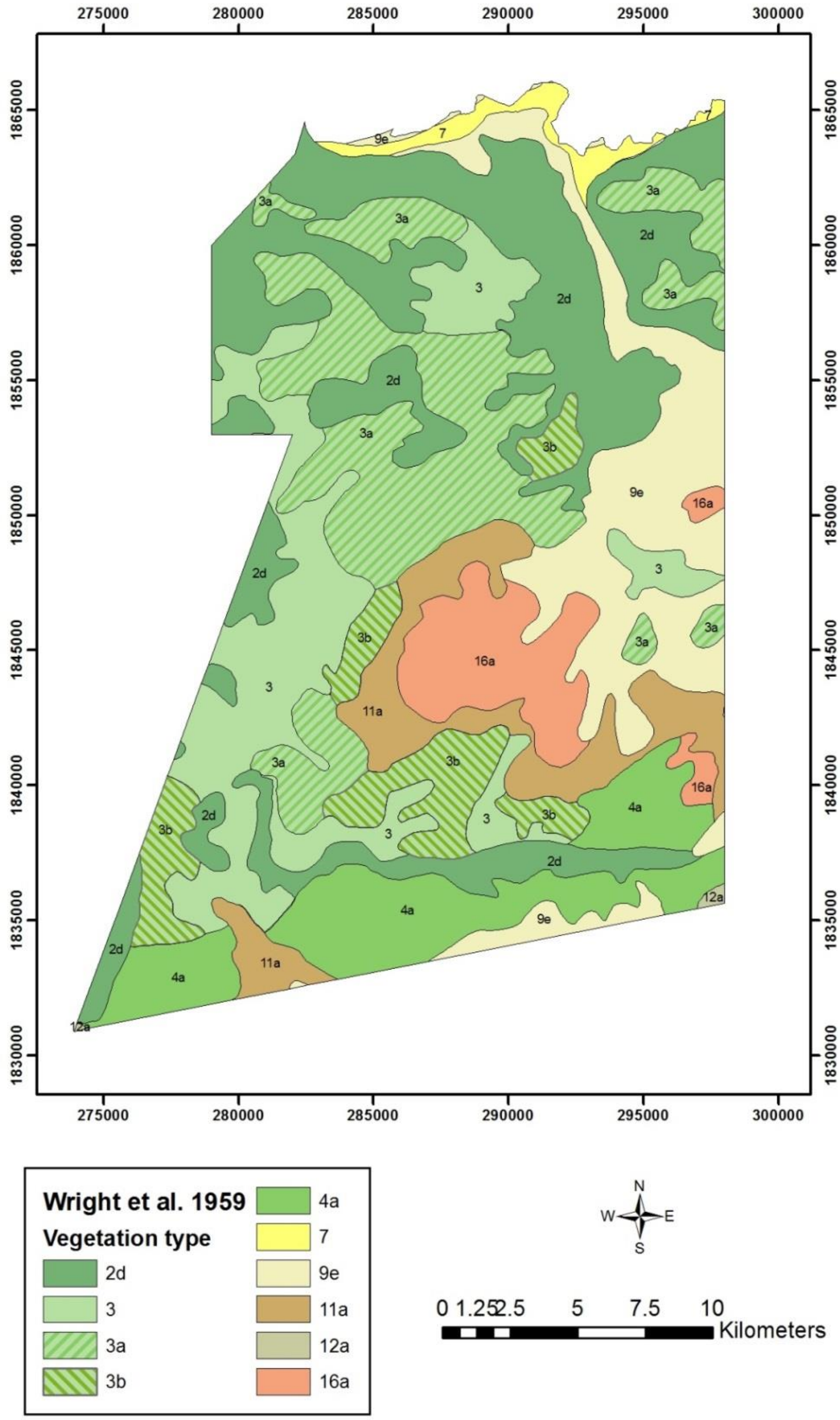


Figure 8 Vegetation types in the Chiquibul Forest Reserve according to Wright *et al*. (1959) – see Annex I Table 76 for further description and comparison

to an upland subclass of Wright *et al*. (1959) 'Broadleaf Forests Rich in Lime-Loving Species; Deciduous seasonal forest 70–100 ft. high on limestone' referred to as class '2d Chiquebul-Cherry forest' (Annex I Table 76). Co-dominants of this class were chiquebul *(Manilkara chicle)* and cherry (*Pseudolmedia spuria* (Sw.) Griseb.). Note that the former common name gives its name to the whole forest. Analysis of plot data from Bird (1998) shows that these two species are only moderately abundant in the vegetation, yet are still important. This class equates almost directly to '17 I.2.3.2 Broadleaf hill forests over limestone in steep terrain' described by Iremonger & Brokaw (1995: 12) as a subdivision of 'I.2.3 Hill forests', which they considered distinct from the lowland forests of Belize.

Class 1 is a vegetation type common over much of the karstic limestone of the Vaca Plateau. It occurs on steep, limestone terrain where water availability in the dry season is low, and the vegetation is correspondingly stressed. A large proportion of species are deciduous and the general canopy is at 20–30 m. According to Wright *et al*. (1959), common species include white breadnut (*Brosimum alicastrum* Sw.), cedar (*Cedrela odorata* L.), white copal (*Protium copal*), sapodilla (*Manilkara zapota*) and fiddlewood (*Vitex gaumeri*). However, Bird (1998) recorded that the most abundant tree was white poisonwood (*Sebastiania tuerckheimiana*), and Penn *et al*. (2004) also found woody Euphorbiaceae common on these dry and rocky hills. Included within Class 1 are the narrow valley bottoms and depressions typical of a limestone terrain. These have a relatively wet microclimate, with considerable variation in soil depth and water-retention properties. Only the deepest valleys have permanent water courses, otherwise there is very little surface water. Localized pockets of comparatively large mahogany (*Swietenia macrophylla*) trees exist.

Broadleaf: Class 1a, Dry deciduous forest

This vegetation is restricted to small pockets, mainly on the top of limestone hills or on exposed hillsides. One of the permanent sample plots (Plot 8) described by Bird (1998: 8, 46–47) is situated in this sort of terrain. Characteristic species include black poisonwood (*Metopium brownei* (Jacq.) Urb.), fiddlewood (*Vitex gaumeri*), madre cacao (*Gliricidia sepium* (Jacq.) Kunth. ex Walp.) and white mapola (*Pseudobombax ellipticoideum* A. Robyns).

Broadleaf: Class 2, Seasonal forest

This vegetation has an approximate canopy height of 20–30 m and is characterized by white breadnut (*Brosimum alicastrum*), chiquebul (*Manilkara chicle*), ironwood (*Dialium guianense*), savanna white poisonwood (?) (*Cameraria latifolia* L.), botan (*Sabal mauritiiformis*), santa maria (*Calophyllum brasiliense* var. *rekoi* (Standl.) Standl. and wild grape (*Coccoloba belizensis*

Standl.), as well as an abundant palm layer. This class corresponds more or less to class '3 Chiquebul-Ramon Forest' of Wright *et al*. (1959), grouped again within 'Broadleaf Forests Rich in Lime-loving Species; Semi-evergreen forest 80–100 ft. high on limestone'. Iremonger & Brokaw (1995) took a broader concept in their class '16 I.2.3.1 Broadleaf hill forests over limestone in rolling or flat terrain'. Their class has a coarser resolution and includes another class of Wright *et al*. (1959: 290), found in the south of the Chiquibul and differing mainly in the crown height, '4a Ramon-Chiquebul Forest' within 'Broadleaf Forests rich in Lime-loving species; Semi-evergreen forest 100–120 ft. high on limestone'. The latter category could be interpreted as older, more evergreen forest, which has not had such recent major hurricane impact, and therefore more or less equivalent to the lower forest further to the north. With this interpretation, one would expect a higher preponderance of species from early succession in the northern class. However, the more evergreen forest could also be interpreted as a response to the wetter climate of the southern basin and could therefore include species that are less drought-tolerant. The satellite imagery supports the maintenance of a separate class (Broadleaf: Class 12, High evergreen forest). This class is widespread in the western and central part of the reserve, with the exception of the strongly karstic areas. It is exemplified by the vegetation immediately around Las Cuevas Research Station and includes the selective logging permanent sampling plots (Bird, 1998).

Broadleaf: Class 3, Semi-evergreen forest (cohune ridge)

This vegetation is located on deeper fertile soils and is dominated by the cohune palm (*Attalea cohune*), nargusta (*Terminalia amazonia*), red gombolimbo (*Bursera simaruba*, chiquebul (*Manilkara chicle*), sapotillo (*Pouteria reticulata* (Engl.) Eyma) and white breadnut (*Brosimum alicastrum*).

Broadleaf: Class 4, Semi-evergreen forest (highland)

Wright *et al*. (1959) list two classes within their classification of 'Broadleaf Forests with Fewer no Lime-loving Species; Semi-evergreen seasonal forests' which were termed as class '9b Negrito-Santa Maria forest' and class '9e Nargusta-Santa Maria forest'. Taken together, these correspond to the Iremonger & Brokaw (1995: 14) class '21 I.2.3.3.4 Negrito nargusta variant'. Penn *et al*. (2004) not only distinguish Wright's subclasses but split the semi-evergreen vegetation into three different classes, highland, lowland and riparian (for the latter see Riparian: Class 16, Riverine). The highland class is mainly semi-evergreen in composition, with the dominant tree species being quamwood (*Schizolobium parahyba*), nargusta (*Terminalia amazonia*), southern wild mahogany (*Mosquitoxylum jamaicense* Krug & Urb.), copal (*Protium schippii* Lundell), cedar (*Cedrela odorata*) and pimientillo (*Xylopia frutescens* Aubl). The canopy height is higher than in the adjacent slopes and valleys at approximately 30–35 m. This class appears to be secondary forest. The hill-tops have quite a dry forest with conspicuous, large cedar (*Cedrela odorata*) trees. The presence of *Xylopia frutescens* is surprising as it is much more commonly found as an understorey component of the savannah vegetation (classes 17–18) in Mountain Pine Ridge and the Stann Creek coastal savannahs. Finally it should be noted that this area is less affected by a prolonged dry season and as a result fewer trees are deciduous.

Broadleaf: Class 4a, Semi-evergreen forest (lowland)

This class is mainly found below 550 m and is characterized by a lower canopy height (25–30 m), and it should be noted that this forest is highly impacted by hurricanes. The composition is similar to the highland class, and a characteristic example of this vegetation is that found in the Upper Raspaculo River Basin, including the permanent sampling plot at Cuxta Bani (Sutton, 1991). Sutton (1991) found the following species to be common: salmwood (*Cordia alliodora* (Ruiz & Pav.) Oken), white salmwood (*Cordia bicolor* A. DC.), white gombolimbo (*Dendropanax arboreus* (L.) Decne.&Planch.), ironwood (*Dialium guianense*), carbon (*Guarea grandifolia* DC.), monkey apple (*Licania platypus* (Hemsl.) Fritsch), frijolillo (*Lonchocarpus guatemalensis* Benth.), ambaibillo (*Piper arboreum* Aubl.), *Pourouma bicolor* subsp. *scobina* (Benoist) C.C. Berg & Heusden, mammee ciruela (*Pouteria durlandii* (Standl.) Baehni), mountain kaway (*Pterocarpus rohrii* Vahl), *Quararibea funebris* (La Llave) Vischer, hogplum (*Spondias mombin*), mahogany (*Swietenia macrophylla*), cojon de caballo (*Tabernaemontana alba* Mill.), nargusta (*Terminalia amazonia*), yemeri (*Vochysia hondurensis* Sprague) and prickly yellow (*Zanthoxylum riedelianum* Engl.), with guamo negro (*Inga davidsei* M. Sousa) the commonest tree. Short-lived, early successional elements include peine de mico (*Alchornea latifolia* Sw.) and pointed trumpet (*Cecropia obtusifolia* Bertol.), which are comparatively. Perhaps one of the most striking features is the presence of what Brokaw (1991) called 'liana forests', which engulf many parts of this lowland forest.

Broadleaf: Class 5, Transitional semi-evergreen forest

This semi-evergreen forest corresponds more or less to class '11b Nargusta-Bastard banak forest' of Wright *et al*. (1959) within 'Transitional Broadleaf Forests; Medium-high semi-evergreen seasonal forest poor in lime-loving species'. Their class is more or less equivalent to class '18 I.2.3.3.1 Banak-nargusta variant (quartzite hills)' of Iremonger & Brokaw (1995) within their 'Broadleaf hill forests over non-calcareous rocks'.

Transitional semi-evergreen vegetation is considered to be species-rich (Sutton, 1991) but has been poorly collected and explored. The canopy height is lower than the previous classes, being approximately 15–20 m. Most abundant species include nargusta (*Terminalia amazonia*), *Schippia concolor* Burret, *Virola multiflora* (Standl.) A.C. Sm. and yemeri (*Vochysia hondurensis*), and there are isolated pockets of cohune palm (*Attalea cohune*).

Broadleaf: Class 6, Evergreen southern forest

Wright *et al*. (1959) distinguished a wet forest type in the south of the Maya Mountains as another subdivision of 'Transitional Broadleaf Forests; Medium-high evergreen seasonal forest poor in lime-loving species', naming it class '12a Nargusta-Yemeri forest'. Iremonger & Brokaw (1995) adopted a similar distinction in their vegetation class '19 I.2.3.3.2 Yemeri nargusta variant'. The distinction between this 'Evergreen southern forest' vegetation zone and that found in the wet parts of the northeast of the Chiquibul is supported by the present classification based on remote sensing. This class is distinguished from Class 5 by the presence of more drought intolerant species. It is characterized by its evergreen composition and common tree species include mountain cabbage palm (*Euterpe precatoria* var. *longevaginata* (Mart.) A.J. Hend.), nargusta (*Terminalia amazonia*), yemeri (*Vochysia hondurensis*), santa maria (*Calophyllum brasiliense* var. *rekoi*), palo negro (*Miconia argentea* (Sw.) DC.) and the palm *Astrocaryum mexicanum*.

Broadleaf: Class 8, Semi-evergreen forest (broken ridge)

This vegetation bordering the San Pastor area is clearly distinguishable within the classification; it forms an annulus to the 'Savannah: Class 21, Open with *P. oocarpa*[1] vegetation of San Pastor, and is a semi-evergreen forest, distinct from the nearby deciduous forest on limestone. This class is mainly restricted to the area surrounding the savannahs at San Pastor and benefits from what are probably wetter soils of quartzite/sandstone origin in a gently undulating landscape. Iremonger & Brokaw(1995) equated it with the upland non-calcareous class '18 I.2.3.3.1 Banak-nargusta variant (quartzite hills)', but it approaches their class '20 I.2.3.3.3 Santa Maria variant'. Wright *et al*. (1959) distinguished this vegetation as semi-evergreen forest '11a Nargusta-Santa Maria forest'. The present study defines a larger geographical area for this class, but did not find other zones of this particular class within the reserve. The boundary of this class is located near Grano de Oro. This area has been loosely defined as 'broken ridge', and it has a permanent plot located nearby (Bird, 1998). Tree species data are available for this area (Bird, 1998). A distinctive element is *Erblichia odorata* Seem., known locally as the butterfly tree or conop, a species of the Turneraceae immediately recognizable when fertile by its large orange flowers. Other common taxa include *Calophyllum brasiliense* var. *rekoi* (santa maria), large individuals of *Terminalia amazonia* (nargusta) and *Vochysia hondurensis* (yemeri), and local pockets of *Swietenia macrophylla* (mahogany). The canopy height of this class is approximately 25–30 m with a palm understorey of mainly xaté (*Chamaedorea elegans* Mart. and *C. oblongata* Mart).

[1] Apparently this species is *Pinus patula* ssp. *tecunumanii*

Broadleaf: Class 12, High evergreen forest

Located in the southern Chiquibul and clearly visible within this classification, is a vegetation class of two discrete areas. Both lie within the vicinity of large rivers (mainly the Chiquibul River) and on predominantly alluvial soils. This vegetation is not clearly delimited within the classification of Wright *et al*. (1959), but it is likely that they included it in class '4a Ramon-Chiquebul forest' which also represents a high forest class. Within the classification of Iremonger & Brokaw (1995) this vegetation was not represented but was probably included within their class '19 I.2.3.3.2 Yemeri-nargusta variant'.

This class is mostly evergreen with a high canopy of approximately 30–35 m. Common tree species include cohune palm (*Attalea cohune*), mountain cabbage palm (*Euterpe precatoria* var. *longevaginata*), nargusta (*Terminalia amazonia*)*,* cedar (*Cedrela odorata*)*,* fig (*Ficus* spp.), mahogany (*Swietenia macrophylla*) and paradise tree (*Simarouba glauca*). Within the understorey *Myriocarpa longipes* Liebm., Melastomataceae, Bryophyta, Pteridophyta, and epiphytes are frequent. The trees within this vegetation class seem to represent one of the few genuinely high evergreen forest areas within the Chiquibul. This class is also characterized by an understorey of tree ferns, with *Cyathea myosuroides* (Liebm.) Domin. locally abundant.

Broadleaf: Class 13, Evergreen palm forest

Further investigation is needed to delimit and characterize this spectrally distinct vegetation class. The vegetation is apparently dominated by the palms *Attalea cohune* and *Astrocaryum mexicanum* and tree species *Virola multiflora*. It is located in isolated areas north of the divide but south of Ceibo Grande.

Riparian: Class 16, Riverine

A distinct vegetation class borders the major rivers of the Chiquibul. Wright *et al*. (1959) described this vegetation as '7 Cohune-Banak forest' within their categorization as 'Broadleaf Forest with Occasional Lime-Loving Species; Semi-evergreen seasonal forest'. This rather variable vegetation included characteristic species such as quamwood (*Schizolobium parahyba*) and widespread patches of *Attalea cohune* palm (on the relatively deep soils). Likewise banak (*Virola koschnyi* Warb.) was considered to be abundant, as well as particularly tall individuals of cotton (*Ceiba pentandra*) and large, often solitary trees of *Ficus ovalis* (Liebm.) Miq. lining the river banks. Iremonger & Brokaw (1995: 18) described this vegetation as class '48 II.2.3 Disturbed scrub*'* and comment on the high variability and the dominance of graminoids and shrubs. Subsequently Meerman (1999) called this vegetation class 'Riparian shrubland in hills'. Minty *et al*. (2001) found that this class is critical for the survival of a number of endangered animal species including *Tapirus bairdii* (Gill, 1865, in Penn *et al*., 2004) and *Ara macao cyanoptera* (Wiedenfeld, 1994, in Penn *et al*., 2004).

This classification clearly depicts quite a linear shaped area which follows the Macal, lower reaches of the Raspaculo and part of the Chiquibul rivers. In the narrower Chiquibul valley the vegetation is less well-developed and discontinuous when compared with the broader Macal and Raspaculo valleys.

Savannah: Class 17, Pine forest

This savannah class is typical of the Mountain Pine Ridge and is characterized by Caribbean pine (*Pinus caribaea* var. *hondurensis*); a patch of this class is found is found within the Chiquibul Forest Reserve bordering the Macal River, close to the Chalillo Dam. Wright *et al.* (1959) classified this area as 'Pine Forest and Orchard Savanna; Orchard savanna (without lime-loving species) and true savanna' and gave it the rather unwieldy descriptive title '18a Oak-Pine-Clusia spp. forest'. This vegetation class most closely approximate to Iremonger & Brokaw's (1995) class '22 I.2.3.4 Needle-leaf hill forests over poor soils'. Deeper valley soils have another species of pine; Tecun Uman pine (*Pinus patula* Schiede and Deppe ssp. *tecunumanii* (Eguiluz and Perry) Styles or *P. tecunumanii* Eguiluz & J.P.Perry). There are also frequent, highly localized pockets of broadleaf forest (Class 11).

Savannah: Class 18, Oak and pine

Wright *et al*. (1959: 297) distinguished a predominantly deciduous broadleaved forest class from the Pine forest above as "18 Oak-Pine-Florosul forest". This savannah class is dominated by species of oak, including *Quercus oleoides* Schltdl. & Cham., and includes *Vitex kuylenii* Standl. (florosal of Wright *et al*. (1959) or florazul). It has an open structure with much light reaching the shrubby understorey. This class is dominated by species of Melastomataceae, and epiphytes are abundant. During the height of the dry season the *Quercus* spp. may be deciduous but in wetter years they retain much of their foliage. Distinctive species include tecumasuche (*Cochlospermum vitifolium* (Willd.) Spreng) and *Inga pinetorum* Pittier. This vegetation is visible on the slope leading down to Guacamallo Bridge on the edge of MPR.

Savannah: Class 19, Transitional pine, grass and palmettoes

The pine savannah of MPR is a dynamic assemblage of successional vegetation maintained in a subclimax state mainly by fire, hurricane or, more recently, insect predation. Pine dominated forests are highly distinctive in the spectral analysis, to the extent that the ages of different stands give measurably different signatures. The broadleaf-dominated oak forests and the open grasslands are also very distinctive, but a large part of MPR consists of open vegetation lacking a continuous canopy, and most of the woody vegetation consists of multi-stemmed shrubs. This vegetation class is delimited here as a transitional savannah, recognizing that it is variable in structure. Amongst the scattered oak and pine are frequent clumps of the common palmetto of the savannah, *Acoelorraphe wrightii* (Griseb. & H. Wendl.) H. Wendl. ex Becc. Other woody components include *Agarista mexicana* var. *pinetorum* (Standl. & L.O. Williams) Judd, *Byrsonima bucidaefolia* Standl. (craboo), *Clusia massoniana*, as well as typical savannah elements such as *Curatella americana* L. The shrubs include a great many species of Melastomataceae.

Savannah: Class 21, Open with Pinus patula *ssp.* tecunumanii

The open savannah at San Pastor could be classed as similar to the vegetation of Mountain Pine Ridge, though it is far more open than MPR and has relatively large pines and more of a scrubby understorey. Wright *et al*. (1959) distinguished this vegetation as 'shrubland with pine' and did not include this in the pine savannahs of MPR, instead they called it '16a Oak- Pine forest'. Iremonger & Brokaw (1995) amalgamated this vegetation into their MPR class '22 I.2.3.4 Needle-leaf hill forests over poor soils' with *Pinus caribaea* var. *hondurensis* common. Penn *et al.* (2004) concluded that this vegetation is distinctive from the MPR pine savannah, with many of the pines being *Pinus patula* ssp. *tecunumanii* , rather than *P. caribaea* var. *hondurensis*. Other common species include *Quercus* spp., *Ilex guianensis* (Aubl.) Kuntze, and shrubs including *Hypericum terrae-firmae* Sprague & L. Riley, *Psychotria fruticetorum* Standl. and many Melastomataceae. The herbaceous layer has a very different species composition than MPR and is dominated by a large sterile grass (cf. *Gynerium sagittatum* (Aubl.) P. Beauv.). This class is mainly found near San Pastor. It is mainly restricted to areas of poor, shallow soils of cretaceous origin.

Savannah: Class 22, Pine, oak and Liquidambar

This vegetation class was not recognized by either Wright *et al. (*1959) or Iremonger & Brokaw (1995). The class is usually quite open, with scattered pine trees (not at the same density as MPR or San Pastor), and an understorey of grasses and herbs. The main trees and tree-fern species represented within this class are *Pinus caribaea* var. *hondurensis*, *Quercus* spp., *Ilex guianensis*, pockets of *Euterpe precatoria* var. *longevaginata, Cibotium regale* Verschaff. & Lem. and, importantly, substantial areas of *Liquidambar styraciflua* L. Within the understorey Melastomataceae, Poaceae and *Clusia* spp. were found, as well as dense patches of *Dicranopteris flexuosa* (Schrad.) Underw. In isolated pockets, many orchids were seen, most of them being epiphytic.

Scrubland: Class 25, Open pine scrub forest

Both the classifications of Wright *et al*. (1959) and Iremonger& Brokaw (1995), do not specifically represent this vegetation, though one could argue that Wright *et al*. amalgamated this vegetation into their '12c Yemeri-Rosewood-Polewood forest' class with 'occasional pine trees', and Iremonger & Brokaw (1995) amalgamated it into their '29 III.2.1 Fire induced herbaceous vegetation' class (see next class). Within the analysis of satellite imagery and field-based vegetation classification this class was clearly distinguishable from the larger herbaceous class nearby. Dominant tree species include *Pinus caribaea* var. *hondurensis*, *Quercus sapotifolia* Liebm., *Ilex guianensis*, as well as zones of Cyperaceae consisting mainly of *Rhynchospora exaltata* Kunth.,*Ternstroemia tepezapote* Schltdl. & Cham. and *Dicranopteris flexuosa*. The uncommon rosewood in the class name used by Wright *et al*. (1959) is probably

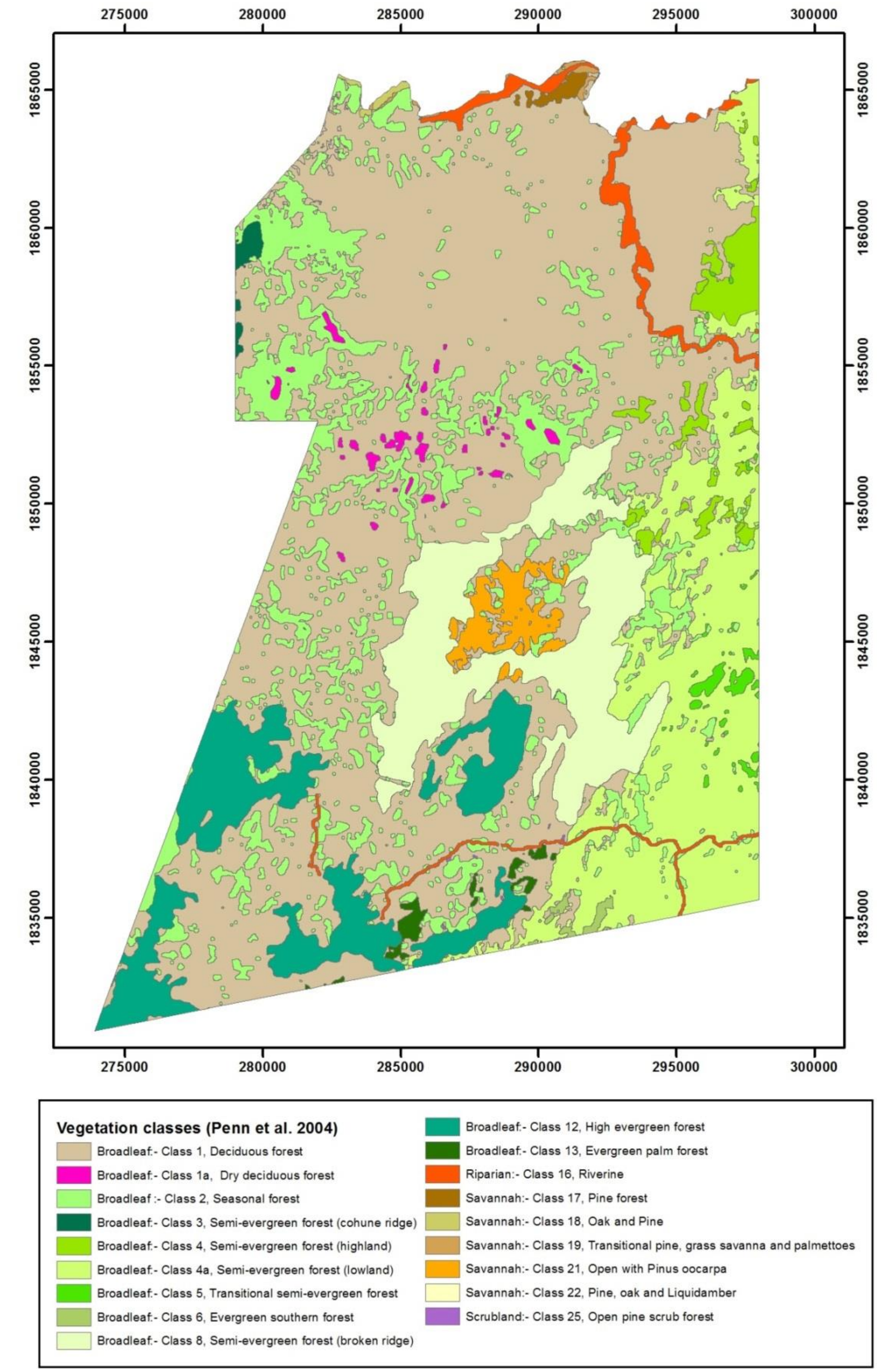


Figure 9 Vegetation classes across the Chiquibul Forest Reserve according to Penn et al. (2004)

Dalbergia stevensonii Standl. This class also has abundant epiphytic and ground-dwelling Orchidaceae.

Figure 9 shows the general vegetation classification produced by Penn *et al*. (2004). Total coverage of each vegetation class within the Chiquibul Forest Reserve is given in Table 1.

Eighteen vegetation classes can be distinguished within the boundaries of the Chiquibul Forest Reserve according to Penn *et al*. (2004). The majority (50%) of the Forest Reserve is classified as Broadleaf: Class 1, Deciduous forest; followed by Class 2, Seasonal forest, with 14% and Class 4a, Semi-evergreen forest (lowland), with 13%. Other noteworthy vegetation classes are: Class 8, Semi-evergreen forest (broken ridge), with 9% and Class 12, High evergreen forest, with 7% and to a certain extent Class 4, Semi-evergreen forest (highland), Class 16, Riverine, Class 21, Open with *Pinus patula* ssp. *tecunumanii* , and Class 1a, Dry deciduous forest. The remaining nine vegetation classes all have a limited total coverage with a combined spatial extent representing just 2% of the Forest Reserve area.

Table 1 Spatial extent of the 18 classes defined within the Chiquibul Forest Reserve according to Penn *et al*. (2004).

Type	Class	Class description	Area (ha)
Broadleaf	Class 1	Deciduous forest	29,868
Broadleaf	Class 1a	Dry deciduous forest	4,207
Broadleaf	Class 2	Seasonal forest	236
Broadleaf	Class 3	Semi-evergreen forest (cohune ridge)	306
Broadleaf	Class 4	Semi-evergreen forest (highland)	8,127
Broadleaf	Class 4a	Semi-evergreen forest (lowland)	150
Broadleaf	Class 5	Transitional semi-evergreen forest	1,089
Broadleaf	Class 6	Evergreen southern forest	7,987
Broadleaf	Class 8	Semi-evergreen forest (broken ridge)	277
Broadleaf	Class 12	High evergreen forest	110
Broadleaf	Class 13	Evergreen palm forest	5,383
Riparian	Class 16	Riverine	953
Savannah	Class 17	Pine forest	125
Savannah	Class 18	Oak and Pine	64
Savannah	Class 19	Transitional pine, grass savanna and palmettoes	86
Savannah	Class 21	Open with *Pinus patula* ssp. *tecunumanii*	841
Savannah	Class 22	Pine, oak and Liquidamber	2
Scrubland	Class 25,	Open pine scrub forest	9
		Total area of classification	59,822

Meerman (2015)

Meerman & Sabido (2001) produced a Map of the Ecosystems of Belize in 2001; essentially an update of the vegetation map produced by Iremonger and Brokaw (1995).This update had corrections where necessary and brought the classification nomenclature in conformity with the UNESCO classification system. Meerman subsequently updated this Map of the Ecosystems of Belize in 2004, 2011 and 2015. The latest 2015 version was enhanced using a substantial set of new data. The classification follows the UNESCO system developed for the Central American Ecosystems Map. The classification developed by Meerman differs from the earlier classifications by Wright, *et al.* (1959) and Iremonger and Brokaw (1996) in that the broader divisions in the hierarchy are based first on vegetation structure (forest, scrub. herbaceous), followed by seasonality, altitudinal aspects, vegetation type (broadleaf, needle-leaf. palm), ground-water regime and ultimately underlying geology and soil.

Figure 10 shows the vegetation classification produced by Meerman (2016). Total coverage of each vegetation class within the Chiquibul Forest Reserve is given in Table 2.

Table 2 Spatial extent of the 11 classes defined within the Chiquibul Forest Reserve according to Meerman (2015).

Vegetation class	Area (ha)
Deciduous broad-leaved lowland riparian shrub-land in hills	455
Deciduous broad-leaved sub-montane disturbed shrub-land	11
Tropical evergreen seasonal broad-leaved lowland forest, well drained, on rolling karstic hills	660
Tropical evergreen seasonal broad-leaved lowland forest, well drained, on steep karstic hills	1548
Tropical evergreen seasonal broad-leaved lowland forest, well drained, over acidic soils	612
Tropical evergreen seasonal broad-leaved lowland forest, well drained, over acidic soils: Steep	1199
Tropical evergreen seasonal broad-leaved sub-montane forest on rolling karstic hills	32624
Tropical evergreen seasonal broad-leaved sub-montane forest on steep karstic hills	8872
Tropical evergreen seasonal broad-leaved sub-montane forest, over acidic soils	8879
Tropical evergreen seasonal broad-leaved sub-montane forest, over acidic soils: Steep	3390
Tropical evergreen seasonal needle-leaved sub-montane forest	1049
Total area of classification	59822

Eleven vegetation classes can be distinguished within the boundaries of the Chiquibul Forest Reserve according to Meerman (2015). The majority (55%) of the Forest Reserve is classified as Tropical evergreen seasonal broad-leaved sub-montane forest on rolling karstic hills; followed by Tropical evergreen seasonal broad-leaved sub montane forest, over acidic soils and Tropical evergreen seasonal broad-leaved sub-montane forest on steep karstic hills, both with 15%. Other noteworthy vegetation classes are: Tropical evergreen seasonal broad-leaved sub-montane forest, over acidic soils: Steep, with 6% and Tropical evergreen seasonal broad-leaved lowland forest, well drained, on steep karstic hills, with 3% and to a certain extent Tropical evergreen seasonal broad-leaved lowland forest, well drained, over acidic soils: Steep and Tropical evergreen seasonal needle-leaved sub-montane forest, both with 2%. The remaining four vegetation classes all have a limited total coverage with a combined spatial extent representing just 3% of the Forest Reserve area.

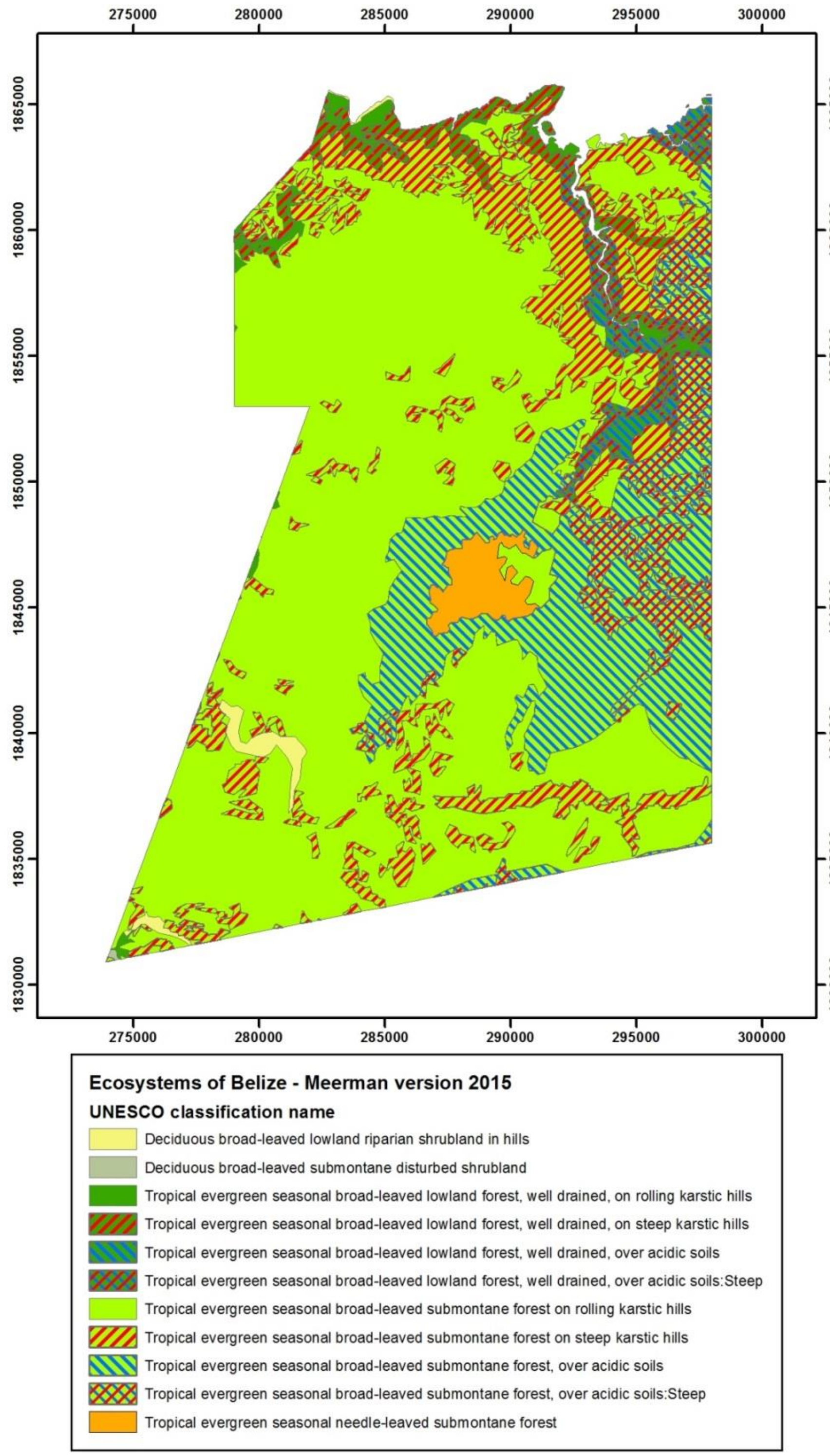


Figure 10 Vegetation classes across the Chiquibul Forest Reserve according to UNESCO classification (Meerman, 2015)

Cedar (*Cedrela* odorata) occur typically on dry steep limestone hillsides, whereas mahogany, *(Swietenia macrophylla*) occurs more typically on the gentler lower slopes between the hills in vegetation dominated by sapodilla and breadnut. However, cedar can still be present on the lower slopes and mahogany on the steeper higher slopes.

3.6 Description of principal fauna

Mammals

The large cats, the jaguar, locally called tiger (*Felis onca*), the puma, locally called red tiger, (*Feliz concolor*) and the smaller ocelot, locally tiger cat, (*Felis pardales*) occur. They present little threat to man but are of tourism and biodiversity importance.

Wild pig, the peccary, (*Dictoyles tajacu*) and the white-lipped peccary, locally called warrie, (*Dictoyles labiatus*) are common. They are hunted for meat by Guatemalan xateros (xate gatherers).

Deer occur, the savanna deer (*Odocoileus truei*) and the antelope (species unknown). The latter is probably much the commoner in Chiquibul.

The tapir, locally called mountain cow, (*Tapirella bairdii*) is locally common. The meat is generally not eaten in the Western District and so it is normally not molested; Apart from causing local damage by trampling down vegetation it is not harmful.

Both the howler monkey, locally called baboon, (*Alouatta villosa*) and the spider monkey (*Ateles paniscus*) occur. Their numbers are said to have been seriously reduced in an epidemic of yellow fever in the early 1950s. A programme to vaccinate the whole human population against yellow fever was operated in the period 1953-57, (Belize Government (1959), as a precaution against the danger of contracting the disease from monkeys.

Other mammals which are seen occasionally and may interest the tourist include the armadillo (*Tatusia novemcincta*), the bush dog (*Galictis Barbara*), fox (*Urocyon cinereo argentus*), gibnut (*Coelogenys paca*), otter locally called water dog (*Grison canaster*), quash, coati or coatimundi (*Nasau nasica*) and various opossums.

At least one species of forest rat is host to the disease dermal leishmaniasis (locally called Bay Sore) which can infect forest workers to whom it is transmitted by a species of sandfly.

Some of the free range zebu (or Brahmin) cattle, *Bos indicus*, wandered from the Mountain Pine Ridge into the northern fringe of Chiquibul, presumably in search of grazing.

Birds

Johnson and Chaffey (1973):

How much birds influence tree species of economic importance is unknown. Certainly the parrots are voracious seed eaters. Insectivores help to limit the insect population. Birds of prey help to limit the numbers of small birds and mammals. Forest workers and BDF soldiers supplement their otherwise meager diet by shooting and eating such species as the great curassow (*Crax rubra*), the crested guan (*Penelope purpurascens*), the plain chachalaca (*Ortaliz vetula*) and the spotted wood quail (*Odontophorus guttatus*). Among the many striking birds in the area are the vultures, the king vulture (*Sarcoramphus papa*), turkey vulture (*Cathartes aura*), swallow-tailed kite (*Elanoides forficatus*), white hawk (*Leucopternis albicollis*), ocellated turkey (*Meliagris ocellata*), scarlet macaw (*Ara macao*), and Montezuma oropendola or yellowtail (*Gymnostinops Montezuma).*

Reptiles

Johnson and Chaffey (1973):

Crocodile *(Crocodylus sp.)* are said to occur in the Raspaculo branch. They are protected by law.

Iguana lizard, locally called bamboo chicken, *(Iguana iguana)* occur along some stretches of river bank. They were observed along the upper Raspaculo branch. They are sometimes hunted for food. The female is particularly prized when full of eggs which are eaten in addition to the flesh.

Various snakes, venomous and non-venomous occur. Particularly dangerous is the fer-de-lance, tommy goff, yellow jaw or barba amarilla, *(Bothrops atrox)* which is very venomous. Less dangerous but commoner is the jumping tommy goff *(Bothrops nummifer).* Coral snakes *(Micrururus sp.)* occur. The most conspicuous non-venomous species is the boa constrictor or wowla *(Constrictor constrictor imperator).*

Insects

Johnson and Chaffey (1973):

The shoot borer moth (*Hypsipyla grandella* Zell), is very important because it attacks mahogany and cedar. The larva tunnels up the centre of the young shoots causing them to die back. This can severely distort and restrict the growth of saplings. Particularly affected are said to be saplings which are isolated. The data collected by inventory teams shows that the form of the natural seedlings and saplings of mahogany in the dense regrowth in Chiquibul is on the whole good. Little evidence of serious deformation due to shoot borer attack was found. Cedar seedlings frequently had poorer form with kinks in the stem, probably caused by shoot borer attack killing the leading shoot. At the time of writing attempts are being made to introduce parasites of the shoot borer moth to reduce its numbers.

Parasol ants *(Atta sp.)* are a pest because they can completely defoliate a small tree. Significant damage to saplings of valuable species was not noted by the inventory teams. The ants are more damaging in plantations than in natural forest.

Threats to wildlife

Despite the protected status of the Chiquibul Natural Park and Forest Reserve, the area is under severe pressure from incursions on the western border that threaten to destroy the reserve's integrity and cultural heritage. Poverty and a lack of land in Guatemala drive incursions and illegal farming within Belize and the systematic devastation occurring in the reserve stems from a lack of border control and security (Briggs *et al*., 2013). Reportedly, illegal incursions by Guatemalan villagers to harvest the leaves of the *xate* palm commonly referred to as '*xateros*' are the source of the various threats to the Chiquibul forest. Indiscriminate hunting and poaching for the pet trade often accompany *xate* harvesting. *Xatero* camps are littered with remains of poached wildlife and refuse (Bridgewater *et al.* 2006).

Many game species, including some not usually hunted for consumption such as Baird's tapir (*Tapirus bairdii*), spider monkeys (*Ateles geoffroyi*), black howler monkeys (*Alouatta pigra*), and scarlet macaws (*Ara macao cyanoptera)* have been found at *xatero* camps within the Chiquibul Forest (Walker *et al.* 2008). Guatemalan poachers raid nests to supply the pet trade's demand for yellow-headed parrot (*Amazona oratrix*) and scarlet macaw nestlings, and juvenile spider and black howler monkeys (Walker *et al.* 2008). Illegal hunting is primarily linked to *xatero* activity but also occurs in the Chiquibul Forest from within Belize (Walker *et al.* 2008.). Illegal bush meat hunting reduces wildlife populations, such as the white-lipped peccary (*Tayassu pecari*), which has been extirpated from the Chiquibul (Briggs *et al.*, 2013).

3.7 History of management

During Maya civilisation

At least the limestone area of Chiquibul forest was inhabited at the time of the ancient Maya civilisation. It is evident that large areas were cleared for cultivation, as indicated by widespread terracing of the gentler slopes between the limestone hills still in evidence today. Much of the gently sloping ground between the steep limestone hills was terraced by the Mayas and these terraces, usually 30-100 cm (12-39 in) high, still survive, often with the retaining walls still visible. It has been postulated that the terraces are silt traps rather than hand raised works, and that the valleys were enriched by trapping of soil washed down from the steep hillsides as a result of removal of the vegetation. Ruins of dwellings still remain on raised mounds and many hilltops. Just to the west of the Chiquibul Forest Reserve are the ruins of Caracol and others elsewhere. During the classic period of the Maya civilisation circa A.D. 200 - A.D. 925 large areas of Chiquibul must have been clear of forest. The collapse of the classic Maya civilisation occurred in the period A.D. 800 - A.D. 925 (Thompson, 1966) and the ceremonial centres were abandoned. At some time the population declined and habitation in the Chiquibul area ceased. Cultivated area reverted to forest. It is assumed that the forest remained relatively undisturbed by man for several centuries up until recent times. Modern commercial exploitation of the timber did not commence until the early 1920s and has mostly been confined to selective felling of mahogany and cedar. (Johnson and Chaffey, 1973).

Commencement of timber exploitation

Chiquibul was not penetrated for exploitation of its timber until the 20th century. Hooper (1887) mentioned ‘fine (mahogany) trees, though unworkable, are found on the precipitous slope adjoining the Great Southern Pine Ridge, (i.e. the Mountain Pine Ridge) on the eastern bank of the Belize River from Vaca Falls upwards’, and ‘(mahogany) wood is reported among the steep hills east and south-east from The Cayo, distant and unattainable’. However in the early 20th Century a railway was built southwards from Vaca Falls along the Vaca plateau towards Chiquibul. Logs could then be transported by rail to Vaca Falls and there be dumped into the Macal River below the falls for floating to the coast. The railway penetrated at least as far south as Camp 6. Beyond that truck passes were made for extraction to the railhead. Initially bullock-drawn wagons were used. These were replaced by motor trucks and trailers in the 1930s. (Johnson and Chaffey, 1973).

By 1925 the Mengel Company had reached Retiro and in the following years the forest produced an estimated average of 3 million bdft. The Mengel Company relinquished the concession at Vaca at the end of 1928. Worldwide trade depression in the following years seriously affected the timber trade in Belize. There were retrenchments in Forest Department staff in 1931 and again in 1933. A lapse in exploitation operations in Chiquibul probably occurred at this time. (Johnson and Chaffey, 1973).

Exploration south of Vaca was reported in 1935 and two concessionaires were operating there in 1936. In 1953, two contractors were operating in the two license areas covering the forest. In 1953 Wahib Habet was granted a license to extract and utilize logs and branches of mahogany and cedar abandoned by Stuart in the eastern half of the forest and shortly after to fell trees rejected by Start as hollow. By 1955 the logging operations had penetrated south beyond

Resumidero. In 1955 both major licenses expired and were not renewed. (Johnson and Chaffey, 1973).

Establishment of the Chiquibul Forest Reserve

In 1956 the entire forest came under one long-term licence (Forest Licence LT 3/56). An annual timber yield of 240,000 ft^3 (6,796 m^3) was set for mahogany and cedar (Bird, 1998). In the same year Chiquibul was gazette as a Forest Reserve. The first year of harvesting saw 256,149 ft^3 (7,253 m^3) felled in the first year of the license. Logging of the two species reached 330,000 ft^3 (9,345 m^3) in 1962, although this was justified as 'salvage logging' after hurricane Hattie (Bird, 1998). Salvage logging continued until 1964 when the license was revised to apply for the period 1965-1976. This second license allowed the cutting of mahogany and cedar to remain at 240,000 ft^3 each year within the 'main felling series' (see Johnson & Chaffey, 1973). Other species of hardwood could be cut without limit. The recorded timber harvest for mahogany and cedar in the first year of this revised licence was 310,144 ft^3 (8,782 m^3) (Bird, 1998). The average annual production over the licence period was 130,000 ft^3/year (3,681 m^3/year) for mahogany and cedar and 120,000 ft^3/year (3,398 m^3/year) for other hardwoods, totalling 250,000 ft^3/year (7,079 m^3/year) (Bird, 1998).

A third long-term licence (Forest Licence LT 1/77) was issued to the same licensee in 1977. The permissible annual cut for mahogany and cedar was halved to 120,000 ft^3. This licence expired in January 1987, with a mean cut for mahogany and cedar of only 14,000 ft^3/year (396 m^3/year). The mean harvest for other hardwoods was 113,500 ft^3/year (3,214 m^3/year). The actual cut was apparently only 12% of the allowable cut suggesting that little exploitable timber remained and no felling took place for the next 10 years (Bird, 1998).

Forest Planning and Management Project

In 1996, felling recommenced but now based on controlling sustained yield, among other ecological and restoration considerations, with the issuance of two long-term licenses in the Chiquibul reserve (Bird, 1998). Timber harvesting since the 1950s had been carried out at a rate much higher than the forest could sustain. Cutting of the prime species (mahogany and cedar) was for a time occurring at a level more than double what is currently estimated as the sustained yield for all species. As a consequence, in 1996 the forest was in a degraded state from which it was expected to take decades to recover (Bird, 1998). It shows that previous approaches had failed to control a sustained yield and therefore the improved system was introduced.

The new system was based on the concept of area control, where each year logging is confined to one part of the production forest area. The size of the annual coupe is determined on the basis of the felling cycle (the period of time between successive harvests) of 40 years, using general estimates of growth and mortality (Alder, 1993). Based on this 40-year cycle, the production forest area was divided into eighty compartments of approximately 500 ha each, of which two would be allowed to be harvested every year (Bird, 1998). Although this approach does not take account of variation in the stocking of commercial trees, area control represented a major step forward in the control of timber harvesting. Previously, logging was characterized by felling operations which took place throughout the area under licence. The same part of the forest could therefore be logged repeatedly, giving no time for a particular stand of trees to recover between harvests.

The second level of control was based upon detailed knowledge of the trees within the compartment. A stock survey was conducted providing information on the number of trees, by species, and their spatial distribution over a compartment, allowing crop trees to be selected prior to the start of the logging operation itself. Seed trees and reserve trees were to be retained in such a way that would allow for the same timber harvest in 40 years' time. Reserve trees or potential future crop trees were defined as trees between 30 and 60 cm dbh in size. At least 10 seed trees must be retained per 100 hectare. For each species where there were not 10 reserve trees identified during the stock survey the balance is selected from the potential crop trees ≥ 60 cm dbh (Bird, 1998).

The results from the stock survey thus aimed to determine the timber yield at the local or compartment level that could be sustained for at least two felling cycles. In terms of the present yield, the potential crop trees are identified as the number of merchantable trees less the number of seed trees which need to be retained. In terms of the future yield, the number of reserve trees plus the number of seed trees is discounted by 40%, the assumed cumulative mortality over the felling cycle of 40 years. The number of potential crop trees for each species is then adjusted, where necessary, so that the present yield does not exceed the expected yield at the next felling cycle. Timber harvests therefore vary from year to year depending on timber stocks and size class distribution, by species, within a particular compartment (Bird, 1998).

Compartment 58 was the first area to come under comprehensive timber harvesting control within the Chiquibul Forest Reserve. Logging was carried out by Belize Timber Ltd., under Forest licence No. 2 of 1996. An estimated timber volume of 78,000 ft^3 (2,209 m^3) was cut from within the 500-ha compartment. Overall, 754 trees belonging to 15 different species were harvested. The majority of the harvested trees were nargusta (36%) and sapodilla (23%), while only 46 mahogany and 5 cedar trees were harvested. On the other hand, 756 reserve mahogany trees between 30 and 60 cm dbh were encountered, probably the result of a wave of regeneration that took place after hurricane Hatti (Bird, 1998). The 1969 inventory of Johnson and Chaffey

(1973) had estimated only 62 trees/500 ha in the same size class. For the two dominant species, nargusta and sapodilla, the present cutting level could be sustained, but in view of the low harvestable stock of mahogany and cedar a moratorium was agreed to by both licensees.

Compartments 38 and 64 were harvested in 1998, which implies that a total area of 1,853 ha was harvested between 1997 and 1998.

In 2002, mahogany became the first widely traded timber species to be listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Appendix II listing requires exporting nations to verify that timber supplies originate from sustainably managed forests; sustainability is based on established non-detriment findings.

Bull Ridge Limited

No logging took place from 1998 until 2007 after a new license was issued in 2006 to Bull Ridge Limited Between 2006 and 2017, Bull Ridge Limited harvested 16 compartments covering in total 8,226 ha, resulting in a total area harvested since 1997 of 10,079 ha or 24%[2] of the production forest as defined by the FPMP management plan. In 2017, two compartments are being harvested with a total area of 965 ha, which will result in a total area harvested since 1997 of 11,044 ha or 26%[3] of the production forest by the end of 2017.

Bull Ridge Limited operates according to Annual Plans of Operation based on stock surveys that need to be approved by the Forest Department before logging may commence. The company focuses on the species mahogany, cedar, barbajolote, sapodilla, nargusta and santa maria, while occasionally rosewood and billy web also have been harvested.

Unfortunately records on volumes by species produced are not readily available from the Forest Department exploitation control and trade felling programme. Based on the APOs an estimate could be made of number and the volume of the crop trees that were selected for harvesting over the years. From 2015 chain of custody records are available from the Bull Ridge Ltd sawmill, allowing an assessment of the volume delivered at the sawmill.

The APO for 2007 considered compartments 59 and 60 located around La Flor, totalling 1,001 ha. According to the APO, 757 mahogany trees equivalent to 1,183 m^3, and 84 cedar trees equivalent to 210 m^3 were selected for felling. Nineteen other species were identified for harvesting in the APO, but it is unlikely that those species were actually harvested, perhaps with the exception of nargusta, barbajolote, santa maria, sapodilla and rosewood. Eventually, compartment 59 was harvested in 2007 while compartment 60 was harvested in 2008. If all

[2] 9,668 ha or 28% of the redefined production forest area (see Chapter B2 Forest Organization)

[3] 10,633 ha or 30% of the redefined production forest area (see Chapter B2 Forest organization)

selected crop trees of the six species above have indeed been harvested a maximum number of 1,440 trees with a harvested volume of 2,106 m^3 may have been harvested during 2007-08.

The annual cutting compartment for 2009 comprised compartments 34 and 35, covering a total area of 951 ha. According to the APO, seven species were to be harvested, involving 2,193 trees equivalent to 2,531 m^3. Of this total, 571 mahogany trees, equivalent to 859 m^3 were to be harvested and 138 cedar trees equivalent to 266 m^3. Besides mahogany and cedar, the following species were considered for harvest: barbajolote, billy web, nargusta, rosewood and santa maria.

The annual cutting compartment 2010 was located in the Broken ridge surrounding the San Pastor Pine ridge, a compartment that was added later to the 80 compartments defined by Bird (1998) as compartment 81. According to the APO, seven species were to be harvested, adding up to a total of 1,797 trees with a total volume of 2,240 m^3. This included 628 mahogany trees equivalent to a volume of 924 m^3 and 262 cedar trees equivalent to 478 m^3. The same species were considered for harvesting as in 2009.

The annual cutting compartment, 2011 was located in compartments 52 and 53; southeast of the San Pastor Pine ridge, approximately 8.5 kilometres south east of San Pastor Camp. Again, seven species were to be harvested, with a total of 1,155 trees equivalent to a volume of 1,553 m^3. Of this total, 942 mahogany trees were to be harvested equivalent to a volume of 1,193 m^3 and 67 Cedar trees equivalent to 109 m^3. Besides mahogany and cedar, the following five species were considered for harvest: barbajolote, nargusta, rosewood and santa maria and sapodilla.

The company was placed under a 'cease and desist' by the Forest Department in May 2011 pending a post-harvest assessment of 2011 activities. As a result no harvesting activities took place in 2012. In preparation of the APO for 2013, the following species were assessed during the inventory: mahogany, santa maria, nargusta, rosewood, sapodilla, cedar, barbajolote, billy webb and black cabbage bark. Harvesting in 2013 took place in compartment 45, measuring 446 ha. Overall, 1,302 trees were selected as crop trees equivalent to a volume of 1,705 m^3. Of this total, 591 mahogany trees were to be harvested equivalent to a volume of 900 m^3 and 40 Cedar trees equivalent to 79 m^3.

The annual cutting compartment, 2014 was located in compartments 61 and 62; southeast of compartments 52 and 53 mentioned above, approximately 10.5 km south east of San Pastor Camp. Eight species were surveyed but only 5 had sufficient stocking to be harvested, with a total of 1,133 trees equivalent to 1,622 m^3 of round wood. Of this total, 814 mahogany trees were to be harvested equivalent to 1,285 m^3 of round wood. Besides mahogany the following species were earmarked for harvest: nargusta, rosewood, santa maria and chico sapote. The stock survey showed insufficient trees of barbajolote, cedar and sapodilla to warrant a justification for harvest if keeping with the sustained yield stipulation. Hence, those three species were excluded from harvesting in 2014. In the end, 727 of the mahogany crop trees were harvested, of which 465 from compartment 62 and 262 from compartment 61. The actually produced net mahogany volume, as delivered at the sawmill amounted to 1,345 m^3; of which 806 m^3 originated from compartment 62 and 539 m^3 from compartment 61.

Forest Department introduces new sustained yield rules

Until 2015, the calculation of the allowable cut was based on the system introduced by Neil Bird in 1998. The main characteristics of this system are that the local allowable cut is calculated for the annual coupe based on a 40-yr cutting cycle. In addition, 100 seed trees need to be retained for each harvested species per 1,000 ha (average annual coupe size) and sufficient reserve trees need to be retained in order to ensure that the present cut does not exceed the next cut. In this respect, it is assumed that 40% of the trees will die during a 40-yr cycle. If these are insufficient reserve trees below the minimum cutting diameter limit (MCDL), additional reserve trees are selected from the trees above the MCDL. Furthermore, a maximum cutting diameter of 100 cm dbh is prescribed (Bird, 1998).

In 2015, an updated system for preparing APOs was introduced by the Forest Department. The new system increased the number of seed trees to be retained for mahogany; i.e. 200 seed trees per 1,000 ha, while the maximum cutting diameter was reduced to 90 cm dbh. Also, a spreadsheet-based growth and yield model was introduced to compute the local allowable yield using increment functions derived from Permanent Sample Plots measurements, mainly located in the Chiquibul Forest and the Rio Bravo Conservation and Management Area (Bird, 1998; Cho *et al*., 2013). The new growth model required an intensification of the pre-harvest inventory. The minimum diameter limit was reduced from 30 cm dbh to 10 cm dbh for mahogany and to 25 cm for other species. These changes meant that the time and cost involved in the preparation of the APO were substantially increased.

The annual cutting compartment, 2015 was located in compartments 3, 9, 10 and 15, in the Mountain Cow area in the northwest of the reserve. The shift to this area was induced by alleged illegal logging in this area. There is a lot of rugged and rocky terrain in compartments 3 and 15 and only 12.5% and 20% of these compartments respectively were harvested. Eight species were inventoried but only 4 had sufficient stocking to be harvested, with a total of 1,589 trees equivalent to a roundwood volume of 3,270 m^3. Of this total, 1,109 mahogany trees were to be harvested equivalent to 2,171 m^3 of round wood. Besides mahogany the following species had adequate stocks for harvesting: cedar, nargusta and santa maria. The stock survey showed insufficient trees of barbajolote, rosewood, chico sapote and sapodilla to warrant a justification for harvest. Hence, those three species were excluded from harvesting in 2014. The allowable cut for this annual coupe was based on a 25-yr cutting cycle instead of a 40-yr one.

In 2013 and 2014, Rosewood was not harvested due to the moratorium put in place. Due to this moratorium, rosewood was not felled in compartments 45, 61 or 62 in the past two years. These compartments were revisited to extract 191 rosewood trees from compartments 61 and 62 and 324 rosewood trees from compartment 45, and to extract 26 logs left in barquadiers in compartments 61 and 62. No new roads or barquadiers were opened to extract those rosewood trees.

The annual cutting compartment, 2016 was located in compartments 19 and 20 just north of Las Cuevas. The same seven species were inventoried but rosewood had insufficient stocking to be harvested. The survey revealed a total stock of 1,552 trees equivalent to a roundwood volume of 2,790 m^3. Of this total, 743 mahogany trees were to be harvested equivalent to 1,301 m^3 of round wood.

The annual cutting compartment, 2017 is located in compartments 4 and 11 west of the main Chiquibul road and east of Mountain Cow. The same seven species were inventoried but barbajolote and rosewood had insufficient stocking to be harvested, leaving five species with a total of 1,645 trees equivalent to a roundwood volume of 3,433 m3. Of this total, 840 mahogany trees were to be harvested equivalent to 1,749 m^3 of round wood.

Table 3 Bull Ridge Ltd annual harvests since 2007 – crop trees: trees selected for harvest above species-specific MCD; residual trees: reserve trees (dbh ≥ 25(30) cm dbh), seed trees, preserved trees

Year	Compartment	Gross (net) area (ha)	Mahogany			Other species		
			Crop trees		Residual trees	Crop trees		Residual trees
			N	V (m^3)	N	N	V (m^3)	N
2007/08	59 & 60	1000	754	1,182	2,385	1,010	1,696	2,438
2009	34 & 35	951	571	859	1,946	1,622	1,672	4,865
2010	81	829	628	924	1,851	1,391	1,316	4,085
2011	52 & 53	1000	942	1,193	2,829	213	364	963
2013	45	446	591	900	1,643	711	805	1,488
2014	61 & 62	1000	814	1,285	1,894	319	339	1,206
2015	3, 9, 10 & 15	2000 (1163)	1,109	2,171	2,489	480	1,099	1,695
2016	19 & 20	1000 (794)	743	1,302	2,078	809	1,489	4,241
2017	4 & 11	965 (870)	840	1,749	6,808	805	1,685	4,174

Bull Ridge Limited conscientiously has been applying the FPMP sustained yield method in the selection of crop trees and the retaining of reserve, preserve and seed trees over the years 2007-2014. Since the introduction of the more stringent rules by the Forest Department in

2015, the company painstakingly has been applying the new rules. Table 3 shows that the company has been selecting 1,595 trees per year for harvest on average equivalent to a volume of 2,448 m^3 (86,435 ft^3) over an average (gross) annual cutting area of 919 ha. On average, 777 mahogany trees were selected for harvest per year equivalent to a volume of 1,285 m^3 (45,373 ft^3). It is clear that the annual harvests conducted by Bull Ridge Ltd fulfil the established criteria for sustainable forest management in Belize with just 1.6 trees felled per hectare of which only 0.8 mahogany trees per hectare. A considerable number of reserved, preserved and seed trees are being retained; as many as 5.3 trees of the harvested species per hectare and 2.6 mahogany trees per hectare, on average. In other words, for each mahogany tree being harvested 3.4 trees (≥ 30 cm dbh) are being retained. Similarly, for each tree of the other harvested species 3.4 trees are retained.

In comparison with the first long-term licence (Forest Licence LT 3/56) issued in 1956 for which an annual allowable yield of 240,000 ft^3 (6,796 m^3) was set for mahogany and cedar, current forest management practice denotes a drastic reduction in annual yield. For the period 1965-1976, the average annual production over the licence period was 130,000 ft^3/year (3,681 m^3/year) for mahogany and cedar, and 120,000 ft^3/year (3,398 m^3/year) for other hardwoods, totalling 250,000 ft^3/year (7,079 m^3/year). After the depletion of the Chiquibul forest over the period 1955-1985 a mere 400 m^3/year was available for harvest in 1987. The currently available mahogany stock indicates that the species had the ability to recover after being over-exploited for over 30 years and the devastation havocked by hurricane Hatti. On the other hand, it must be noted that the devastating impact of hurricane Hatti followed by wild fires, probably has been the cause of the prodigious mahogany regeneration which resulted in the current adequate stock.

Minimum cutting diameter limits (MCDL) were set based on the sustainable yield analysis of each species; i.e. depending on the diameter frequency distribution in the particular annual cutting compartment (Table 4).

Table 4 Minimum cutting diameter limits for the years 2016-2017 with historical (2007-2015) lower or higher MCDLs in brackets

Species	MCDL (cm)
Barba Jolote	50 (70) cm
Billy Webb	50 cm
Cedar	60 (55) cm
Mahogany	55 (50) cm
Nargusta	50 (65) cm
Rosewood	35 (25) cm
Santa Maria	50 (45) cm
Sapodilla	50 (65) cm

Records on the actually extracted trees by species are available for the years 2014-16, while records on volumes delivered at the sawmill gate are available for 2015-16 (Table 5). In comparison with the number of selected crop trees as shown in Table 3, 98% of the selected mahogany trees were actually extracted in 2014, 87% in 2015, and 97% in 2016. In terms of volume, 74% of the estimated mahogany volume was realised in 2015 and 98% in 2016. For all species, 81% of the selected trees were actually extracted in 2014, 92% in 2015, and 92% in 2016. In terms of volume, 76% of the estimated volume was realised in 2015 and 86% in 2016. The difference between the number of selected crop trees and the number of actually extracted trees is due to inaccessibility of certain trees or defects that were not noticed during the inventory. The differences in volumes may be further related to overestimation of trees diameters above the buttress or faulty measuring of diameters, e.g. over buttresses, or poor estimation of tree height. It may also be possible that the volume equation that is being applied in the Forest Department model overestimates tree volumes.

Table 5 Numbers and volumes of actually extracted trees by species over the period 2014-16

Species	2014	2015		2016	
	N	N	V (m^3)	N	V (m^3)
Barbajolote	-	-	-	37	68
Cedar	-	441	792	115	238
Mahogany	801	960	1,604	718	1,281
Nargusta	78	41	64	373	514
Santa Maria	34	23	39	103	162
Sapodilla	-	-	-	88	139
Total	913	1,850	2,690	1,434	2,402

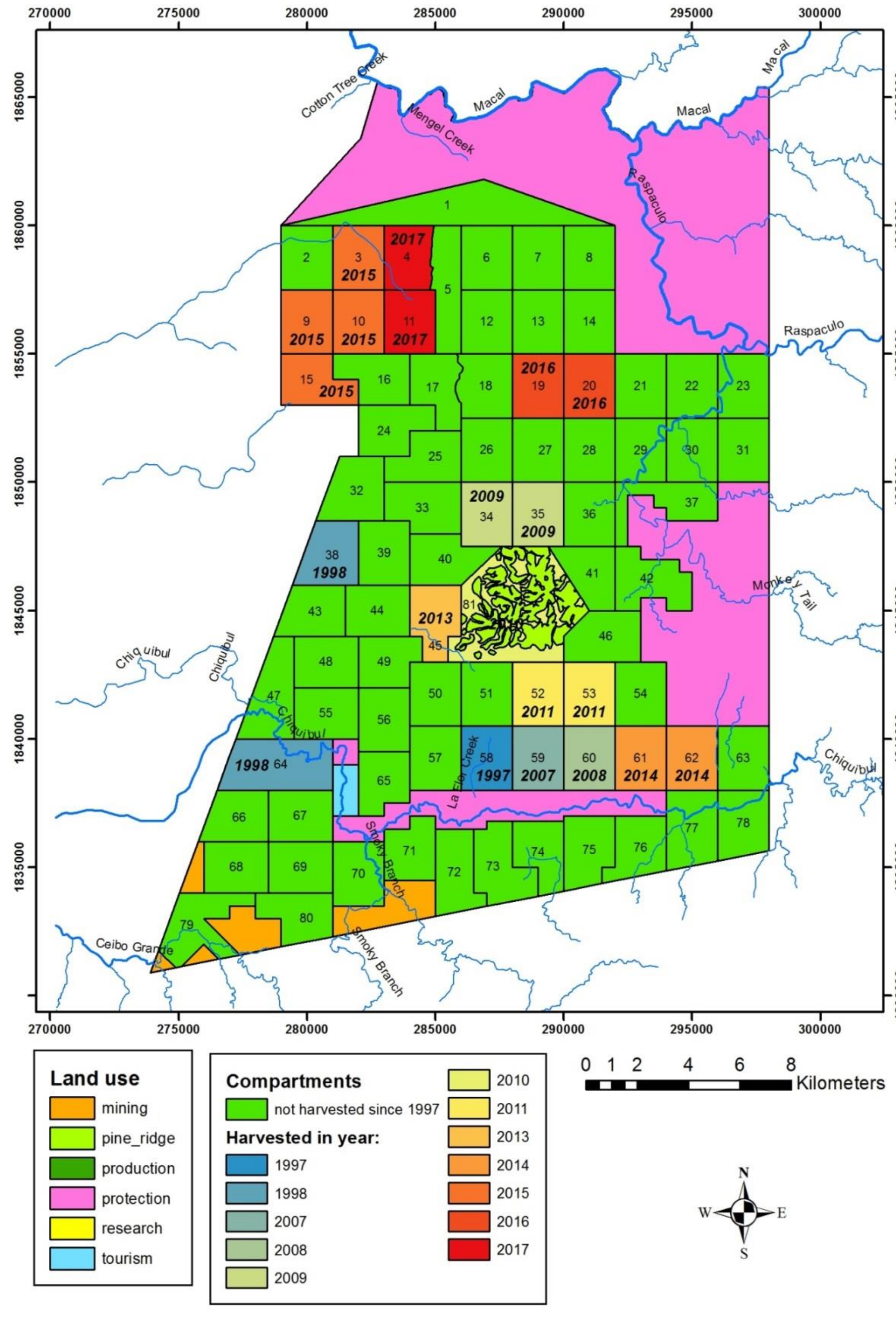


Figure 11 Production forest, protection forest, mining, research and tourism designation in the Chiquibul Forest Reserve; with logging compartments and year of harvesting since 1997.

3.8 Threats to the Chiquibul forest

There are various threats to the Chiquibul Forest. These threats range from agricultural activities, fires, illegal logging, wildlife depletion and looting of cultural artefacts to vandalism by desecrating both cultural and geological assets. Nearly all threats are linked to illegal incursions by Guatemalan poachers.

Hurricanes and fire

The Chiquibul forest is subject to two occasional, yet significant, natural disturbances: fire and wind. The latter is most destructive when winds reach hurricane intensity. The most recent serious hurricane affecting the Chiquibul forest was hurricane Hattie in 1961. In 1998, the variable impact of this hurricane was still evident, with the forest cover consisting of a mosaic of well-developed high forest, low secondary forest and thicket (Bird, 1998). Logging began in the Chiquibul in the 1920s and continued, with increasing intensity, for the next sixty years. A moratorium on logging was put in place in 1987 and sustainable yield logging recommenced prematurely in 1997 for two years to be upheld again until 2007.

Fire damage as a result of logging activity was first reported in the Chiquibul by Lundell (1940). Widespread fires also occurred in 1945 when a total of 450 square miles of broadleaf forest, including the Chiquibul Forest, were severely burnt (Bird, 1998). Johnson and Chaffey (1973) reported fire outbreaks occurring in 1955 and 1964.

It has been suggested that fire is an important trigger for the regeneration of both mahogany and cedar (Fogg, un-dated; Wolffsohn, 1961). Mahogany suffers from infestations by shoot borers but the amount of damage caused by borers appears to vary locally. Experiments in the Chiquibul Forest in 1958 and 1959 demonstrated that insect attack may partially explain reductions in mahogany regeneration, which led Wolffsohn (1961) to suggest that the relative abundance of regeneration on large, burned areas may be partly due to the temporary elimination and slow recovery of local insect populations.

It appears that the combined effect of hurricane damage and unrestricted logging may have drastically affected the structure of the Chiquibul forest.

Xate harvesting

According to FCD, *xate* collection by Guatemalan border communities is considered the largest threat to the Chiquibul Forest. The over-harvesting of *xate* leaves in Mexico and Guatemala for the floral trade in Europe, Japan, and the United States has spurred *xate* leafcutters to extend illegal harvesting into the protected areas of Belize and is the principal source of income for several communities in Guatemala (Bridgewater *et al.* 2006). It is common for *xate* trading companies to contract residents of border communities to collect *xate* leaves. Because *xate* is a multi-million dollar enterprise for Guatemala (selling the leaves to markets internationally), *xate* leaves are heavily exploited. Plants are being stripped entirely of their leaves, reducing the chance of regeneration, which is compounded by the removal of seeds and seedlings (Bridgewater et al. 2006).

FCD believes that people who engage primarily in *xate* harvesting also poach wild animals. Research has reported anecdotal notes of increased incidence of hunting within Chiquibul associated with *xatero* activity and observations of carcasses of protected animals in *xatero* camps by the study authors (Bridgewater et al. 2006). The first reports of Guatemalans illegally entering Belize to harvest *xate* were in 1972. As of 2008, FCD estimated that between 1,500 and 2,000 people were working inside the Chiquibul Forest. In the Chiquibul forest the number of *xateros* continues to increase, creating a greater problem because they are sometimes armed and violent, for example, recent shooting at local hunters and Belizean defence soldiers (Briggs *et al*., 2013).

Hunting

Illegal *xate* harvesting is associated with indiscriminate hunting activity within protected areas in the Greater Maya Mountains (Bridgewater *et al.* 2006). Many game species, including some not usually hunted for consumption such as Baird's tapir (*Tapirus bairdii*), spider monkeys (*Ateles geoffroyi*), black howler monkeys (*Alouatta pigra*), and scarlet macaws (*Ara macao cyanoptera)* have been found at *xatero* camps within the massif (Walker *et al.* 2008).

Guatemalan poachers raid nests to supply the pet trade's demand for yellow-headed parrot (*Amazona oratrix*) and scarlet macaw nestlings, and juvenile spider and black howler monkeys (Walker *et al.* 2008; FCD 2011).

Illegal hunting is primarily linked to *xatero* activity but also occurs in the Greater Maya Mountains from within Belize (Walker *et al.* 2008.). Illegal bush meat hunting reduces wildlife populations, such as the white-lipped peccary (*Tayassu pecari*), which has been extirpated from the Chiquibul, an area that was once the species' primary stronghold in Belize (Kelly 2003 in: Briggs *et al*., 2013).

Illegal logging

Illegal logging In the Chiquibul Forest was first detected in 2006. By March 2008, a joint forces patrol documented that illegal logging was escalating and a logging trail network was evident. In 2009, aerial flights conducted by FCD observed numerous illegal logging clusters. By 2010, joint patrols reported frequent and persistent illegal logging activities. An assessment conducted by FCD in 2012 demonstrated that an estimated 5,803,538 board feet of lumber had been extracted illegally. Based on the data obtained it was clear that all extraction of illegal timber was of a trans-boundary nature, namely from Guatemala. Illegal logging occurring up to 17 kilometres inside Belize was severely destroying the mahogany and cedar populations within that zone of influence (Arevalo & Chan, 2015).

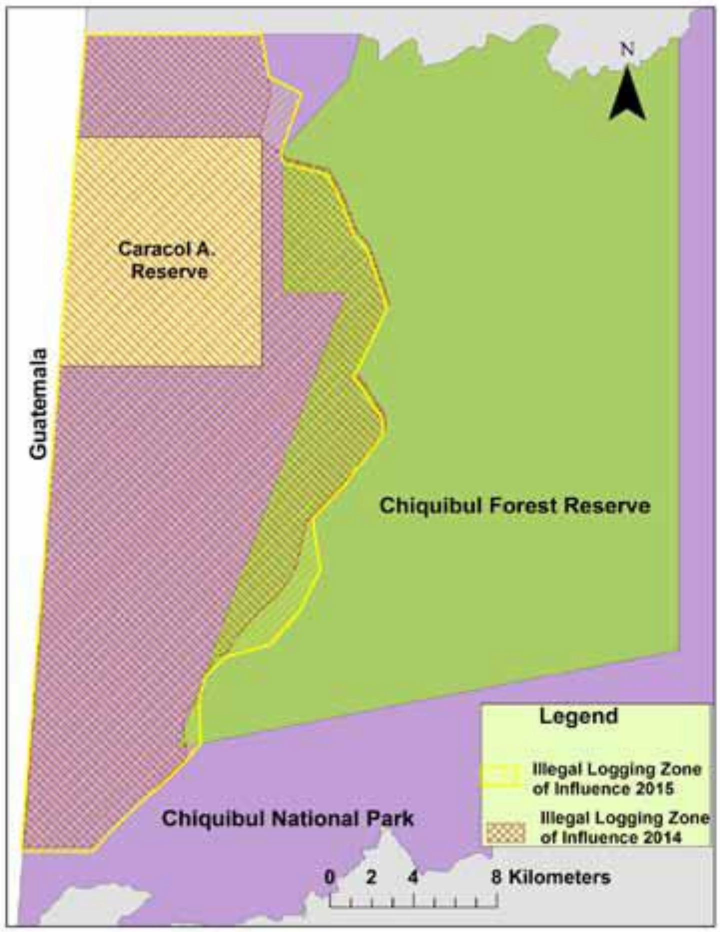


Figure 12 The area affected by illegal logging activities in the Chiquibul Forest (source: Arevalo and Chan (2015)

According to Arevalo and Chan (2015) the area impacted by illegal logging has shown an increase of 2.5 times from 2010 to 2015 and appears to have reached a saturation point in 2014. From May 2014 illegal logging has shown a 3.3% increase, but no new illegal logging activity was reported in the Chiquibul Forest since September 2014. The intensity of illegally logged mahogany was 0.2 trees per hectare, while 0.1 cedar trees per ha had been illegally logged. A total of 8,725,833 board feet of lumber have been illegally extracted from the Chiquibul Forest.

A factor that may have helped decreasing illegal logging is the increased presence of mobile law enforcement units in Southern Petén, Guatemala that target illegal logging. In addition, the higher number of FCD rangers and security forces in the Chiquibul Forest meant more law enforcement patrols within the illegal logging hotspots in the Chiquibul, helping to reduce the illicit activity (Arevalo & Chan, 2015).

Removal of ancient artefacts

Ancient artefacts were removed from many of the Mayan sites in Belize with permission during the colonial period, and today are still housed in museums and collections abroad (Walker *et al*. 2008). Ancient archaeological temples are being defaced and valuable historical artefacts are removed by looters, fuelled by black-market demand for exotic antiquities. Present-day looting comes in many forms. Local looters may raid a temple or unearthed mound by tunnelling in and removing articles to sell in local villagers or to foreign visitors (Matsuda 1998 in: Briggs *et al*., 2013). With the increase in tourism of Mayan culture, visitors to temples and ruins occasionally take pieces of pottery or remains as souvenirs (Walker et al. 2008). *Xateros* are particularly destructive looters because they are skilled at locating ancient Mayan dwellings overgrown by the forest and they are opportunistic in removing all items with market potential (Awe 2010 in: Briggs *et al*., 2013).

Gold mining

Illegal gold-panning is on the rise, stripping some areas of vegetation. This activity pollutes streams and drinking water, and causes river banks to erode (Briggs *et al*., 2013).

3.9 Economic environment

3.9.1 Existing physical infrastructure

The Chiquibul is accessible only by an unpaved road which extends for 53 km to the George Price highway at Georgeville. The Chiquibul Forest Reserve itself is dissected by numerous disused roads established since the heydays of logging between 1950 and 1975. The main road from Tapir Camp to Las Cuevas was upgraded in 2013 by the company, also were culverts installed to improve drainage and run-off. Improvement in drainage has led to major improvement in road conditions year round. Vegetation on the shoulders of the road was brushed by rotary mower (brush hog or "bush hog") to allow sunlight and wind to dry the road surface more quickly after rains.

The company maintains a mobile camp within the Reserve year round. A stationary base camp has been set up near the former New Maria Camp, about 3.5 km ESE of Tapir Camp to house workers. The area has good cell phone reception. Radio communications have been improved with the placement of a relay station at Gravy hill just south of Tapir Camp.

The road from the Guacamallo Bridge to Georgeville, near where the Company's mill site is, is an all-weather road. The distance from the Guacamallo Bridge to Georgeville is 53 km. From Georgeville to the mill site is just 1 km along the George Price Highway

3.9.2 Social infrastructure

The Las Cuevas Forest Research Station and the Tapir Base Camp currently managed by Friends for Conservation and Development (FCD) represent the main social infrastructures inside the Reserve. Additionally, as mentioned in the preceding section, the company is constructing a base camp at New Maria Camp, southeast of Tapir Camp, to house visitors and company staff. There are no medical facilities inside the Reserve, the nearest being in the town of San Ignacio about 60 km away. The nearest village, from where most workers hail, is San Antonio about 45 km from the Guacamallo Bridge.

3.9.3 Other resource activities within the management area

Non-Timber Forest Products

The Chiquibul Forest provides multiple non-timber forest products (NTFPs) including seeds, leaves, flowers, fruits, bark, latex, resins, pulp, roots, and oils (Ticktin 2004 in: Briggs *et al*., 2013)). Historically, chicle (from the sapodilla tree: *Manilkara zapota*) harvesting and chocolate production from cacao trees (*Theobroma cacao*) dominated the NTFP market in Belize but these have since declined and been replaced by a variety of palms. These palms serve a prominent role in traditional Belizean cultures, and harvesting tends to be harmful to the plants' persistence. The cohune palm (*Orbignya cohune*) produces oil-rich nuts, an edible heart that is also used for wine, and sturdy leaves and fibre for thatching and craft-making; the leaves of the bay palmetto (*Sabal mauritiiformis)* are also used for thatching (O'Hara 1999; Balick *et al.* 2000 in: Briggs *et al*., 2013).

Chamaedorea is clearly widespread across the Chiquibul Forest, and is an important component of the understorey vegetation. *Chamaedorea oblongata* is the most abundant; it is more than twice as abundant as *C. ernesti-augustii*, the second most common *Chamaedorea* species (Bridgewater, 2006). Legislation permits extraction of NTFPs from the Chiquibul Forest Reserve by Bull Ridge Ltd.

In 2006, Derrick Codd of San Ignacio was issued with a two-year license for the harvesting of *xate* palm leaves (*Chamaedora* spp.) within the Chiquibul Forest Reserve by the Belize Forest Department. Leaves of the following species of *xate* palms are allowed to be harvested under the license: *Chamaedorea tepejilote*, *Chamaedorea elegans*, *Chamaedorea oblongata* and *Chamaedorea ernesti-augustii*. This licence is now held by Gosen Product Co Ltd. This license has however not been activated. Therefore, all harvesting of leaf in the Chiquibul has been and continues to be illegal (Bridgewater, 2006). Over 400 million *xate* palm (*Chamaedorea spp.*) leaves are illegally harvested for the floral trade every year. More than 1,500 *xateros* are penetrating deeply into the reserve, creating a security problem because they are sometimes armed and violent (Briggs *et al*., 2013).

Military training areas

The Belize Defence Force and the British Army Training and Support Unit have for many years used the Chiquibul Forest as a military training area.

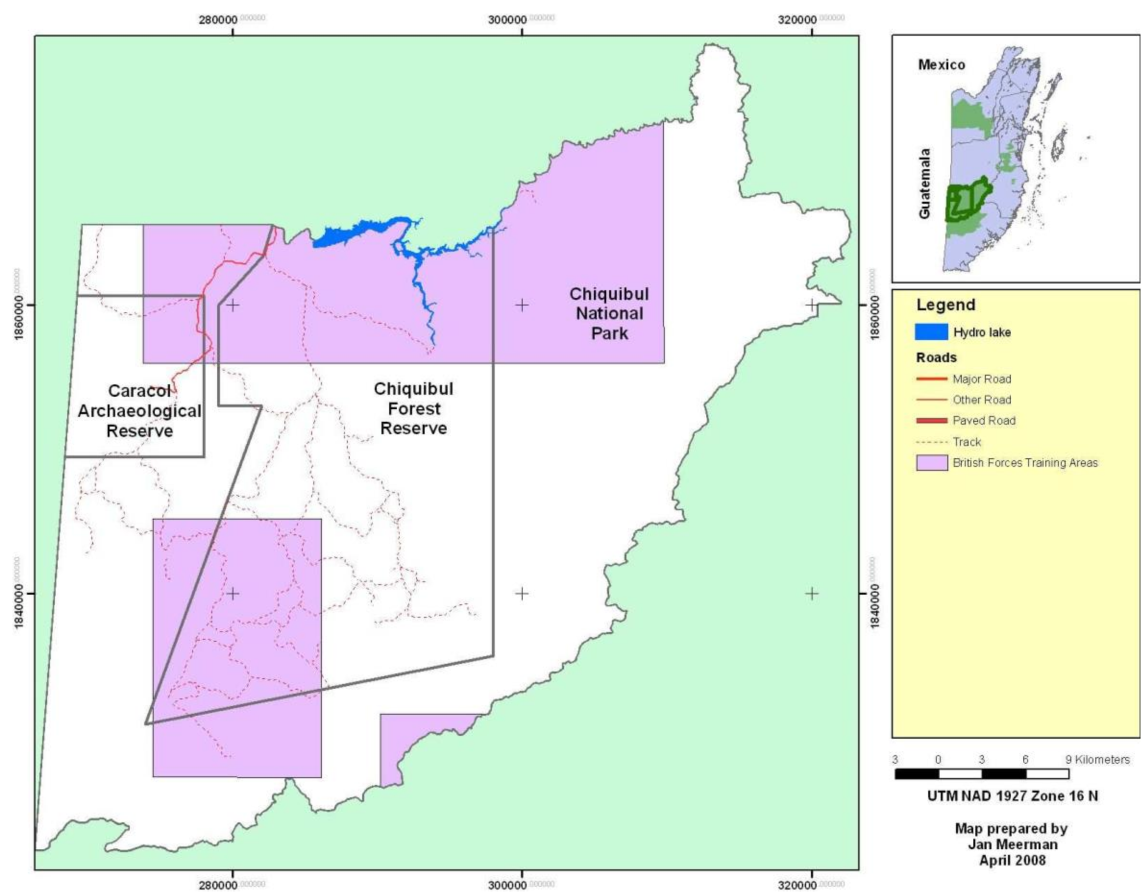


Figure 13 Military training areas in the Chiquibul Forest (Source: Salas & Meerman, 200)

As Figure 13 shows, large areas of the Chiquibul Forest are designated as military training zones. At times of high activity, troop levels have reached battalion strength, with training activities crisscrossing over wide swaths of the Chiquibul Forest. Training includes the firing of live and blank ammunition, etc., which primarily results in noise pollution that may have impacts on wildlife populations and tourism activities. Other associated impacts include damage to the vegetation and forest floor through the explosion of military shells, and compaction of the soil caused by base camp operations and use of military hardware (Salas & Meerman, 2008).

Tourism and Recreation Use

Tourism use within the Chiquibul Forest has been largely limited to the Caracol archaeological site, which is accessed by an all-weather road through the Mountain Pine Ridge Forest Reserve (the final 6 km stretch of this access road within the CAR is paved).

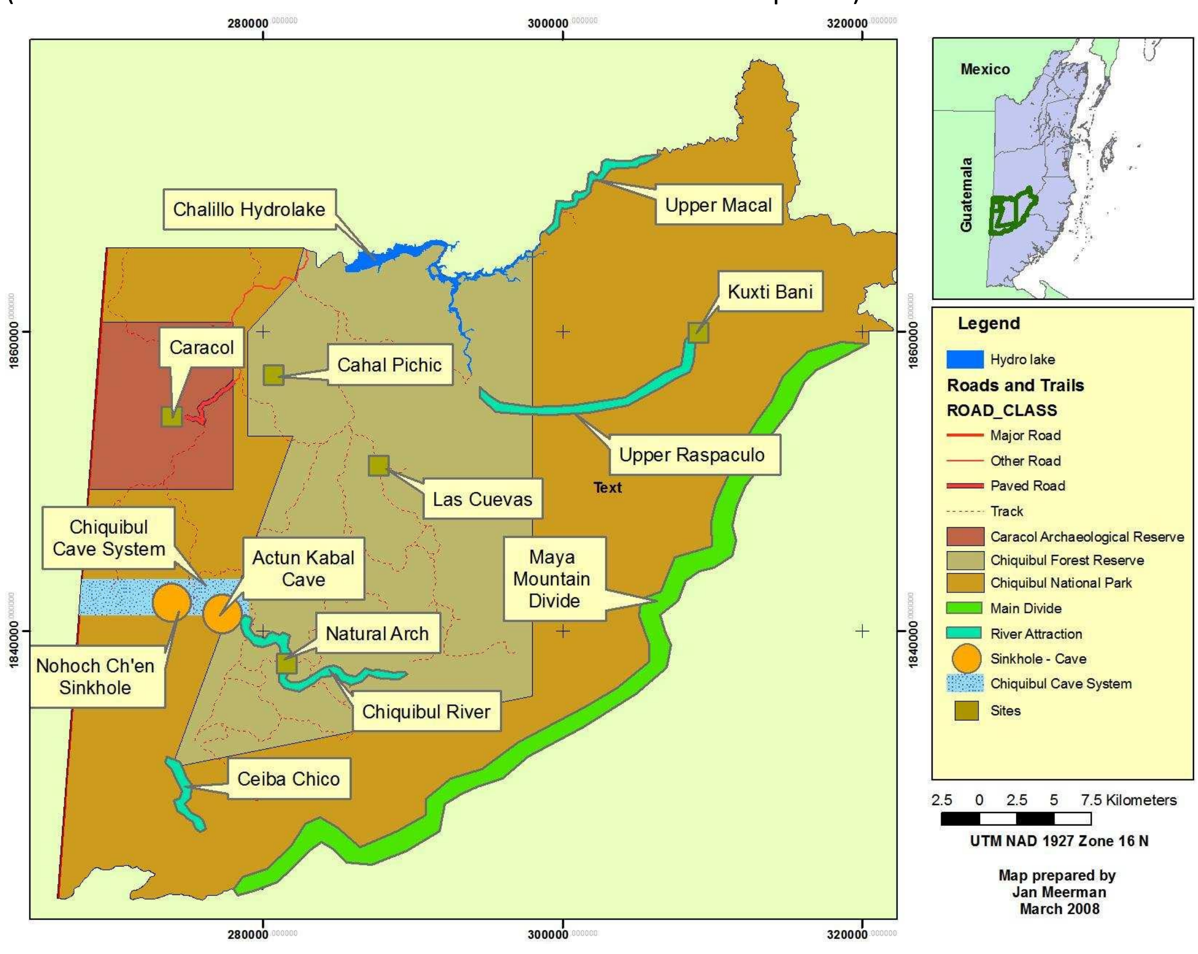


Figure 14 Selected current and potential tourism sites within the Chiquibul Forest (Source: Salas & Meerman, 2008)

There is also the occasional hiker/trekker, birdwatcher and spelunker. The two other well-known but less-visited tourism destinations in the area include the caves at Las Cuevas and the Natural Arch; both located within the CFR (see Figure 14 above). Las Cuevas is accessible year-round. The Natural Arch has recently not been accessible to regular 4x4 vehicles due to severe road conditions.

Gold prospecting

Gold prospecting in the Ceibo Chico area of the Chiquibul Forest has been an ongoing activity since the late 1980s, and continues under Boiton Minerals/Erin Ventures Inc. (under Ceiba Resources Ltd.). The first exploration license was issued in 1999, and the operation has been slowly increasing in size since the extension of the exploration license in 2004. The company has held prospecting licenses for four contiguous blocks, covering a total of 34 km^2, and a mining license covering 38.85 hectares (96 acres), which has recently been renewed for another 5 years, and extended in September, 2007, to cover 160.25 hectares (396 acres), to give the mining company mining rights to the total area of alluvial fan associated with the Ceibo Chico drainage system (Wildtracks, 2008 in: Salas & Meerman, 2008). A new company, Orion, is preparing to commence work in the nearby licence area of Erin Ventures Inc.

Education Use

FCD has commenced the development of an education and outreach program, which is targeting schoolchildren, youth and adults within the communities of Arenal, Benque Viejo del Carmen, San Ignacio, San José Succotz, Siete Millas, Cristo Rey and San Antonio. These communities buffer the Vaca Forest Reserve and Mountain Pine Ridge Forest Reserve, which are themselves adjacent to the Chiquibul Forest. Eight communities in Guatemala are also being targeted with the assistance of CONAP. The primary objective of the first year of the education outreach campaign has been to promote the importance of the Chiquibul Forest in the overall Chiquibul-Maya Mountain region and to promote awareness of the multiple benefits derived from the area such as air, water and recreational opportunities.

Bull Ridge Ltd. yearly invites students from the University of Belize.

3.9.4 Existing equipment

Bull Ridge Ltd. shares some equipment with its sister company Pine Lumber Co. Ltd., which holds and manages long-term forest license LTFL1 / 02 situate in the Mountain Pine Ridge. Forest and roading equipment used by the two companies is shown in Table 6 below. The Table indicates the type of operation a piece of equipment is employed in and whether a piece of equipment is shared or not.

Logging in the CFR by BRL takes place in the dry season from February until mid-May. Re-opening of logging roads and upgrading of roads in the CFR takes place in January. Logging in the MPRFR by PLC takes place between June and December. Upgrading of roads in the MPR takes place concurrently.

Table 6 Equipment used by Bull Ridge Ltd and its sister company Pine Lumber Co. Ltd. Equipment may be shared between the two companies

Equipment				Bull Ridge Limited				Pine Lumber Company				Equipment Shared
Year	***Model***	***Description***	***License#***	**Road Unit**	**Logging Tractor**	**Logging Trucks**	**Vehicles**	**Road Unit**	**Logging Tractors**	**Logging Trucks**	**Vehicles**	
2014	BT50	Mazda Pickup	CYC-34164								Yes	No
2015	BT50	Mazda Pickup	CYC-36081				Yes					No
1994	RD690S	Mack Truck Tractor	CYA-3741			Yes				Yes		Yes
1999	RD	Mack Truck Tractor	CYA-3531			Yes				Yes		Yes
1998	3500	Dodge Ram 3500 Serv. Truck	CYA-4056	Yes				Yes				Yes
1999	C7500	GMC Dump Truck	CYA-4061	Yes				Yes				Yes
1992	F800	Ford F800 Fuel Truck		Yes								No
1989	R688ST	Mack Truck Tractor	CYA-4052			Yes				Yes		Yes
1985	R688ST	Mack Truck Tractor	CYA-4361			Yes				Yes		Yes
1999	T800	Blue Kenworth Truck	CYA-4647			Yes				Yes		Yes
1993	910F	CAT Wheel Loader							Yes			No
2003	517	CAT Track Skidder			Yes				Yes			Yes
1996	240B	Timberjack Skidder			Yes							No
2006	540	Green John Deere Skidder							Yes			No
1996	548G	Yellow John Deere Skidder			Yes							No
1984	D5B	CAT Crawler Tractor							Yes			No
2007	D3G	CAT XL Crawler Tractor		Yes				Yes				Yes
	5715	Green John Deere Tractor			Yes				Yes			Yes
2007	140H	CAT VHP Plus Grader		Yes				Yes				Yes
1996	D6	CAT Crawler Tractor		Yes				Yes				Yes
2004	W200	Komatsu Wheel Loader			Yes							No
2006	310G	CAT 4x4 loader Backhoe		Yes				Yes				Yes
2000	SD115D	Ingersoll Rand Propac vibratory roller		Yes				Yes				Yes
2005	TR-21	Freightliner Water Truck						Yes				No

B FOREST RESOURCE MANAGEMENT

1 OBJECTIVES OF MANAGEMENT

Forests have multiple functions that are interdependent, such as production, biodiversity conservation, soil and water protection, cultural and spiritual functions, or combinations of these and others. Sustainable Forest Management is a multidimensional and multipurpose concept. Forests can perform many functions simultaneously and deliver various combinations of goods and services. This capacity and flexibility requires that the multiple values of forests are maintained in perpetuity.

Main objective:

The main objective of Bull Ridge Ltd forest management is to ensure a stable flow of roundwood of desired timber species without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment.

Our forest-related activities shall not damage the forest to the extent that its capacity to deliver general products and services - such as timber, water and biodiversity conservation, and cultural heritage - is reduced. Our forest management aims to balance the needs of different forest users so that its benefits and costs are shared equitably.

Specific objectives:

- Ensure long-term, stable supply of high quality timber to Bull Ridge Ltd sawmill
- Preserve biological diversity
- Maintain and improve the condition and productivity of forest ecosystems
- Conserve soil and water
- Maintain forest ecosystem contributions to major ecological cycles
- Maintain socio-economic benefits the general Belize society and local communities derive from the CFR
- Apply adaptive forest management by identifying, monitoring and evaluating impacts of management practices
- Preserve national heritage such as archaeological sites and artefacts and karst landscapes (caverns and sinkholes)
- Promote tourism and recreational activities within the CFR

Strategies:

- Apply area control to ensure that annual harvest areas are visited only once during the stipulated felling cycle

- Apply volume control in such a way that the amount of trees extracted in any given compartment is equal to or less than the amount of trees that the forest can replace naturally over the intervening cutting cycle.
- Mitigate impact of forestry operations on forest structure, composition, or the ability of the forest to maintain such over time.
- Carry out vine cutting to release future crop trees from competition and reduce felling damage, and, where necessary and economically viable, carry out enrichment of the forest through the planting and tending of seedlings and saplings.
- Match timber marketing efforts with forecasted sustainable yield of individual timber species
- Protect water quality and flow by establishing buffer zones along water courses and bodies
- Prevent forest fires by establishing firebreaks
- Preserve archaeological sites and special landscape features by identifying those during 100% pre-harvest inventory and establish buffer zone around the sites
- Upgrade and maintain forest roads within the CFR as needed, particularly by improving drainage
- Encourage research and education activity within the CFR in collaboration with FCD and national and international education institutions
- Discourage and stem illegal incursions into the CFR in collaboration with FCD and BFD
- Develop tourism and recreational activities within the CFR in collaboration with FCD, Belize Tourism Board, Belize Tourism Industry Association and Cayo Tour Guide Association

2 FOREST ORGANIZATION

When gazetted under Statutory Instrument No. 55 of 1956 the total area of the Forest Reserve was estimated at 714 square miles (184,926 ha), of which 330 square miles (85,470 ha) [46%] was classified as protection forest (Bird, 1998). The size of the Forest Reserve was considerably reduced in 1991 when the major part of the area was re-designated as a National Park (approximately 107,605 ha) under Statutory Instrument No. 166 of 1991. On the basis of environmental, biodiversity and land-use criteria a further evaluation was done in 1994 resulting new boundaries being recommended. These new boundaries were subsequently gazetted under Statutory Instruments Nos. 54 and 55 of 1995. The area of the Forest Reserve is now 59,820 hectares.

2.1 Classification of forested areas

2.1.1 Production forest

In 1998, controlled timber harvesting was to occur over 41,423 ha (69% of the area) in 80 forest compartments, generally measuring 500 ha each, whose boundaries basically follow the UTM grid system (Bird, 1998). The San Pastor Pine ridge and surrounding broken ridge was excluded from the management area. The remainder of the reserve was designated as protection forest. At a later stage the broken ridge surrounding and interlacing the San Pastor Pine ridge was added to the production forest, resulting in an area of 42,024 ha.

Within the 81 compartments, only those areas of forests that meet topographical and ecological criteria for suitability for logging may be logged. Production forest within the compartments must be on slopes less than 25°, be at least 100 m away from major water bodies, roads, or cultural sites, and be of the type known to contain timber species. Production forests must also not contain any areas known to be habitat for critically endangered species.

2.1.2 Non-production forest

Non-production forests are all forests that do not fall into the production category; i.e. protection forest and forest with the designation tourism, mining and research. These forests will not be logged but may be traversed to reach production forests.

2.1.3 Zonation into working circles

The Chiquibul Forest Reserve was declared as one area with no legally defined separate blocks or administrative units. In order to best meet overall management objectives the forest is zoned into five working circles. These are the hardwood production working circle, the pine working circle, the protection working circle, the tourism and recreation working circle, the mining working circle and the research working cycle.

Zonation according to Bird (1998) and subsequent minor modifications

Zonation according to Bird (1998) considered a hardwood working circle which is designated for harvesting of hardwood tree species for timber production and covers much of the flat or rolling terrain. The pine working circle is designated for harvesting of pine for timber production and covers the San Pastor Pine ridge. The protection forest was identified mainly on the basis of a slope criterion. All areas with slope ≥25° were placed under protection along with a considerable buffer area. In addition, river gorges were placed under protection. The protected working circle included the area identified by Bird (1994) as well as additional areas. The research working circle was identified to exclude research areas from unintended logging disturbance. This was not done under the Bird (1994) management plan. The research working circle refers specifically to the four areas containing permanent sample plots under the long-term logging experiment at Grano de Oro, New Maria, San Pastor and Las Cuevas. The tourism working circle focuses mainly on the area surrounding the natural arch. This was not included in the Bird (1996) management plan and is thus an improvement in the protection of cultural sites. The original working cycles are shown Table 7 and on the corresponding map in Figure 15.

Proposed zonation adjusted for accessibility of compartments and redefined mining and tourism working cycles

After careful examination of the topography of the CFR it appears that certain parts of the production forest are difficult to access (see Figures 3 and 4). The gorge of the Monkey Tail River appears to be just as steep as the one of the Raspaculo River. The compartments situate beyond the Monkey Tail River are hence just as inaccessible as the compartments east of the Raspaculo River. Similarly the south-eastern corner consisting of the eastern part of compartment 77 and compartment 78 is wedged between the gorge of the Chiquibul River and an unnamed tributary appear difficult to access. The perceived cost of accessing this area renders harvesting of this part uneconomic. Parts were also excluded from compartments 64 and 67 near Arabato Camp, compartment 72 near Moses Head Camp and from compartments 74 and 75 due to a concentration of steep slopes greater than 25° in these areas. For the same reason, parts are excluded from compartment 1, 8 and 14.

Further adjustments are made in order to incorporate the recommendations of the Chiquibul Cave System Management Plan (Meerman & Moore, 2010), changing the designation to tourism within a buffer zone along the Chiquibul River downstream of the Natural Arch according to Figure 5 and Section 3.4.4b. Other adjustments are made based on a rationalisation of the boundaries of the mining areas in the southwestern corner of the reserve. The results of the adjustments are shown in Table 8 and Figure 16.

Overall, these modifications lead to a reduction of the production forest by 15% against an increase in protection forest by 35%, the mining working cycle by 32% and the tourism working cycle by 373%.

Table 7 Zonation of the CFR in hardwood, pine, protection, tourism and recreation, mining working circle and research working cycle according to Bird (1998) with minor modifications

Working Circle	Area (ha)	Percentage of total area	Timber Harvesting	Silviculture	Tourism	Research
Hardwood	42,097	70.4%	Yes	Polycyclic	No	Yes
Pine	1,001	1.7%	Yes	Monocyclic	No	Yes
Protection	15,225	25.5%	No	NA	No	Yes
Tourism	200	0.3%	No	NA	Yes	Yes
Mining	1,081	1.8%	No	NA	No	No
Research	216	0.4%	Research	Research	No	Yes

Table 8 Zonation of the CFR after adjustment for accessibility of compartments and redefined mining and tourism working cycles

Working Circle	Area (ha)	Percentage of total area
Hardwood	35,751	59.8%
Pine	1,001	1.7%
Protection	20,481	34.2%
Tourism	945	1.6%
Mining	1,426	2.4%
Research	216	0.4%

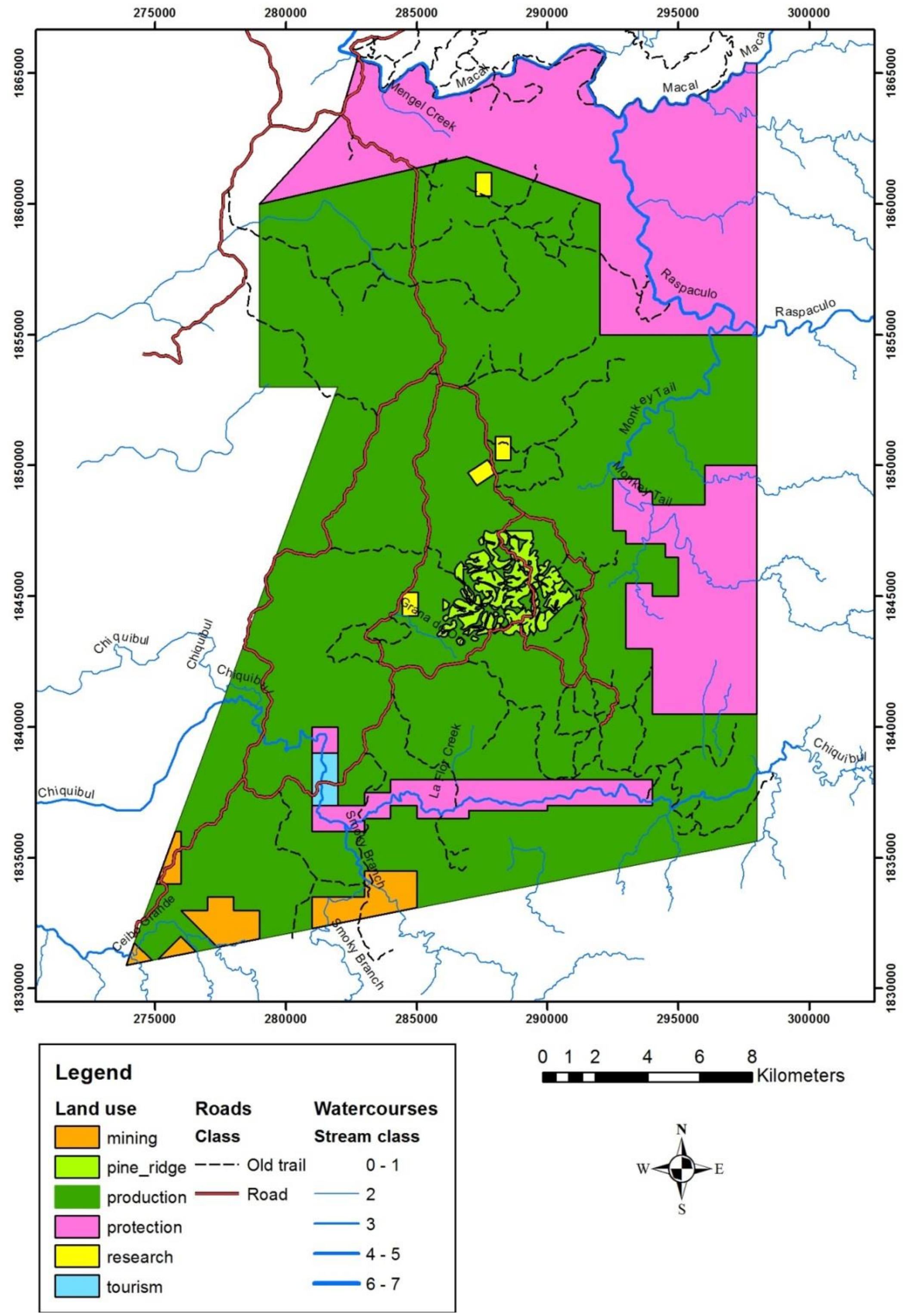


Figure 15 Zonation of the CFR into working circles according to Bird (1998) with minor modifications

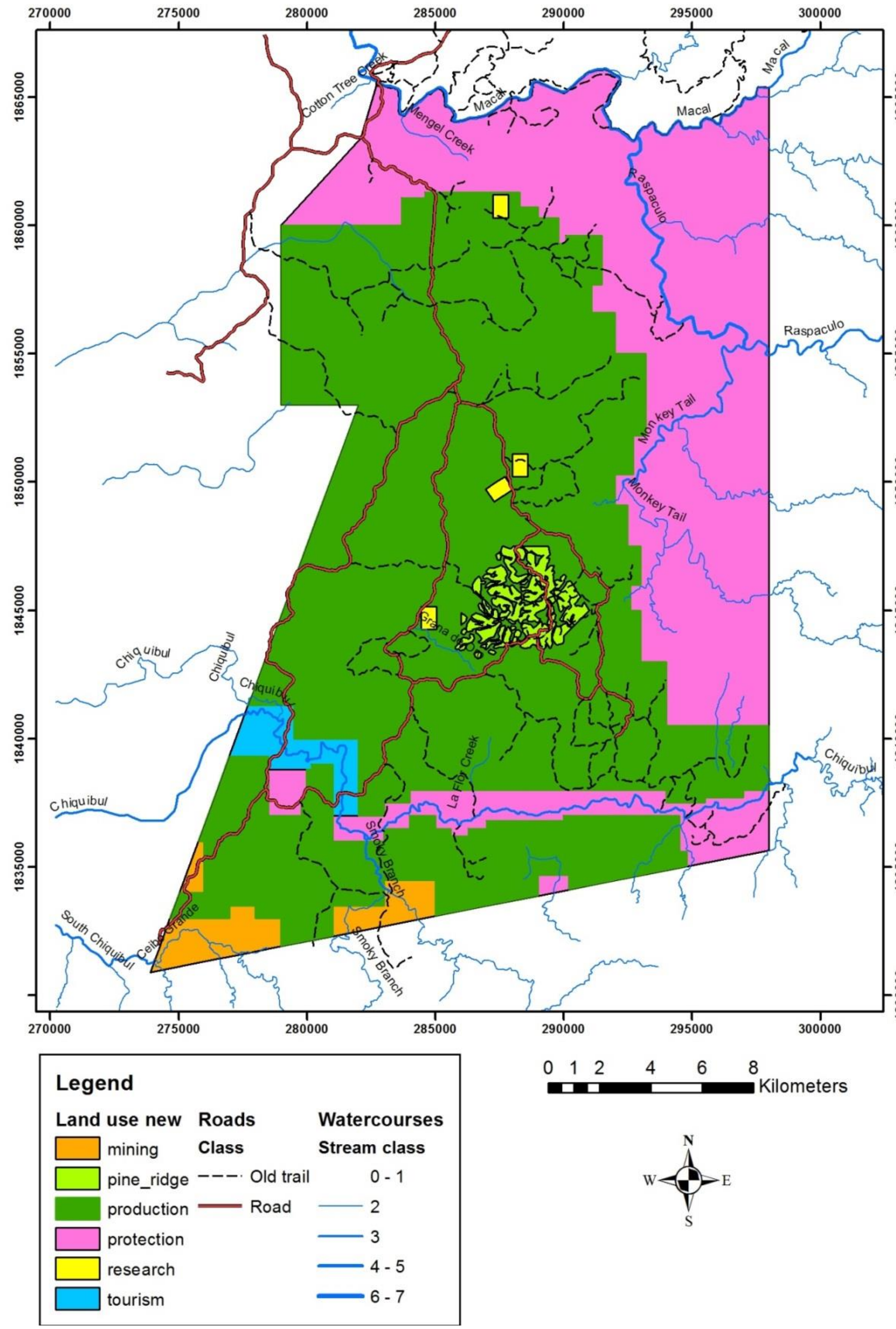


Figure 16 Zonation of the CFR into working circles after adjustment for accessibility of compartments and redefined mining and tourism working cycles

2.2 Division of production forest

2.2.1 Compartments and sub-compartments

The production forest area is broken down into 80 cutting blocks known as compartments. This allows for area control of the annual harvest such that each compartment is harvested only once during the felling cycle.

The boundaries of the 80 compartments were aligned to the UTM grid system in 1994 (Bird, 1998). No adjustment of compartment boundaries was made to take account of the different forest types that exist in the production area or the variation in timber stocking among compartments. Equally, natural boundaries, which make delineating compartments on the ground easier and subsequently working a compartment easier, were also ignored. To a certain extent this forms a constraint to forest management, yield regulation, and continuity of timber supply. On the other hand, it is not very well possible to determine the variation in timber stocking adequately beforehand without performing a forest inventory with a high sampling intensity (e.g. 10%), while the use of rectangular compartments are conceptually easier to relocate on the ground and their areas easier to compute than when natural (watercourses, divides) or man-made (roads) boundaries are used. Therefore the 1994 compartmentalization has been maintained in this management plan.

The San Pastor Pine Ridge and a zone surrounding this pine ridge were excluded by Bird (1994) when developing his management plan for the CFR. The broadleaf forests inside this San Pastor Pine Ridge zone was later added to the CFR natural broadleaf production forest and now constitutes the 81st compartment under this new management plan. This area of broadleaf forest was logged in 2008 and 2010. The pine forests within it form a different working cycle under a different (monocyclic) seed-tree regeneration system. The pine forest was also logged in 2008.

2.2.2 Transition of the felling cycle from 40 to 25 years

Rationale

Adjustment of production forest area

Several compartments have already been logged since the start of sustained yield forest management in the reserve in 1997. A total of 21 out of 81 compartments equivalent to 11,044 ha have been logged inclusive of 2017. The readjustment in the zonation of the CFR, as described in section B.2.1.3 of this management plan, resulted in the foregoing of a part of the already logged compartment 64, implying that 10,633 ha of the redefined production forest area of 35,751 ha has been logged, which means that 70% of the reserve is still available to be logged in a first felling cycle. If two compartments of 500 ha are being logged per year on average, there will be another 25 years before logging needs to return to the first compartment that was logged. This is compartment 58 which was logged in 1997. Based on the 40-yr felling cycle this compartment will be eligible for a second harvest in 2037, implying that the company will run out of forest at the current harvest rate due to the reduced production forest area.

Effect of maximum cutting diameter and expected mahogany growth rate

The FPMP project postulated a felling cycle of 40 years on the assumption of a constant annual diameter growth rate of 5 mm for all tree species and size-classes following Alder (1993), implying that reserve trees of 40 cm dbh and over would reach the minimum cutting diameter 60 cm (as set by FPMP at the time) or more within one felling cycle.

BRL's main species of interest is mahogany. Bird (1998: page 11) indicated that mahogany is one of the fast growing species and seems to be capable of sustained diameter increments of 8 mm/year and even close to 1 cm/year in case of trees ≥ 50 cm dbh. Mahogany canopy trees may achieve diameter increment rates of 1 cm/yr. and even over 1 cm/yr., as confirmed by several scientific publications. Shono & Snook (2006) studied growth of 75 mahogany trees at Hill Bank over a period of four years and concluded that the mean diameter increment exceeded 1 cm/yr., with the fastest-growing individuals even growing at rates greater than 2 cm/yr. Growth rates of mahogany canopy trees close to and over 1 cm/yr. have also been reported by Lamb (1966), Gullison *et al*. (1996), Weaver & Sabido (1997), Grogan (2001), Free *et al*. (2014) and da Cunha *et al*. (2016). Significant variation in growth rate occurs and may reflect differences in regional precipitation patterns, soil properties (Shono & Snook, 2006), and forest type (Weaver & Sabido, 1997). Inter-individual variation in growth rates may be significant as well, reflecting size class and crown or stem damage, but more importantly growth rates are linked to growth autocorrelation, crown illumination and crown vine coverage (liana load) (Grogan & Landis, 2009; da Cunha *et al*., 2016.). Growth autocorrelation; i.e. previous growth explaining variation in annual diameter growth, is strong and persistent while releasing trees from vine loads increases growth rates significantly (Grogan & Landis, 2009).

The current stock of mahogany trees purportedly results from a wave of regeneration following the damage caused by hurricane Hattie in 1961 and subsequent fires (Johnson & Chaffey, 1973; Alder, 1993). According to Johnson & Chaffey (1973) very few merchantable sized trees of mahogany and cedar remained in 1969, after 50 years of exploitation and the destruction wrought by hurricane Hattie in 1961, but mahogany regeneration appeared to be adequate. Presuming the current harvestable mahogany trees (and reserve trees ≥ 30 cm dbh) have established just after hurricane Hattie, harvestable trees of 60 cm would have grown at a rate of 60 cm/55 years or 1.1 cm/yr. Equally, a reserve tree of 40 cm, established in 1962, would have had an average growth rate of 0.7 cm/yr. Although the reserve trees may not have been the fastest growing trees, they will achieve full crown illumination after the present harvest, while release from vines will further stimulate diameter growth. It is therefore not unlikely that these trees may reach and sustain a diameter growth rate of 1 cm/yr. after the first harvest.

In 2015, the Forest Department reduced the maximum cutting diameter from 100 cm dbh to 90 cm dbh. If we assume a growth rate of 1 cm/yr. for the reserve trees, the application of a 40-yr. felling cycle would mean that reserve trees ≥ 50 cm dbh will surpass the 90-cm limit before the scheduled year of the second harvest. Hence, with a 40-yr felling cycle, the harvest of these trees will have to be forgone; the same applies to reserve and seed trees above the minimum cutting limit of 55 cm that had to be retained based on the Forest Department's yield model.

BRL is concerned that the necessary adjustment to the production forest area will imply that the current annual cutting area cannot be maintained and as such will have to be reduced drastically to maintain the area control method. Added to this BRL is concerned that the reduction of the maximum cutting limit in combination with an expected diameter growth rate of 1 cm/yr. of mahogany canopy trees that are released from their vine load will result in a substantial proportion of reserve and seed trees surpassing the maximum diameter limit with a felling cycle of 40 years. BRL therefore proposes to apply a 25-yr felling cycle in this management plan.

In terms of the principle of sustained yield management shortening the felling cycle does not conflict with the yield regulation system that is prescribed by the Forest Department because that model will generate a sustained yield with both a 25-yr and 40-yr cycle. The only real problem of changing the felling cycle before the cycle has been completed, is that the two cycles will have to be blended in such a way that the felling cycle of the individual annual cutting areas is maintained while ensuring that harvestable cutting areas are available in any and every year of the cycle. The transition for a 40-yr to 25-yr cycle will only be completed after all compartments that have been cut so far according to a 40-yr cycle have been cut for a second time. The last time the sustainable yield of an annual cutting compartment was determined using a 40-yr cycle was in 2016, implying that the transition will only be complete by 2056.

Effect of transition on division of annual cutting areas

The 40-yr. felling cycle was applied from 1997 until 2017 with the exception of 2015 when the 25-yr. cycle was applied. From 2017 onwards the 25-yr. cycle is being applied. The total production forest area is reduced from 42,024 ha to 35,751 ha in this plan, discarding the original compartments 22, 23, 30 and 31 and parts of compartments 1, 8, 14, 21, 29, 37, 42, 47, 64, 67, 72, 74, 77, 78 and 79. Compartments 24, 62 and 63 were slightly increased in size; by a total area of 193 ha.

Since 1997, 10,633 ha (30%) of the adjusted production forest area[4] have been logged, leaving 25,119 ha of unlogged production forest. Table 9 shows that 7,668 ha have been logged following a 40-yr. felling cycle and 2,965 ha following a 25-yr. felling cycle.

Table 9 Compartments logged so far applying 40-yr. and 25-yr. felling cycles, and compartments to be logged applying 25-yr. felling cycle

Years	Compartments	Total area (ha)	Felling cycle
1997-2014, 2016	19, 20, 34, 35, 38, 45, 52, 53, 58, 59, 60, 61, 62, 64, 81	7,668	40 years
2015, 2017	3, 4, 9, 10, 11, 15	2,965	25 years
to be logged	1, 2, 5, 6, 7, 8, 12, 13, 14, 16, 17, 18, 21, 24, 25, 26, 27, 28, 29, 32, 33, 36, 37, 39, 40, 41, 42, 43, 44, 46, 47, 48, 49, 50, 51, 54, 55, 56, 57, 63, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 79, 80	25,119	25 years

Once the transition process will have been completed in 2056, the desired annual cutting area should amount to 35,751 ha/25 yr. equalling 1,430 ha. There are 76 compartments remaining with an average size of 470 ha, implying that the annual cutting area will eventually be equivalent to 3 compartments.

The next 20 years, 2018-2037, new, unlogged compartments will be harvested. In 2037, compartment 58 will be harvested for a second time and in 2038 compartments 38 and 64 also, but the sustained yield will this time be based on a 25-yr. felling cycle. In 2040, compartments 3, 9, 10 and 15 will be harvested for a second time and in 2042 compartments 4 and 11; these compartments were harvested applying a 25-yr. cycle in 2015 and 2017 respectively. In 2039 and 2041 again new, unlogged compartments will be harvested. From 2043 to 2048 compartments that will have been harvested for the first time during 2017-2023 will be

[4] As a matter of fact 11,044 ha have been logged, but a large proportion of compartment 64 has been taken out of the hardwood production working cycle.

harvested for a second time. From 2049-2051 and in 2053, 2054 and 2056 compartments that had been harvested in a 40-yr cycle will be harvested for a second time.

Table 10 Compartments that have been logged during 1997-2017 and their combined area with the year of their projected successive harvest

Compartments	Area	Year
58	500	2037
38, 64	851	2038
3, 9, 10, 15	2,000	2040
4, 11	965	2042
59	500	2047
60	500	2048
34, 35	951	2049
81	829	2050
52, 53	1,000	2051
45	446	2053
61, 62	1,090	2054
19, 20	1,000	2056

In principle, the 55 unlogged compartments should be divided over the years until the first compartment is cut for the second time plus the years in between second cut years as indicated above. Furthermore it is necessary to cut additional unlogged compartments in years where compartments are subjected to a second cut in order to arrive at the desired annual cutting area of three compartments. Because of the extended time span that needs to be filled in order to guarantee a steady yearly supply of timber, it is not possible to start harvesting 3 compartments per year until 2030. A preliminary division of the annual cutting areas is shown in Figure 17. Chronological selection of the annual cutting compartments is principally based on two factors; 1) the estimated harvestable mahogany volume in each compartment as indicated by the general inventory 2011-14 (see Section 3 'Inventory of Forest Resources') and 2) vicinity to compartments that have been logged before so as to cluster added compartments when compartments will be harvested for a second time. This chronological sequence in annual cutting compartments is mainly a guide. BRL will conduct reconnaissance surveys of potential compartments to verify the results of the general inventory. It must be noted that often just one or two sample plots were located in a compartment. This number is too small to apply any statistical analysis at the compartment level and no confidence levels can be determined. This goes both ways. One plot in a compartment rich in mahogany is no guarantee the entire compartment will be rich in mahogany and vice versa. Also, there is a considerable amount of compartments without any sample plot, in which case there is no indication whether a compartment may be rich in mahogany or not. Extrapolation based on stratification is limited as will be described in Section 3 'Inventory of Forest Resources'.

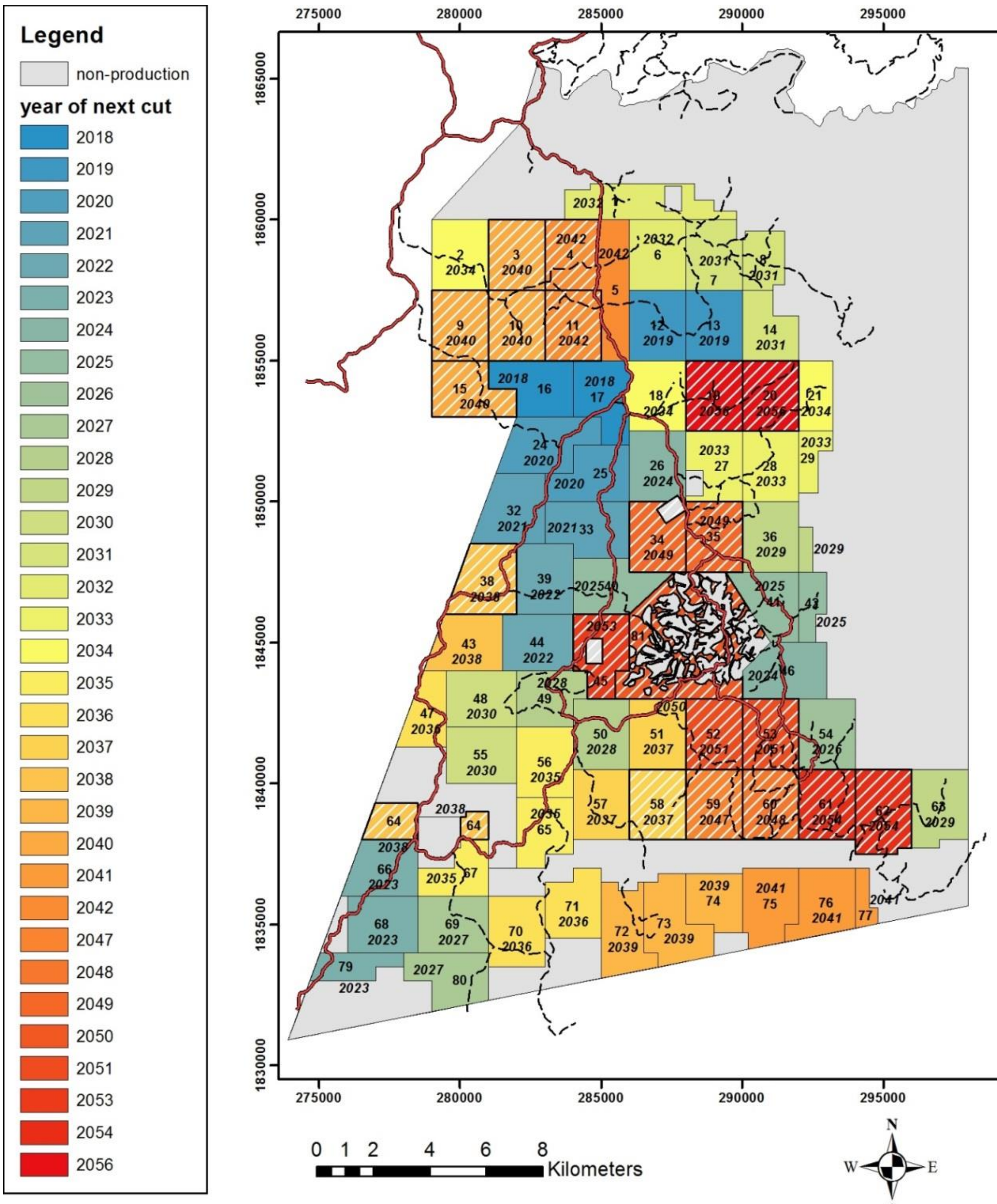


Figure 17 Distribution of annual cutting compartments and year of the next harvest; white hatched compartments have been logged during 1997-2017

2.2.3 Stands and forest type stratification

Most of the production forest in the CFR falls in Wright's (1959) vegetation type Semi-evergreen forest', or Penn's (2004) 'Deciduous forest' and 'Semi-evergreen forest'. Meerman (2015) integrated previous vegetation assessments. For the CFR, one of his main distinctions is the division between forest on karstic (calcareous) soils and forest on acidic (siliceous) soils. In addition, there is a distinction between forest on flat to rolling hills and forest on steep hills; soils in the latter landscape being shallower. Undoubtedly a link exists between these four vegetation classes and merchantable timber volumes. Analysis of Variance performed on the general inventory plot data, however, did not show any significant differences in harvestable volume between forest on acidic soils and forest on karstic soils (see Section 3 'Inventory of Forest Resources'). As shown on the vegetation map according to Meerman (2015) for the CFR, the portion of forest on steep hills (either karstic or acidic) inside the production forest is quite limited and very few sample plots were established here.

It is not unlikely that the disturbance history in terms of damage inflicted by wind and fires in combination with the logging history overrides the effect of soil type and topography on the vegetation and hence timber stocks. In this sense, it is not possible to stratify the production forest based on stand type, except for the obvious difference between pine and hardwood stands.

Compartments in principle measure 2000 x 2500 m (500 ha) and are subdivided in 4 sub-compartments or quadrats measuring 1000 x 1250 m (125 ha) for practical purposes, particularly in implementing the stock survey.

The effective area of a compartment that will be surveyed and can be logged varies with topography, waterways and archaeological sites, which are excluded from the formal logging area within a compartment. The effect of topography is particularly substantial. Such exclusions can only be identified while the stock survey is being conducted on the ground. The area control method is based on the gross area of each set of annual cutting compartments and not the effective area. This implies that the actually logged area may differ considerably even if a consistent gross area (usually consisting of two compartments of 500 ha each) is being worked.

3 INVENTORY OF FOREST RESOURCES

3.1 1969 Johnson & Chaffey inventory

During 1969-1971 an inventory was performed in western and southern part of the Chiquibul Forest, in an area that is now predominantly within the Chiquibul National Park. It was based on a sampling design proposed by Dawkins (1958) that used fixed size blocks and laid two transects within each (Johnson & Chaffey, 1973) as a two-stage sampling design. The forest was divided into two parts to be sampled separately: the Main Felling Series and the Mountain Felling Series. These felling series were first introduced in the 1957 Chiquibul Forest Working Plan. The Main Felling Series was available for immediate exploitation while the Mountain Felling Series was not to be available for immediate exploitation except as a supplement to workings in the Main Felling Series. The latter Mountain Felling was later excised from the CFR and now forms part of the CNP, while also a considerable portion of the Main Felling Series to the west of the present day CFR now forms part of the CNP (see Figure 18).

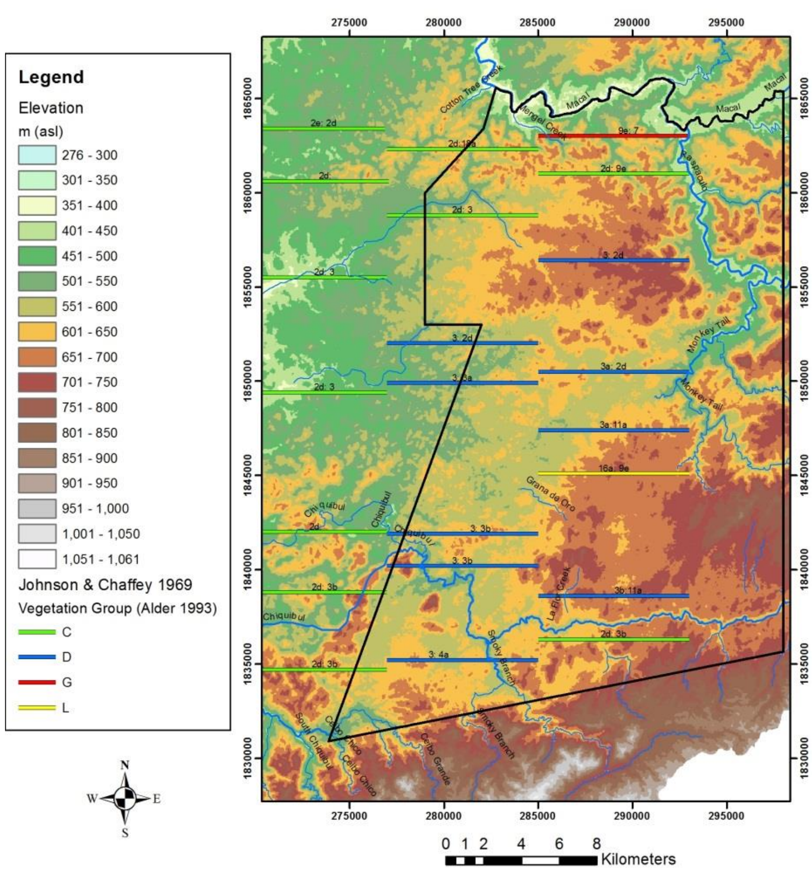


Figure 18 **Location of transects in the Main Felling Series in Johnson & Chaffey's 1969 inventory; provisional vegetation groups according to Alder (1993)**

Johnson & Chaffey's inventory was not stratified according to any natural features, such as vegetation, topography, soils, etc. Alder (1992a, 1993) re-analysed Johnson & Chaffey's (1973) inventory using post-stratification by vegetation groups. Wright's vegetation maps were adopted by Alder (1992a, 1993) as the basis of stratification. To this effect he defined pooled vegetation types, called Provisional Vegetation Groups (PVGs), such that each PVG that comprised broadleaf forest included two or more transects. This was achieved by determining with the GIS the proportion of each transect that fell into different vegetation types, then sorting them on the dominant type, and grouping them to arrive at suitable PVGs.

In Alder's re-analysis (1993) timber species are categorised in three major groups, as defined in Bird (1993b; in: Alder, 1993). The groups are termed Prime, Elite and Select. The Prime group includes cedar and mahogany; the Elite group includes species with comparable marketability but at a lower price and acceptance. Select species are somewhat less valuable with a correspondingly weaker marketability.

A summary of Alder's (1992a) re-analysis is shown in Tables 11 and 12. The Tables show that the reserve had been nearly completely depleted of its prime species mahogany and cedar in 1969 with on average less than 1 tree ≥ 50 cm dbh for every 7 hectares or a mere 150 trees for a current day annual cutting compartment. A reliable minimum volume estimate was found of only 28 m^3 mahogany and 113 m^3 cedar per 1,000 ha (current annual cutting compartment). It is clear that this was sufficient reason for imposing the moratorium on logging in the reserve until 1996. The only species of interest to BRL that show adequate stocking are nargusta and sapodilla. Nevertheless, regeneration of both mahogany and cedar although not abundant appeared adequate. In 1969, the reserve was still in the early stages of recovery from Hurricane Hattie.

Table 11 Estimated volume (m^3/km^2) by species over 10 cm, 30 cm and 50 cm diameter, Coefficient of Variation (%) and Reliable Minimum Estimate for selected species and species groups; according to Johnson & Chaffey's inventory of the Chiquibul Main Felling Series of 1969; re-analysed by Alder (1992a)

Species name	Volume ≥10 (m^3/km^2)	CV of mean ≥10 (%)	RME ≥10 (p=.95) (m^3/km^2)	Volume ≥30 (m^3/km^2)	CV of mean ≥30 (%)	RME ≥30 (p=.95) (m^3/km^2)	Volume ≥50 (m^3/km^2)	CV of mean ≥50 (%)	RME ≥50 (p=.95) (m^3/km^2)
Cedar	55.8	19.7	31.6	43.8	24.8	19.9	33.6	30.2	11.3
Mahogany	46.5	22.5	23.5	33.4	30.0	11.4	22.8	39.8	2.8
Prime species	**102.3**	**17.6**	**62.8**	**77.2**	**23.6**	**37.2**	**56.3**	**30.0**	**19.2**
Barbajolote	84.9	12.6	61.5	83.4	12.6	60.3	76.1	13.9	52.8
Rosewood	5.1	50.4		4.0	38.0	0.7	0.9	100.0	
Elite species	**549.0**			**387.6**			**146.4**		
Nargusta	608.0	9.4	482.8	589.1	9.4	466.8	529.5	9.8	415.2
Sapodilla	787.7	7.4	660.1	704.8	8.2	577.6	458.2	10.2	355.6
Santa Maria	38.0	17.1	23.7	26.1	21.0	14.0	14.2	26.9	5.8
Select species	**3,631.1**			**3,117.0**			**1,909.3**		
Unclassified spp	3,436.4			2,006.7			796.1		
Total (all spp)	**7,720.0**	**3.3**	**7,159.7**	**5,589.7**	**3.3**	**5,182.5**	**2,909.3**	**4.0**	**2,655.7**

Table 12 Stand table by species (group) of Johnson & Chaffey's inventory of the Chiquibul Main Felling Series of 1969; re-analysed by Alder (1992a) - Highlighted species are BRL's species of interest

	Trees per km² by cm diameter classes										Cumulative N/km²		
Species name	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**	**100+**	**≥10**	**≥30**	**≥50**
Cedar	87	21	11	4	3	2	2	1		2	133	25	10
Mahogany	72	13	7	4	2	1	1	1	0	0	101	16	5
Prime species	**160**	**35**	**18**	**8**	**5**	**4**	**3**	**1**	**0**	**2**	**236**	**41**	**15**
Barbajolote		8	5	4	5	4	4	2	2	2	36	28	19
Bastard Rosewood		22	22	17	8	1	1	1			72	50	11
Black Cabbage Bark		33	18	11	4	1	1	0			68	35	6
Cortez		16	7	4	3	1	1				32	16	5
Granadilo		44	18	5	2	1	0				70	26	3
Palo Mulatto (Hobillo)		96	34	7	2	0					139	43	2
Mylady		79	40	8	1	1					129	50	2
Salmwood		76	16	3	1	0					96	20	1
Black Poisonwood		20	12	4	1						37	17	1
Mayflower		12	3	4	1			0			20	8	1
Billy Webb		20	14	2	0						36	16	0
Rosewood		4	3	1			0				8	4	0
Elite species		**430**	**192**	**70**	**28**	**9**	**7**	**3**	**2**	**2**	**743**	**313**	**51**
Sapodilla	3	246	158	104	59	41	18	11	7	4	651	402	140
Nargusta		51	33	25	20	22	21	18	11	16	217	166	108
White Breadnut		296	275	118	54	19	8	3	0	0	773	477	84
Fiddlewood		40	35	29	26	19	12	7	3	2	173	133	69
Hogplum		115	42	29	20	7	3	1			217	102	31
Ironwood	1	79	57	29	12	8	3	1	0		190	110	24
Kaway		18	10	9	5	4	2	1	1	1	51	33	14
Male Bullhoof		103	56	18	7	1	0				185	82	8
Sillion		89	57	15	5	2	0	0			168	79	7
Wild Grape		23	16	8	4	1	1	1	0		54	31	7
Bastard Mahogany		34	7	2	2	1	1	1	1		49	15	6
John Crow Wood (Hesmo)		8	5	3	3	2	1	0		0	22	14	6
Santa Maria		31	8	3	3	1	1				47	16	5
Cotton		7	1	2		1	1	1		2	15	8	5
White Gombolimbo	1	99	46	11	4						161	61	4
Bitterwood		13	4	3	2	1	1			0	24	11	4
Glassywood		86	43	9	2	1					141	55	3
Red Gombolimbo		70	26	10	2	1					109	39	3
Red Wood		56	22	8	2	1					89	33	3

Species name	Trees per km² by cm diameter classes 10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	Cumulative N/km² ≥10	≥30	≥50
Timbersweet (Laurel)		42	23	4	1	1	1				72	30	3
Fig		25	7	3	1	1	0	0		1	38	13	3
Cramantree (Cedrillo)		14	7	1	1	1	0				24	10	2
San Juan Macho				1	1	0	0	1			3	3	2
Negrito		7	7	3	1	0					18	11	1
Carbon		3			0	0					3	0	0
Yemeri				1	0						1	1	0
Banak										0	0	0	0
Monkey Apple				0							0	0	0
Select species	**5**	**1,555**	**945**	**448**	**237**	**136**	**74**	**46**	**23**	**26**	**3,495**	**1,935**	**542**
Unclassified species	1,070	4,252	1,312	292	133	67	39	20	11	12	7,208	1,886	282
Total (all species)	**1,235**	**6,272**	**2,467**	**818**	**403**	**216**	**123**	**70**	**36**	**42**	**11,682**	**4,175**	**890**

3.2 Timber Resources – management level inventory

A second general forest inventory was started out in the Chiquibul Forest Reserve on behalf of BRL during April and May 2011 in order to guide the development of a new (this) management plan. Due to unforeseen delays caused by a 'cease and desist' order from the Forest Department for works in the Chiquibul, the inventory was not completed until December 2014. In 2011 the southern portion of the reserve was sampled and in 2014 the northern portion. Plots in the northern part were distributed evenly while plots in the southern part appear to be concentrated along roads.

The inventory was carried out more specifically to assess the growing stock, commercial stock, and regeneration of the Chiquibul forest. In addition, the spatial distribution of timber stocks was to be assessed.

3.2.1 Type of inventory and sampling design

The inventory was originally set up according to a stratified random sampling design. The production forest working cycle was stratified according to topographical, drainage and phenology criteria. Topographical classifications used included: Cockpit (karstic or egg box terrain); Hill (high elevation areas); Alluvial (river floodzone); Flat (level terrain), and Rolling (undulating). Drainage categories recognized included: well-drained (on sloping land); drainage-induced (seasonally waterlogged); waterlogged (permanently waterlogged), and gallery (deep incised valleys draining pine). Leafing phenology was also used to stratify the forest and included: evergreen (no leaf shedding during the dry season), semi-evergreen (most trees keep their leaves during the dry season); deciduous (leaf shedding during the dry season), and semi-deciduous (most trees shed their leaves during the dry season).

The classification resulted in a large number of classes; most with a small aggregate area. This meant that the classes were in fact sampled at a rate too low to carry out any meaningful statistical analysis using a stratified random sampling design or extrapolate results to estimate numbers and volumes per stratum.

Plot characteristics

Plots were rectangular, measuring 20 m x 250 m (0.5 ha), aligned east to west. Each plot was sub-divided into 10 quadrats each 10 x 50 m in size and numbered 1 to 10. A nested design was used where large trees (≥ 25 cm) were enumerated and measured over the entire plot of 0.5 ha, while small trees measuring 5 to 9.9 cm and medium size trees measuring 10 to 24.9 were measured in sub-plots of 0.02 ha and 0.1 ha, respectively (see Figure 19). Similar plot sizes and design are used in other forest inventories across Belize.

Unfortunately, the sampling design was reportedly not implemented consistently with trees measuring 10 to 24.9 being measured over the entire 0.5 ha plot instead of in the 0.1 ha sub-plot in some cases. Preliminary analysis of a number of diameter class frequency distributions in the northern (2014) and southern (2011) samples suggests that this particularly applies to mahogany in the northern section which was sampled in 2014. In our analysis we therefore consider that mahogany trees between 10 and 25 cm were sampled over the entire 0.5 ha plot in the northern (2014) sample. It goes without saying that this inopportune implementation of the sampling design considerably reduces the confidence in the estimates for this size class 10-25 cm dbh and hence prevents any proper assessment of the regeneration potential of mahogany in particular.

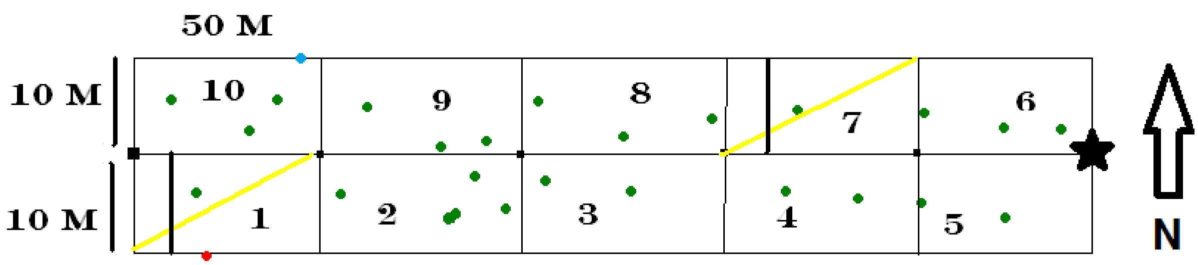


Figure 19 Design of a 0.5 ha sample plot used in the general inventory; quadrats 1 and 7 constitute the 0.1 ha sub-plots for measuring trees ≥10 cm <25

Plots were placed at random within each stratum by using GIS with a minimum allowable distance between plots of 300 m to allow for plot length and a maximum allowable distance between plots of 1000 m.

Sampling Intensity

Overall, 173 plots were established. Four plots appear to have fallen in the protection forest working cycle and were excluded from this analysis. 167 plots fell within the modified production forest working cycle. Two plots fell within the part of compartment 79, whose allocation was changed to mining. It was decided to still include these two plots to maximize the available data for this type of forest. The four discarded plots fell in the gorges of the Raspaculo and Chiquibul Rivers and the Smokey Branch Creek and were considered situate in a forest type that does not occur in the production working cycle proper. After including all of compartment 79 the area being sampled was 36,096 ha. The sampling intensity hence is 0.23%.

Post-stratification

The sample design is still treated as a stratified random sample *post hoc*, but with sufficiently large hence more meaningful strata. Plots were stratified *post hoc (*or "*a posteriori"*) according to their logging history at the time of the inventory; i.e., logged before 2011 or unlogged (Table

13). In addition, plots were stratified according to Meerman's (2015) vegetation classification (Table 14). Meerman's (2015) classes were grouped into only two classes to obtain a sufficiently large number of plots per stratum. Plots were classified as being situate on either karstic (calcareous) or acidic (siliceous) soils.

Table 13 Post-stratification according to logging history; area logged and unlogged and number of plots in each stratum

Logging history	Area (ha)	Percentage of total area	No. of plots	Percentage of plot total	Sampling intensity
Logged 1997-2011	5,578	15%	30	18%	0.27%
Not logged	30,518	85%	139	82%	0.23%
Total	36,096	100%	169	100%	0.23%

Table 14 Post-stratification according to landscape type according to Meerman (2015); karstic (calcareous) and acidic (siliceous) landscape and number of plots in each stratum.

Landscape	Area (ha)	Percentage of total area	No. of plots	Percentage of plot total	Sampling intensity
Karstic	30,541	85%	137	81%	0.22%
Acidic	5,555	15%	32	19%	0.29%
Total	36,096	100%	169	100%	0.23%

Strata are weighted by stratum area to derive pooled means. Variance of the mean for a parameter is calculated using pooled within-stratum variances only if the within-stratum variances do not differ significantly. If variances appear unequal, the Behrens and Fisher approach is used to estimate the standard error (De Vries, 1986).

Statistical testing of differences between strata

Analysis of Variance was carried out to assess whether the differences between the landscapes or logging history in terms of the mean stem number ≥30 cm and ≥50 cm dbh and in terms of mean volume ≥30 cm and ≥50 cm dbh were significant.

The statistical significance of a result (*p*-level) is an estimated measure of the degree to which it is "true" (in the sense of "representative of the population"). The higher the *p*-level, the less we can believe that the observed relation between variables in the sample is a reliable indicator of the relation between the respective variables in the population. Specifically, the *p*-level represents the probability of error that is involved in accepting our observed result as valid, that is, as "representative of the population". For example, a *p*-level of .05 indicates that there is a 5% probability that the difference between the variables found in our sample is a "fluke." In other words, assuming that in the population there was no difference between those variables whatsoever, and we were repeating experiments like ours one after another, we could expect that approximately in every 20 replications of the experiment there would be one in which the difference between the variables in question would be equal or stronger than in ours. In many areas of research, the *p*-level of .05 is customarily treated as a "border-line acceptable" error level.

How to determine that a result is "really" significant. There is no way to avoid arbitrariness in the final decision as to what level of significance will be treated as really "significant." That is, the selection of some level of significance, up to which the results will be rejected as invalid, is arbitrary. In practice, the final decision usually depends on whether the outcome was predicted *a priori* or only found *post hoc* in the course of many analyses and comparisons performed on the data set, on the total amount of consistent supportive evidence in the entire data set, and on "traditions" existing in the particular area of research. Typically, in many sciences, results that yield $p \leq .05$ are considered borderline statistically significant but remember that this level of significance still involves a pretty high probability of error (5%). Results that are significant at the $p \leq .01$ level are commonly considered statistically significant, and $p \leq .005$ or $p \leq .001$ levels are often called "highly" significant. Nevertheless, those classifications represent nothing else but arbitrary conventions that are only informally based on general research experience.

Tree volume equations

No attempt was made to incorporate stem quality and bole length assessments on sample plot trees since this would introduce two additional stochastic parameters with their own specific variance and confidence limits; i.e., confidence limits would in principle have to be applied to estimates of height and quality classes for each diameter (class), increasing the total variance of the estimated mean volumes many times. Instead, actual sawmill input and output figures from the BRL sawmill are used to convert diameter measurements on standing trees into extracted volumes and produced processed volumes. Both sawmill input (in ft^3) and output (in BF) volume data are available for 2016. Since we considered not using bole length estimates made in the sample plots a one-entry volume equation is preferred.

Johnson & Chaffey (1973) developed tree volume equations based on sample trees along transects that were measured by Relascope to record diameter at breast height or above buttress, at the mid-point of the bole, and at the point of crown break. Height of buttresses and the crown-break point were recorded. Alder (1992a) calculated volumes using Johnson & Chaffey's (1973) original date applying Newton's formula. He subsequently fitted species-specific lines regression equations of the form:

$$\log(V) = a + a_x + b.\log(D) + b_x.\log(D)$$

Wherein, a and b are mean coefficient values, and a_x, b_x are species effects. Table 15 below shows the fitted coefficients for each species. Most of the sampling was done in Chiquibul forest reserve during the 1969/1971 inventories.

Table 15 Volume equation coefficients for $\log(V) = a + a_x + b.\log(D) + b_x.\log(D)$ volume equation (Alder, 1992a)

Species	Species group	a	b
Mahogany	Prime	-7.608	2.092
Cedar	Prime	-8.33	2.198
Barba Jolote	Elite	-8.78	2.313
Mylady	Elite	-6.038	1.755
Cotton (Ceiba)	Select	-6.725	1.909
Hogplum	Select	-12.636	3.315
Kaway	Select	-2.731	0.909
Redwood	Select	-6.756	1.845
Cedrillo	Select	-7.666	2.142
Fiddlewood	Select	-7.796	2.129
Sillion	Select	-8.72	2.426
Santa Maria	Select	-8.307	2.295
White Breadnut	Select	-9.45	2.511
Nargusta	Select	-7.908	2.158
Bitterwood	Select	-8.463	2.31
Male Bullhoof	Select	-6.69	1.839
Sapodilla	Select	-8.231	2.233
Ironwood	Select	-8.37	2.308
All species		-8.095	2.19

Species Grouping

Species are grouped according to the national standard for timber species grouping, namely: prime, elite and select. This classification system is based on six properties related to ecology and industry: timber quality, workability, durability, growth, log form and large tree abundance.

3.2.2 Inventory results for the production forest working cycle

In this section, inventory results are presented for the entire production forest area on the basis of simple random sampling without stratification. It comprises a stand table of trees per km^2, a table of trees per km^2 in several size classes (10-25 cm, 25-60 cm, 60-90 cm, ≥ 90 cm; ≥30 cm and ≥50 cm), and a table of mean volumes above given size limits. For the table of size classes and table of mean volumes, sampling statistics are presented, including the standard error (%) of the mean, and the reliable minimum estimates (RME), or lower confidence limits at the 95% probability level of a one-sided probability distribution (e.g. De Vries, 1986). In some cases the RME is blank, indicating that if calculated it would give a negative value. This reflects the unsatisfactory nature of confidence limits based on normal distribution assumptions for small samples. For planning purposes preference may therefore be given to using mean stem numbers and volumes. These represent the more likely and least biased estimate of stand density and volume. For certain species that are well distributed across the sample plots, the RME is a useful indicator and can then be used to define lower limits for the resource (Alder, 1992a).

Table 16 Stand table by classified species and species group; highlighted species are BRL's species of interest

Species name	Trees per km² by cm diameter classes										Cumulative
	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	≥10
Mahogany	172	209	175	128	64	30	9	4	2	0	793
Cedar	41	77	24	17	15	13	2	2	2	1	195
Prime species	**213**	**286**	**199**	**144**	**79**	**43**	**12**	**6**	**5**	**1**	**988**
Barbajolote	77	58	39	32	13	9	4	4	5	1	241
Black Cabbage Bark	479	315	114	50	26	9	2				995
Bastard Rosewood	107	80	20	12	0	2	1	2	0	0	225
Mylady	888	279	65	22	2		2				1,259
Salmwood	562	544	86	24	2		1				1,220
Hobillo	195	109	17	4	2						327
Granadilo	18	2	8	8	1						38
Billy Webb	18	32	8	6	1						65
Rosewood	36	39	13	1							89
Cortez	18	2	5	1							26
Black Poisonwood		12	2	2							17
Elite species	**2,183**	**1,323**	**282**	**101**	**24**	**11**	**7**	**4**	**5**	**1**	**3,940**
Nargusta	994	582	267	163	65	38	15	15	28	9	2,179
Sillion	1,249	744	221	121	51	50	26	2	6	8	2,478
Sapodilla	479	321	123	84	38	50	26	2	6	8	1,137
White Breadnut	527	338	93	39	24	30	2	1	1		1,056
Fiddlewood	491	357	157	45	17	9	11	5	2		1,095
Hogplum	716	782	308	134	50	15	6	1	1		2,013
Ironwood	65	64	28	20	7	7	2				194
Santa Maria	491	230	58	25	8	4	1				817
Fig			1	4	1	5		2	1	1	15
Kaway	24	20	9	6	5	1	2	2			70
Ceiba	6	1	1	4	1	1		2		2	19
Yemeri	30	50	30	15	5	1	2				133
Bitterwood	18	17	13	6	5	1	1				60
Wild Grape	675	414	72	12	2	2	0	0	0	0	1,178
Hesmo	47	31	11	5	5				1		99
Carbon	30	58	7	5	1				1		102
Red Wood		15	4	1		1					21
Bastard Mahogany	18	20	2	2			1				44
Red Gombolimbo	213	160	43	15	2						433
White Gombolimbo	1,077	580	58	12	1						1,728
Male Bullhoof	373	117	26	12	1						529
Monkey Apple	18	4	2	2	1						27
Glassywood	95	8	8	1							112
Cedrillo	71	6	2	2							82
Timbersweet (Laurel)	213	92	2								308
Negrito	71	51									122
Select species	**7,538**	**4,763**	**1,434**	**654**	**253**	**164**	**71**	**30**	**41**	**20**	**14,970**
Unclassified species	35,053	12,996	2,620	948	312	127	45	34	17	11	52,163
Total (all species)	**44,988**	**19,369**	**4,535**	**1,847**	**669**	**344**	**135**	**73**	**67**	**33**	**72,062**
BRL species (excl rosewood)	2,254	1,477	686	449	204	143	58	27	44	20	5,362

Table 17 Trees per km² in size classes: 10-25 cm, 25-60 cm, 60-90 cm, ≥ 90 cm; ≥30 cm and ≥50 cm, with standard error (%) of the mean, and reliable minimum estimates (RME); highlighted species are BRL's species of interest

Species name	10-25			25-60			60-90			≥90			≥30			≥50		
	mean per km²	SE[5] of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²
Mahogany	301	21%	199	447	9%	383	43	22%	27	2	70%	0	412	9%	350	109	15%	82
Cedar	107	27%	58	67	22%	42	18	31%	9	4	57%	0	77	19%	53	37	23%	23
Prime species	**407**	**22%**	**257**	**515**	**8%**	**448**	**60**	**18%**	**42**	**6**	**44%**	**2**	**489**	**8%**	**425**	**146**	**12%**	**117**
Barba Jolote	118	35%	51	101	27%	56	17	26%	10	6	44%	2	107	21%	69	36	21%	23
Black Cabbage Bark	722	16%	532	262	12%	210	12	31%	6				201	14%	155	38	22%	24
Bastard Rosewood	172	23%	106	47	18%	33	6	44%	2				38	19%	26	6	44%	2
Mylady	1,112	11%	912	144	12%	116	2	70%					92	14%	70	5	61%	
Salmwood	994	13%	776	225	16%	166							114	19%	79	4	57%	0
Hobillo	290	19%	201	37	19%	25							22	23%	14	2	70%	
Granadilo	18	57%	1	20	38%	8							18	41%	6	1	100%	
Billy Webb	41	62%		24	56%	2							15	72%		1	100%	
Rosewood	65	53%	8	24	54%	2							14	61%				
Cortez	18	74%		8	47%	2							6	53%	1			
Black Poisonwood	6	100%		11	69%								5	50%	1			
Elite species	**3,237**	**8%**	**2,833**	**676**	**8%**	**588**	**21**	**22%**	**13**	**6**	**44%**	**2**	**433**	**9%**	**371**	**51**	**17%**	**36**
Nargusta	1,408	14%	1,090	664	10%	553	69	15%	51	38	23%	23	602	9%	512	172	13%	134
Sillion	1,870	11%	1,541	516	8%	447	78	16%	58	14	33%	7	485	8%	420	143	12%	114
Sapodilla	740	13%	584	305	10%	254	78	16%	58	14	33%	7	337	10%	282	130	13%	101
White Breadnut	793	17%	568	228	16%	166	33	33%	15	1	100%		191	18%	135	58	26%	33
Fiddlewood	787	17%	563	280	14%	217	25	23%	16	2	70%		246	13%	193	44	19%	30
Hogplum	1,331	12%	1,078	658	10%	548	22	27%	12	1	100%		515	11%	424	73	16%	54
Ironwood	112	36%	45	72	28%	39	9	39%	3				65	27%	36	17	31%	8
Santa Maria	675	15%	511	137	14%	105	5	50%	1				96	15%	72	13	32%	6
Fig				6	66%		7	52%	1	2	70%		15	36%	6	11	39%	4
Kaway	41	42%	12	22	27%	12	6	44%	2				26	25%	15	11	39%	4
Ceiba	6	100%		7	40%	2	4	57%	0	2	70%		12	37%	5	7	47%	2

[5] Due to the inconsistent implementation of the sampling design (at least in the case of mahogany two different sampling levels were used for the size class 10-25 cm dbh) the estimated density in this size class should be taken with caution for mahogany and consequently for the prime species, all species and BRL species groups. The Standard Error for mahogany was pooled between the SEs of the two different plot sizes, while SEs for the species groups are cumulative; i.e. by summing the SE of mahogany with the SE of the group minus mahogany. The true SEs are presumably lower, hence the RME presumably higher.

Species name	10-25			25-60			60-90			≥90			≥30			≥50		
	mean per km²	SE[5] of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²
Yemeri	65	39%	23	64	33%	29	4	57%	0				53	30%	27	8	37%	3
Bitterwood	30	44%	8	28	25%	17	2	70%	0				26	25%	15	7	40%	2
Wild Grape	994	20%	664	181	18%	127	2	70%					89	19%	60	5	61%	0
Hesmo	71	35%	30	27	26%	15				1	100%		21	27%	12	6	44%	2
Carbon	71	51%	11	30	35%	12				1	100%		14	42%	4	2	71%	
Red Wood	12	100%		8	74%		1	100%					6	82%		1	100%	
Bastard Mahogany	30	44%	8	13	45%	3	1	100%					6	53%	1	1	100%	
Red Gombolimbo	320	19%	221	114	17%	82							60	20%	40	2	70%	
White Gombolimbo	1,592	13%	1,239	136	16%	101							71	19%	49	1	100%	
Male Bullhoof	479	21%	313	50	25%	29							39	27%	22	1	100%	
Monkey Apple	18	100%		9	68%								6	82%		1	100%	
Glassywood	101	31%	49	12	39%	4							9	46%	2			
Cedrillo	77	39%	27	5	50%	1							5	50%	1			
Timbersweet (Laurel)	290	21%	189	18	44%	5							2	70%				
Negrito	112	35%	48	9	46%	2												
Select species	**11,331**	**6%**	**10,223**	**3,312**	**4%**	**3,088**	**265**	**9%**	**227**	**62**	**17%**	**44**	**2,669**	**4%**	**2,485**	**580**	**7%**	**515**
Unclassified species	45,609	4%	42,858	6,321	4%	5,937	206	9%	174	27	23%	17	4,114	4%	3,818	546	7%	482
Total (all species)	**60,585**	**4%**	**56,778**	**10,824**	**3%**	**10,341**	**553**	**6%**	**494**	**101**	**13%**	**79**	**7,704**	**3%**	**7,305**	**1,322**	**5%**	**1,216**
BRL species (excl rosewood)	3,348	10%	2,806	1,722	6%	1,541	228	9%	193	64	17%	45	1,631	6%	1,472	496	8%	430

Table 18 Stock table: mean volumes above size limits: ≥30 cm, ≥50 cm and ≥60 cm, with standard error (%) of the mean and reliable minimum estimates (RME); highlighted species are BRL's species of interest

Species name	Bole Volume ≥30 (m^3/km^2)	SE of mean ≥30 (%)	RME ≥30 (p=.95) (m^3/km^2)	Bole Volume ≥50 (m^3/km^2)	SE of mean ≥50 (%)	RME ≥50 (p=.95) (m^3/km^2)	Bole Volume ≥60 (m^3/km^2)	SE of mean ≥60 (%)	RME ≥60 (p=.95) (m^3/km^2)
Mahogany	610.3	10%	508.8	289.0	15%	215.8	157.8	21%	102.6
Cedar	149.9	32%	70.9	120.5	39%	43.1	97.5	47%	21.5
Prime species	**760.2**	**10%**	**636.4**	**409.5**	**15%**	**306.4**	**255.3**	**22%**	**163.0**
Barba Jolote	159.0	20%	106.5	105.3	24%	64.3	85.5	27%	47.4
Black Cabbage Bark	214.1	14%	162.8	80.2	22%	51.6	33.6	31%	16.2
Bastard Rosewood	50.9	24%	31.0	21.1	46%	5.2	21.1	46%	5.2
Mylady	129.2	17%	92.1	16.6	63%		10.8	71%	
Salmwood	89.5	18%	62.2	7.9	61%		4.0	100%	
Hobillo	19.6	24%	11.8	3.8	71%				
Granadilo	18.2	49%	3.3	2.6	100%				
Billy Webb	15.6	75%		2.0	100%				
Rosewood	9.1	59%	0.3						
Black Poisonwood	5.1	53%	0.6						
Cortez	4.9	55%	0.4						
Elite species	**481.1**	**10%**	**405.3**	**143.9**	**19%**	**97.7**	**103.4**	**24%**	**63.0**
Nargusta	1,099.7	12%	882.4	693.2	17%	502.5	566.0	19%	390.1
Sillion	833.8	10%	691.3	499.9	15%	376.4	395.5	18%	278.3
Sapodilla	663.1	13%	524.5	469.5	16%	345.4	395.5	18%	278.3
Fiddlewood	304.8	13%	241.4	131.8	20%	88.8	101.2	24%	61.4
White Breadnut	229.0	22%	146.0	139.1	29%	72.8	99.0	34%	43.8
Hogplum	407.7	12%	330.0	179.8	18%	127.2	96.8	28%	52.4
Fig	59.7	44%	16.0	55.2	48%	11.8	53.1	49%	9.8
Cotton	62.3	49%	12.1	55.1	52%	7.5	52.6	52%	7.4
Ironwood	103.1	27%	56.3	51.8	33%	23.4	35.8	41%	11.7
Kaway	58.1	27%	31.8	30.9	40%	10.7	19.4	44%	5.1
Santa Maria	119.6	16%	87.1	36.9	33%	16.9	18.0	50%	3.1
Yemeri	60.2	28%	32.5	20.5	39%	7.3	11.4	58%	0.4
Bitterwood	33.9	27%	18.6	16.8	42%	5.0	7.9	72%	
Hesmo	27.7	34%	12.0	15.1	53%	1.9	7.0	100%	
Wild Grape	70.8	22%	45.4	10.4	62%		6.1	71%	
Carbon	21.0	49%	3.9	9.6	79%		7.3	100%	
Bastard Mahogany	9.7	59%	0.2	4.9	100%		4.9	100%	
Red Wood	7.4	86%		2.8	100%		2.8	100%	
Red Gombolimbo	49.1	21%	31.6	3.8	71%				
Monkey Apple	7.0	79%		2.2	100%				
Male Bullhoof	36.9	29%	19.3	2.0	100%				
White Gombolimbo	51.7	20%	35.0	1.9	100%				
Glassywood	6.3	48%	1.3						
Cedrillo	5.1	51%	0.8						
Timbersweet (Laurel)	1.5	71%							
Select species	**3,637.8**	**5%**	**3,308.9**	**1,923.5**	**8%**	**1,654.8**	**1,441.0**	**10%**	**1,197.3**
Unclassified species	4,406.1	5%	4,062.9	1,546.5	9%	1,328.5	967.4	11%	785.2
Total (all species)	**9,285.2**	**3%**	**8,760.2**	**4,023.4**	**6%**	**3,651.0**	**2,767.1**	**7%**	**2,448.0**
BRL species (excl rosewood)	2,801.7	8%	2,452.1	1,714.6	10%	1,427.9	1,320.2	12%	1,069.0

3.2.3 Inventory results according to soil type

Inventory results are presented here for the production forest area on karstic soils and on acidic soils for the seven species of interest to BRL. It comprises a stand table of trees per km^2, a table of trees per km^2 in several size classes (10-25 cm, 25-60 cm, 60-90 cm, ≥ 90 cm; ≥30 cm and ≥50 cm), and a table of mean volumes above given size limits. For the table of size classes and table of mean volumes, sampling statistics are presented, including the standard error (%) of the mean, and the reliable minimum estimates (RME), or lower confidence limits at the 95% probability level. In some cases the RME is blank, indicating that if calculated it would give a negative value.

Subsequently, pooled means are derived by weighing by stratum area. Variance of the mean for a parameter is calculated using pooled within-stratum variances if the within-stratum variances do not differ significantly. If variances are unequal, the Behrens and Fisher approach is used to estimate the standard error (De Vries, 1986).

Table 19 Stand table of species of interest to BRL in karstic and acidic landscape strata as mapped by Meerman (2015)

Species name	Landscape	Trees per km² by cm diameter classes										Total
		10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	≥10
Mahogany	karstic	180	194	153	108	60	35	12	4	3	0	749
	acidic	138	275	269	213	81	6	0	0	0	0	981
Cedar	karstic	51	88	23	19	16	13	1	3	1	1	218
	acidic	0	31	25	6	13	13	6	0	6	0	100
Barbajolote	karstic	51	41	31	22	10	10	4	3	4	1	178
	acidic	188	131	75	75	25	6	0	6	6	0	513
Rosewood	karstic	7	1	3	0	0	0	0	0	0	0	12
	acidic	156	200	56	6	0	0	0	0	0	0	419
Nargusta	karstic	701	448	212	152	66	35	15	18	23	7	1,676
	acidic	2,250	1,156	506	213	63	50	19	6	50	19	4,331
Sapodilla	karstic	496	336	118	85	41	54	29	3	6	10	1,178
	acidic	406	256	144	81	25	31	13	0	6	0	963
Santa Maria	karstic	328	215	54	28	10	4	0	0	0	0	639
	acidic	1,188	294	75	13	0	0	6	0	0	0	1,575

Table 20 Trees per km² of species of interest to BRL in karstic and acidic landscape strata as mapped by Meerman (2015); in size classes: 10-25 cm, 25-60 cm, 60-90 cm, ≥ 90 cm; ≥30 cm and ≥50 cm, with standard error (%) of the mean, and reliable minimum estimates (RME). Letters indicate significant differences *p*-level <.05 (≥30 cm, ≥50 cm only; non-significant differences not indicated)

Species name	Landscape	10-25			25-60			60-90			≥90			≥30			≥50		
		mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²
Mahogany	karstic	312	23%	195	382	11%	316	51	22%	32	3	70%		375[a]	11%	307	114	17%	83
	acidic	250	49%	47	725	14%	556	6	100%					569[b]	16%	418	88	32%	40
Cedar	karstic	124	28%	66	73	25%	43	18	34%	8	3	70%	0	79	21%	51	36	26%	21
	acidic	31	100%		44	49%	7	19	74%		6	100%		69	40%	22	38	44%	9
Barbajolote	karstic	80	34%	35	74	18%	52	18	28%	9	6	49%	1	86	15%	64	34	20%	22
	acidic	281	64%		213	61%		13	70%		6	100%		194	55%	15	44	61%	
Rosewood	karstic	7	100%		4	57%	0							3[a]	70%				
	acidic	313	56%	13	106	62%								63[b]	71%				
Nargusta	karstic	1,036	12%	827	542	10%	450	67	16%	49	31	28%	17	527[a]	10%	437	164	15%	124
	acidic	3,000	27%	1,623	1,188	21%	769	75	41%	23	69	40%	22	925[b]	17%	654	206	31%	97
Sapodilla	karstic	781	14%	605	295	11%	239	86	17%	62	16	34%	7	346	11%	282	143	14%	109
	acidic	563	36%	223	350	23%	212	44	40%	14	6	100%		300	21%	191	75	31%	35
Santa Maria	karstic	511	18%	355	124	17%	90	4	57%	0				96	17%	69	15	34%	6
	acidic	1,375	22%	860	194	28%	103	6	100%					94	27%	51	6	100%	

Table 21 Mean volumes of species of interest to BRL in karstic and acidic landscape strata as mapped by Meerman (2015); above size limits: ≥30 cm, ≥50 cm and ≥60 cm, with standard error (%) of the mean, and reliable minimum estimates (RME); Letters indicate significant differences *p*-level <.05 (≥30 cm, ≥50 cm only; non-significant differences not indicated)

Species name	Landscape	Bole Volume ≥30 (m^3/km^2)	SE of mean ≥30 (%)	RME ≥30 (p=.95) (m^3/km^2)	Bole Volume ≥50 (m^3/km^2)	SE of mean ≥50 (%)	RME ≥50 (p=.95) (m^3/km^2)	Bole Volume ≥60 (m^3/km^2)	SE of mean ≥60 (%)	RME ≥60 (p=.95) (m^3/km^2)
Mahogany	karstic	589.6	12%	473.7	314.7	17%	227.4	190.2	21%	123.3
	acidic	697.1	18%	486.2	178.1	33%	78.0	18.8	100%	
Cedar	karstic	157.4	37%	61.8	125.8	45%	32.0	101.3	55%	9.2
	acidic	117.7	44%	30.1	97.9	50%	14.7	81.2	60%	
Barbajolote	karstic	144.2	19%	99.3	104.0	25%	61.7	89.3	28%	47.6
	acidic	222.2	55%	15.5	110.8	66%		69.2	83%	
Rosewood	karstic	2.9[a]	70%							
	acidic	38.6[b]	70%							
Nargusta	karstic	1,010.8	15%	765.3	658.8	20%	445.3	530.7	23%	332.6
	acidic	1,480.4	19%	1,013.6	840.6	31%	399.7	717.1	32%	322.7
Sapodilla	karstic	712.8	14%	547.3	523.5	17%	374.2	444.0	19%	302.5
	acidic	450.2	24%	268.9	238.4	34%	102.4	187.8	37%	69.5
Santa Maria	karstic	123.2	19%	85.2	39.0	35%	16.7	15.7	57%	0.8
	acidic	104.5	33%	45.2	28.0	100%		28.0	100%	

3.2.4 Inventory results according to logging history

Inventory results are presented here for the group of compartments that had been logged between 1997 and 2011 and the other compartments that had not been logged recently for the seven species of interest to BRL. Although the inventory of the northern portion of the CFR did not take place until 2014, no compartments were harvested in this section of the CFR between 2011 and 2014. The results presented comprise a stand table of trees per km^2, a table of trees per km^2 in several size classes (10-25 cm, 25-60 cm, 60-90 cm, ≥ 90 cm; ≥30 cm and ≥50 cm), and a table of mean volumes above given size limits. For the table of size classes and table of mean volumes, sampling statistics are presented, including the standard error (%) of the mean, and the reliable minimum estimates (RME), or lower confidence limits at the 95% probability level. In some cases the RME is blank, indicating that if calculated it would give a negative value.

Analysis of Variance was carried out to assess whether the differences between the landscapes in terms of stem numbers ≥30 cm and ≥50 cm dbh and in terms of volumes ≥30 cm and ≥50 cm dbh were significant

Subsequently, pooled means are derived by weighing by stratum area. Variance of the mean for a parameter is calculated using pooled within-stratum variances if the within-stratum variances do not differ significantly. If variances are unequal, the Behrens and Fisher approach is used to estimate the standard error (De Vries, 1986).

Table 22 Stand table of species of interest to BRL in stratum with group of compartments that were logged between 1997 and 2011 (logged) and stratum of group of compartment that were not logged recently

Species name	Logging history	Trees per km² by cm diameter classes										Cumulative >10
		10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100+	
Mahogany	logged	167	200	167	213	33	7	7	7	7	0	807
	unlogged	173	212	177	109	71	35	10	3	1	0	790
Cedar	logged	0	0	7	7	13	0	0	0	0	0	27
	unlogged	50	94	27	19	16	16	3	3	3	1	232
Barbajolote	logged	0	20	27	13	0	0	0	7	0	7	73
	unlogged	94	66	42	36	16	12	4	3	6	0	278
Rosewood	logged	167	53	20	7	0	0	0	0	0	0	247
	unlogged	7	36	12	0	0	0	0	0	0	0	55
Nargusta	logged	1,067	547	280	233	87	47	27	13	47	20	2,367
	unlogged	978	590	265	148	60	36	13	16	24	7	2,138
Sapodilla	logged	467	313	180	93	73	73	13	0	13	20	1,247
	unlogged	482	322	111	82	30	45	29	3	4	6	1,114
Santa Maria	logged	800	367	107	7	7	0	0	0	0	0	1,287
	unlogged	424	200	47	29	9	4	1	0	0	0	715

Table 23 Trees per km² of species of interest to BRL in logged (1997-2011) and unlogged strata; in size classes: 10-25 cm, 25-60 cm, 60-90 cm, ≥ 90 cm; ≥30 cm and ≥50 cm, with standard error (%) of the mean and reliable minimum estimates (RME). The differences in stem density between logged and unlogged strata in the size classes ≥30 cm and ≥50 were not significant at a *p*-level <.05 for any of the seven species.

		10-25			25-60			60-90			≥90			≥30			≥50		
Species name	Logging history	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²
Mahogany	logged	280	58%	10	500	20%	329	20	74%		7	100%		440	19%	301	60	36%	23
	unlogged	305	22%	192	436	10%	366	47	23%	29	1	100%		406	10%	336	119	16%	88
Cedar	logged				27	59%	0							27	59%		13	69%	
	unlogged	129	27%	71	76	24%	47	22	31%	11	4	57%	0	88	20%	59	42	24%	25
Barba Jolote	logged				60	33%	27	7	100%		7	100%		53	36%	21	13	69%	
	unlogged	144	34%	62	109	30%	56	19	27%	10	6	49%	1	118	23%	73	40	22%	26
Rosewood	logged	200	84%		47	100%								27	100%				
	unlogged	36	60%	0	19	64%								12	77%				
Nargusta	logged	1,400	42%	390	813	16%	597	87	31%	42	67	36%	26	753	14%	578	240	21%	153
	unlogged	1,410	14%	1,084	632	12%	504	65	18%	46	32	29%	16	570	11%	467	157	16%	115
Sapodilla	logged	733	27%	398	393	22%	248	87	34%	36	33	51%	5	467	18%	322	193	26%	106
	unlogged	741	14%	564	286	12%	232	76	18%	54	10	42%	3	309	12%	250	117	15%	87
Santa Maria	logged	1,100	32%	499	187	27%	101							120	29%	60	7	100%	
	unlogged	583	16%	431	127	17%	92	6	49%	1				91	17%	65	14	34%	6

Table 24 Mean volumes of species of interest to BRL in logged (1997-2011) and unlogged strata; above size limits: ≥30 cm, ≥50 cm and ≥60 cm, with standard error (%) of the mean, and reliable minimum estimates (RME); the differences in volume between logged and unlogged strata in the size classes ≥30 cm and ≥50 were not significant at a *p*-level <.05 for any of the seven species..

Species name	Logging history	Bole Volume ≥30 (m^3/km^2)	SE of mean ≥30 (%)	RME ≥30 (p=.95) (m^3/km^2)	Bole Volume ≥50 (m^3/km^2)	SE of mean ≥50 (%)	RME ≥50 (p=.95) (m^3/km^2)	Bole Volume ≥60 (m^3/km^2)	SE of mean ≥60 (%)	RME ≥60 (p=.95) (m^3/km^2)
Mahogany	logged	619.8	20%	411.8	193.1	43%	53.0	131.4	61%	
	unlogged	608.3	12%	492.4	309.7	16%	225.7	163.4	23%	102.5
Cedar	logged	27.2	56%	1.4	18.2	70%				
	unlogged	176.4	33%	80.7	142.6	40%	48.8	118.5	47%	26.2
Barbajolote	logged	136.4	61%		105.4	79%		105.4	79%	
	unlogged	163.9	21%	107.2	105.3	23%	64.8	81.2	27%	45.1
Rosewood	logged	18.2	100%							
	unlogged	7.1	73%							
Nargusta	logged	1,533.4	18%	1,076.0	1,026.3	25%	594.3	860.6	28%	455.4
	unlogged	1,006.1	15%	761.0	621.3	21%	408.4	502.4	24%	306.5
Sapodilla	logged	1,014.7	27%	540.8	759.7	36%	292.5	625.5	43%	170.5
	unlogged	587.2	14%	452.4	406.9	17%	292.8	345.8	18%	240.1
Santa Maria	logged	116.1	33%	51.4	16.5	100%				
	unlogged	120.4	19%	83.1	41.4	35%	17.7	21.9	50%	3.8

3.3 Analysis and evaluation of inventory results

3.3.1 Analysis of the simple random sampling design

The 2011/2014 general inventory indicated that the prime species added up to 1.4% of all trees ≥ 10 cm dbh, the elite species made up 5.5%, the select species 20.8% and the unclassified species 72.4%. It is indicated that the following merchantable tree species in the CFR are the most common: sillion, nargusta and hogplum with all over 20 trees/ha ≥ 10 cm dbh; together representing 9.3% of all trees ≥ 10 cm dbh, followed by white gumbolimbo, mylady, salmwood, wild grape, sapodilla, fiddlewood and white breadnut with all over 10 trees/ha ≥ 10 cm dbh; representing 12.0% of all trees ≥ 10 cm dbh.

If the minimum cutting diameter is set at 50 cm dbh for convenience, the prime species constituted 11.0% of the total tree density in this size class [1.5 trees/ha ≥ 50 cm dbh], the elite species 3.8% [0.5 trees/ha], the select species 43.9% [5.8 trees/ha] and the unclassified species 41.3% [5.5 trees/ha]. Nargusta was the most common species among the trees of harvestable size with 1.7 trees/ha ≥ 50 cm dbh [13.0% of the total tree density in this size class], followed by sillion with 1.4 trees/ha [10.8%], sapodilla with 1.3 trees/ha [9.8%], mahogany with 1.1 trees/ha [8.2%] and hogplum with 0.7 trees/ha [5.6%]. Cedar, barbajolote and santa maria had lower densities with 0.37 trees/ha [2.8%], 0.36 trees/ha [2.7%] and 0.13 trees/ha [1.0%] respectively. Rosewood does not grow to such dimensions, but even if the cutting diameter is set at 30 cm dbh for this species, it appears to be scarce; 0.14 trees ≥ 30 cm dbh per ha.

In terms of standing volume over 50 cm dbh, nargusta has the highest estimated standing volume with 6.9 m^3/ha [17.2% of the total volume in this size class], followed by sillion with 5.0 m^3/ha [12.4%], sapodilla 4.7 m^3/ha [11.7%] and mahogany 2.9 m^3/ha [7.2%]. Cedar and barbajolote also have reasonable volumes due to the larger sizes of the trees than the species above; 1.2 [3.0%] and 1.1 m^3/ha [2.6%] respectively. Santa maria has 0.4 m^3/ha [0.9%] and rosewood, considering a minimum cutting diameter of 30 dbh, only 0.09 m^3/ha. Reliable minimum estimated volumes (p=.95) are some 72-75% of the estimated mean in case of nargusta, sapodilla and mahogany, but are only 36% in case of cedar and 61% in case of barbajolote due to their more irregular distribution over the reserve.

By targeting mahogany, nargusta and sapodilla BRL is thus targeting common, well distributed species with substantial standing volumes. Mahogany, as a CITES Appendix II listed species, is well represented and distributed with a volume of 6.1 m^3/ha (dbh ≥ 30 cm; SE = 10%) and a stem density of 4.1 trees/ha (dbh ≥ 30 m; SE = 9%) and does not appear to be threatened in the slightest way regarding the low proportion of trees that may be cut (see Table 3 in Section A3.7). Cedar and barbajolote have lower but adequate standing volumes, while volumes of santa maria and rosewood appear be of no more than marginal commercial interest. Other common species with considerable volumes such as sillion, hogplum and fiddlewood are not in demand and of low value. BRL may consider exploring the market potential of white breadnut with 1.4 $m^3/ha \geq 50$ cm dbh [3.5% of the total volume in this size class] and, particularly, black cabbage bark with 0.8 $m^3/ha \geq 50$ cm dbh [2.0%], given the observation that these are the only other species with acceptable standing volumes.

Comparison with the 1969 Johnson & Chaffey (1973) inventory

Comparison of the 2011/14 inventory with the inventory of Johnson & Chaffey of 1969 shows that mahogany has made a remarkable recovery after the species had been completely depleted in 1969 (Figure 20). As a matter of fact all species of interest to BRL have shown a strong increase in stem density in all size classes, except for cedar and sapodilla. This is not surprising because most species except for sapodilla and santa maria are light-demanding species (Bird, 1998). Decades of overharvesting and hurricane Hattie followed by forest fires had devastated the Chiquibul forest but also created ideal circumstances for lush regeneration of most of the light-demanding species.

Johnson & Chaffey (1973) inventoried only mahogany and cedar down to 10 cm dbh, while the other species were inventoried down to 20 cm dbh. Nothing much can be said about the rate of regeneration of the other species over the last 30-40 years; the time it presumable takes these species to grow to 20 cm dbh. The shape of the diameter class frequency distributions of mahogany and cedar suggests that the rate of regeneration has decreased over the past 10-20 years, but little can be said about the rate of regeneration of mahogany and cedar following logging over the last 10-20 years, presuming any regeneration would still be below 10 cm diameter. Current logging gap sizes and lower harvesting intensities of less than two trees per hectare may not be sufficient to trigger regeneration of these two species (see e.g. Shono & Snook, 2006). In case of mahogany, confidence in the stem density in the class 10-25 cm dbh is limited due to erratic implementation of the sampling design.

It must be noted that Johnson & Chaffey's inventory of the Main Felling Series included the part west of the present forest reserve, which is now part of the CNP. As much as 39% of their sampling area was located outside the current CFR area (see Figure 18).

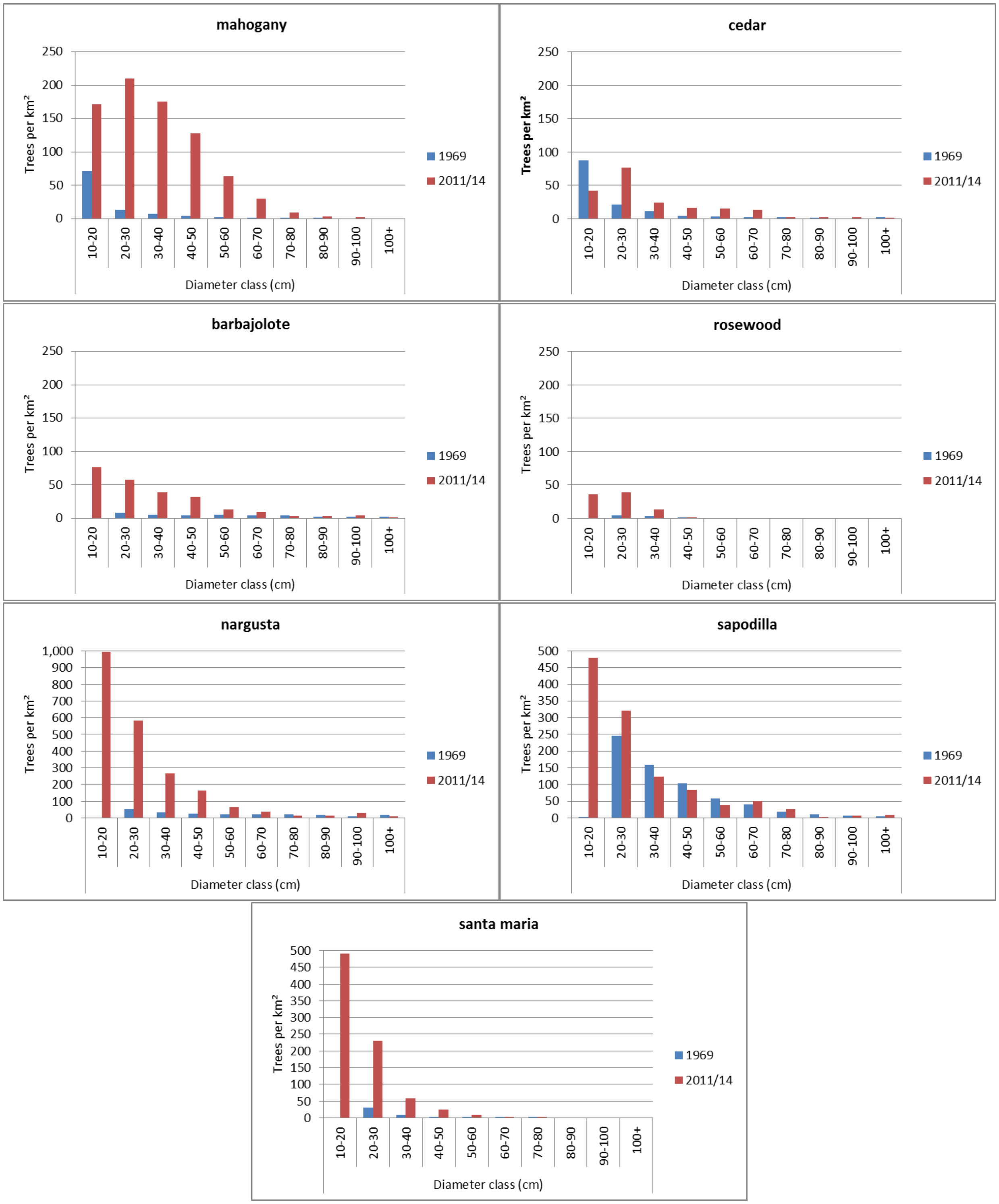


Figure 20 Diameter class frequency distributions of seven selected species in the 1969 and 2011/14 inventories; note different vertical axis scales.

3.3.2 Difference between landscape strata: karstic and acidic soils

The partitioning of plots on karstic soils and those on acidic soils (according to Meerman, 2015) into two strata suggests that barbajolote, santa maria and particularly nargusta and rosewood have a preference for acidic soils (Table 19). Cedar shows a preference for karstic soils while mahogany and sapodilla appear indifferent. Mahogany has higher densities on acidic soils in the medium size classes but not in the larger size classes.

The difference between densities by soil type was statistically tested for the size classes ≥30 cm and ≥50 cm (see Table 20 and Appendix II 2.1). In the size class ≥30 cm mahogany, barbajolote, rosewood and nargusta show a preference for acidic soils, while cedar, sapodilla and santa maria seem to have no preference. The difference proved significant for mahogany, rosewood and nargusta.

In the size class ≥50 cm differences were less conspicuous but it is interesting to see that the density of mahogany trees was higher on karstic soils in this class (non-significantly so). The size class distributions also show higher densities on karstic soils in the smaller size classes for both mahogany and cedar. These aberrations may result from recent disturbance on karstic soils; perhaps fires occurred there after 1969. It is not likely that the difference is linked to recent logging history because these trees established before BRL started its sustained yield logging operations in 2007. It would have been worthwhile to also test the difference between the soil types for the class 10-25 cm dbh but this was omitted due to the lack of consistency of the sampling level for this size class. Results for the class 10-25 cm dbh should therefore be treated with caution.

The difference between volumes by soil type was statistically tested for the size classes ≥30 cm and ≥50 cm (see Table 21 and Appendix II 2.2). The trends shown in the tree densities by species by soil type in these classes are amplified when comparing volumes. Trends are not always amplified consistently depending on the density of very large trees (e.g. dbh ≥70 cm); the high volumes of trees in those classes may reverse trends shown when regarding stem densities.

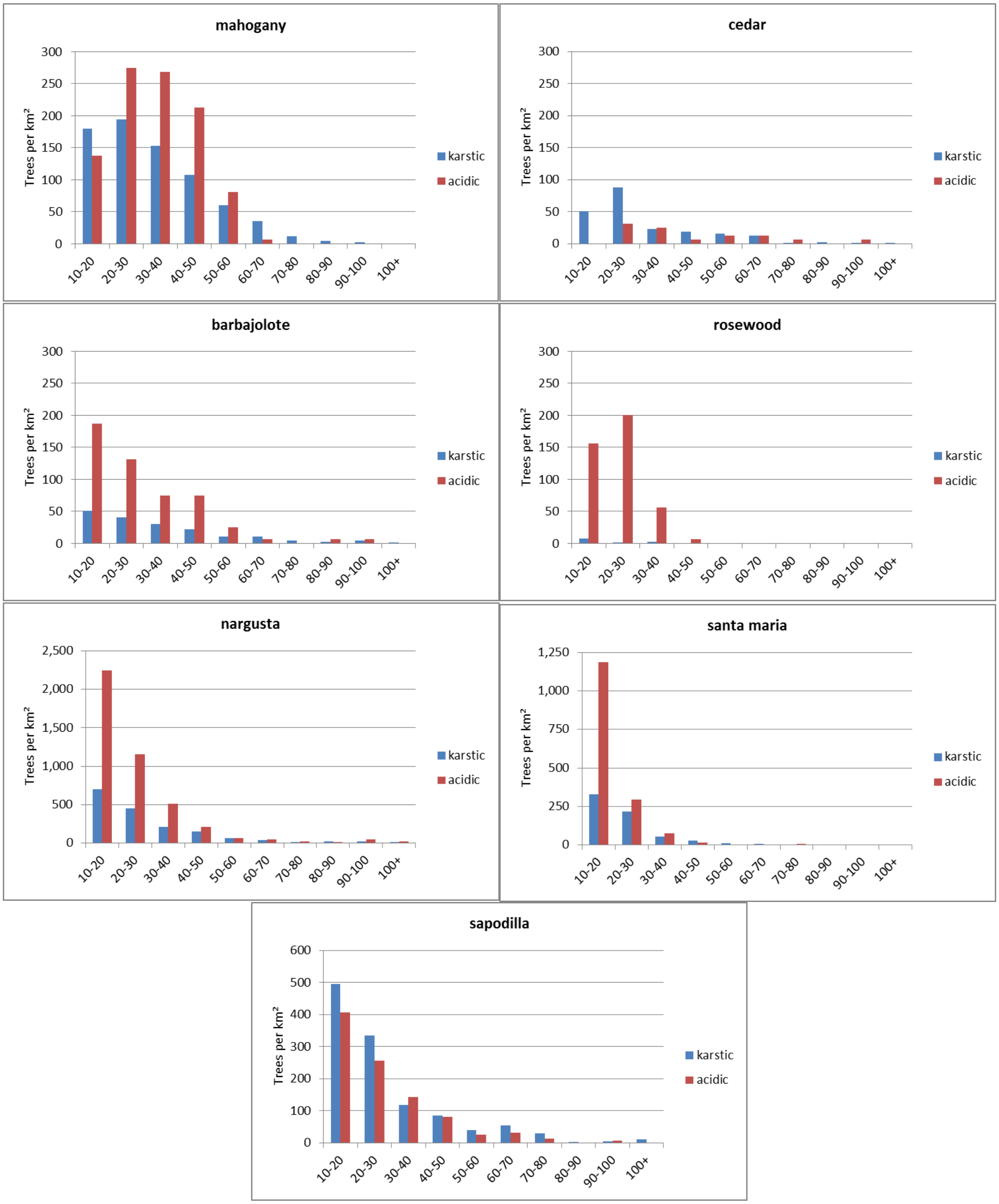


Figure 21 Diameter class frequency distributions of seven selected species on karstic and acidic soils. Note different vertical axis scales

3.3.3 Difference in logging history: recently and not recently logged compartments

Compartments that were logged between 1997 and 2011 are expected to have fewer trees in the size classes above 50 cm dbh. This was true in case of mahogany, cedar, barbajolote and santa maria, but not in case of the other three species. In fact rosewood, nargusta and sapodilla had more trees of harvestable size ≥30 cm or ≥50 cm in logged plots (see Table 22 and Figure 22). It is also interesting to note that mahogany had considerably more trees in the 40-50 cm class in the logged plots than in the unlogged plots.

It was further observed that cedar and barbajolote had conspicuously fewer trees in the size classes 10-20 and 20-30 cm in the logged pots. There are several possible explanations for this; most of which are not related to the recent logging operation. If logging damage would be the cause, this should have affected all species indiscriminately. It is more likely that local variation in size class distributions stemming from before the logging operations is responsible, especially because these species regenerate well after major disturbances such as large scale windthrows as a result from hurricanes and wild fires.

The difference between densities by logging history was statistically tested for the size classes ≥30 cm and ≥50 cm (see Table 23 and Appendix II 2.3). In the size class ≥30 cm cedar and barbajolote had fewer trees in the logged compartments; mahogany did not differ, while rosewood, nargusta, sapodilla and santa maria all had fewer trees in the unlogged compartments. None of the differences in stem densities proved significant and differences may also be attributable to other factors.

As mentioned earlier mahogany, cedar, barbajolote and santa maria had, as to be expected, fewer trees in the size class ≥50 cm in the logged compartments, while the other species, unexpectedly, showed the opposite. None of the differences in stem densities proved significant and differences may also be related to other factors.

The difference between volumes by logging history was statistically tested for the size classes ≥30 cm and ≥50 cm (see Table 24 and Appendix II 2.4). The trends shown in the tree densities by species by logging history in these classes are amplified when comparing volumes. This applied to all species except for barbajolote, which is probably due to the presence of very large trees (dbh ≥70 cm); reversing trends shown when regarding stem densities. Also in case of volume, these differences did not prove significant and differences may also be attributable to other factors.

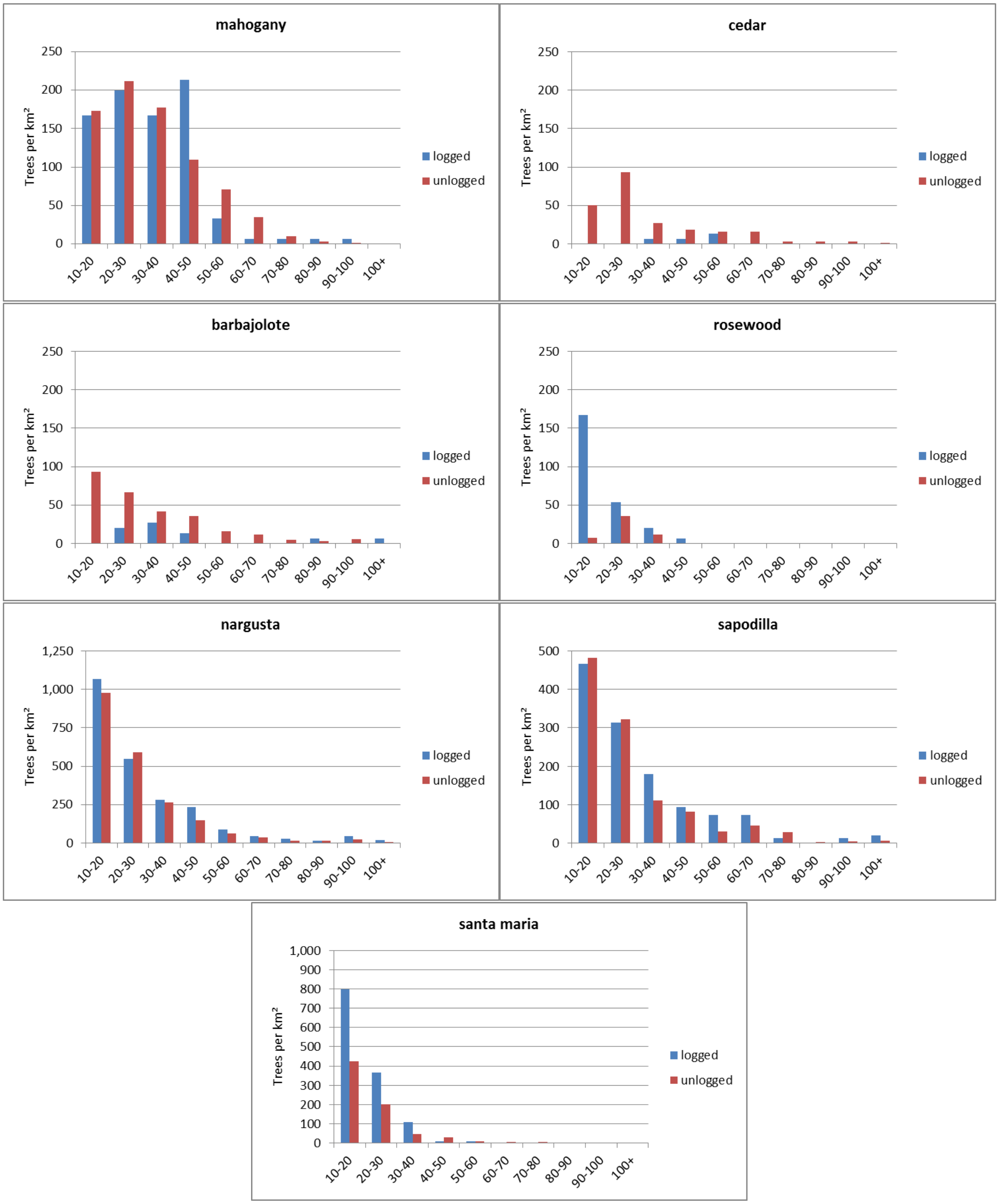


Figure 22 Diameter class frequency distributions of seven selected species in logged and unlogged compart aments. Note different vertical axes scales.

3.3.4 Results based on the stratified random sampling design

The main reason why forest inventory experts recommend stratified random sampling in cases like the CFR is that it reduces the overall variance estimate resulting in more precise information (De Vries, 1986, Zöhrer, 1980).

Factorial Analysis of Variance was carried out to detect any interaction between the two factors logging intensity and soil type. Interaction basically means that the effect of one factor on the mean of a population variable is modified (qualified) by the effect of the other factor. For instance, if fewer trees would be allowed or possible (accessible) to be harvested on the one soil type compared to the other soil type, an interaction effect could be detected. However, no interaction was detected as shown in Appendix C 2.5. Therefore, we can safely carry out stratification by soil type and by logging history independently.

Stratification by soil type

The stratification by soil type resulted in the statistics shown in Tables 25 and 26.

Table 25 Trees per km² and in the entire CFR production forest for selected tree species in size classes: ≥30 cm and ≥50 cm; standard error (%) of the mean, and reliable minimum estimates (RME) after stratification by soil type

Species name	≥30			≥50			≥30		≥50	
	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	CFR	RME (p=.95) CFR	CFR	RME (p=.95) CFR
Nargusta	589	9%	503	170	13%	133	210,562	179,733	60,842	47,524
Sapodilla	339	10%	283	133	13%	103	121,166	101,337	47,860	37,190
Mahogany	405	9%	344	110	15%	83	144,915	122,954	39,253	29,493
Cedar	77	19%	53	37	23%	23	27,630	19,018	13,106	8,168
Barbajolote	103	19%	70	35	20%	24	36,778	25,047	12,572	8,421
Santa Maria	96	15%	73	13	31%	6	34,310	25,924	4,757	2,236
Rosewood	12	58%	0				4,354	153		

Table 26 Volumes per km² and in the entire CFR production forest for selected tree species in size classes: ≥30 cm and ≥50 cm; standard error (%) of the mean, and reliable minimum estimates (RME) after stratification by soil type

Species name	≥30			≥50			≥30		≥50	
	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	CFR	RME (p=.95) CFR	CFR	RME (p=.95) CFR
Nargusta	1083	12%	867	687	17%	496	387,313	309,915	245,682	177,427
Sapodilla	672	13%	530	479	16%	352	240,302	189,467	171,366	125,771
Mahogany	606	10%	505	294	16%	218	216,821	180,513	104,936	78,101
Cedar	151	33%	70	121	40%	41	54,095	24,875	43,434	14,829
Barbajolote	156	19%	107	105	23%	65	55,910	38,347	37,578	23,177
Santa Maria	110	16%	81	32	55%	3	39,347	28,865	11,604	1,122
Rosewood	8	56%	1				2,804	207		

Stratification by logging history

Stratification by logging history resulted in the statistics shown in Tables 27 and 28.

Table 27 Trees per km² and in the entire CFR production forest for selected tree species in size classes: ≥30 cm and ≥50 cm; standard error (%) of the mean, and reliable minimum estimates (RME) after stratification by logging history

Species name	≥30			≥50			≥30		≥50	
	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	CFR	RME (p=.95) CFR	CFR	RME (p=.95) CFR
Nargusta	598	9%	508	170	13%	132	213,942	181,789	60,709	47,251
Sapodilla	334	10%	279	129	13%	100	119,372	99,720	45,950	35,803
Mahogany	411	9%	349	110	15%	83	146,972	124,752	39,381	29,692
Cedar	78	19%	54	37	23%	23	27,971	19,262	13,334	8,328
Barbajolote	108	21%	70	36	21%	24	38,575	24,888	12,900	8,476
Santa Maria	95	15%	72	13	32%	6	34,045	25,676	4,713	2,219
Rosewood	14	62%					4,961			

Table 28 Volumes per km² and in the entire CFR production forest for selected tree species in size classes: ≥30 cm and ≥50 cm; standard error (%) of the mean, and reliable minimum estimates (RME) after stratification by logging history

Species name	≥30			≥50			≥30		≥50	
	mean per km²	SE of mean (%)	RME (p=.95) per km²	mean per km²	SE of mean (%)	RME (p=.95) per km²	CFR	RME (p=.95) CFR	CFR	RME (p=.95) CFR
Nargusta	1088	12%	872	685	17%	494	388,907	311,611	244,724	176,774
Sapodilla	654	12%	520	462	16%	343	233,771	185,741	165,150	122,460
Mahogany	610	10%	508	292	15%	218	218,109	181,755	104,225	78,081
Cedar	153	32%	72	123	39%	44	54,748	25,887	44,041	15,769
Barbajolote	160	20%	107	105	23%	65	57,057	38,254	37,652	23,266
Santa Maria	110	16%	80	33	33%	15	39,231	28,751	11,684	5,361
Rosewood	9	59%	0				3,160	86		

When comparing the results of the stratified random sampling with simple random sampling (see Tables 17 and 18 in Section 3.2.2), it shows that the effect of stratification is marginal. This suggests that other, unknown factors play a bigger role in stem density and volume of the selected species than recent logging history or soil type (karstic versus acidic). Historical logging impact in the period 1955-1985, hurricane Hattie, topography and recurring forest fires seem more pivotal in forming the current densities and distributions of the selected species than the factors soil type and recent logging history.

3.3.5 Relation between standing and extracted roundwood and produced lumber volume

The gross standing tree volumes were estimated using volume equations developed by Denis Alder (1992a). Relationships between the tree diameter (dbh) and the gross standing volume, the APO volume, the net extracted volume (sawmill input) and recovered volume (sawmill output) were determined using BRL's chain of custody records of the 2016 harvest. Records were available for mahogany (657 trees), cedar (103 trees) and nargusta (47 trees)

Mahogany roundwood to sawn lumber volume conversion

Exponential regression between the respective volumes and the diameter at breast height of the standing trees provided the best fit, whereby it was found that the APO volume corresponded closely to the sawmill input volume (see Figure 23).

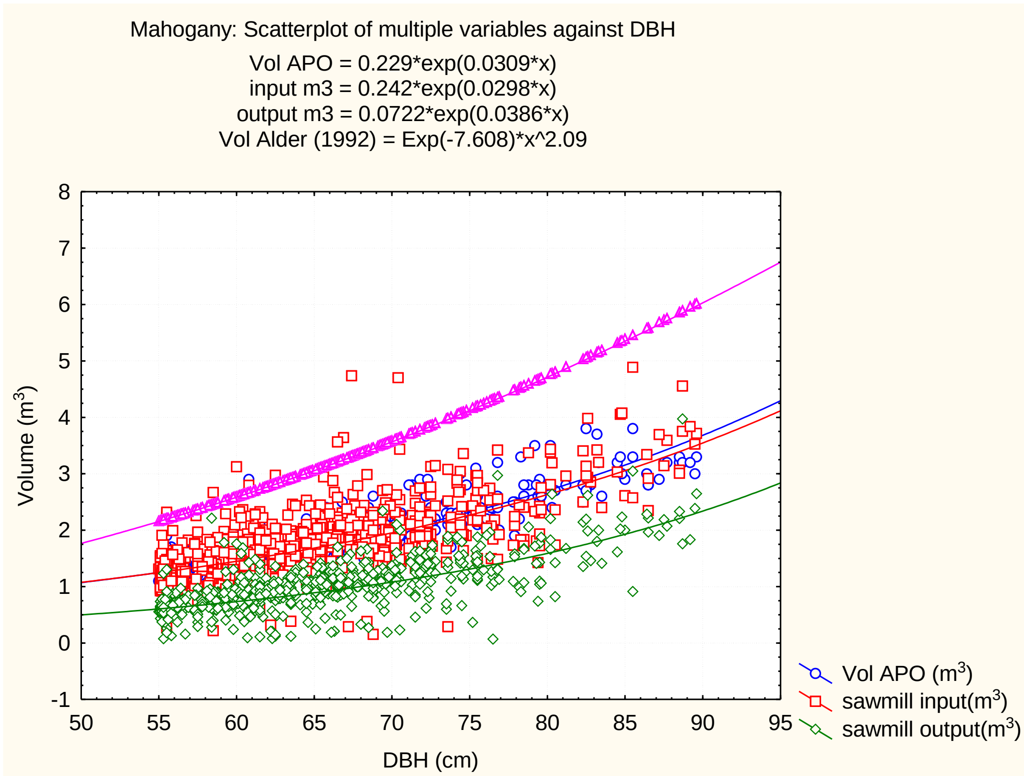


Figure 23 Mahogany: fitted exponential regression models of multiple variables against diameter at breast height of standing trees; volume according to APO equation, sawmill input, sawmill output and volume according to Alder (1992a) equation

The exponential regression model was highly significant for all variables; Vol APO: $F_{1,655}$=3595.0, p<0.0000; sawmill input: $F_{1,655}$=395.86 p<0.0000 and sawmill output: $F_{1,655}$=362.13 p<0.0000. The model explained most of the variation in the volume against the dbh in case of Vol APO (R^2=0.85). Also in case of the sawmill input and output the model explained a reasonable amount of the variation (R^2=0.36 and R^2=0.38, respectively).

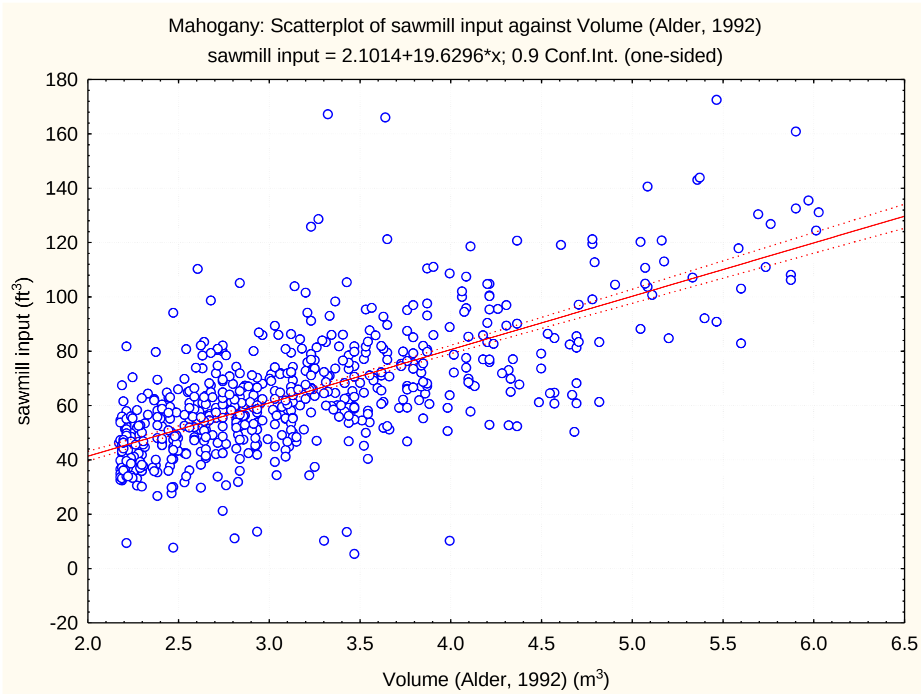


Figure 24 Mahogany: fitted linear regression model of net extracted roundwood volume in cubic feet against gross volume of standing trees in m³; $F_{1,655}$=636.76, p<0.0000, R^2=0.49 and standard error of estimate = 16.665

The 2016 net extracted volume (sawmill input) was determined at the Georgeville sawmill gate. The linear relationship between the net extracted volume and the gross standing volume is shown in Figure 24. The standard error of estimate is an overall indication of the accuracy with which the fitted regression function predicts the dependence of *Y* on *X* and allows calculation of confidence intervals for the parameter being estimated (Zar, 1974).

The standard error of predicted values of *Y* is minimal for $x_i=\bar{x}$ and it increases as estimates are made at values of x_i farther from the mean (Zar, 1974). If confidence limits are calculated for all points on the regression line, the result is the confidence bands shown in Figure 24 and the next Figures.

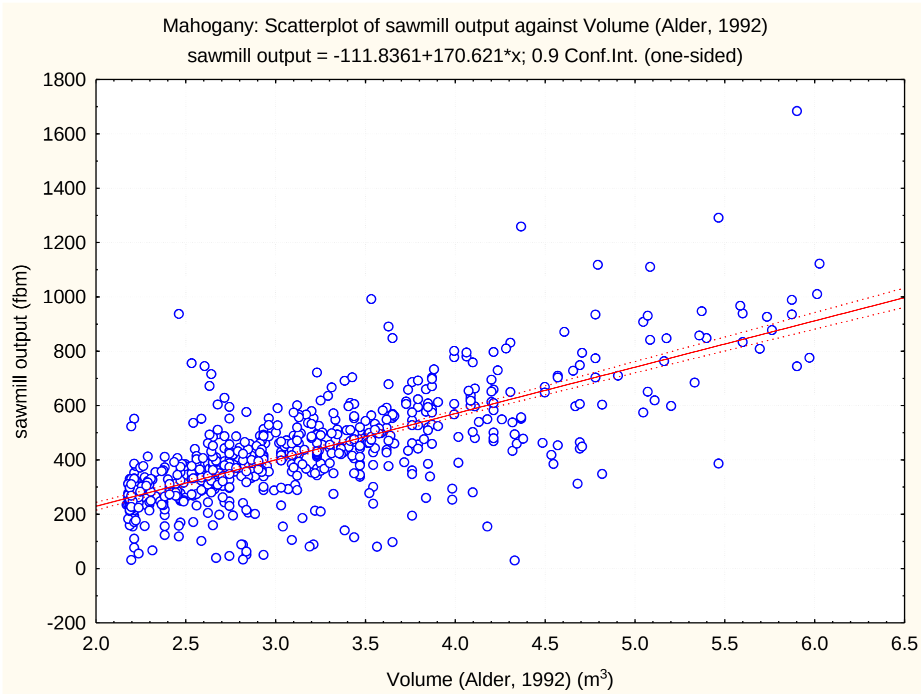


Figure 25 Mahogany: fitted linear regression model of roundwood converted into sawn lumber in BF against gross volume of standing trees in m³; $F_{1,655}$=742.47, p<0.0000, R^2=0.53 and standard error of estimate = 134.15

Sawmill output was measured in BF. The linear relationship between the net extracted volume and the gross standing volume is shown in Figure 25. For explanation of confidence bands and standard error of estimate see text under Figure 25.

The APOs traditionally have been using a conversion factor of 212 to estimate BF sawn lumber from m³ roundwood (APO volume equation), assuming the APO volume is equal to the sawmill input (net extracted volume) and a sawmill recovery of 50%. The roundwood volume in the APO itself is calculated with a double-entry exponential equation including dbh, bole length and stem quality class. The conversion factor to estimate BF sawn lumber from m³ roundwood was recently reduced to 169 by the Forest Department; reportedly to express the average proportion of grade 'select or better' lumber. The CITES export quota for mahogany is 67% of the estimated 'select or better' grade sawn BF.

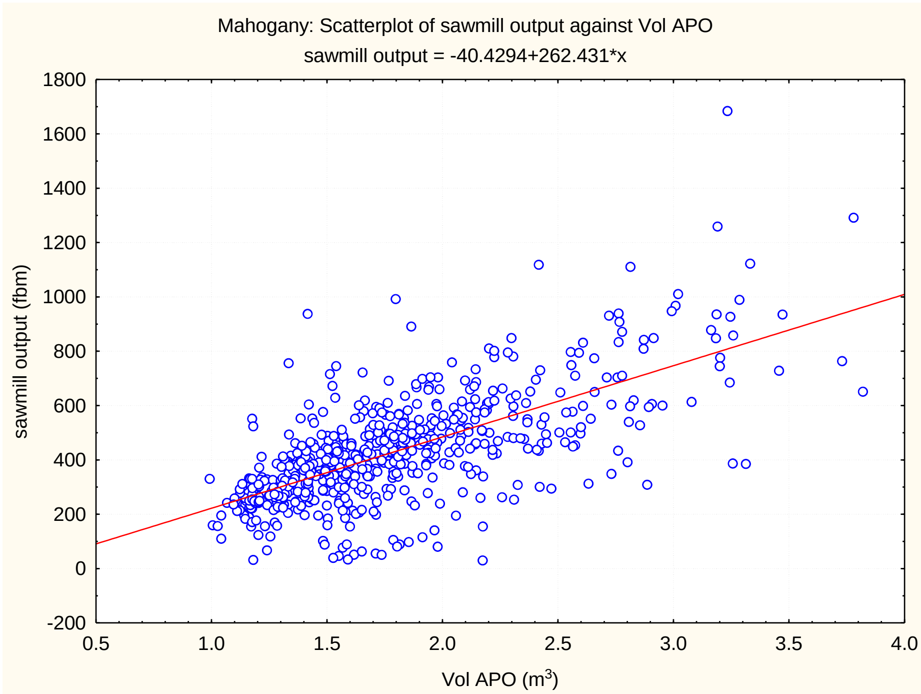


Figure 26 Mahogany: conversion of m³ roundwood according to the set of APO equations into sawn lumber in BF; $F_{1,655}$=583.94, p<0.0000 and R^2=0.47

For mahogany, the actual conversion from m³ roundwood according to the APO set of equations into BF sawn lumber was examined by using simple linear regression as shown in Figure 26. Based on this linear relationship the true conversion factor varies between 222 BF/m³ for small logs of 1 m³ and 252 BF/m³ for big logs of 4 m³. The 2016 mean log volume according to the APO set of equations amounted to 1.77 m³, which would yield 239.6 BF/m³ (the median log volume of 1.7 m³ would yield 238.6 BF/m³). This indicates that the current APO conversion factor yields on average 70.5% of the true recovery, with as a consequence a CITES export quota of just 47.3% (67% x 70.5%) of the true sawn lumber output. The actual recovery against the APO Volume was 56% on average, while it was 58% against the true sawmill input as measured at the sawmill gate.

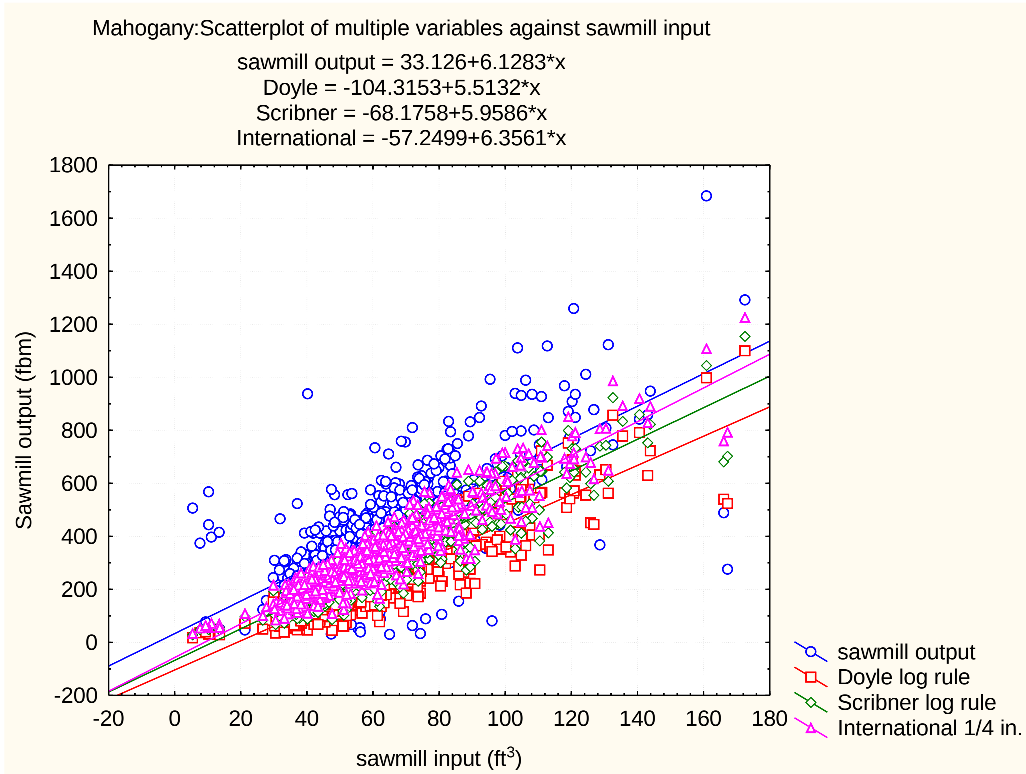


Figure 27 Estimated total volume (expressed in board feet) of lumber that can be sawn according to three common log rules and actually recovered lumber volume against sawmill input

The actual sawmill output exceeds the estimated output volume (BF) according to the three most common log rules; i.e. the Doyle, Scribner and International ¼" log rules, as shown in Figure 27.

Cedar roundwood to sawn lumber volume conversion

Exponential regression was used to assess the relationships between the APO volume, the sawmill input in ft^3, the sawmill output in BF and the diameter at breast height of the standing trees. The results, shown in Figure 28, indicate that the APO set of volume equations overestimated the net extracted volume in the case of cedar.

The exponential regression model was highly significant for all variables; Vol APO: $F_{1,101}=550.33$, $p<0.0000$; sawmill input: $F_{1,101}=55.992$, $p<.00000$ and sawmill output: $F_{1,101}=37.709$, $p<.00000$. The model explained most of the variation in the volume against the dbh in case of Vol APO ($R^2=0.84$). In case of the sawmill input and output the model explained a reasonable proportion of the variation ($R^2=0.36$ and $R^2=0.27$, respectively).

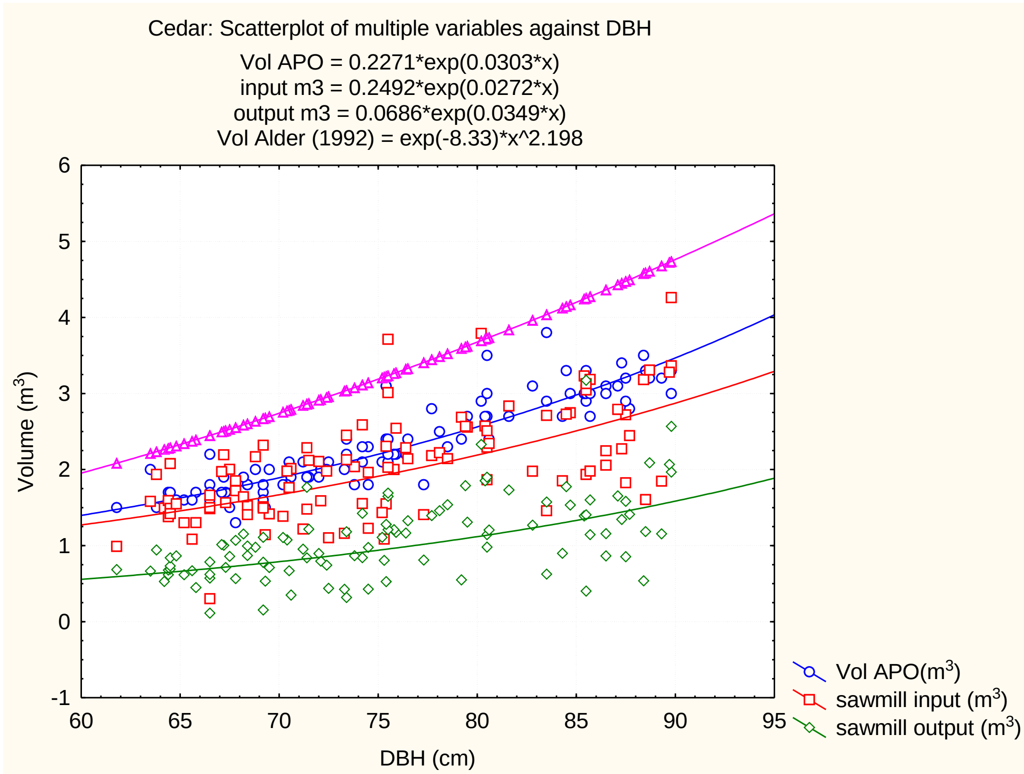


Figure 28 Cedar: fitted exponential regression models of multiple variables against diameter at breast height of standing trees: volume according to APO equation, sawmill input and sawmill output (all expressed in m³)

The net extracted volume (sawmill input) was determined at the Georgeville sawmill gate. The linear relationship between the net extracted volume and the gross standing volume is shown in Figure 29.

Sawmill output was measured in BF. The linear relationship between the net extracted volume and the gross standing volume is shown in Figure 30.

For cedar, the actual conversion from m³ roundwood according to the APO set of equations into BF sawn lumber was examined by using simple linear regression as shown in Figure 31. Based on this relationship the conversion factor is lower than for mahogany; 198 BF/m³ independent of log size. For cedar, the average recovery against the sawmill input was only 24% in 2016, while recovery against the APO Volume was 47%.

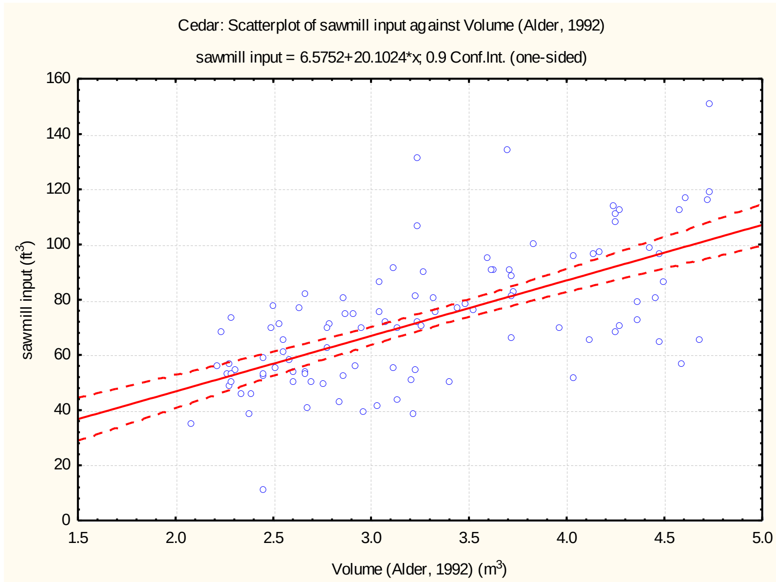


Figure 29 Cedar: fitted linear regression model of net extracted roundwood volume in cubic feet against gross volume of standing trees in m³; $F_{1,101}$=68.991, p<.00000 , R^2=0.41 and standard error of estimate = 18.716

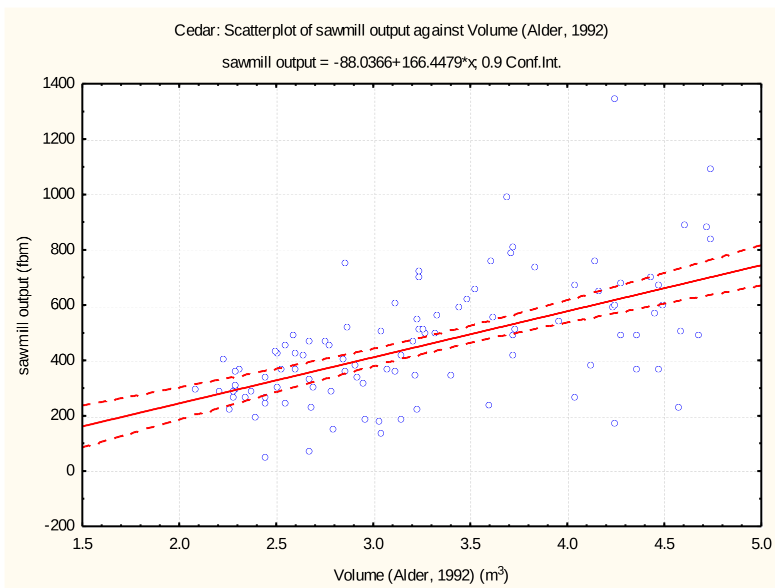


Figure 30 Cedar: fitted linear regression model of roundwood converted into sawn lumber in BF against gross volume of standing trees in m³; $F_{1,101}$=50.279, p<.00000, R^2=0.33 and standard error of estimate = 181.53

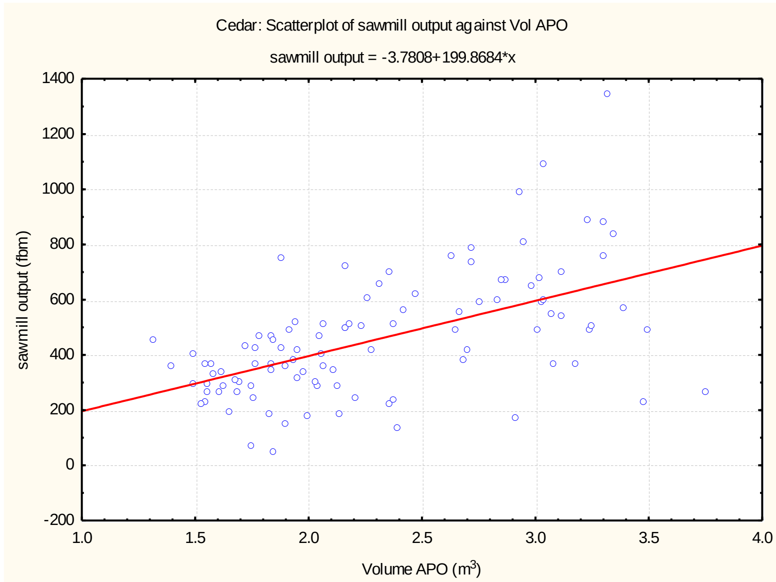


Figure 31 Cedar: conversion of m³ roundwood according to the set of APO equations into sawn lumber in BF. $F_{1,101}$=44.393, p<.00000 and R^2=0.31

Nargusta roundwood to sawn lumber volume conversion

Simple linear regression was used to assess the relationships between the APO volume, the sawmill input in ft³, the sawmill output in BF and the diameter at breast height of the standing trees for nargusta. The results, shown in Figure 32, indicate that the APO set of volume equations overestimated the net extracted volume in case of nargusta.

The exponential regression model was significant for all variables; Vol APO: $F_{1,44}$=91.056, p<.00000; sawmill input: $F_{1,44}$=25.260, p<.00001 and sawmill output: $F_{1,44}$=7.7647, p<.00783 . The model explained most of the variation in the volume against the dbh in case of Vol APO (R^2=0.67). In case of the sawmill input and output the model explained less of the variation (R^2=0.36 and R^2=0.15, respectively). The net extracted volume (sawmill input) was determined at the Georgeville sawmill gate. The linear relationship between the net extracted volume and the gross standing volume is shown in Figure 33.

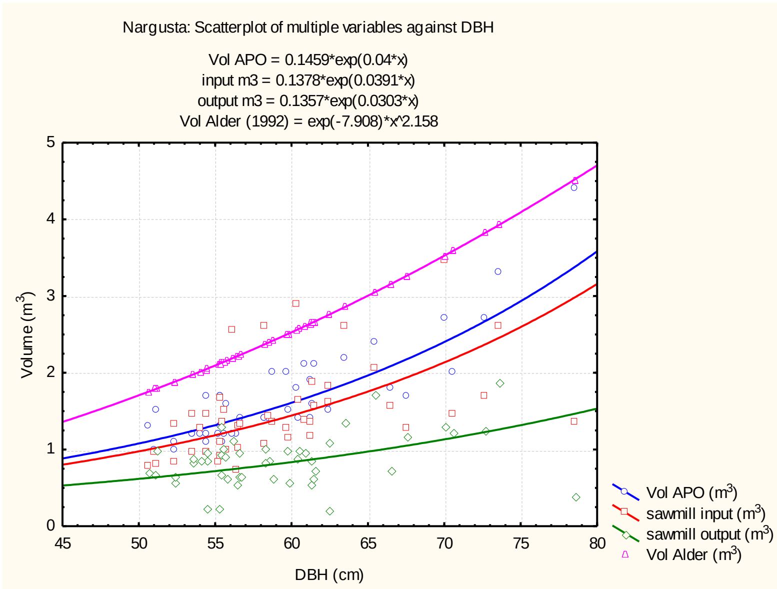


Figure 32 Nargusta: fitted exponential regression models of multiple variables against diameter at breast height of standing trees: volume according to APO equation, sawmill input and sawmill output (all expressed in m³)

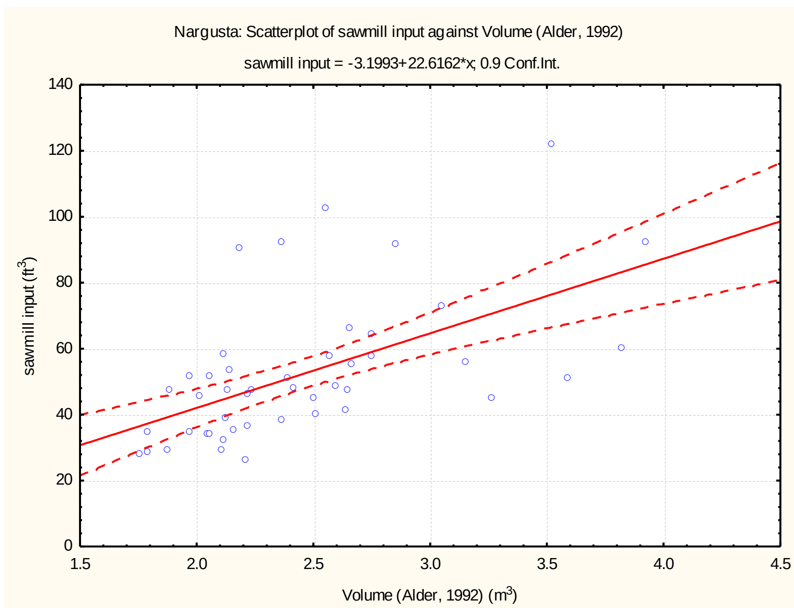


Figure 33 Nargusta: fitted linear regression model of net extracted roundwood volume in cubic feet against gross volume of standing trees in m³; $F_{1,44}$=20.303, p<.00005, R^2=0.31 and standard error of estimate = 17.929

Sawmill output was measured in BF. The linear relationship between the net extracted volume and the gross standing volume is shown in Figure 34.

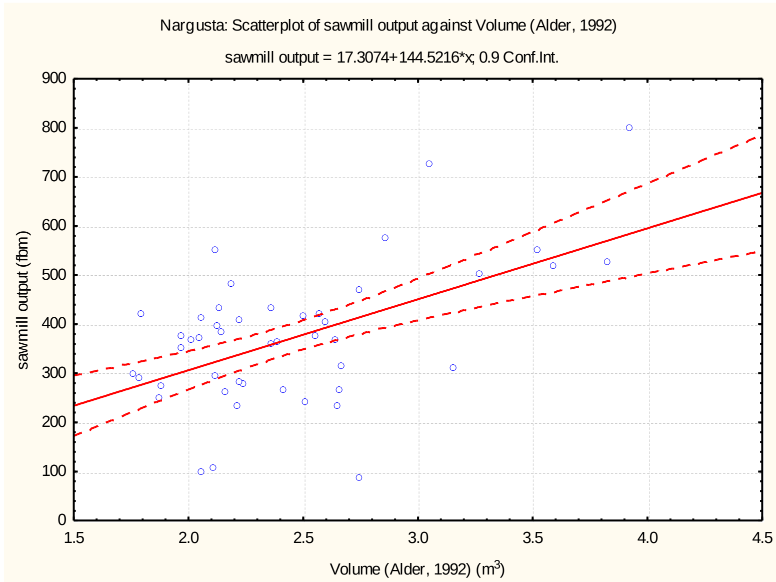


Figure 34 Nargusta: fitted linear regression model of roundwood converted into sawn lumber in BF against gross volume of standing trees in m³; $F_{1,44}$=18.519, p<.00009, R^2=0.29 and standard error of estimate = 119.96

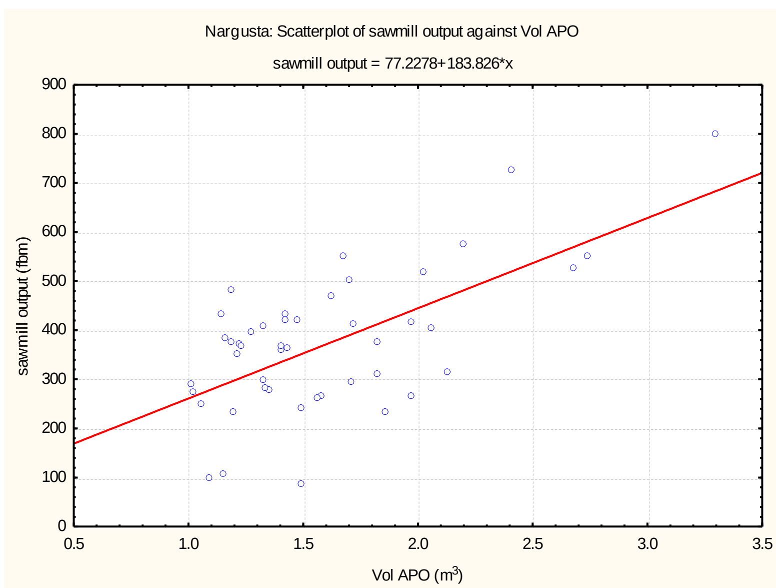


Figure 35 Nargusta: conversion of m³ roundwood according to the set of APO equations into sawn lumber in BF. $F_{1,44}$=30.496 p<.00000 and R^2=0.41

For nargusta, the actual conversion from m³ roundwood according to the APO set of equations into BF sawn lumber was examined by using linear regression as shown in Figure 35. Based on this linear relationship the conversion factor varies between 261 BF/m³ for small logs of 1 m³ and 203 BF/m³ for big logs of 4 m³. The mean 2016 log volume according to the APO set of equations amounted to 1.6 m³, which would yield 232 BF/m³. The recovery against the APO

Volume was 55% on average, while it was 63% against the sawmill input as measured at the sawmill gate.

3.3.6 Estimated net extractable volume and estimated sawn lumber volume

The standing volumes reported in section 3.3.5 were converted into net extractable volumes (sawmill input) using the relationships described for mahogany, cedar and nargusta in the previous section. For barbajolote, rosewood, sapodilla and santa maria pooled data of the three species above are used. Conversion from roundwood into estimated sawn lumber builds upon the relationships described for mahogany, cedar and nargusta in the previous section.

As described above the fitted regression functions predict the dependence of *Y* on *X* and the standard error of the estimate allows calculation of confidence intervals for the parameter being estimated. Confidence intervals were calculated for the predicted values of the sawmill input and sawmill output for each plot using standard mathematical statistical (biometric) methods (e.g. Zar, 1974). Subsequently, the standard error of the mean of the lower confidence values of the predicted values was determined for both sawmill input and sawmill output. This means that both the standard error in the conversion factor and the general sampling standard error of the mean are discounted for.

The figures in Tables 29 and 30 indicate the estimated available volumes ≥30 cm dbh and ≥50 cm dbh per year and for the entire cutting cycle. Not all trees above 50 cm dbh can be harvested because trees ≥90 cm dbh may not be harvested, 100 (200 in case of mahogany) seed trees must be retained in each annual cutting area (1,000 ha) and a variable number of trees between 55 (50) cm and 90 cm dbh have to be retained depending on the density of 'future' trees (10)20-50(55) cm dbh to guarantee a 'sustainable[6]' harvest volume.

It should be noted that the reliable minimum estimates for the gross volume are relatively higher for mahogany, nargusta and sapodilla. This is caused by a more even distribution of those species across the sample plots; i.e. the production forest. The reliable minimum estimates for the sawmill input and output are relatively high for mahogany in comparison with the other species; particularly cedar and nargusta. This is caused by the greater sample of chain of custody records for mahogany.

[6] In Belize sustainability of the harvest is limited to two cutting cycles only because there is inadequate information on regeneration densities and mechanisms to determine adequate, non-detrimental criteria that would guarantee sustainability of harvests on the long term.

Table 29 Estimated gross standing volume, net extractable volume and sawn lumber output of trees ≥30 cm dbh for BRL species of interest and reliable minimum estimates for the general annual cutting area of 1,000 ha (top) and the entire production forest area of 35,759 ha (bottom). Reliable minimum estimates (RME*) of sawmill input and output volumes consider the standard error of the predicted values for each sample plot and subsequently the standard error of the mean of the minimum predicted values; the latter is more or less equal to the standard error for the mean gross volume.

Trees ≥30 cm dbh	Annual cutting area: 1,000 ha						
	Gross Volume (m^3)	SE of mean Gross Volume (%)	RME Gross Volume (p=.95) (m^3)	Sawmill input (ft^3)	RME* Sawmill input (ft^3)	Sawmill output (BF)	RME* Sawmill output (BF)
Mahogany	6,103	10%	5,088	128,458	98,125	845,524	628,507
Cedar	1,499	32%	709	35,196	13,362	221,940	53,376
Barbajolote	1,590	20%	1,065	34,193	21,009	225,282	132,478
Rosewood	91	59%	3	2,169	59	12,534	417
Nargusta	10,997	12%	8,824	238,661	119,365	1,693,599	870,538
Sapodilla	6,631	13%	5,245	139,732	103,888	945,203	680,048
Santa maria	1,196	16%	871	26,150	17,192	165,802	103,970
Trees ≥30 cm dbh	Production forest area: 35,759 ha						
	Gross Volume (m^3)	SE of mean Gross Volume (%)	RME Gross Volume (p=.95) (m^3)	Sawmill input (ft^3)	RME* Sawmill input (ft^3)	Sawmill output (BF)	RME* Sawmill output (BF)
Mahogany	218,245	10%	181,948	4,593,537	3,508,840	30,235,122	22,474,812
Cedar	53,612	32%	25,336	1,258,592	477,818	7,936,356	1,908,675
Barbajolote	56,858	20%	38,079	1,222,709	751,268	8,055,865	4,737,294
Rosewood	3,246	59%	99	77,578	2,094	448,201	14,909
Nargusta	393,252	12%	315,534	8,534,278	4,268,368	60,561,477	31,129,586
Sapodilla	237,110	13%	187,557	4,996,676	3,714,932	33,799,547	24,317,869
Santa maria	42,784	16%	31,139	935,085	614,759	5,928,917	3,717,856

Table 30 **Estimated gross standing volume, net extractable volume and sawn lumber output of trees ≥50 cm dbh for BRL species of interest and reliable minimum estimates for the general annual cutting area of 1,000 ha (top) and the entire production forest area of 35,759 ha (bottom). Reliable minimum estimates (RME*) of sawmill input and output volumes consider the standard error of the predicted values for each sample plot and subsequently the standard error of the mean of the minimum predicted values; the latter is more or less equal to the standard error for the mean gross volume**

Trees ≥50 cm dbh	Annual cutting area: 1,000 ha						
	Gross Volume (m^3)	SE of mean Gross Volume (%)	RME Gross Volume (p=.95) (m^3)	Sawmill input (ft^3)	RME* Sawmill input (ft^3)	Sawmill output (BF)	RME* Sawmill output (BF)
Mahogany	2,890	15%	2,158	59,022	42,693	404,287	289,653
Cedar	1,205	39%	431	26,638	9,359	180,473	45,781
Barbajolote	1,053	24%	643	21,710	12,885	151,157	86,679
Nargusta	6,932	17%	5,025	151,793	89,000	1,031,564	611,767
Sapodilla	4,695	16%	3,454	96,038	68,918	677,971	477,241
Santa maria	369	33%	169	7,630	3,413	51,611	22,781
Trees ≥50 cm dbh	Production forest area: 35,759 ha						
	Gross Volume (m^3)	SE of mean Gross Volume (%)	RME Gross Volume (p=.95) (m^3)	Sawmill input (ft^3)	RME* Sawmill input (ft^3)	Sawmill output (BF)	RME* Sawmill output (BF)
Mahogany	103,351	15%	77,170	2,110,555	1,526,655	14,456,902	10,357,699
Cedar	43,094	39%	15,429	952,556	334,653	6,453,545	1,637,078
Barbajolote	37,660	24%	22,999	776,338	460,773	5,405,216	3,099,570
Nargusta	247,892	17%	179,682	5,427,986	3,182,559	36,887,716	21,876,180
Sapodilla	167,900	16%	123,501	3,434,225	2,464,424	24,243,584	17,065,665
Santa maria	13,210	33%	6,044	272,847	122,054	1,845,559	814,620

3.3.7 Comparison with stock surveys (APO)

The results from the general inventory were compared with the results of the annual stock surveys over the period 2010-17. The minimum diameter limits for the pre-harvest inventory of the target species changed frequently over this 8 year period (see Table 31).

Table 31 **Minimum diameter inventoried (MDI) for stock surveys over the period 2010-17**

Species	2010 (cm)	2011 (cm)	2013 (cm)	2014 (cm)	2015 (cm)	2016 (cm)	2017 (cm)
Barbajolote	60	70	45	30	25	25	25
Cedar	55	55	40	30	25	10	10
Mahogany	50	50	40	30	10	10	10
Nargusta	50	55	30	30	25	25	25
Rosewood	30	35	25	25	25	25	25
Santa Maria	50	50	35	30	25	25	25
Sapodilla	X	60	55	50	25	25	25

The comparison between the stock surveys and the general inventory casts serious doubts on the reliability of the general inventory; not only are the stem densities in the size class 10-25 cm dbh much higher according to the general inventory as mentioned earlier (only verifiable in case of mahogany and cedar; Figures 43 and 44), stem densities in the size class ≥30 cm dbh seem inflated for barbajolote, nargusta, santa maria and sapodilla according to the general inventory (see Figures 36 to 42). Only the stem densities of cedar and rosewood seem to be in line with the stock surveys for all size classes ≥30 cm dbh. The stem densities of mahogany are also in line with the exception of the size class 30-40 cm dbh which seems to be overestimated by the general inventory.

The higher stem density of barbajolote and santa maria in the general inventory could be attributed to the greater spatial variation in stem density of these two species as indicated by their greater standard errors (see Table 17), but the astonishing difference in population structure of nargusta and sapodilla between the general inventory and the stock surveys cannot be explained easily.

Yet, the stem densities of harvestable trees (dbh ≥50 cm dbh) do not differ for mahogany, cedar, barbajolote, santa maria and rosewood. However, this does not apply to nargusta or sapodilla; both species have considerably less harvestable trees according to the stock surveys than indicated by the general inventory.

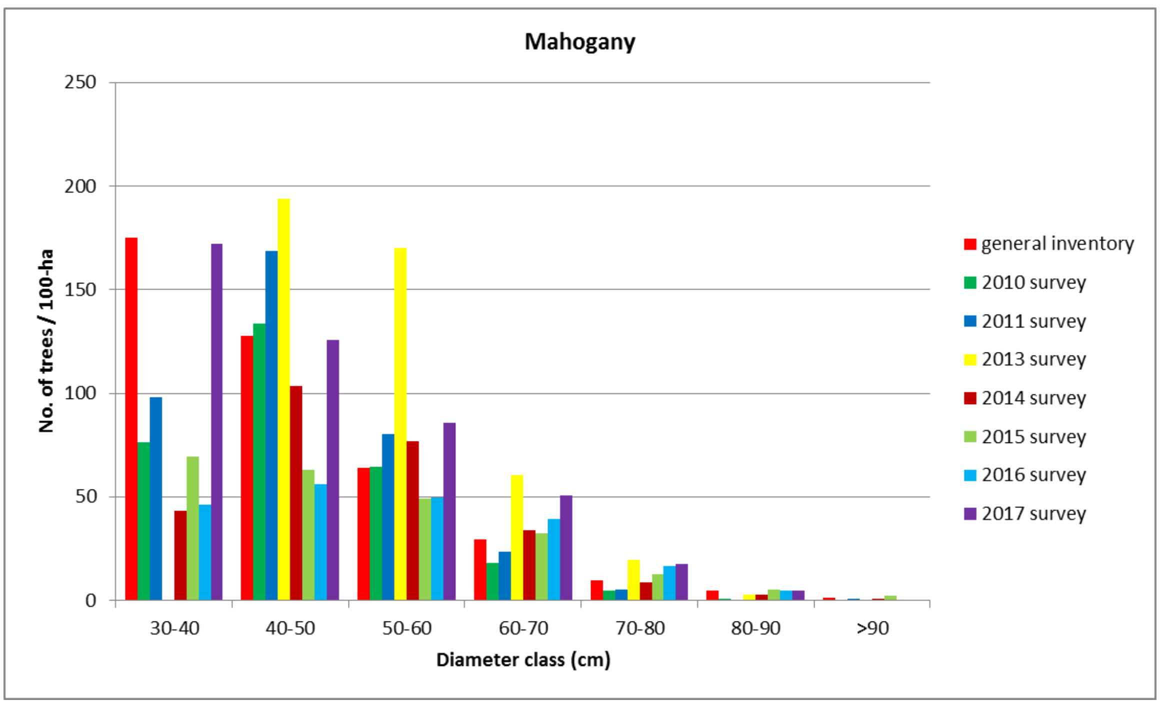


Figure 36 Stem density per 100-ha of mahogany in 10-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2010-17

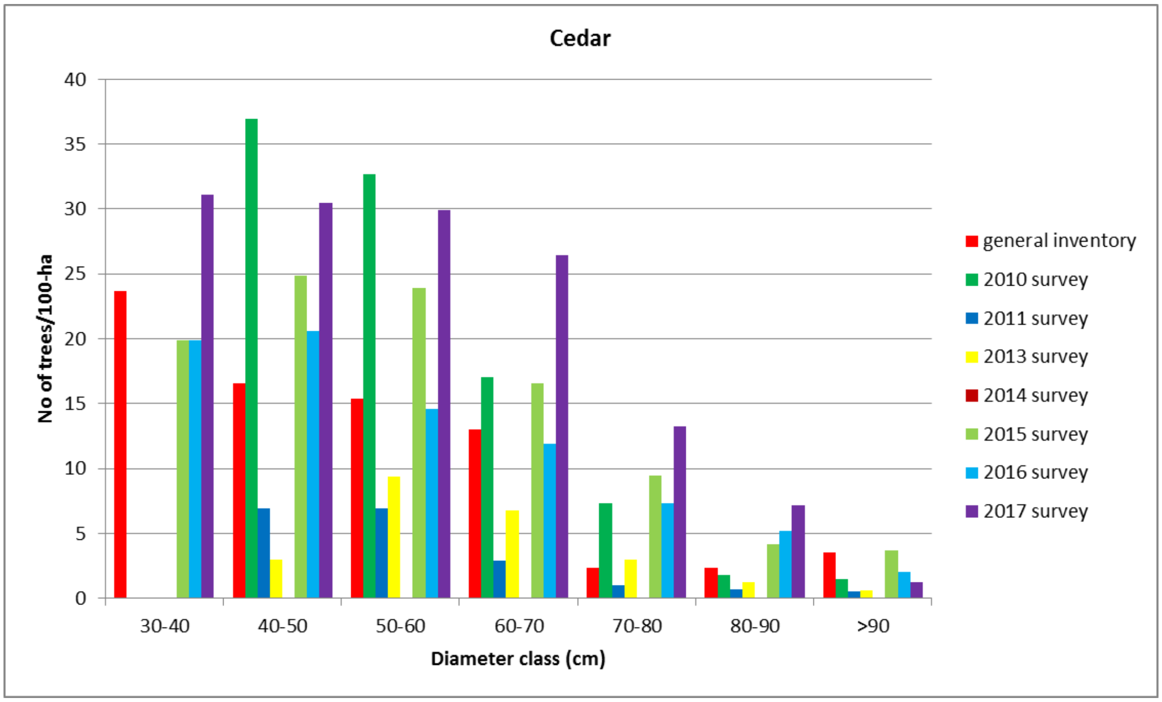


Figure 37 Stem density per 100-ha of cedar in 10-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2010-17

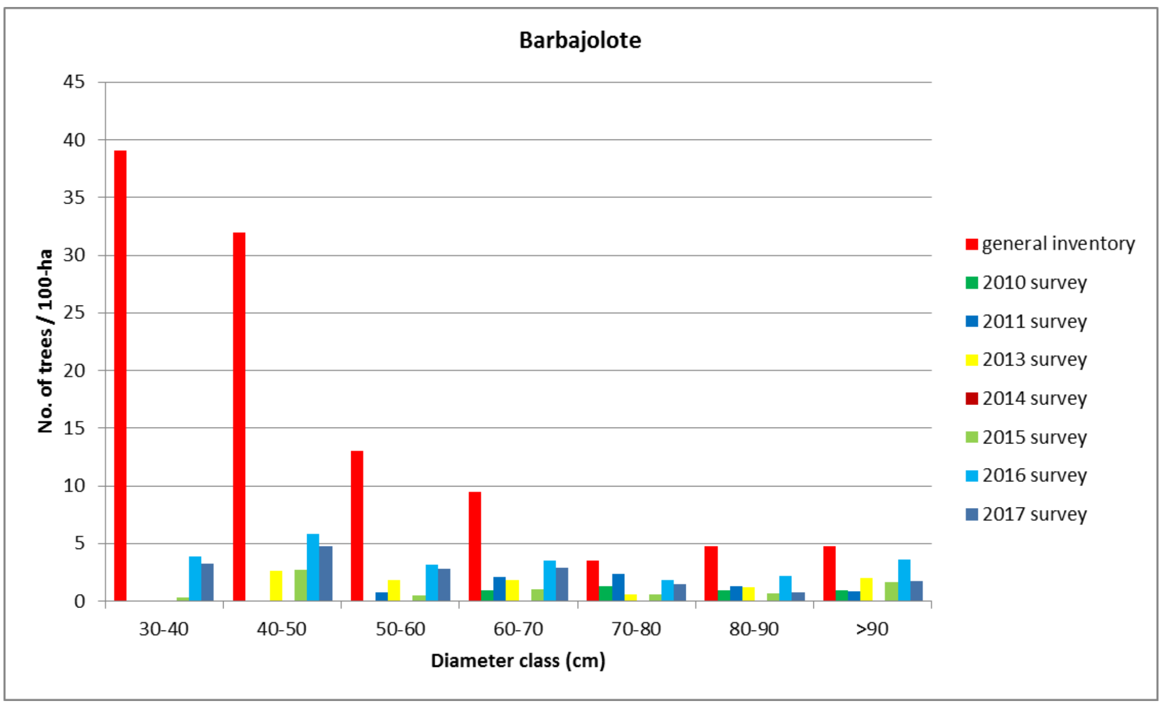


Figure 38 Stem density per 100-ha of barbajolote in 10-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2010-17

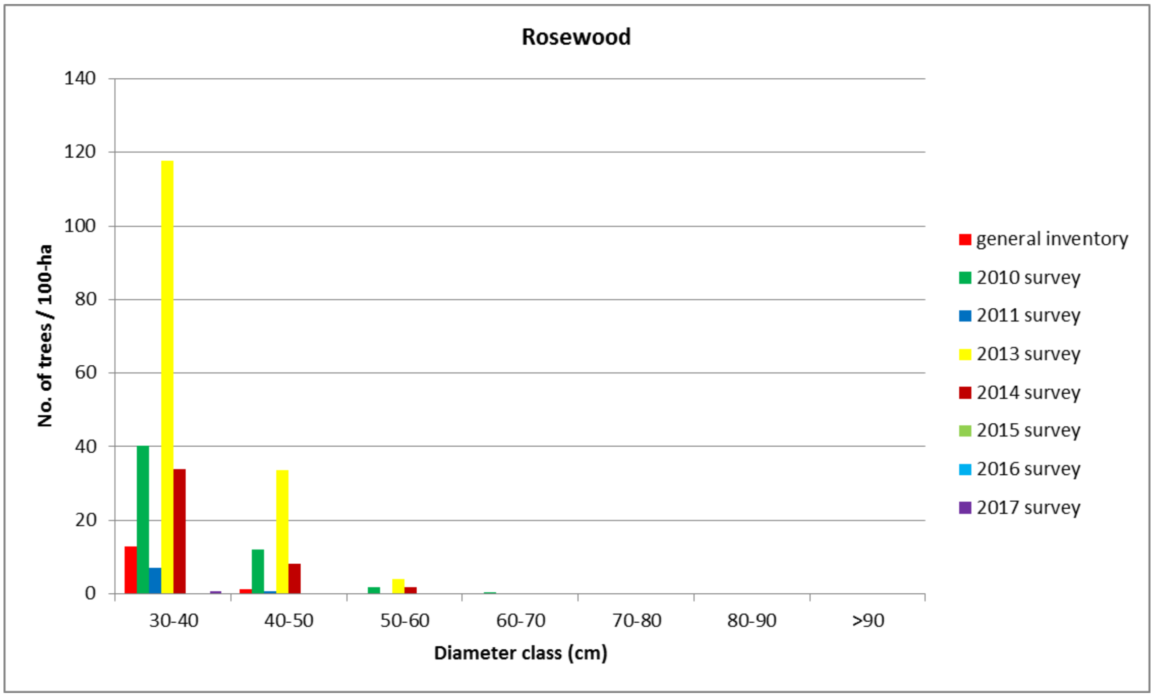


Figure 39 **Stem density per 100-ha of rosewood in 10-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2010-17**

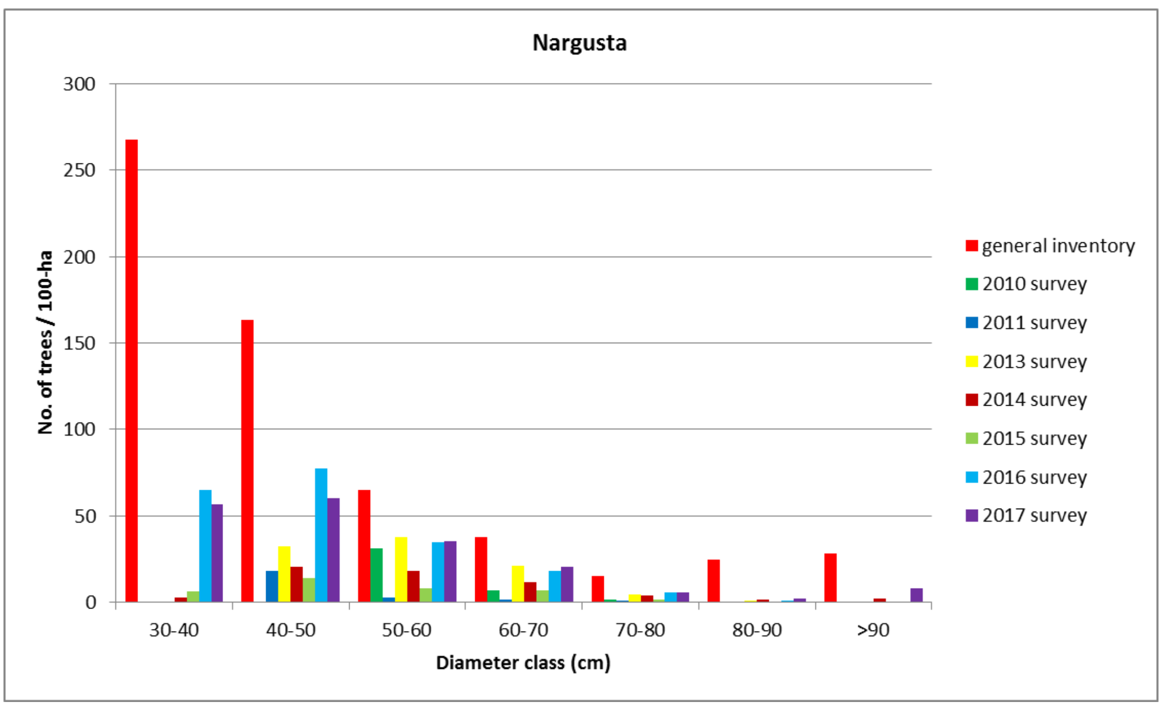


Figure 40 **Stem density per 100-ha of nargusta in 10-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2010-17**

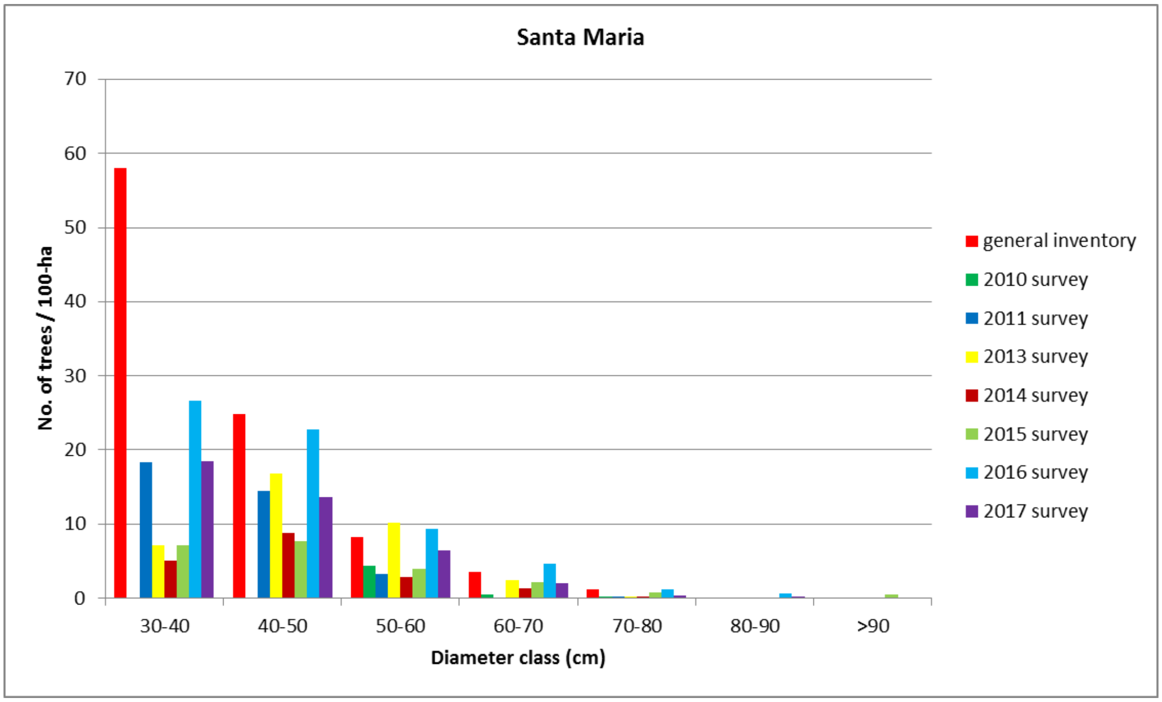


Figure 41 **Stem density per 100-ha of santa maria in 10-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2010-17**

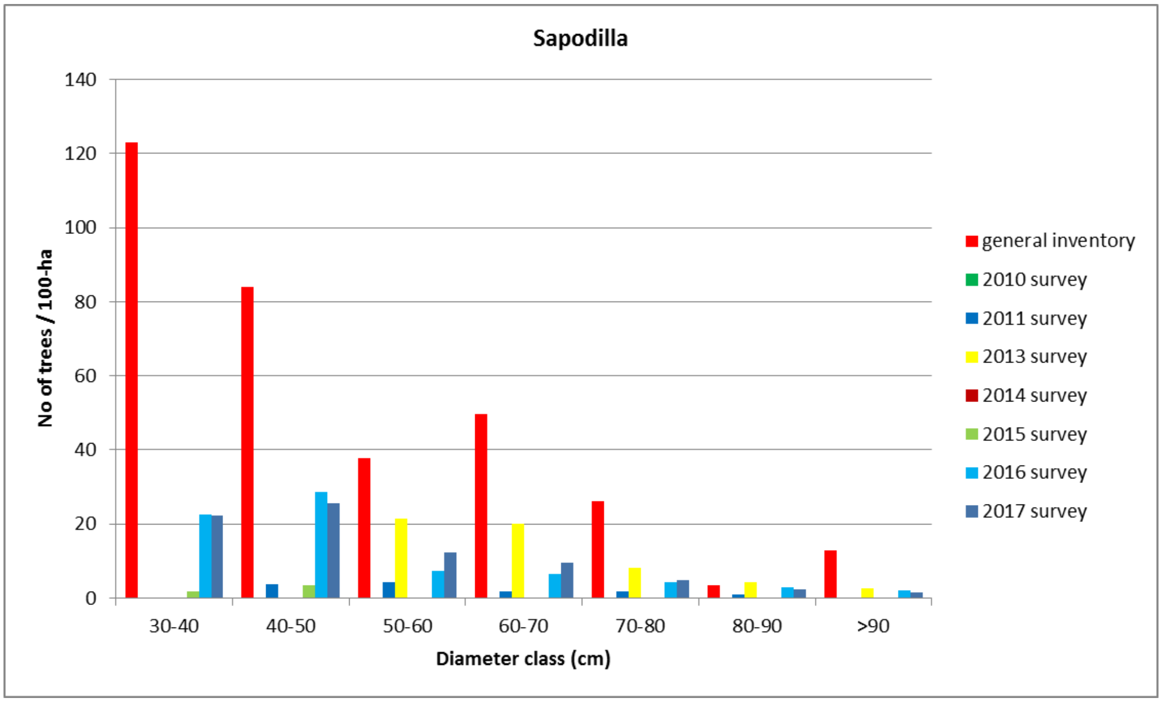


Figure 42 **Stem density per 100-ha of sapodilla in 10-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2010-17**

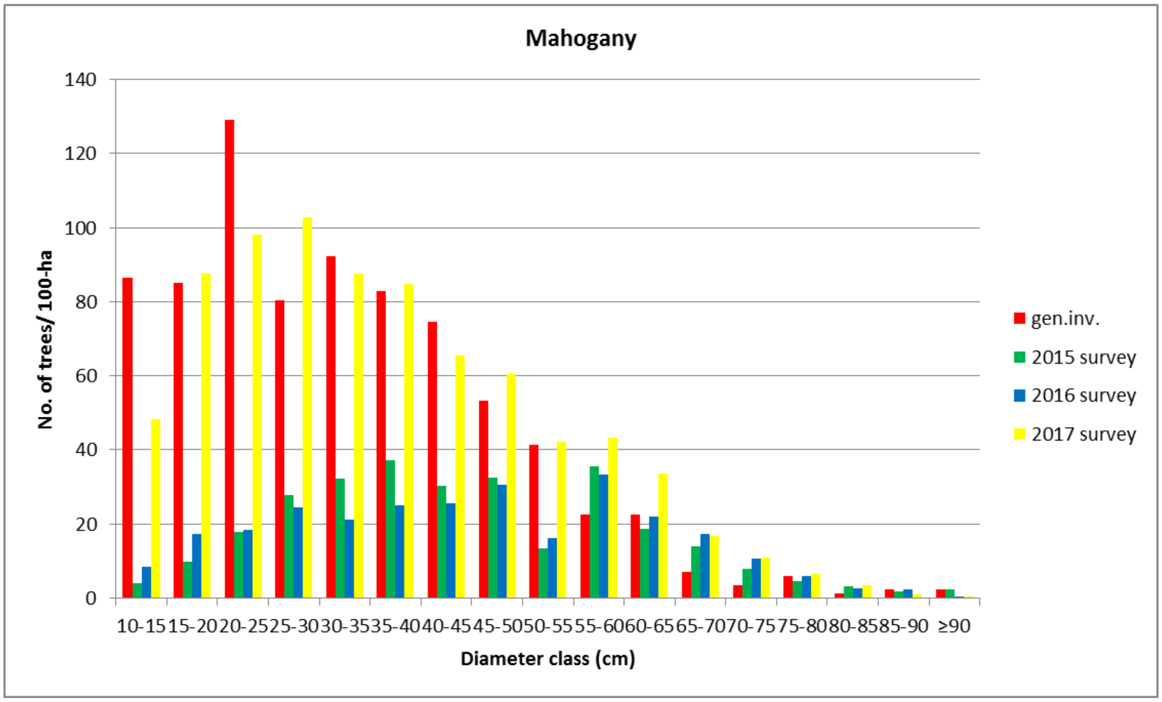


Figure 43 Stem density per 100-ha of mahogany in 5-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2015-17

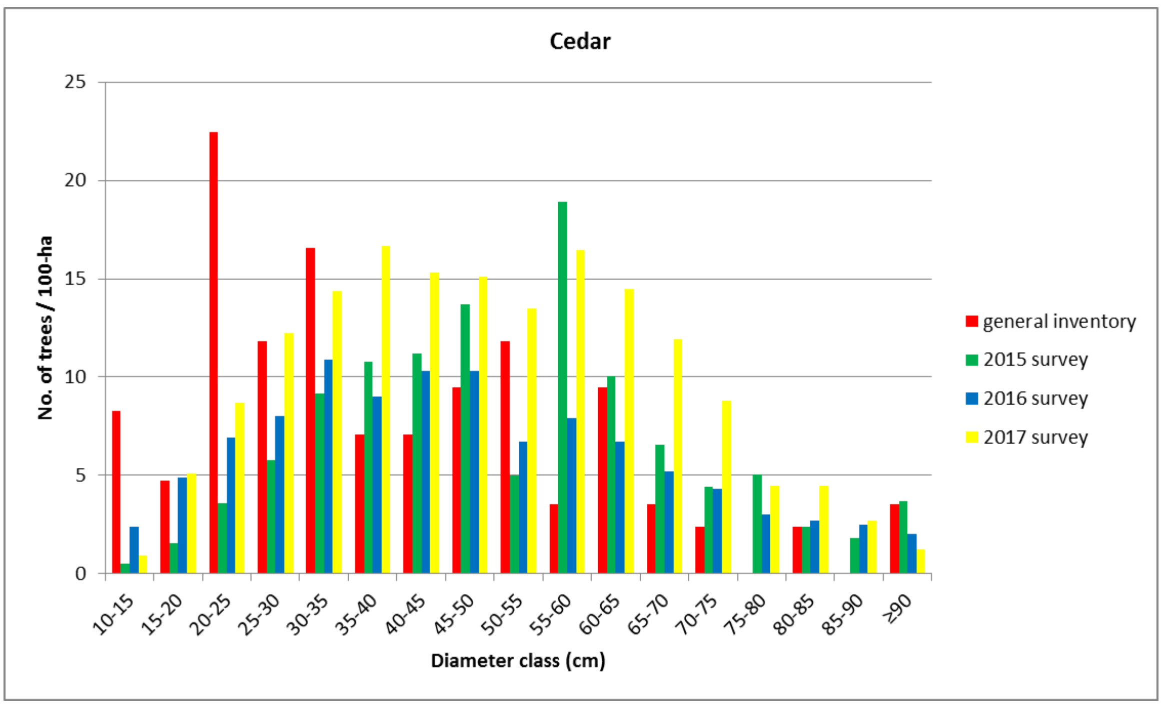


Figure 44 Stem density per 100-ha of cedar in 5-cm size classes according to the general inventory and according to stock surveys of the annual cutting area (c. 1,000 ha) over the period 2015-17

3.3.8 Spatial distribution of mahogany across the reserve

Harvestable mahogany trees

Special attention was paid to the spatial distribution of mahogany across the reserve. The inventory suggests that harvestable mahogany trees – here defined as trees ≥50 cm dbh – occur mainly in the northern, south-eastern and south-western parts of the production forest. There seem to be few harvestable trees in the central western and southern part. However, it must be noted that the 2011 sample plots in the southern part were neither evenly nor randomly distributed. Their distribution suggests that the plots were selected based on their vicinity to the existing road network. There is a scarcity of plots in the central western part while plots are completely absent south of the Chiquibul River and in compartments 58 and 59; compartments that were harvested in 1997 and 2007 respectively.

Harvesting took place since the general inventory in compartments 3, 4, 9, 10, 11, 15, 19, 20, 45, 61 and 62 and a considerable proportion of the mahogany trees depicted in Figure 23 will consequently have been removed. It is interesting to note that harvestable trees were found in compartments 52, 53 and 35. These could be seed trees or preserved trees that have been retained during harvesting but could also be reserved trees that have surpassed this diameter limit.

Reserve mahogany trees

Mahogany trees in the size class 25-50 cm dbh follow the spatial distribution of the harvestable trees with the difference that portray (much) higher densities, particularly to the southeast of the San Pastor Pine ridge and north and northeast of Millionario. Just as with the trees ≥50 cm dbh a dearth of mahogany reserve trees is indicated in the central western and southern part, but this may be misleading due to the scarcity of plots in the central western part while plots are completely absent south of the Chiquibul River and in compartments 58 and 59. It should also be noted that the sampling intensity was a mere 0.23% and the 10% Standard Error applies to the entire sample and not at the compartment level. The indicated spatial distribution should therefore be taken with caution.

The very high suggested densities in the 25-50 cm dbh class in harvested compartments 52, 53, 35 and 61 warrants a further examination of these compartments with a view to validating the 40-yr cutting cycle. The 40-yr cutting cycle is based on an average diameter increment rate of 0.5 cm/yr. The general inventory reinforces the observation made elsewhere that mahogany canopy trees may be growing at a rate twice as high, particularly after logging and vine cutting. This probably also applies to compartments 58-60, harvested 1997-2008, although this could not be ascertained due to the lack of sample plots. Field observations by the Forest Department in compartment 58 (Usher, 2017 pers.comm.) confirm possible growth rates of mahogany of up to 2 cm/yr.

Future trees

Future mahogany trees in the size class 10-25 cm dbh show a similar spatial distribution with lower densities than the 25-50 cm dbh class, although regeneration appears strong particularly in the northern part of the reserve. This may reflect large-scale disturbance since hurricane Hattie, such as fires, but could also be linked to repeated logging in this relatively easily accessible portion of the reserve during 1955-1985 according to the Forest Department (Usher, 2017 pers.comm.).

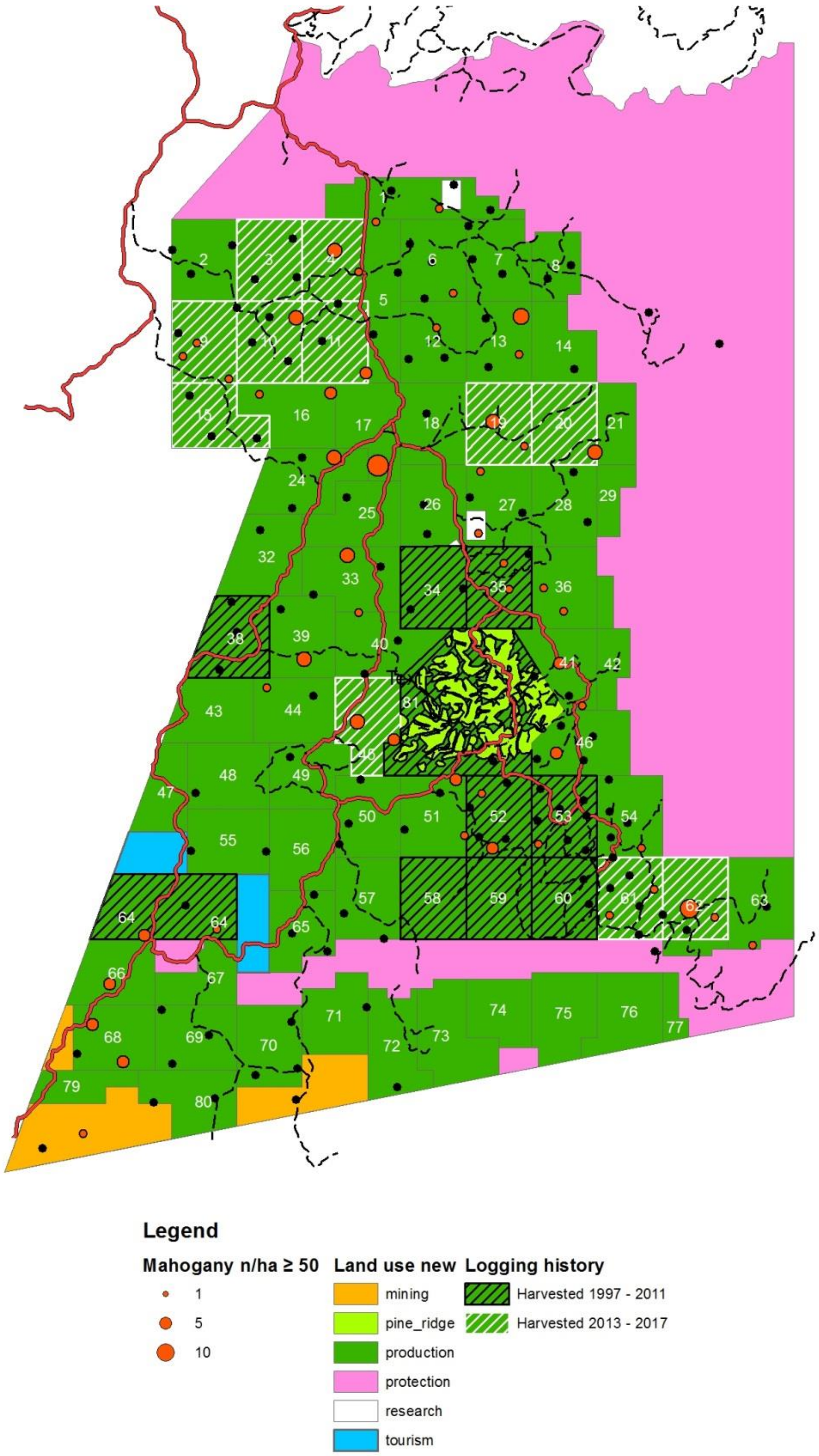


Figure 45 Spatial distribution of harvestable mahogany trees (≥50 cm dbh) as found in the general inventory. Note that trees in recently harvested compartments (2013-17) may have been harvested since the inventory. Black dots are plots devoid of mahogany

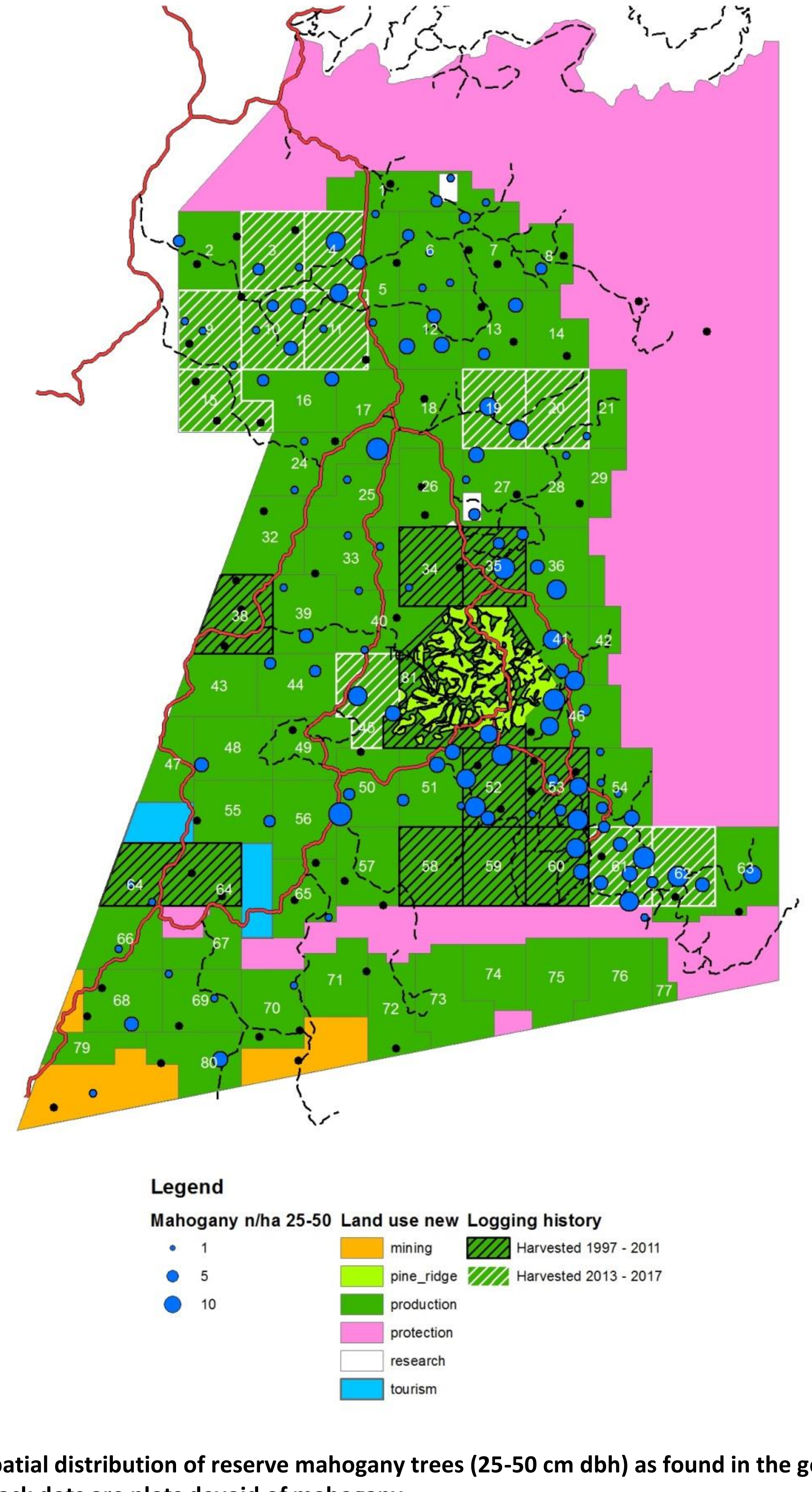


Figure 46 Spatial distribution of reserve mahogany trees (25-50 cm dbh) as found in the general inventory. Black dots are plots devoid of mahogany

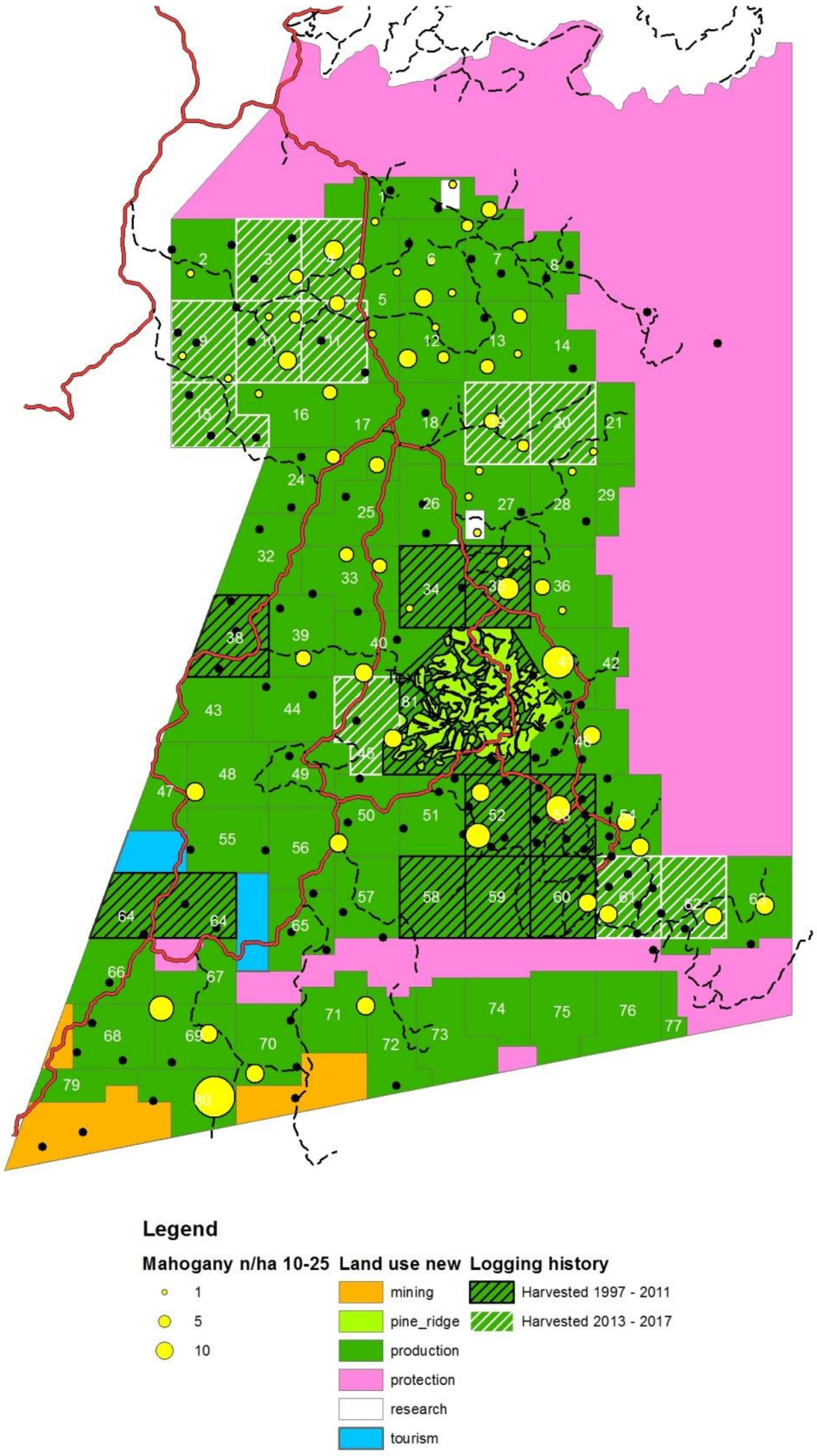


Figure 47 Spatial distribution of future mahogany trees (10-25 cm dbh) as found in the general inventory. Black dots are plots devoid of mahogany

3.3.9 Evaluation of the 2011/14 general forest inventory

Comparison of the outcome of the 2011/14 general forest inventory with the findings of Johnson and Chaffey (1973) and the outcomes of stock surveys of the annual cutting areas (c. 1,000 ha on average) over the period 2010-17 casts serious doubts on the reliability of this general inventory. This clearly applies to the size class 10-25 cm dbh which was supposed to be subsampled over 20% of each sample plot. It is clear that the implementation of the sampling design was erratic with the 10-25 cm dbh size class sometimes being sampled over the entire plot, sometimes in the subplot only. Moreover, this erratic implementation apparently varied by species, while there were no clear patterns that could indicate which species was sampled at which level in this size class. It was therefore decided not to consider the findings concerning this size class any further, particularly when determining sustained yield (Section 5).

Nevertheless, the general inventory shows that BRL is targeting common, well distributed species with substantial harvestable volumes. Mahogany, as a CITES Appendix II listed species, is well represented and distributed and does not appear to be threatened in the slightest way regarding the low proportion of trees that may be cut. Cedar and barbajolote have lower but adequate standing volumes, while volumes of santa maria and rosewood appear be of no more than marginal commercial interest. BRL may consider exploring the market potential of white breadnut and black cabbage bark, given the observation that these species show acceptable standing volumes.

Comparison of the 2011/14 inventory with the inventory of Johnson & Chaffey of 1969 shows that mahogany has made a strong recovery after the species had been as good as annihilated in 1969. As a matter of fact all species of interest to BRL have shown a strong increase in stem density in all size classes, except for cedar and sapodilla. Although there are some doubts on the high estimated volumes of nargusta and sapodilla, harvestable volumes of mahogany, cedar, barbajolote and santa maria have strongly recovered from decades of overharvesting and hurricane Hattie in 1961 followed by forest fires.

Stratification by soil type (karstic against acidic soils) and by logging history (logged between 1997 and 2011 against unlogged since 1985) did not show any major differences between soil types or logging history. In the size class ≥30 cm, mahogany, barbajolote, rosewood and nargusta show a preference for acidic soils, while cedar, sapodilla and santa maria seem to have no preference. The difference proved significant for mahogany, rosewood and nargusta for the size class ≥30 cm.

Logging did not have any major effect either. In the size class ≥30 cm cedar and barbajolote had fewer trees in the logged compartments; mahogany did not differ, while rosewood, nargusta, sapodilla and santa maria all had fewer trees in the unlogged compartments. None of the differences in stem densities proved significant and differences may also be attributable to other factors. Mahogany, cedar, barbajolote and santa maria had, as to be expected, fewer trees in the size class ≥50 cm in the logged compartments, while the other species, unexpectedly, showed the opposite. However, none of the differences in stem densities proved significant and differences may also be related to other factors.

The analysis of the general inventory used volume equations developed by Alder (1992a) to estimate the standing volume of the sample trees. During the inventory, stem quality and bole length were assessed on the sample trees besides diameter at breast height. However, those assessments were not considered here because this would introduce two additional stochastic parameters, i.e. bole length and stem quality, each with its own population distribution and variance for each single tree diameter. In order to use these assessments to estimate volumes the standard error of the mean tree height and mean stem quality class relative to each tree diameter (class) would need to be assessed. Instead, actual 2016 sawmill input and output records from the BRL sawmill are used to convert diameter measurements on standing trees into extracted roundwood and sawn lumber volumes.

The standing volumes emanating from the general inventory were converted into net extractable volumes (sawmill input) and sawn lumber (sawmill output) based on linear regression models for mahogany, cedar and nargusta. The theoretical annually available sawmill lumber output based on the density of trees ≥50 cm dbh is estimated at c. 400,000 BF (minimum c. 290,000 BF) for mahogany, c. 180,000 BF (minimum c. 46,000 BF) for cedar, c. 150,000 BF (minimum c. 87,000 BF) for barbajolote, c. 1,000,000 BF (minimum c. 610,000 BF) for nargusta, c. 680,000 (minimum c. 480,000 BF) for sapodilla and c. 50,000 BF (minimum c. 23,000 BF) for santa maria. The estimates for nargusta and sapodilla are not very trustworthy due to suspicious general inventory estimates. Not all trees above 50 cm dbh can be harvested because trees ≥90 cm dbh may not be harvested; 100 (200 in case of mahogany) seed trees must be retained in each annual cutting area (1,000 ha); and a variable number of trees between 55 (50) cm and 90 cm dbh have to be retained depending on the density of 'future' trees (10)20-50(55) cm dbh to guarantee a 'sustainable' harvest volume at the subsequent harvest.

Examination of the 2016 sawmill input and output revealed that the Forest Department prescribed set of equations to calculate volumes results in tree volumes that correspond closely to the sawmill input (net extracted) roundwood volumes. The application of the prescribed set of equations hence generates adequate results and should be maintained. This cannot be said about the official conversion factor to estimate BF sawn lumber from m^3 roundwood. The

Forest Department recently reduced the conversion factor from 212 to 169 BF/m³ (APO volume). The actual conversion factor (2016 harvest) appears to be 240 BF/m³ (222-252 BF/m³ depending on the tree diameter) in case of mahogany sawn lumber; 198 BF/m³ in case of cedar and 232 BF/m³ (261-203 BF/m³ depending on the tree diameter) in case of nargusta.

There are serious concerns about the reliability of the general inventory; not only are the stem densities in the size class 10-25 cm dbh much higher according to the general inventory as mentioned earlier, stem densities for the size classes ≥30 cm dbh also seem inflated for barbajolote, nargusta, santa maria and sapodilla. Only the stem densities of cedar and rosewood seem to be in line with the stock surveys for all size classes ≥30 cm dbh, and in case of mahogany for the size classes ≥40 cm dbh.

Yet, the stem densities of harvestable trees (dbh ≥50 cm dbh) appear accurate for mahogany, cedar, barbajolote, santa maria and rosewood, but not for nargusta or sapodilla; both species have considerably less harvestable trees according to the stock surveys than indicated by the general inventory.

3.4 Pre-harvest inventory

3.4.1 General description of the pre-harvest inventory

The pre-harvest inventory or stock survey methodology follows the established protocol of dividing the compartment into transects 100 m wide and surveying all trees of the target species above the minimum inventory diameter within the compartments forming the annual cutting area. Each tree is assessed for species, diameter, crown height, form class, crown position and crown form (sensu Dawkins) and degree of vine infestation. The location of each tree is mapped by GPS with ± 3 metres accuracy.

The pre-harvest inventory has three principal objectives: to identify the potential crop trees for the current harvest; to identify potential crop trees for the next harvest and to identify seed trees to guarantee sufficient regeneration in the longer term. The latter two objectives are as important as the first. In polycyclic felling a sustained yield depends on there being a sufficient number of established trees remaining in the residual stand to form a significant part of the next timber harvest. The marking of immature crop trees (the reserve trees) to ensure their protection during the current felling operation is therefore an important element of the stock survey operation. This objective is met by paint-marking all healthy reserve trees.

The location of the annual compartment is determined from a reconnaissance of preselected compartments. The UTM co-ordinates are read from the Forest Management Map for each corner of the compartment and an assessment is made to determine the point of easiest access. This starting point is found in the field using a global positioning system (GPS) receiver. The compartment boundaries are then established by cut lines, with the cut line direction maintained by compass sight. This line is cleaned so that it is well defined and easy to walk along. Clearly marked off-sets are made around large trees. A slope correction is made whenever the angle of slope exceeds 5°. This adjustment is made by step chaining, where short distances are measured whilst the survey tape is kept horizontal. The directions of the compartment boundaries are given on the Forest Management Map. Most boundaries are aligned on the cardinal bearings. At each corner of the compartment boundary the UTM position is confirmed using the GPS unit.

The annual compartment is then divided into 100 x 125 m harvesting quadrats (or sub-compartments) and cut lines are made to define these internal boundaries. For each quadrat stakes are placed at 100-m intervals along the northern and southern boundaries. Stakes are placed at 20-m intervals along the eastern and western boundaries; with double stakes set at every 100 m. Cut lines are then made within each quadrat from south to north linking the 100-m stakes. These lines are lightly cut, yet opened sufficiently to allow easy access. Stakes are again placed at 20-m intervals, with double stakes at 100 m intervals. Each harvesting block is thus defined by ten parallel transects of 1,250 x 100 m.

Potential crop trees, seed trees and future trees are mapped and measured. All trees over the MCDL are tagged with flagging tape and labelled with a sequential number which is painted onto the stem. Seed trees are selected afterwards based on crown position and crown form. Seed tree are marked with a red painted line. For mahogany, a minimum of 20 seed trees are allocated per 100 ha. For other species 100 seed trees are selected per 100 ha.

The minimum diameter limits for the pre-harvest inventory have changed frequently over the past 10 years (see Section B 3.3.7). The 2017 official required recordings and limits are given below (Figure 48).

The FD General Yield Model version 3 is used to determine crop trees, reserve trees and seed trees. Reserve trees may be selected from the potential crop trees to guarantee a sustained yield. The General Yield Model is described in Section B 5 ‘Yield Regulation and Production’. The Yield Model may be updated during the validity period of this management plan.

After the crop trees have been selected, the final crop trees in collaboration with the Forest Department. Any anomalies on the stock map are identified and each tree is double-checked to ensure that it is suitable for felling. A red paint mark is made at breast height so that it is clearly visible to the licensee's felling gangs. A broad line is also painted from the dbh paint band down to ground level. This ensures that each stump has a paint mark, acting as a further control to be checked during the post-harvest inspection. The final crop tree is then hammer stamped by the forest guard at a prominent position close to the base of the tree, formally releasing the tree for felling.

Any climbers on the stem of all crop, seed and reserve trees are cut. The proposed direction of all the indicative skid trails is also assessed and any alterations required due to local site conditions are marked on the stock map.

3.4.2 Pre-harvest inventory requirements

Applicable rules

The pre-harvest stock survey is carried out in the proposed annual cutting area in the year prior to harvesting. The aim is to measure and map the growing stock of all species to be included in the harvest so that the data may be analysed to estimate an allowable cut. The following set of rules will apply in each annual compartment surveyed:

1. Mahogany trees shall be enumerated and assessed down to a minimum diameter of 10 cm;
2. All other hardwood species shall be enumerated and assessed down to a minimum diameter of 25 cm, except for Sapodilla which may be enumerated and assessed down to a minimum diameter of 35 cm;
3. All trees surveyed shall be liberated from vines during the stock survey;
4. Trees shall be classified as: Crop (commercial stems ≥MCD), Future (pre-commercial stems <MCD) and Seed trees (trees of any size ≥30 cm of excellent stem and crown form; half of which must be selected from trees ≥MCD). There may also be a fourth category of Reserve trees which are trees ≥MCD but which may not have good merchantable form or quality and therefore not harvestable nor qualify as seed trees;
5. For all trees, regardless of size or function, the following shall be assessed: species, diameter at breast height and X and Y coordinates;
6. For Crop trees the following shall also be assessed: stem height to the first major branch, log grade (1 to 5), Dawkins crown form (1 to 5) (Dawkins, 1958), Dawkins crown position (1 to 5), Synnott climber presence (1 to 5, before liberation) (Synnott, 1979). The log grade, Dawkins and Synnott indices are important data to guide the selection of seed trees.
7. All diameter measurements shall be made to the nearest millimetre (0.1 cm) and all height measurements should be made to the nearest decimetre (0.1 m);
8. A layout of the survey transects within the compartment shall be provided with the stock survey data in shapefile format;

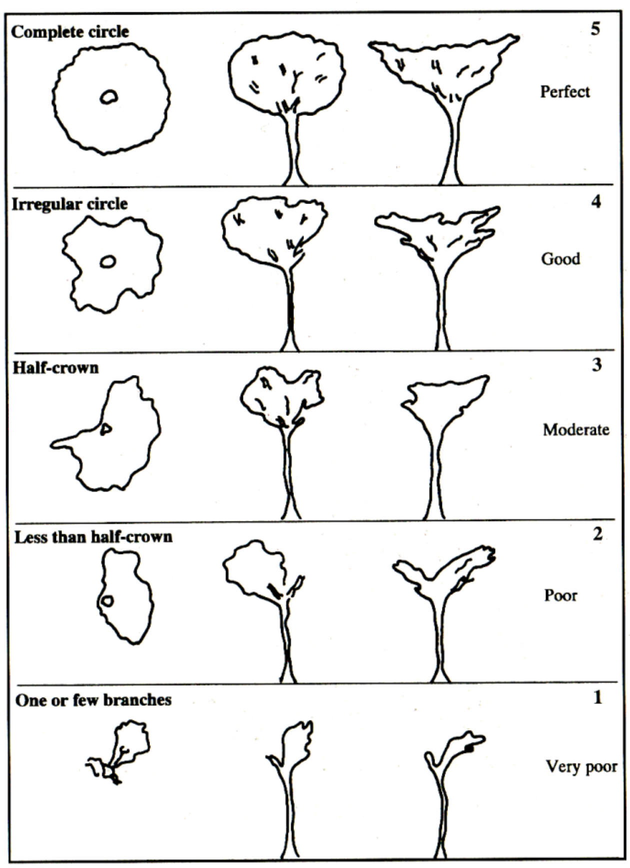
9. The stock survey data shall be presented digitally as a single Excel spreadsheet; for format see below

Log grade system

Log grade relates to the straightness and soundness of the log. A log with a grade of 1 is a straight log with no visible defects. A class 2 log has a curve that deviates more than 3 inches over 16 feet but has no other defects and can still qualify as a seed tree. A class 3 log is straight but is defected over less than 25 % of its length but can still qualify as a seed tree. A class 4 log is either: a) straight and defected over more than 25 % of its length, b) defected over less than 25 % of its length but curved by more than 3 inches over 16 feet, or c) both defected over more than 25% of its length and curved by more than 3 inches over 16 feet, and will not qualify as a seed tree. A class 5 log is forked and short.

Dawkins crown form

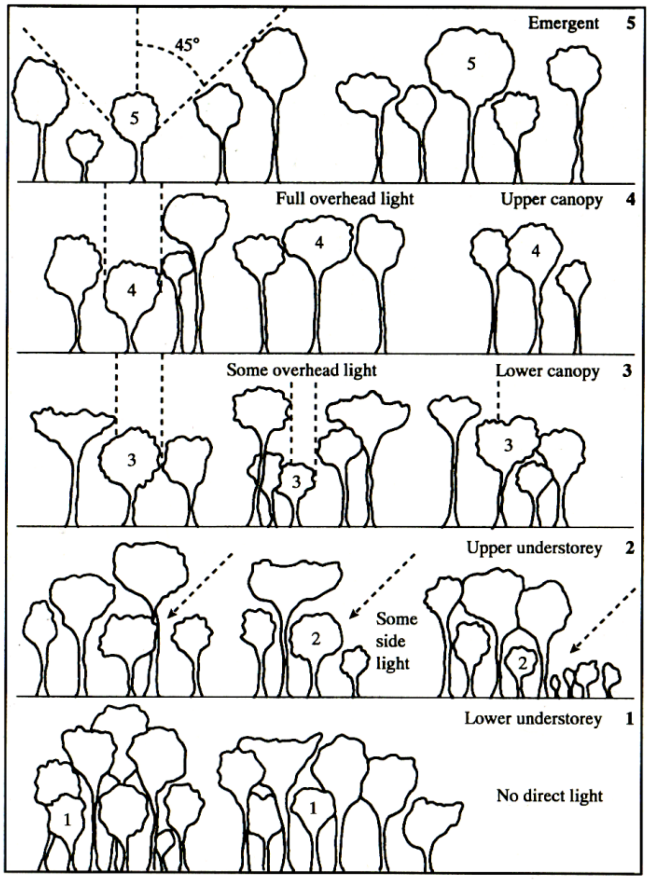
The Dawkins crown form classification



Code	Description
5	The best size and development generally seen.
4	Very nearly ideal, silviculturally satisfactory, but with some slight defect of symmetry or some dead branch tips.
3	Just satisfactory, distinctly asymmetrical or thin, but capable of improvement if given more room.
2	Distinctly unsatisfactory, with extensive die-back, strong asymmetry and few branches.
1	Definitely degenerating or suppressed, or badly damaged. No true crown present.

Dawkins crown position:

The Dawkins crown position classification



Code	Description
5	Crown plan exposed vertically, and free from competition at least within a 90° inverted cone subtended by the stem.
4	Crown plan fully exposed vertically but adjacent to other crowns of equal or greater height within the 90° cone.
3	Crown plan partly exposed vertically but partly shaded by other crowns.
2	Crown plan entirely vertically shaded but exposed to some light due to gap or edge.
1	Crown plan entirely shaded vertically and laterally.

The Synnott (1979) climber presence code classification:

Code	Description
1	Tree free from climbers
2	Climbers on main stem only, crown free
3	Climbers in crown but main stem free
4	Climbers on main stem and in crown
5	Whole crown smothered by climbers, and present on main stem

Pre-harvest inventory data recording template

Tree #	Function	Species	DBH (cm)	HC (m)	X (UTM)	Y (UTM)	Log Grade	Crown Position	Crown Form	Climber Presence
…	…	…	…	…	…	…	…	…	…	…

- Tree no. - the Tree no. shall consist of the strip number and number of the tree as it is encountered on the strip, for example 9-35, which would be the 35th tree encountered on the 9th transect. The tree number shall appear on the stump of each tree as well as on the ends of the logs.

- Function - describes the role of the tree (Crop, Future, Seed or Reserve).
- Species - the common name of the species.
- DBH - diameter at breast height (1.3 m from the ground).
- Stem height - height of the tree stem from the ground to the first major live branch.
- X (UTM) - the easting of the tree in NAD27 UTM Zone 16 coordinate format.
- Y (UTM) - the northing of the tree in NAD27 UTM Zone 16 coordinate format.
- Log grade - the numerical commercial class of the log as described above.
- Crown form - the ordinal class of the crown form as described above.
- Crown position - the ordinal class of the crown position as described above.
- Climber presence - the ordinal class indicating the level of presence of climbers as described above.

3.5 Post-harvest inventory

A post-harvest audit is conducted in collaboration with the Forest department; primarily to assess damage caused by logging operations. Post-harvest audits (PHA) are performed within 2 months after the close of logging operations. The aim is to assess compliance with the approved APO and assess forest damage. The full PHA methodology is described in the Post-harvest Audit Methodology (version 1) (Forest Department).

The PHA uses a sample of 2 hectares out of every 100 hectares. For each sub-compartment, one transect measuring 20 x 1,250 metres is assessed. The following assessments are made during the audit:

- Felled trees are verified against the stock map to ascertain whether they were approved for felling under the APO. Any tree felled that was not designated for felling, such as a Future, Reserve, Preserve or Seed Tree, is noted on the Felling Damage Form.
- Damage to residual trees is recorded using a standard recording form. All stems ≥25 cm dbh within the canopy gap including a 3-metre buffer around the perimeter of the gap are assessed for damage.
- Felling gap size: two gap width measurements are taken in order to calculate area - one along the longest axis and another perpendicular to the long axis situated at the centre. The average of these two will be the gap diameter. Area of the gap is calculated as a circle.
- Accuracy of the Stock Survey - Each standing tree with a tag or paint within the transect is verified against the stock map to ascertain correct designation as Future, Reserve,

Preserve, or Seed Tree. Likewise the existence of trees appearing on the stock map is verified in the field.

- Eligibility of Seed Trees is assessed; any discrepancy is noted.
- General Road Conditions; for each road encountered along a transect, observations are made about the road class (skid, main extraction route), condition and width.
- Residual Skidding and Hauling Damage: at the first skid trail and extraction road encountered on each transect damage to trees ≥25 cm dbh is assessed along a 50 metres length including a 3-metre buffer along both sides of the road.
- Residual Barquadier Damage; half of all barquadiers in the annual compartment are measured and assessed for damage to residual stems at the perimeter of the barquadier. The lengths of longest and shortest axes of the barquadier are measured to determine average barquadier diameter. Residual damage to stems of all species >=25 cm is assessed within a 3 metre zone around the perimeter of the barquadier.
- Social Impacts; the total number of employees/contractors of the logging company involved in the APO work and the number who live in nearby communities are recorded. Camp sites are examined for unhygienic conditions, waste pollution, etc. Safety precautions and equipment used during the logging operation are assessed. Leaders of nearby communities and adjacent land owners are interviewed to establish if there are any issues concerning road damage, safe handling of logging trucks and machinery, excessive dust, donations to communities, pollution to water sources, negative effects of burning of wood waste, or improper waste disposal.

It is important to note that long-term monitoring of logging operations requires the same methodology to be used over as many years as PHAs are to take place so that results may be comparable from year to year.

3.6 Non-timber forest resources

Bull Ridge Ltd is not involved in the exploitation of any non-timber forest resources, nor are there any other active non-timber licenses.

4 SILVICULTURAL SYSTEM

Silviculture is the science and art of controlling the regeneration, growth, composition and quality of forest vegetation to maintain or enhance production of the full range of forest goods and services, while fulfilling forest resource management objectives. Different objectives in forest resource management and different forest characteristics will lead to the adoption of different silvicultural systems. It follows then, that a silvicultural system defines the nature and timing of harvesting, regeneration, and tending of a forest to meet management objectives and maintain or enhance forest productivity, resilience and value. Silvicultural systems in natural forests are categorized broadly as either monocyclic (uniform, even-aged) or polycyclic (selective, uneven-aged). Monocyclic systems involve harvesting all marketable timber in a single felling operation, after which the forest is regenerated naturally or artificially and tended until the species under exploitation are matured and ready to be harvested again. The length of time between harvests depends on how long it takes the species to grow from seedling to harvestable size and is known as the rotation length. Polycyclic systems involve the selective harvesting of trees above a minimum cutting diameter in a continual series of harvests, between which existing saplings and poles grow to mature size during the intervening period. The length of time between harvests is usually about half the time required for the species to reach harvestable size and is known as the felling cycle.

The sustained yield is defined as the level of timber harvest which allows a constant number of trees to be felled over two felling cycles. In principle a constant annual diameter growth rate of 5 mm is assumed for all tree species and size-classes (Bird, 1998), implying that all trees move up one size-class in 40 years (the felling cycle period). In polycyclic felling a sustained yield depends on there being a sufficient number of established trees remaining in the residual stand to form a significant part of the next timber harvest. The estimated time for a tree to grow from seed to a diameter of 60 cm dbh for many species is believed to be between 80 and 120 years. Hence a felling cycle of 40 years will result in at least one return period during the life of most trees. The marking of immature crop trees (the reserve trees) to ensure their protection during the current felling operation is therefore an important element of the stock survey operation.

The silvicultural system for the Chiquibul Forest Reserve is based on the following ecological and silvicultural objectives, principles and strategies:

1. **Silvicultural Goal**: Prepare the forest for the next stand initiating event (hurricane).
2. **Silvicultural Principle**: Multiple yields may be attainable before the stand reaches a minimum stocking threshold below which stem density may be too low to withstand annual mortality plus mortality caused by the next stand initiating event such that

sufficient stems survive to allow for regeneration and stand replenishment. This threshold is termed the "restocking threshold".

3. **Silvicultural Strategy**: Determine a yield that the population can sustain at least twice before reaching the restocking threshold.
4. **Restocking threshold**: Prime and Rosewood: >=50 evenly distributed stems per square km that are >=25 cm DBH; Other species groups: >=20 evenly distributed stems per square km that are >=25 cm DBH.
5. **Ecological Goal**: Maintain or improve forest structure, forest resilience and species distribution.
6. **Ecological Principle**: The larger the tree the more it contributes to resiliency of the population through better survival and seeding.
7. **Ecological Strategy**: Leave all trees >=90 cm DBH. Future relative forest structure should shadow present relative forest structure.

4.1 Regeneration method

The regeneration method relies on natural regeneration. In this respect, it is understood that species of interest vary in their ecological guild as expressed by their seed dispersal mode, light conditions for seedling establishment and growth, and wood density (Table 32).

Table 32 Ecological traits of tree species of interest including guild, wood density and seed dispersal mode

Common name	Scientific name	Guild	Wood density (g/cm^3)	Seed dispersal
Prime				
Mahogany	(*Swietenia macrophylla*)	light-demanding	0.42-0.54	wind
Cedar	(*Cedrela odorata*)	light-demanding	0.38	wind
Elite				
Barbajolote	(*Cojoba arborea*)	light-demanding	0.58-0.74	bird
Billywebb	(*Acosmium panamense*)	light-demanding	0.81	wind
Black cabbage bark	(*Lonchocarpus castilloi*)	light-demanding	0.51	bird/wind
Rosewood	(*Dalbergia spp*)	light-demanding	0.71-0.86	wind
Select				
Nargusta	(*Terminalia amazonia*)	light-demanding	0.66	wind
Sapodilla	(*Manilkara zapota*)	shade-tolerant	0.81	mammal/bird
Santa Maria	(*Calophyllum brasiliense*)	shade-tolerant	0.54	bat/water

Mahogany, cedar and other light demanding species do not regenerate well under an intact canopy, supposedly even one heavily disturbed by logging, in sufficient numbers to replace the stocking in the harvestable diameter classes. However, there is evidence to suggest that the species regenerates profusely following hurricane disturbance. Hurricane disturbance may induce a heavy fire load and therefore be succeeded by wide spread wild fires, especially during the often intensely dry period between February and May. The general inventory shows that 53 years after hurricane Hattie, in areas where hurricane damage coincided with fire, mid-sized mahogany trees are especially abundant. Fire is reported to play an important role by temporary eliminating local populations of the mahogany shoot borer moth *Hypsipyla grandella* (Wolffsohn, 1961).

Poor regeneration after harvesting only shows the inherent conflict between impacts of harvesting or management, and the longer term distribution of species and age-classes within the forest. Higher intensity logging will create more light, improving regeneration, but increasing disturbance. Single tree selective logging as advocated in Belize will allow less light, reducing regeneration, but causing less disturbance. There may therefore be inherent trade-offs between the objectives of reducing short term environmental impact, and the longer term environmental objective of regeneration.

Other, secondary hardwoods are reported to be able to regenerate under an intact canopy and thus the standard forest management model of sustainable yield, *i.e*. the level of harvest that is replaced by natural recruitment, can be applied. Despite this, the size and structure of the pre-commercial population will determine the size of the harvest and the cutting cycle. Like mahogany, the spatial distribution of secondary hardwoods is also often patchy, leading to variable-sized populations from compartment to compartment. Because the growth pattern of secondary hardwoods differs from that of primary hardwoods, the same population size across the two groups can lead to different cutting cycles.

It is suggested to designate the cutting cycle based on the population of mahogany as the overall cutting cycle for the compartment, and apply it to all secondary hardwoods so as to adjust the harvest of each secondary species until it is sustainable at the designated cutting cycle. If the harvest of a particular secondary species cannot be made sustainable at the designated cutting cycle, then the species should not be harvested in that particular compartment.

A shortage of information on regeneration patterns and triggers means that the proposed system is preliminary. Unfortunately, the general inventory was implemented in an erratic manner and can therefor contribute little to our understanding of the evolvement of population structures of the various desirable species. Casual observations in compartment that were harvested between 1997 and 2011 suggest that canopy trees of the target species grow faster than anticipated by Neil Bird (1998) and a shorter cutting cycle may be warranted. BRL intends to carry out diagnostic sampling in these compartments to estimate appropriate cutting cycles.

4.2 Post-harvest treatments

Although there may be merit in the liberation of seedlings (Weaver & Sabido, 1997), post-harvest treatments are not regularly implemented in Belize due to the high cost and long cutting cycles. In general, silvicultural approaches are thought necessary to address the relative depletion of some commercial tree species caused by past logging interventions, to address the flurry of regeneration of other commercial species caused by past hurricane disturbance, to increase the growth of commercial species suppressed by the abundance of climbers in the hurricane-disturbed forest, and to optimize the commercial value of the forest.

As such selection of trees to harvest and retaining seed trees and reserve trees can be seen as a silvicultural approach:

(ii) **Harvests** - reduced-impact harvests which maintain structure in the residual stand, protect advance regeneration from injury, minimize soil damage, prevent unnecessary damage to high value species (e.g. those important for wildlife), and protect critical ecosystem functions such as water catchment and carbon sequestration

(iii) **Regeneration treatments** - retention and management of sufficient seed trees and growing stock of commercially valuable species to induce regeneration for the event of hurricane disturbance. Natural regeneration will be relied upon.

(iv) **Stand-tending treatments** - liberation thinning from climbers to favour growth of future crop trees of commercial value

Trees in the stand are therefore designated into functional groups:

a) Future crop - Any tree of a target species that is between the minimum diameter inventoried (MDI) and the minimum cutting diameter (MCD)
b) Crop - Any tree of a target species that is between the MCD and the maximum cutting diameter (MaxCD), that is decided through yield selection to be part of the sustainable crop
c) Reserve - Any tree of a target species that is between the MCD and the MaxCD, that is decided through yield selection to not form part of the crop
d) Seed - Any tree of a marketable species greater than the MDI, that is decided through the Seed Tree Selection Algorithm to be of good form and quality to serve as a seed tree
e) Preserve - Any tree greater than the MaxCD

Following Bird (1918) the Forest Department emphasizes the need to preserve forest structure, particularly the emergent canopy comprising the largest of trees. Therefore, a maximum cutting diameter is prescribed for all species. This is usually 90 cm for most species such as mahogany and cedar, or is lessened in the case of species that do not generally attain large tree status. The minimum and maximum cutting diameters for the different species are as per below (Table 33).

Table 33 Minimum and maximum cutting diameter limits as ordained by the Forestry Department for Long-term Forest Licensees

Species	MCD (cm)	MaxCD (cm)
Barbajolote	50	90
Bastard rosewood	50	90
Billy webb	50	90
Bullet tree	50	90
Cabbage bark (black)	50	90
Cedar	60	80
Chico zapote	50	90
Granadillo	50	90
Hobillo	50	90
Mahogany	55	80
Mylady (red)	45	80
Nargusta	50	90
Poison wood (black)	45	80
Rosewood	35	70
Salmwood	45	80
Santa maria	50	90
Sapodilla	50	90
Yemeri	50	90

Liberation of trees from the frequent vine loads in this heavily disturbed forest is combined with the stock survey to minimize costs of re-entry into the forest and consist of crews cutting lianas with machetes on all future, crop, seed, reserve and preserve trees. This is expected to have the effect of releasing future trees from some liana competition, aiding their growth and boosting wood quality over the felling cycle. Vine cutting is also expected to result in a reduction of felling damage.

Seed tree selection will also be combined with the stock survey and be performed on the basis of data collected about tree stem form, crown form, crown position and liana presence. An algorithm is used to calculate the suitability of individual trees to serve as seed trees based on these variables.

Harvesting operations will be carried out according to Reduced-impact Logging (RIL) techniques as per the national RIL code. Harvests will be based on the outputs of a yield model which aims to maintain forest structure, as described in the next chapter.

4.3 Thinning

No thinning or other silvicultural interventions such as liberation from competing trees are planned.

4.4 Supplementary planting

No supplementary or enrichment planting is planned

4.5 Tending

No tending operations are planned until the subsequent harvest with the exception of salvage cuts in response to wind or fire damage.

5 YIELD REGULATION AND PRODUCTION

5.1 Estimating growth and yield

The annual allowable cut (AAC) should ideally constitute the volumes which can be sustainably removed over an indefinite period, taking into account all aspects of stand dynamics, environmental and social considerations. Generally, the amount of timber that a forest or stand can yield on a periodic basis is equal to the volume accrual that has accumulated between periods. The sustainable yield can be less than the accrual since deductions are often made to ensure the quality of future crops, preserve forest structure, induce regeneration, or maintain biological diversity. In some instances the sustainable yield can be greater than the accrual, if for example, there is an overabundance of future stock relative to current crop. The sustainable yield of a stand is therefore determined by present and future stocking, the length of the cutting cycle, and growth and mortality.

The level of growth and especially its partitioning between species is uncertain. In undisturbed natural tropical forest, net growth may well be zero or negative. Following logging or tree falls, rapid increment occurs for up to 20-30 years until the fully stocked condition is approached. However, even when net growth is zero, large trees in the canopy continue to grow at the expense of smaller, shaded trees. Mortality in the large tree component may or may not neutralize the effects of growth over broad areas.

Information of growth, mortality and recruitment is not readily available for mixed, uneven-aged tropical forest such as the CFR. This problem is usually approached through a consideration of tree growth and mortality rates derived from permanent sample plots (PSPs).

The current 40-yr. cutting cycle defined for the Chiquibul Forest Reserve dates back to the management plan that was drawn up by Neil Bird (1994). The decision to employ a 40-yr cycle is based on some preliminary work by Denis Alder (1992a). Alder (1992a) considered a number of PSPs that were maintained under the British Honduras colonial administration. The mean increment of those plots on five different sites over a size range from 20 to 110 cm was 0.68 cm/yr. The increment figures for mahogany are quite typical of those for other fast-growing tropical species. Other species may be expected to show rather slower growth rates, typically of the order of 0.5 cm/yr. Alder (1992a) postulated that if, as a rule of thumb, 0.5 cm/yr. increment would apply, then all trees in the size range 40-60 cm would grow to mature size (60+ cm) over a 40 year period. However, with 1.5% annual mortality, only 55% of the trees would survive; the remainder would die. Consequently the ratio of tree numbers in the 40-60 cm class to those in the 60+ cm class must be greater than 1/0.55 or 1.8 if there is to be sufficient stock in the lower class to replace all the mature stock.

The Forest Planning and Management Project established 12 PSPs in the Chiquibul Forest Reserve between 1992 and 1994 (Bird, 1998), the majority of these plots (8) were part of a logging experiment whereby four sets of two neighbouring plots were established; one of each twin plot was subjected to logging while the other plot was maintained as a control plot.

A number of these plots were re-measured in the period 2010-2013 now forming part of a national network of permanent sample plots (FORMNET-B) which consists of 32 one-hectare plots that have been measured multiple times since 1992 (Cho *et al.* 2013).

5.2 The General Yield Model

5.2.1 Basics of the General Yield Model

The General Yield Model (version 3) is the model that forest licensees are required to use when preparing their APO. The General Yield Model is a basic Excel-based model but unfortunately not open source and the exact operation and functions in the model are not accessible to the user. The growth functions in this plan are taken from version 3 of the Model. Reportedly, the model takes the form of an 'individual tree' growth model, which grows trees through time, based on size-dependent growth rates applied in 5-year increments, and removes trees based on a fixed mortality rate over the full length of the cutting cycle. The model produces an estimated population at either year 25 or year 40, thereby allowing the estimation of accrual in terms of size class densities in between the present and future populations. The sustainable yield of the forest is determined as follows: trees may be removed through harvesting as long as the same potential yield can be achieved in another 25 or 40 years' time, *i.e.* over 2 cutting cycles. If the same yield cannot be achieved, the level of the harvest should be reduced using cutting intensities, until the present and future yields balance. The result of this approach is that forest structure in the merchantable size classes would be sustained. In the context of the determination of a sustainable yield, this means that both the yield and the mature population structure should be sustained. The latter is an uncommon condition and appears to assume that the size class distribution equals an age-class distribution which is obviously not the case in natural uneven-aged mixed forest. In reality, each size class contains trees of (sometimes largely) different ages, growing at largely different rates, which growth rates show strong autocorrelation (see e.g. Grogan & Landis, 2009 or da Cunha *et al*., 2016). This will also be shown when discussing growth rates in the PSPs.

5.2.2 Concept behind the General Yield Model

The argumentation to strive for an ideal size class structure (not the same as an age-class or cohort-based population structure) is given here. The yield selection model calls for the determination of a yield that the present population can sustain without prejudicing the ability of the species in the future to regenerate following a large-scale disturbance in sufficient quantity to replenish or increase its population size. By this definition there may be multiple yields attainable before the stand reaches a minimum threshold below which stem density may be too low to allow the population to endure annual mortality up to the next hurricane and withstand the disturbance with sufficient intact stems to allow for regeneration and stand replacement. This theoretical minimum stem density is termed the 'restocking threshold'. A population approaching this 'restocking threshold' is termed the 'initiation stand'. In this sense the 'initiation stand' is the stand one may expect to find following a devastating hurricane occurrence.

In this respect, the Forestry Department applies the following assumptions:

1) larger mahogany trees have more extensive root systems, bigger buttresses and more mass than smaller trees and are assumed to be too heavy to be easily toppled or broken by strong winds;
2) large trees are generally better seed producers and dispersers (height, wind, crown volume);
3) the size threshold here that defines 'large' is typically 50 cm dbh.

An 'initiation stand' will therefore consist of an adequate number of evenly distributed mahogany trees that are greater than or equal to 50 cm in diameter and are of good phenotype. In an initiation stand, where the number of trees ≥50 cm dbh is inadequate or the distribution not even, they may be supported by trees ≥25 cm dbh but which should comprise no more than half of the total population of the initiation stand. The minimum 50:50 ratio is a precaution against an untimely hurricane. In the selection of the initiation stand, special consideration must be given to large trees ≥90 cm dbh, on account of their scarcity in the CFR, resilience and importance in maintaining upper canopy structure. All trees ≥90 cm must therefore be excluded from crop selection and form part of the initiation stand.

The 'restocking threshold' has been set by the Forest Department based on the following considerations. Previous observations and data collected in Belize have led other authors to propose that a minimum of 10 large mahogany trees ≥60 cm dbh per square kilometre are required to provide adequate seeds to re-stock an area (Bird 1998). This equates to a re-seeding effort of 10 hectares for every tree, or 500 m linear distance. However, other studies in the north of Belize have suggested that mahogany trees seed an area immediately adjacent to them and do not extend very far across the landscape ((Shono & Snook, 2006). Also, annual mortality would have the effect of reducing the number of seed trees between present and the time of the next hurricane. The return period for strong stand-replacing hurricanes (≥category 3) over the same area within the Central American region has been estimated at 100 years

(Lugo, 2008). In 100 years, 10 trees would be reduced to approximately 5, at 0.7 % annual mortality. Therefore, 10 mahogany seed trees per square kilometre may be too low a stocking. Instead, an area of 5 hectares would theoretically leave a distance of 250 m around a tree within which it would be expected to broadcast seeds, much more feasible than 500 m. To achieve 20 mahogany trees in 100 years' time, there would have to be around 50 seed trees left per square kilometre at present. This then represents the restocking threshold and half of the 50 trees can be identified from those trees ≥50 cm DBH and half from below. For other species, such as cedar, barbajolote, nargusta and sapodilla, 20 seed trees must be left per square kilometre.

5.2.3 Parameters used in the General Yield Model

The General Yield Model version 2, which was used to prepare the 2016 APO used the following increment function for mahogany:

$i = a+b \cdot d+c \cdot d^2+d \cdot d^3+e \cdot d^4$

where: i = tree annual increment and d= tree diameter at breast height.

In the second half of 2016 the General Yield Model was updated to version 3 and a new growth function was introduced for mahogany. Three cubic polynomial functions are since defined for the three species groups: prime, elite and select. Species groups are primarily based on the value of the wood of the species and not on ecological guild or wood density. All current functions are of the form:

$i = a+b \cdot d+c \cdot d^2+d \cdot d^3$

Table 34 Coefficients and default parameters used in the 2016 General Yield Model for preparation of 2017 APO

species group	a	b	c	d	e	default	mort.	upper D
prime (2016)	0.405197	-0.04124	2.700E-3	- 4.702E-5	2.417E-7	0.17	0.07%	90
prime (2017)	0.074729	0.00868	4.100E-4	-6.537E-6		0.17	0.07%	80
elite	-0.220669	0.04614	-8.385E-4	4.141E-6		0.15	0.29%	90
rosewood	1.047767	-0.07757	3.028E-3	-3.297E-5		0.10	0.21%	50
select	-0.035483	0.02506	-4.355E-4	2.022E-6		0.16	2.05%	90

The new growth function for mahogany results in slightly lower growth rates for the medium diameter classes and slightly higher growth rates for the larger classes (Figure 49). It is assumed the default increment rate in Table 34 is applied where the function yields increment rates below the default threshold in the GYM version 3. Growth rates are shown in a tabular form in Table 35. The difference between the two versions of the GYM function for prime species group is shown in Figure 48.

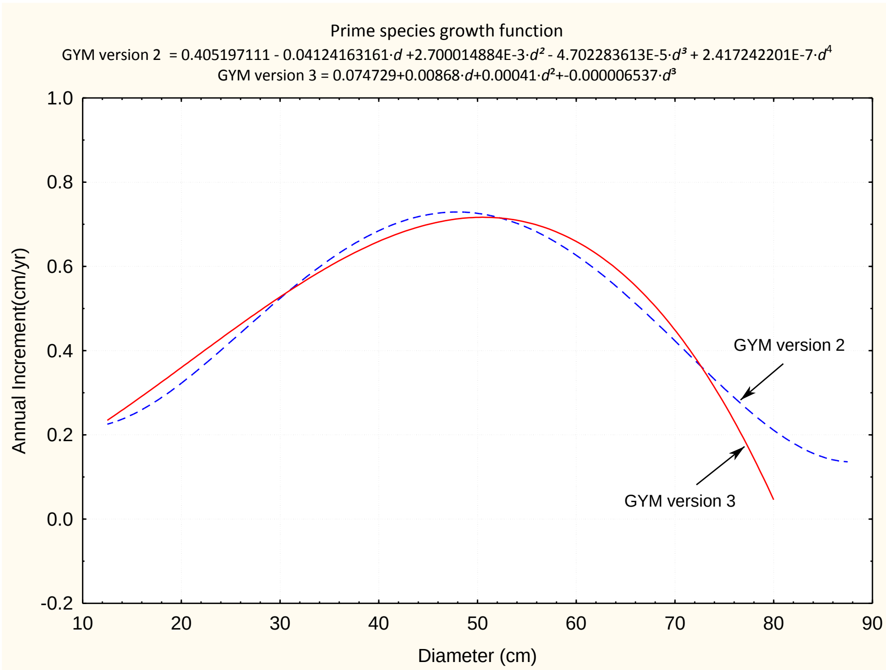


Figure 48 Growth functions in the General Yield Model version 2 (blue broken line) used to prepare 2016 APO and version 3 (red line) used to prepare 2017 APO.

Table 35 Growth and mortality rates for the different species groups in tabular form. Growth rates are based on the functions used in the General Yield Model version 3

5 cm DBH class	Prime		Elite		Select	
	Inc. (cm/yr.)	Mort. (%/yr.)	Inc. (cm/yr.)	Mort. (%/yr.)	Inc. (cm/yr.)	Mort. (%/yr.)
10-14.9	0.23	0.7	0.23	0.29	0.21	2.05
15-19.9	0.32	0.7	0.35	0.29	0.28	2.05
20-24.9	0.40	0.7	0.44	0.29	0.33	2.05
25-29.9	0.49	0.7	0.50	0.29	0.37	2.05
30-34.9	0.57	0.7	0.54	0.29	0.39	2.05
35-39.9	0.63	0.7	0.55	0.29	0.40	2.05
40-44.9	0.68	0.7	0.54	0.29	0.40	2.05
45-49.9	0.71	0.7	0.52	0.29	0.39	2.05
50-54.9	0.71	0.7	0.49	0.29	0.37	2.05
55-59.9	0.69	0.7	0.45	0.29	0.35	2.05
60-64.9	0.62	0.7	0.40	0.29	0.32	2.05
65-69.9	0.52	0.7	0.35	0.29	0.29	2.05
70-74.9	0.37	0.7	0.30	0.29	0.26	2.05
75-79.9	0.17	0.7	0.25	0.29	0.23	2.05
80-84.9	0.17	0.7	0.20	0.29	0.20	2.05
85-89.9	0.17	0.7	0.17	0.29	0.18	2.05
≥90	0.17	0.7	0.15	0.29	0.16	2.05

How the model works:

1. The only input data required is the list of all mahogany (only) of the stock survey for the respective APO, and the size of the annual cutting compartment. The data should represent the population of all live Mahogany trees ≥10 cm DBH within an annual cutting compartment.
2. Each tree is then iteratively "grown" in 5-year increments out to 25 or 40 years.
3. Next, the model counts the present stocking in each DBH class and counts future stocking while deducting 0.7% annual mortality. The difference between future and present stocking in the 50 to 89.9 cm DBH range represents the number of new trees that grew into the merchantable classes, and this is known as the "Indicative yield". The "Indicative yield" roughly represents what the forest can sustain to lose over the cutting cycle while maintaining similar forest structure. This is the starting point for further yield analysis.
4. The present stocking in each DBH class is then used as a weight to estimate the required cutting intensity to produce a yield equivalent to the "Indicative yield". The yield contributed by each DBH class, as well as the CI and the residual stocking are then displayed.
5. The user should then use the numbers provided by the "Indicative yield" in each DBH class to identify an equivalent number of trees that will comprise this yield. This is where the user selects the crop. Crop trees can be identified in a number of ways according to user preference, but ideally, all seed trees should have been first identified in the GIS according the ecological and silvicultural guidelines. Crop trees can similarly be identified in the GIS to ensure they are distributed appropriately. Or they can be identified according to log grade and/or diameter. The user must identify each individual crop tree to tell the model which trees will be killed by logging.
6. The model then deducts both annual mortality and trees killed by logging to estimate future stocking after logging. This is displayed next to stocking without logging for comparison.
7. Given the future stocking after logging, and the need to match the future and present yields, the model then calculates the cutting intensity required to produce a similar yield. The future yield contributed by each DBH class, as well as the CI and the residual stocking are then displayed.
8. If the "Indicative yield" can be sustained now and in the future, both present and future residual forests will satisfy all silvicultural and ecological criteria, as indicated by the graphs and other logical outputs of the model. If not, the user must adjust down the present yield until all criteria are met.

5.3 Commercial species

Bull Ridge Ltd. mainly targets five species: mahogany, cedar, nargusta and sapodilla, while occasionally barbajolote, rosewood and billywebb are harvested when available. As shown in Section B 3, some occur abundantly and evenly while others are either scarce or unevenly distributed from compartment to compartment. Another constraint on availability in any given compartment is the size class distribution of the population. Depending on the size class distribution, a different approach to estimating yield is demanded by the Forestry Department. Generally speaking, species can be grouped according to similarity in size class distribution, assuming the size class distribution represents a species (group) ecological guild. If this is true the same yield model can be applied to all species within a group.

The size class distribution or stand structure for each of the six target species are shown in Section B 3.3.1, but note the uncertainty in this respect in Section B 3.3.7. Two overall patterns are apparent: an inverse-J curve and a bell-shaped curve. The former is typical of a species with continuous regeneration, usually shade bearing species, while the latter indicates periodic regeneration, usually light demanding species that regenerate after major disturbances such as hurricanes, fire, milpa or heavy logging (with soil scarification). The contrasting groups require contrasting approaches to yield regulation.

Nevertheless, the General Yield Model applies different growth model parameters to the different merchantability classes: prime, elite and select. Although the population dynamics of the two prime species, mahogany and cedar, can be regarded as being similar and hence their grouping appropriate, this cannot be said about the elite and select species groups. The size class distributions and ecological guilds of sapodilla, nargusta and santa maria are very different as shown by the diameter class frequency distributions as depicted in Figures 39-41 (Section B 3.3.7) and species ecological characteristics in Table 32 (section B 4.1)

5.4 Species requiring protection (and justification thereof)

The population structure of a species can inform about its status in terms of regenerative capacity and potential for detrimental harm to the population from logging. Populations with relatively few reproductive mature trees *and* relatively few young trees are at the greatest risk from logging. The landscape level average stand structures shown in Sections B 3.2.1 and B 3.3.7 suggests that rosewood, barbajolote and cedar can be vulnerable to logging and special consideration must be given to their protection. These 'at risk' species may require protection from logging, through exclusion from harvest selection and through the prevention of logging-related damage and mortality. The size class distributions represent the average situation, however, and in some compartments the species may be locally abundant and able to sustain a modest harvest. The concept behind the General Yield Model includes a number of mechanisms that protect such species from involuntary overharvesting in contrast to a mere minimum cutting diameter limit system that would lead to progressively dwindling stocks for species with such size class distributions. First a restocking threshold applies requiring that a minimum of 20 evenly distributed trees ≥25 cm dbh should be retained per 100 ha, or 200 trees ≥25 cm dbh per average annual cutting area. Secondly, a maximum cutting diameter limit of 90 cm is applied and, thirdly, the remaining eligible trees may only be harvested as long as the same potential yield can be achieved in another 25 or 40 years' time, i.e. over 2 cutting cycles. This often implies that species such as barbajolote and rosewood could not be harvested from an annual cutting area, such as e.g. in 2015 and 2017.

5.5 Appraisal of the General Yield Model

5.5.1 Individual tree growth model characteristics

The General Yield Model is a simple Excel-based model that grows individual trees in 5-yr steps on a polynomial[7] growth function and applies a fixed mortality rate afterwards over the full cutting cycle. The model claims to be an individual tree growth model but is no true individual growth model which would consider competition indices calculated from e.g. spatial relationships or local basal area, crown position, crown form, damage etc. in determining diameter increment and mortality probability as functions of all these characteristics together (e.g. Alder, 1995). Crown position, crown form and vine infestation are recorded for each tree during the stock survey but are not used in the model.

5.5.2 Diameter increment rates

For the critical analysis of the General Yield Model, diameter increment rates for the CFR were assessed on the basis of 10 PSPs that were established in the period 1992-1994 during the Forest Planning and Management Project. Four of these PSPs were harvested as part of that project. A few plots were re-measured between 2010 and 2012 as part of the FORMNET-B project (Cho *et al.* 2013). Data were kindly made available by the author. Data of the last census during 2010-2012 were available for 5 out of the 10 plots in the CFR. Data of the 1994 and 1997 censuses of the eight plots of the FPMP were also available; data of the 2010-2012 census for three of the FPMP logging experiment plots were available. For each of the mahogany trees that were still alive at their last census the periodic annual diameter increment was determined over the period between the first and last census in which it was included. In this respect it must be noted that measurement periods varied; i.e. 1994-1997, 1994-2010, 1993-2010, 1992-2010, 1994-2012 and 1994-2013 and PAIs for different periods may not be truly comparable

[7] The growth function for mahogany was a quartic function in the 2016 APO and a cubic function in the 2017 APO.

because of variation in growth year by year due to e.g. climatic variation. The diameter of a tree was considered as the mean of its first and last diameter measurements.

Mahogany

The results pertaining to mahogany are depicted in Figure 49. Mahogany diameter increment rates in the CFR PSPs appear to vary greatly, particularly in the mid-size range, overall ranging between -1.7 and 19.4 mm per year. The coefficient of determination (R^2) of the polynomial regression was only 0.33, hence explains little of the variation in diameter growth rate. The estimated increment rates are higher than the ones determined by the General Yield Model, but not to an extent large enough to arrive at an appreciably different yield if the function would be substituted by the fitted function for the CFR (see Tables 35 and 36).

However, it is questionable whether the least squares averages predicted by the regression function or, for that matter, the General Yield Model function are good predictors for the true diameter increment of the trees that will eventually grow to harvestable size. This is easily demonstrated as follows. Imagine a tree is persistently growing at a rate of 2 mm/yr. Such a tree will take 250 years to reach 50 cm diameter. If we apply the academic mortality rate of 0.7% to all size classes (as in the Yield Control Model), only 17% of these trees will survive to reach 50 cm diameter. If instead the tree would be continually growing at a rate of 7 mm per year, it would take the tree 72 years to reach a 50-cm diameter and its survival rate would be 60%. The fact that mahogany portrays a bell-shaped diameter class frequency distribution implies that the species reproduces irregularly, which does not fit a population dynamics type with continual low growth rates and concomitant high effective mortality among juveniles. This suggests that trees that are growing at low rates are better omitted from the increment prediction because such trees are not likely to survive until they reach harvestable size.

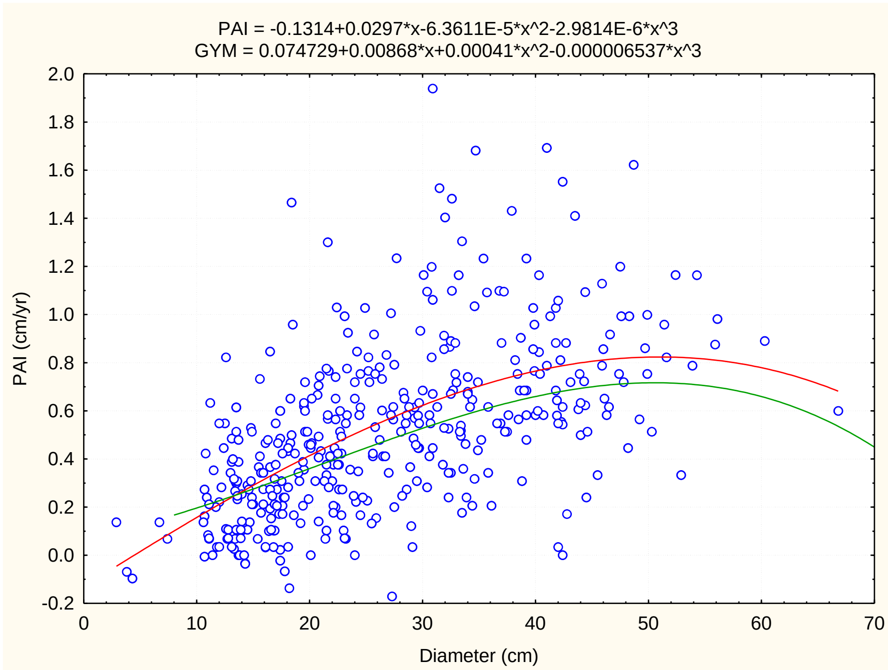


Figure 49 Periodic annual increment against the diameter of mahogany trees in the CFR PSPs; the diameter is the mean diameter of the first and last diameter measurement. PAI (red line) is the polynomial regression fitted with the CFR data ($F_{3,406}$=67.55, p=0.00, R^2=0.33), while GYM (green line) is the function used in the General Yield Model for the prime species group.

Bird (1998) and several other authors already suggested to predict the growth rate of the future crop trees based on the faster growing trees because those are the ones that are most likely to survive until the tree reaches the harvestable size limit. Several authors therefore recommend using the upper quartile instead of the mean (or the median) of a distribution of growth rates for each size class (see Figure 50). This proposition is further confirmed by the extremely low stocking of mid-size and mature mahogany in 1969 according to Johnson and Chaffey, reportedly following the devastating impact of hurricane Hattie and many years of overharvesting, in comparison with the current abundance of mahogany in the size class ≥50 cm dbh. It is generally assumed that the current harvestable mahogany stock originated following and as a result of hurricane Hattie in 1961. The currently harvestable trees are thus no older than 56 years, implying that all currently harvestable trees must have been growing at a mean annual increment of 1 cm/yr. or more. It is general knowledge that trees below 10 cm dbh grow at reduced rates because of competition, shade and shoot borers. This suggests that the currently harvestable mahogany trees must have been growing periodically at a rate that was considerably higher than 1 cm/yr. and definitely higher than 0.7 cm/yr., the maximum rate according to the General Yield Model.

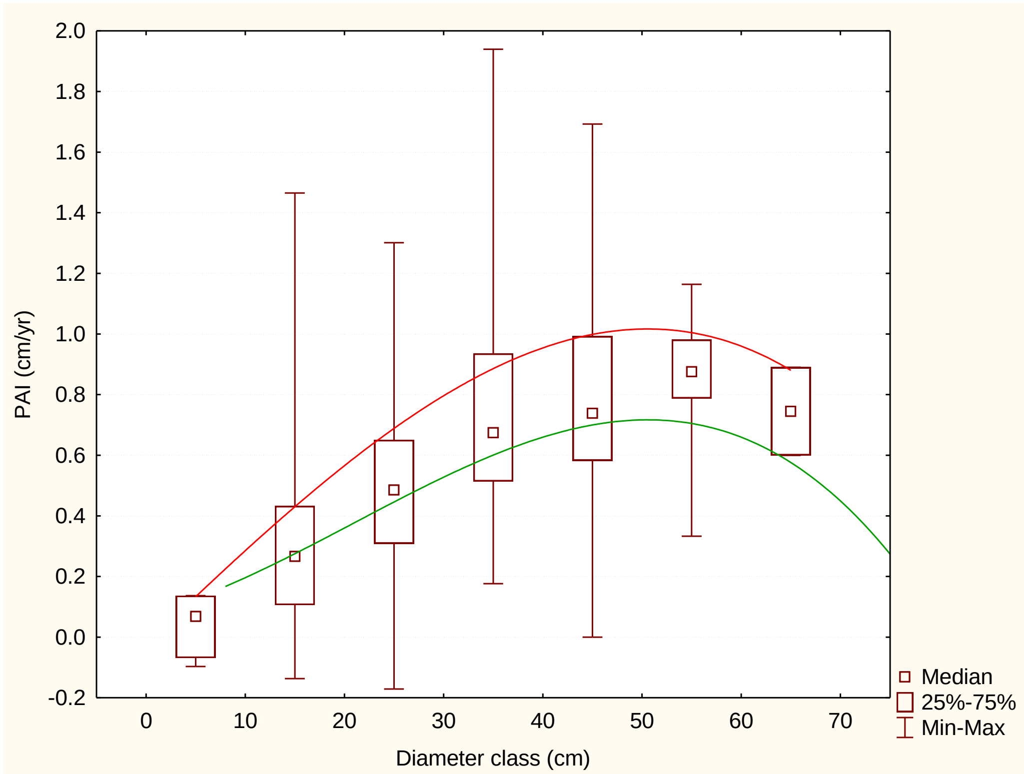


Figure 50 Median periodic annual diameter increment rates of mahogany in CFR PSPs in 10-cm diameter classes together with lower and upper quartile (boxes) and minimum and maximum (whiskers) values; the green line represents the General Yield Model growth function for prime species, the red line emulates a polynomial function for the upper quartile growth rate values.

Table 36 Computation of cumulative age and percent survival of mahogany trees using the increment function and mortality rate used in the General Yield Model.

Diam. class (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Increment (cm/yr.)	0.17	0.28	0.45	0.60	0.70	0.70	0.58	0.27	0.17
Annual Mortality (% /yr.)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Time of Passage (yrs.)	58.8	36.3	22.4	16.7	14.3	14.2	17.4	36.5	58.8
Cumulative age*	58.8	95.2	117.6	134.3	148.5	162.7	180.1	216.6	275.4
Cumulative % survival**	66.2	51.2	43.8	38.9	35.2	31.9	28.2	21.8	14.4

*Cumulative age sums the time of passage for a class with all preceding classes to give the mean age at which the tree reaches a given diameter class upper bounds.

** Cumulative % survival gives the number of trees which survive to the age corresponding to the class upper bound from an initial cohort of 100. It is calculated as: (% survivors in preceding class) x $(1\text{-m\%})^{\text{time of passage}}$ where m% is the class annual mortality as a fraction (e.g. 0.7% is 0.007).

Table 37 Computation of cumulative age and percent survival of mahogany trees using polynomial regression fitted for the CFR PSP data and mortality rate used in the General Yield Model.

Diam. class (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Increment (cm/yr.)	0.17	0.29	0.52	0.70	0.80	0.81	0.71	0.48	0.17
Annual Mortality (% /yr.)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Time of Passage (yrs.)	58.8	34.5	19.1	14.2	12.4	12.3	14.1	20.8	58.8
Cumulative age	58.8	93.3	112.4	126.6	139.1	151.4	165.4	186.2	245.0
Cumulative % survival	66.2	51.9	45.4	41.1	37.6	34.5	31.3	27.0	17.9

Table 38 Computation of cumulative age and percent survival of mahogany trees from increment based on upper quartile (75%) PAI for each diameter class in the CFR PSP data and mortality rate used in the General Yield Model

Diam. class (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90
Increment (cm/yr.)	0.17	0.43	0.69	0.89	1.00	1.00	0.88	0.60	0.17
Annual Mortality (% /yr.)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Time of Passage (yrs.)	58.8	23.2	14.5	11.3	10.0	10.0	11.4	16.6	58.8
Cumulative age	58.8	82.1	96.6	107.9	117.9	127.9	139.2	155.8	214.6
Cumulative % survival	66.2	56.2	50.7	46.9	43.7	40.7	37.6	33.5	22.1

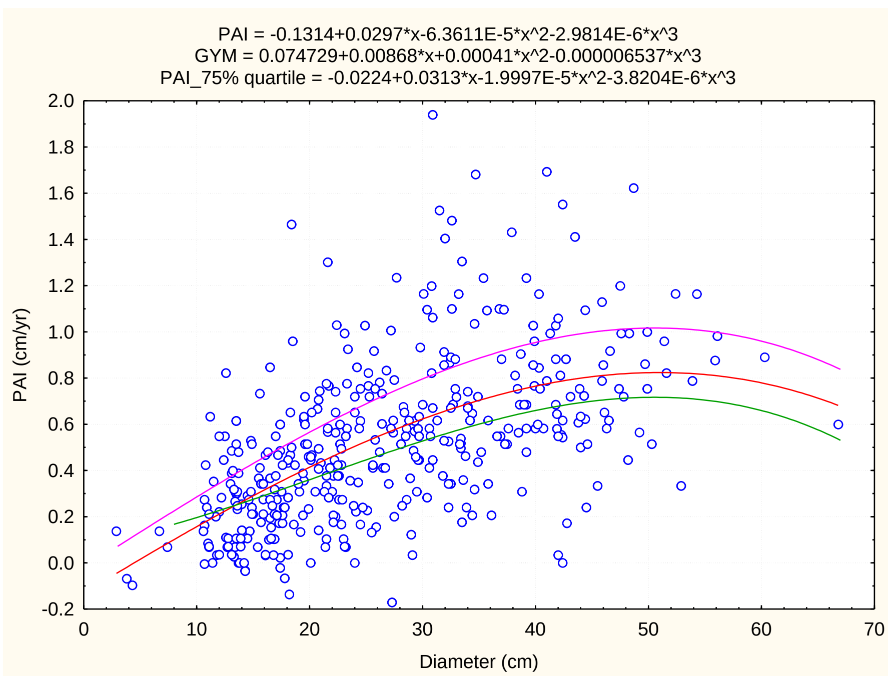


Figure 51 Periodic annual increment against the diameter of mahogany trees in the CFR PSPs; PAI (RED line) is the polynomial regression fitted with the CFR data, GYM (green line) is the function used in the General Yield Model for the prime species group and PAI_75% quartile (purple line) is the upper quartile (75%) increment for each diameter class fitted as a function

It is shown that the higher increment rates according to the polynomial (cubic) regression and the upper quartile values for each diameter class result in shorter times of passage and higher cumulative survival, hence higher harvestable volumes at the second cut than predicted by the General Yield Model. A higher increment rate also means that more seed trees will survive during each '100-yr major hurricane interval' (see Section B 5.2.2). This could be taken into consideration when determining the minimum number of seed trees, currently 50 trees per 100-ha, to be retained.

Cedar

The results pertaining to cedar are depicted in Figure 52.

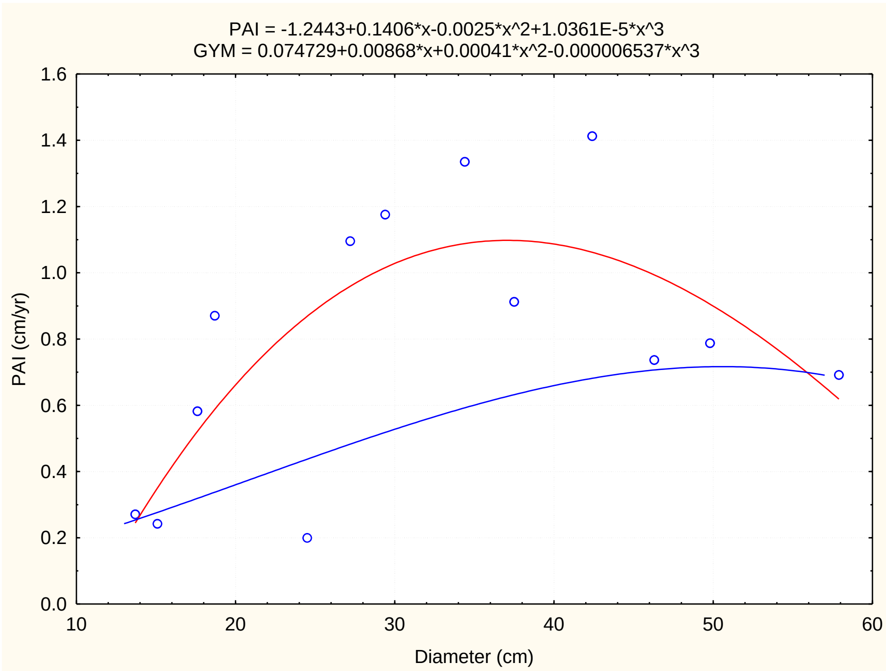


Figure 52 Periodic annual increment against the diameter of cedar trees in the CFR PSPs; PAI (red line) is the polynomial regression fitted with the CFR PSP data (R^2=0.54), GYM (blue line) is the function used in the General Yield Model for the prime species group

There were few cedar trees in the CFR PSPs; only 13 out of a total of 18 trees were measured more than once. The cubic polynomial regression fitted for these few data was just not significant ($F_{3,9}$=3.471, p=0.06) but with a relatively high coefficient of determination R^2=0.54. Even with this small number of sample trees it is suggested that the General Yield Model underestimates cedar increment rates.

Barbajolote

The CFR PSP data that were available included data pertaining to 25 barbajolote trees of which 18 trees were measured more than once (see Figure 53). Tree sizes varied from very small (2 cm dbh) to very big (110 cm dbh) with the majority of trees growing slowly (< 0.3 cm/yr.) and only two trees growing more rapidly (max 0.8 cm/yr.). The variation was such that the increment rates were not significantly diameter-dependent ($F_{3,14}$=1.659, p=0.22) and the coefficient of determination equally low R^2=0.26. The parameters for elite species in the General Yield Model cannot be contested based on this small sample.

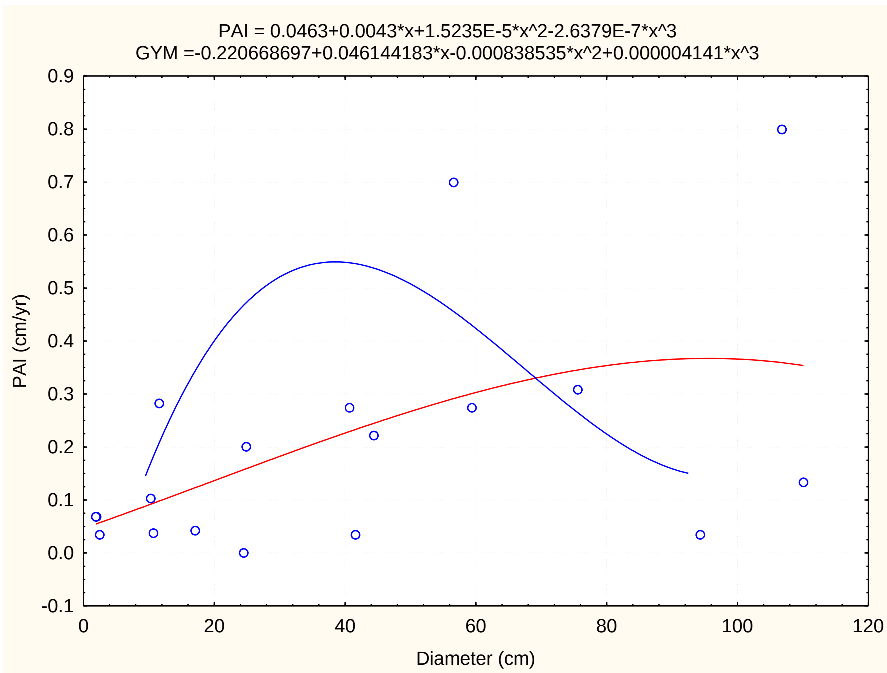


Figure 53 Periodic annual increment against the diameter of barbajolote trees in the CFR PSPs; PAI (red line) is the polynomial regression fitted with the CFR PSP data, GYM (blue line) is the function used in the General Yield Model for the elite species group

Rosewood

The results pertaining to rosewood are depicted in Figure 54.

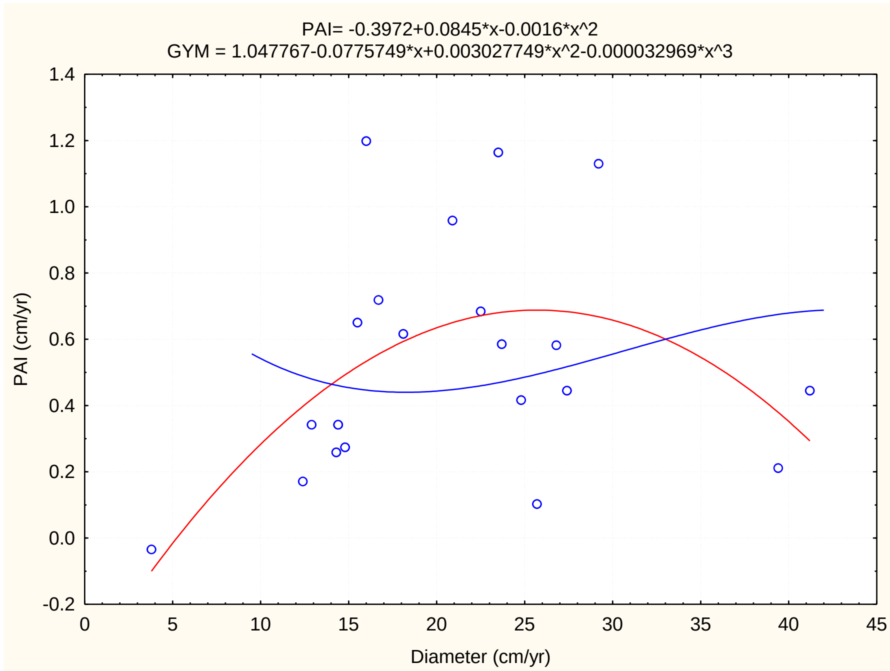


Figure 54 Periodic annual increment against the diameter of rosewood trees in the CFR PSPs; PAI (red line) is the polynomial regression fitted with the CFR PSP data, GYM (blue line) is the function used in the General Yield Model for rosewood

Periodic diameter increment rates for rosewood in the CFR PSPs appear to vary greatly, ranging from -0.3 to 11.9 mm per year. All sample trees were smaller than 45cm dbh; the usual maximum size of rosewood. The polynomial regression fitted for rosewood was significant ($F_{2,19}$=3.851, p=0.039) with a low coefficient of determination R^2=0.29. The estimated mean increment rates are higher than the increment rates for elite species in the General Yield Model but the parameters for elite species cannot be contested based on such small sample.

Nargusta

The results pertaining to nargusta are depicted in Figure 55.

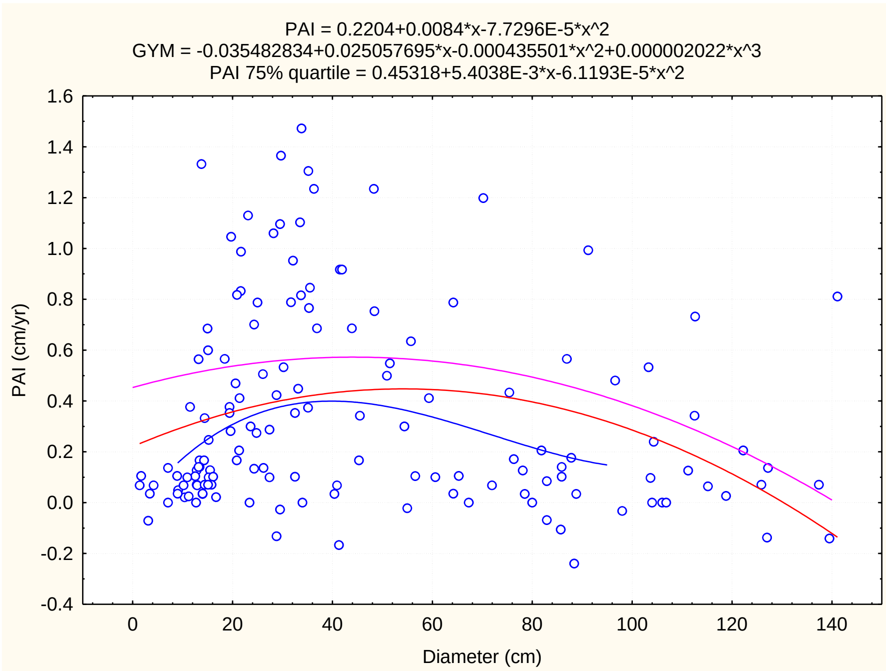


Figure 55 Periodic annual increment against the diameter of nargusta trees in the CFR PSPs; PAI (red line) is the polynomial regression fitted with the CFR data, GYM (blue line) is the function used in the General Yield Model for the select species group and PAI_75% quartile (purple line) is the upper quartile (75%) increment for each diameter class fitted as a function

Periodic diameter increment rates for nargusta in the CFR PSPs appear to vary greatly, ranging from -2.4 to 14.7 mm per year. The cubic polynomial regression fitted for nargusta was significant ($F_{2,141}$=5.770, p=0.004) but with a very low coefficient of determination R^2=0.08. The estimated mean increment rates are marginally higher than the General Yield Model increment rates. Upper quartile (75%) increment rates are consistently higher than the General Yield Model increment rates for select species and it is suggested that the General Yield Model underestimates nargusta increment rates (Figure 55).

Santa maria

The results pertaining to santa maria are depicted in Figure 56.

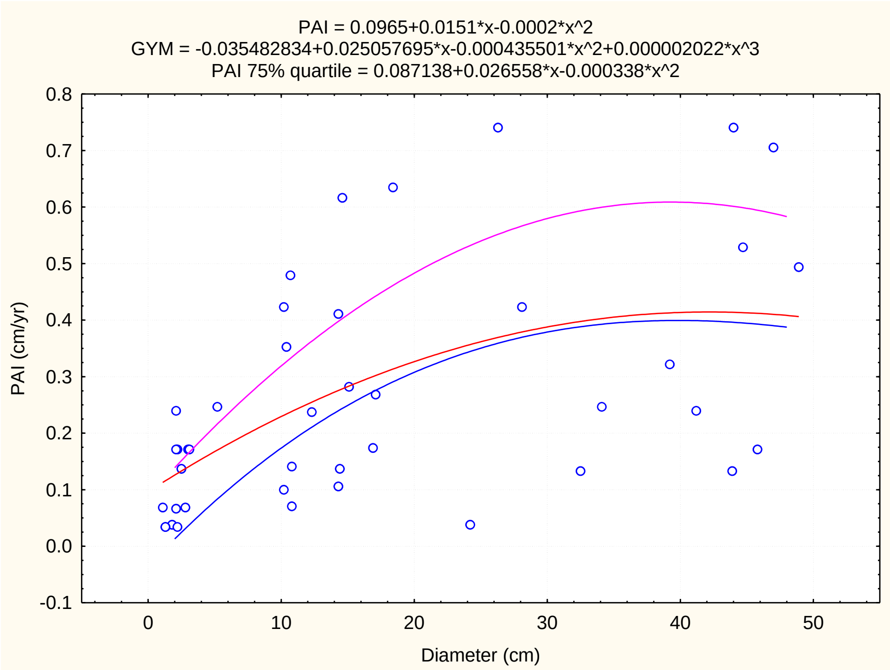


Figure 56 Periodic annual increment against the diameter of santa maria trees in the CFR PSPs; PAI (red line) is the polynomial regression fitted with the CFR data, GYM (blue line) is the function used in the General Yield Model for the select species group and PAI 75% quartile (purple line) is the upper quartile (75%) increment for each diameter class fitted as a function

Periodic diameter increment rates for santa maria in the CFR PSPs appear to vary greatly, ranging from 0.3 to 7.4 mm per year. All sample trees were smaller than 55 cm dbh; close to the maximum size of santa maria. The polynomial regression fitted for santa maria was highly significant ($F_{2,39}$=7.896, p=0.0013) with a low coefficient of determination R^2=0.29. The estimated mean increment rates are similar to the increment rates for select species in the General Yield Model. Upper quartile (75%) increment rates are considerably higher than the General Yield Model increment rates for select species and it is therefore suggested that the General Yield Model underestimates santa maria increment rates (Figure 56).

Sapodilla

The results pertaining to sapodilla are depicted in Figure 57.

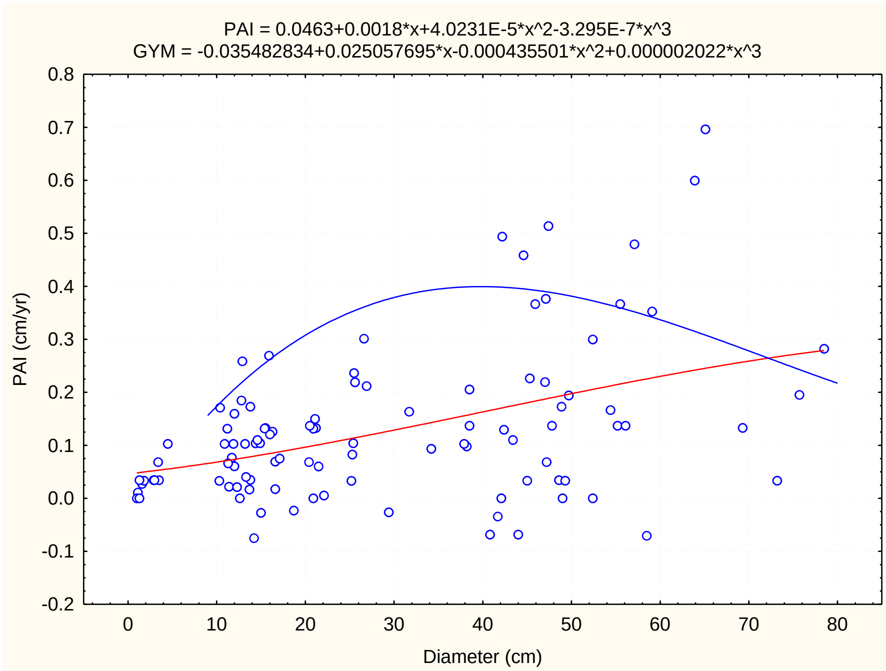


Figure 57 Periodic annual increment against the diameter of sapodilla trees in the CFR PSPs; PAI (red line) is the polynomial regression fitted with the CFR data and GYM (blue line) is the function used in the General Yield Model for the select species group

Periodic diameter increment rates for sapodilla in the CFR PSPs appear to vary from -0.7 to 7.0 mm per year. The cubic polynomial regression fitted for sapodilla was significant ($F_{3,98}$=7.746, p=0.0001) but with a low coefficient of determination R^2=0.19. The estimated mean increment rates are lower than the increment rates for select species in the General Yield Model. It is suggested that the General Yield Model overestimates sapodilla increment rates.

Comparison of General Yield Model with diameter increment rates in CFR PSPs

The diameter increment rates in the CFR PSPs suggest that the General Yield Model (GYM) underestimates growth rates for mahogany, cedar, nargusta and santa maria, while the growth rate for sapodilla seems to be overestimated. Higher increment rates imply higher sustainable yields and lower cumulative mortality. PSP data could not give a conclusive answer in case of barbajolote or rosewood.

The mahogany and cedar increment rates are probably 150% of the rates used in the GYM for prime species. The increment rate of nargusta and santa maria are probably 130% and 150%, respectively, of the rates used in the GYM for select species, while the increment rate for sapodilla increment rate is probably only 40% of the rates used in the GYM. There were insufficient PSP data on barbajolote and rosewood to contest or confirm the GYM function for elite species.

The elite and select species groups are primarily based on the value of the species and not so much on the ecological guild or wood density of the species. The ecological guild would indicate whether a species is e.g. light-demanding or shade-bearing and their seed dispersal mechanism. The wood density is an indication of the diameter growth rate of a species at maturity. Barbajolote and nargusta are both light-demanding species; while sapodilla and santa maria are shade-tolerant species (see Table 32). Barbajolote, nargusta and santa maria have similar wood densities and can be expected to have similar growth rates at maturity, Sapodilla has a higher wood density which would place this species in a different group.

5.5.3 Annual mortality rates

The GYM models use a fixed annual mortality rate for each species group (Table 34), which are kept constant throughout the life of a tree. The computation in the GYM applies the mortality rate at the end of the full felling cycle. The annual mortality rates for the prime and elite species group seem low while the rate for the select species seems high.

One of the main weaknesses in the model is the application of the mortality rate at the end of the full cutting cycle. In a standard diameter class (or stand table) projection model, transition matrix or cohort model the impact of the mortality rate varies with the time of passage of a defined diameter class or transition period. If the annual mortality rate for mahogany is fixed at 0.7% and the time of passage period for mahogany for e.g. the size class 30-35 cm dbh amounts to 8.9 years, as assumed in the model, then the proportion of survivors moving into the next class would be 93.9%, while for e.g. the size class 50-55 dbh where the time of passage is7 years 95.2% of the trees will survive passage through this diameter class. According to the General Yield Model a fixed percentage of 75.5% of the trees will survive at the end of a 40-yr cutting cycle irrespective of the size of the initial tree thereby ignoring the variation of the impact of the time of passage of each class on the overall size class distribution. A 30-cm mahogany tree will grow to a size of 56.3 cm in 40 years according to the 2016 model, meaning that it will move up through 5.26 5-cm diameter classes. Converting back to single 5-cm diameter classes the model thus calculates that each time a fixed proportion of survivors of 94.8% are moving over to the next 5-cm size class, hence the mortality among the lower size class (30-35 cm dbh) in undervalued while mortality among the higher size class is overvalued. This pattern becomes clearer when we consider the small size classes < 20 cm dbh where the time of passage is much longer. The resulting size class distribution at the end of the cutting cycle will thus show relatively fewer trees than there should be in the higher diameter classes and more than there should be in the lower classes.

The annual mortality rate cannot be determined properly from the available PSP data because of the limited number of trees that were assessed over a long enough period, e.g. 1992/94 – 2010/13. However, a simple approach to estimating annual mortality is proposed by Alder *et al* (2002). They estimate the annual mortality rate from the 95% point on the cumulative diameter distribution (D95) and the time taken by that tree to grow to this D95 diameter (T95). In the simple pantropical approach, they determine T95 based on the assumption that diameter increment (Dinc) is constant over the life of the tree. The assumptions that both the mortality and diameter increment rate are constant over the life of a tree are not true in practice. However, variability of both increment and mortality is so high that the average behaviour of increment and mortality for many species does not appear to deviate greatly from these simple assumptions (Alder *et al.*, 2002). In theory, the time taken by a tree to grow to the D95 diameter could also be estimated from the diameter distribution of the general inventory and the GYM diameter increment functions. However, both the diameter increment, hence time of passage through the 0-25 cm diameter class, and the stem density in this size class are highly uncertain and variable. Hence, the estimate of the mean annual mortality rate, in %/yr. (AMR) is determined as follows:

The time taken by a tree to grow to the D95 diameter is estimated as:

$$T95 = D95 \div Dinc \qquad \{eqn.1\}$$

The number of trees surviving to the D95 diameter represents 5% of the initial population:

$$0.05 = (1 - AMR)^{T95}$$

Substituting equation {1} for T95 and changing the above expression to give AMR on the left hand side results in:

$$AMR = 1 - 0.05^{[Dinc \div D95]} \qquad \{eqn.2\}$$

Two approaches were followed in estimating D95 and Dinc. The first approach estimated D95 from stand tables produced from the general inventory and Dinc from the CFR PSP data. Estimation of the Dinc from PSP data considered all specimens by species irrespective of diameter or diameter class distribution. The second approach estimated D95 from the average stand table of the APO stock surveys 2009-2017. Dinc was estimated by applying the respective GYM function to the midpoint of each 5-cm diameter class and taking the mean of the midpoint growth rates of all 5-cm diameter class below the D95 point.

Table 39 95% point on the cumulative diameter distribution (D95) of the general inventory and the combined 2009-17 stock surveys; mean annual diameter increment (Dinc) in the CFR PSP dataset and according to GYM growth function; annual mortality (AMORT) for two approaches (see text) and according to the GYM version 3.

Species	D95 (cm)		Dinc (cm)		AMORT		
	General Inventory	Stock surveys 2009-17[a]	PSPs CFR[b]	GYM <D95[c]	D95 Gen.Inv. & Dinc PSP CFR	D95 stock surveys & Dinc GYM <D95	GYM
mahogany	60.7	65.6	0.52	0.59	2.5%	2.7%	0.70%
cedar	70.9	77.9	0.52	0.66	2.2%	2.5%	0.70%
barbajolote	80.0	102.5	0.20	0.50	0.7%	1.5%	0.29%
rosewood	35.2	47.4	0.53	0.52	4.4%	3.2%	0.29%
nargusta	75.0	68.0	0.34	0.38	1.3%	1.7%	2.05%
santa maria	48.5	60.3	0.26	0.36	1.6%	1.8%	2.05%
sapodilla	70.2	80.8	0.16	0.39	0.7%	1.4%	2.05%

[a] often higher in the combined stock surveys than in general inventory, because D95 is influenced by MDI of stock surveys

[b] considers diameter increment of all diameter classes

[c] mean diameter increment of trees below D95 (based on 5-cm diameter class midpoints)

The simple approach to estimating annual mortality proposed by Alder *et al* (2002) indicates that the GYM version 3 applies relatively low annual mortality rates for mahogany, cedar and rosewood, while mortality rates in GYM for nargusta and sapodilla are relatively high.

The approach by Alder *et al* (2002) assumes that a specific population structure is stable. It is clear that the mahogany and cedar populations in the CFR are still in the recovery phase after years of overharvesting and hurricane damage. Perhaps this applies to rosewood as well. This implies that most trees are comparatively young and few large trees occur. This results in the observed relatively low D95 and relatively high Dinc, which requires a high mortality rate in order to be able to explain the encountered size class distribution. However, to achieve a mortality rate as low as 0.7% as used in the GYM, a D95 of e.g. 110 cm combined with a Dinc of 0.25 cm/yr. would be required. This would mean that under natural conditions the prime species must be (very) long-lived and capable of reaching massive diameters (150+ cm) and must show a high diameter increment only in the midsize classes which must slow down substantially when the tree reaches a greater diameter. This seems indeed true for both mahogany and cedar.

Modelling future structure of the stand table and the ultimate timber yield is at least as sensitive to mortality as it is to mean tree increment, and probably more so. Accurate observations on tree mortality and any identifiable predisposing factors are therefore most important on PSPs. Further research on (diameter-dependent) mortality rates is clearly needed for Belize.

Mortality rates over a range of sizes in mixed tropical forest have typically been found to vary from 1% to 5% (Alder, 1995). Considering all species and trees of 10 cm dbh or larger, typical mortality rates are of the order of 1.5% per year in forest that has not been recently disturbed. However, in forests where logging or other disturbances have occurred, higher mortality rates, of the order of 2.5% or more, may be expected.

For any given species, the mortality rate by size class tends to show only weakly defined differences above 10 cm dbh. There may be a tendency for mortality to rise again above average levels for the largest trees, associated with their greater propensity to decay and their exposure to greater wind stresses in an emergent position above the canopy (Alder, 1990).

Mortality rates, like growth rates, depend on species, tree competitive status, and on site conditions. Among small trees, as may be expected, mortality under shade conditions tends to be associated with ecological guild. Pioneers may show high mortality, of the order of 5%/yr. or more, whilst shade bearers may have very low mortality rates, less than 1% (Alder, 1995); e.g. in heavily logged forest, 10–15 yrs. prior to start of measurements, in Bobiri, Ghana Alder (1995) found the following mortality rates for three ecological guilds:

Shade bearers:	0.3-0.7%
Non-pioneer light demanders:	1.2-1.5%
Pioneers:	3.0-4.5%

Sapodilla and santa maria qualify as shade bearers, while mahogany, cedar, barbajolote, and nargusta qualify as non-pioneer (long-lived) light demanders. Barbajolote and nargusta have a higher wood density than mahogany and cedar which normally means a lower diameter increment. Mature tree sizes (D95) do not differ between these four species. Therefore, barbajolote and nargusta should have lower mortality rates than mahogany and cedar.

5.5.4 Simple diameter class projection model for mahogany

In order to compare the effect of the incorrectly applied mortality rate and lower estimated increment rates in the General Yield Model with time of passage adjusted mortality rates and higher predicted increment rates when using the upper quartile growth rates, a simple stand projection model is applied to the 2016 APO data.

Stand table or diameter class projection is a classical method to estimate (stand) growth and is one of the most seasoned techniques to determine the future composition of uneven-aged forests, with numerous examples in the literature and in standard textbooks (see e.g. Vanclay 1994, Alder 1995). The basic concept of the classical diameter class projection model is that the forest is represented as a stand table of tree numbers classified by diameter classes; usually of equal width (e.g. 5-9.9, 10-14.9, 15-19.9,…, 90+ cm dbh). The method predicts the future stand table from the present stand table by adjusting each entry in the table with the estimated diameter increment and mortality for that class; calculated over an interval of for instance 5-10 year using periodic increment data. The revised table is then used as the starting point to repeat the calculations. Increment, mortality and ingrowth observations made from PSPs are normally used to estimate growth over a full felling cycle or rotation, which may be 25 years or more. It is often difficult to compile outgrowth rates directly from PSP data and it will need to be estimated from mean increment for a diameter class. Such approach assumes that trees in each diameter class are uniformly distributed through the class and that each tree grows at the average rate; the so-called Uniform Distribution, Mean Increment assumptions (Alder 1995). For each class, a 'movement ratio' is then determined from the class width and average increment, and this indicates the number of trees moving to the next class (Vanclay 1994, Alder 1995).

Ingrowth, outgrowth, mortality and harvest

The change in a stand table over a period of time can be described in terms of ingrowth, outgrowth, mortality, and harvest. These are defined as follows:

- **Ingrowth**: trees which grow into a diameter class over a given period. Trees growing into the lowest measured diameter class are termed Recruitment.
- **Outgrowth**: trees which grow out of a particular diameter class over a period. Ingrowth into a class corresponds to outgrowth from the preceding class.
- **Mortality**: trees which die during a growth period. The causes may be internal to the stand, as a result of suppression, shading, or age; or external, as a result of catastrophes such as tropical storms.
- **Harvest**: trees which are removed during logging over a period.

Mathematically, the process of diameter class projection can be defined as (Alder, 1995):

$$N_{k,t+1} = N_{k,t} + I_k - O_k - M_k - H_k$$

where:

$N_{k,t+1}$ =the number of trees In the *k*'th class at period *t+1*
$N_{k,t}$ = the number of trees In the *k*'th class at period *t*
I_k = the ingrowth Into the *k*'th class during the period
O_k = the outgrowth from the *k*'th class during the period
M_k = the mortality from the *k*'th class during the period
H_k = the trees harvested from the *k*'th class during the period.

The general assumption of diameter class projection is that values of ingrowth, outgrowth and mortality derived from PSP data measured over intervals of 5-10 years or so can be applied repetitively to obtain new estimates of a stand table over successive periods.

Stand table projection based on the polynomial regression of the CFR PSP data

Such simple stand table projection model was constructed based on Uniform Distribution, Mean Increment assumptions (Alder 1995) and the General Yield Model version 2 parameters. The inventory data for the initial stand table for mahogany is taken from the 2016 APO (Table 40). The results of the stand table projection model are compared with the General Yield Model.

Table 40 2016 Allowable Cut (Sustainable Yield) for mahogany according to the General Yield Model taken from the 2016 APO

Presentation of Allowable Cut for Mahogany								
	Present				At next cutting cycle			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10 to 14.9	85			85	0			0
15 to 19.9	173			173	0			0
20 to 24.9	183			183	39			39
25 to 29.9	246			246	51			51
30 to 34.9	213			213	54			54
35 to 39.9	250			250	72			72
40 to 44.9	256			256	72			72
45 to 49.9	305			305	85			85
50 to 54.9	163			163	111			111
55 to 59.9	333	71.2%	237	96	116	69.0%	80	36
60 to 64.9	219	85.0%	186	33	181	69.1%	125	56
65 to 69.9	174	84.0%	146	28	249	69.1%	172	77
70 to 74.9	108	78.0%	84	24	374	69.0%	258	116
75 to 79.9	59	87.0%	51	8	113	69.0%	78	35
80 to 84.9	26	80.0%	21	5	38	68.4%	26	12
85 to 89.9	23	80.0%	18	5	5	60.0%	3	2
≥90	5			5	8			8
TOTAL	**2,821**	**80.7%**	**743**	**2,078**	**1,568**	**67.6%**	**742**	**826**

The 2016 allowable cut and residual stocking at the first cut and the stocking at and following the next cut as computed by the General Yield Model are presented in Table 40. Table 41 presents the same results as computed by the stand table projection model based on the parameters given in Table 42.

Table 41 2016 yield for mahogany following the General Yield Model but stocking and residual stocking at the next (40-yr) cut after stand table projection based on increment rates in CFR PSPs (Table 42)

Stand table projection on 2016 APO								
	2016				2016			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10 to 14.9	85			85	7			7
15 to 19.9	173			173	14			14
20 to 24.9	183			183	21			21
25 to 29.9	246			246	28			28
30 to 34.9	213			213	35			35
35 to 39.9	250			250	45			45
40 to 44.9	256			256	56			56
45 to 49.9	305			305	70			70
50 to 54.9	163			163	88			88
55 to 59.9	333	71.2%	237	96	112	62.5%	70	42
60 to 64.9	219	85.0%	186	33	143	62.9%	90	53
65 to 69.9	174	84.0%	146	28	189	63.0%	119	70
70 to 74.9	108	78.0%	84	24	251	63.0%	158	93
75 to 79.9	59	87.0%	51	8	265	63.0%	167	98
80 to 84.9	26	80.0%	21	5	173	63.0%	109	64
85 to 89.9	23	80.0%	18	5	48	62.5%	30	18
≥90	5			5	20			20
TOTAL	**2,821**	**80.7%**	**743**	**2,078**	**1,565**	**62.8%**	**743**	**822**

Table 42 Parameters for the stand table projection for mahogany; increment and outgrowth based on the polynomial regression of the CFR PSP data (least squares), mortality parameters based on the General Yield Model and stocking and harvest based on 2016 APO

5cm DBH class	Stocking (N/1000 ha)	From (cm)	To (cm)	Increment cm/yr.	Outgrowth %/5·yr	Mortality %/5·yr	Harvest %
10-15	85	10	15	0.22	22%	3.5%	
15-20	173	15	20	0.35	35%	3.5%	
20-25	183	20	25	0.47	47%	3.5%	
25-30	246	25	30	0.58	58%	3.5%	
30-35	213	30	35	0.67	67%	3.5%	
35-40	250	35	40	0.74	74%	3.5%	
40-45	256	40	45	0.79	79%	3.5%	
45-50	305	45	50	0.82	82%	3.5%	
50-55	163	50	55	0.82	82%	3.5%	
55-60	333	55	60	0.80	80%	3.5%	71%
60-65	219	60	65	0.75	75%	3.5%	85%
65-70	174	65	70	0.67	67%	3.5%	84%
70-75	108	70	75	0.55	55%	3.5%	78%
75-80	59	75	80	0.40	40%	3.5%	87%
80-85	26	80	85	0.21	21%	3.5%	80%
85-90	23	85	90	0.17	17%	3.5%	80%
≥90	5	≥90		0.17	0%	3.5%	0%

The stand table projection results in marginal difference in the stocking at the next felling cut after a cutting cycle of 40 years; a total stocking of 1565 against 1568 trees; perhaps caused by rounding in the GYM functions. Because the same allowable cut was used in both models the residual stocking did not differ. However, the accrual in number of stems 55-90 cm dbh is greater when the polynomial regression based on the CFR PSPs is used than when the General Yield Model is used; i.e. 733 stems against 670 stems. This is further evidenced by the lower indicative cutting intensity of 62.8% against 67.6%.

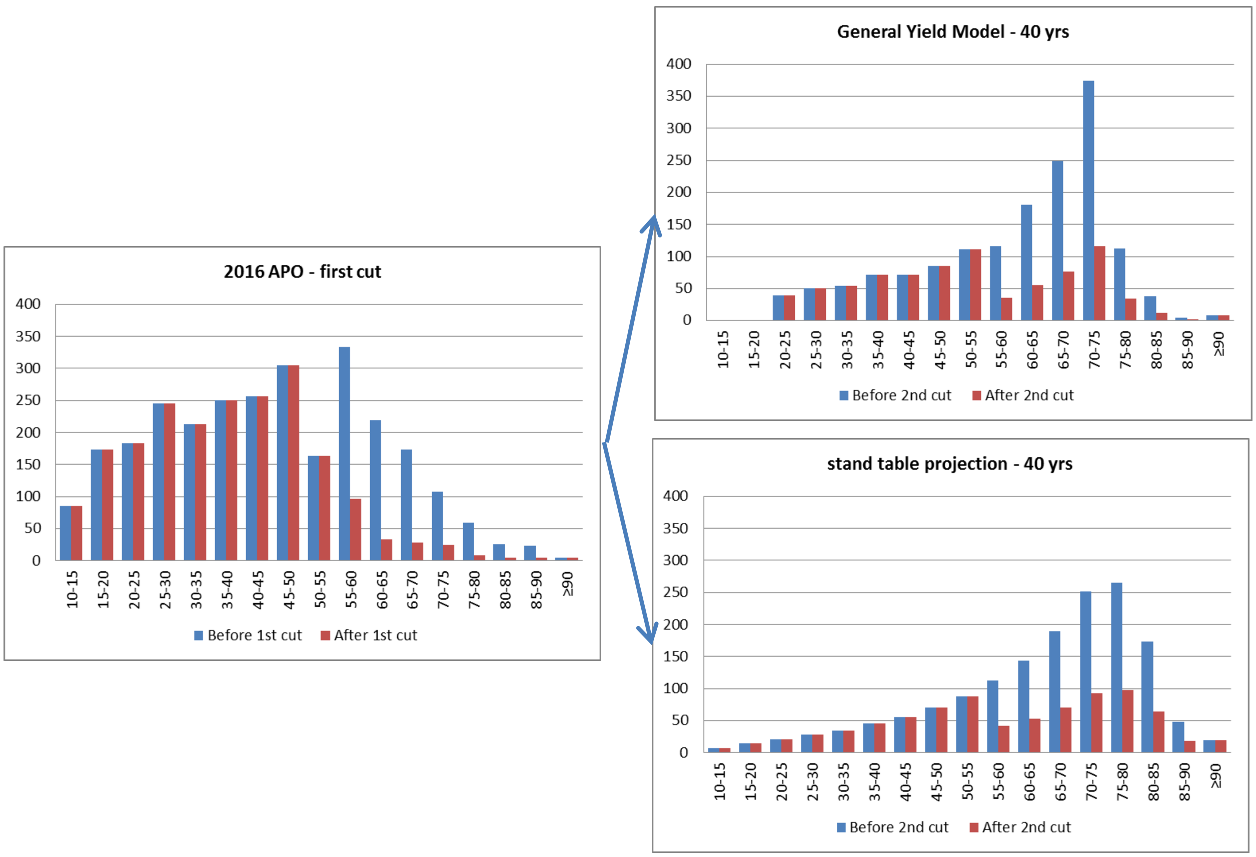


Figure 58 Initial diameter class frequency distribution and residual stock at first cut (left) and distribution at next cycle according to the General Yield Model (right, top) and stand table projection based on CFR PSP data (right, bottom)

The main difference between the models is in the diameter class frequency distribution, which is smoother with the stand table projection and contains more dbh ≥75cm class trees. This is also shown in Figure 58. Higher numbers in the higher diameter classes will, obviously, result in higher volumes available for harvesting at the second cut.

Stand table projection based on upper quartile increment rates

Another stand table projection model was constructed to measure the effect of predicting future stand development based on the upper quartile increment values for each diameter class, which are shown in Table 43. The inventory data for the initial mahogany stand table is taken from the 2016 APO.

The stand table projection, using the upper quartile increment rates, also results in a marginal difference in the total stocking at the next felling cut after a cutting cycle of 40 years (Table 44). However, the accrual in number of stems 55-90 cm dbh is much greater when using the upper quartile increment rates. The previous stand table projection (polynomial least squares regression) showed an accrual of 733 stems 55-90 cm dbh, while the accrual is 850 stems 55-90 cm dbh when the upper quartile increment rates are used. The indicative cutting intensity is further reduced to 55.7%. This basically means that a much greater number of residual trees 55-90 cm dbh will be relinquished as crop trees. According to the GYM there are 334 residual trees in the 55-90 cm dbh class after the second cut that have to be relinquished, according to the stand table projection with the GYM version 2 function 346 trees, according to the polynomial regression on the CFR PSP data 438 trees and according to the upper quartile increment rates even 590 trees. In principle this imminent loss in roundwood production could be lessened by allowing higher cutting intensities at the first cut. However, the cutting intensity at the first cut is already at its prescribed maximum value of 80%.

Table 43 Parameters for the stand table projection; increment, outgrowth based on upper quartile increment rates per diameter class, mortality based on the General Yield Model and stocking and harvest based on accrual with higher growth rates

5cm DBH class	Stocking (N/1000 ha)	From (cm)	To (cm)	Increment cm/yr.	Outgrowth %/5·yr	Mortality %/5·yr	Harvest %
10-15	85	10	15	0.36	36%	3.5%	
15-20	173	15	20	0.50	50%	3.5%	
20-25	183	20	25	0.63	63%	3.5%	
25-30	246	25	30	0.74	74%	3.5%	
30-35	213	30	35	0.84	84%	3.5%	
35-40	250	35	40	0.92	92%	3.5%	
40-45	256	40	45	0.98	98%	3.5%	
45-50	305	45	50	1.01	101%	3.5%	
50-55	163	50	55	1.01	101%	3.5%	
55-60	333	55	60	0.99	99%	3.5%	71%
60-65	219	60	65	0.92	92%	3.5%	85%
65-70	174	65	70	0.83	83%	3.5%	84%
70-75	108	70	75	0.69	69%	3.5%	78%
75-80	59	75	80	0.51	51%	3.5%	87%
80-85	26	80	85	0.28	28%	3.5%	80%
85-90	23	85	90	0.17	17%	3.5%	80%
≥90	5	≥90		0.17	0%	3.5%	0%

Another key difference between the three results is that the number of stems that will surpass the 90 cm maximum diameter limit before the next cut will increase from 3 to 15 to 25, according to the General Yield Model, the polynomial regression of the CFR PSP data and the upper quartile increment rates respectively. The conclusion is that either the maximum 80% cutting intensity for every diameter class should be reviewed or the cutting cycle should be shortened, allowing greater flexibility. This is already advocated because of the reduction in production forest area (see Section B 2.2).

Table 44 2016 yield for mahogany following the General Yield Model but stocking and residual stocking at the next (40-yr) cut after stand table projection based on upper quartile increment rates in CFR PSPs (Table 43)

Stand table projection on 2016 APO								
	2016				2016			
5cm DBH class	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**
10 to 14.9	85			85	1			1
15 to 19.9	173			173	4			4
20 to 24.9	183			183	7			7
25 to 29.9	246			246	11			11
30 to 34.9	213			213	16			16
35 to 39.9	250			250	23			23
40 to 44.9	256			256	32			32
45 to 49.9	305			305	44			44
50 to 54.9	163			163	61			61
55 to 59.9	333	71.2%	237	96	81	55.6%	45	36
60 to 64.9	219	85.0%	186	33	109	56.0%	61	48
65 to 69.9	174	84.0%	146	28	166	56.0%	93	73
70 to 74.9	108	78.0%	84	24	219	55.7%	122	97
75 to 79.9	59	87.0%	51	8	334	55.7%	186	148
80 to 84.9	26	80.0%	21	5	314	55.7%	175	139
85 to 89.9	23	80.0%	18	5	110	55.5%	61	49
≥90	5			5	30			30
TOTAL	**2,821**	**80.7%**	**743**	**2,078**	**1,562**	**55.7%**	**743**	**819**

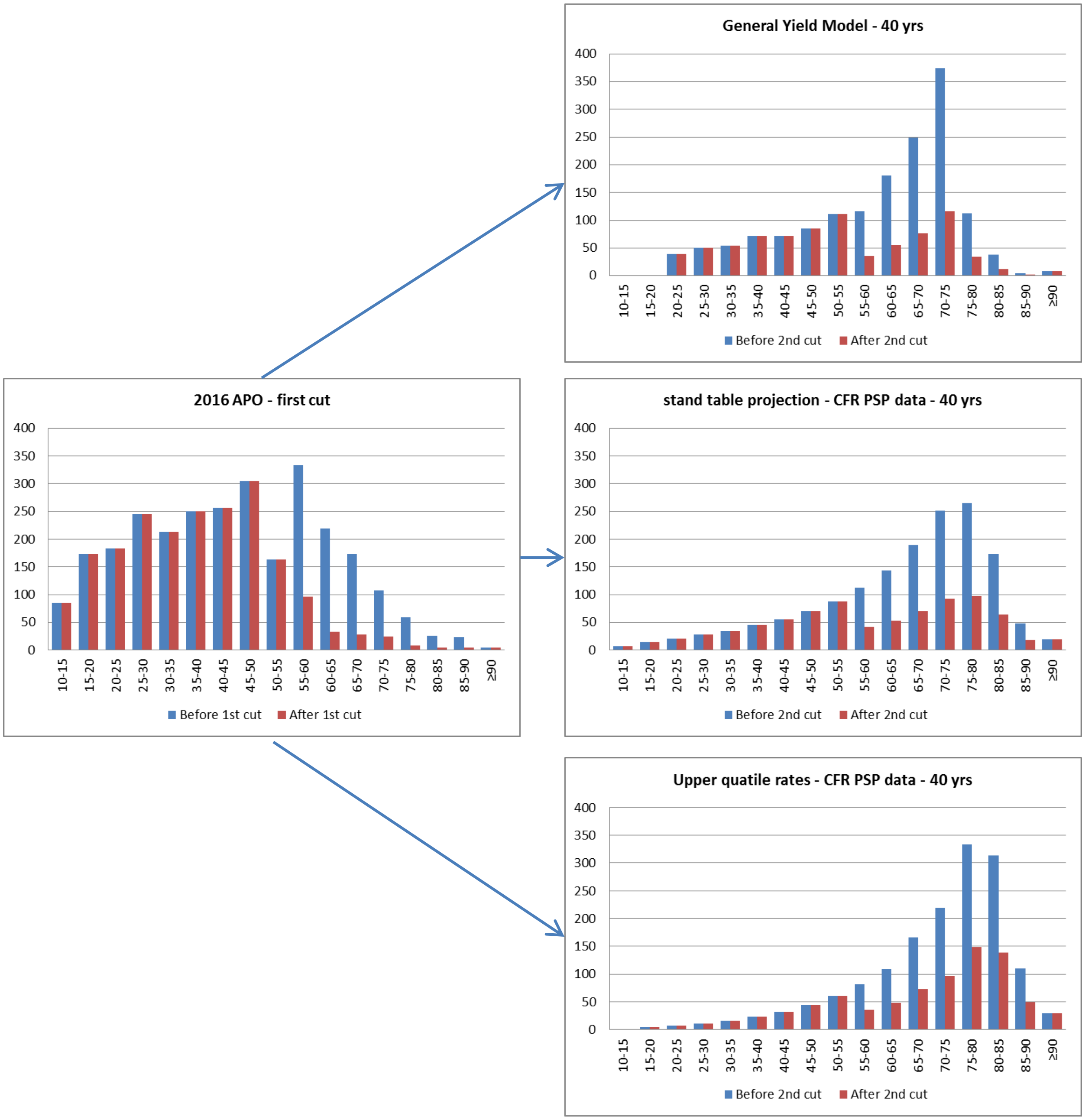


Figure 59 Initial diameter class frequency distribution and residual stock at first cut (left) and distribution at next cycle according to the General Yield Model (right, top) and stand table projection using least squares of CFR PSP data (right, middle) and stand table projection using upper quartile increment rates of CFR PSP data

5.5.5 *Felling diameter limit for maximum roundwood production*

It is possible to calculate the felling diameter limits that are appropriate to maximize roundwood production from the data in Table 36, because the mean annual volume increment achieved by a cohort of 100 seedlings (MAI%) can be calculated as (Alder, 1992b):

MAI% = (Cum. % survival) x (tree volume) ÷ (Cumulative age)

Conceptually, this measure of MAI is fully equivalent to that used in determining the optimum rotation for a plantation crop. Diameter is thereto treated as a direct function of age; it follows that expressing a felling regime in terms of diameter limit is equivalent to using a rotation age for a crop (Alder, 1992b). The diameter which maximizes MAI% represents an efficient maximum size to which the species should be grown. Beyond that size, reduced growth and natural mortality imply that retention of the trees will diminish the productivity of the forest as a whole. Productivity, in this context, assumes roundwood production to be the primary goal; there may be other, non-timber benefits that require larger sized trees to be retained. In the Belize context trees ≥90 cm dbh are excluded from harvesting and a cutting intensity of 80% is applied for every size class above the minimum cutting diameter limit to ensure a stable canopy structure. The effectiveness of the latter measure was questioned in Section B 5.5.4 because it does not reckon with an accelerating decrease in growth rate after trees will have surpassed 70 cm diameter.

Table 45 Computation of cumulative age, percent survival and mean annual increment % of mahogany trees according to the increment function and mortality rate used in the General Yield Model version 3.

Diam. class upper bound, cm	10	20	30	40	50	60	70	80	90
Volume; Alder equation (m³)	0.06	0.26	0.61	1.12	1.78	2.60	3.60	4.76	6.08
Sawmill input (m³)	0.09	0.20	0.40	0.68	1.05	1.51	2.06	2.70	3.44
Increment (cm/yr.)	0.17	0.28	0.45	0.60	0.70	0.70	0.58	0.27	0.17
Annual Mortality (% /yr.)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Time of Passage (yrs.)	58.8	36.3	22.4	16.7	14.3	14.2	17.4	36.5	58.8
Cumulative age	58.8	95.2	117.6	134.3	148.5	162.7	180.1	216.6	275.4
Cumulative % survival	66.2	51.2	43.8	38.9	35.2	31.9	28.2	21.8	14.4
MAI% (m³/yr.)	0.11	0.11	0.15	0.20	0.25	0.30	**0.32**	0.27	0.18

The appropriate diameter limit to achieve maximum mahogany roundwood production is 70 cm dbh (see Table 45). Felling mahogany below this diameter limit or retaining trees above will diminish the roundwood productivity of the forest. It is clear that the result is strongly dependent on the annual mortality rate and further study into annual mortality by size class is required to refine this estimate. If instead of 80% of trees in the size class 55-90 cm dbh, all trees in the size class 70-90 cm dbh would be harvested, the number of felled trees would drop drastically, based on the GYM growth function, by 70% from 743/100-ha to 216 trees/100-ha, while the net volume would drop by 60% from an estimated 1,300 m³/100-ha to 525 m³/100-

ha. Sustainability, however, would improve substantially with an accrual of 910 trees 70-90 cm dbh or a volume of 2,240 m³ by the time of the second cut.

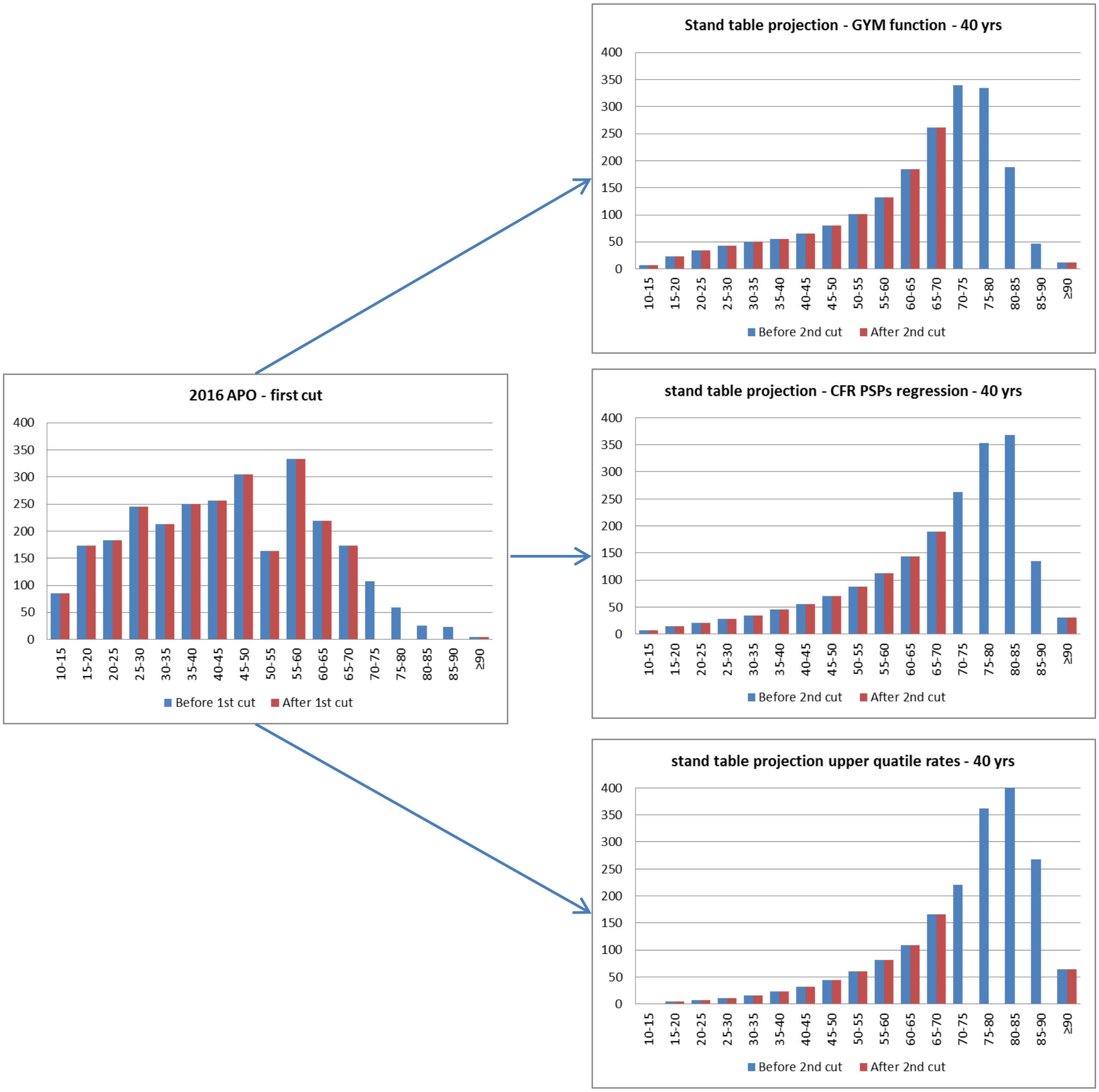


Figure 60 Hypothetical mahogany stand table development if silviculturally appropriate minimum cutting diameter limit of 70 cm dbh is applied; at first cut (left) and distribution at next cycle according to the General Yield Model (right, top) and stand table projection using least squares of CFR PSP data (right, middle) and stand table projection using upper quartile increment rates of CFR PSP data

5.6 Calculation of cutting cycle and annual allowable cut

5.6.1 Selection of species and data to calculate the cutting cycle and allowable cut

The cutting cycle is first and foremost determined by the population dynamics of mahogany which is the main species of interest and, as a matter of fact, the only species that can be managed profitably with the high cost of currently prescribed management practices in Belize. Other species can only be considered if harvested in addition to mahogany, bearing only marginal cost. In other words, management without mahogany production would not be profitable given the cost of current management requirements.

The calculation of the annual allowable cut must be done by applying the parameters in the General Yield Model version 3. In section 5.5 we propose higher diameter increment and mortality rates for mahogany but it would be futile to calculate the annual allowable cut based on the proposed parameters because actual allowable cuts are ultimately required to be based on the GYM, which is compulsory when preparing the APOs.

Stand tables have been prepared with the general inventory data and with the stock survey data of 2009-17 (see Section B 3.3.7). A combined stand table was produced of eight combined stock surveys over 2009-17, which covers 7,500 ha production forest. Because the minimum diameter for inclusion in the inventory (MDI) varied over the years (see Table 31), averaging was done for each 5-cm diameter class separately.

Inventory data are often unevenly distributed between classes, requiring some method of smoothing be applied to obtain proper projections. Smoothing was accomplished by fitting a polynomial (quadratic) function to the smaller size classes in the stand table and an exponential function to the larger size classes. The two smoothed stand tables, one based on the general inventory and the other on the 8 stock surveys, are represented in Figure 61

Using a precautious approach the calculation of the cutting cycle and annual allowable cut appropriate to mahogany will be based on the more conservative stand table of the combined stock surveys of 2009-17.

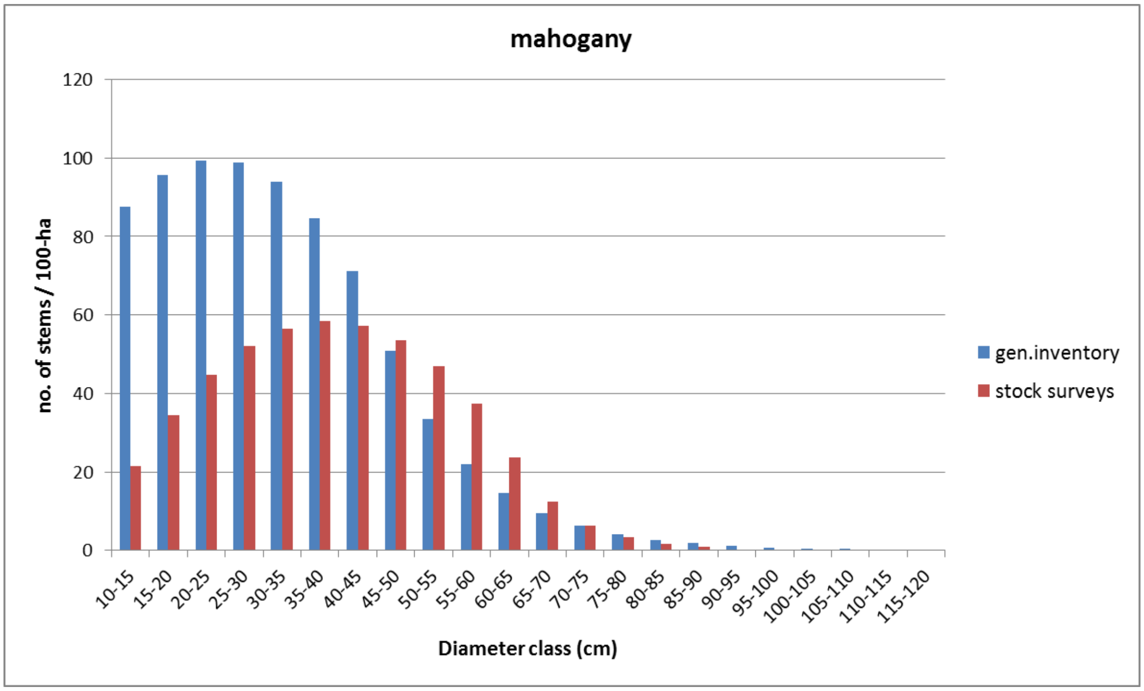


Figure 61 Smoothed diameter class frequency distribution of mahogany according to the general inventory and combined stock surveys 2009-17

5.6.2 40-year cutting cycle and sustainable yield of mahogany

There is no obvious way to determine the optimum cutting cycle from tree increment data alone. If factors relating to felling damage and regeneration are considered, together with the ecology of major crop species, then long cycles combined with heavy felling (a uniform system) may be preferred, as argued by Dawkins (1958). On the other hand, if the objective is to create the minimum change in the ecosystem, frequent light felling (a polycyclic system) would appear preferable. These imply short felling cycles.

In the case of mahogany there is a disparity between the species' ecological characteristics and the objective to restore the canopy of the CFR. Mahogany is essentially light demanding and high intensity logging would create more light, improving mahogany regeneration, but increasing disturbance and fragmenting the canopy. Single tree logging will allow less light, reducing regeneration, but causing less disturbance. There exists therefore an inherent trade-off between the objectives of reducing short term environmental impact, and the longer term environmental objective of regenerating mahogany.

Until recently, a 40-year felling cycle has been adopted for the CFR on the basis of various considerations described by Bird (1998) but FD also allows a 25-year felling cycle. In principle, compartments may be managed under different felling cycles but this poses serious problems when organizing forest management of the reserve over two felling cycles (see Section B 2.2).

Given a prior decision as to possible felling cycles, it is possible to apply a simple spreadsheet method to show how the CFR can be managed to give a sustainable yield from growth rate and mortality data. The procedure is here applied for a 40-year and 25-year cycle.

The simple spreadsheet method is based on annual diameter increment and mortality rates and has been published by Alder (1992b). The diameter increment of mahogany appears to be diameter-dependent and, according to the GYM, to vary between 0.17 and 0.71 cm/yr. depending on the size class. Given a 40-year felling cycle and restrictions on logging being imposed by the FD, the current harvestable size class is 55-90 cm dbh. The size class that will form the next cut in 40 years is determined to be 30-55 cm dbh based on the average growth rate of this class. Similarly, the second next cut in 80 years should be formed by the trees that are presently in the class 15-30 cm dbh corresponding to the lower growth rate in this size class. By compiling inventory data into these size classes one obtains an impression of the yields of trees that will be available in the present and succeeding felling cycles.

The numbers of trees in the smaller classes need to be discounted by the anticipated mortality rate. Annual mortality for trees of 10 cm or above is taken as 0.7% according to the GYM. This corresponds over a 40-year cycle to $(1-0.007)^{40}$ or 75.5% survival.

Table 46 shows the pattern of stock survey data for mahogany forest grouped into size classes that make up the present, next and second next cut. The data is taken from the combined 2009-17 stock survey stand tables. The table shows the actual numbers, and then the numbers discounted to allow for mortality prior to maturity. Exploitation is assumed to occur above 55 cm.

Table 46 Calculation of sustainable yield of mahogany in CFR at three successive cuts with a 40-yr. cutting cycle, using stock survey data 2009-17 and applying current restrictions (see text)

Felling cycle	+80 yrs.	+40 yrs.	Present	OverSize
Present diameter class (cm)	15-30	30-55	55-75	75-90
Initial stocking (N/km²)	131	273	80	6
Survival %	57.0%	75.5%	100%	100%
Final stocking (N/km²)	75	206	80	6
Accrual from last cycle	113	13	NA	NA
Total stocking (N/km²)	188	219	80	6
Harvest	69	69	64	5
Retained trees (N/km²)	119	150	16	1

The table is organized by diameter class columns, each of which corresponds to a single felling cycle. The stocking is derived from the combined stock survey data. The survival % row uses the 75.5% survival over a 40-year period to calculate net survival to harvest. For the 15-30 cm class, with 80 years to maturity, this net survival will be approximately $(1-0.007)^{80}$ or 57%. For the currently mature and over-sized trees, survival to harvest is 100% as they are currently available for harvest.

The survival % is applied to the stock survey stocking to give a final stocking at the time of harvest. Final stocking fluctuates between felling cycles depending on the overall stand structure. No trees above 90 cm may be cut. Those are therefore ignored in the table. The maximum cutting intensity is 80% in each size class; hence both in the present and over-sized class. The allowable minimum total stocking is 50 trees ≥ 25 cm dbh per 1 km², of which at least 25 trees must be ≥ 50 cm dbh. Once the sustainable yield is set at 80% of the currently mature (55-75 cm) and over-sized trees (75-90 cm), all other data relating to trees harvested, retained, and accrued from previous stocks are calculated depending on this entry.

In the two right-most columns, for the present cycle and the stock of over-mature trees, the harvest is distributed proportionately between the two columns, so that some current stock and some over-mature stock will be removed to make up the desired number of trees (80% of 86 trees = 69 trees). The retained trees in each column are calculated as the final stocking, plus any accruals from the previous cycle, minus the harvest. The accruals comprise the retained trees from the preceding cycle (i.e. the column to the right), reduced by the survival factor of 75.5% or 57.0%. These are the trees which were retained at the previous cycle and carried over to the next cycle.

Table 47 Calculation of sustainable yield of mahogany in CFR at three successive cuts with a 40-yr. cutting cycle, using stock survey data 2009-17 with full harvest of 55-90 cm stock

Felling cycle	+80 yrs.	+40 yrs.	Present	OverSize
Present diameter class (cm)	15-30	30-55	55-75	75-90
Initial stocking (N/km²)	131	273	80	6
Survival %	57%	76%	100%	100%
Final stocking (N/km²)	75	206	80	6
Accrual from last cycle	91	0	NA	NA
Total stocking (N/km²))	166	206	80	6
Harvest	86	86	80	6
Retained trees (N/km²)	80	120	0	0

Consistent application of the current cut in number of trees means that the cutting intensity will be just 32% (69÷219) at the next cut and 37% (69÷188) at the second next. The current maximum cutting intensity can thus easily be maintained; even after two full felling cycles. This is not surprising given the current average stand structure of mahogany with relatively few trees of harvestable size and an abundance of midsize trees in the 25-55 cm class.

Table 47 shows that capping the harvest at 80% is not necessary from a sustained yield point of view. The relatively high abundance of trees in the 25-55 cm is basically a guarantee that the size class 55-75 cm will be restocked adequately during the felling cycle. If we set the sustainable yield at 100% of the currently mature (55-75 cm) and over-sized trees (75-90 cm), the sustainable yield is increased to 86 trees per 1 km². Consistent application of this cutting level at succeeding cuts appears fully sustainable because the cutting intensity remains below the current 80% threshold; i.e., 42% (86÷166) at the next cut and 52% (86÷166) at the second next cut.

5.6.3 25-year cutting cycle and sustainable yield of mahogany

The same procedure was applied to estimate sustained yield of mahogany in the CFR with a 25-year felling cycle. In theory, a 25-yr. cycle should capture a higher proportion of the natural mortality and should result in higher sustained yields. Table 48 shows the pattern of stock survey data for mahogany forest grouped into classes of variable size, corresponding to variable mean diameter increment rates, which represent the trees that make up four successive cuts.

Table 48 Calculation of sustainable yield of mahogany in CFR at four successive cuts with a 25-yr. cutting cycle, using stock survey data 2009-17 and applying current restrictions (see text)

Felling cycle	+75 yrs.	+50 yrs.	+25 yrs.	Present	OverSize
Present diameter class (cm)	15-25	25-40	40-55	55-70	70-90
Initial stocking (N/km²)	79	167	158	73	12
Survival %	59.0%	70.4%	83.9%	100%	100%
Final stocking (N/km²)	47	118	132	73	12
Accrual from last cycle	81	65	14	NA	NA
Total stocking (N/km²)	128	183	146	73	12
Harvest	68	68	68	58	10
Retained trees (N/km²)	60	115	78	15	2

The initial maximum cutting intensity is again set at 80% in each size class as required by the FD; hence both in the present and over-sized class. This cutting level can be maintained for four successive cuts over a period of 75 years compared to three successive cuts over a period of 80 years with a 40-yr. cycle. Successive application of the current maximum cut of 68 trees per km² results in cutting intensities of 47% (68÷146) at the second cut, 37% (68÷183) at the third cut and 53% at the fourth cut. The number of retained trees ≥ 50 cm dbh stays above 50 trees per km² at each of the cuts. With a 25-yr. cycle 107 trees in the size class 15-55 cm would be lost due to natural mortality over a period of 75 years against 123 trees over a period of 80 years with a 40-yr. cycle. Over a period of 75 years, the total harvest consists of 272 trees with a 25-yr. cycle, while 207 trees are harvested in total over a period of 80 years with a 40-yr. cycle. At first glance, a 25-year cycle is preferred from a silvicultural point of view because better use is made of the forest's productive capacity and the, possibly temporary, abundance of mahogany trees in the midsize class (25-50 cm dbh). Cumulative logging damage could, however, be greater with shorter felling cycles.

Table 49 Calculation of sustainable yield of mahogany in CFR at four successive cuts with a 25-yr. cutting cycle, using stock survey data of 2009-17 with full harvest of 55-90 cm stock

Felling cycle	+75 yrs.	+50 yrs.	+25 yrs.	Present	OverSize
Present diameter class (cm)	15-25	25-40	40-55	55-70	70-90
Initial stocking (N/km²)	79	167	158	73	12
Survival %	59.0%	70.4%	83.9%	100%	100%
Final stocking (N/km²)	47	118	132	73	12
Accrual from last cycle	51	39	0	NA	NA
Total stocking (N/km²)	98	157	132	73	12
Harvest	85	85	85	73	12
Retained trees (N/km²)	13	72	47	0	0

If the sustainable yield is set at 100% of the currently mature (55-75 cm) and over-sized trees (75-90 cm), the yield will be increased to 85 trees per 1 km². Consistent application of this cutting level at succeeding cuts appears not to be sustainable after the third cut because the cutting intensity will exceed the current 80% threshold at the fourth cut in 75 years; i.e., 87% (85÷98) and the number of residual trees will be less than the restocking level of 25[8] trees ≥ 50 cm dbh per 1 km².

BRL proposes to apply a 25-yr felling cycle in this management plan for the following three reasons:

1. The production forest area is adjusted downward to 35,751 ha – of which 10,633 ha has been logged during the present felling cycle – due to inaccessibility of perceived production forest along and beyond the Raspaculo River and Monkey Tail Rivers, incorporation of the recommendations of the Chiquibul Cave System Management Plan and rationalisation of the boundaries of the mining areas. BRL will run out of production forest at the current harvest rate of 1,000 ha per year due to this adjusted production forest area (see Section B 2.1.3).
2. Secondly, the Forest Department reduced the maximum cutting diameter from 100 cm dbh to 90 cm dbh in 2015 and is planning to reduce this limit further to 80 cm dbh. Diameter increment rates of 1 cm/yr. for mahogany canopy trees are quite credible as explained in Section B 5.5.3. With such a diameter increment rate application of a 40-yr. felling cycle would imply that many reserve trees will surpass the 90(80)-cm limit before the scheduled year for the second harvest. Hence, with a 40-yr felling cycle, the harvest of many trees will be forgone.

[8] Surviving trees in the present diameter class 15-25 cm are supposed to have moved over into the 55-70 cm class at the time of harvest. No information on juvenile trees at the time of harvest is included in this simple model, but it is assumed that 25 residual (reserve) trees ≥ 25 cm dbh and < 50 cm dbh are retained per 1 km²

3. With the present diameter class frequency distribution of mahogany a 'sustained' yield can be maintained for at least four successive cuts over a period of 75 years with a 25-yr. cycle against three successive cuts over a period of 80 years with a 40-yr. cycle. The annual yield as such is capped as 80% of the present harvestable stock, and can be maintained in either a 40-yr. or 25-yr. felling cycle. A 25-yr. felling cycle will suffer less loss of production due to natural mortality and will produce a higher total yield over a period of 80 years (see Section B 5.6.3).

5.6.4 Calculation of annual allowable cut using stand table projection

Stand table projection as described by Alder (1995) and a 25-year cutting cycle are used to estimate the annual allowable cut. The parameters in the stand table projection model are taken from the General Yield Model version 3 including all pertinent harvesting restrictions that were in force at the time of writing this FMP. Initial diameter class distributions are taken from the 2009-17 stock survey average by virtue of the precautionary principle; i.e. the diameter distribution pattern is more conservative in the stock survey average than in the general inventory. In addition, confidence in the estimates for the 10-25 cm class in the general inventory is low. Recruitment into the 10-15 cm diameter class is ignored mainly because no reliable information is available about mahogany recruitment after current sustained yield logging in the CFR. Even if recruitment would be growing at 1 cm/yr. in diameter after moving into the 10-15 cm size class, it would take it 40 years to reach the minimum cutting diameter limit.

Mahogany

The annual cutting area will comprise two 500-ha compartments for the duration of this management plan; 2018-2022 (see Section B 2.2). For an annual cutting area of 1,000 ha, the combined stock surveys over 2009-17 indicate an average of 5,130 mahogany trees ≥ 10 cm dbh and 860 mahogany trees of harvestable size (55-90 cm dbh). The size class frequency distribution of mahogany shows an abundance of trees in the size class 25-50 cm dbh (see Table 50). If no logging takes place, accrual into the harvestable size class over a period of 25 years will be as much as 1,437 trees/1,000-ha, more than one and half times the current harvestable stock. Hence, a 100% cutting intensity would be sustainable for at least two felling cycles because the residual stock after the second cut is still estimated at 1,993 trees ≥ 50 cm dbh, while the restocking level is 500 trees ≥ 25 cm dbh. However, the cutting intensity is officially capped at 80%, which results in a sustainable yield of 687 trees (see Table 50) with a net extracted volume of 1,158 m^3 (40,902 ft^3) per annum. The sawn lumber output is estimated at 266,138 BF per annum, based on actual conversion rates at the Georgeville sawmill.

Table 50 Stand table projection for mahogany with a 25-year felling cycle based on combined results of 2009-2017 stock surveys; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle: mahogany								
	present cycle				+25 years			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10-15	214			214	45			45
15-20	344			344	96			96
20-25	446			446	142			142
25-30	520			520	182			182
30-35	566			566	219			219
35-40	584			584	256			256
40-45	574			574	296			296
45-50	535			535	342			342
50-55	469			469	393			393
55-60	374	80.0%	299	75	447	39.8%	178	269
60-65	237	80.0%	190	47	488	39.8%	194	294
65-70	124	80.0%	99	25	444	39.6%	176	268
70-75	64	80.0%	51	13	253	39.5%	100	153
75-80	34	80.0%	27	7	79	39.2%	31	48
80-85	18	80.0%	14	4	15	40.0%	6	9
85-90	9	80.0%	7	2	4	50.0%	2	2
≥90	18			18	18			18
Total	5,130	80.0%	687	4,443	3,719	41.1%	687	3,032

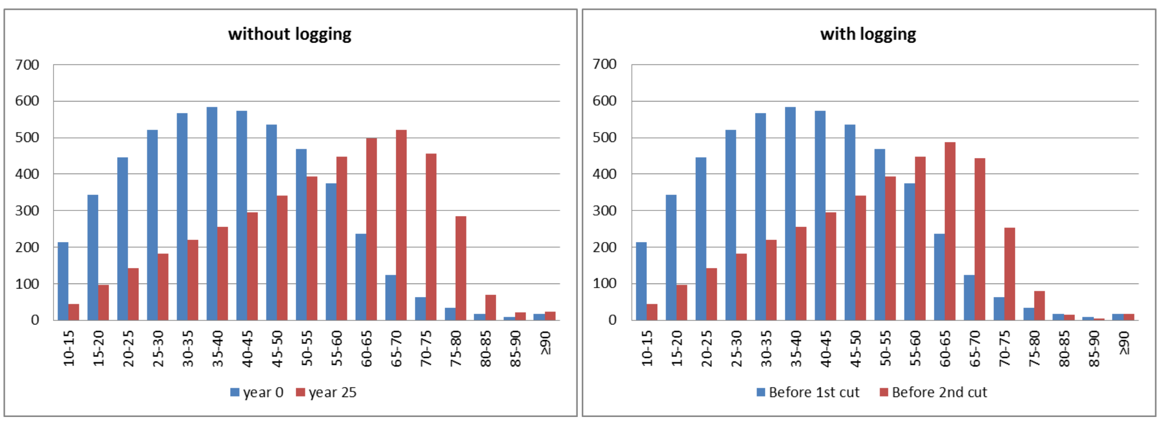


Figure 62 Mahogany: stand structure development over the next 25 years, whereby possible recruitment into the 10-15 cm diameter class is ignored; without and with logging.

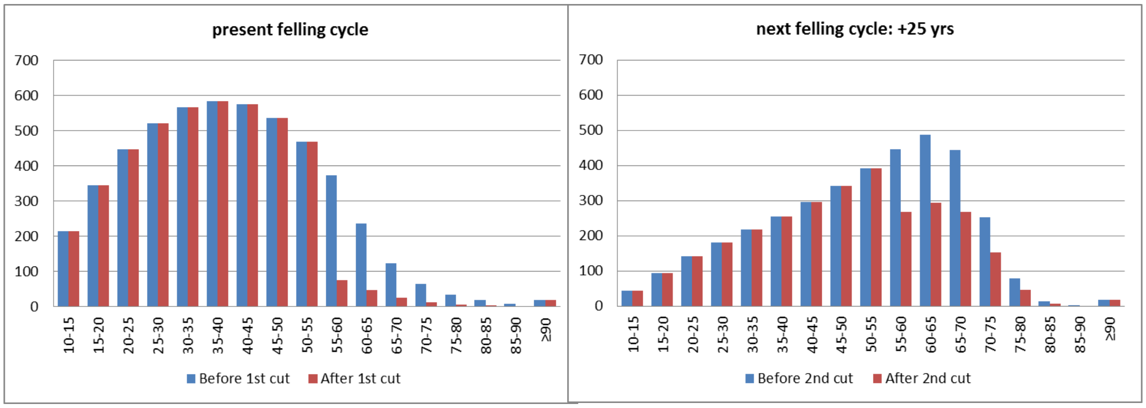


Figure 63 **Mahogany: impact of harvesting on size class distribution during present and next 25-yr felling cycle, whereby possible recruitment into the 10-15 cm diameter class is ignored**

Table 51 **Expected sustained yield of mahogany during present and next 25-year felling cycle based on 2009-17 stock surveys and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5**

	present felling cycle	next felling cycle
No. of trees	687	687
Net extracted volume (ft^3)	40,902	43,214
Net extracted volume(m^3)	1,158	1,224
Sawn lumber produced (BF)	266,138	286,239

A second stand table projection model was constructed based on the size class distribution found with the general inventory. Sustained yield is lower according to the general inventory, but there are questions concerning the reliability of the general inventory (Tables 52 and 53).

Table 52 **Stand table projection for mahogany with a 25-year felling cycle based on the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored**

Stand table projection 25-year felling cycle (1,000 ha)								
	present cycle				**+25 years**			
DBH class	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**
10-55	7,151			7,151	4,267			4,267
55-90	612	80.0%	490	122	1,815	25.7%	490	1,325
≥90	35			35	33			33
Total	**7,798**		**490**	**7,308**	**6,115**		**490**	**5,625**

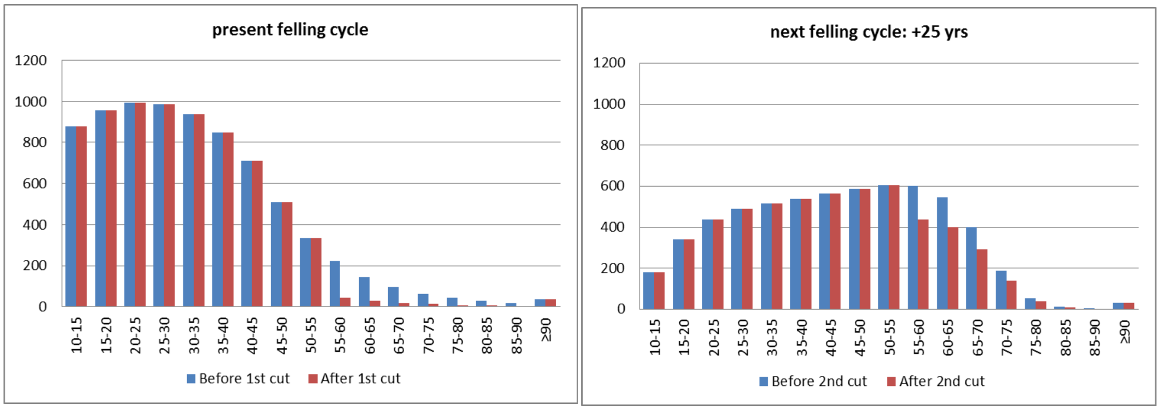


Figure 64 Mahogany: impact of harvesting on size class distribution during present and next 25-yr felling cycle, according to the general inventory whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 53 Expected sustained yield of mahogany during present and next 25-year felling cycle based on general inventory (2011/14) and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	490	490
Net extracted volume (ft3)	31,341	29,623
Net extracted volume(m3)	887	839
Sawn lumber produced (BF)	208,663	193,731

Cedar

The annual cutting area will comprise two 500-ha compartments for the duration of this management plan; 2018-2022 (see Section B 2.2). For an annual cutting area of 1,000 ha, the combined stock surveys over 2009-17 indicate an average of 1,005 cedar trees ≥ 10 cm dbh and 194 cedar trees of harvestable size (60-90 cm dbh). The size class frequency distribution of cedar shows an abundance of trees in the size class 30-55 cm dbh (see Table 54).

Table 54 Stand table projection for cedar with a 25-year felling cycle based on combined results of 2009-2017 stock surveys; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle: cedar								
	present cycle				+25 years			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10-15	23			23	5			5
15-20	48			48	11			11
20-25	68			68	18			18
25-30	84			84	25			25
30-35	95			95	32			32
35-40	102			102	40			40
40-45	104			104	48			48
45-50	101			101	57			57
50-55	93			93	68			68
55-60	81			81	80			80
60-65	64	67.6%	43	21	93	38.7%	36	57
65-70	43	67.9%	29	14	99	39.4%	39	60
70-75	34	68.4%	23	11	82	39.0%	32	50
75-80	24	67.6%	16	8	43	39.5%	17	26
80-85	17	66.8%	11	6	11	36.4%	4	7
85-90	12	67.6%	8	4	5	40.0%	2	3
≥90	12			12	12			12
Total	1,005	67.6%	130	875	729	38.8%	130	599

If no logging takes place, accrual into the harvestable size class over a period of 25 years will be 244 trees/1,000-ha; about 125% of the current harvestable stock. The cutting intensity is, however, limited to 68% in order to keep the restocking level above 250 trees ≥ 50 cm dbh. A cutting intensity of 68% results in a sustainable yield of 130 trees (see Table 54) with a net extracted roundwood volume of 233 m³ (8,237 ft³) per annum. The sawn lumber output is estimated at 49,681 BF per annum, based on actual conversion rates at the Georgeville sawmill.

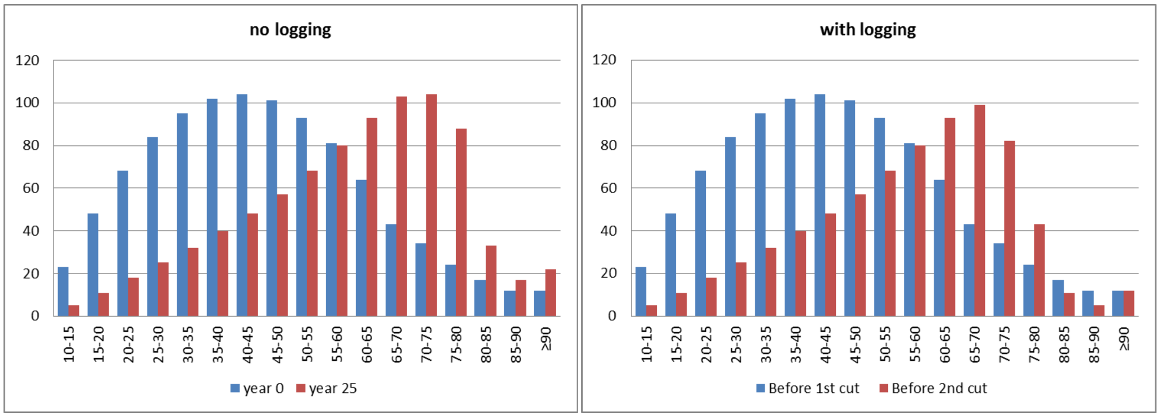


Figure 65 Cedar: stand structure development over the next 25 years, whereby possible recruitment into the 10-15 cm diameter class is ignored; without and with logging.

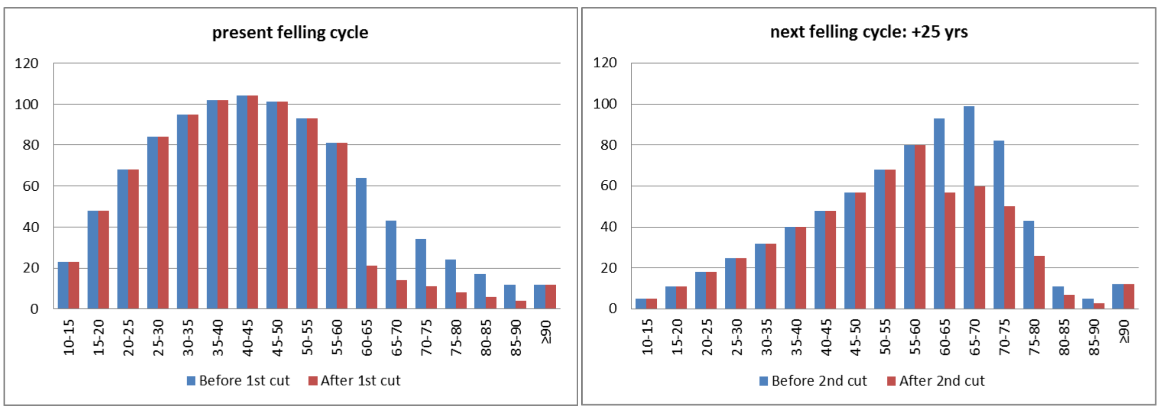


Figure 66 Cedar: impact of harvesting on size class distribution during present and next 25-yr felling cycle, whereby possible recruitment into the 10-15 cm diameter class is ignored

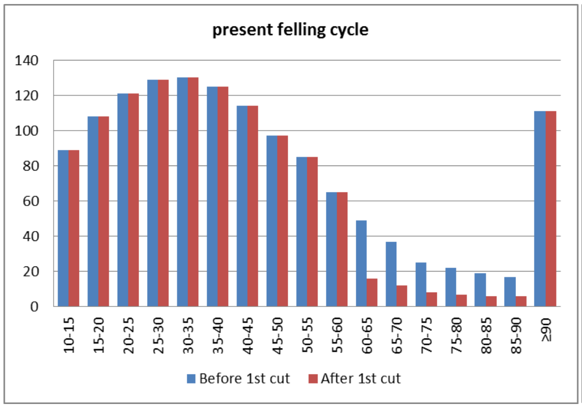
Table 55 Expected sustained yield of cedar during present and next 25-year felling cycle based on 2009-17 stock surveys and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	130	130
Net extracted volume (ft³)	8,237	7,956
Net extracted volume(m³)	233	225
Sawn lumber produced (BF)	49,681	47,356

A second stand table projection model was constructed based on the size class distribution found with the general inventory. Sustained yield according to the general inventory is similar to the yield according to the combined stock surveys 2009-27 (See Tables 56 and 57).

Table 56 Stand table projection for cedar with a 25-year felling cycle based on the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle (1,000 ha)								
	present cycle				+25 years			
DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10-60	1,063			1,063	622			622
60-90	169	67.6%	114	55	309	38.8%	114	195
≥90	111			111	97			97
Total	**1,343**		**114**	**1,229**	**1,028**		**114**	**914**



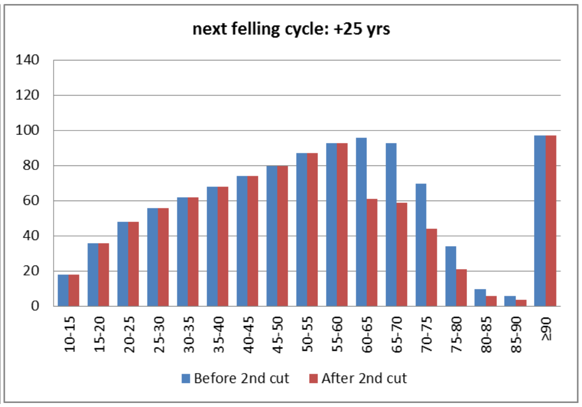


Figure 67 Cedar: impact of harvesting on size class distribution during present and next 25-yr felling cycle, according to the general inventory whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 57 Expected sustained yield of cedar during present and next 25-year felling cycle based on general inventory (2011/14) and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	114	114
Net extracted volume (ft3)	7,501	6,921
Net extracted volume(m3)	212	196
Sawn lumber produced (BF)	45,866	41,065

Barbajolote

The annual cutting area will comprise two 500-ha compartments for the duration of this management plan; 2018-2022 (see Section B 2.2). For an annual cutting area of 1,000 ha, the combined stock surveys over 2009-17 indicate an average of 199 barbajolote trees ≥ 25 cm dbh and 106 barbajolote trees of harvestable size (50-90 cm dbh). The size class frequency distribution of barbajolote shows an abundance of trees in the size class 40-60 cm dbh (see Table 58). In principle, the stocking lies below the official restocking level of 200 trees ≥ 25 cm dbh, but there are 122 trees ≥ 50 cm dbh, which stocking is higher than the required restocking level of trees ≥ 50 cm dbh. Therefore, we still estimate a sustained yield, assuming density of sub-adult trees may be more variable than shown in the stock surveys to date. If no logging takes place, accrual into the harvestable size class over a period of 25 years will be 36 trees/1,000-ha; about one-third of the current harvestable stock. By keeping the residual stock ≥ 50 cm dbh above the restocking level of 100 trees per 1,000 ha, a cutting intensity of 20% is suggested. A cutting intensity of 20% results in a sustainable yield of 21 trees (see Table 58) with a net extracted roundwood volume of 29 m^3 (1,025 ft^3) per annum. The sawn lumber output is estimated at 6,223 BF per annum.

Table 58 Stand table projection for barbajolote with a 25-year felling cycle based on combined results of 2009-2017 stock surveys; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle: barbajolote								
	present cycle				+25 years			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
25-30	8			8	0			0
30-35	13			13	1			1
35-40	17			17	4			4
40-45	19			19	8			8
45-50	20			20	13			13
50-55	27	21.1%	6	21	17	17.6%	3	14
55-60	21	20.4%	4	17	21	19.0%	4	17
60-65	16	20.8%	3	13	22	18.2%	4	18
65-70	13	21.9%	3	10	20	15.0%	3	17
70-75	10	19.0%	2	8	16	18.8%	3	13
75-80	8	17.8%	1	7	12	16.7%	2	10
80-85	6	23.8%	1	5	10	20.0%	2	8
85-90	5	19.0%	1	4	7	14.3%	1	6
≥90	16			16	18			18
Total	199	20.5%	21	178	169	17.4%	22	147

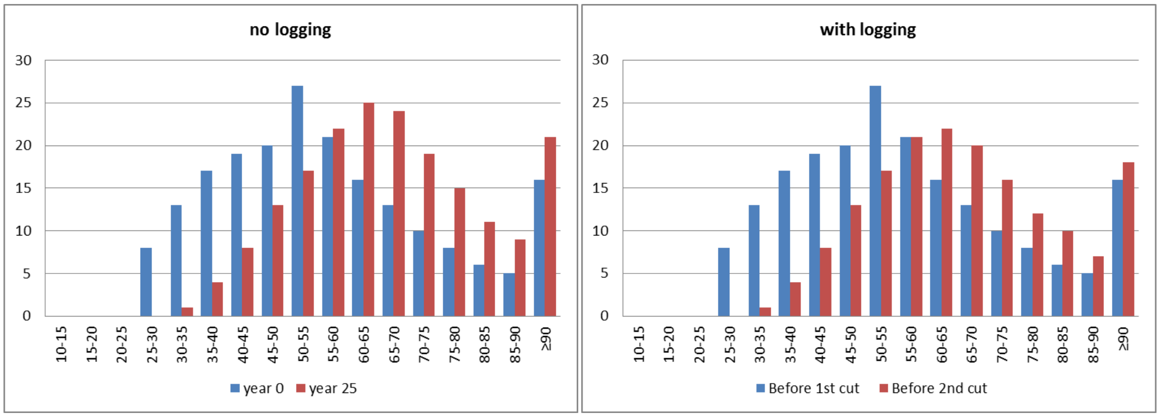


Figure 68 Barbajolote: stand structure development over the next 25 years, whereby possible recruitment into the 10-15 cm diameter class is ignored; without and with logging.

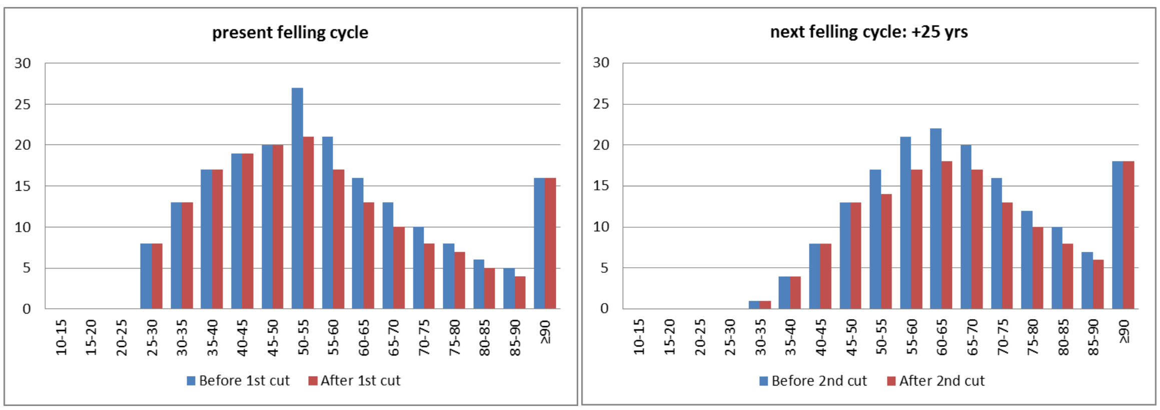


Figure 69 Barbajolote: impact of harvesting on size class distribution during present and next 25-yr felling cycle, whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 59 Expected sustained yield of barbajolote during present and next 25-year felling cycle based on 2009-17 stock surveys and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	21	22
Net extracted volume (ft³)	1,025	1,199
Net extracted volume (m³)	29	34
Sawn lumber produced (BF)	6,223	7,562

A second stand table projection model was constructed based on the size class distribution according to the general inventory. Sustained yield is a lot higher, but there are questions concerning the reliability of the general inventory (see Tables 60 and 61).

Table 60 Stand table projection for barbajolote with a 25-year felling cycle based on the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle (1,000 ha)								
	present cycle				+25 years			
DBH class	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**
10-50	1,622			1,622	1,201			1,201
50-90	336	76.8%	258	78	375	69.6%	258	117
≥90	258			258	244			244
Total	**2,216**		**258**	**1,958**	**1,820**		**258**	**1,562**

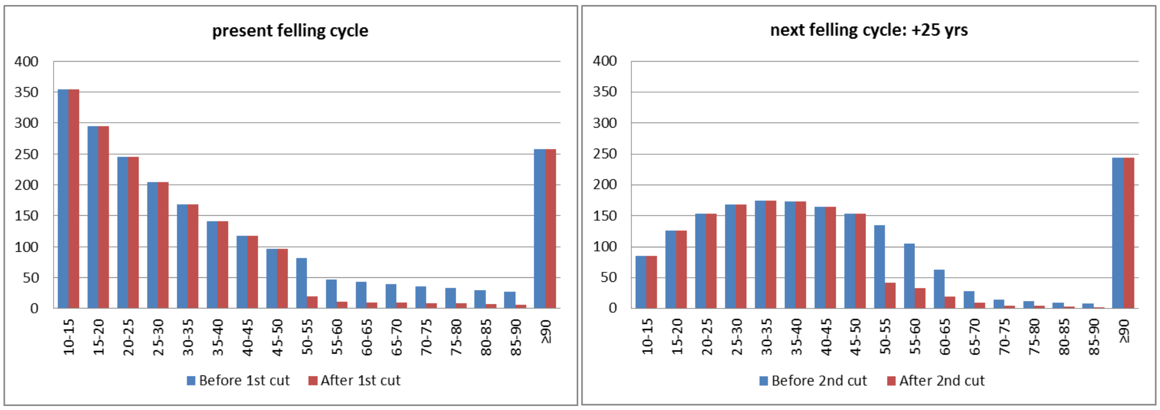


Figure 70 Barbajolote: impact of harvesting on size class distribution during present and next 25-yr felling cycle, according to the general inventory whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 61 Expected sustained yield of barbajolote during present and next 25-year felling cycle based on general inventory (2011/14) and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	258	258
Net extracted volume (ft3)	14,082	11,095
Net extracted volume(m3)	399	314
Sawn lumber produced (BF)	88,888	63,871

Rosewood

The annual cutting area will comprise two 500-ha compartments for the duration of this management plan; 2018-2022 (see Section B 2.2). For an annual cutting area of 1,000 ha, the combined stock surveys over 2009-17 indicate an average of 761 rosewood trees ≥ 20 cm dbh and 270 rosewood trees of harvestable size (35-70 cm dbh). The size class frequency distribution of rosewood shows an abundance of trees in the size class 25-35 cm dbh (see Table 62). In principle, the stocking lies below the official restocking level of 250 trees ≥ 50 cm dbh, but this limit is not applicable to rosewood, which has a D95 of 47 cm according to the stock surveys. The minimum stocking ≥ 25 cm dbh is achieved without difficulty; 643 trees after the present felling cycle and 622 after the next. If no logging takes place, accrual into the harvestable size class over a period of 25 years will be 422 trees/1,000-ha; one and half times the current harvestable stock. In order to keep the residual stock ≥ 25 cm dbh at the next cut above the restocking level of 500 trees per 1,000 ha, a cutting intensity of 44% is suggested. A cutting intensity of 44% results in a sustainable yield of 113 trees (see Table 62) with a net extracted roundwood volume of 77 m³ (2,721 ft³) per annum. The sawn lumber output is estimated at 10,069 BF per annum.

Table 62 Stand table projection for rosewood with a 25-year felling cycle based on combined results of 2009-2017 stock surveys; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle: rosewood								
	present cycle				+25 years			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
20-25	9			9	1			1
25-30	208			208	7			7
30-35	274			274	25			25
35-40	154	42.3%	65	89	59	18.6%	11	48
40-45	63	42.0%	26	37	107	19.6%	21	86
45-50	29	41.9%	12	17	153	19.6%	30	123
50-55	14	42.5%	6	8	148	19.6%	29	119
55-60	6	40.5%	2	4	84	19.0%	16	68
60-65	3	45.0%	1	2	28	17.9%	5	23
65-70	1	54.1%	1	0	3	33.3%	1	2
≥70	0		0	0	0		0	0
Total	761	44.1%	113	648	615	21.1%	113	502

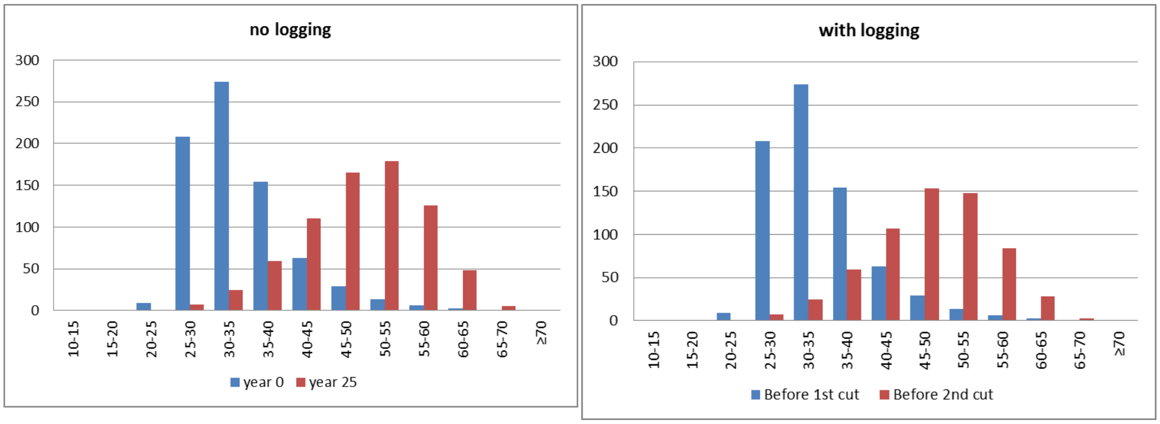


Figure 71 **Rosewood: stand structure development over the next 25 years, whereby possible recruitment into the 10-15 cm diameter class is ignored; without and with logging.**

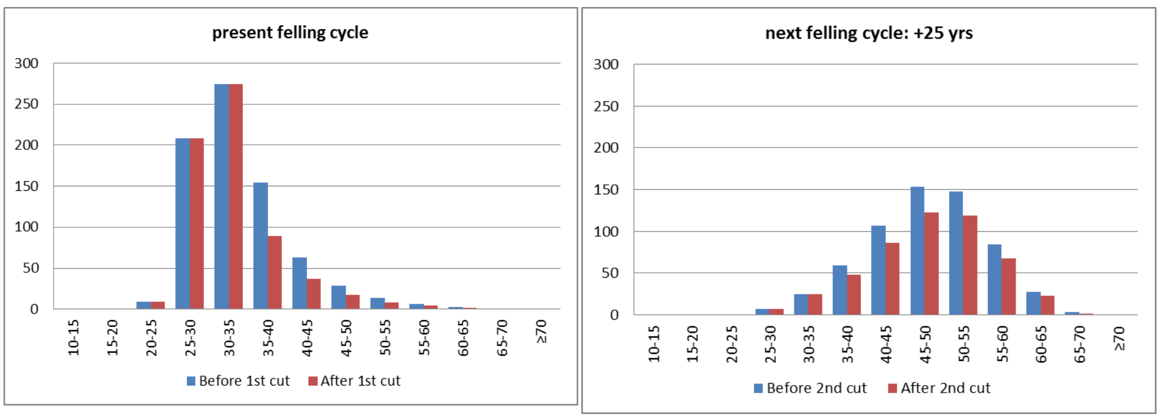


Figure 72 **Rosewood: impact of harvesting on size class distribution during present and next 25-yr felling cycle, whereby possible recruitment into the 10-15 cm diameter class is ignored**

Table 63 **Expected sustained yield of rosewood during present and next 25-year felling cycle based on 2009-17 stock surveys and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5**

	present felling cycle	next felling cycle
No. of trees	113	113
Net extracted volume (ft³)	2,721	3,826
Net extracted volume(m³)	77	108
Sawn lumber produced (BF)	10,069	19,322

A second stand table projection model was constructed based on the size class distribution found with the general inventory. According to the general inventory stocking of rosewood is too low to be harvested sustainably (see Table 64). The present stocking according to the general inventory is only 231 trees ≥ 25 cm dbh, which lies below the restocking level of 500 trees ≥ 25 cm dbh. Accrual into the harvestable size class is 202 trees per 1,000 ha, while recruitment into the juvenile size classes remains unknown for the moment. Rosewood is unevenly dispersed across the reserve (see Section B 3.3.4). Individual stock surveys will need to show whether harvestable rosewood stands occur in certain compartments, but any rosewood production should be seen as a bonus.

Table 64 Stand table projection for rosewood with a 25-year felling cycle based on the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle (1,000 ha)								
DBH class	present cycle				+25 years			
	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10-35	316			316	98			98
35-70	53	0.0%		53	255	0.0%		255
≥70	0			0	0			0
Total	**369**			**369**	**353**			**353**

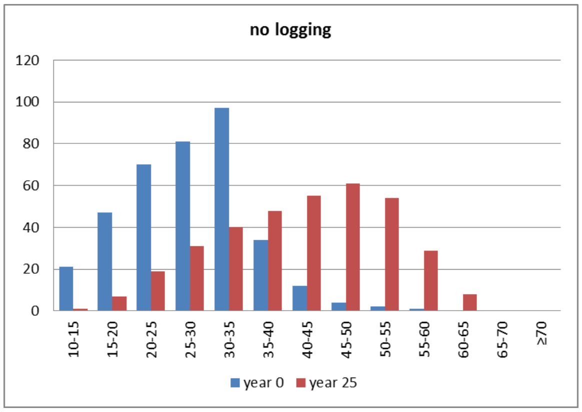


Figure 73 Rosewood: present size class distribution and its projected development over the next 25 years, according to the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored

Nargusta

The annual cutting area will comprise two 500-ha compartments for the duration of this management plan; 2018-2022 (see Section B 2.2). For an annual cutting area of 1,000 ha, the combined stock surveys over 2009-17 indicate an average of 1,320 nargusta trees ≥ 25 cm dbh and 410 nargusta trees of harvestable size (50-90 cm dbh). The size class frequency distribution of nargusta shows an abundance of trees in the size class 30-50 cm dbh (see Table 65). If no logging takes place, accrual into the harvestable size class over a period of 25 years will be only 131 trees/1,000-ha due to the perceived slow growth rate in the GYM. The GYM for select species uses an annual mortality rate of 2.05%. It is shown in Section B 5.5.6 that the mortality rate must be lower in the light of the mature size, growth rate and stand structure. An annual mortality rate of 1.5% is used in the stand table projection model. Sustained yield is estimated at 268 trees per 1,000 ha, based on the residual stocking after the second cut. In order to keep the residual stock ≥ 50 cm dbh above the restocking level of 100 trees per 1,000 ha, a cutting intensity of 68% is suggested. A cutting intensity of 68% results in a sustainable yield of 268 trees (see Table 65) with a net extracted roundwood volume of 407 m^3 (14,359 ft^3) per annum. The sawn lumber output is estimated at 101,874 BF per annum.

Table 65 Stand table projection for nargusta with a 25-year felling cycle based on combined results of 2009-2017 stock surveys; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle: nargusta								
	present cycle				+25 years			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
25-30	159			159	9			9
30-35	180			180	35			35
35-40	191			191	72			72
40-45	190			190	105			105
45-50	177			177	124			124
50-55	154	65.2%	100	54	126	74.6%	94	32
55-60	118	64.5%	76	42	103	73.8%	76	27
60-65	62	64.2%	40	22	65	73.8%	48	17
65-70	36	67.3%	24	12	34	73.5%	25	9
70-75	21	65.9%	14	7	17	76.5%	13	4
75-80	12	72.1%	9	3	9	77.8%	7	2
80-85	4	86.5%	3	1	5	80.0%	4	1
85-90	3	57.7%	2	1	2	50.0%	1	1
≥90	13			13	9			9
Total	1,320	67.9%	268	1,052	715	72.5%	268	447

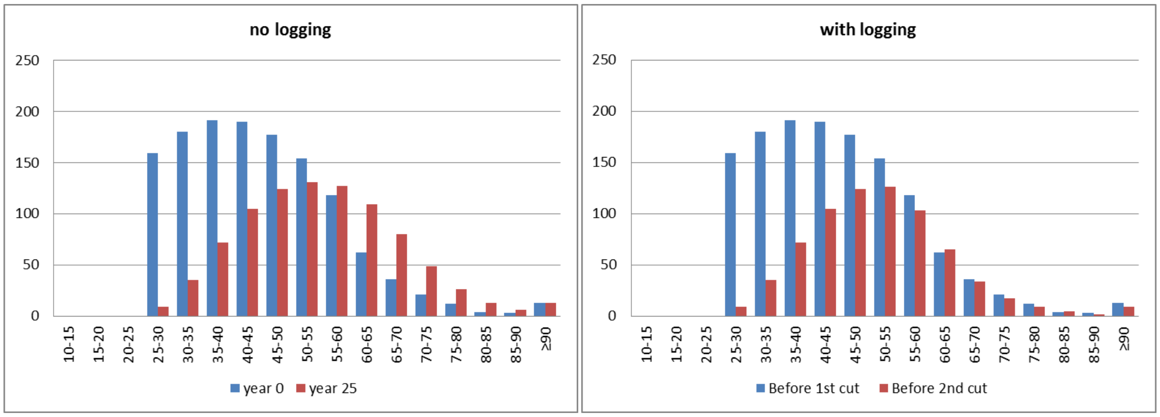


Figure 74 **Nargusta: stand structure development over the next 25 years, whereby possible recruitment into the 10-15 cm diameter class is ignored; without and with logging.**

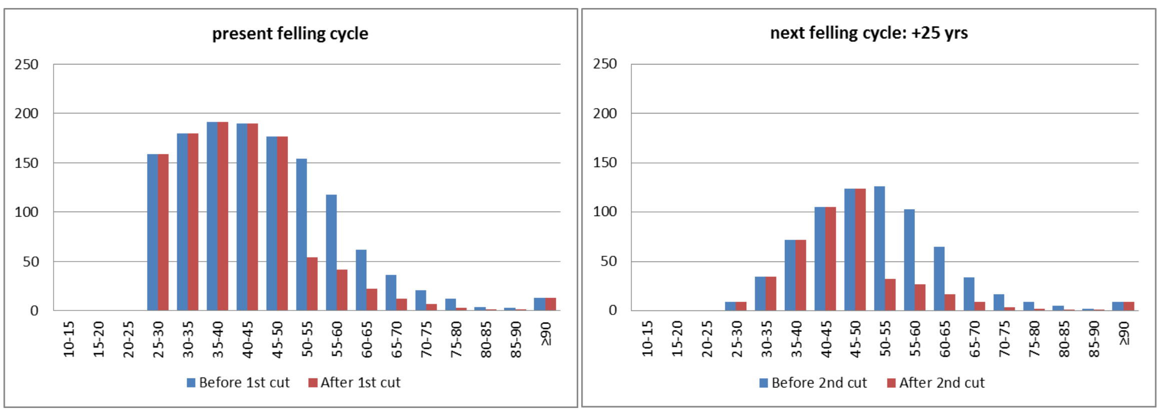


Figure 75 **Nargusta: impact of harvesting on size class distribution during present and next 25-yr felling cycle, whereby possible recruitment into the 10-15 cm diameter class is ignored**

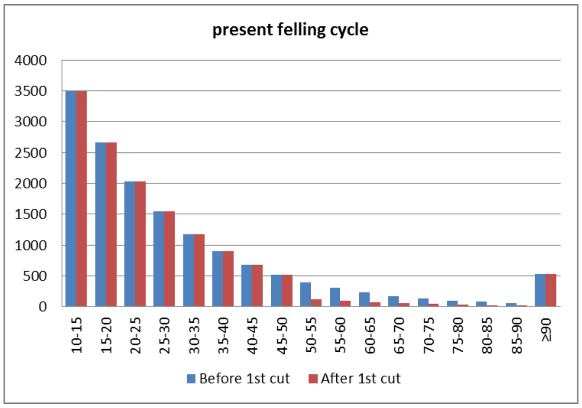
Table 66 **Expected sustained yield of nargusta during present and next 25-year felling cycle based on 2009-17 stock surveys and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5**

	present felling cycle	next felling cycle
No. of trees	268	268
Net extracted volume (ft^3)	14,359	14,375
Net extracted volume(m^3)	407	407
Sawn lumber produced (BF)	101,874	101,977

A second stand table projection model was constructed based on the size class distribution found with the general inventory. Sustained yield is quite a bit higher according to the general inventory, but there are questions concerning the reliability of the general inventory (Tables 67 and 68).

Table 67 Stand table projection for nargusta with a 25-year felling cycle based on the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle (1,000 ha)								
	present cycle				+25 years			
DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10-50	4,835			4,835	4,838			4,838
50-90	1,480	68.9%	1,023	460	1,278	80.0%	1,023	255
≥90	535			535	377			377
Total	**6,850**		**1,023**	**5,830**	**6,493**		**1,023**	**5,470**



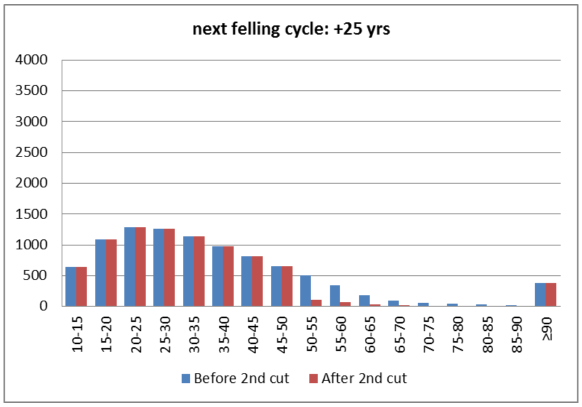


Figure 76 Nargusta: impact of harvesting on size class distribution during present and next 25-yr felling cycle, according to the general inventory whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 68 Expected sustained yield of nargusta during present and next 25-year felling cycle based on general inventory (2011/14) and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	1,023	1,023
Net extracted volume (ft^3)	64,705	55,202
Net extracted volume(m^3)	1,832	1,563
Sawn lumber produced (BF)	452,099	391,373

Santa maria

The annual cutting area will comprise two 500-ha compartments for the duration of this management plan; 2018-2022 (see Section B 2.2). For an annual cutting area of 1,000 ha, the combined stock surveys over 2009-17 indicate an average of 485 santa maria trees ≥ 25 cm dbh and 83 santa maria trees of harvestable size (50-90 cm dbh). The size class frequency distribution of santa maria shows an abundance of trees in the size class 25-40 cm dbh (see Table 69). If no logging takes place, accrual into the harvestable size class over a period of 25 years will be 78 trees/1,000-ha due to the small maximum size of the species. The GYM for select species uses an annual mortality rate of 2.05%. It is shown in Section B 5.5.6 that the mortality rate must be lower in the light of the mature size, growth rate and stand structure. An annual mortality rate of 1.5% is used in the stand table projection model. Application of the official maximum cutting intensity of 80% results in a sustainable yield of 65 trees (see Table 69) with a net extracted roundwood volume of 110 m^3 (3,870 ft^3) per annum. The sawn lumber output is estimated at 28,223 BF per annum.

Table 69 Stand table projection for santa maria with a 25-year felling cycle based on combined results of 2009-2017 stock surveys; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection on 2016 APO								
	present cycle				+25 years			
5cm DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
25-30	84			84	4			4
30-35	89			89	18			18
35-40	86			86	37			37
40-45	78			78	51			51
45-50	64			64	56			56
50-55	38	77.7%	30	8	52	53.8%	28	24
55-60	21	78.1%	16	5	37	54.1%	20	17
60-65	11	74.5%	8	3	19	52.6%	10	9
65-70	6	82.0%	5	1	7	57.1%	4	3
70-75	3	82.0%	2	1	3	66.7%	2	1
75-80	2	82.0%	2	0	1	80.0%	1	0
80-85	1	82.0%	1	0	0	0.0%	0	0
85-90	1	82.0%	1	0	0	0.0%	0	0
≥90	1			1	1			1
Total	485	80.0%	65	420	286	45.5%	65	221

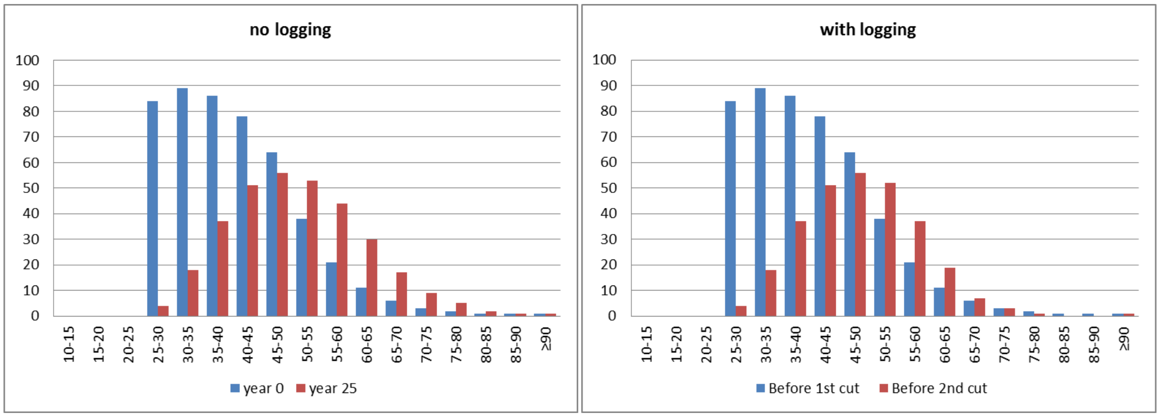


Figure 77 **Santa maria: stand structure development over the next 25 years, whereby possible recruitment into the 10-15 cm diameter class is ignored; without and with logging.**

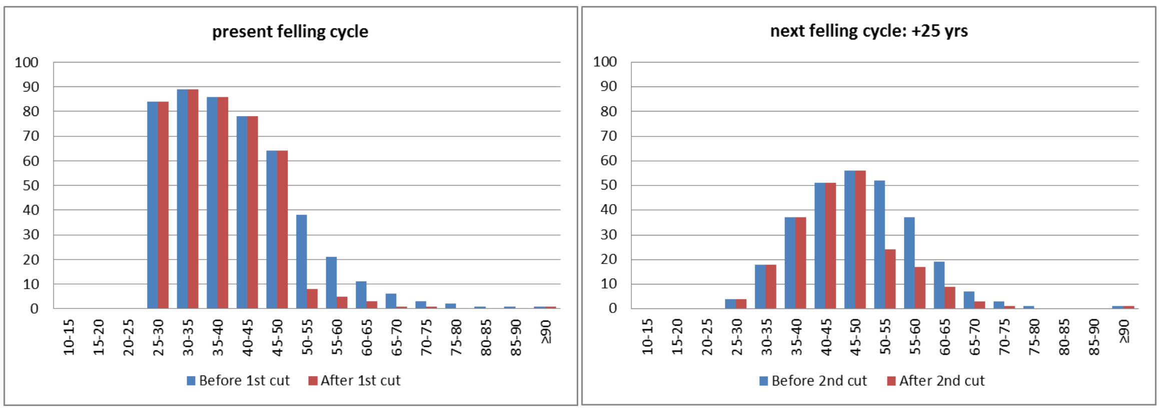


Figure 78 **Santa maria: impact of harvesting on size class distribution during present and next 25-yr felling cycle, whereby possible recruitment into the 10-15 cm diameter class is ignored**

Table 70 **Expected sustained yield of santa maria during present and next 25-year felling cycle based on 2009-17 stock surveys and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5**

	present felling cycle	next felling cycle
No. of trees	65	65
Net extracted volume (ft^3)	3,870	3,682
Net extracted volume(m^3)	110	104
Sawn lumber produced (BF)	28,223	26,843

A second stand table projection model was constructed based on the size class distribution found with the general inventory. Sustained yield is higher according to the general inventory, but there are questions concerning the reliability of the general inventory (Tables 71 and 72).

Table 71 Stand table projection for santa maria with a 25-year felling cycle based on the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle (1,000 ha)								
DBH class	present cycle				+25 years			
	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10-50	5,243			5,243	3,347			3,347
50-90	156	80.0%	123	33	225	43.7%	123	102
≥90	5			5	5			5
Total	**5,404**		**123**	**5,281**	**3,577**		**123**	**3,454**

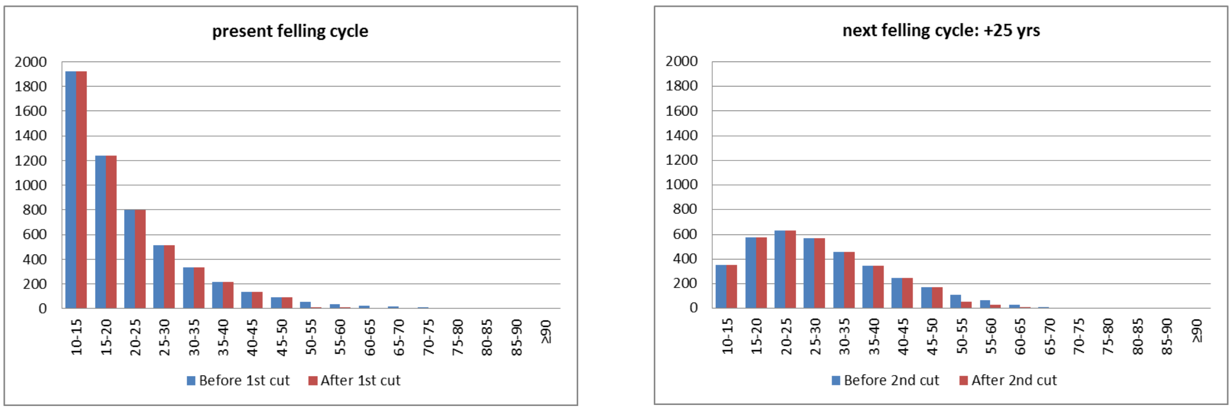


Figure 79 Santa maria: impact of harvesting on size class distribution during present and next 25-yr felling cycle, according to the general inventory whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 72 Expected sustained yield of santa maria during present and next 25-year felling cycle based on general inventory (2011/14) and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	123	123
Net extracted volume (ft^3)	7,850	6,694
Net extracted volume(m^3)	222	190
Sawn lumber produced (BF)	57,272	48,790

Sapodilla

The annual cutting area will comprise two 500-ha compartments for the duration of this management plan; 2018-2022 (see Section B 2.2). For an annual cutting area of 1,000 ha, the combined stock surveys over 2009-17 indicate an average of 821 sapodilla trees ≥ 25 cm dbh and 303 sapodilla trees of harvestable size (50-90 cm dbh). The size class frequency distribution of sapodilla shows an abundance of trees in the size class 35-50 cm dbh (see Table 73). If no logging takes place, accrual into the harvestable size class over a period of 25 years will be only 54 trees/1,000-ha due to the perceived slow growth rate in the GYM. The GYM for select species uses an annual mortality rate of 2.05%. It is shown in Section B 5.5.6 that the mortality rate must be lower in the light of the mature size, growth rate and stand structure. Here, an annual mortality rate of 1.5% is used in the stand table projection model. Sustained yield is estimated at 165 trees per 1,000 ha, based on the residual stocking after the second cut. In order to keep the residual stock ≥ 50 cm dbh above the restocking level of 100 trees per 1,000 ha, a cutting intensity of 56% is suggested. A cutting intensity of 56% results in a sustainable yield of 165 trees (see Table 73) with a net extracted roundwood volume of 276 m^3 (9,755 ft^3) per annum. The sawn lumber output is estimated at 71,142 BF per annum.

Table 73 Stand table projection for sapodilla with a 25-year felling cycle based on combined results of 2009-2017 stock surveys; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle: sapodilla								
	present cycle				+25 years			
5cm DBH class	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**	**Stocking (no. trees)**	**CI %**	**Yield (no. trees)**	**Residual (no. trees)**
25-30	62			62	3			3
30-35	96			96	15			15
35-40	115			115	34			34
40-45	119			119	55			55
45-50	108			108	71			71
50-55	83	54.2%	45	38	77	64.9%	50	27
55-60	62	52.3%	32	30	65	64.6%	42	23
60-65	56	53.6%	30	26	43	65.1%	28	15
65-70	38	52.6%	20	18	27	66.7%	18	9
70-75	26	57.7%	15	11	18	66.7%	12	6
75-80	18	55.6%	10	8	12	66.7%	8	4
80-85	12	62.5%	8	5	8	62.5%	5	3
85-90	8	62.5%	5	3	4	75.0%	3	1
≥90	18			18	13			13
Total	821	56.4%	165	657	445	66.5%	166	279

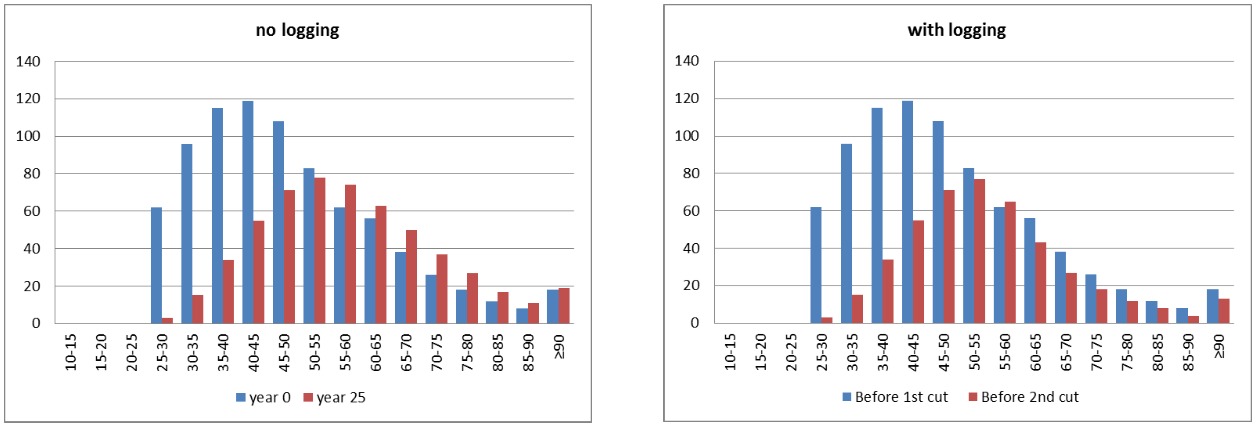


Figure 80 Sapodilla: stand structure development over the next 25 years, whereby possible recruitment into the 10-15 cm diameter class is ignored; without and with logging.

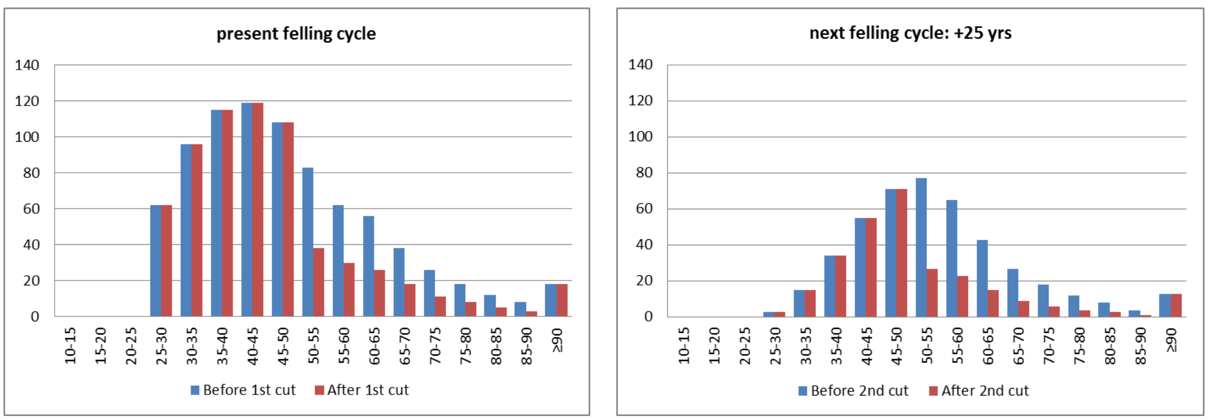


Figure 81 Sapodilla: impact of harvesting on size class distribution during present and next 25-yr felling cycle, whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 74 Expected sustained yield of sapodilla during present and next 25-year felling cycle based on 2009-17 stock surveys and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	165	166
Net extracted volume (ft^3)	9,755	9,225
Net extracted volume(m^3)	276	261
Sawn lumber produced (BF)	71,142	67,253

A second stand table projection model was constructed based on the size class distribution found with the general inventory. Sustained yield is quite a bit higher according to the general inventory, but there are questions concerning the reliability of the general inventory (Tables 75 and 76).

Table 75 Stand table projection for sapodilla with a 25-year felling cycle based on the general inventory; whereby possible recruitment into the 10-15 cm diameter class is ignored

Stand table projection 25-year felling cycle (1,000 ha)								
	present cycle				+25 years			
DBH class	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)	Stocking (no. trees)	CI %	Yield (no. trees)	Residual (no. trees)
10-50	5,612			5,612	3,264			3,264
50-90	1,096	59.6%	655	441	818	79.9%	654	164
≥90	266			266	197			197
Total	**6,974**		**655**	**6,319**	**4,279**		**654**	**3,625**

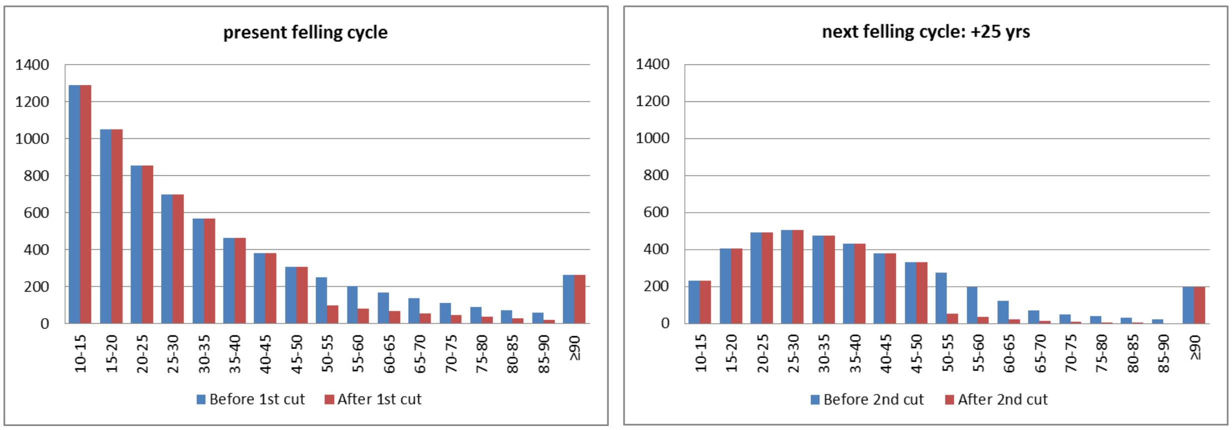


Figure 82 Sapodilla: impact of harvesting on size class distribution during present and next 25-yr felling cycle, according to the general inventory whereby possible recruitment into the 10-15 cm diameter class is ignored

Table 76 Expected sustained yield of sapodilla during present and next 25-year felling cycle based on general inventory (2011/14) and conversion from stem densities in 5-cm size classes according to conversion rates in Section B 3.3.5

	present felling cycle	next felling cycle
No. of trees	655	654
Net extracted volume (ft^3)	41,396	36,446
Net extracted volume(m^3)	1,172	1032
Sawn lumber produced (BF)	301,985	265,698

5.7 Division of the forest into annual harvesting units

The production forest area was initially set at 41,423 ha and broken down into 80 cutting blocks known as compartments, generally measuring 500 ha each, whose boundaries basically follow the UTM grid system (Bird, 1998). BRL proposes in this management plan to reduce the production forest area to 35,751 ha, which implies an annual cutting area of 1,430 ha. After the reduction of the production forest area 76 compartments remain with an average area of 470 ha, implying that the annual cutting area will eventually be equivalent to 3 compartments. Refer to Section B 2.2 for further details regarding the adjustment of the production forest area.

During the present felling cycle 15 compartments with a total area of 7,668 ha were cut on the basis of a 40-yr felling cycle and 6 compartments with a total area of 2,965 ha based on a 25-yr cycle. This means that a transition period is required during which the two different cycles have to be blended in. The transition process will only be completed in 2056 when the last compartment that was harvested based on a 40-yr cycle will have completed its felling cycle. The next 20 years, 2018-2037, new, unlogged compartments will be harvested. In 2037, compartment 58 will be harvested for a second time and in 2038 compartments 38 and 64 also, but the sustained yield will this time be based on a 25-yr. felling cycle. In 2040, compartments 3, 9, 10 and 15 will be harvested for a second time and in 2042 compartments 4 and 11; these compartments were harvested applying a 25-yr. cycle in 2015 and 2017 respectively. In 2039 and 2041 again new, unlogged compartments will be harvested. From 2043 to 2048 compartments that will have been harvested for the first time during 2017-2023 will be harvested for a second time. From 2049-2051 and in 2053, 2054 and 2056 compartments that had been harvested in a 40-yr cycle will be harvested for a second time.

In principle, the 55 unlogged compartments should be divided over the years until the first compartment is cut for the second time plus the years in between second cut years as indicated above. Because a steady yearly supply of timber must be guaranteed the time span over which new compartments will be harvested needs to be extended, implying that only two compartments can be cut per year until 2030 (see Section B 2.2 for details).

BRL intends to carry out diagnostic sampling in the compartments that were felled according to a 40-yr cycle between 1997 and 2008 to assess the stand development inn those compartments. There are indications that mahogany is growing (much) faster in diameter than the 0.5 cm/yr. on which the 40-yr. cycle was based (Bird, 1998). Based on the diagnostic survey the feasibility to shorten the cutting cycle will be examined, while keeping with the restrictions imposed in the GYM. This may lead to a (much) shorter transition from the 40-yr. to 25-yr. cycle. Nevertheless, no changes are foreseen for the duration of this management plan; i.e.

2018-2022. A preliminary selection of compartments for the period 2018-2022 was made on the basis of the distribution of mature mahogany trees across the reserve according to the general inventory (refer to Section B 2.2 for details; Table 77).

Table 77 Preliminary selection of compartments to be harvested during 2018-2022

Year	Compartment nos.	Area (ha)
2018	16, 17	981
2019	12, 13	1,000
2020	24, 25	1,073
2021	32, 33	1,098
2022	39, 44	1,000

5.8 Schedule of timber production

Table 78 shows the annual hardwood production from the CFR as estimated by way of stand table projection on the basis of the average stock surveys results over the period 2009-2017. Harvesting normally takes place between February and May.

Table 78 Projected annual timber production for the duration of this management plan 2018-2022 on the basis of previous stock surveys (2009-17)

Timber species	Roundwood volume (ft^3)	Roundwood volume (m^3)	Sawn lumber produced (BF)
mahogany	40,902	1,158	266,138
nargusta	14,359	407	101,874
sapodilla	9,755	276	71,142
cedar	8,237	233	49,681
santa maria	3,870	110	28,223
rosewood	2,721	77	10,069
barbajolote	1,025	29	6,223

The projected annual timber production is also estimated by way of stand table projection on the basis of the general inventory (Section B 3). This generates much higher volumes of nargusta and sapodilla (4 times higher for both species), barbajolote (14 times higher) and santa maria (2 times). Timber production estimates of cedar and mahogany are somewhat lower according to the general inventory; respectively 8% and 12% lower (Table 79). However, confidence in the general inventory estimates is lower than the estimates on the basis of the 8 most recent annual stock surveys. Not only did the sampling level of the smallest size class (10-25 cm dbh) vary, hence producing unreliable estimates. Given the inconsistent implementation of the sampling level of the smallest size class, it is surmised that the inventory was poorly supervised. This warrants serious reservations regarding the estimates of the larger size classes and more value is attached to the estimated timber production on the basis of past stock surveys.

Table 79 Projected annual timber production for the duration of this management plan 2018-2022 on the basis of the general inventory (2011/14)

Timber species	Roundwood volume (ft^3)	Roundwood volume (m^3)	Sawn lumber produced (BF)
nargusta	64,705	1,832	452,099
sapodilla	41,396	1,172	301,985
mahogany	31,341	887	208,663
barbajolote	14,082	399	88,888
santa maria	7,850	222	57,272
cedar	7,501	212	45,866
rosewood	stocking is below restocking level		

As a general conclusion, mahogany, nargusta and sapodilla must be regarded as the main species. Production of steady supplies of cedar and santa maria seem possible but at limited levels. Production of barbajolote and rosewood remains unpredictable and any production of these species should be regarded as a bonus only.

6 TIMBER HARVESTING OPERATIONS

6.1 License conditions regarding felling and skidding operations

6.1.1 Seed trees

BRL will follow the protocol of the Forest Department for the control of marking of those trees that shall remain reserved as seed trees (Appendix III). These seed trees will be the only remaining source of seeds for natural regeneration and therefore will not be felled until stands are well established.

6.1.2 Buffer zones

To ensure that the watershed functions of the CFR are protected, BRL will refrain from felling and removing trees and/or effecting the presence of heavy equipment within a perpendicular distance of 30.5 metres (100 feet) from both sides of rivers, streams, creeks, lagoons, and lakes.

6.1.3 Research and experimental plots

BRL will not enter into or fell any tree within any research or silviculture experimental plot unless the Chief Forest Officer (CFO) expresses in writing that the activities of BRL should form part of the research being carried out in a particular plot. Research or experimental plots are indicated on the working cycle map (see Section B 2) and normally marked with at least one post at each corner of the plot and painted white at the top end. BRL will also refrain from felling and extraction within a 100-m buffer zone surrounding research and experimental plots.

6.1.4 Slash and debris

BRL will dispose of logging slash and debris in the stand as required by the CFO to ensure natural regeneration.

6.1.5 Felling height

All hardwood trees will be felled with a stump height not exceeding twelve (12) inches (30 centimetres) above the buttress for those hardwood species with buttress and eighteen (18) inches (46 centimetres) above the ground for those trees without buttress. Pine trees will be felled with a stump height not exceeding twelve (12) inches (30 centimetres) above the ground.

6.2 Pre-harvesting activities

Pre-harvest activities consist essentially of the pre-harvest inventory, which is described in Section B 3.4. In advance of the pre-harvest inventory, a reconnaissance survey is conducted of potential compartments. Compartments are then selected based on adequate stocking of mahogany. The pre-harvest inventory commences after completion of the harvest season

(February-May), usually in July and runs until December. Improvement of roads leading to the respective compartments takes place in January, consisting of re-cambering of the carriageway, installing of ditches and culverts, where necessary, and brush cutting on the shoulders along the carriageway by tractor pulled bush hog.

6.3 Type of machinery

The company deploys CAT D6 and D3 bulldozers in road improvement operations, small (120 hp, 2.9-m wheelbase) wheeled cable skidders (JD 548G, TJ 240B) and a 140 hp track cable skidder (CAT 517), equipped with chokers for easy choking of logs, in skidding operations, and wheeled front-end loaders (Komatsu W200, CAT 910F) in barquadier operations. Three-axle (10-wheel) logging tractor (Mack) and double-axle (8-wheel) pole trailer trucks are utilized in hauling operations with relatively low weight per axle to prevent road surface damage (rutting). A backhoe loader (CAT 310G), GMC dump truck, 170 hp motor grader (CAT 140H), 4WD tractor (JD 5715) and vibratory roller are also used in road improvement and maintenance operations, along with light utility vehicles. A water truck with front and rear pressure nozzle is utilized during the dry season and during logging operations to support the crew with water and to act as the first line of defence in the case of fire.

All machinery is in good working order and the company continuously invests in parts and new equipment.

6.4 Harvesting activities

Harvesting activities typically commence in January or February and last until the end of April or early May. In any case, harvesting operations are closed off as soon as the rainy season starts.

Reduced impact logging (RIL) methods are utilized during the stock survey, felling, skidding and hauling in order to minimize logging damage in the annual harvesting block. The RIL methods follow the national code for timber harvesting.

A primary action to minimize logging damage is the cutting of climbers during the pre-harvest stock survey. Since the pre-harvest stock survey is usually done about 2-7 months before the logging operation, most lianas and vines would have died but may not have weakened by the time trees are felled. Still climber cutting reduces damage potentially caused by felled trees pulling down or snapping branches off neighbouring trees. To assess the effectiveness of RIL methods, and consequently to adjust where necessary, an assessment of damage is made following the close of the logging coupe by the Forest Department via the Post-harvest Audit system.

6.5 Felling operations

Several felling crews are employed in order to complete the logging operation before the rainy season sets in. Felling typically takes place in advance of skidding operations and so can occur before the roads completely dry out at the start of the dry season. Felling is done 6 days prior and 6 days after a full moon, and thus there are typically only two windows open for felling to occur. Directional felling is applied where possible using the hinge technique, but often times lianas interrupt the planned felling direction.

6.6 Extraction/skidding operations

Skidding operations commence as soon as the forest dries up enough to prevent soil damage. There are typically two skidders operating at any given time in the logging compartment. These are operated by skilled and experienced drivers. A winch is employed to minimized residual tree damage and high-lead skidding is always practiced. Trees are skidded along planned routes designed to minimize skidding damage and reduce the number of times the skidder traverses a particular skid road. Existing, old skid trails are reused whenever this is practical to minimize damage to the forest. Typically logs are skidded no more than 1,000 m to the nearest barquadier.

The Belize Code of Practice rules for skidding are applied:

- The full capacity of the skidder is used and efforts are made to accumulate a full payload whenever possible, which usually means that more than one log should be extracted each trip. This increases efficiency and reduces daily fuel consumption.
- The leading end of the log is raised at all times to prevent ploughing, to reduce skidding resistance, to reduce the formation of ruts (causing erosion, mud holes). This also increases the payload, hence skidding efficiency, reduces fuel consumption and tyre wear.
- Skidder blades are raised when travelling and skidding
- Vegetation litter is retained on skid trails.
- Once leaving a branch trail, the skidder reverses towards the log along the skid track.
- Skidding commences at the rear end of the block and proceed along the main skid trails towards the barquadier.
- No repetitious skidding over the same trail again and again is allowed, resulting in deep ruts. This is especially true on soft, wet ground. The ruts, after a time, turn into mud holes that can scar the land for a long time and create a problem in skidding.
- When forward motion is stopped or wheels or tracks start spinning because of mud or a steep grade, the winch is released, the load dropped, and the machine runs ahead while

spooling out line. When the machine is on solid ground the winch is used to haul up the load.

6.7 Hauling operations

Hauling is done from barquadiers to the mill at Georgeville. Typically a truck will make 2 or 3 trips per day commencing before the break of dawn and returning into the forest at dusk. Pole trucks are utilized which are lighter and take up less space on the road when empty. Tractor-trailer combinations have 5 axles, 4 of which with double wheels, which reduce axle load substantially.

6.8 Post-harvesting activities

At the close of logging operations, all debris and garbage will be removed and the compartment will be prepared for inspection by the Forest Department constituting its annual Post-harvest Audits.

6.9 Environmental considerations in logging

BRL will refrain from:

a) logging in defined areas where, due to topography, or edaphic conditions, the CFO considers that excessive soil erosion or compaction would follow logging
b) ground logging, ground extraction or skidding operations on slopes steeper than 25° but where sub-paragraph (a) is applied this may apply to slopes less than 25°
c) logging in areas where the CFO believes that there will be serious damage or harm to the ecological system
d) from operating heavy equipment during periods of rainy weather

BRL will take reasonable steps to prevent erosion and compaction to the soil caused by its logging operations; and

BRL will not transport timber on public roads outside the boundaries of the licence area between the hours of 6:00 pm and 6:00 am and on weekends.

6.10 Occupational Safety and Health

Employee safety is paramount for efficient execution of forest management throughout all operations. The company is responsible for the safety of its employees during logging operations and abides by all national laws regarding occupational safety hazards. Personal protection equipment and clothing is used at all times and fire hazard equipment and fire extinguishers are available in all work sites.

Safe equipment handling and use, such as during the felling of trees with chainsaws, is required of operators, and to this end, all employees have participated in periodic trainings to ensure a high level of safety at all times.

7 NON-TIMBER HARVESTING OPERATIONS

BRL is not engaged in extracting Non-Timber Forest Products

8 OTHER GOODS AND SERVICES

BRL is not engaged in the Management for Payment for Environmental Services or any other goods besides timber, such as e.g.:

- Watershed Protection:
  - Hydrological benefits: controlling the timing and volume of water flows and protecting water quality;
  - Reduced sedimentation: avoiding damage to downstream reservoirs and waterways and so safeguarding uses such as hydroelectric power generation, irrigation, recreation, fisheries, and domestic water uses;
  - Disaster prevention: preventing floods, soil erosion and landslides
- Biodiversity Conservation/Protection;
- Carbon storage and sequestration: acting as Carbon Sinks and mitigating against higher temperatures by creating their own micro climate;
- Landscape Beauty e.g. Nature-based Tourism
- Non-timber goods (medicines, food, fuel etc.).

Nevertheless, BRL forest management operations are conducted in such a way as to minimize any adverse impacts on the sustainable provision of environmental services mentioned above.

9 MARKETS AND UTILIZATION

9.1 Expected products

BRL's sawmill produces mainly rough sawn lumber of mahogany, cedar, barbajolote, rosewood, nargusta, santa maria, and sapodilla. Mahogany, cedar and rosewood primarily for export and barbajolote, nargusta and santa maria mostly for the local market although some nargusta has recently been exported as well.

Some harvesting and milling figures for 2015-17 are presented in Tables 73-75. On the basis of the actual lumber production figures of 2015-16 the annual production of export grade (Sel & Btr and COM 1-2) mahogany is estimated at 186,500 BF and of export grade cedar at 49,000 BF, of which 125,000 BF mahogany and 33,000 BF cedar may be exported. The remainder (including grade Com 3-4) 141,000 BF mahogany and 17,000 BF cedar will be sold to local buyers.

Table 80 Roundwood extracted, lumber produced and lumber exported by grade according to the APO and actually realised volumes for 2015

Species	Volume (APO) (m^3)	Lumber (APO) (BF)	Lumber Produced (BF)				Export (BF)	
				Grade			Grade	
			Total	Sel & Btr	COM 1-2	COM 3-4	Sel & Btr	COM 1-2
Mahogany	2,171	460,407	353,899	127,424	119,262	107,213	119,486	94,116
Cedar	936	198,693	161,825	84,041	75,475	2,309	74,271	nil
Barbajolote	nil	nil	nil	nil	nil	nil	nil	nil
Santa Maria	52	10,948	no data	no data	no data	no data	no data	no data
Nargusta	112	23,743	no data	no data	no data	no data	no data	no data
Sapodilla	nil	nil	nil	nil	nil	nil	nil	nil
Rosewood	nil	nil	nil	nil	nil	nil	nil	nil
TOTAL	3,270	693,790	515,724	211,465	194,737	109,522	193,757	94,116

Table 81 Roundwood extracted, lumber produced and lumber exported by grade according to the APO and actually realised volumes for 2016

Species	Volume (APO) (m^3)	Lumber (APO) (BF)	Lumber Produced (BF)				Export (BF)	
				Grade			Grade	
			Total	Sel & Btr	COM 1-2	COM 3-4	Sel & Btr	COM 1-2
Mahogany	1,302	275,940	334,484	131,420	104,479	98,585	128,882	55,960
Cedar	358	75,896	51,039	29,346	21,191	502	20,859	15,879
Barbajolote	89	18,953	no data	no data	no data	no data	no data	no data
Santa Maria	160	33,985	no data	no data	no data	no data	no data	no data
Nargusta	650	137,863	no data	no data	no data	no data	no data	no data
Sapodilla	231	48,908	no data	no data	no data	no data	no data	no data
Rosewood	nil	nil	nil	nil	nil	nil	nil	nil
TOTAL	2,790	591,545	385,523	160,766	125,670	99,087	149,741	71,839

Table 82 Roundwood extracted and lumber produced according to the 2017 APO and projected volumes for the duration of this SFMP and sustained yields on the basis of 2009-2017 APO averages

Species	2017		2018-2022 annual estimate	
	Roundwood (APO) (m³)	Lumber (APO) (BF)	Roundwood (SFMP) (m³)	Lumber (SFMP) (BF)
Mahogany	1,749	370,682	1,158	266,138
Cedar	773	163,770	233	49,681
Barbajolote	nil	nil	29	6,223
Santa Maria	90	19,059	110	28,223
Nargusta	602	127,518	407	101,874
Sapodilla	221	46,810	276	71,142
Rosewood	nil	nil	77	10,069
TOTAL	3,433	727,838	2,290	533,350

9.2 Industrialization

The hardwood section of the Georgeville mill is equipped with a state-of-the-art Wood-Mizer LT40 hydraulic portable single head sawmill for cutting mahogany and cedar and a Hurdle Sawmill and Single head Baker Resaw for other hardwoods. Export only concerns rough sawn lumber in various quarter inch sizes. Hardwood that is destined for the local market is often subjected to secondary processing into flooring, panelling or moulding. Mahogany for the local market is mainly sold to the local furniture industry as rough sawn lumber.

9.3 Marketing including demands and constraints

9.3.1 CITES Appendix II listing of mahogany and rosewood

The present state of the economy as it pertains to timber is relatively good. Export markets for mahogany and rosewood are still strong. However, there has been increased international attention for the sustainable management and trade of these two species, and international trade is regulated by the stipulations of the Convention on International Trade in Endangered Species (CITES); mahogany has been listed on Appendix II since 2002. A CITES Appendix II listing requires that exports must comply with Non-Detrimental Findings (NDF), as determined by a CITES Scientific Authority in the country of origin, while a CITES export permit must be issued by a national Management Authority on the basis of a annually determined national export quota.

CITES held a conference from 24th September – 4th October 2016 in Johannesburg, South Africa where it was decided that all species of rosewood under the genus *Dalbergia* will be protected under CITES Appendix II, taking effect on 2nd January 2017. The listing of *Dalbergia* is annotated to indicate that the following all parts and derivatives are included, except: a) Leaves, flowers, pollen, fruits, and seeds; and b) Non-commercial exports of a maximum total weight of 10 kg per shipment. Interestingly, *Dalbergia* spp. originating and exported from Mexico are covered by an annotation indicating that only logs, sawn wood, veneer sheets and plywood are included.

9.3.2 Export markets

The export of mahogany is limited to 67% of the APO estimate of produced lumber. The national export quota is determined by the FD based on BRL's APO and APO's of other mahogany exporters. The APO's traditionally have been using a conversion factor of 212 to estimate BF sawn lumber from m^3 roundwood. Effective from January 2017, the conversion factor to estimate BF sawn lumber from m^3 roundwood has been reduced to 169 by the Forest Department. However, the actual conversion rate rather amounts to 240 BF/m^3, while 70% of the sawn lumber (mahogany) is of export grade (Select or better or COM 1-2). The current APO conversion factor yields on average 70.5% of the true recovery, resulting in a CITES export quota of just 47.3% (67% x 70.5%) of the true sawn lumber output.

The main export market is the USA (95%) with some export to Jamaica (5%). Some cedar is exported to the USA but the price is low due to competition by plantation grown cedar from African countries and elsewhere.

The export price for mahogany is around 5 US$/BF FOB while locally mahogany (grade COM 1-3) is sold at 2.50 Belize dollar per BF or less. The production cost (forest management, logging and milling) is around 2.10 Belize dollars per BF. It is clear that the operation would barely break even if it would depend on local hardwood sales alone.

Annually, 80,000 BF of mahogany is sold locally; grades 1 and 2 to furniture makers as rough sawn lumber, while grade 3 is secondary processed to produce siding and mouldings.

Markets for secondary hardwoods have expanded slowly both domestically and internationally; BRL has recently started to export a small shipment of nargusta to Jamaica. BRL only trades and exports lumber and does not trade logs. Upcoming markets such as India and China are mainly interested in logs (roundwood). There is increased demand from local furniture producers but these can procure mahogany and cedar from one-year licenses, petty permits and illegally at a for BRL uneconomic price per board foot.

9.3.3 Constraints

- The local mahogany market situation is difficult due to unfair competition by other suppliers; competition is unfair because mahogany is supplied from short-term license areas and illegal sources (reserves and parks), both having much lower production cost;

e.g. no cost for forest management (pre-harvest inventory, preparation of APO and SFMP, etc.)

- The export quota and imposed conversion rates limit potential trade (export)
- Sustained yield of mahogany is probably higher than the yield estimated by the GYM (see Section B 5.5)
- Calculation of export quota depends on timely submission of APO's of other companies that harvest mahogany for export (not necessarily exported by the roundwood producer) as well, leading to delays in issuing export permits. This entails the risk that buyers may become sceptical about BRL; buyers become suspicious that material might be illegal or otherwise unavailable, because an export permit is not being granted with delay.
- Operational challenges: FD procedures regarding quota and sustained yield are fluid; e.g. rules governing APO's, conversion factors, diameter increment formulas, cutting diameter limits, etc. have been updated frequently within the past three years.

9.3.4 Opportunities

- Resort construction boom; in order to maintain a 'green' image resorts may demand timber sourced form properly managed forest
- Demand for mahogany export remains huge, but due to supply limitations prices are under pressure. Supply limitations have urged buyers to seek alternatives for American mahogany (*Swietenia*), resorting to African mahoganies (*Khaya*, *Entandrophragma*), plantation grown mahogany (Africa) and other species in the mahogany family Meliaceae, which are widely available at lower prices.
- BRL considers exploring opportunities to have its forest management FSC certified; BRL will take a stepwise approach in FSC certification, commencing with exploring options for FSC COC certification.

10 ROADING OPERATIONS

10.1 General road network

The Chiquibul Forest Reserve is accessible only by an unpaved road which extends for 53 km to the George Price highway at Georgeville. The Chiquibul Forest Reserve itself is dissected by numerous disused roads established since the heydays of logging between 1950 and 1975. The main road from Tapir Camp to Las Cuevas was upgraded to an all-weather road in 2013, installing culverts to improve drainage and run-off. Improvement in drainage has led to major improvement in road conditions year round. Vegetation on the shoulders of the road was brushed by rotary mower (brush hog or "bush hog") to allow sunlight and wind to dry the road surface more quickly after rains.

The road from the Guacamallo Bridge to Georgeville, near where the Company's mill site is, is an all-weather road. The distance from the Guacamallo Bridge to Georgeville is 53 km. From Georgeville to the mill site is just 1 km along the George Price Highway

Extraction roads ('truck passes' or minor haul roads) needed to access compartments are formed, shaped and drained ahead of logging operations. An overview of road improvements is given in Section 10.5 below.

10.2 Right to access

- BRL has no exclusive rights to extraction routes in the CFR. Officers and employees of the Forest Department, and others authorised by the CFO, have the right to use any roads or tracks that BRL has constructed or maintained, as long as BRL's operations are not interrupted.
- Forest roads are not open access roads to the public, other than along established rights of way. The Forest Department may construct and man road barriers, or authorize BRL in writing to do so, at any or all access points. A barrier has been installed at Tapir Camp preventing further access into the CFR and to the road leading to the Caracol archaeological site. This barrier is manned by FCD.
- On the termination of its license, BRL will leave all roads and tracks constructed by BRL and will relinquish without compensation any and all rights therein.

10.3 Roading requirements

- By virtue of its long-term license, BRL is required to maintain any forest road in the CFR that is used by BRL and to make good any damage caused by BRL to such roads to the satisfaction of the CFO.

- BRL is liable for the payment of damages done by BRL to any private or public road within or for the entire extent traversed outside the CFR. Instead, BRL will effect satisfactory repairs to the road damage in lieu of monetary payments.
- BRL shall maintain extraction roads in a suitable condition that allows the movement of wheeled traffic until the road is no longer required for timber extraction

10.4 Standards for construction and maintenance

- Extraction roads (in this case 'truck passes' or minor haul roads) will be formed, shaped, drained and surfaced to the satisfaction of the CFO.
- All roads will have a maximum width of 16 feet (4.9 metres), provided that the CFO may approve such wider dimensions in light of the equipment employed, and a maximum gradient of 15 percent.
- Extraction roads are constructed only on alignments approved by the CFO. Such roads are spaced so that logs are not skidded along the ground for more than 3,280 feet (1 kilometre) from felling site to the point of loading onto trucks. Where possible, old extraction routes are used in an effort to minimise environmental damage.
- All perennial watercourses are crossed without impeding the stream flow. Bulldozing through dry ephemeral and intermittent watercourses is avoided wherever it is reasonably possible. BRL is putting in culverts or constructing bridges, according to specifications approved by the CFO. Roads crossing watercourses are at right angles to the banks of rivers or streams.
- BRL will ensure that skid trails are laid out efficiently in the sub-compartment to the satisfaction of the CFO. Skid trails have a maximum width of 12 feet (3.6 metres), provided that the CFO may approve such wider dimensions in light of the equipment employed, and a maximum gradient of 15 per cent when the grade exceeds a distance of 150 feet (45.7 metres). Where possible skid trails follow contours and the direction of skidding is uphill. Skid trails do not cross extraction roads.
- The location of each barquadier (log landing) requires the prior approval of the CFO. Proposed locations of barquadiers are presented in the APO. No barquadier will be placed within 300 feet (91.5 metres) of a permanent watercourse. The number of barquadiers is kept to a minimum consistent with efficient timber extraction.

10.5 Recently completed roadwork

The Chiquibul Forest Reserve is dissected by numerous disused roads (old “truck passes”) established since the heydays of logging between 1950 and 1975. Old truck passes are usually overgrown and in a deplorable state (rutting, eroded) due to lack of drainage features and use by vehicles and tractors with high axle loads during rains.

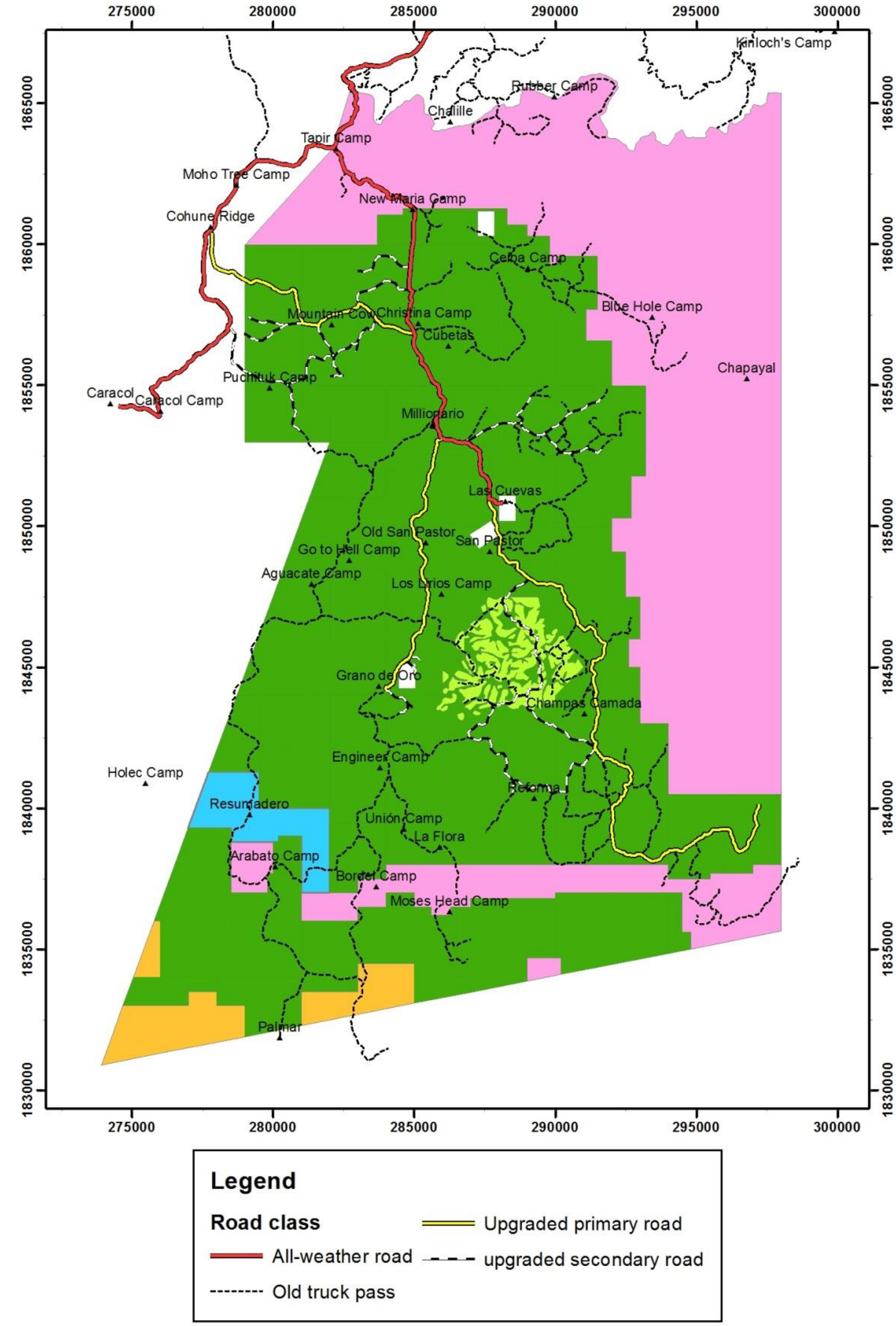


Figure 83 Upgraded primary and extraction roads in the CFR (2010-2016) and old truck passes

Truck passes are upgraded and reused either as extraction roads (secondary or feeder road) or as main skid trails as needed when opening up the annual cutting compartment. Restoration of old truck passes and main roads has seriously taken off since 2014; some 72.5 km of main and extraction roads were rebuilt during 2014-2016 (see Figure 83). The main road between Tapir Camp and Las Cuevas (17 km) was upgraded to an all-weather road with 5 culverts, side drains and turnout drains installed, re-cambering of the carriage way and brushing of the shoulders in order to allow quicker drying of the road surface and improved line of sight. Other main roads that were rebuilt are the roads to Grano de Oro (10 km), Champas Camada (25 km) and Cohune Ridge (10 km). Restoration of the main roads also serves visitors to Las Cuevas (FDC, researchers and nature tourists), patrolling by FDC and improves road safety considerably.

11 ENVIRONMENTAL CONSERVATION MEASURES

11.1 Buffer zones

To ensure that the watershed functions of the license area are protected, the BRL will not fell and/or remove trees and/or cause the presence of heavy equipment within a perpendicular distance of30.5 metres (100 feet) from both sides of rivers, streams, creeks, lagoons, and lakes.

11.2 Wildlife conservation

The forest management area is an important zone for wildlife conservation and this management target extends over the entire area. Forest management and wildlife conservation zones are one and the same. The idea is to minimize the impacts to wildlife populations through reduced-impact logging operations and the setting aside of buffers and HCVFs.

11.3 Use of chemicals

11.3.1 Pesticides

BRL takes a precautionary approach to pesticide use, in part because experience has repeatedly shown the difficulty of ensuring consistent proper use, and the limits of knowledge of the ecological and environmental impacts of pesticides and the consequent unforeseen consequences of their use. Nevertheless, pesticides may be necessary to control pests that are harmful or perceived as harmful and as prejudicing the achievement of management goals, such as pinhole borers in logs left on the ground, on barquadiers or on the log yard at the Georgeville mill.

BRL makes all possible efforts to remove felled logs out of the forest as soon as possible; e.g. by hauling as many logs as possible per day (4-6 trips by 2 logging trucks). There may circumstances whereby logs cannot be removed out of the forest yet, e.g. because log have not been stamped by FD yet. In such cases BRL may spray logs with pesticides but will avoid or control use ‘highly hazardous’ pesticides. Mahogany and cedar have precedence for milling because orders are normally filled as soon as an APO is approved; usually in January. Orders for elite and select species, predominantly local, arrive more slowly and ponds will be constructed to store logs of elite and select species in order to prevent insect and/or fungus attacks.

11.3.2 Fuel and oil

The main fuel, oil and hazardous chemical storages are located at the main camp and the log yard in a well-drained area; at least 50 m from any watercourse; and no closer than 50 m to any habitation

Mobile fuel tankers, refuelling points, and maintenance areas are located in well-drained areas such as barquadiers; outside areas excluded from harvesting and their buffer strips; and more than 50 m away from any watercourse or water body. Care is taken to prevent spillage during refuelling or repairs; adequate equipment – e.g. hand pumps – is installed and used. Sump oil is not dumped in the harvesting areas, but collected and removed to the main disposal facility.

11.4 Bio-diversity conservation

11.4.1 Protected Areas

Protected areas inside, adjacent to or around the license area have been clearly marked on the working cycle map and will be marked on the ground when logging compartments are established. With regards to demarcating protected areas on the ground, such activity will be achieved through a cooperative effort between the Forest Department, BRL and FDC (where applicable). Entry into protected areas for timber exploitation is strictly prohibited. BRL will comply with all applicable laws in relation to protected areas. BRL will not traverse nor open any road through any protected area without the prior written approval from the CFO. Where such approval is given the same shall deal with the disposal or removal of logs from trees felled during the road construction. *Protected Areas* include areas declared, at the date of issuance of this licence or any time subsequent thereto, under the National Parks Systems Act or any subsequent amendments thereto and areas defined in Section B 2.

11.4.2 Hunting

The hunting of animals and birds is strictly forbidden in the CFR. BRL will be responsible for the actions of its servants, employees, agents and independent contractors in this matter

11.5 Soil and water conservation

The conservation of fragile soils and water bodies is achieved through the use of buffer zones along rivers, swamps and sinkholes. These buffer zones extend for 30.5 metres (100 feet) on either side of sensitive areas to ensure logging impacts are excluded from stream banks and steep slopes. In addition, operational safeguards have been put in place during logging to ensure impacts from equipment use are minimized. For example, small (120 hp) wheeled skidders and a tracked skidder with low ground pressure tracks are used for skidding to minimize soil impacts. Skidding distance is minimized through skid trail planning data while old skid trails are reused where applicable to minimize the area affected.

11.6 Reducing the carbon footprint

Damage caused by logging operations and wastage from felling and milling can be a major source of carbon dioxide emissions from Land Use and Land Use Change and Forestry (LULCF) activities. Measures are being taken to reduce the carbon footprint through the efficient utilization of residual wood from branches, efficient use of the stem by cutting down to ground level, increased milling efficiency and reduction of logging damage through reduced-impact logging methods. An improved milling facility has been established at Georgeville to process the material coming out of the annual harvesting blocks. This mill is a state-of-the-art facility maintained and managed by staff. Reduced-impact logging methods are employed in the annual harvesting block and branches and other residual material is utilized by artisans to make long-lasting furniture and other wood products.

11.7 Archaeological sites

BRL will report to the Director of the Institute of Archaeology, through the CFO, any relics or archaeological sites encountered within the license area. In addition, BRL employees, agents and independent contractors will refrain from destroying or interfering in any way with such sites and relics.

12 MONITORING AND RESEARCH

12.1 Previous and current research

Early research in the Chiquibul Forest focused largely on forest resources (Wolffsohn, 1956, 1960. Smith, Bird, 1998). But more recently the focus has been more on biodiversity. Some species have been subject to multiple studies such as the Scarlet Macaw (Kainer, 1990; Mallory & Matola, 1998; Matola & Sho, 2003; Renton, 1998) and the Xaté palm (Bridgewater et al, 2006; Wicks, 2004). There is also a substantial body of research on caving and particularly on the Chiquibul Cave System (Miller 1984-2001). Much of the biological research originated from the Las Cuevas Research Station. An overview of research (published and unpublished) can be viewed at http://www.mayaforest.com/projects.htm.

The CFR has been an important area for scientific research. The Las Cuevas Research Station, which is located in the middle of the CFR, has been operating since 1995 to document the biodiversity of the Chiquibul Forest and contribute practical knowledge to Belize's sustainable development and conservation. Priorities include understanding the maintenance and structure of the forest, evaluating human and natural impacts on the forest and linking science with conservation policy. Recent collaborative research activities have included the Harpy Eagle Release Program (Belize Zoo and Peregrine Fund), the Darwin Initiative Sustainable Conservation of Xaté (Natural History Museum, Belize Botanical Gardens and New York Botanical Gardens), Jaguar Population Survey (WCS), Scarlet Macaw Artificial Nest Program (BECOL and FCD), and Genetic Studies of Spiders and Reptiles (Memphis Zoo and NHM) (C. Minty, 2005).

12.1.1 PSPs established by FPMP

Permanent sample plots are plots set up to measure forest dynamics over a sufficiently lengthy time to observe average rates of growth, mortality and recruitment, which are basic demographic rates that inform sustainable yield estimation and overall forest productivity. In the early 1990s 12 plots were established in the CFR (Bird, 1998); 8 of these plots formed part of the Bird's (1998) logging experiment, where 4 sets of twin plots were established, one subjected to logging and maintained as control plot. A number of these plots were re-enumerated and re-measured as part of the FORMNET-B network. Studies are underway in conjunction with the Forest Department and Oxford University. BRL supports this mutually beneficial research.

12.1.2 PSPs established by BRL (NPV)

Eight permanent sample plots were established by Fundación Naturaleza para la Vida (FNPV) of Guatemala in the month of April 2008, 2009 and 2010. Two plots were established in order to monitor growth and regeneration of mahogany, which are located in the 2008 ACC and 2009 ACC, while the 2010 ACC established six plots in order to monitor the dynamics of all forest species represented in the Chiquibul Forest Reserve. Unfortunately, BRL has not been able to re-measure the plots. Original plot data have been requested from NPV.

12.2 Proposals for experimental or permanent sample plots

BRL will restore PSPs that were set up by NPV during 2008-2010. The PSP protocol that was used in the FORMNET-B network will be employed.

12.3 Current research activities and sites

Dan Mills, a M.Sc. student of the University of Florida, is doing his thesis work on the efficacy of liana cutting on Future Crop Trees in the CFR. An update on the outcome of this research has recently been requested.

12.4 Plans for monitoring effects of logging and/or other forest management activities

As a management activity, logging has impacts that are immediate and those that are more long-term. Both classes of impacts need to be taken account of in adaptive management strategies. Whereas the short-term impacts can be assessed immediately following the logging operation, long-term impacts are difficult to assess and best monitored through the use of robust, standardized long-term sample plots set up across the forest management area.

Short-term impacts are monitored as part of annual Post-Harvest Inspections that are conducted in collaboration with the Forest department to assess compliance with the approved APO and damage caused by the logging operation. Post-harvest audits (PHA) are performed within 2 months after the close of logging operations (see Section B 3.5). Long-term monitoring relies upon the FPMP PSPs established 199294 and recently established plots (2008-10). In addition, BRL will design and conduct diagnostic surveys, whereby regeneration of prime species in compartments that were harvest between 1997 and 2010 will be surveyed at a 10% sampling level. The main purpose of this diagnostic survey is to assess the validity of the 40-year cutting cycle according to which those compartments were logged.

12.5 Cooperation with research organizations

BRL has signed an agreement on collaboration pertaining to research and development of tropical forest management with Michael G. Andreu, Associate Professor Forest Systems of the School of Forest Resources and Conservation, Institute of Food and Agricultural Sciences of the University of Florida, Gainesville, Florida, USA.

BRL also supports FCD in its research work.

12.6 Monitoring of Biodiversity and Rare, Threatened and Endangered Species

Areas of special importance for biodiversity within the production forest area are not identified on maps, or specifically protected from harvesting and other site disturbance. There are no current plans for the identification, protection & ongoing evaluation of the status of rare, threatened and endangered plant or animal species. However, FCD has identified nesting sites of scarlet macaws (*Ara macao cyanoptera)* and has been conducting a monitoring programme.

12.7 Monitoring of illegal harvesting, settlement and other unauthorised activities

Despite the protected status of the Chiquibul Natural Park and Forest Reserve, the area is under severe pressure from incursions on the western border that threaten to destroy the reserve's integrity and cultural heritage. There are various threats to the Chiquibul Forest. These threats range from agricultural activities, fires, illegal logging, wildlife depletion, looting of cultural artefacts to vandalism by desecrating both cultural and geological assets. Nearly all threats are linked to illegal incursions by Guatemalan villagers (see Section A 3.6).

Illegal logging In the Chiquibul Forest was first detected in 2006. By March 2008, a joint forces patrol documented that illegal logging was escalating and a logging trail network was evident. By 2010, joint patrols reported frequent and persistent illegal logging activities. All extraction of illegal timber was of a trans-boundary nature, namely from Guatemala. The area impacted by illegal logging has shown an increase of 2.5 times from 2010 to 2015 and appears to have reached a saturation point in 2014.

The Chiquibul Forest Joint Enforcement Unit (CFJEU) comprising of the Belize Defence Force, Police and Friends for Conservation and Development (FCD) rangers provides a robust patrolling system to combat and contain (trans-boundary) illegal activities in the Chiquibul Forest. Bullridge Co. Ltd provides a conservation post to the CFJEU. Currently, two additional conservation posts are being erected along the Guatemalan border with support from BRL

13 FACTORS WHICH INFLUENCE MANAGEMENT AND HOW TO DEAL WITH THEM

13.1 Bio-physical conditions

There are several bio-physical factors which may influence management. These include fire, wind (hurricanes) and mahogany shoot borer attacks. Fire normally is no serious threat in the CFR because of the high precipitation and high humidity levels. Selective single-tree forest exploitation does not result in high enough fuel loads to increase the propensity for fire during the dry season (February – May). Hurricanes may lead to high fuel loads and an increase of the propensity for fire.

BRL is well-equipped to fight and prevent fires due to its experience with fire-fighting and prescribed burns in their long-term forest license in the Mountain Pine Ridge. BRL has fire-fighting equipment, including water truck, equipment (bulldozers and motor grader) to create fire breaks and torches to light prescribed burns and back-burns.

Although no major hurricane hit the CFR since hurricane Hattie in 1961, wind damage occurs frequently. For instance 90% of white poisonwood trees fell by windthrow during hurricane Earl in August 2016. BRL has not applied for any salvage permits to date. Criteria for salvage permits are given by the FD.

13.2 Markets, industrialization

- The local mahogany market situation is difficult due to unfair competition by other suppliers; competition is unfair because mahogany is supplied from short-term license areas and illegal sources (reserves and parks), both having much lower production cost; e.g. no cost for forest management (pre-harvest inventory, preparation of APO and SFMP, etc.)
- The export quota and imposed conversion rates limit potential trade (export)
- Sustained yield of mahogany is probably higher than the yield estimated by the GYM (see Section B 5.5)
- Calculation of export quota depends on timely submission of APO's of other companies that harvest mahogany for export (not necessarily exported by the roundwood producer) as well, leading to delays in issuing export permits. This entails the risk that buyers may become sceptical about BRL; buyers become suspicious that material might be illegal or otherwise unavailable, because an export permit is not being granted with delay.

- Operational challenges: FD procedures regarding quota and sustained yield are fluid; e.g. rules governing APO's, conversion factors, diameter increment formulas, cutting diameter limits, etc. have been updated frequently within the past three years.
- A few years ago the market price of cedar (export) was at the same level as mahogany. The price has dropped substantially due to supplies from plantation grown cedar from Africa, bringing down the price from US$ 5.00 to US$ 2.50 per BF.
- For several reasons, among which the difficulty in obtaining mahogany due to the CITES Appendix II restrictions, American buyers have resorted to importing African mahoganies (*Khaya*, *Entandrophragma*) and plantation grown mahogany. This has put the price for mahogany under pressure. Buyers have already indicated that prices for 2018 will drop from the current level.
- The CITES Appendix II listing of mahogany and rosewood is still not incorporated in the legislation of Belize. This may influence willingness to buy CITES listed species from Belize.

13.3 Social conditions

13.3.1 Employment policies and issues

BRL employs 15 persons in logging, 12 persons in milling, 2 persons in logistics and 6 persons in administration. Of the 6 admin personnel, 4 are female. Although BRL does not have a formal employment policy, no employment issues have been reported.

13.3.2 Health and occupational safety

BRL does not have a formal Health and Safety policy nor has a risk assessment taken place to assess the risk to workers of particular tasks and equipment, or measures identified to reduce or eliminate such risks. BRL does not have a joint workplace safety and health committee, but employees notify their supervisor directly of any hazardous situations or malfunctioning of equipment beyond normal operating conditions. All incidents and injuries are reported to management or supervisors without delay, regardless of the nature of the injury.

Appropriate personal protection equipment and tools are provided to all workers free of cost, including safety boots, safety trousers (chaps), safety gloves, safety helmet, visor (mesh) and ear muffs. Good housekeeping of all work areas and equipment is being practiced.

13.3.3 Training initiatives

No practical forestry or safety training is being offered in Belize nor are there any training providers in mapping in Belize. No formal training is provided by the FD in APO preparation besides short briefing sessions. Training at BRL is provided by senior staff members (apprentice system) and through cross training.

BRL would heartily welcome any training initiatives, including health and safety, felling and skidding, mapping and APO preparation.

13.3.4 Trade unions

BRL recognizes the right of employees to be members of a trade union of their choice and all workers are free to associate, seek representation and/or bargain collectively.

There is no union membership amongst BRL staff at present nor is there any union representation in the company but union membership, free association and collective bargaining are open options if desired by employees.

13.3.5 Employee welfare (social security, supply of rations, potable water, accommodations, etc.)

All workers are employees and social security contributions are paid for all workers. Ration, potable water and accommodation (portable wooden houses on skids) are provided in the forest. A cook is employed to prepare meals for forest workers and truck drivers.

13.3.6 Communications systems

No special communication systems are needed because mobile telecom networks can be used. There is a strong mobile signal at top of the hill near New Maria Camp.

A 4WD pick-up accompanies field crews and is available in case of emergencies.

13.3.7 Community Consultations

Where it is a requirement instituted by the CFO or where it is socially desirable, BRL will conduct community consultations with those communities immediately impacted by BRL before commencing logging operations and will make all reasonable efforts to ameliorate or mitigate the negative impacts of its operation. In this regard, BRL will be guided by the CFO and a third party approved by the Minister responsible for forestry.

At this point of time no communities are immediately impacted by BRL's logging operations. There are no settlements within the boundaries of the CFR. There is frequent consultation and communication FDC who mans the barrier at Tapir Camp, conducts patrols throughout the Chiquibul Forest (CNP and CFR) and co-manages and mans Las Cuevas Research Station. The nearest community is San Antonio and there are several resorts, farms and camps close the

Chiquibul Road between Guacamallo Bridge and the junction with the road to San Antonio and the junction with the George Price Highway.

13.4 Resource use conflicts

The Chiquibul Forest area offers various opportunities for resource use, including timber operations, nature tourism, research, NTFPs. At present, tourism is very limited because of poor access (Chiquibul Cave System) and security concerns (‘*xateros*’). Important other resource use is formed by the road that provides access to the Caracol archaeological site, which branches of the Chiquibul Road at Tapir Camp; Las Cuevas, there is good communication with FCD who informs BRL when there are researchers active in and around Las Cuevas.

Due to the single entry point to the Chiquibul Forest at Guacamallo Bridge (Tapir Camp barrier) and multiple resource users FCD recommends managing of the Chiquibul Forest as a single multi-zone unit

FCD aspires a future ideal scenario whereby the entire Chiquibul Forest area is managed as a single multi-zone unit, encompassing the entire Chiquibul Forest area (Chiquibul NP, Chiquibul FR and Caracol Archaeological Reserve), but legal changes will be required for this ideal scenario (Salas & Meerman, 2008). Salas & Meerman (2008) present an extended zoning plan for the entire Chiquibul Forest (Figure 84). For the implementation of objectives focused towards further developing the Chiquibul Forest area as an integrated protected area with multiple use zones, it should be borne in mind that management planning is an adaptive process, and over the five-year period, it may be necessary to amend zoning to allow for new activities and rearrangement of priorities. To achieve this, a functional multi-stakeholder governance and management structure should be put in place for the Chiquibul National Park and the Chiquibul Forest. Considerations underlying the ideal scenario include among others:

- Management of the Chiquibul Forest Reserve cannot be done in isolation; for ecological and practical reasons, management of the CFR must in fact be integrated with that of the Chiquibul Forest.
- There are numerous stakeholders within the Chiquibul Forest, and therefore management needs to be inclusive in order to take into account the interests of the various stakeholders
- Currently FCD, the co-manager of both the CNP and the Chiquibul Cave system has no income generating activities, such as entry and user fees, but only grant funding.

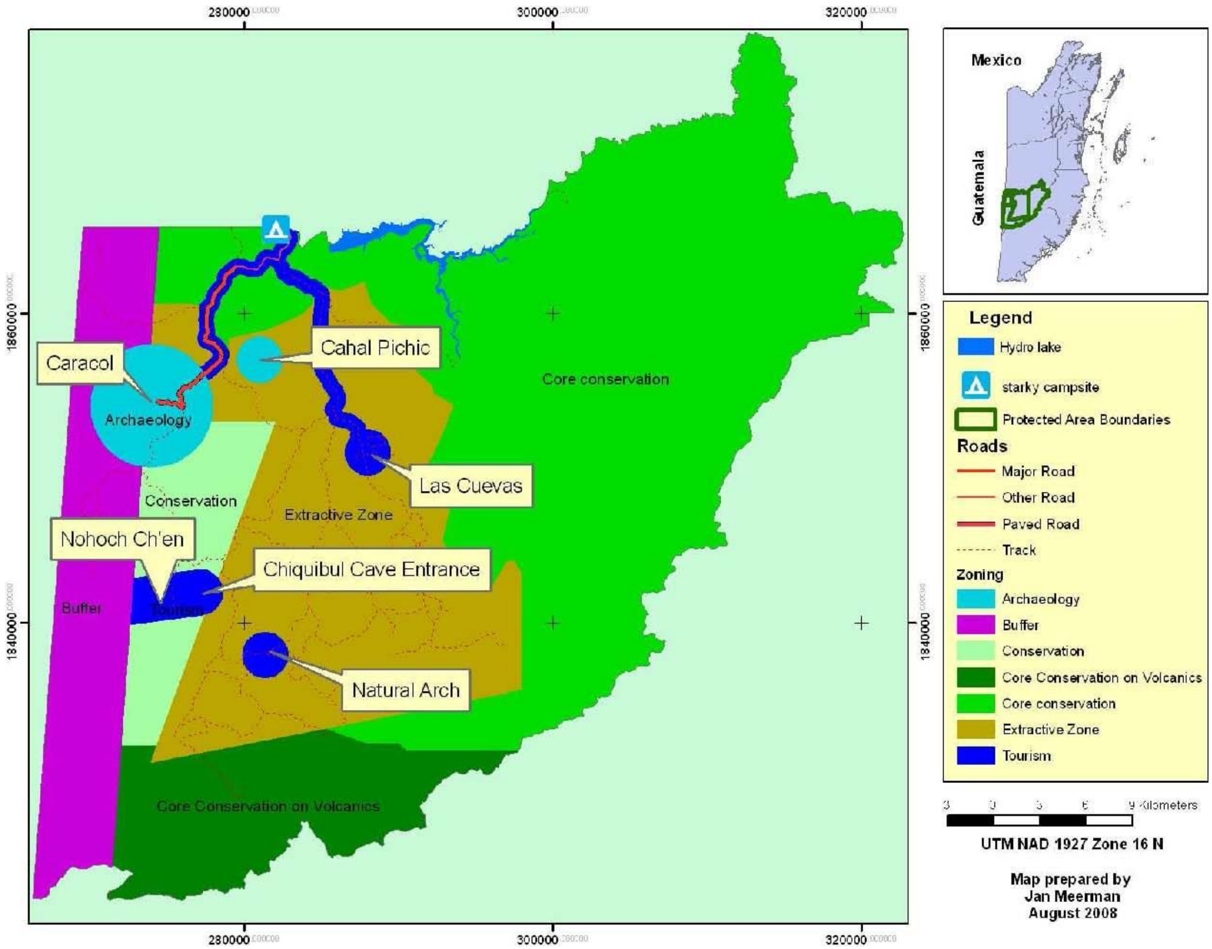


Figure 84 Zonation for the Chiquibul Forest managed as a single, integrated multi-zone unit as proposed by FCD (source: Salas & Meerman 2008)

14 FOREST PROTECTION

The Chiquibul Forest Reserve is surrounded by the Chiquibul National Park and as such benefits from the patrolling of the CNP. Illegal logging In the Chiquibul Forest was first detected in 2006. By March 2008, a joint forces patrol documented that illegal logging was escalating and a logging trail network was evident. In 2009, aerial flights conducted by FCD observed numerous illegal logging clusters. By 2010, joint patrols reported frequent and persistent illegal logging activities. The area impacted by illegal logging has shown an increase of 2.5 times from 2010 to 2015. Arevalo & Chan (2015) have shown that illegal logging has taken place along the entire western border of the CFR; occurring up to 4 kilometres inside the forest reserve and severely affecting the mahogany and cedar populations within that zone of influence (see Section A 3.8).

The Forest Department does not maintain a steady presence in this area, and only the NGO Friends for Conservation and Development (FCD) routinely patrol the area. In conjunction with the Company, FCD has established a Chiquibul Advisory Panel to advocate for better protection of the Chiquibul forest, inclusive of the National Park. A higher number of FCD rangers and security forces in the Chiquibul Forest mean more law enforcement patrols within the illegal logging hotspots in the Chiquibul, helping to reduce the illicit activity (Arevalo & Chan, 2015).

The Company has suffered losses and damages resulting from the presence of roaming Guatemalans in the forest. This is a serious matter for the Company and represents a security threat not only to the Company but to any one present in the reserve. Although the Company would like to do something about the security issues, it is understood that the matter is one of national security and is outside the hands of the Company. In the meantime, partnership with FCD is the most viable option for working towards the security of the reserve.

Other than roaming Guatemalans, there are not any other major threats to the Chiquibul Forest that the Company can have influence over. Beetles and other forest pests do not affect broadleaf forest to any significant level warranting specific protection.

Fire has not been a factor in the Chiquibul since the 1960's and perhaps even as late as the 1970's. The area is too moist and humid to trigger fires.

14.1 Security and vigilance plans

The main threat to the forest resources in the Chiquibul Forest is the illegal felling of trees by Guatemalan trespassers. In recent years this threat has increased and has spread into the Reserve along the western boundary with the National Park. Because of the sensitivity of the situation with respect to national security and the diplomatic angle being taken by the authorities, the matter is left to the national security forces to address.

However, the company plans to contribute to securing the forest resources by reducing the temptation for poachers. It plans to do this through the pre-emptive felling of compartments along the western boundary to remove merchantable trees that would otherwise attract poachers. These compartments are at the greatest risk of uncontrolled harvesting, and the company plans to target these areas within the next few years. Already four compartments along the western boundary have been harvested and the threat of illegal logging there has been reduced.

14.1.1 Demarcation, signage, and maintenance of boundary lines of management area

BRL has sole responsibility for ensuring that appropriate boundary markers and/or signs are put in place and maintained on the ground to clearly demarcate the licence area boundaries, especially where such boundaries coincide with publicly active areas. The determination of alignments for boundary markers and positions for signs shall be achieved through a cooperative effort between the Forest Department and the Licensee.

The license boundaries coincide with the CNP boundaries, and are clearly marked on the license map but not on the ground. BRL is improving the signage at the moment through a cooperative effort with FCD.

14.2 Measures for monitoring and patrols

In terms of vigilance, the company and its employees continually record and report the movements of illegal loggers to the authorities and where possible the company assists in the opening of roads to facilitate access by security forces. Furthermore, the company has plans to establish a forward operating base for its logging crew to establish a more or less permanent presence in the area which, it is hoped, will help to dissuade poachers from being around the area.

Through its annual operations, the company through its employees will monitor all movements in and out of the license area and report any suspicious activity to the authorities.

FCD patrols the entire Chiquibul Forest, including both the CFR and the CNP due to the fact that access to the southwestern part of the CNP is only possible by way of old truck passes crossing the CFR.

14.2.1 Integrated pest management plans

There are no major pests known to be active inside the Chiquibul Forest at this time, except for mahogany shoot borer attacks to mahogany and cedar regeneration. The mahogany shoot borer, *Hypsipyla grandella* (Lepidoptera: Pyralidae), is a major pest of several of the most valuable commercial hardwood timber species in the Neotropics, including mahogany and cedar. *Hypsipyla grandella*'s larvae feed on new growth, tunnelling internally and causing death of the terminal shoot. Young trees are particularly vulnerable to damage since only one larva in the apical stem can kill the tip and cause excessive branching and deformation, making the tree unmarketable. Intensive control of *H. grandella* to limit deformation and branching may only be necessary for 4–8 years, until trunks reach a merchantable height (Mayhew and Newton, 1998). Mahogany shoot borers attack mainly new shoots and are seldom seen attacking hardened-off shoots. High levels of shoot borer activity typically coincide with growth flushes of mahoganies between April and June.

Several strategies are available to control *Hypsipyla grandella* including synthetic pesticides and biological pest control systems. Due to resource constraints and high opportunity cost BRL is not in the position to implement any pest control system at present.

BRL through the presence of its inventory and logging crews continually make observations in the forest regarding any insect or fungal activity that may be out of the ordinary and report any findings immediately to the authorities.

14.3 Fire management plans

14.3.1 Prevention

The Chiquibul Forest is currently under low risk for fire. The canopy is closed and logging disturbance affects a small fraction of the area only, building up minimal debris to the forest floor. However, vigilance is important especially during severe dry seasons. To this end, the forest crews practice safe fire handling at campsites by clearing to mineral soil a minimum of 12 feet around any camp fires. No fires are allowed away from established campsites. Additionally, the company has a water bowser on hand at all times during the logging operation. BRL field crews have received fire training in the past and continually build upon their skills through annual prescribe fire exercises in the Mountain Pine Ridge.

15 INFORMATION MANAGEMENT SYSTEM

15.1 Description of information management system

BRL does not have a full information management system but intends to contract outside services to design and install such services.

At present, information is stored in stand-alone Excel, Word and Adobe pdf files which are stored on the company's intranet at the Georgeville sawmill office.

15.2 Stand and sub-compartment registers

No separate stand and sub-compartment registers are kept besides the Excel files, including GYM for 2015-2017, that were used to develop APOs and chain of custody information (mahogany and cedar only).

Stock survey information can be traced back to 2009, but in various formats. APOs back to 2007 are available, but also in various formats. There is an obvious need to rationalise information management.

Maps are created using ArcGIS 10 GIS software, but GIS work is outsourced and only maps exported from the GIS package (jpg and/or pdf format) are presently available at the company

15.3 Harvesting registers

No separate harvesting registers are kept besides the Excel files needed to develop APOs and chain of custody information (mahogany and cedar only).

15.4 Accounting registers

QuickBooks accounting software for small businesses is used to store all financial management information, including purchases and orders, and pay-rolling.

15.5 Fire management registers

No fire management registers are kept because fires are exceptional in the CFR

15.6 Pest management registers

No pest management registers are kept because major pests are exceptional in the CFR

15.7 Road maintenance registers

No separate road maintenance registers or GIS are kept besides the Excel and Word files needed to develop APOs and chain of custody information (mahogany and cedar only).

15.8 Inventory registers

No separate inventory registers are kept besides the Excel files, including GYM for 2015-2017, that were used to develop APOs.

15.9 Record storage and retrieval

Record storage and retrieval is manual from Excel files, except for QuickBooks financial management system which can produce customised reports.

16 SCHEDULE FOR IMPLEMENTATION OF ACTIVITIES

16.1 Prescriptions

16.1.1 Natural forest management

a) June – July: Reconnaissance to select compartments for next year's annual cutting area
b) July – December: Pre-harvest inventory of the annual cutting area
c) December – January: prepare and submit APO
d) January: Upgrade extraction roads leading to the annual cutting area
e) February – May: Felling and extraction

16.1.2 Plantation management

Not applicable

16.1.3 Social forestry

Not applicable

16.1.4 Other

Not applicable

16.1.5 Information Management System

An information management system is an indispensable tool in modern forest management. Such system not only allows easy, error-free storage and retrieval of stock survey or chain of custody data, it also allows linking of the two data sets and comparison between planned and realised harvests.

Stock survey data are entered in the GYM, after which crop trees, seed trees, preserved trees and reserve trees (juvenile trees and residual potential crop trees) are selected. At present, information relative to those trees is not updated after the harvest. Compilation of data to review previous year's harvest can be made easy by storing updated information on the function of the trees in the GYM. The same applies to planned roading and skid trail work and actually realised roading and skid trail work.

GIS is another indispensable tool in modern forest management. GIS-based maps are now produced as needed by outsourcing GIS work. Ideally, GIS would be integrated in the Information Management System so that all updated information can be stored in an integrated GIS project. Integrating GIS in the information management system requires the purchase of expensive software and training of personnel in managing GIS data. Outsourcing may still be the more cost-efficient method, but all GIS data and information needs to be compiled, consolidated and managed properly.

BRL will evaluate the current information management and GIS system and contract service providers to develop same further.

C MAPS

1 Topography maps

1.1 Existing and proposed roads

See Figures 2, 3, 83

1.2 Settlements, camps, etc.

See Figure 83

2 Watersheds and drainages

See Figure 3 and 4

3 Ecosystems maps

See Figures 7, 8, 9 & 10

4 Forest type classification

See 15, 16 & 17

D ANNEXES

I. Comparison of vegetation classes

Table 83 Comparison of vegetation classes applicable to the Chiquibul Forest Reserve; Penn et al. (2004), Wright et al. (1959) and Iremonger & Brokaw (1995).

Penn *et al.*	Wright *et al.*	Iremonger & Brokaw
1, Deciduous forest	2d Chiquebul-Cherry forest	17 I.2.3.2 Broadleaf hill forests over limestone in steep terrain
1a, Dry deciduous forest	–	–
2, Seasonal forest	3 Chiquebul-Ramon forest	16 I.2.3.1 Broadleaf hill forests over limestone in rolling or flat terrain
2a, Seasonal high forest.	–	–
3, Semi-evergreen forest (cohune ridge)	–	8 I.2.2.1.4 Central-western variant
4, Semi-evergreen forest (highland)	9b Negrito-Santa Maria forest	21 I.2.3.3.4 Negrito-nargusta variant
4a, Semi-evergreen forest (lowland)	9e Nargusta-Santa Maria forest	21 I.2.3.3.4 Negrito-nargusta variant
5, Transitional semi-evergreen forest	11b Nargusta-Bastard banak forest	18 I.2.3.3.1 Banak-nargusta variant (quartzite hills)
6, Evergreen southern forest	12a Nargusta-Yemeri forest	19 I.2.3.3.2 Yemeri-nargusta variant
8, Semi-evergreen forest (broken ridge)	11a Nargusta-Santa Maria forest	18 I.2.3.3.1 Banak-nargusta variant (quartzite hills)
12, High evergreen forest	4a Ramon-Chiquebul forest	19 I.2.3.3.2 Yemeri-nargusta variant
13, Evergreen palm forest	9c Nargusta-Negrito forest	–
16, Riverine	7 Cohune-Banak Forest	48 II.2.3 Disturbed scrub
17, Pine forest	18a Oak-Pine-Clusia spp. forest	22 I.2.3.4 Needle-leaf hill forests over poor soils
18, Oak and pine	18 Oak-Pine-Florosul Forest	–
19, Transitional pine, grass and palmettoes	–	–
21, Open with *Pinus oocarpa*	16a Oak-Pine forest	22 I.2.3.4 Needle-leaf hill forests over poor soils
22, Pine, oak and *Liquidambar*	–	–
25, Open pine scrub forest	12c Yemeri-Rosewood-Polewood forest	29 III.2.1 Fire-induced herbaceous vegetation

II. Statistical tests – landscape effect and logging effect

1.1 one-way ANOVA – landscape effect – karstic/acidic – stem density per plot

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Mahogany_N_30 Means	Mahogany_N_30 N	Mahogany_N_30 Std.Dev.
karstic	1.875912	137	2.393144
acidic	2.843750	32	2.515877
All Grps	2.059172	169	2.439028

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Mahogany_N_30	24.29902	1	24.29902	975.1093	167	5.838978	4.161520	0.042928

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Mahogany_N_50 Means	Mahogany_N_50 N	Mahogany_N_50 Std.Dev.
karstic	0.569343	137	1.103441
acidic	0.437500	32	0.800705
All Grps	0.544379	169	1.051974

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Mahogany_N_50	0.450919	1	0.450919	185.4662	167	1.110576	0.406022	0.524868

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Cedar_N_30 Means	Cedar_N_30 N	Cedar_N_30 Std.Dev.
karstic	0.394161	137	0.980379
acidic	0.343750	32	0.787375
All Grps	0.384615	169	0.944911

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Cedar_N_30	0.065922	1	0.065922	149.9341	167	0.897809	0.073425	0.786748

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Cedar_N_50 Means	Cedar_N_50 N	Cedar_N_50 Std.Dev.
karstic	0.182482	137	0.558609
acidic	0.187500	32	0.470929
All Grps	0.183432	169	0.541787

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Cedar_N_50	0.000653	1	0.000653	49.31296	167	0.295287	0.002212	0.962541

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Barbajol_N_30 Means	Barbajol_N_30 N	Barbajol_N_30 Std.Dev.
karstic	0.430657	137	0.774555
acidic	0.968750	32	2.989059
All Grps	0.532544	169	1.476142

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Barbajol_N_30	7.511015	1	7.511015	358.56	167	2.147066	3.49827	0.063183

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Barbajol_N_50 Means	Barbajol_N_50 N	Barbajol_N_50 Std.Dev.
karstic	0.167883	137	0.394248
acidic	0.218750	32	0.750672
All Grps	0.177515	169	0.479798

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Barbajol_N_50	0.06712	1	0.06712	38.60744	167	0.231182	0.290334	0.590724

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Rosewood_N_30 Means	Rosewood_N_30 N	Rosewood_N_30 Std.Dev.
karstic	0.014599	137	3.180538
acidic	0.312500	32	1.255632
All Grps	0.071006	169	0.562456

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Rosewood_N_30	2.302126	1	2.302126	50.8458	167	0.304466	7.561195	0.006621

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Nargusta_N_30 Means	Nargusta_N_30 N	Nargusta_N_30 Std.Dev.
karstic	2.635036	137	3.152129
acidic	4.625000	32	4.520562
All Grps	3.011834	169	3.545601

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Nargusta_N_30	102.7245	1	102.7245	2009.252	167	12.03145	8.538000	0.003960

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Nargusta_N_50 Means	Nargusta_N_50 N	Nargusta_N_50 Std.Dev.
karstic	0.817518	137	1.399679
acidic	1.031250	32	1.822518
All Grps	0.857988	169	1.485228

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Nargusta_N_50	1.185010	1	1.185010	369.4067	167	2.212016	0.535715	0.465240

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Sapodilla_N_30 Means	Sapodilla_N_30 N	Sapodilla_N_30 Std.Dev.
karstic	1.729927	137	2.257353
acidic	1.500000	32	1.813925
All Grps	1.686391	169	2.177234

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sapodilla_N_30	1.371399	1	1.371399	795.0073	167	4.760523	0.288077	0.59217

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Sapodilla_N_50 Means	Sapodilla_N_50 N	Sapodilla_N_50 Std.Dev.
karstic	0.715328	137	1.212368

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sapodilla_N_50	3.004557	1	3.004557	213.3978	167	1.277831	2.351294	0.127071

acidic	0.375000	32	0.659912
All Grps	0.650888	169	1.134949

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Sta Maria_N_30 Means	Sta Maria_N_30 N	Sta Maria_N_30 Std.Dev.
karstic	0.481752	137	0.963314
acidic	0.468750	32	0.717719
All Grps	0.479290	169	0.919943

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sta Maria_N_30	0.004385	1	0.004385	142.1731	167	0.851336	0.005151	0.942870

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Sta Maria_N_50 Means	Sta Maria_N_50 N	Sta Maria_N_50 Std.Dev.
karstic	0.072993	137	0.287868
acidic	0.031250	32	0.176777
All Grps	0.065089	169	0.270406

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sta Maria_N_50	0.045201	1	0.045201	12.23882	167	0.073286	0.616768	0.433364

1.2 one-way ANOVA – landscape effect – karstic/acidic – volume per plot

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Mahogany_V_30 Means	Mahogany_V_30 N	Mahogany_V_30 Std.Dev.
karstic	2.948247	137	4.095989
acidic	3.494113	32	3.519304
All Grps	3.051607	169	3.989099

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Mahogany_V_30	7.729583	1	7.729583	2665.639	167	15.96191	0.484252	0.487470

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Mahogany_V_50 Means	Mahogany_V_50 N	Mahogany_V_50 Std.Dev.
karstic	1.57331	137	3.082429
acidic	0.896220	32	1.673419
All Grps	1.445104	169	2.877342

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Mahogany_V_50	11.89257	1	11.89257	1378.996	167	8.257462	1.440222	0.231803

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Cedar_V_30 Means	Cedar_V_30 N	Cedar_V_30 Std.Dev.
karstic	0.78723	137	3.381499

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Cedar_V_30	1.02298	1	1.02298	1621.347	167	9.708662	0.105368	0.745887

acidic	0.588647	32	1.461877
All Grps	0.749629	169	3.107565

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Cedar_V_50 Means	Cedar_V_50 N	Cedar_V_50 Std.Dev.
karstic	0.629031	137	3.313145
acidic	0.489261	32	1.38667
All Grps	0.602566	169	3.040381

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Cedar_V_50	0.506773	1	0.506773	1552.471	167	9.296232	0.054514	0.815673

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Barbajol_V_30 Means	Barbajol_V_30 N	Barbajol_V_30 Std.Dev.
karstic	0.721175	137	1.587649
acidic	1.111137	32	3.449257
All Grps	0.795014	169	2.063817

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Barbajol_V_30	3.944833	1	3.944833	711.6242	167	4.261223	0.925751	0.33736

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Barbajol_V_50 Means	Barbajol_V_50 N	Barbajol_V_50 Std.Dev.
karstic	0.520189	137	1.495673
acidic	0.553967	32	2.062811
All Grps	0.526585	169	1.611302

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Barbajol_V_50	0.029597	1	0.029597	436.1478	167	2.611664	0.011333	0.915349

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Rosewood_V_30 Means	Rosewood_V_30 N	Rosewood_V_30 Std.Dev.
karstic	0.010923	137	0.09007
acidic	0.192948	32	0.764719
All Grps	0.045389	169	0.345821

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Rosewood_V_30	0.859506	1	0.859506	19.23197	167	0.115161	7.463488	0.006974

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Nargusta_V_30 Means	Nargusta_V_30 N	Nargusta_V_30 Std.Dev.
karstic	5.054073	137	8.674361
acidic	7.401958	32	7.787306
All Grps	5.498643	169	8.541273

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Nargusta_V_30	143.0006	1	143.0006	12113.16	167	72.53391	1.971500	0.162146

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Landscape	Nargusta_V_50	Nargusta_V_50	Nargusta_V_50

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS	F	p

	Means	N	Std.Dev.
karstic	3.294042	137	7.544885
acidic	4.202941	32	7.355572
All Grps	3.466141	169	7.496232

	Effect	Effect	Effect	Error	Error	Error		
Nargusta_V_50	21.42967	1	21.42967	9419.078	167	56.40166	0.379947	0.538471

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Sapodilla_V_30	Sapodilla_V_30	Sapodilla_V_30
Landscape	Means	N	Std.Dev.
karstic	3.564002	137	5.849927
acidic	2.250972	32	3.024737
All Grps	3.315381	169	5.445885

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Sapodilla_V_30	44.72324	1	44.72324	4937.764	167	29.56745	1.512584	0.220475

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Sapodilla_V_50	Sapodilla_V_50	Sapodilla_V_50
Landscape	Means	N	Std.Dev.
karstic	2.617584	137	5.27739
acidic	1.192021	32	2.268294
All Grps	2.347655	169	4.879459

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Sapodilla_V_50	52.71778	1	52.71778	3947.214	167	23.63601	2.2304	0.137206

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Sta Maria_V_30	Sta Maria_V_30	Sta Maria_V_30
Landscape	Means	N	Std.Dev.
karstic	0.615858	137	1.340893
acidic	0.522719	32	0.990073
All Grps	0.598222	169	1.279741

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Sta Maria_V_30	0.225035	1	0.225035	274.9148	167	1.646196	0.136700	0.712053

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Sta Maria_V_50	Sta Maria_V_50	Sta Maria_V_50
Landscape	Means	N	Std.Dev.
karstic	0.195187	137	0.789285
acidic	0.139824	32	0.790965
All Grps	0.184704	169	0.787545

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Sta Maria_V_50	0.079508	1	0.079508	104.1185	167	0.623464	0.127527	0.721461

1.3 one-way ANOVA – logging effect – stem density per plot

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Mahogany_N_30	Mahogany_N_30	Mahogany_N_30

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS	F	p

	Means	N	Std.Dev.
recent	2.200000	30	2.234525
unlogged	2.028777	139	2.487483
All Grps	2.059172	169	2.439028

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Mahogany_N_50	Mahogany_N_50	Mahogany_N_50
Logging_History	Means	N	Std.Dev.
recent	0.300000	30	0.595963
unlogged	0.597122	139	1.121072
All Grps	0.544379	169	1.051974

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Cedar_N_30	Cedar_N_30	Cedar_N_30
Logging_History	Means	N	Std.Dev.
recent	0.133333	30	0.434172
unlogged	0.438849	139	1.015211
All Grps	0.384615	169	0.944911

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Cedar_N_50	Cedar_N_50	Cedar_N_50
Logging_History	Means	N	Std.Dev.
recent	0.066667	30	0.253708
unlogged	0.208633	139	0.583279
All Grps	0.183432	169	0.541787

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Barbajol_N_30	Barbajol_N_30	Barbajol_N_30
Logging_History	Means	N	Std.Dev.
recent	0.266667	30	0.52083
unlogged	0.589928	139	1.605303
All Grps	0.532544	169	1.476142

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

	Barbajol_N_50	Barbajol_N_50	Barbajol_N_50
Logging_History	Means	N	Std.Dev.
recent	0.066667	30	0.253708
unlogged	0.201439	139	0.513299
All Grps	0.177515	169	0.479798

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep.

	Effect	Effect	Effect	Error	Error	Error		
Mahogany_N_30	0.723392	1	0.723392	998.6849	167	5.980149	0.120966	0.728428

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Mahogany_N_50	2.694484	1	2.694484	183.3055	167	1.097638	2.454803	0.119059
	2.178311	1	2.178311	183.7388	167	1.100233	1.979864	0.161263

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Cedar_N_30	2.303118	1	2.303118	147.6969	167	0.884412	2.604121	0.108474

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Cedar_N_50	0.497303	1	0.497303	48.81631	167	0.292313	1.701266	0.193917

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Barbajol_N_30	2.57844	1	2.57844	363.4926	167	2.176602	1.184617	0.277986

Analysis of Variance Marked effects are significant at p < .05000

	SS	df	MS	SS	df	MS		
	Effect	Effect	Effect	Error	Error	Error	F	p
Barbajol_N_50	0.448177	1	0.448177	38.22638	167	0.2289	1.957957	0.163587

Analysis of Variance Marked effects are significant at p < .05000 var. list)

Logging_History	Rosewood_N_30 Means	Rosewood_N_30 N	Rosewood_N_30 Std.Dev.
recent	0.133333	30	0.730297
unlogged	0.057554	139	0.521561
All Grps	0.071006	169	0.562456

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Nargusta_N_30 Means	Nargusta_N_30 N	Nargusta_N_30 Std.Dev.
recent	3.766667	30	2.824564
unlogged	2.848921	139	3.671105
All Grps	3.011834	169	3.545601

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Nargusta_N_50 Means	Nargusta_N_50 N	Nargusta_N_50 Std.Dev.
recent	1.200000	30	1.399507
unlogged	0.784173	139	1.497644
All Grps	0.857988	169	1.485228

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sapodilla_N_30 Means	Sapodilla_N_30 N	Sapodilla_N_30 Std.Dev.
recent	2.333333	30	2.324285
unlogged	1.546763	139	2.127198
All Grps	1.686391	169	2.177234

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sapodilla_N_50 Means	Sapodilla_N_50 N	Sapodilla_N_50 Std.Dev.
recent	0.966667	30	1.401559
unlogged	0.582734	139	1.062532
All Grps	0.650888	169	1.134949

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sta Maria_N_30 Means	Sta Maria_N_30 N	Sta Maria_N_30 Std.Dev.
recent	0.600000	30	0.968468
unlogged	0.453237	139	0.910670

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Rosewood_N_30	0.141694	1	0.141694	53.00624	167	0.317403	0.446417	0.504964

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Nargusta_N_30	20.78233	1	20.78233	2091.194	167	12.52212	1.659649	0.199433

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Nargusta_N_50	4.266536	1	4.266536	366.3252	167	2.193564	1.945025	0.164976

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sapodilla_N_30	15.26599	1	15.26599	781.1127	167	4.677322	3.263831	0.072624

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sapodilla_N_50	3.637139	1	3.637139	212.7652	167	1.274043	2.8548	0.092968

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sta Maria_N_30	0.531472	1	0.531472	141.6460	167	0.848180	0.626602	0.429727

All Grps	0.479290	169	0.919943

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sta Maria_N_50 Means	Sta Maria_N_50 N	Sta Maria_N_50 Std.Dev.
recent	0.033333	30	0.182574
unlogged	0.071942	139	0.285908
All Grps	0.065089	169	0.270406

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sta Maria_N_50	0.036781	1	0.036781	12.24724	167	0.073337	0.501542	0.479811

1.4 one-way ANOVA – logging effect – volume per plot

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Mahogany_V_30 Means	Mahogany_V_30 N	Mahogany_V_30 Std.Dev.
recent	3.098835	30	3.352074
unlogged	3.041413	139	4.124364
All Grps	3.051607	169	3.989099

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Mahogany_V_30	0.081358	1	0.081358	2673.288	167	16.00771	0.005082	0.943251

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Mahogany_V_50 Means	Mahogany_V_50 N	Mahogany_V_50 Std.Dev.
recent	0.965661	30	2.257879
unlogged	1.548580	139	2.991124
All Grps	1.445104	169	2.877342

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Mahogany_V_50	8.384289	1	8.384289	1382.504	167	8.278469	1.012782	0.315693

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Cedar_V_30 Means	Cedar_V_30 N	Cedar_V_30 Std.Dev.
recent	0.135980	30	0.415125
unlogged	0.882071	139	3.408894
All Grps	0.749629	169	3.107565

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Cedar_V_30	13.73515	1	13.73515	1608.634	167	9.632541	1.425911	0.234126

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Cedar_V_50 Means	Cedar_V_50 N	Cedar_V_50 Std.Dev.
recent	0.090928	30	0.346287
unlogged	0.712991	139	3.34052
All Grps	0.602566	169	3.040381

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Cedar_V_50	9.548126	1	9.548126	1543.429	167	9.242093	1.033113	0.310899

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep.

Analysis of Variance Marked effects are significant at p < .05000 var. list)

Logging_History	Barbajol_V_30 Means	Barbajol_V_30 N	Barbajol_V_30 Std.Dev.
recent	0.682062	30	2.294489
unlogged	0.819392	139	2.018803
All Grps	0.795014	169	2.063817

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Barbajol_V_30	0.465351	1	0.465351	715.1037	167	4.282058	0.108675	0.742071

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Barbajol_V_50 Means	Barbajol_V_50 N	Barbajol_V_50 Std.Dev.
recent	0.526795	30	2.266091
unlogged	0.526540	139	1.442767
All Grps	0.526585	169	1.611302

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Barbajol_V_50	0.000002	1	0.000002	436.1774	167	2.611841	0.000001	0.999375

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Rosewood_V_30 Means	Rosewood_V_30 N	Rosewood_V_30 Std.Dev.
recent	0.090917	30	0.497971
unlogged	0.035563	139	0.304847
All Grps	0.045389	169	0.345821

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Rosewood_V_30	0.075604	1	0.075604	20.01587	167	0.119856	0.630793	0.428192

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Nargusta_V_30 Means	Nargusta_V_30 N	Nargusta_V_30 Std.Dev.
recent	7.667245	30	7.373546
unlogged	5.030599	139	8.726074
All Grps	5.498643	169	8.541273

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Nargusta_V_30	171.5351	1	171.5351	12084.63	167	72.36304	2.370480	0.125542

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Nargusta_V_50 Means	Nargusta_V_50 N	Nargusta_V_50 Std.Dev.
recent	5.131353	30	6.962768
unlogged	3.106742	139	7.582131
All Grps	3.466141	169	7.496232

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Nargusta_V_50	101.1422	1	101.1422	9339.365	167	55.92434	1.808555	0.180505

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sapodilla_V_30 Means	Sapodilla_V_30 N	Sapodilla_V_30 Std.Dev.
recent	5.073261	30	7.63817
unlogged	2.935982	139	4.798752

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sapodilla_V_30	112.7125	1	112.7125	4869.775	167	29.16033	3.865267	0.050953

All Grps	3.315381	169	5.445885

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sapodilla_V_50 Means	Sapodilla_V_50 N	Sapodilla_V_50 Std.Dev.
recent	3.798702	30	7.530819
unlogged	2.034480	139	4.063312
All Grps	2.347655	169	4.879459

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sapodilla_V_50	76.79905	1	76.79905	3923.133	167	23.49182	3.269183	0.072392

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sta Maria_V_30 Means	Sta Maria_V_30 N	Sta Maria_V_30 Std.Dev.
recent	0.580696	30	1.043269
unlogged	0.602005	139	1.328519
All Grps	0.598222	169	1.279741

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sta Maria_V_30	0.011204	1	0.011204	275.1286	167	1.647477	0.006801	0.934374

Breakdown Table of Descriptive Statistics N=169 (No missing data in dep. var. list)

Logging_History	Sta Maria_V_50 Means	Sta Maria_V_50 N	Sta Maria_V_50 Std.Dev.
recent	0.082518	30	0.451970
unlogged	0.206758	139	0.842241
All Grps	0.184704	169	0.787545

Analysis of Variance Marked effects are significant at p < .05000

	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p
Sta Maria_V_50	0.380866	1	0.380866	103.8172	167	0.621660	0.612660	0.434896

1.5 Factorial ANOVA – main effects and two-way interactions - landscape & logging history – stem number per plot

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Mahogany_N_30 SS	Mahogany_N_30 MS	Mahogany_N_30 F	Mahogany_N_30 p
Intercept	1	410.7557	410.7557	69.51701	0.000000
Logging_History	1	0.0830	0.0830	0.01404	0.905826
Landscape	1	16.2267	16.2267	2.74624	0.099383
Logging_History*Landscape	1	0.0122	0.0122	0.00207	0.963738
Error	165	974.9368	5.9087		
Total	168	999.4083			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Mahogany_N_50 SS	Mahogany_N_50 MS	Mahogany_N_50 F	Mahogany_N_50 p
Intercept	1	12.1654	12.16536	10.94989	0.001149
Logging_History	1	1.9830	1.98301	1.78488	0.183391
Landscape	1	0.4231	0.42312	0.38084	0.538004
Logging_History*Landscape	1	0.1334	0.13336	0.12004	0.729433
Error	165	183.3155	1.11100		
Total	168	185.9172			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Cedar_N_30 SS	Cedar_N_30 MS	Cedar_N_30 F	Cedar_N_30 p
Intercept	1	5.6960	5.696039	6.363994	0.012592
Logging_History	1	1.6237	1.623694	1.814099	0.179864
Landscape	1	0.0066	0.0066	0.007374	0.931673
Logging_History*Landscape	1	0.0011	0.001081	0.001207	0.972322
Error	165	147.6819	0.895042		
Total	168	150.0000			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Cedar_N_50 SS	Cedar_N_50 MS	Cedar_N_50 F	Cedar_N_50 p
Intercept	1	1.56300	1.563001	5.286991	0.022739
Logging_History	1	0.27534	0.275337	0.931351	0.335924
Landscape	1	0.02839	0.028394	0.096047	0.757017
Logging_History*Landscape	1	0.02892	0.028917	0.097813	0.754865
Error	165	48.77918	0.295631		
Total	168	49.31361			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Barbajol_N_30 SS	Barbajol_N_30 MS	Barbajol_N_30 F	Barbajol_N_30 p
Intercept	1	20.8433	20.8433	9.808339	0.002056
Logging_History	1	7.1782	7.17817	3.377869	0.067876
Landscape	1	1.6556	1.65565	0.779106	0.378699
Logging_History*Landscape	1	4.4476	4.44756	2.092912	0.149881
Error	165	350.6347	2.12506		
Total	168	366.0710			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Barbajol_N_50 SS	Barbajol_N_50 MS	Barbajol_N_50 F	Barbajol_N_50 p
Intercept	1	1.44660	1.446599	6.290932	0.013102
Logging_History	1	0.66557	0.665573	2.894425	0.090770
Landscape	1	0.00149	0.001492	0.006487	0.935905
Logging_History*Landscape	1	0.18109	0.181086	0.787502	0.376148
Error	165	37.94173	0.22995		
Total	168	38.67456			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Rosewood_N_30 SS	Rosewood_N_30 MS	Rosewood_N_30 F	Rosewood_N_30 p
Intercept	1	2.66687	2.666868	8.719535	0.003608
Logging_History	1	0.24503	0.24503	0.801146	0.372055
Landscape	1	2.43059	2.430591	7.947009	0.005407
Logging_History*Landscape	1	0.32379	0.323789	1.058654	0.305028
Error	165	50.46522	0.30585		
Total	168	53.14793			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Nargusta_N_30 SS	Nargusta_N_30 MS	Nargusta_N_30 F	Nargusta_N_30 p
Intercept	1	1005.857	1005.857	84.16206	0.000000
Logging_History	1	0.411	0.411	0.03437	0.853143
Landscape	1	30.535	30.535	2.55489	0.111867
Logging_History*Landscape	1	23.981	23.981	2.00656	0.158506
Error	165	1971.985	11.951		
Total	168	2111.976			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Nargusta_N_50 SS	Nargusta_N_50 MS	Nargusta_N_50 F	Nargusta_N_50 p
Intercept	1	72.3950	72.39500	32.94524	0.000000
Logging_History	1	0.6821	0.68214	0.31043	0.578173
Landscape	1	0.0301	0.03015	0.01372	0.906903
Logging_History*Landscape	1	2.9330	2.93304	1.33476	0.249631
Error	165	362.5767	2.19743		
Total	168	370.5917			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Sapodilla_N_30 SS	Sapodilla_N_30 MS	Sapodilla_N_30 F	Sapodilla_N_30 p
Intercept	1	268.8661	268.8661	57.57594	0.000000
Logging_History	1	24.3229	24.3229	5.2086	0.023753
Landscape	1	0.0743	0.0743	0.01592	0.899745
Logging_History*Landscape	1	8.2430	8.2430	1.76518	0.185814
Error	165	770.5112	4.6698		
Total	168	796.3787			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Sapodilla_N_50 SS	Sapodilla_N_50 MS	Sapodilla_N_50 F	Sapodilla_N_50 p
Intercept	1	32.9558	32.95581	26.01258	0.000001
Logging_History	1	3.6136	3.61363	2.8523	0.093132
Landscape	1	2.2040	2.20402	1.73967	0.189008
Logging_History*Landscape	1	0.0516	0.05158	0.04071	0.840346
Error	165	209.0415	1.26692		
Total	168	216.4024			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Sta Maria_N_30 SS	Sta Maria_N_30 MS	Sta Maria_N_30 F	Sta Maria_N_30 p
Intercept	1	18.1199	18.11993	21.19961	0.000008
Logging_History	1	0.0582	0.05817	0.06806	0.794505
Landscape	1	0.2837	0.28371	0.33193	0.565309
Logging_History*Landscape	1	0.5979	0.59785	0.69946	0.404173
Error	165	141.0303	0.85473		
Total	168	142.1775			

Univariate Results for Each DV Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of Freedom	Sta Maria_N_50 SS	Sta Maria_N_50 MS	Sta Maria_N_50 F	Sta Maria_N_50 p
Intercept	1	0.12386	0.123864	1.674038	0.197527
Logging_History	1	0.02512	0.025117	0.339458	0.560938
Landscape	1	0.03049	0.030487	0.412033	0.521830
Logging_History*Landscape	1	0.00036	0.000356	0.004805	0.944821
Error	165	12.20853	0.073991		
Total	168	12.28402			

III. Superior Seed Tree Selection Criteria

The following is meant to act as the FD's guidelines regarding the selection of seed trees. The guidelines will be followed by BRL during its operations. Below are some tree characteristics which are readily determined from external appearances and generally believed to reflect some degree of genetic control. Wherever possible, trees will be compared with neighbours of the same species and age. Potential seed trees should exhibit the following phenotypic traits:

1. Superior height
2. Superior diameter
3. Superior volume – by reason of 1 and/or 2
4. Superior growth rate – as distinguished from 1, 2 or 3 where direct comparisons are difficult to make, e.g., a young tree surrounded by older ones
5. Superior branching – small, short limbs and/or with a low branch angle (nearly horizontal)
6. Excellent crown form – dense foliage, good colour and other qualities revealing high vigour without excessive size
7. Excellent stem form – straight, low taper, high form class
8. Excellent natural pruning – few or no dead limbs below live crown, absence of large stubs, epicormic branches few or none
9. Excellent seed production – past evidence reveals tree to be a good seed producer
10. High resistance to disease – indicate the disease
11. High resistance to insect damage – indicate the insect
12. High resistance to weather injury – resistance to high wind, drought or high salt content moisture
13. Other – specify here any unusual condition connected with the tree that is not accounted for by the above listed items.

Marking of Seed Trees:

1. Trees chosen as seed trees will be painted the same colour at breast height and at 12 inches up from the ground.
2. The UTM coordinate of each seed tree will be recorded using a GPS or other equipment.

Spacing of Seed Trees:

1. Seed Trees will be spaced according to the approved parameters in the SFMP and APO.

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