SUSTAINABLE FOREST MANAGEMENT PLAN

2022 TO 2026

for

The Rio Bravo Conservation and Management Area

Orange Walk

Programme for Belize

August 2021

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EXECUTIVE SUMMARY

The Rio Bravo Conservation and Management Area encompasses part of one of the most productive tropical broadleaf systems in Belize. It has an impressive two century long history of logging, which by all accounts herein will continue well into the future. Especially so if the management of the forest adheres to the systems and prescriptions made for the area and contained in this management plan.

This present sustainable forest management plan (SFMP) is the fourth plan of its kind that has been prepared for the RBCMA. These SFMPs have taken the approach of planning around a 5 year cycle, by inventorying an area equal to 5 annual cutting compartments and preparing a management plan for same. This approach saves cost and time but lacks a longer term view of resource availability, since year to year maneuvering of harvesting is restricted to the same 5 annual cutting compartments to be worked under the 5 year plan. Therefore, in the third plan, an area equal to 10 annual cutting compartments was inventoried to aid in planning and yield selection, and allows for wider maneuvering from year to year across cutting compartments to meet market demands and resource management objectives.

In reality, these 5 year plans all fit within a larger forest management framework developed for the RBCMA and contained within the original 5-year plan written by R. Wilson in 2006. Much of the geographical and ecological context of the RBCMA is contained within this original plan and need not be re-written here. For example, the compartmentalization of the RBCMA into cutting blocks is as it was in 2006 and there is no need to re-design the compartments under this new management plan. But for context, several paragraphs of relevant text have been carried over to this new plan and referenced.

This SFMP is a strategic document that provides the planning framework for forest management at the annual unit level. This document will be a reference for the planning of on ground operations and activities and will guide the selection of

the sequence of annual cutting compartments. It should be viewed as an integral component of the suit of management tools available to PfB.

This 5-year area can sustain a yield of timber that will be very profitable under optimal management and administrative performance. On average, Mahogany is available annually in amounts approaching 214,000 bdft of sawn lumber from a typical logging area of 1,000 hectares. The amount can be adjusted from year to year to meet company preferences and market conditions. Other precious hardwoods are also available in economically viable volumes. Some species will require protection from logging when and where they occur sparsely. The company is encouraged to harvest and utilize as many species as possible according to the sustainable yield models and regulation methods provided.

Paramount to the execution of this management plan will be an intrinsic understanding that the forest, in its present state, affords the production of timber and generation of revenue at levels exceeding those normally associated with timber operations in Belize, but that this will change with the coming of the next hurricane. Therefore, the forest should be utilized as efficiently as possible to maximize economic benefits but without undue harm.

The current management plan represents an innovative advancement in the field of forest management in Belize as it proposes long needed improvements to the yield regulation and silvicultural system for tropical broadleaf forests of Belize. These improvements are data-driven and should therefore as much as possible continue to be informed by relevant data. This 2022-2026 RBCMA management plan will represent a benchmark example for other forest management operations in Belize.

List of Figures and Tables

ACKNOWLEDGEMENTS

PfB acknowledges the work under the previous management plans, which is a critical basis for the development of this latest plan. The hard work and dedication of the staff of PfB is commendable. As well, the involvement of the Forest Department staff in the monitoring of PfB's operations, including through the post-harvest assessment process, has been fruitful. PfB also acknowledges the Forest Stewardship Council's Auditors for their continued support of PfB's forest management activities.

1. INTRODUCTION

1.1. Purpose of the Plan

This is the fourth Sustainable Forest Management Plan for the RBCMA. This management plan represents the aims and desires of Programme for Belize (PfB) regarding the management of its timber and forest resources, and is consistent with the commitment to achieve environmental sustainability. This plan applies specifically to the current five-year forest management portion of the RBCMA, which is more broadly managed at the property level according to the wider management plan for the RBCMA.

Programme for Belize is committed to sustainable land management and has preserved its landholding under continuous forest cover since it acquired the area in 1989. Since 2006, PfB has been involved in sustainable forest management and wishes to continue sustainable forestry on the estate in order to serve as a source of predictable income to support its protection operations whilst ensuring compatibility of its logging operations with forest conservation. The purpose of this plan is to lay out the methods and objectives that will allow PfB to achieve its goal for forest management of the RBCMA. PfB's goal of forest management on the RBCMA is to demonstrate sustainable use of forest resources, while generating revenues for re-investment in conservation management through activities that neither compromise the biodiversity of the area nor the future value of the resource. The main objectives of this plan are to:

(i) Produce quality hardwood logs for sale to local mills;
(ii) Maintain continuous forest cover in the timber production zone;
(iii) Ensure that other forest goods and services are not negatively affected by logging;
(iv) Ensure that its operations comply with all national laws and stipulations;
(v) Minimize the carbon footprint of its logging operations;

(vi) Maintain a ban on hunting, and promote wildlife populations throughout its property.

1.2. Scope and Context

Programme for Belize is a registered non-profit, non-governmental organization established in 1988 for the specific purpose of managing the Rio Bravo Conservation and Management Area (RBCMA), a 101,813 hectare parcel of public land entrusted to it for perpetuity as private property under a formal Memorandum of Understanding (MoU) with the government. The RBCMA, owned and managed by PfB on behalf of all Belizeans, was established in 1989 as a private reserve to conserve forested land in the Orange Walk District threatened with deforestation and fragmentation following the break-up of the landholdings of the Belize Estate and Produce Company. The MoU with the government requires that the management of the RBCMA must further national policy towards protected areas and proper resource use. The organizational aim of PfB is to preserve the natural heritage and biological diversity of the RBCMA while demonstrating sustainable use as well as ensuring the conservation of its natural resources.

The RBCMA is divided into four zones: (i) protection (50,358 hectares); sustainable forest management (37,086 hectares); savannah management (11,687 hectares); and infrastructure and tourism (2,683 hectares). While this SFMP provides a sustainable forest management framework for all of the timber management zone of the RBCMA, in reality the focus of the on ground timber management activities is within the current five-year (quinquennial) portion identified within the sustainable timber management zone.

Although registered as non-profit, PfB is allowed under the formal MoU to conduct income generating activities, the proceeds of which must be re-invested in further actions to achieve its organizational and management aims. PfB maintains two field stations within the RBCMA, Hillbank and La Milpa. The Hillbank field station is the base for its logging operations but also hosts tourists and other visitors.

Programme for Belize maintains a crew of forestry workers at its Hillbank Field Station who conducts stock surveys, monitors harvests and remeasures silvicultural plots. However, PfB does not conduct its own logging and instead operates through timber harvesting agreements with private contractors who are responsible for road operations, felling, skidding, and hauling. All wood is milled offsite.

On a daily basis PfB's timber operations are managed by a Technical Coordinator based out of Belize City. Frequent trips are made to the RBCMA and in particular to the Hillbank Field Station by the Technical Coordinator as well as other administrative staff. On the ground, the forestry crew is supervised by a head forester who is based permanently at Hillbank.

Programme for Belize maintains a fleet of work vehicles at Hillbank to use in its timber operations but does not possess logging machinery or equipment. There is also a ranger crew based at Hillbank who are charged with patrolling the RBCMA, working in close conjunction with the forestry crew.

The RBCMA is PfB's flagship project, where it demonstrates the practical application of sustainable forestry, aiming to achieve the highest level of compliance with national and international best practices and to improve upon existing knowledge and methods in order to conserve the biodiversity and promote the sustainable use of the forest resources.

1.3. Legal Status of the Management Area

The RBCMA consists of parcels of private land held in trust through unencumbered titles by PfB on behalf of the people of Belize, and there are no other rights or claims to the land or its resources. It was officially declared a private Protected Area in 1989 under the management of PfB corresponding to an IUCN category

VI managed resource area. Programme for Belize itself was incorporated as non-profit organization limited by guarantee under Chapter 206 of the laws of Belize, and granted ownership and management of the RBCMA by the government of Belize through an official Memorandum of Understanding first signed on June 1st 1988 with subsequent amendments in 1991 and 1998 and 2020. The RBCMA cannot be alienated from the purposes of conservation and sustainable development. The terms of the MoU with the government define a management regime designed to ensure management by PfB for biodiversity conservation and sustainable use of natural resources but giving it wide scope of action to achieve those goals. If PfB is for any reason unable to continue in its role, its successor must follow the same objectives, so ensuring that the management regime of the RBCMA remains perpetually in place.

All major roads on the property are owned and managed by PfB, and none are public access. All entrances to the RBCMA are gated and manned by PfB employees or authorized third parties, and access to and via the property is only by permission from PfB Management. There is a shared access agreement with adjacent landowners including the Gallon Jug Estate.

Under free-hold title, ownership of all above-surface resources is vested in PfB but permission from the government is needed to convert trees into lumber and in doing so, royalties on roundwood are payable to the government. PfB retains the right to utilize all timber and non-timber forest resources on its property, after being granted permission from the government through Long-term Private Forest Permit #1 of 2007 (LTPFP 01/07), and subject to any accompanying provisions.

Programme for Belize's timber operation is certified by agents acting on behalf of the international body known as the Forest Stewardship Council. Although this certification program is not nationally recognized or required for forest management operations, it does form an integral part of PfB's internal policy.

1.4. Description of the Management Planning Process

Programme for Belize has used a similar process to develop its management plan since the first plan was written in 2006. The process involves first an internal analysis of the organization's objectives and scope of planned work over the five year period, followed by a scientifically robust survey of the forest resources within the designated five year area, and subsequent analysis of the data to inform management prescriptions. PfB's plans are written around the national guidance regarding reduced-impact logging and sustainable yield prediction. PfB also conducts routine community consultations with surrounding communities during development of its management plans but more importantly throughout the five year period of the plan and regularly incorporates findings and improve outreach activities based on feedback from communities. PfB's land is freehold title and therefore it exercises all its rights to ensure protection of its property and the resources therein.

2. DESCRIPTION OF THE AREA

Biogeography is the study/description of the geographic distribution of organisms or ecosystems across the land. This section describes important aspects of the biogeography of the area covered by this 5-year SFMP. For a wider account of the biogeography of the entire RBCMA see the original 2006 SFMP by R. Wilson.

2.1. Location, Size and Boundary

The RBCMA comprises approximately 101,813 hectares of land situated in the Orange Walk District and bounded on the west by the border with Guatemala, to the north and east by Mennonite lands and other communities, and to the south by the Maya Forest Trust lands (Fig. 1). It is centered on geographic coordinates 17°45'N 88°50'W. The RBCMA is one of the largest protected areas in the country, covering around 4.4% of Belize's land mass and some 21.2% of the

Orange Walk District. Except for where there are natural boundaries, all boundary lines are surveyed and clearly demarcated on the ground.

The sustainable forest management zone corresponds to all those green areas in Fig. 1 below, which is recognized as the boundary of the forest management area under LTPFP 01/07. The portion of the timber management inventoried for this new 5-year SFMP is represented by black outlines and amounts to approximately 5,630 hectares of tropical broadleaf forest nested within the larger sustainable forest management zone comprising 37,085 hectares. The current forest management area is relatively small and consists of separate parcels in close proximity, so the biogeography is expected to be broadly homogenous, differentiated into only a few categories. The main determinants of bio-geographical patterns within the current forest management area are geology, soils and elevation. Other typical determinants such as rainfall and temperature are homogenous across the area and so will not necessarily influence variation in vegetation across the 5-year management area.

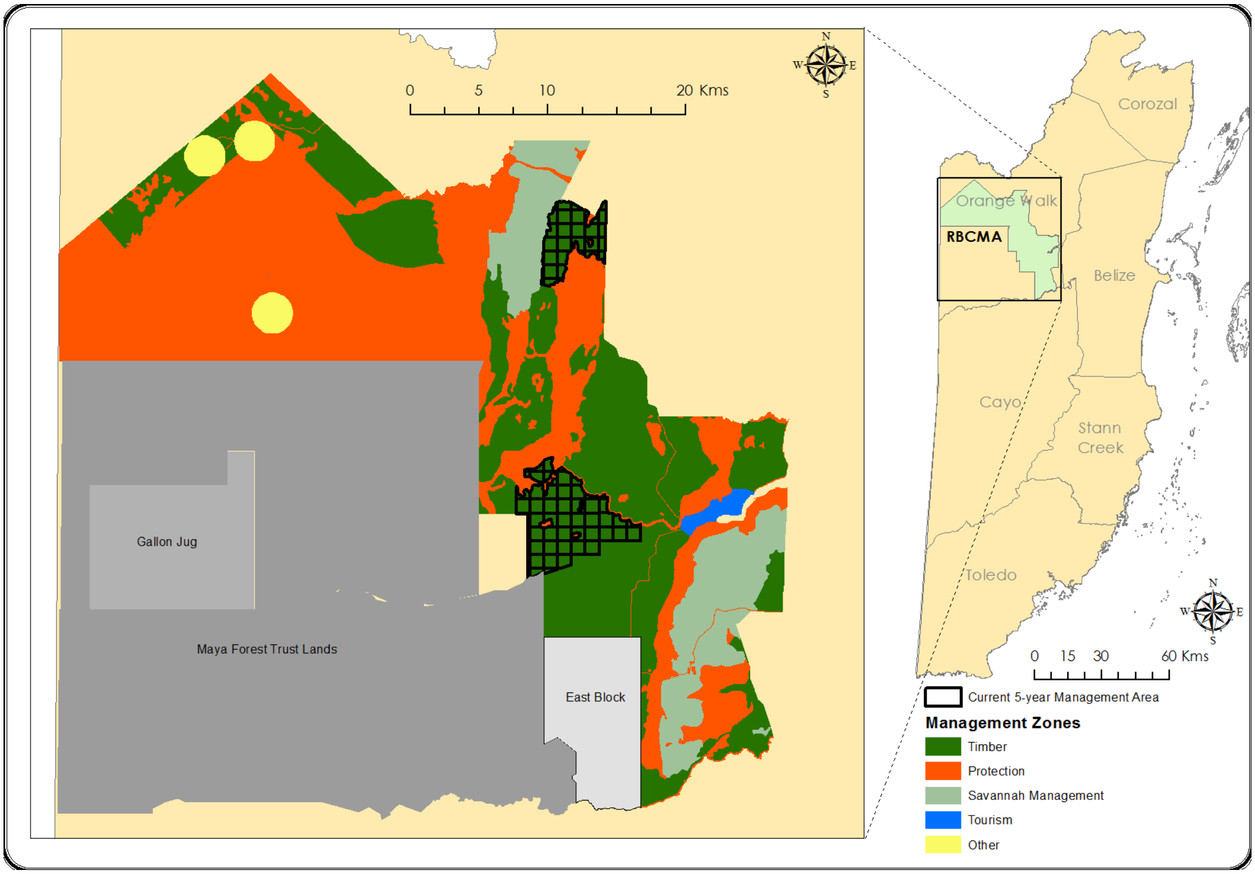


Figure 1. Location of the new quinquennial forest management area.

The inset shows the location of the RBCMA in the wider country. The zoomed area shows the configuration of management zones in the RBCMA, the location of the 5-year management area and the spatial relationship with adjacent properties.

2.2. International, regional and national significance

The RBCMA lies adjacent to the international frontier, so linking directly onto the Rio Azul National Park in Guatemala as well as Aguas Turbias National Park (which also adjoins the international frontier with Quintana Roo, Mexico). It forms part of the Selva Maya, which is comprised of large tracts of protected forest in north-eastern Guatemala and south-eastern Mexico. The Selva Maya is both regionally and internationally significant as it is the largest block of forest in Mesoamerica and it is the largest remaining contiguous block of tropical forest after the

Amazon. It is habitat to regionally and internationally significant species of concern such as the Jaguar, White-lipped Peccary and Baird's Tapir.

Nationally, the RBCMA is of great importance as a demonstrative attempt at sustainable land management along with financial sustainability. The RBCMA has served as training ground and study area for many national efforts at improving forest management as well as international efforts at investigating the impact of logging on tropical forests.

2.3. Physical Environment

Geology and Soils

The underlying geology of the management area is characterized by substrates deposited during two periods in the geological timescale: the Pleistocene epoch and the much older Paleocene-Eocene epoch. The Pleistocene epoch lasted from about 2.6 million to 11,700 years ago, while the Paleocene-Eocene epoch lasted from 66 to 34 million years ago, at the end of the Cretaceous period which saw the extinction of the dinosaurs. The majority of the management area covered by this 5-year plan is underlain by sediments deposited near the end of the Paleocene and into the early Eocene epoch (Paleocene-Eocene epoch), meaning these are much more weathered and ancient substrates consisting of limestone bedrock formed when the area was submerged under shallow seas. Pleistocene sediments are found in low lying regions along the Rio Bravo and other water bodies, deposited there as wash down from mountainous areas further inland, while Paleocene-Eocene sediments are found on higher ground punctuated by limestone mounds (Fig. 2). The consequence of this for vegetation is that the Paleocene-Eocene substrates are better drained and more lime-enriched, which is favoured by species such as Mahogany, while the Pleistocene substrates are usually waterlogged and as a consequence more acidic in nature, which is favoured by tree species of lesser or no commercial value.

Since soil is generated from the weathering of rocks over millions of years, the soils formed from the two types of sediments are likewise different, and influence tree growth differently. Soils formed from the weathering of Paleocene-Eocene limestone are typically shallow, rocky soils and are called leptosols, and because the leptosols are over calcareous rocks they are more specifically called rendzinas. On the other hand, the Pleistocene sediments were deposited by the movement of fresh water (alluvial deposits) after the limestone formed and constitute mostly acidic sediments brought down from the weathering of more ancient igneous and metamorphic rocks from further away.

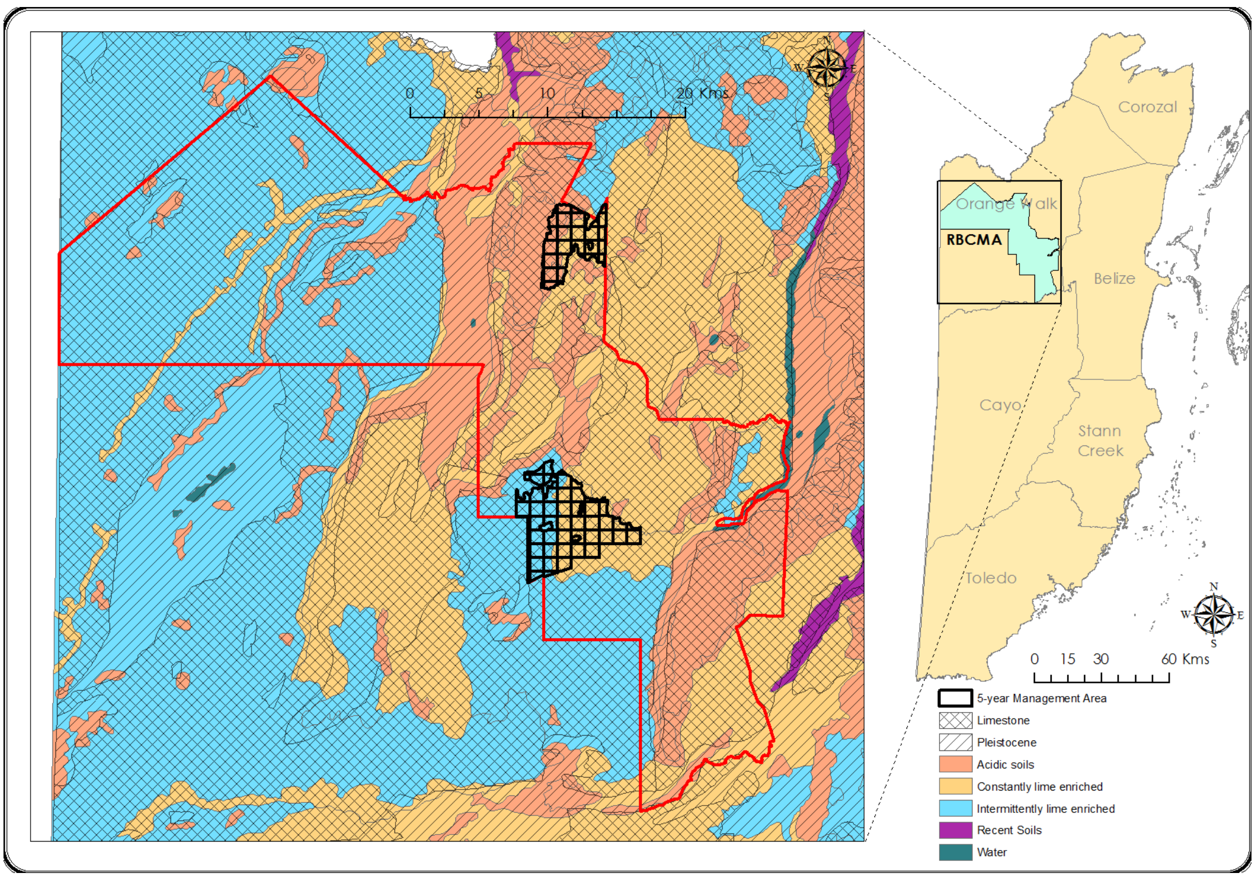


Figure 2. Geology and soils of the management area.

Geology is depicted by different hatch and line patterns, which also correspond to accepted global soil classification. Diagonal lines represent leptosols and *hatch lines represent rendzinas. Local soil characteristics according to the Wright et al. (1959) classification are depicted by different colours.*

Soils formed by the movement of water are typically located in depressions or lower areas and are prone to waterlogging during the rainy season, furthering their acidic nature. These types of soils are known as gleysols. However, because the gleysols are lower in elevation relative to the rendzinas, they have also formed under constant lime-enrichment through erosion and wash down, but still maintain their acidic-character. Where there are even lower depressions within with the gleysols region, water bodies or ponds develop.

Gleysols and rendzinas are globally recognized names for different soil types. However, it is also useful to discuss the soil types in the management area according to the local soil classification system of Wright *et al*. (1959). Wright *et al.* (1959) describes the Yaxa suite as the principal soil type within the management area, which comprises large areas of both the gleysols and rendzinas. Soils of the Yaxa suite are considered shallow, lime-enriched clays. There are smaller pockets of other soil types scattered within the management area. For example, soils underlying permanently waterlogged areas within the gleysols are classified under the Pucte suite. And soils on the exposed escarpment regions of the rendzinas are classified as skeletal soils and fall under the Chacalte suite. To summarize, in local soil terminology there are three soil types in the management area: Yaxa (the most extensive), Pucte, and Chacalte. Detailed descriptions of the properties of these soils and the vegetation which grow on them are provided in Wright *et al*. (1959), but for completeness they are briefly described below.

Yaxa suite: This suite is comprised of six different sub-suites, all variations of the Jolja clays. Jolja clays are usually dark grey-brown, gravelly clays over limestone and can occur on hillsides, but are usually on flat to rolling terrain. They are typically well-drained. Mahogany and Sapodilla prefer Jolja clays and are usually in abundance. Although over limestone, Jolja clays are relatively deep, about 12 inches or more, consequently they are locally considered to no longer be rendzinas. And although formed under constant lime-enrichment, free calcium has mostly been leached through heavy rainfall, and pH is now slightly acidic, from 6.3 to 6.5. The overriding characteristic of this soil type is its shallow depth, compared to other soils. This makes it best kept under forest cover, or risk extensive erosion especially on the steeper slopes.

Pucte: These are mostly sandy clays, pale to very dark grey in colour, and have very poor water drainage. They occur in depressions scattered throughout the management area. Fertility is quite high but because of poor drainage and water control, it is not readily suitable for agriculture and is best kept under forest or as ponds to support aquatic life. If drained, it can support cattle pasture, especially if adjacent to Yaxa clays. Forest growing on Pucte clays would constitute production forest at the level of the management area, but within an annual logging compartment they may comprise protection zones or areas of high conservation value, for soil preservation.

Chacalte: Like Yaxa, Chacalte soils can be considered rendzinas in the global soil classification. They are typically rocky, shallow clays on steep to very steep and precipitous slopes, underlain by very hard limestone, and are very susceptible to erosion. They are skeletal soils totally unsuitable for agriculture. They are typically light brown to red-brown or grey-grown in colour. Mahogany and Sapodilla occur, but not in great numbers. The characteristic of this soil type is that it is very erodible, and thus should fall under protection. In the RBCMA Chacalte soils are found on the escarpments. Forests growing on Chacalte would constitute High Conservation Value Forests (HCVF).

Topography and Hydrology

Topography is the arrangement of the natural and artificial physical features of an area of land, and the characterization and study of topography can inform how this arrangement influences elevation, slope, aspect and other physical processes such as water movement. Topography may also influence the type of vegetation that occurs in a particular location, as well as the land use activities that can be carried out. For example, areas with steep slopes may be prone to erosion as water flows swiftly and thus vegetation should not be disturbed, while lower lying areas may fill up with water and be sensitive to soil compaction from heavy machinery. Vegetation growing in these areas may reflect moisture levels. In contrast, land that is not too steep or too low is suitable for logging. Fig. 3 and accompanying legend provides a general topographic overview of the 5-year management area, according to the topographic map series for the country.

The management area consists of mostly flat terrain with interspersed low lying drainages. Escarpment areas and other vulnerable soils have already been excluded from the timber management zone during the development of the original plan in 2006. It is not expected that the topography in the current 5-year management area will include any areas of High Conservation Value Forests resulting from topographical sensitivity.

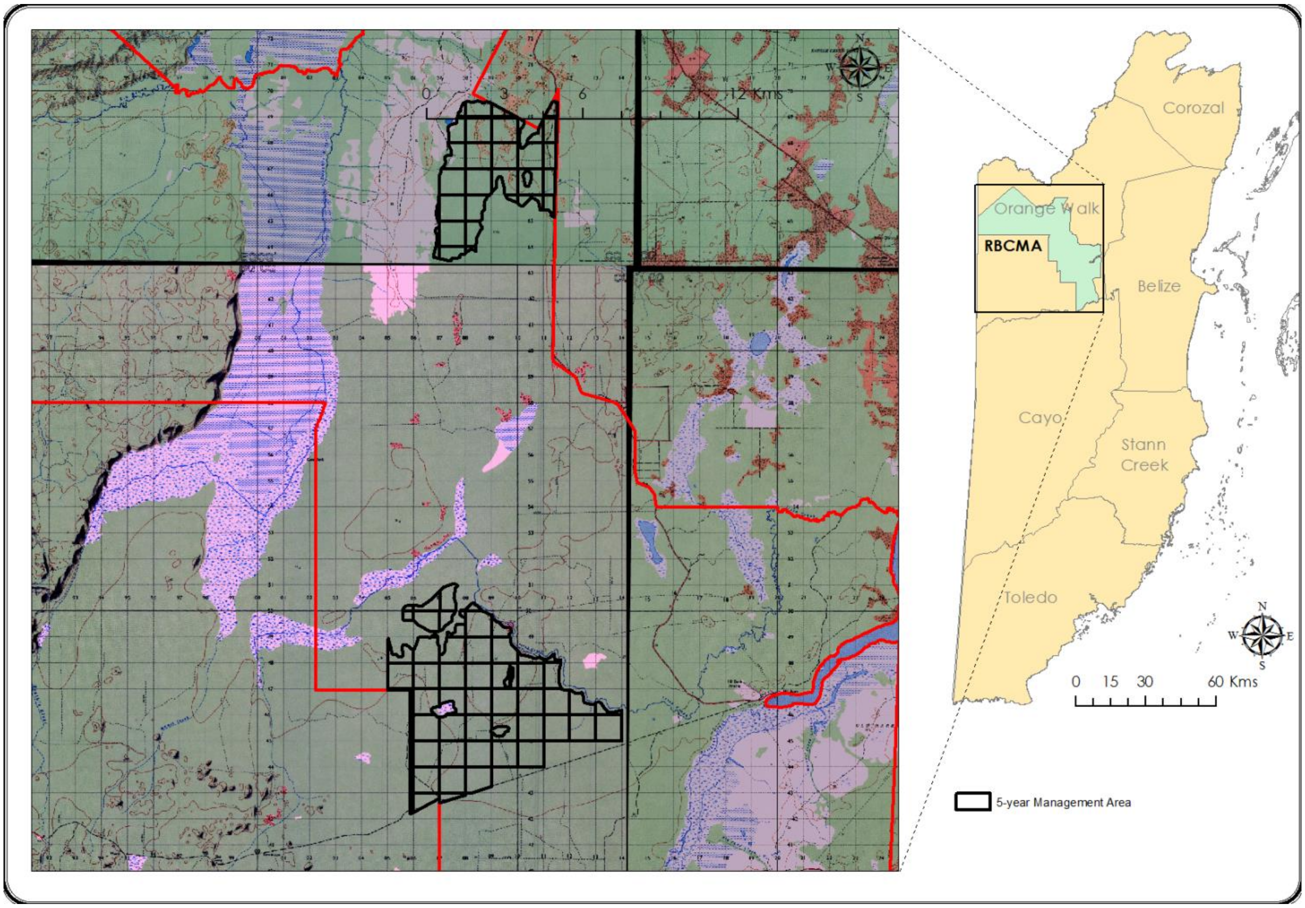


Figure 3. Topography of the management area.

On the topographic map, dark shaded areas are steep hillsides; brown curvy lines are contours and are labeled with elevation in metres; blue curvy lines represent waterways; blue areas represent water bodies; white shaded areas with blue hashes represent areas of lower elevation than their surroundings; white shaded areas with no hashes are agricultural lands and brown shaded areas are rural areas. Overlain on the topographic map is the management area in thick black.

Fig. 4 which characterizes the elevation of the management area, indicates quite clearly where depressions and swamps may occur in low lying areas. Elevation ranges from around 25 metres in the lowest areas to around 85 metres in the highest areas. There is not a large elevational difference across the area –around

50 metres at most, but usually only a metre or two difference in any given locality, resulting in waterways forming in microtopography. As a result, frequently inundated areas are large and common and often spillover to flood surrounding forest during exceptionally wet periods.

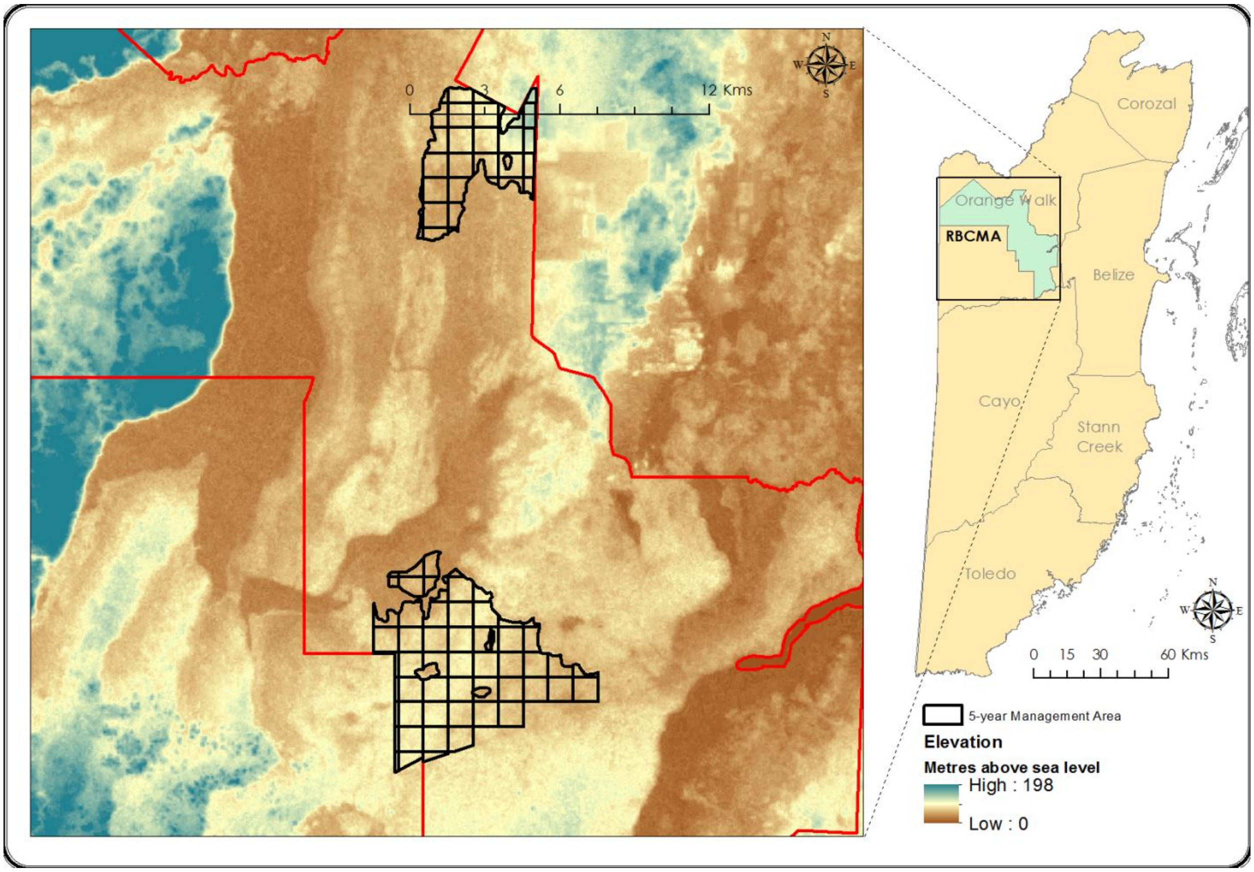


Figure 4. Elevation of the management area (previous page).

Elevation values correspond to vegetation height but are indicative of the underlying terrain because vegetation height is generally homogenous.

To protect perennial waterways from erosion and soil compaction due to heavy machinery, all perennial waterways shown in blue in Fig. 5 have been excluded from the management area with a buffer of around 50 metres on either side. Intermittent and ephemeral streams are not excluded as these tend to be void of water during the dry-season when logging occurs, and hence the hardened soil in the banks and channel can sustain the weight of rubber-wheeled machinery without soil compaction. Fig. 5 shows the location of major perennial waterways.

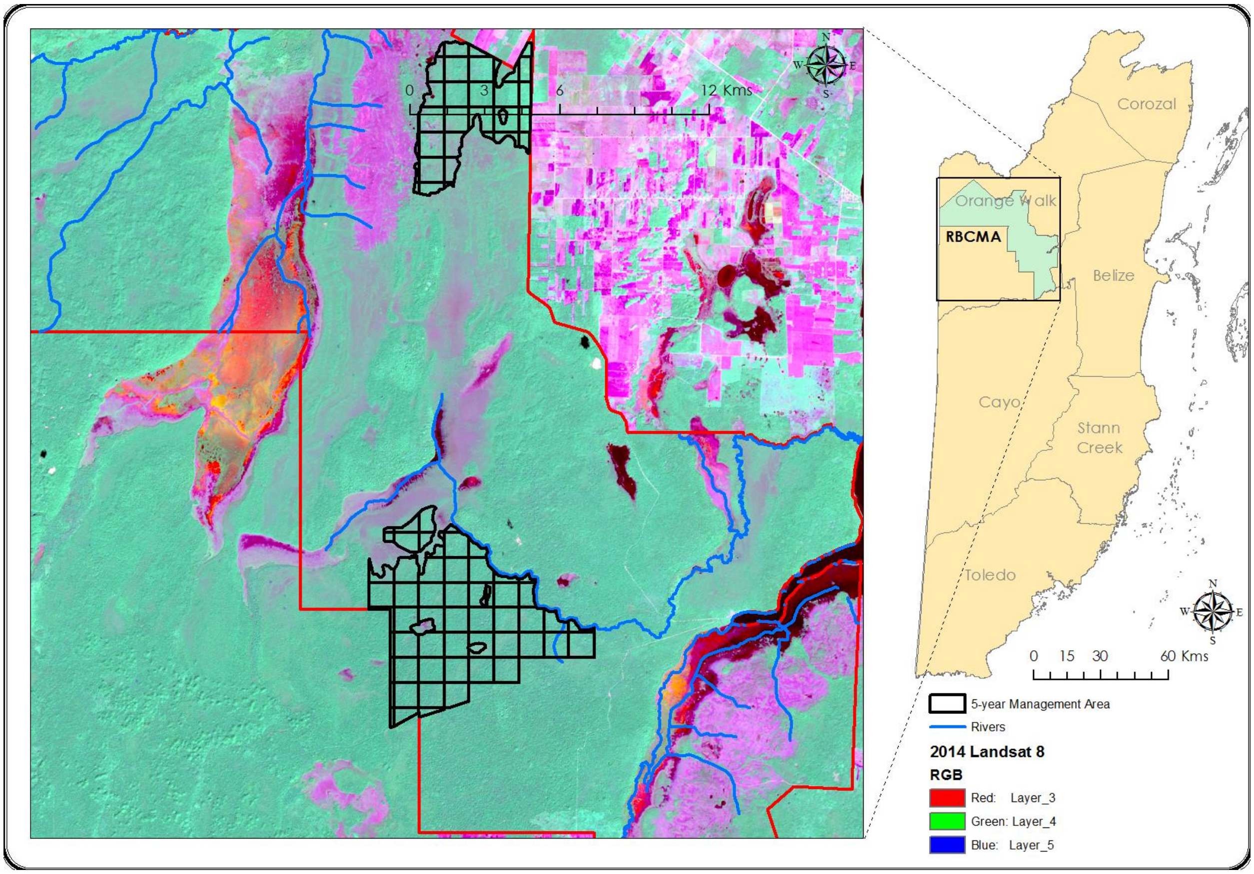


Figure 5. Perennial waterways in the management area.

The underlying image is a false colour composite of a July 2014 Landsat 8 image in R-G-B mode.

Climate

The climate of the management area is typical of the northwestern portion of Belize, where the dry climate of the Yucatan peninsula meets the wet climate of the Bay of Honduras. Mean annual rainfall ranges from 1,500 to 1,700 mm yr^{-1}, which places the forests in the category of moist tropical. There is strong seasonality over the year with a dry season, when cumulative monthly rainfall is less than 100 mm, lasting around 4.7 months from February to mid-June. The rest of the year is humid, but the months of June to October are exceptionally humid, and constitute the 'rainy season'. Throughout the year temperature varies widely, from a low of around 17°C in December and January when cold fronts come down from North America, to over 35°C during the height of the dry season, with an average of around 26°C across the year.

Climate is one of the major drivers of forest composition, structure and dynamics. Dry-season length exerts particularly strong influence, as only the hardiest species survive long periods of drought. Exposed hillsides and drier areas may experience elevated tree mortality, as weaker trees unable to cope with low soil water potential are 'thinned out'. During the dry-season, low lying areas such as swamps and 'bajos' which remain moist, act as refuges for less hardy species and for those hardier species which happen to occur there. The management area supports many waterlogged refuges and these must be safeguarded during logging operations.

Current Land Use/Land Cover and Vegetation

The RBCMA is managed for multiple uses, the four main land use activities being forestry, tourism/recreation, savannah management and protection (see Fig. 1). These land uses occupy varying proportions of the RBCMA as shown in Fig. 2, with Protection accounting for the greatest proportion, approximately 50%. Forestry follows at 36%, then Savannah Management at 11% and Tourism at 3%.

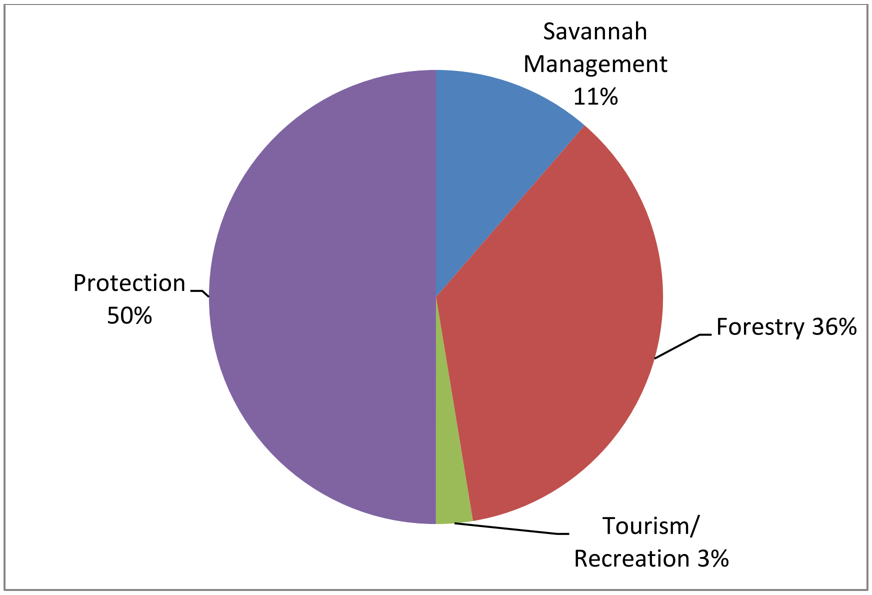


Figure 6. Proportion of land under different uses on the RBCMA.

At the level of the current 5-year management area, Forestry is the dominant land use occupying around 98% of the area. Fig. 7 shows the location of the different land use types within the 5-year management area. Although the primary land use is Forestry, this can be broken down further during annual planning into areas designated for timber production and buffer areas designated for conservation of soil, water and wildlife. This further categorization of annual cutting compartments within the 5-year management area occurs following the stock survey and ahead of logging, and is elaborated within the Annual Plan of Operations.

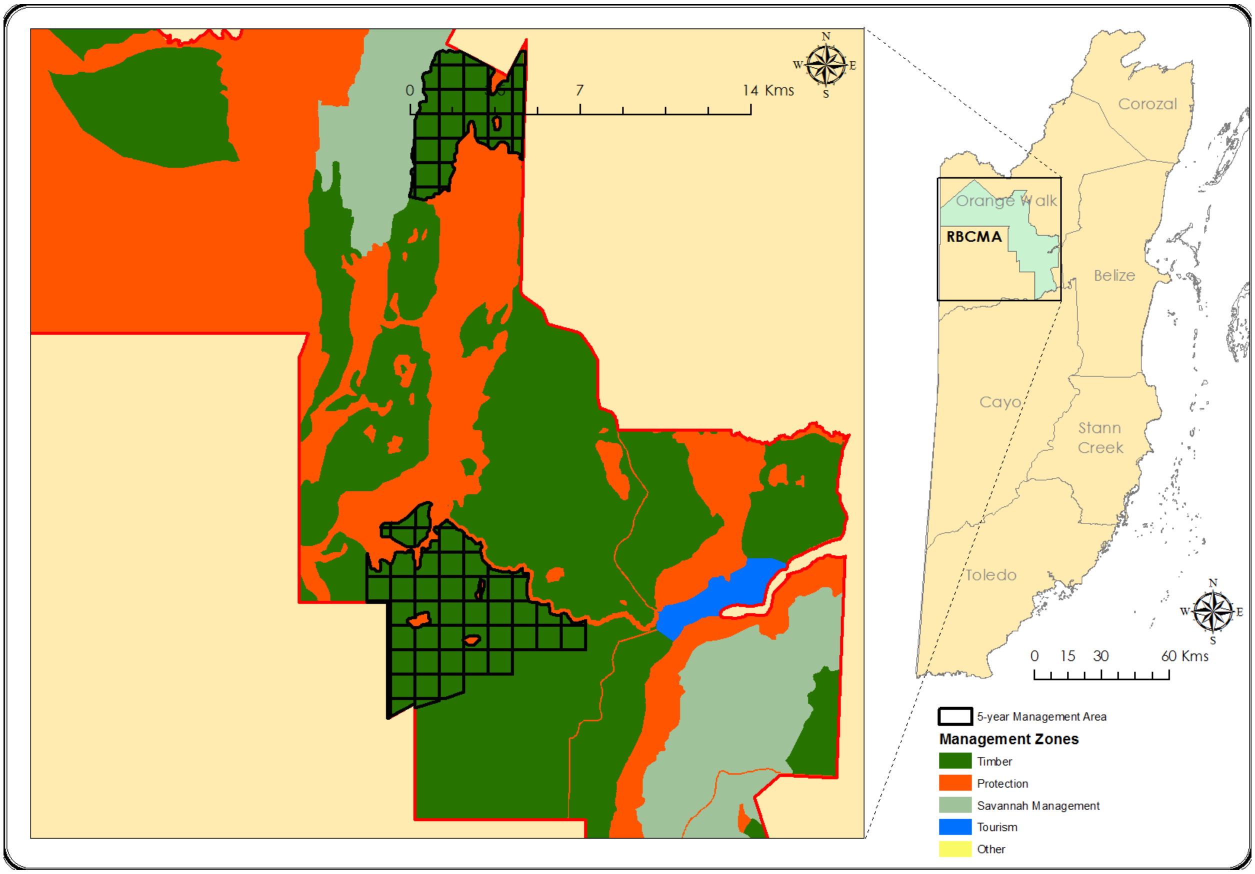


Figure 7. Different land uses within the 5-year management area.

Land use differs from land cover in that the former describes anthropogenic activities occurring on the land while the latter describes natural and anthropogenic surface features of the land. Land cover therefore includes the types of natural vegetation growing on the land, as well as features that are present where natural vegetation has been removed or is absent. Often land cover maps are maps of vegetation. Fig. 8 shows the different land cover/vegetation types within the 5-year management area gleaned from analysis of the forest inventory data as well as multi-spectral Aster and Landsat satellite imagery. For a full vegetation classification of the RBCMA see the original 2006-2010 management plan.

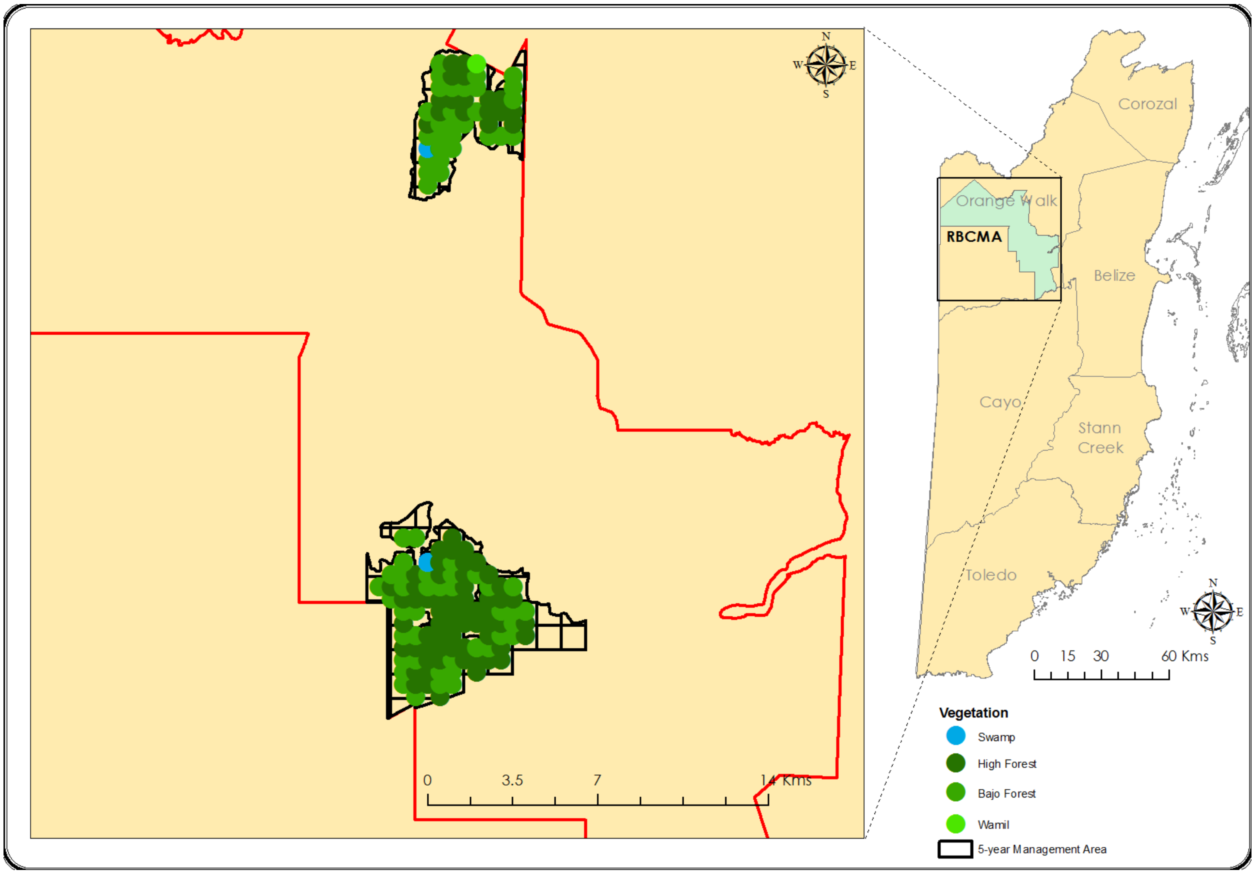


Figure 8. Land cover and vegetation types within the 5-year management area.

2.4. Biological Environment

The Rio Bravo is one of the highest-scoring sites within the National Protected Area System on both biophysical and management/land use criteria (Meerman, 2005). The principal features conferring high value include:

- Key role in biological connectivity at a regional level.
- Size – the evaluation actually gives a maximum score to any area above 2000 acres in extent. The RBCMA is over 150 times that size, conferring special importance by conserving ecosystem processes operating at a landscape scale. This is further enhanced by being part of a single forested bloc including the neighbouring Maya Forest (Yalbac and Gallon Jug), Aguas Turbias N.P. and Colby property.

- Inclusions of special habitats – 16 major habitats are recognized in the area. In four of these types, the RBCMA contributes over 90% of the national protected area coverage. It also makes a significant contribution in conserving extensive tracts of a further three that are poorly represented (i.e. > 25% shortfall on target coverage) and another one that is under-represented (i.e. >10% shortfall on target coverage) in the national system.
- An important wildlife refugium, serving as a source area for the surrounding region. This is essentially a function of size, allowing the area to support viable populations characteristic of the region. Many of these species are of conservation concern and under pressure elsewhere, with the area acting as a source of replenishment.
- Although the flat to rolling terrain over much of the area is not particularly scenic, the sheer extent of good-quality natural habitat is exceptional while the New River lagoon – the largest inland water-body in the country - is outstanding. The area also contains an array of archaeological sites including La Milpa, one of the largest Maya sites of the Classic period.
- A large proportion of the headwaters of the New River lie within the eastern Rio Bravo and a substantial area of those of the Hondo (Rio Azul, Rio Bravo, and Booth's River) lie in the west. The area can therefore be assumed to provide significant environmental services in protecting these watersheds.

Of the thirty-four different ecosystems present in the landscape shown in Figure 9 below, which includes the RBCMA, fifteen of these ecosystem types are present within the RBCMA.

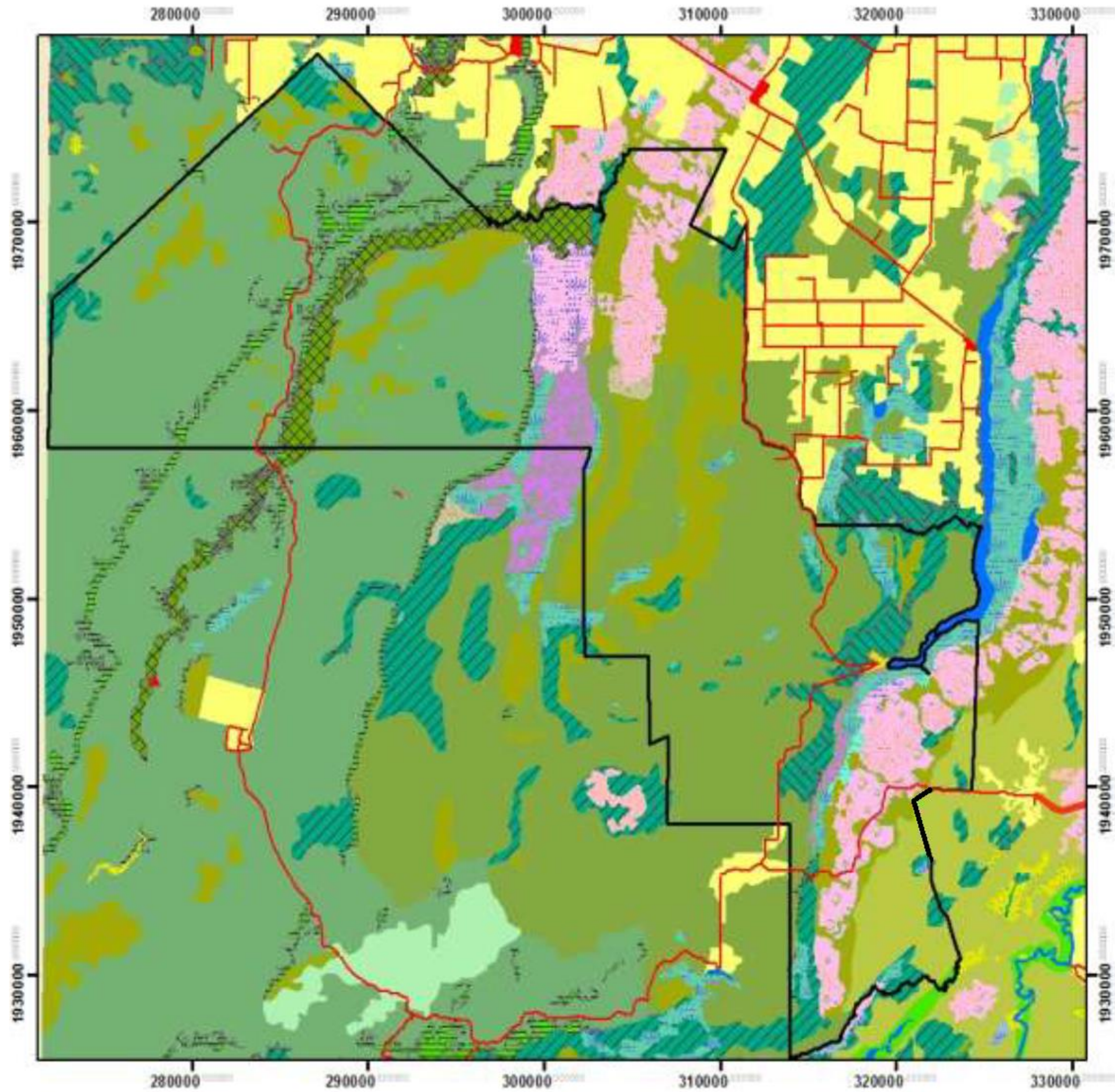
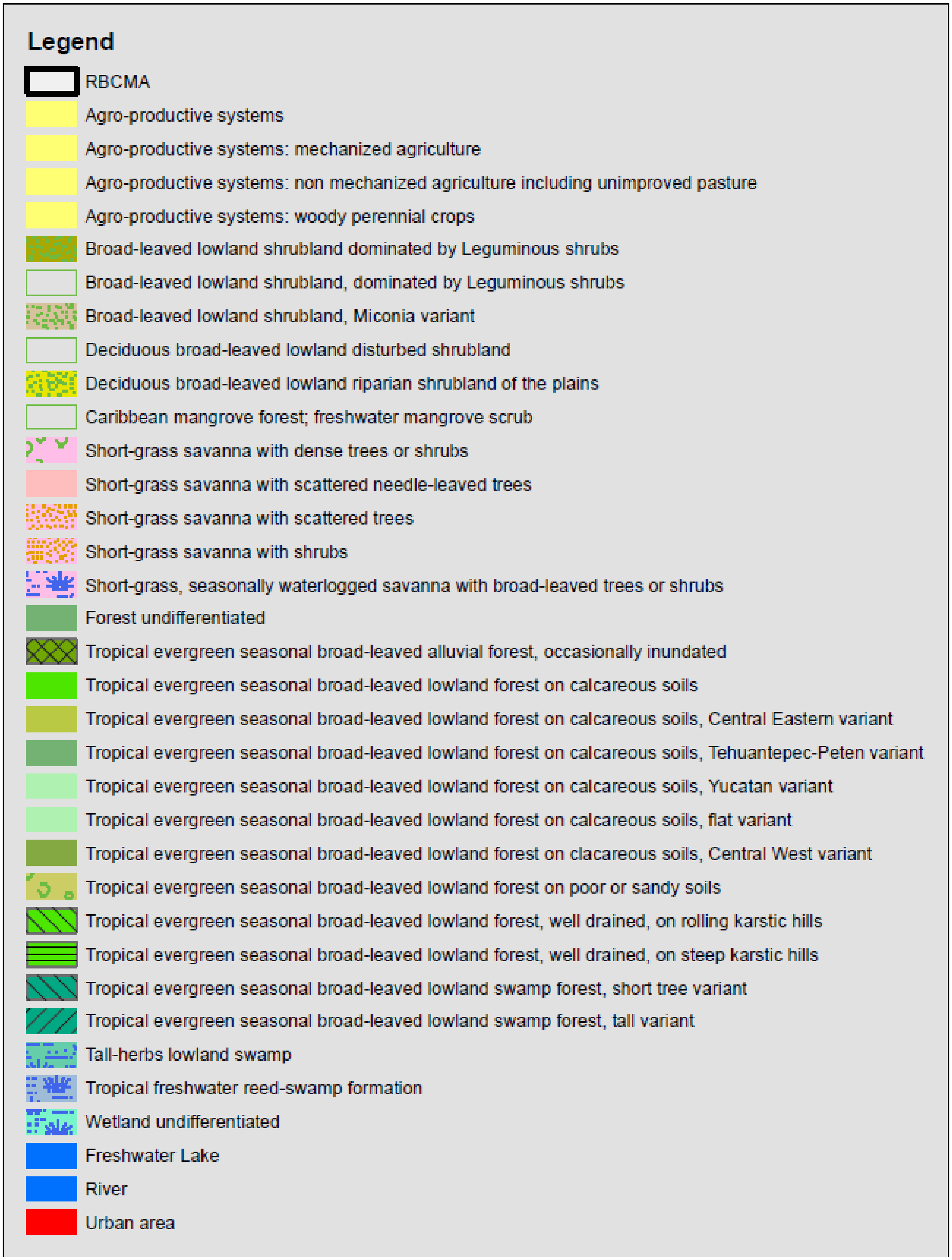


Figure 9. Ecosystems in the RBCMA and surrounding landscape.

Legend is shown on next page.


Legend
RBCMA
Agro-productive systems
Agro-productive systems: mechanized agriculture
Agro-productive systems: non mechanized agriculture including unimproved pasture
Agro-productive systems: woody perennial crops
Broad-leaved lowland shrubland dominated by Leguminous shrubs
Broad-leaved lowland shrubland, dominated by Leguminous shrubs
Broad-leaved lowland shrubland, Miconia variant
Deciduous broad-leaved lowland disturbed shrubland
Deciduous broad-leaved lowland riparian shrubland of the plains
Caribbean mangrove forest; freshwater mangrove scrub
Short-grass savanna with dense trees or shrubs
Short-grass savanna with scattered needle-leaved trees
Short-grass savanna with scattered trees
Short-grass savanna with shrubs
Short-grass, seasonally waterlogged savanna with broad-leaved trees or shrubs
Forest undifferentiated
Tropical evergreen seasonal broad-leaved alluvial forest, occasionally inundated
Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils
Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Central Eastern variant
Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Tehuantepec-Peten variant
Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, Yucatan variant
Tropical evergreen seasonal broad-leaved lowland forest on calcareous soils, flat variant
Tropical evergreen seasonal broad-leaved lowland forest on clacareous soils, Central West variant
Tropical evergreen seasonal broad-leaved lowland forest on poor or sandy soils
Tropical evergreen seasonal broad-leaved lowland forest, well drained, on rolling karstic hills
Tropical evergreen seasonal broad-leaved lowland forest, well drained, on steep karstic hills
Tropical evergreen seasonal broad-leaved lowland swamp forest, short tree variant
Tropical evergreen seasonal broad-leaved lowland swamp forest, tall variant
Tall-herbs lowland swamp
Tropical freshwater reed-swamp formation
Wetland undifferentiated
Freshwater Lake
River
Urban area

A healthy population of Jaguars and Pumas roam the RBCMA according to wildlife studies carried out in recent years. This suggests the population of natural prey species such as Gibnut, Peccary and Deer are otherwise vibrant, in addition to the possibility that the adult large prey population consists of mostly healthy individuals. The obvious abundance of deer along the main roads of the RBCMA is testament to healthy herbivore populations. To some extent, deer are becoming somewhat of a nuisance around the field stations, where they feed on shoots of ornamental trees and other planted vegetation.

Other principal fauna species include Ocellated Turkey, Crested Guan, Howler Monkey, Spider Monkey, Tapir and Red Brocket Deer, any of which can be encountered on a typical journey through the forest. Small bird species, including migratory species, are also plentiful on the property, suggesting a vibrant population of seed dispersers. For a fuller description of the principal fauna, refer to the first management plan.

2.5. Detailed Forest Inventory

All forest management plans that are aimed at the sustainable management of timber must be informed by an enumeration of the timber resource. This enumeration aims to provide a sample of the whole population of different species of interest, similar to a human population census. In a census, the size of different components of the population (young, middle-aged, old) is quantified, along with birth and mortality rates. This data is required for estimating the productivity of the population, and in the case of trees, this corresponds to the off-take or yield. However, unlike a human population, it is neither worthwhile nor feasible to census all the trees in a forest, rather a sample is taken to estimate the size or stocking of the whole population and the size or stocking of its different components with a focus on commercial timber species. This sample is known as a forest inventory and, in Belize, usually consists of surveying between 0.4 and 1% of the area of the forest.

A forest inventory provides a snapshot of the population structure and the spatial distribution of trees across the management area, and at coarse scale. The resulting information is used for determining which species can be included in logging operations based on population structure and can be used to guide the selection of cutting compartments from year to year. For example, the patchy distribution of specie is such that one may be locally abundant within an annual cutting block, but at the landscape level being relatively rare. The exploitation of this species would not be in line with sustainability principles, unless strict safeguards are put in place to protect the highly heterogeneous population. The inventory is also a general assessment of the forest resource across the extent of area under management and aids in economic planning as well as in the development of silvicultural prescriptions. The analytical outputs of the inventory provides an overall picture that reflects the stocking in the average cutting compartment.

Recognizing that inherent spatial variation across the landscape will undoubtedly lead to annual deviation from the average situation, PfB had formerly discounted the usefulness of a forest inventory and instead focused on 100% census of timber trees within annual cutting compartments as the primary source of information on the forest resource. This approach did not allow for foresight with respect to the timber resource in future cutting blocks and in so doing constrained economic planning and silvicultural development. It wasn't until 2011 that the first forest inventory was performed in 5 annual cutting compartments as part of the development of the second 5-year sustainable forest management plan for the RBCMA 2011 to 2015. With this new endeavor, the value of the forest inventory for operational planning has now been solidified in the management approach of PfB. However, the forest inventory was still not performed at the level of the entire management unit as is the norm, and instead the assessment of an area equal to 5 annual cutting blocks allowed little room to maneuver through the years depending on the population size versus demand of different species. Each of those 5 annual cutting blocks had to be cut within the 5 years covered by the management plan and so operational planning was still constrained by the lack of a longer term view of the resource.

Under the third 5-year management plan from 2016-2021, a larger area equal to 10 annual cutting compartments was inventoried to make up this shortfall in planning. Although still not a property wide assessment of the timber resource, this approach affords longer-term view of the timber resource across the land and therefore allows for more flexibility in planning to meet timber demand while ensuring the protection of species which may be vulnerable at the landscape level but abundant in individual cutting blocks.

In this fourth 5-year management plan from 2022-2026, an additional area equivalent to 5 annual cutting compartments (5,630 hectares) was inventoried and added to the pool of compartments that are eligible for logging under this new 5-year management plan (currently ten compartments totaling 12,131 hectares). Thus, planning flexibility has been preserved.

Objective of the Timber Inventory

A general management unit level inventory provides an estimation of the situation as it pertains to timber stocking in the average annual cutting compartment and forms the basis for management prescriptions. PfB carried out a general inventory of 5,630 hectares of the timber management zone during May to June 2021 to support its 2022 to 2026 management plan.

The objective of the new inventory was to provide current timber volume estimates for operational valuation and forest management planning.

Materials and Methods

The inventory crews (numbering 2 or 3) were comprised of between four to five individuals: one leader/data logger, one DBH measurer, one height measurer, and two cutlass assistants. The team leader was also responsible for identifying trees where possible, but all members assisted when possible. Plot demarcation was headed by the team leader but all individuals participated. The inventory was designed as a full forest cruise, focusing on trees of all species ≥25 cm DBH inside a 0.25 hectare rectangular plot, since this is the size class which forms the numerical basis for the calculation of the sustainable yield. The quantification of the population of small trees of all species 10 to 24.9 cm DBH was performed at the level of a 0.025 subplot nested within the larger 0.25 hectare plot, except for small Mahogany trees which were assessed at the full 0.25 hectare level. The sampling of different size components of the tree population is aimed at a full assessment of stocking across all size classes, and with additional focus being placed on important timber species. The presence of logged stumps and old truck-o-passes were also recorded in each subplot. The job control document describing the inventory method and materials is included in ANNEX I. JOB CONTROL DOCUMENT.

Species

All species which occur as trees ≥25 cm DBH were included in the inventory at the level of an entire plot. The estimation of per hectare stocking is done on an individual species basis. Some species are, however, rare in the forest and are often represented by a single or few stems per km^2. The generation of property wide volume estimates and calculation of associated statistics on such species requires that they be grouped along with similar species in order to achieve a large enough sample. Species were grouped according to the national standard for timber species grouping, namely: prime, elite and select. This classification system is based on six properties: wood quality, workability, durability, growth rate, log form and large tree abundance. Fig. 10 shows the grouping in relation to the six properties while Table 1 lists the species by groups.

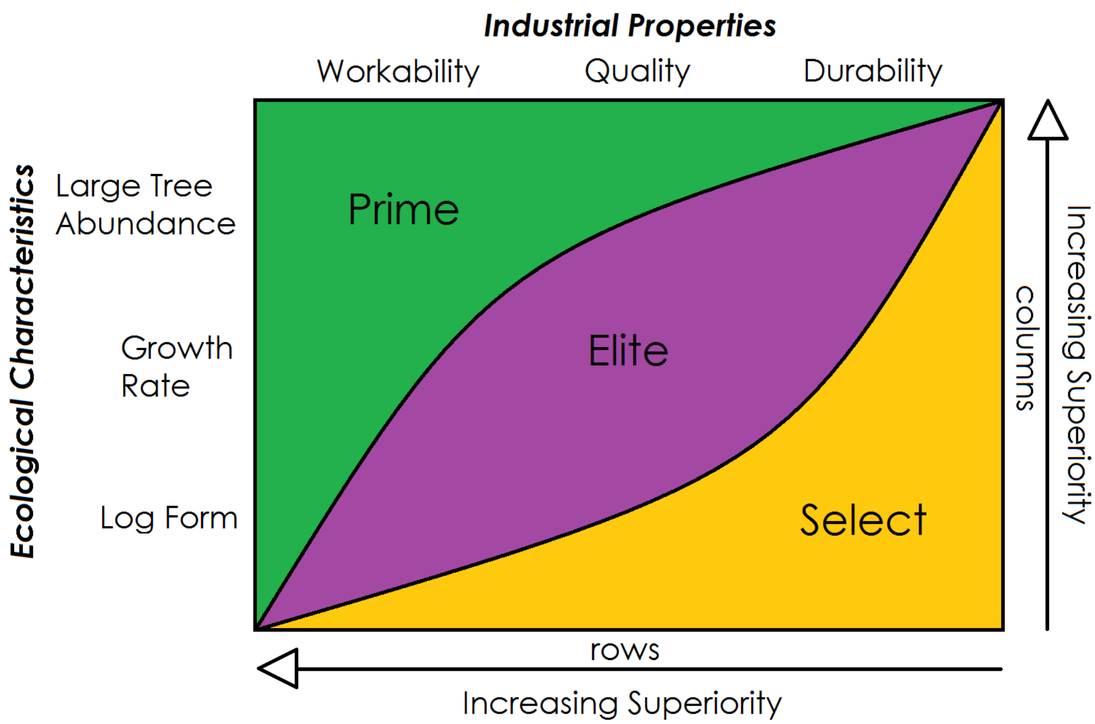


Figure 10. Species grouping rubric.
Arrows represent direction of increasing superiority for a given attribute in a row or column.

Table 1. List of species in the different groups.

Prime	Elite	Select
Mahogany	Barbajolote	Bullet Tree
Cedar	Bastard Rosewood	Chicle Macho
	Beefwood	Hormiga
	Billywebb	Nargusta
	Black Cabbage Bark	Red Mylady
	Black Poisonwood	Redwood
	Granadillo	San Juan Macho
	Hobillo	Santa Maria
	Mayflower	Sapodilla
	Salmwood	Sillion (Red)
		Timbersweet
		Yemeri

Sampling Frame and Sampling Intensity

The basic sampling design involved the collection of tree data from 0.25 hectare rectangular plots (20 m x 125 m) distributed systematically across the area to be sampled using a 500 m grid, which constitutes a simple random sample. Under a simple random sample design all potential 0.25 hectare units have equal probability of being selected for inclusion in the sample. This type of sampling is suitable for use in a heterogeneous population, and at the same time, with the aid of geo-statistical techniques such as probabilistic and deterministic interpolation, it allows for mapping of any patterns associated with variations in population density across the area sampled. To allow for good spatial spread, the minimum distance allowed between plots was 375 metres east to west and 480 metres north to south.

The area sampled included only potentially productive forests within the area planned for this 5-year management plan, and amounted to around 5,630 hectares. However, the area is broken up into 2 contiguous blocks of forest (see Fig. 11). Dividing this area by the 500 m x 500 m sampling grid size gives 217 potential sampling units in the sampling frame. However, not all units warranted the placement of a sample plot because of edge effects at the periphery of the management area. Therefore, 70% of the sampling units were subsequently selected for the placement of a sample plot, which resulted in 150 plots. One plot was discarded in the field due to unsuitable vegetation type, thus a total of 149 plots were eventually enumerated. The overall sampling intensity achieved based on a total of 149 quarter hectare sample plots was therefore 0.68%. This sampling intensity has been shown from experience with previous inventories in the area to be suitable for the estimation of mean stocking where the error is within 10 % of the mean. Fig. 11 shows the location of the sampling plots within the 5-year management area.

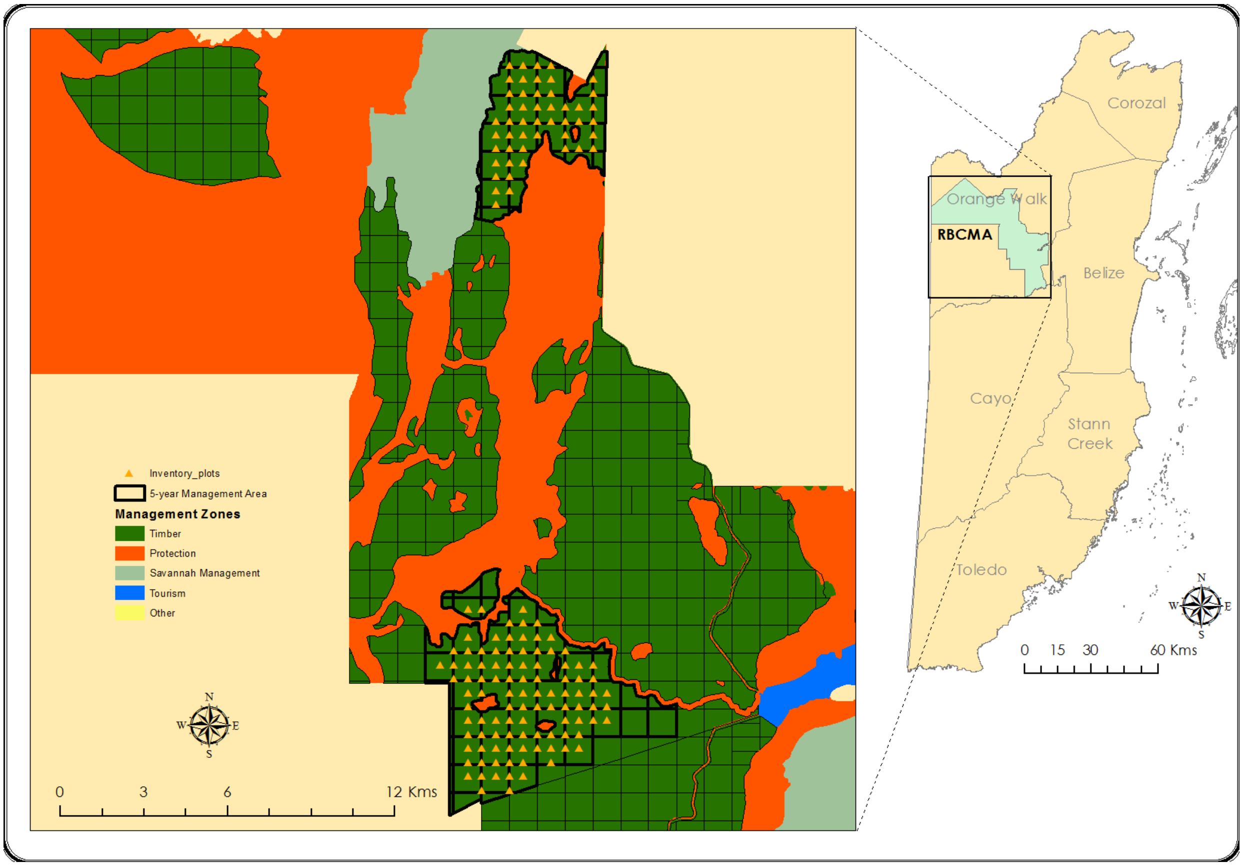


Figure 11. Systematically distributed sampling points used in the forest inventory.

Plot Design and Layout

Plots are designed as rectangles also known as belt transects each 20 m wide and 125 m long, oriented east to west along the longer axis. This design follows the standard that has been accepted nationally for inventories in broadleaf forests. Plots were located by means of UTM coordinates which marked the centre of the eastern end of the plot (black dot in Fig. 12). A thick stake standing 1.3 m was placed at this point to mark the beginning of the plot. From this point a cut line was cleared due west for 125 m, and stakes were placed every 25 m to mark the subplots. For ease of measuring and recording, this plot was broken down into 10 subplots each 25 x 10 metres (0.025 ha), in which all trees ≥25 cm DBH were sampled (Fig. 12). Trees were then enumerated within each individual subplot starting at 1 and then moving progressively east to west covering subplots 1 through 5 and then back to the start from subplot 6 to 10.

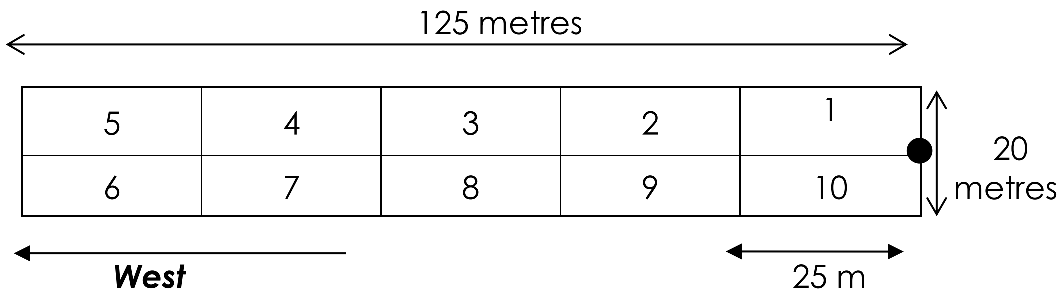


Figure 12. The plot/subplot layout used in the inventory.

The black dot indicates the starting point. All Mahogany trees ≥10 cm DBH are sampled in the entire plot. For all other species, including palms, trees ≥10 cm DBH are sampled in subplot 1 only. In all other subplots, trees ≥25 cm DBH of all other species, including cohune and other palms, are sampled. All logged stumps of any species and all old truck-o-passes are recorded in the entire plot.

Tree Measurements

All trees ≥25 cm DBH were tallied in each plot. The attributes recorded for all trees of all species included species and DBH at 1.3 m to the nearest 0.1 cm. For trees of timber value, the attributes recorded include merchantable height to the nearest 1 m, straightness grade, crown position, crown form, liana presence, hurricane damage and visible defects. DBH was measured with a standard metric diameter tape. Height was measured using a Bosch laser rangefinder with integrated viewfinder. Straightness grade consisted of five levels: 1 = straight bole with no defects; 2 = curved bole with no other defects; 3 = straight bole with defect covering >25%; 4 = curved bole with defect covering >25 %; and 5 = forked bole within the first 5 m. Hurricane damage and visible defects were assessed according to the numerical scale in Table 2.

Table 2. Hurricane damage and visible defects classification.

Damage Class	Short Description	Long Description
1	No damage	No visible damage from either the hurricane or other source.
2	Leaning	Trees leaning in excess of 30 degrees from vertical.
3	Damaged crown	Trees missing ≥25 % of the live crown.
4	Broken crown	Trees missing ≥100 % of the live crown but stem intact.
5	Broken stem	Trees with broken main stems.
6	Standing dead	Trees still standing intact but are now dead.
7	Downed alive	Trees that have fallen but are still alive and are expected to remain that way for the foreseeable future.
8	Other damage	Trees with other damages not attributable to the hurricane.

Further details about the measurement procedure are contained within the job control document governing the 2021 inventory found in ANNEX I.

Data processing

Error checking based on the audits of a random sample of data sheets provided a means to correct common mistakes in data recording. Once observed errors were corrected, the data were entered into Excel spreadsheets and further corrections were made to the data to reduce transcriptions errors as much as possible. Species names were standardized against the national list from the permanent sample plot network. The data were then transposed into an Access database for further filtering and processing.

Basal area for all stems was calculated in the database using the formula:

$$BA\,(m^2) = \pi \times \left[\frac{\left(\frac{DBH}{100}\right)}{2}\right]^2$$

Standing round volume of stems ≥ 25 cm DBH was determined as the over bark volume of the stem from the ground to the first major branch, inclusive of the stump, and was calculated using a local volume equation developed from over 700 tree and log measurements taken by the Forest Planning and Management Project in the 1990s (Cho, 2013):

$$\text{Vol}\ (m^3)=\exp(-9.480+0.975\ln DBH^2H)$$

Where merchantable height measurements were not available for some stems, the version of the volume model which excluded height was used:

$$\text{Vol}\ (m^3) = \exp(-8.367 + 2.261\ln \mathit{DBH})$$

Standing stem volume estimates were then corrected for straightness and visible defects to produce standing merchantable volume. Each straightness grade was given an appropriate level of deduction: 1 = 0 %; 2 = -25 %; 3 = -25 %; 4 = -50%; 5 = -75%. The deductions were then applied to the stem volume produced by the volume equation. Deductions were not made for the stump or for log bucking into standard lengths. It is thus expected that the resulting final standing merchantable stem volume may slightly overestimate true commercial volume as it would be once the log reaches the log yard. However, further deductions for conversion efficiency may neutralize any overestimation.

Round standing stem volume for stems ≥ 45 cm DBH was converted to sawn volume in board feet using a 50 % conversion ratio from round to sawn. Based on this conversion ratio each cubic metre of round wood was expected to yield 212 boardfeet of rough sawn lumber. All dead and unsalvageable trees (damage class ≥ 5) were excluded from the analysis, as these trees are no longer considered to be part of the growing stock.

A forest inventory aims to produce an estimate of the quantity of timber in a given forest at a specified point in time. Plots are installed to give a representative sample of the total timber standing in the forest without having to count every tree. The precision of the sample varies with plot size, sample intensity, and variations in timber volumes across the forest. The inventory was designed to provide estimates of mean volume per hectare of trees ≥ 25 cm DBH with statistical precision, represented by the 95 % confidence interval of the mean, of around ±10 % or less. Statistics were calculated based on volume of all species then separately for the different species groups. All statistical analyses were performed in R version 2.13.1.

Results

Summary Statistics and Precision of the Sample

In statistics, sampling error is the error in the estimate caused by observing a sample instead of the whole population. The difference between the statistic and the actual population parameter is as a result of the sampling error. In the forest inventory, 0.7 % of the 5,630 ha of forest was sampled as opposed to a 100% census of the entire area, therefore the estimates will contain some level of error. The expected sampling error of the 2021 inventory, as it pertains to total volume per hectare, was approximately 7.92 % based on probabilistic modeling of the sample.

More important than the sampling error, however, is the precision associated with the estimates of volume per hectare obtained from the sample. Precision is represented by the proportion of the mean volume per hectare taken up by the confidence interval. The confidence interval is the level of uncertainty around a sample estimate, and represents the lower and upper limit (-/+) of the range of values containing the sample estimate at a specified probability (in this case 95%).

Table 3 presents standard error of sample estimates of mean volume per hectare of trees of all species ≥ 25 cm DBH and trees of different species groups ≥ 25 cm

DBH. In terms of total per hectare volume of all species combined ≥ 10 cm, the inventory provided a level of statistical precision of 7.89%, which exceeds the expected value. Simply put, this means that if the forest were inventoried 100 times again in the condition it is now using the same method, 95 times out of 100 the mean volume per hectare would be within 7.89% of each other.

As expected, precision degrades when the sample is broken down into species groups. For example, the precision of the sample for prime species was 20. 8 % of the mean. This means that the plot to plot variation in volume was higher than for all species, which is indicative of the patchy distribution of prime species across the forest. The same can be said for the other species groups. Never-the-less, overall, the sample precision for the species group were within the typical 20% range that is generally acceptable for forest inventories. It appears that the inventory captured a representative sample of each species group and allowed for an otherwise acceptable estimate of the mean volume per hectare.

Table 3. Precision of the sample based on the mean merchantable volume (m^3) per hectare of trees ≥25 cm DBH of all species and species groups: prime, elite and select.

Timber species as percent of total volume is also shown.

Statistic	All Species	Prime	Elite	Select	Timber Species % of Total Vol
n	149	149	149	149	
∑ in sample	12,578.1	963.3	1,682.4	3,867.3	
CV	51.6	131.9	95.0	58.8	
Mean (m^3 ha^{-1})	84.4	6.5	11.3	25.9	
StDev	43.6	8.5	10.7	15.2	
Std Error (m^3 ha^{-1})	3.6	0.69	0.88	1.2	
95% CI (m^3 ha^{-1})	7.0	1.3	1.7	2.4	
CI as % of mean	8.4	20.8	15.2	9.1	51.7 %

Another important finding from the inventory is the timber potential of the RBCMA. The last column in Table 3 shows that approximately 51% of the growing stock ≥25 cm DBH is comprised of marketable timber species per the timber species grouping in Table 1. This is an improvement over the previous area inventoried in the last management plan which yielded a timber potential of 38%. However, this is still much lower than neighbouring Gallon Jug which has a timber potential of around 84% of growing stock. This statistic is useful in forest valuation; for example, if we assume an across species stumpage value of $0.20 BZD per boardfeet, a total ≥25 cm DBH growing stock of 84.4 m^3 per ha with 51.7 % marketability, and a total forest area of 5,630 ha, the total gross value of the growing stock in the current management area in terms of standing timber would amount to around $10 million BZD or about $1,850 BZD per hectare.

The Stand Table

A stand table shows the number of trees per hectare in each diameter class for all species based on their abundance in the sample. It provides a numerical distribution of stems by diameter classes for each species that can be used in stand projection. The overall significance of the stand table is that it shows the structure of the stand with regards to the relative proportion of trees of different sizes and species.

A drawback to the stand table is that it may produce misleading trends for size classes that were underrepresented in the sample. For example, if there was one large tree ≥90 cm DBH in a forest 10,000 ha in size, and this tree was detected in a sample of 100 1-ha plots undertaken in the forest, the average distribution of such trees in the sample would be 0.01 trees per ha. Extrapolated to the whole forest, there would be 100 such trees, which is clearly erroneous. In reality such high densities are not observed in the forest and a correction is necessary to reflect a more realistic situation. The problem lies in the fact that forest inventory sample estimates implicitly assume that the trees sampled are evenly distributed across the forest. This assumption is often violated in reality, however, since tropical trees show clumped distribution, and there may be areas of the forest completely devoid of trees.

There are two ways to account for this inaccuracy, the first being to take sample spatial distribution explicitly into account and partition the forest into blocks which may have different estimates based on their location with respect to the sample. However, this may not be desirable when the situation in the average logging block needs to be known, such as when projecting the average sustainable yield of the forest. The second corrective measure involves *posteriori* normalization of the sample tally according to abundance (i.e. the percentage of sample plots containing trees in the given diameter class). Given the previous example above, the single stem ≥90 cm DBH had to have been detected in one plot, and therefore would have a detectability of 0.01. The sample estimate of 0.01 trees per ha would be normalized by 0.01 to 0.0001 trees per ha. The extrapolated estimate to the whole forest would then be 1 tree. This corrective measure was applied to the sample data in the stand table to produce realistic estimates of tree stocking.

The resulting stand table (Table 4) is useful for drawing conclusions regarding the structure of the forest in the management area in terms of timber potential. A simple interpretation that can be made from the stand table is that Red Mylady is the most abundant timber species with over 14,000 trees ≥10 cm DBH in the average 1000 ha compartment, while Barbajolote is the rarest timber species with only 8 trees in the average 1000 ha block. This exactly matches the findings from the previous inventory. Another interpretation that can be made which requires a greater appreciation of forest dynamics is that species such as Chicle Macho, Wild Grape, Red Mylady, and Sapodilla are shade tolerant and recruit heavily under an intact canopy because the highest abundance per diameter class is in the sapling size class. On the other hand, those species which are less abundant in smaller size classes relative to larger size classes are those species which are shade-intolerant or semi-shade-intolerant and which likely recruit periodically perhaps when the canopy is more open such as after major hurricanes, for example, Mahogany. It follows then that a simple classification of species into shade-tolerant and -intolerant can be made using the stand table.

With regards to Mahogany, the situation is different compared to the previous inventory in that there is lesser trees in the pre-commercial classes this time around but almost twice as many trees in the commercial size classes. This means the average cutting compartment will yield a much better harvest than under the previous cycle. However, as with the previous inventory, and as is the case with many other inventories across Belize, it appears that the numbers of Mahogany saplings are insufficient to replace the trees in the larger size classes. This is an indication that it cannot be assumed during stand projection that this species auto-replenishes through seeding in the interim period between two cutting cycles. Rather, a better assumption is that this species will be able to regenerate sufficiently following periodic disturbances in the future if sufficient seed trees survive the disturbance. Given the stochastic nature of disturbances, stand projection of this species must then assume zero seedling recruitment between cutting cycles, to be on the conservative side, so that the off-take is moderated downward. It is also known that the species level mortality for Mahogany is rather low at 0.7%, giving it a survival advantage in the interim period between disturbances. These findings have important implications for calculating the sustainable yield, as it suggests that forest management should aim to sustain a healthy population of large seed bearing trees at the end of a cutting cycle, and furthermore that there will be a point when the population cannot sustain further harvests in the absence of regenerative disturbance.

Table 4. Stand table for the management area showing number of stems in the average 1000 ha block.

Species	Timber Group	Number of stems per the average annual cutting compartment (1000 hectares)																	Yearly	% of All	5-year
		10 to 14.9	15 to 19.9	20 to 24.9	25 to 29.9	30 to 34.9	35 to 39.9	40 to 44.9	45 to 49.9	50 to 54.9	55 to 59.9	60 to 64.9	65 to 69.9	70 to 74.9	75 to 79.9	80 to 84.9	85 to 89.9	>=90	Total	Species	Total
Barbajolote	Elite	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	8	0.0%	43
Billywebb	Elite	0	0	189	198	264	220	242	132	0	8	8	24	16	0	0	0	0	1,300	1.3%	7,047
Bitterwood	Select	0	757	189	132	53	53	26	159	53	35	0	0	0	35	0	0	0	1,493	1.5%	8,096
Bullet Tree	Select	568	1513	1324	1748	1271	1245	1086	874	424	388	247	159	283	106	35	71	13	11,355	11.6%	61,567
Cabbage Bark (Black)	Elite	189	63	63	220	418	330	308	198	48	32	8	8	8	0	0	0	0	1,891	1.9%	10,253
Cedar	Prime	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0.0%	63
Chicle Macho	Select	378	189	946	185	185	132	79	106	35	0	18	18	18	0	0	0	0	2,290	2.3%	12,418
Cortez	Select	378	0	0	106	26	26	53	0	0	0	0	0	0	0	0	18	0	608	0.6%	3,296
Granadillo	Elite	63	0	0	44	0	22	44	0	0	0	0	0	0	0	0	0	0	173	0.2%	938
Grape (Wild)	Select	3784	3027	2649	1854	556	132	26	26	0	0	0	0	0	0	0	0	0	12,055	12.3%	65,360
Hesmo	Select	0	189	0	424	530	477	530	344	88	71	35	35	0	0	35	0	0	2,758	2.8%	14,955
Hobillo	Elite	0	126	0	264	198	66	110	22	8	8	0	0	0	0	0	0	0	801	0.8%	4,345
Kaway (Mountain)	Select	0	0	189	26	0	0	0	26	0	0	0	0	0	0	0	0	0	242	0.2%	1,313
Mahogany	Prime	279	294	248	398	234	234	199	293	178	188	129	79	129	50	59	30	10	3,032	3.1%	16,440
Mayflower	Select	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	0	0	26	0.0%	144
Mylady (Red)	Select	6243	1703	1703	1907	1457	795	371	238	0	0	0	0	0	0	0	0	0	14,416	14.7%	78,161
Nargusta	Select	946	1135	757	1165	980	715	874	583	212	124	124	106	53	35	0	18	5	7,831	8.0%	42,458
Poisonwood (Black)	Elite	946	757	946	2132	1758	1143	506	110	24	8	8	0	0	0	0	0	0	8,337	8.5%	45,205
Prickly Yellow	Select	0	0	0	0	26	26	0	0	0	0	0	0	0	0	0	0	0	53	0.1%	287
Redwood	Select	1324	757	1324	503	185	26	0	0	0	0	0	0	0	0	0	0	0	4,120	4.2%	22,341
Rosewood (Bastard)	Elite	126	0	63	352	352	198	308	242	48	40	71	32	16	24	8	8	0	1,886	1.9%	10,224
Santa Maria	Select	1324	1135	378	1059	900	662	609	159	177	18	35	71	53	18	0	0	0	6,599	6.7%	35,778
Sapodilla	Select	2459	2270	1513	1563	795	662	397	212	106	35	18	35	0	0	0	0	0	10,066	10.2%	54,576
Sillion (Red)	Select	946	1703	568	795	636	344	106	26	53	18	0	35	0	0	0	18	0	5,247	5.3%	28,447
Timbersweet	Select	0	0	378	318	185	26	53	0	18	0	0	0	0	0	0	0	0	979	1.0%	5,306
Tzalam	Select	0	0	0	238	212	79	26	26	18	0	18	0	0	0	18	0	2	637	0.6%	3,455
Zericote	Elite	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0.0%	119
Total		19,954	15,618	13,428	15,665	11,222	7,642	5,953	3,777	1,488	980	718	602	575	268	156	161	30	**98,236**	**100%**	**532,518**
% of All Trees		20.3%	15.9%	13.7%	15.9%	11.4%	7.8%	6.1%	3.8%	1.5%	1.0%	0.7%	0.6%	0.6%	0.3%	0.2%	0.2%	0.0%	**100.0%**		
Estate Total		108,189	84,681	72,804	84,938	60,847	41,435	32,279	20,480	8,069	5,313	3,895	3,263	3,115	1,451	844	874	160	**532,637**		

The Stock Table

The stock table is similar to the stand table in terms of structure and interpretation, but instead of trees, the stock table shows the volume per hectare in each diameter class. It provides a numerical distribution of volume by diameter classes for each species that can be used to assess the timber value of the forest.

As with the stand table, the data per diameter class must be normalized to represent close to the real situation on the ground when it comes to the less abundant diameter sizes. A similar normalization procedure was performed on the volume per hectare estimates in the stock table.

The overall significance of the stock table is that it shows what proportion of the growing stock occurs in the different size classes: small pre-commercial trees versus large commercial trees. A simple interpretation that can be made from the stock table of the current RBCMA management area (Table 5) is that the size class making the largest individual contribution to the growing stock is the 30 to 35 cm class. This is similar to the previous 5-year area. However, in contrast, to the previous area, Bullet Tree (not Red Mylady) contributes the most to the growing stock out of all species while Zericote contributes the least.

An important note about the stock table is that it represents growing stock, which is not the same as commercial volume. The volumes shown in the stock table are round volume over bark and would have to be converted using a factor of 176 bdft to a cubic metre. The figures suggest that Mahogany is the seventh most voluminous species in the management area. In terms of commercial stocking of trees between 50 and 90 cm DBH, there is approximately 1,455 m^3 of potential crop of Mahogany in the average 1,000 ha of forest within the current management area. This translates to an estimated commercial volume output of 257,203 bdft from the average cutting block.

Table 5. Stock table for the management area showing round volume over bark (m^3) in the average 1000 ha.

Species	Timber Group	Volume (m^3) per the average annual cutting comparatment (1,000 hectares)																	Total	% of All Species	Estate Total
		10 to 14.9	15 to 19.9	20 to 24.9	25 to 29.9	30 to 34.9	35 to 39.9	40 to 44.9	45 to 49.9	50 to 54.9	55 to 59.9	60 to 64.9	65 to 69.9	70 to 74.9	75 to 79.9	80 to 84.9	85 to 89.9	>=90			
Barbajolote	Elite	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	17	0.0%	94
Billywebb	Elite	0	0	17	41	94	92	113	96	0	11	10	34	34	0	0	0	0	543	1.4%	2,942
Bitterwood	Select	0	97	43	50	34	39	33	222	95	78	0	0	0	152	0	0	0	844	2.2%	4,575
Bullet Tree	Select	15	115	208	424	433	592	637	642	391	414	370	242	484	243	84	185	33	5,512	14.6%	29,887
Cabbage Bark (Black)	Elite	8	5	8	49	154	172	197	159	58	45	9	11	9	0	0	0	0	883	2.3%	4,788
Cedar	Prime	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0.0%	27
Chicle Macho	Select	13	19	192	48	66	54	52	103	36	0	27	29	46	0	0	0	0	685	1.8%	3,714
Cortez	Select	24	0	0	47	17	23	53	0	0	0	0	0	0	0	0	104	0	269	0.7%	1,459
Granadillo	Elite	5	0	0	19	0	19	49	0	0	0	0	0	0	0	0	0	0	91	0.2%	494
Grape (Wild)	Select	274	405	682	727	327	109	27	40	0	0	0	0	0	0	0	0	0	2,590	6.9%	14,042
Hesmo	Select	0	15	0	89	169	192	261	262	62	91	42	51	0	0	65	0	0	1,298	3.4%	7,040
Hobillo	Elite	0	6	0	80	86	33	88	19	8	8	0	0	0	0	0	0	0	328	0.9%	1,780
Kaway (Mountain)	Select	0	0	62	10	0	0	0	42	0	0	0	0	0	0	0	0	0	114	0.3%	616
Mahogany	Prime	14	29	43	100	95	127	143	250	192	226	229	162	264	113	172	96	41	2,296	6.1%	12,452
Mayflower	Select	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	23	0.1%	127
Mylady (Red)	Select	333	189	380	633	723	538	320	230	0	0	0	0	0	0	0	0	0	3,347	8.9%	18,145
Nargusta	Select	34	83	113	260	309	332	533	461	207	137	114	165	93	52	0	19	11	2,923	7.8%	15,851
Poisonwood (Black)	Elite	69	116	253	870	1064	949	546	147	41	17	20	0	0	0	0	0	0	4,094	10.9%	22,195
Prickly Yellow	Select	0	0	0	0	16	21	0	0	0	0	0	0	0	0	0	0	0	37	0.1%	199
Redwood	Select	87	103	325	211	112	20	0	0	0	0	0	0	0	0	0	0	0	858	2.3%	4,651
Rosewood (Bastard)	Elite	9	0	19	152	212	161	342	343	85	89	188	97	60	105	39	46	0	1,948	5.2%	10,560
Santa Maria	Select	66	108	59	274	322	373	364	155	171	27	61	167	95	46	0	0	0	2,289	6.1%	12,409
Sapodilla	Select	177	337	406	649	471	555	448	297	185	82	49	110	0	0	0	0	0	3,765	10.0%	20,416
Sillion (Red)	Select	77	237	131	323	385	281	119	39	93	37	0	117	0	0	0	97	0	1,938	5.1%	10,508
Timbersweet	Select	0	0	107	132	105	24	56	0	32	0	0	0	0	0	0	0	0	456	1.2%	2,474
Tzalam	Select	0	0	0	96	131	70	27	37	32	0	45	0	0	0	86	0	10	534	1.4%	2,897
Zericote	Elite	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0.0%	40
Total		1,206	1,864	3,048	5,289	5,326	4,799	4,407	3,544	1,690	1,280	1,163	1,184	1,086	712	446	547	96	**37695**	**100%**	**204,381**
% of All Trees		3.2%	4.9%	8.1%	14.0%	14.1%	12.7%	11.7%	9.4%	4.5%	3.4%	3.1%	3.1%	2.9%	1.9%	1.2%	1.5%	0.3%	**100.0%**		
Estate Total		6,538	10,105	16,528	28,679	28,876	26,022	23,894	19,216	9,164	6,939	6,308	6,422	5,886	3,858	2,420	2,967	518	**204,341**		

Overall Demographic Trends

The most informative result of a forest inventory is the diameter distribution curve of the sample, which is essentially the data from the stand table, extracted for a given species or group of species and displayed graphically. The diameter distribution represents a demographic (age structure) snapshot of the forest, indicating the relative proportion of the different size classes within the population. The diameter distribution will inform the silvicultural prescriptions for the forest including whether harvesting is feasible.

The following series of graphs present the normalized mean diameter distribution curves for prime, elite and select species, respectively, calibrated to 10 km^2, which is the size of a typical annual cutting block. These diameter distribution curves show the estimated situation in the average 10 km^2 block. It is expected that there will be some 10 km^2 blocks that are above average and others that are below average, with respect to the stocking in each diameter class.

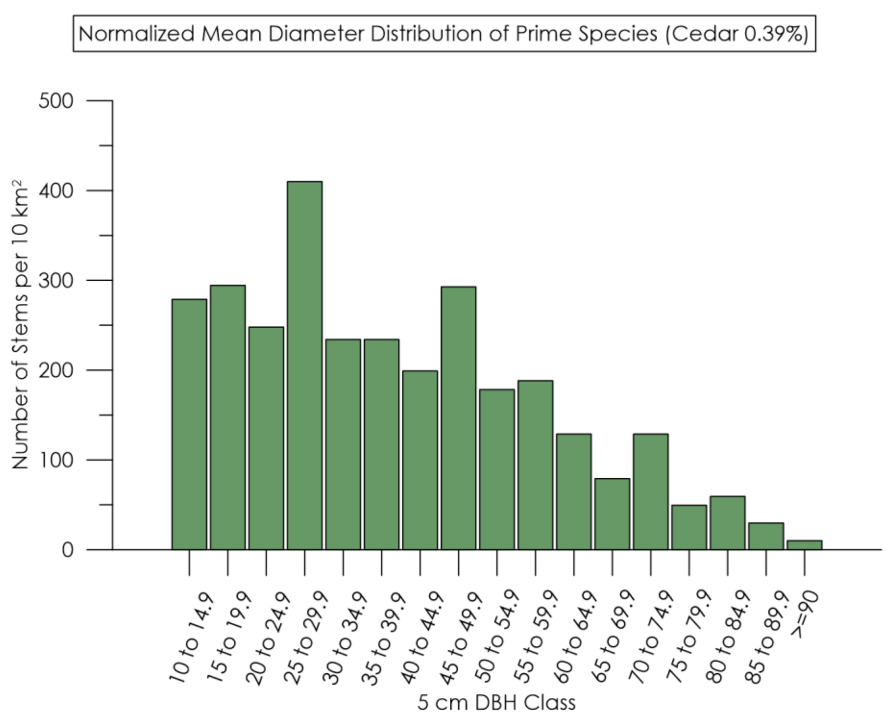


Figure 13. Diameter distribution curve for the population of Mahogany and Cedar in the average 10 km^2 compartment.

The diameter distribution in Fig. 13 presents an interesting scenario with respect to prime species. Unlike the previous 5-year management area, it does not show strong clues of past intensive logging in terms of scarcity of trees larger than 70 cm DBH, as was the case in the last inventory. Additionally, unlike the last inventory, the stocking in the smaller diameter classes is high. As discussed below, this could be due to a couple of reasons, with one having more likelihood than the other.

The last wave of logging in the area occurred sometime at the end of the 1980s, which is about 26 years ago. At that time, according to logging rules in effect, all trees above 60 cm DBH would have been cut out, save and except for those trees which were hollow or otherwise not commercially attractive. The logged over forest would have had very low subsequent stocking in the classes above 60 cm compared to the classes immediately below. In the 30 or so years since the last logging, trees in the 55 to 59.9 cm class would grow to 70 cm, according to the known growth curve of Mahogany. Above 70 cm dbh there should therefore be a stark drop in the number of stems. However, this is not the case. It is possible that this new 5-year area was logged further in the past than the 1980s, and therefore had a longer recovery time. It is equally possible, but perhaps more likely than the latter, that this area generally exhibits more favourable growing conditions for Mahogany, leading to faster growth following logging and higher recruitment.

Unlike the previous inventory, the observed diameter distribution does not conform to a normal distribution, and is more in alignment with the distribution expected for tropical tree species. The diameter distribution curve suggests that recruitment is enough to restock the lower diameter classes, implying that recruitment in this area did occur in sufficient numbers in the past.

The diameter distribution curve also indicates that there must be serious consideration given to forgoing the use of the 60 cm DBH minimum cutting diameter as the primary harvest control measure in favour of more ecologically functional models, such as those which seek to maintain forest structure above an industrially-sensible minimum cutting diameter. Meaning that the harvest must first be ecologically viable before it can be economically viable at a certain MCD. The MCD must allow for suitably marketable wood quality and, based on the population within each compartment, may vary from compartment to compartment. This is explained in latter sections in more detail.

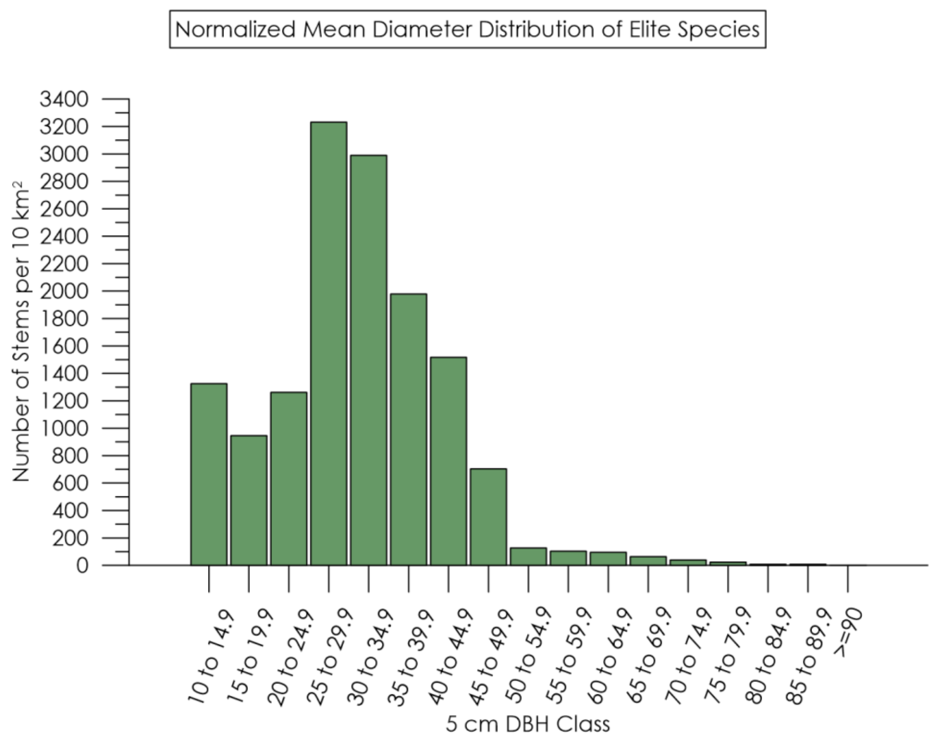


Figure 14. Diameter distribution curve for the population of all Elite species in the average 10 km² compartment.

The diameter distribution curve for Elite species shown in Fig. 14 above presents a contrasting picture to Prime species, in that it is reflective of an even-aged population, but with constant recruitment under an intact canopy, a contradiction. There is a large number of individuals in the smaller size classes, suggestive of constant recruitment, whereas the majority of individuals are in a few classes centred around 30 cm DBH. Never-the-less, this group of species is probably influence by a few populous species when in fact there is evidence of some recruitment limitation among most species in the group. The implications for management are similar to those of Prime species in that careful attention has to be placed on developing a silvicultural system that promotes the maintenance of large trees to facilitate seeding during times when conditions are amenable to recruitment. As with Prime species there is some evidence of past logging in terms of the scarcity of trees above 50 cm DBH.

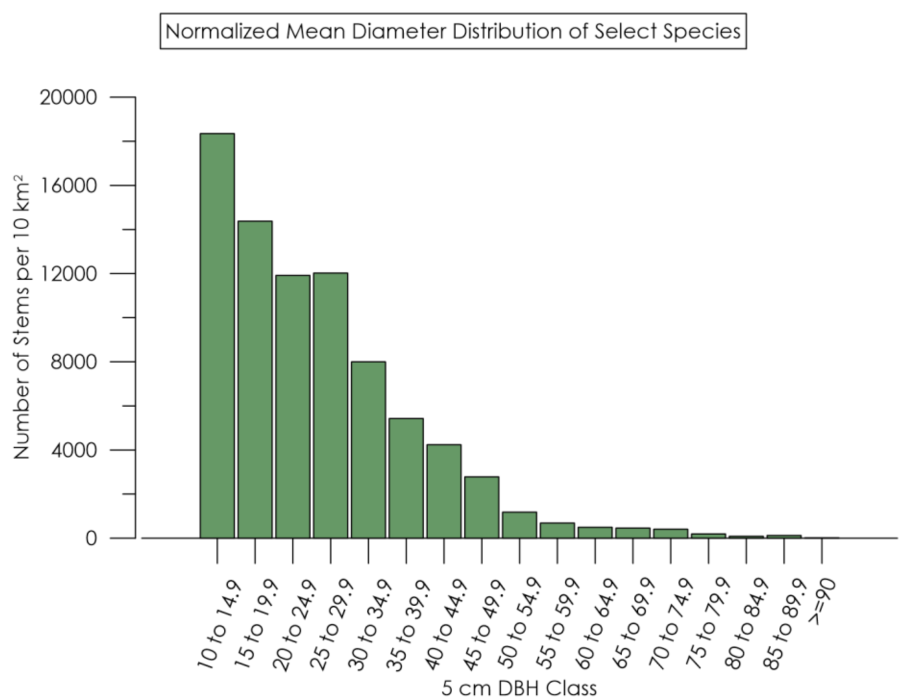


Figure 15. Diameter distribution curve for the population of all Select species in the average 10 km² compartment.

Fig. 15 above presents a completely different picture to the other species groups. It must be born in mind however that there are 8 times as many Select species as there are prime. As individual species, the above scenario may not be entirely applicable, but as a group it shows that Select species comprise those that regenerate continuously under an intact forest canopy, in the absence of catastrophic disturbance. This population structure is termed uneven-aged, where trees differ significantly in ages (sizes) such that the spread of ages (sizes) exceeds 25% of the age (size) at maturity. The spread of ages (sizes) in the Select species group spans the entire age (size) range of the stand. For the Select species group, an average cutting compartment of 1,000 ha can contain around 7,000 trees in the 25 to 29.9 cm class, the smallest class surveyed during the stock survey. As is expected, annual mortality decreases these trees as they grow through successive DBH classes. In addition, some trees grow slower than others and only a fraction may actually grow into successive classes over a given period of time, so mortality may not be the sole contributor to the inverse-j curve shape of the diameter distribution.

The most important finding from the diameter distribution curve of Select species is that, as with the other species, serious consideration must be given to adjusting the harvest to maintain forest structure in the upper size classes while providing an adequate economic return by taking trees from smaller DBH classes, since there is no immediate risk for poor recruitment. Equally important is the contrasting mode of regeneration compared to prime species. Since Select species appear to be mostly shade-tolerant as a group, and can recruit sufficiently under an intact canopy, the silvicultural implications of managing for hurricanes may not be relevant for this species group.

Spatial Distribution of Mahogany Saw Timber

In addition to the stocking in the average compartment, the inventory data can tell us where the stocking is located in terms of spatial variation across the landscape. This type of information aids in forest planning and can guide the efficient allocation of resources where profits are expected to be the highest during the early years of the operation when costs are also expected to be the highest.

Figure 16 below shows the spatial distribution of the saw timber age class for Mahogany (50 to 89.9 cm) in the current management area.

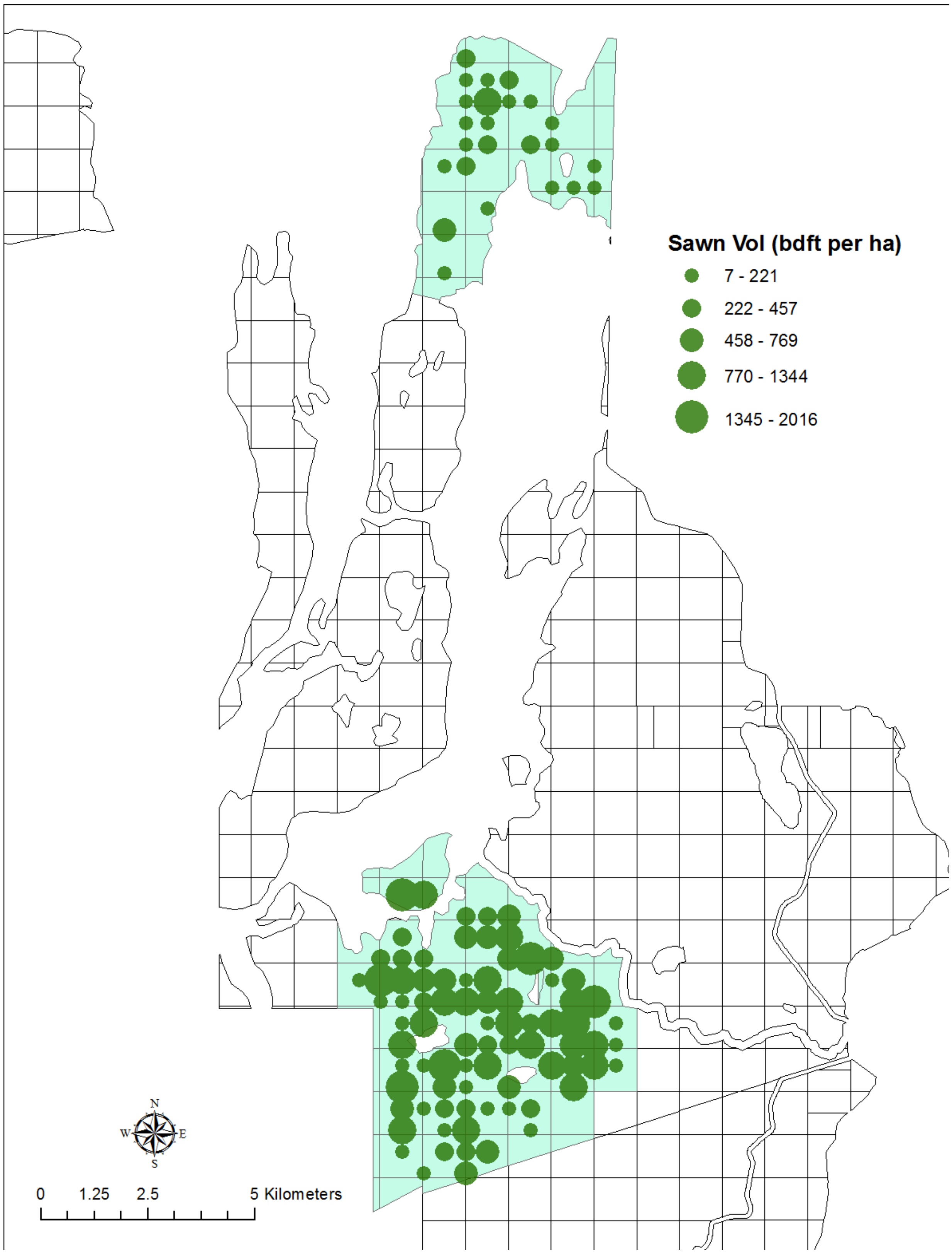


Figure 16. Spatial distribution of Mahogany saw timber in the management area.

As seen in Fig. 16, in terms of potential crop, most areas are well stocked save for some periphery parts in the north. Overall, based on the spatial distribution of stocking, it can be said that this 5-year area appears to be very productive in terms of timber potential.

2.6. Socio-economic Context

Communities

On the RBCMA there are no communities; however, several occur on the periphery. These include the Mennonite settlements of Blue Creek and Shipyard to the north, and San Felipe and Rancho Dolores to the east. These communities are occupied chiefly by farmers and workers of the agricultural and logging industries. PfB maintains continuous communication with the communities and frequently hire temporary field staff from among residents.

Estate Policies

Although workers reside at Hillbank on rotation from 2 weeks to 1 month, they are not allowed to bring their families. Workers are not prohibited from leaving to visit their families but if they do the travel distance is so long that it is unlikely that they will return in time for work the next day. Alcohol is prohibited on the RBCMA among employees as is hunting and carrying of firearms. Monitoring of traffic in and out of the RBCMA is carried out at two gated and permanently staffed checkpoints, one at the north entrance and the other at the south-eastern entrance to the property. Vehicles are routinely checked and each trip is logged. The operating hours of the gates are during the hours of 6 am to 6 pm, outside of which no traffic may enter or leave the estate. All visitors to the RBCMA must receive prior permission to visit as none of the roads are considered public right of ways.

2.7. Cultural and Socio-economic Values

The Ancient Maya

Evidence of Mayan occupation is provided by archaeological sites in the RBCMA. The archaeological evidence suggests extensive occupation of the RBCMA by the ancient Maya, and it is believed that this caused almost complete deforestation of the area with high intensity use of all resources during the Late Classic Period (6th to 8th century) when population densities were very high. The ancient Maya probably caused the most impact on the vegetation, its distribution and structure in recent times, with considerable implications for future development of ecosystems and forest structure. After the collapse of the Classic Maya culture, the area experienced a massive decline in population and it is assumed that a recovery of forest cover followed. However, there is evidence that Mayan inhabitants remained in the area. Therefore, shifting slash and burn agriculture continued until the early 17th century when after rebelling against Spanish rule, the remaining Mayas migrated to the west.

Maya settlements in the form of small mounds are frequently encountered on the RBCMA, in addition to the large complex at La Milpa. Most of the important Maya settlements in the northwestern part of Belize commonly encircle bajos or intermittently wet environments because perennial rivers and streams are not very common (Beach *et al.*, 2009). Bajos are common on the RBCMA thus it is likely that a significant portion of the area was under utilization for crops or settlements by the ancient Maya during the Preclassic to Classic period. Interestingly, Mahogany is also very common around some of the bajos, which may imply a kind of cultivation of the species perhaps for its usefulness and ease of working with stone tools. Similarly, Breadnut, which produces an edible nut, is often found in abundance around temple complexes, again suggesting cultivation of the species.

In terms of forest management, the presence of Maya mounds on the property means that special attention will have to be given to preserving these areas during logging operations. A simple way to ensure this is through the stock survey, where mounds are mapped and buffers placed around them.

Present Day Values

PfB values its employees and their well-being, and demonstrates this through competitive compensation packages that reflect a hierarchy based on experience and qualifications. Another way PfB demonstrates that it values its employees is through the strict safety policy in place to protect employees from on the job injuries. Employees in the forest must wear all personal protective equipment typical to the best logging operations in North America.

PfB also values its customers and visitors, and demonstrates this through world class accommodations and food and scenic attractions. Although PfB has no road works equipment, it maintains its roads in excellent condition year round, and engages in an active schedule of maintenance involving logging contractors. PfB offers attractive and fair prices for its timber to potential buyers and always delivers to satisfaction.

PfB values ancient culture and contemporary culture, and demonstrates this through preservation of all apparent mounds and cultural sites through the use of no-touch buffers placed generous distances around sites. PfB also promotes and facilities archaeological research on its properties to increase understanding of the ancient Maya and how they interacted with the area. Modern communities surrounding RBCMA are actively engaged in social outreach and community awareness about the benefit of the RBCMA and the purpose and scope of the work of PfB. Although PfB has a strict no hunting policy, surrounding communities have come to understand the importance of this through constant communication, and there have been very little prevalence of illegal hunting on PfB lands.

2.8. Infrastructure and Equipment

RBCMA housing infrastructure is comprised of its two field stations. There is the La Milpa field station where there are visitor cabanas, a dormitory, full services and staff accommodation. This site is primarily a tourism facility. Then there is the Hill Bank field station, with similar infrastructure to La Milpa but used both for tourism and field operations.

Road infrastructure consists of an all-weather road system connecting the area to Orange Walk (via Blue Creek and New Hope) and Belize City (via Bermudian landing and Rancho Dolores). The RBCMA has a good network of principal roads which are shared with Yalbac and Laguna Seca, now known as the Belize Maya Forest. Each entry point is served by a manned gate-house (North Gate, East Gate and Bergen's Gate). The Maya Forest also maintains gate-houses at Rancho Dolores and Cedar Crossing. The forest has a network of seasonal trails dating back to BEC ownership which are often more or less closed over by vegetation. These are re-opened as needed and some are in regular use. To date there has been no need for new road construction. While the private roads on the RBCMA, Yalbac, and Gallon Jug are maintained in fairly good condition and their use by the public is controlled, the unpaved sections of the public road system connecting to Belize City and Orange Walk tends to deteriorate during the wet season.

Programme for Belize does not own any logging equipment, instead contractors provide all the equipment necessary for road works, logging and trucking. Milling is done offsite at mills owned by buyers of PfB logs. This has implications for the economics of forest management as the overhead costs of surveying and monitoring need to be exceeded by the stumpage fees offered by contractors who purchase and log PfB trees. In most operations, the survey costs account for the greatest proportion of overall logging costs.

Overall operating budget for PfB averages around $1.6 million per annum. There has been a shortfall of circa $0.3 million per annum that has been traditionally filled through grant support.

3. ANALYSIS OF ISSUES

3.1. Threats/pressures and their sources

Disturbance and the Importance of Hurricanes

Hurricanes are the single most important factor determining forest structure and composition in the management area. This concept is increasingly being adapted into mainstream forest management and new concepts and prescriptions are emerging to cater to the influence of hurricanes. For example, studies of Mahogany population dynamics in the Rio Bravo Conservation and Management Area and further north in the Yucatan Peninsula suggest that Mahogany regenerates in cohorts after severe hurricane disturbance followed by fire (Snook 1996). Without this type of catastrophic disturbance the species does not self-regenerate under a mature forest canopy to the extent needed to replace the individuals removed through logging or other mortality events. This suggests that a viable population of mature seed producers must survive a hurricane in order for there to be sufficient seed dispersal in the post-hurricane post-fire forest. It is also possible that, in the absence of any survivor seed trees, Mahogany seeds dispersed before the hurricane somehow survive the post-hurricane fires in the litter layer and germinate in the nutrient-rich top soil following the hurricane and subsequent fires. However, given the vulnerable nature of seeds of broadleaf species to fire, the latter regeneration pathway is more unlikely than the former.

A complex relationship between hurricane disturbance and past logging emerges under the above hypothesis, whereby logging which removes all trees above a certain minimum cutting diameter, for example 60 cm, may lead to a lack of regeneration following a hurricane if hurricane-related mortality among the trees <60 cm is high. This may help to explain the patchiness of Mahogany on the adjacent Gallon Jug property and elsewhere in Belize, whereby previously Mahogany rich areas near to main access roads which were logged of all trees >60 cm earlier on in the 18th and 19th Centuries were later affected by hurricanes and suffered poor regeneration, while areas which were further away from roads and were not logged prior to a major hurricane managed to regenerate sufficiently large cohorts which we now see today. Furthermore, the uneven nature of forest fires which follow hurricanes may also contribute to explaining the same patchy distribution of Mahogany. For example, an area affected by hurricane and later by fire with a large number of survivor seed trees with bark thick enough to provide protection from fire heat stress may experience a larger cohort of regeneration than a similar area where survivor trees are too young and therefore the bark insufficiently thick to provide protection from forest fire.

The timing of hurricane and fire disturbance is just as important to consider as their effects. Unfortunately, little data exists on fire occurrence following hurricanes on the RBCMA. However, dates of hurricane occurrence are available since the mid-19th Century. Table 1 shows the year of occurrence of all major hurricanes falling within category 1 or higher. It shows that for the past 150 years there have been only two catastrophic storms of the intensity needed to open the canopy on such a scale as to allow light-demanding species such as Mahogany to regenerate, and which may have inputted enough dried fuel to facilitate post-hurricane fires. The first was in 1892 and the second was in 2010, a time span of 118 years. The 1892 storm was closely preceded by a storm of lesser strength but which may have contributed to its effects, thus only the stronger subsequent storm is considered here. No data exists to verify whether regeneration occurred after the 1892 storm or in what quantity, but the current stocking of Mahogany in some compartments on the RBCMA indicates that a large cohort of regeneration occurred sometime in the past, possibly related to the effects of the 1892 storm. In relation to the 2010 and 2016 storms, it will be important to monitor the regeneration of Mahogany and other species in areas of the forests where significant canopy opening had occurred as a result of the hurricane. It will be equally important to assess the influence of large survivor trees coupled with the occurrence of fire or lack thereof on any regeneration observed.

Table 6. Major hurricanes which affected the RBCMA in the past 157 years

Year	Name	Effective Wind Speed	Eye Distance to Property
1864	Not Named	80 mph	7 km
1892	Not Named	97 mph	15 km
1916	Not Named	46 mph	15 km
1931	Not Named	40 mph	28 km
1932	Not Named	46 mph	0 km
1945	Not Named	40 mph	32 km
2010	Richard	97 mph	21 km
2016	Earl	85 mph	30 km

Extensive hurricane damage is possible in any season, and will also require total re-organisation of forest management. The immediate need would be to assess the severity of the damage and the size of the area affected. Hurricane contingency actions already include:

• The disposition of the management zone on a broad NW-SE alignment. It is unlikely that the entire zone will be seriously damaged, so allowing a shift in operations;

• Reschedule the logging sequence to allow for extraction in less-affected areas and post-hurricane management actions in impacted areas.

• Produce an emergency revision of the management and operational plans. Guidelines for the affected area are as follows:

• Clean access into all areas previously logged and thus with full post-logging resource inventories and open trail systems. Salvage operations will have an effective life of c. 12 months before insect damage devalues the timber and will be most effective in these areas. Speedy action is important.

• Upgrade fire preparedness. Fire risk becomes extremely high after storm damage.

• Concentrate salvage operations in the early to mid dry season. If necessary, concentrate all resources on bringing the logs to the truck-passes and then to the all-weather road. It is important to get them out of the forest. Germination is likely to be prolific after the first rain and must be allowed to proceed

• Avoid over-enthusiasm in salvaging. The stock-survey maps can be used to relocate and check all large trees of commercial species, including seed-trees. These should be salvaged regardless of DBH if they are snapped in the trunk or wind-thrown. They must be left if damage consists of crown damage, even if severe or involving a snap high on the trunk. Such trees are crucial seed-sources in the immediate aftermath of the storm. They are also fully capable of living to great age in that condition, contributing to structural diversity in the forest.

• Repeat the inventory procedure in compartments covered in the inventory programme. These will then be re-measured at 5 year intervals. The aim is to assess hurricane impacts on standing stocks, regeneration and mortality.

• Follow the liberation procedure established for post-fire impacts and reschedule the logging sequence as necessary, aiming to avoid re-entry for at least 20 years.

The general thrust is to protect and promote post-hurricane regeneration in the affected area. Prescriptions are therefore similar to post-fire actions but operate at larger scale.

Forest Fires

The savannahs are an extremely important part of the Belizean ecosystem and a management priority on the RBCMA. The savannah programme includes a pine timber management component though this currently targets rehabilitation rather than utilisation and is the subject of a separate planning exercise. The most important interaction with broad-leaf forest activities lies in fire management. This is the primary management tool on savannah, both in controlled burning to promote desirable conditions and in preventing or extinguishing uncontrolled fire. The Forestry crew are also involved here and the skills are transferable to the broad-leaf forest.

Broad-leaf forest fire is a double-edged issue. On one hand it is an important factor in forest dynamics and regeneration and on the other is extremely destructive of standing timber stocks. Experiments with managed fire in broadleaf forest in the Petén have met considerable success and it has been considered as a potential management tool, in combination with patch cuts, on the RBCMA. Such an approach, however, is felt to set a dangerous precedent. The emphasis is therefore on prevention (primarily through good community relations) and control. The field crews are equipped to deal with fire and are trained in fire management techniques (fire-breaks, back-burning, beating, etc). This capacity – both in equipment and skills – will be maintained and the general guideline is to contain fire within as restricted an area as possible.

Controlling broadleaf forest fire is nonetheless notoriously difficult and extensive areas will be burnt if a fire is not detected early and takes a hold. Here the emphasis shifts to promotion of regeneration and conserving what remains of the standing resource. Recently burnt areas therefore need special management prescriptions – this applies now to southern West and East Marimba (burnt in 2011) and any areas that may be affected in the future. Planning guidelines are:

• Undertake a preliminary survey of fire impacts on the standing stock and any permanent sample plots in the area. A local plan is then developed for the area that supersedes any existing schedules. The following elements should be included.

• Establish an inventory transect (Protocol C) in each compartment affected, marking it as a permanent plot with 5-yearly re-measurements. The aim here is to track post-fire mortality regeneration and mortality.

• Undertake a stock survey (Protocol A, but including an assessment of form – i.e. 'marketability'). This assesses impacts on the standing stock and is especially useful if the area has already been surveyed. If the compartment has already been covered by an inventory cruise this step is unnecessary.

• Re-measure any permanent study or demonstration plots in the area. These will give useful 'before and after' information.

• Use the opportunity to locate and clean any trails serving the compartment.

• Avoid any over-enthusiastic salvage operations. Surviving trees are precious seed-sources at this stage – this extends to damaged and dying trees where the stress may stimulate prolific flowering and seeding. This is a more important function than any revenue likely to be generated. Furthermore, any activity likely to crush the newly established seedlings must be avoided.

• The area will constitute a dense thicket with vigorous growth of vines until the forest begins to reconstitute itself. Every two years (starting the year after the fire) the area must be systematically covered to i) liberate all surviving trees of good form and commercial species; ii) clean all seedlings of commercial species that can be located. This process must be repeated until the saplings are out of severe competition.

• Re-organise the extraction schedule for the compartment. Truck-passes may be used to gain access to the hinterland but logging should not be considered for at least 20 years to allow the newly-established age cohort of light-demanding species time to develop to a size where they can easily be protected during operations.

Illegal Logging and Hunting

PfB maintains a staff of 13 trained rangers who patrol the area regularly while the road entrances are all gated with permanently manned gate-houses. This follows a protection plan developed for the area and funded by the national 'Debt-for-Nature' scheme. Given the extent of the property, complete interdiction of illicit activity is not possible over the entire area but is held down to tolerable levels and the area is classed one of the best-protected in the country. Some problems are persistent and often recur in the same general areas, especially immediately adjacent to northern communities. These include:

• Hunting – both opportunistic from vehicles passing through and as a local sport doubling as a source of domestic food and some commercialisation.

• Cultivation – although agricultural interests would cultivate land on the RBCMA if it were available, land-ownership and land-rights are respected and unauthorised settlement is not an issue. Marijuana cultivation is, however, a recurrent problem in some areas. This usually handled through joint raids with the police and Belize Defence Force.

• Timber theft – This is again a recurrent problem, exposed by the regular patrols and perhaps worsening as RBCMA mahogany stocks become conspicuously better than any others in northern Belize. Theft is usually detected by patrolling sensitive or 'at-risk' areas – e.g. where logging is occurring adjacent to the

RBCMA. Local tip-offs are becoming more important as more community members become actively involved and develop interests in good management of the area. Timber theft is dealt with by confiscation and legal action, with increasing success.

Essentially the objective is to hold unauthorised resource use to present levels – where it is an annoyance rather than a threat – by maintaining the measures in force. The timber management programme is itself used to suppress illicit activity by expanding the management zones as buffers, projecting a management presence into sensitive areas. Important infractions are reported to the relevant authorities, interventions may be made in collaboration with them, and legal recourse is taken when appropriate

Looting of Archaeological Sites

Looting of archaeological sites and chicle harvesting have been major issues in the past. Though they are not current problems they have the potential to resurge. Occasional instances of unauthorised pole and bayleaf cutting are detected but are not serious.

Invasive Species

A number of invasive species occur on the RBCMA – notably tilapia in the aquatic systems and *Imperata* grass on the savannahs. More recently, Armoured Catfish has been detected in the New River ecosystem. Eradication programs are not feasible and the general approach is to maintain a robust natural ecosystem capable of absorbing the impact. Pine-bark beetle has been effectively controlled on the savannah using mechanical means – i.e. felling a cordon around affected trees. Hardwood resources are affected by a range of pests, notably shoot-borers on mahogany and cedar and wood-borers in the heavier-timbered species. There is a general presumption against use of chemicals, the ‘pests’ are considered part of the ecology of the area and the damage is accepted.

3.2. Management History

The Colonial Logging Estate

After the Maya, the primary settlers and users of the area were the Baymen who were first attracted to the area by the abundance of logwood (*Haematoxylum campechianum*). Subsequently the Baymen switched to the exploitation of Mahogany (*Swietenia macrophylla*) which became the economic mainstay of the colony and remained that way until the mid 1900's. A map from the late 18th century shows camps on New River Lagoon and it is very probable that Mahogany logging was almost certainly under way at that time at Hill Bank and, even though the western portion of the RBCMA was considered Maya territory until the mid-19th century, it is almost certain that Mahogany exploitation started to penetrate into the western RBCMA during the period. In the 19th century Hill Bank became the centre of operations of the Belize Estate and Produce Company (BEC), one of the most important timber companies in the entire British Empire with extraction at an industrial scale, efficiently organized and using the best equipment of the day. BEC divided the area into cutting blocks, each logged in turn with the last of these in the west reached in the mid-1950s. After this Mahogany harvesting became haphazard across the landscape with little if any control other than a minimum cutting diameter of 60 cm. The final year of operations of the BEC was 1982 when close to 8,000 Mahogany trees were taken out. Between 1982 and 1989 when the RBCMA was acquired by PfB, the forest was logged several times over again in a haphazard manner by local companies (Belize Timbers and New River Enterprises). The entire RBCMA has therefore been intensively exploited for over two hundred years.

Concrete estimates of the quantity of timber extracted from the RBCMA since logging began in the 18th century under the former Belize Estate and Produce Company are lacking. However, early estimates of Mahogany production from the then colony of British Honduras during the period 1857 to 1867 suggests an annual average export of eight million board feet, which would equal between 9,000 and 16,000 trees. At the time there was the impression that the best Mahogany was to be found to the north of the Belize River, thus it can be expected that the majority of the Mahogany exported from Belize was sourced from the forests owned by the former Belize Estate and Produce Company, which includes the present RBCMA. The northern forests produced the best Mahogany as a consequence of the nature of the soil, in which marl mixed with loam allows for a longer time to maturity, but when fully grown, the Mahogany was of a harder and firmer texture than that which is found further south, for example in the Chiquibul.

One thing is for certain, the colonial loggers creamed much of the area of the largest and best Mahogany trees from 1800 to 1982, a period of 182 years. The largest squared log ever cut from a Mahogany up to the year 1867 was 5.3 feet wide by 4.7 feet deep by 17 feet long, measuring 5,168 board feet, or 15 tons weight. In colonial times, the season for cutting Mahogany usually commenced around the month of August when gangs of labourers consisting of twenty to eighty men led by a huntsman began scouting the forest to find crop trees. The huntsman was dispatched to the highest point on the land and climbed the tallest tree he found, from which he minutely surveyed the surrounding country. Around August the leaves of the Mahogany trees are typically yellow-reddish and easily detected by the trained eye, which sought out the areas where the trees were most abundant. He determined a general direction and distance and made his way toward the trees to mark each one individually. He was followed by a gang of axe-men, sawyers and hewers whose jobs it was to fall the tree, square it and haul it out to the nearest river bank. Felling a Mahogany a tree was one day's task for two men. On account of the wide buttresses which projected from the trunk, scaffolds had to be built and the tree cut off above the buttresses, which left a stump from ten to fifteen feet high. While felling and hewing was in progress, other gangs were employed in making roads and bridges, over which the logs were to be hauled to the river. One wide truck pass was made through the centre of the forest and branch roads were opened from the main avenue to each tree. Road opening accounted for about two-thirds of the labour and expense of Mahogany cutting. The labour of cutting away the underbrush and small trees with the cutlass was usually performed by task work of one hundred yards each man per day. The larger trees were then cut down by the axe as even with the ground as possible, the task being also at this work one hundred yards per day to each man. If the hardwoods were too hard for the axe, fire was used. The trunks of these trees, although many of them valuable for different purposes, such as Bullet Tree, Ironwood and Sapodilla, were thrown away as useless, unless they happened to be adjacent to some creek or small river which may intersect the road, and in that case they were applied to the construction of bridges across same. Such bridges were frequently of considerable size and required great labour to make them of sufficient strength to bear such immense loads as were brought over them. The quantity of distance of roads to be cut each season depended on the situation of the body of Mahogany trees, which, if dispersed or scattered, would increase the labour and extent of road cutting. It was not uncommon that miles of road and many bridges were made to a single tree, which ultimately yielded one log. After all the vegetation was removed from the roads, there was still the work of breaking rocks and leveling hillocks and stumps as might impede the wheels of the trucks.

Each Mahogany works formed itself a small village on the bank of a river, the choice of location being always regulated by the proximity of such river to the Mahogany intended as the object of future operations. Each workman was capable of performing the labour required to build his own dwelling, many of them in a single day, and with no other implement other than the axe. After completing the village, a main road was opened from it, in as near a direction as possible to the centre of the body of trees to be felled. This same road was used to truck the Mahogany logs to the river.

The trucks employed were clumsy and antiquated, with wheels of solid wood and an iron core. Oxen were used to draw the trucks and were fed on the leaves and twigs of the Breadnut tree, which gave them more strength and power of endurance than any other obtainable food. Mahogany trees, at the time, gave each from two to five logs each ten to eighteen feet long, and from twenty to forty inches in diameter after being hewed. The chief guide for dividing the trees into logs was to equalize the loads the cattle had to draw and prevent their being overburdened. Consequently, as the tree increased in thickness, so the logs were reduced in length. This, however, did not altogether obviate the irregularity of the loads, and a supply of oxen was constantly kept in readiness to add to the usual number according to the weight of the log. Each log was then reduced by means of axe from the round or natural form into the square, although some of the smaller logs were brought out in the round. Squaring was necessary not only to lessen their weight but also to prevent their rolling on the truck or carriage. Trucking was done in the dry season, and logs collected on the bank of the river, and made ready for the floods, which occur on the largest rivers in June and July and on all other rivers in October and November. The logs were turned adrift and caught by booms. Workers followed the logs down the river to release those which were caught by fallen trees or other obstacles.

The only processing done in the colony consisted of sawing off the log ends which were bruised and splintered by rocks in the transit down the river, and in re-lining and re-hewing the logs by skillful workmen, who gave them a smooth and even surface. The logs were then measured, rolled back into the water at the mouth of the river, and made into rafts to be taken to the waiting vessel anchored outside the bar. Mahogany was used in the building of sloops, schooners and larger ships for use in ocean trade, since the wood was durable and resistant to the ravages of worms which abound in the waters.

The most surprising aspect of Mahogany logging in Belize is that despite the obscene quantities of Mahogany extracted during colonial times, the species is still very much abundant and where it occurs today is typically one of the most abundant species of all large forest trees.

Other colonial activities included Chicle tapping which rivalled Mahogany works in importance from the late 19th century to the mid-20th, continuing into the 1990s. The entire area was given out in annual concessions and all Sapodilla (*Manilkara zapota*) trees of any size show signs of being tapped once to several times. The impacts of both the Mahogany and Chicle operations have projected themselves into the present forest structure as well as until recently the land use pattern in some areas of the RBCMA. For example, timber exploitation must have created considerable canopy opening (especially given the size of Mahogany trees during the early years), not only through felling gaps but also for barquadiers and truck-passes. Oxen, used for haulage, required pasture and trampled trails and holding areas. Steam engines were also used, requiring substantial quantities of wood for fuel. Hill Bank supported a population of close to 200 people and food was grown in 'provision grounds' cleared from the forest. Some of these were located in the Punta Gorda area and continued to be used into the early 1990s. The chicleros maintained mule trains that would have contributed to the trampling and also used Breadnut (*Brosimum alicastrum*) as fodder.

The historical legacy therefore has implications for present management. For example, there is an extensive trail system throughout the forest, giving access to all the production forest areas. Although most are overgrown they can still be re-opened and new truck-passes are largely unnecessary. The structure of the present forest has been significantly altered. It is believed that an unlogged forest would be more or less the same height as that seen today but would be overtopped by an emergent canopy consisting of very large Mahogany trees (Snook 1993). These have been more or less wiped out during the previous 200 years of logging, not only taking out the best seed-sources but also an entire upper stratum. Forest management operations favouring biodiversity should therefore have as one of its primary aims the reconstitution of this structure.

Recent Past Timber Management (BEC and PfB)

Large scale logging of the RBCMA began in the 1800s, when it was then a part of a larger estate belonging to the Belize Estate and Produce Company (BEC). The exact dates and location of logging operations on the RBCMA portion of the BEC estate are unknown, but it can be safely assumed that logging operations were conducted multiple times under the stewardship of BEC during the course of the last two centuries. There were no management prescriptions in place to guide logging in the colonial era because no inventories were done. Logging took place as described in the previous section. It was an era of exploitation and administration, and very little if any forest management occurred.

The first attempt at some sort of management prescription was made around the time the Forest Department was instituted in 1922. A diameter control was put in place sometime after, whereby no trees less than 60 cm DBH were to be felled. For the rest of the 20th century, Mahogany was logged according to this minimum cutting diameter. As the cutting and hauling technology improved, so did the relative rate of extraction, and the distance travelled to find trees increased also. Near the end of the 20th century, timber operations began to decline which prompted the BEC to conduct the first forest inventory in 1975 to find out what was left after close to two centuries of logging.

Table 2 was prepared from data collected from 2,028 km of transect lines surveyed during the 1975 forest inventory of the Belize Estate and Produce Company's Mahogany works. The results showed that Mahogany and Cedar accounted for around 8 % of the total growing stock. Being only two species out of over 70 large tree species in the inventory, the results suggested that primary species were close to three times more abundant in terms of volume than if all other species occupied the forest equally. Commercial-sized Mahogany and Cedar trees (60 to 110 cm DBH) accounted for 3.6 % of the total growing stock, or about 10.3 % of all commercial-sized timber. Likewise, if commercial-sized trees of all other species occupied the forest equally in terms of volume, Mahogany and Cedar would take up 8 times the expected space. Similarly, pre-commercial-sized Mahogany and Cedar trees accounted for 11.7 % of all pre-commercial-sized trees, or about 8 times as much if all species were equally abundant volumetrically. Taking the results in total, the inventory revealed that Mahogany and Cedar remained relatively abundant even after close to two centuries of logging. In the large tree classes, primary species dominated the forest. However, although relatively high compared to other species, compared to the historical expectation, the average volume per hectare in the commercial classes was very low. At 1.3 m^3 ha^{-1}, the forest could yield only 140,000 bdft per 500 ha, nowhere near past stocking.

Table 7. Stocking from the 1975 forest inventory of the Belize Estate and Produce Company lands. *Volume estimates include about 7 % defect.*

Species	DBH Class (cm)	Stocking (Stems ha^{-1})	Within Class %	Volume (m^3 ha^{-1})	% of Total Growing Stock
Cedar & Mahogany	10 to 60	3.7	11.7	1.4	3.9
	60 to 110	0.4	10.3	1.3	3.6
	110 to 150	0.01	10.0	0.2	0.6
Other Hardwoods	10 to 60	27.8	88.3	22.8	63.3
	60 to 110	3.5	89.7	10.0	27.8
	110 to 150	0.09	90.0	0.3	0.8

Logging operations began to wind down in importance after 1975 and in 1982 the BEC estate was portioned into separate estates and sold. A full and proper account of what followed next in terms of forest management is contained in the original 2006-2010 management plan by R. Wilson. For continuity and clarity, the relevant section of that management plan is copied here in full below in quotes.

"After the BEC ceased operations in 1981, the area was purchased by Barry Bowen, a Belizean businessman, and divided into three sections, with Mr. Bowen retaining Gallon Jug, Yalbac being sold to the Yalbac Ranch and Cattle Corporation and the remainder being purchased by Coca Cola Foods Inc. Meanwhile the Massachusetts Audubon Society was investigating the possibility of securing land to conserve wintering habitat for North American migrant birds. This was supported by Coca Cola Foods Inc, which donated 17,000 ha (42,000 acres) of its holdings in two transactions in 1988 and 1989, providing the stimulus for the establishment of both PfB and the RBCMA. In 1989 PfB acquired the northern half Mr. Bowen's remaining property on generous terms and the land now represents the 44,515 ha (110,800 acres) of the western RBCMA. This land transaction which was not completed until 1992 also brought a second tract of land – Vachel Keene, in the Mountain Pine Ridge into PfB ownership. Vachel Keene, 3,464 acres (1,402 ha) is presently unmanaged. Further land donations from Coca Cola Inc through The Nature Conservancy and further purchases of land from New River Enterprises brought the area of the RBCMA to its present acreage of 255,049 acres (103,215 ha). The NRE purchases (47,520 acres (19,231 ha) were linked to the Carbon Sequestration Pilot Project, with substantial backing from the Park Foundation and from public donations.

All the land parcels were indiscriminately and for the most part intensively logged between the demise of BEC and acquisition by PfB. Detailed records of BEC operations are no longer available and the exact logging history of any given stand on the RBCMA is therefore unknown. Uncontrolled extraction on the western RBCMA was opportunistic, more localized and of much shorter duration.

The first PfB scheme for timber extraction, developed between 1989 and 1992, involved commissioning Sylviconsult BT AB to undertake a forest inventory and developing plans to purchase New River Enterprises Ltd complete with land and sawmill. In the interim, NRE was given a one-season concession to extract timber from Duck Ridge. The scheme had many attractive features but also carried deep flaws of which many only became apparent at a very late stage. The key issue, however, was that it committed PfB to extracting sufficient timber from the RBCMA to maintain the largest mill in northern Belize without any real information on whether that resource actually existed – the inventory results only becoming available after the fact. It was also unclear over what area the extraction would take place, arousing concern among those donors skeptical of timber extraction as part of conservation management. The plan was aborted in 1993 and PfB re-assessed the situation from first principles.

The RBCMA Action and Provisional Land Use Plans (PfB 1992a, b) were aimed at establishing a framework for re-instating management for timber on a sound footing. These collection of documents set out a provisional zoning system for the area, based on Man and Biosphere Reserve guidelines. In concept the western Rio Bravo was set aside as a fully protected core zone while the eastern Rio Bravo was a buffer area where management included the development of a sustainable regime for timber production in natural forest. The core area was also buffered in the north by a zone permitting managed extraction of non-timber forest products until such time as an appropriate timber management approach, developed on the eastern RBCMA and verified through certification, allowed a reassessment. This approach had the effect of ensuring the lands secured through public support were clearly protected under any interpretation of the term. It also meant that management for timber had to prove itself in the area where uncontrolled logging had already compromised the ecological integrity of the forest to the greatest degree before any consideration was given to its extension to the higher-grown and longer-rested forests to the west. The zonation has been modified slightly in subsequent years and expanded to cover new areas as they were added to the conservation area but remains unaltered in its essential features.

The plans also established the basic parameters for the development of an appropriate management regime. This included adoption of the underlying principles described in Section 5.1 [of the 2006-2010 management plan] and the policy position that no scheme involving timber extraction on the RBCMA would be developed in the absence of information on the resource, on the ecological dynamics of the area, and on a sound, certifiable, plan.

USAID funds were then used to develop a forward strategy (Fountain Forestry 1993). The key findings were that data from the forest inventory carried out by BEC in the mid-1970s were no longer reliable in view of subsequent logging. A new inventory was therefore needed. Certification was desirable and would assist marketing. Available information in the absence of an updated inventory suggested that timber operations were only viable if PfB engaged in adding value and, with a depleted mahogany resource, emphasized lesser known timbers. Local marketing to the tourist sector appeared promising. The RBCMA gave exceptional opportunities for research into ecological dynamics and for experimental silvicultural approaches.

In the absence of immediate funding, PfB concentrated on the research aspect. A programme on forest ecological dynamics, undertaken in partnership with the Manomet Observatory for Conservation Sciences, was initiated in 1989. This was taken into a second phase that shifted from the western to the eastern RBCMA and concentrating on logging impacts on forest structure, regeneration of timber species and on bio-indicator groups. This project is no longer running.

At the same time, efforts were directed towards developing projects to take the work forward and the following action areas have been in place since 1994:

• The Sustainable Forest Management project. The aim of this project, funded by the European Union, was to obtain the information on which to base a sound forest management regime, concentrating on resource assessment, establishment of permanent sample plots to monitor regeneration, growth and mortality, and on experimental extraction and marketing. The work was conducted in close collaboration with the UK-funded Forest Planning and Management Project (FPMP) which aimed at improving forestry operations at a national level. Several modifications to the original aims were made to conform with the FPMP approach, most notably shifting the emphasis from forest-wide inventory to detailed stock-survey of individual stands. Experimental extraction took place in the Punta Gorda, Marimba and Botes areas from 1997-1999. The fully operational regime was established in 2004, under the successor project also funded by the EU. This project is now over.

• The Carbon Sequestration Pilot Project. Here, hardwood timber extraction is integrated with forest conservation in order: i) to prevent CO2 emissions due to forest clearance and ii) to reduce atmospheric CO2 by increasing biomass through silviculture and forest management. In hardwood forest, the emphasis has been on monitoring land use change, monitoring standing biomass, measuring and reducing impacts of timber extraction on that biomass, and developing capability to combat fire. Post-Kyoto, work has concentrated on pine savannah management.

• Experimental silvicultural treatments. One component of the first EU project was to build on the Manomet programme by developing experimental treatments to enhance regeneration and growth of timber species. This work was conducted in collaboration with CATIE (for growth, through 'selective liberation') and Duke University (seedling establishment). The FPMP plots are also designed to compare regeneration, growth and mortality in logged and un-logged forest. Although annual silvicultural research activities ceased in 2002, the plots are designed as long-term experiments with periodic remeasurement.

The RBCMA forest management regime has therefore been built up over a period of twenty years, with heavy emphasis on developing an approach adapted to the natural ecological dynamics of the forest. Expert advice and input has come from the wide range of individuals and institutions including the Natural Resources Institute, (through the Forest Planning and Management Project), World Land Trust, The Nature Conservancy, Winrock International, Fountain Forestry, Manomet Observatory for Conservation Sciences, The Smithsonian Institute, Duke University and CATIE. Drs Nick Brokaw and Laura Snook have made a particularly important contribution. The approach has been certified by the Forest Stewardship Council (FSC) since 1997 (i.e. the first year of operations) and is operated under the first long-term private forest license issued by the Forest Department." (Wilson J. R., 2006a, pp. 7-11)

Fig. 17 chronicles PfB's logging activities since operations began on the RBCMA in 1997 and shows the areas of the timber extraction zone by year.

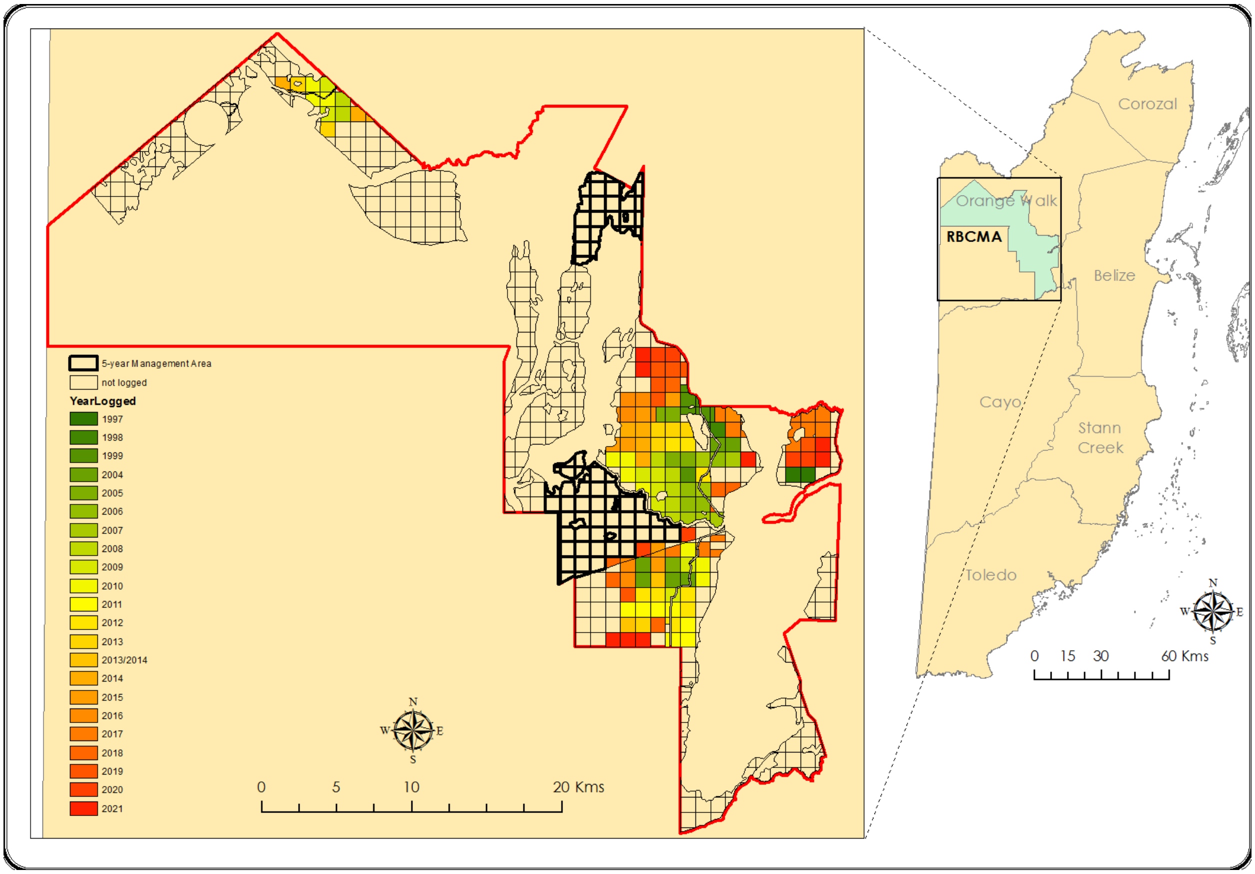


Figure 17. ***Footprint of recent forest management 1997 to 2021 on the RBCMA.***

3.3. Economic Context

The early history of Belize is intimately linked to the exploitation and exportation of timber, primarily logwood (*Haematoxylum campechianum*) which was succeeded by Mahogany exploitation which then became the most important economic activity during the colonial era. However, in contemporary times, the market for timber products within Belize has been a small and traditional one. In Belize the focus of industrialization has been based primarily on the internal market demand. Most of the timber harvested and processed in Belize is used for and in the construction of residential and tourism buildings. The uses in the housing sector vary from all wooden homes to timber used in the construction of concrete homes, to timber used for decorative purposes in homes and offices, and to cabanas in the tourism industry. The export of mahogany lumber over recent years has continued to decrease from 2013 highs, since the North American markets have seen a flood of plantation Mahogany from Africa. However, the export opportunities are still very promising considering that PfB meets the stringent criteria of FSC and CITES.

Mahogany and Cedar dominate the profit margin of logging operations in Belize and their relative stocking determines the rate of return. However, the market price of primary species fluctuates periodically and secondary species are gaining greater economic stature. For example, Black Cabbage Bark and Black Poisonwood are increasingly being sought after by exporters. At the same time, exporters are demanding that timber they buy is certified according to third party standards such as the Forest Stewardship Council principles and criteria. Furthermore, the Convention on the International Trade in Endangered Species requires that harvesting of Mahogany and Cedar be non-detrimental to the species. If this can be proven, the lumber can be traded internationally. There is economic pressure to ensure that logging is done sustainably.

Contemporary forest management involves a balancing act between turning a profit and ensuring the continued ability to sell timber on the international market. The timber operation of the RBCMA needs to be designed to ensure sustainability while at the same time allowing for profitable gains.

3.4. Socio-economic issues

There are presently no village communities within the RBCMA. The nearest communities to the east of the RBCMA are the predominantly Creole and historic Belize River Valley communities of (in order of proximity) Rancho Dolores, St. Paul's Bank and Bermudian Landing, descendants of African slaves and British/Irish immigrants who moved into the area to provide labor in the 18th century. The two nearest communities have traditionally had relatively free access to the land inside what is now the RBCMA for their livelihoods needs for as long as anyone in the area can remember. This access became restricted in the early nineties when the reserve was designated for conservation and PfB assumed stewardship as hunting, logging, fishing or trespassing on RBCMA land were no longer permitted. PfB has since then initiated and/or partnered several initiatives aimed at mitigating these resource use changes through conflict resolution, enabling communities to develop substitute livelihoods and raising community awareness of the conservation values that are maintained by the conservation management of the RBCMA. These efforts on the part of PfB are a work in progress and some measure of success is evidenced by the creation of alternative tourism linked alternative livelihood opportunities in these communities and the creation of a community managed protected area.

To the north the predominantly Mennonite community of Blue Creek and the predominantly Hispanic community of San Felipe are the most adjacent villages to the Northern boundaries of the RBCMA.

Social impacts attributable to forestry operations (and indeed to RBCMA management as a whole) are believed to be neutral to positive. This is based on formal consultations made with local stakeholders (community and industry representatives) in developing the management principles for the forestry programme in 1996, backed by continuing informal and formal contacts through the outreach programme. PfB does, however, have a responsibility to contribute to the socio-economic development of the general region and its performance in this area should be assessed. Part of the exploration of the potential for payment for environmental services must therefore include a Total Economic Evaluation (TEV) to act as a baseline and to identify suitable indicators to monitor trends.

3.5. Biodiversity Conservation Issues

Biological conditions in the timber management zone are favourable to SFM. Reduced impact logging operations are compatible with the conservation of most biodiversity values. Commercially viable timber harvest volumes exist. The removal of these volumes within sustainable parameters does not impede timber resource restoration by the remaining stand.

Nevertheless the above assessment must also be viewed in the context of the following considerations:

- The impacts of extraction at current levels has been assessed over four years, using birds as indicators of alteration to forest structure and butterflies as indicators of species composition. The results (Whitman et al 1996; Valerie & Giles 1996; Brokaw, 1998) show the impacts to be very slight, with no significant change recorded excepting lowered abundance in one bird species (tawny crowned greenlet – *Tunchiornis ochraceiceps*) which remained a frequent species. This is considered unsurprising in a forest adapted to occasional large-scale disturbance far surpassing logging impacts but the assessment needs cautious interpretation.
- Past logging has undoubtedly fundamentally altered the forest structurally and in relative species abundance, notably through a drastic reduction in large mahogany trees;
- All the forest has been logged at some stage and there is little difference to the untrained eye in that logged some years past and that left undisturbed for a longer period. Nonetheless, the longer forest is left undisturbed the better-grown it appears and the more numerous and more visible the wildlife becomes, especially the signs of predatory mammals and birds.

• Disturbed forest actually holds higher biodiversity than undisturbed high forest. This is, however, largely made up of widespread species of forest edge and even open habitat. Special weighting must be given to extensive high forest specialists such as white-lipped peccary and the forest raptors.

Biodiversity is best conserved in Belize through retention of extensive areas of high quality habitat and the need for special protection at species level is limited to the yellow-headed parrot, a savannah species. Timber management on the RBCMA is part of its conservation strategy and should maintain improve overall habitat quality – the logging should leave essential ecological processes intact, retention of seed-trees should help restore the structure and the long 40-year cycle will allow the 'high-grown' characteristics to establish themselves.

Meanwhile, the protected core zone acts as a refuge and the logging schedule allows re-colonization from adjacent undisturbed areas. This assessment does not hold if the cutting intensity and/or degree of canopy opening are significantly increased – as would occur if seed-shadow patch-cuts were to become routine. These cannot be introduced at operational level until biodiversity impacts are reassessed at a large-scale experimental level.

3.6. Environmental Issues

The majority of the 2022 -2026 management area presents physical conditions favourable to forest management:

- Slopes are predominantly gentle to moderate.
- Soil texture and fertility allows for satisfactory forest growth and permits the implementation of logging operations, the most notable exceptions being those blocks on the Rio Bravo Hills and those areas with some inundation during the wet season.
- Climatic and hydrological conditions are not extreme except for tropical storms and hurricanes.

However these conditions do not preclude the need for planning and operational mechanism to minimize the physical impacts of forest management interventions and the following recommendations made in the first management plan remain valid:

Their effectiveness does, however, need verification through impact assessment and monitoring. On the level terrain of the eastern RBCMA, attention centers on soil impaction and water quality over this planning period.

The spot-zoning and operational guidelines are intended to minimize physical impacts – i.e. protective buffers for water-courses, avoidance of bajos, damage to archaeological sites, culverts to avoid blocking drainage, limits on operations on steep slopes, restriction to dry season operations.

Soil impaction has already been assessed on the RBCMA (Whitman et al 1996). Skidding impacts are low where used for one or two runs but impaction rises where more loads are taken out, to the point where seedling establishment can be impeded. This is, however, deemed acceptable as long as the following is observed:

• Using rubber-wheeled vehicles will reduce impaction;

• The alternative is to make more skidder trails, each of which is used less. This is inefficient and creates excessive canopy opening;

• Seedling establishment may be impeded but is not arrested. Mahogany (which was not recorded during the Whitman study) does particularly well under these conditions and the seeding procedure should address the problem. The success of the seeding acts as a practical measure for monitoring purposes.

Logging may also increase sediment loads in surface run-off. This is considered a low risk due to the level terrain and slow flow but the assertion has not been assessed. A programme for water quality monitoring was put in place through the Aquatic Systems Programme. The study area includes the stream systems draining the logged compartments, where chemical parameters are within the norms and sediment loads, though not measured, are considered unexceptional. This programme should be restarted and sediment parameter should now be added to the water quality monitoring programme for verification purposes.

3.7. Forest Protection and Security Issues

Most resource use conflicts that may have originated from traditional albeit unauthorized use of certain areas of the RBCMA namely for hunting, extraction of minor forest products, and to a lesser extent cultivation by nearby communities have been mitigated by a pro-active community outreach and extension programme. Present unauthorized resource use stems from blatant illegal activities.

The threats to the conservation targets are hunting, uncontrolled burning, drug related illicit agriculture, illegal logging, land use change in the upper reaches of the waterways, looting of archaeological sites, unauthorized collection of timber forest products or non-timber forest products, and disturbance through recreational use. All of these threats apply to the broadleaf forest formations. Recurring current threats are poaching, marijuana cultivation, and timber theft. Each conservation target is subject to one or more threats and some threats affect more than one conservation target. Therefore it is impractical to address the threats to the broadleaf forest formations separately from those threats to other ecosystems within the protected area.

Furthermore, the proximate source of threat is usually propelled, or at least facilitated, by one or more factors acting indirectly. In order to mitigate threats, the strategies being implemented are designed to act both on direct sources of threats in order to gain immediate relief and indirect sources to alleviate the condition over the long term.

The geographic areas that are most threatened include the Rancho Dolores/San Felipe Savannas. The entire northern sector ("roof-top" area on the map of RBCMA) and the entire road between San Felipe Village and Bergen Gate are also considered to be at a high risk. The entire RBCMA boundary is unfenced and therefore susceptible to foot incursions and during the dry season even vehicular incursions. There are also indications that cut lines used to facilitate oil exploration activities such as seismic surveys have also facilitated ingress into the RBCMA for the commission of illegal activities.

4. SUSTAINABLE FOREST MANAGEMENT

4.1. Vision and Goals

4.1.1. A New Ecological Model for Forest Management

PfB was established for the conservation of biodiversity and the sustainable development of Belize through the proper management of the Rio Bravo Conservation and Management Area (RBCMA). PfB operates under the terms of a formal Memorandum of Understanding (MoU) with the Government of Belize (GOB). The MoU with GOB requires that the management regime must further national policy towards protected areas and proper resource use. Therefore the management regime is based on ecosystem protection and sustainable use of forest resources, corresponding to an IUCN category VI protected area. The area is also a very important component of the Belize National Protected Area System and a natural cross-border extension of the Maya Biosphere Reserve in Guatemala. The RBCMA is unique in that it is the only officially recognized private protected area that integrates sustainable extractive forest resource management within a strong overarching biodiversity conservation goal in its management regime.

4.1.2. Goal of Forest Management

The goal of forest management on the RBCMA is to demonstrate sustainable use of forest resources while generating revenues for re-investment in conservation without compromising the biodiversity of the area nor the future value of the resource. The primary objective of the forest management operation on the RBCMA is to engage in continuous cover forestry while turning a profit from the selective logging of hardwoods.

General Management Objectives:

(i) Maintain continuous forest cover in the timber management zone;
(ii) Produce quality hardwood logs for sale on the local and international markets;
(iii) Leave a residual forest capable of supporting healthy populations of wildlife;
(iv) Minimize logging impact on the forest and conserve aesthetics of the area according to local regulations and Forest Stewardship Council principles;
(v) Ensure compliance with all national laws and regulations;

Specific Management Objectives:

(i) Carry out forest management according to a scientifically-sound silvicultural system to ensure the continuous supply of timber and other forest goods and services;
(ii) Conduct selective timber harvesting with reduced-impact logging to minimize residual damage to the forest and reduce carbon emissions;
(iii) Efficiently harvest trees for sale on the local and international markets;
(iv) Ensure that all logging operations comply with local forestry, labour and safety laws as well as international guidelines on sustainable forestry such as Forest Stewardship Council principles;
(v) Maintain 'no-logging' buffer zones intended to preserve High Conservation Value Forests and promote the ecological roles they play in protecting soil and water resources and preserving habitat for wildlife.

The goal is achieved through the following strategies:

- Natural forest management is one conservation strategy among several and is only appropriate in certain conditions. An analysis carried out by Brokaw in 1998 confirms that this approach is indeed appropriate within the overall management regime for the RBCMA.

- Management on the RBCMA must be kept relatively strong and focused primarily towards biodiversity conservation for which timber revenues help pay.

- The concept of 'limits of acceptable change' must be applied to sustained forest management in the RBCMA by establishing acceptable thresholds based on adequate scientific knowledge of ecological processes. The aim is to allow for a level of extraction of timber from the forest that, while evidently impacting upon forest structure and relative species abundance, does so at a level that does not compromise ecological processes or biodiversity values.

- The application of the precautionary principle ensures that each step of management remains well within safety margins indicated by the existing levels of information, experience and institutional capacity. The more limited the last three elements, the greater must be the safety margin.

- Adaptive management is applied within the management regime to ensure that evolutionary changes in circumstances, knowledge base and institutional capacity are assimilated into change mechanisms that can positively influence initial or previous planning frameworks and assumptions at regular intervals.

- Certification of the forest management regime is an effective strategy to independently validate PfB's own forest stewardship standards while enhancing marketing opportunities.

4.2. Objectives

Management objectives are inherently in line with the organization's goals, but speak more to practical on-ground aims that seek to satisfy the PfB's broad objectives. These include:

Sustainable Harvesting

(i) Carry out forest management according to a scientifically-sound silvicultural system to ensure the continuous supply of timber and other forest goods and services;

(ii) Conduct selective timber harvesting with reduced-impact logging to minimize residual damage to the forest and reduce carbon emissions;

(iii) Maintain continuous forest cover in the timber management zone;

(iv) Produce quality hardwood logs for sale on the local and international markets;

(v) Leave a residual forest capable of supporting healthy populations of wildlife;

(vi) Minimize logging impact on the forest and conserve aesthetics of the area according to local regulations and Forest Stewardship Council principles;

(vii) Ensure compliance with all national laws and regulations;

Biodiversity and Environmental Conservation

(i) Maintain 'no-logging' buffer zones intended to preserve High Conservation Value Forests and promote the ecological roles they play in protecting soil and water resources and providing habitat for wildlife.

(ii) Landscape-level biodiversity is maintained (i.e. there may be local short-term impacts but ecological processes, ecosystem structure and function and overall biodiversity characteristics are maintained over the site as a whole).

(iii) The natural forest must be maintained in terms of its architecture and species composition. As this is already compromised by its logging history, an element of rehabilitation is involved. Impacts on biodiversity and the environment in general must be assessed, minimized and monitored.

(iv) Certification is applied to management of the whole forest - i.e. the entire RBCMA - rather than the management of the timber production zones alone. Timber harvest is thus taken as one management element in an integrated, multiple use programme. FSC certification is both the strictest scheme and the most acceptable to the international conservation community. It is therefore preferred by PfB, which has held FSC certification for both forest management and chain of custody since 1998.

Forest Protection and Security

(i) There is pressure for conversion of forest land into agriculture but it is controlled. In the case of the RBCMA the land is held under trust and cannot be released into a land use that does not favor conservation and sustainable use of natural resources. Furthermore property rights are strongly upheld in Belize, both in policy and practice.

Social Responsibility

(i) Ensure that PfB continuously engages surrounding communities with capacity building and job opportunities.

Staff Health and Safety

(i) Ensure that all forest operations comply with local forestry, labour and safety laws as well as international guidelines on sustainable forestry such as Forest Stewardship Council principles;

Other Objectives (research)

(i) Ensure understanding of the ecology both of the timber species targeted and of the forest they form part of through maintenance of a long-term RBCMA forest research and monitoring programme.

Financial Sustainability

(i) The timber off-take must generate revenues that at least cover costs (when it is still justifiable in terms of supporting other management programs such as research and in meeting PfB mission aims) and preferably make a profit.

4.3. Zoning

The RBCMA is zoned following the UNESCO 'Man and the Biosphere" model – i.e. a protected core managed on national park precepts buffered by a 'sustainable use' zone managed as a functional forest reserve plus an outer area of engagement with peripheral communities.

The RBCMA is divided into 4 zones:

• Protection zone – managed on national park precept

• Broadleaf forest management zone – production forest under SFM

• Savannah management zone – short grass savannah with pine where fire is an

integral part of the ecology

• Tourism and infrastructure zones – roads, field stations, and gatehouses and areas 3 kms. around each field station for cultural and nature interpretation

To determine the area of annual cutting blocks, foresters typically approximate the total area of productive forest and then divide it by the cutting cycle length. It is a quick and simple approach to yield regulation based on the concept of area control, whereby each equal-area compartment is expected to yield the same amount of wood. The concept originates from monoculture stands of temperate coniferous forests, where there is the assumption of homogenous stocking. The benefit of using equal-area compartments is mainly to synchronize the logging operation with the lifespan of the stands in the management area, so that the recuperation of yield in the first logged stand will be timed with the harvest of the last stand. In mixed-species tropical forests, however, equal-area compartments are not appropriate in practice because of the inherently high variation in species distribution across space and time, leading to very heterogeneous stocking from compartment to compartment. The benefit of equal-sized compartments on a cyclic rotation is outweighed by the infeasibility of achieving a regulated annual yield.

A better approach would be volume control with area regulation, where the location and size of the annual cutting compartments is decided year to year in order to achieve a desired annual yield. Under this volume/area hybrid control, each annual block would be worked independently of the other and need not be worked in any particular sequence. However, as with area control, each compartment can only be logged again at the end of the cutting cycle and would be expected to yield a similar harvest to the first. In other words, each logging compartment will be managed as an individual stand of forest, with prescriptions unique to the area and tailored specifically to the structure of the population of trees occurring within it.

Experience accumulated over the past two decades of sustained yield logging in Belize suggests that the actual area logged in any given year within a management area can range from 250 to 1,000 hectares, and is dependent on dry-season length, stocking and market conditions. Such is the case with the Rio Bravo Conservation and Management Area, where the actual area of forest logged varies from year to year. Dividing the area into sub-compartment sizes of 1 square kilometre allows for maximum flexibility so that annual compartments can be formed by a group of sub-compartments in order to achieve a desired harvest volume. One basic principle must apply, once a group of 1 km^2 sub-compartments is harvested in a year, they should be considered as a single unit at the next cutting cycle and into the foreseeable future.

The timber management zone of the RBCMA is approximately 37,087 hectares in size, already excluding high conservation value forests, buffers and tourism zones. Under the first management plan in 2006 the timber management area was divided into 575 sub-compartments (see Fig. 17), none larger than 100 ha (1 km^2). Compartmentalization is the process of dividing the forest area into approximately equal-sized blocks with as much landmarked boundaries as possible, each block strategically located to allow for control of the yield to make it as homogenous as possible year to year. The block size chosen was 100 ha, which provides flexibility to select up to ten blocks in a given year, allowing for mixing and matching of blocks to produce a relatively normalized yield or to meet periodically high demand, whatever the case may be. Since this has already been done, the most plausible means of approaching normalized harvests year to year is to determine which sub-compartments are located in areas of low, medium and high projected yield, and to make up the annual cutting compartment from a balanced mixture of these. It is impossible to do this for all species so the stratification of the distribution of Mahogany, being the most valuable species, should guide the selection of sub-compartments.

4.4. Management Program

4.4.1. Sustainable Harvesting Program

The objectives of the sustainable harvesting program is to carry out forest management according to a scientifically-sound silvicultural system to ensure the continuous supply of timber and other forest goods and services; to conduct selective timber harvesting with reduced-impact logging to minimize residual damage to the forest and reduce carbon emissions; and to efficiently produce logs for sale to local mills.

The forest management design developed for the RBCMA is modelled on that developed by the Forest Management and Planning Project (FPMP) and being derived from experience in West Africa is innovative in the Mesoamerican context. The key point is that area control replaces volume control as the central principle for forest management. The production forest is divided into compartments or cutting coupes that are logged on a 40-year rotation. The annual cutting area therefore represents 1/40th of the entire production area and, once extraction has taken place, the harvesting coupes are closed for the next 39 years.

The FPMP approach emphasizes management at the scale of individual compartments rather than at the global forest-wide scale of the forest. Nevertheless, experience in the RBCMA has shown that a global forest wide scale inventory is necessary for long term planning over the 40 year cutting cycle. Given the cost of a forest wide FMU scale inventory, an intermediate approach has been taken with the implementation of an inventory for an area that can be sustainably harvested over the next quinquennial in the cutting cycle. The concept of the Annual Allowable Cut (AAC) is applied only to the pre- established annual cutting coupe based on a stock survey and the calculation of cutting intensities for each commercial species or species group.

4.4.1.1 Forest Mapping and Inventory

Quantifying the Population of Trees (The Stock Survey)

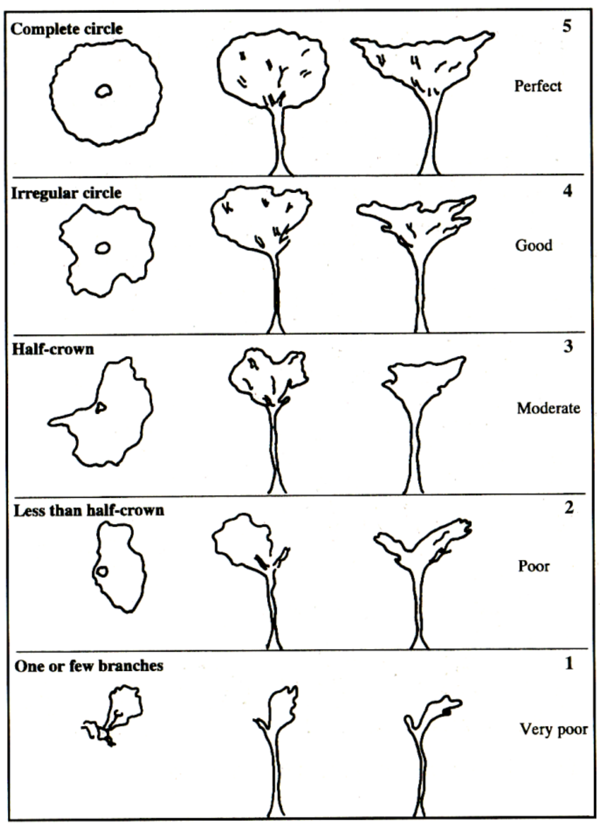
The pre-harvest stock survey is carried out in an annual cutting block in the year prior to harvesting. The aim is to measure and map the growing stock of all species to be included in the harvest so that the data may be analyzed using the yield models to estimate an allowable cut. The physical method used to survey trees may vary over time as improvements in technology allow for more efficient surveys, but the data to be collected and the method of measurement should be standardized across all years. The following set of rules will apply in each annual compartment surveyed:

1. Mahogany trees should be censused to a minimum diameter of 10 cm;
2. All other hardwood species should be censused to a minimum diameter of 25 cm, except for Sapodilla which may be censused to a minimum diameter of 35 cm;
3. All trees surveyed should be liberated from vines during the stock survey;
4. Trees should fall into one of the following categories: Crop (commercial stems ≥MCD), Future (pre-commercial stems <MCD) and Seed trees (trees of any size ≥30 cm of excellent stem and crown form, but 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 should be assessed: species, DBH, X/Y position;
6. For Crop trees the following should 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. Details of these systems are as follows:

   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.

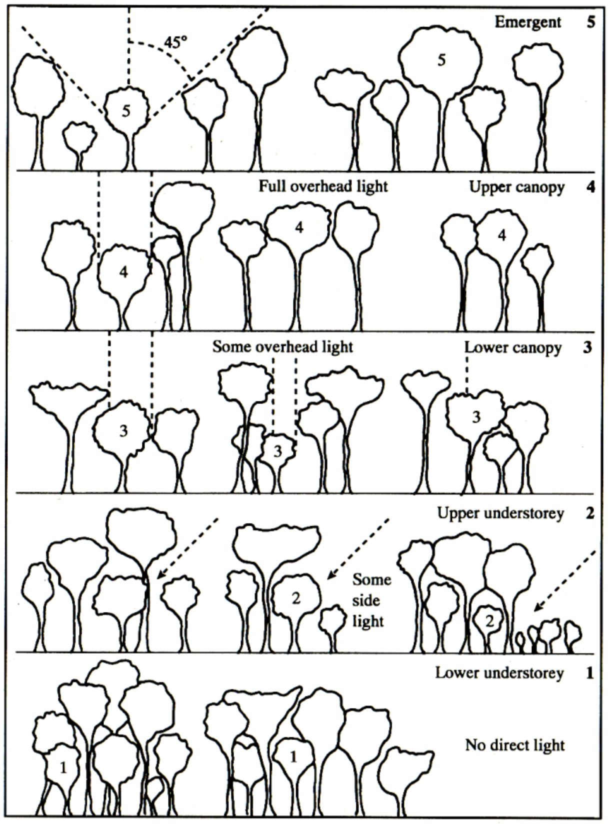
Dawkins crown form:

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.

Source: Bird (1998)

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.

Source: Bird (1998)

Synnott climber presence:

The Synnott climber 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

7. All diameter measurements should be made to the nearest 0.1 centimeter and all height measurements should be made to the nearest 0.1 metre;
8. A layout of the survey transects within the compartment should be provided with the stock survey data in shapefile format;
9. The stock survey data should be presented digitally as a single Excel spreadsheet named Annex II in the following format:

Tree No.	Function	Species	DBH (cm)	Stem Height (m)	X (UTM)	Y (UTM)	Log Grade	Dawkins Crown Form	Dawkins Crown Position	Synnott Climber Presence
..	..	..	..	..	..	..	..	..	..	..

Where, Tree No. should consist of the transect and number of the tree as it is encountered on the transect, for example 9-35, which would be the 35th tree encountered on the 9th transect. Other variations of this numbering system may be used as long as it follows the general concept. The tree number should appear on the stump of each tree as well as the ends of the logs. Function describes the role of the tree (Crop, Future, Seed or Reserve). Species is the common name of the species. DBH is diameter at breast height (1.3 m from the ground). Stem height is the height of the tree stem from the ground to the first major live branch. X (UTM) is the easting of the tree in NAD27 UTM Zone 16 coordinate format. Y (UTM) is the northing of the tree in NAD27 UTM Zone 16 coordinate format. Log grade is the numerical commercial class of the log as described in point 6. Dawkins crown form is the numerical class of the crown form as described in point 6. Dawkins crown position is the numerical class of the crown position as described in point 6. Synnott climber presence is the numerical class indicating the level of presence of climbers as described in point 6.

4.4.1.2 Silviculture

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 (e.g. conservation of tropical forests vs. intensive production from pine plantations) 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 (liberation) of a forest to meet management objectives and maintain or enhance forest productivity, resilience and value. The implementation of a silvicultural system results in forest stands of a distinctive form (physiognomy).

Silvicultural systems in natural forests are categorized broadly as either monocyclic (uniform, even-aged) or polycyclic (selective, uneven-aged). Monocyclic silvicultural systems rely on natural or artificial recruitment of seedlings after felling to produce the next crop of trees, whereas polycyclic silvicultural systems generally make use of existing stock of seedlings, saplings, and poles in the forest to produce the next crop. 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. There are many variations of these two broad systems, depending on biological, ecological, economic, and social conditions and management goals.

In planning a silvicultural system, it is important to have adequate biological and socioeconomic information on the forest collected during the forest inventory, as well as sufficient knowledge of operational aspects such as weather, access, funding and human resources. Also, a good understanding is required of the ecology of the forests in which silvicultural interventions are planned, especially the structure of the existing stand and the requirements for ensuring the adequate regeneration of desirable species. All of this has been discussed in previous chapters.

To design a silvicultural system, first let's review management objectives:

1. Selectively harvest trees from a small fraction of the total forest area per year
2. Harvest an amount of trees that is equal to or less than the amount of trees the forest can replace naturally
3. Maintain continuous forest cover, structure, and composition
4. Where necessary and economically viable, aid natural regeneration through enrichment planting and tending of seedlings and saplings.
5. Biodiversity preservation, watershed management, soil conservation, tourism enhancement, transportation upgrade and research.

Second, let's review relevant ecological and site characteristics of the current forest management area:

1. Naturally regenerating broadleaf forest disturbed by hurricane
2. Mixed-species with several dominants in different vertical strata
3. Uneven-aged with few remnants forming identifiable emergent canopy
4. Natural regeneration with several species requiring hurricane disturbance

Based on the above objectives and the fact that the forest is uneven-aged, the silvicultural system for the current forest management area has to consist of selective logging on a polycyclic basis. Other data-driven considerations in the design of an improved silvicultural system are discussed below.

The Improved Silvicultural System – Cohort Resiliency (CoRe) System

To support the new timber management regime proposed for the current forest management area, a new and improved silvicultural system and forest regulation method is required. In order to present an advancement in forest management, it must build on the previous but outdated and data-lacking outcomes of the Forest Management and Planning Project (FPMP) and must represent an advancement over previous methods. Also, uncertain at the time of FPMP was the growth rates of the different species. Without growth data, sustainable yields could not be calculated with any precision and minimum cutting diameters were only guesswork. Now that all the required data is at hand, these elements of the silvicultural system and yield regulation method can be revised and improved.

The inventory of the current forest management has revealed some vital information about the demographics of all timber species but most importantly it has elucidated important demographic patterns of the most valuable timber species – Mahogany. Based on the sample, two important conclusions can be made. First, it appears Mahogany does not regenerate under an intact canopy, even one heavily disturbed by logging, in sufficient numbers to replace the stocking in the commercial diameter classes. However, there is evidence to suggest that the species regenerates *en masse* following hurricane disturbance. Second, due to repeated logging in the past, without suitable ecological controls to ensure sustainability, the stocking of Mahogany in the commercial size classes is much reduced relative to the mid-sized classes. The demographic pattern of some of the major timber species is shown in Fig. 18 for reference.

There is mounting evidence from FORMNET-B (Cho *et al.*, 2013) and from nationwide forest inventories that supports the notion that primary timber species, Mahogany and Cedar, do not recruit under an intact canopy but rather they require large scale disturbances in conjunction with fire to expose mineral soil in order to recruit in numbers necessary to withstand exceptionally high seedling-phase mortality. Such large scale disturbances come in the form of periodic hurricanes, with return periods more or less matching the rotation age of the species.

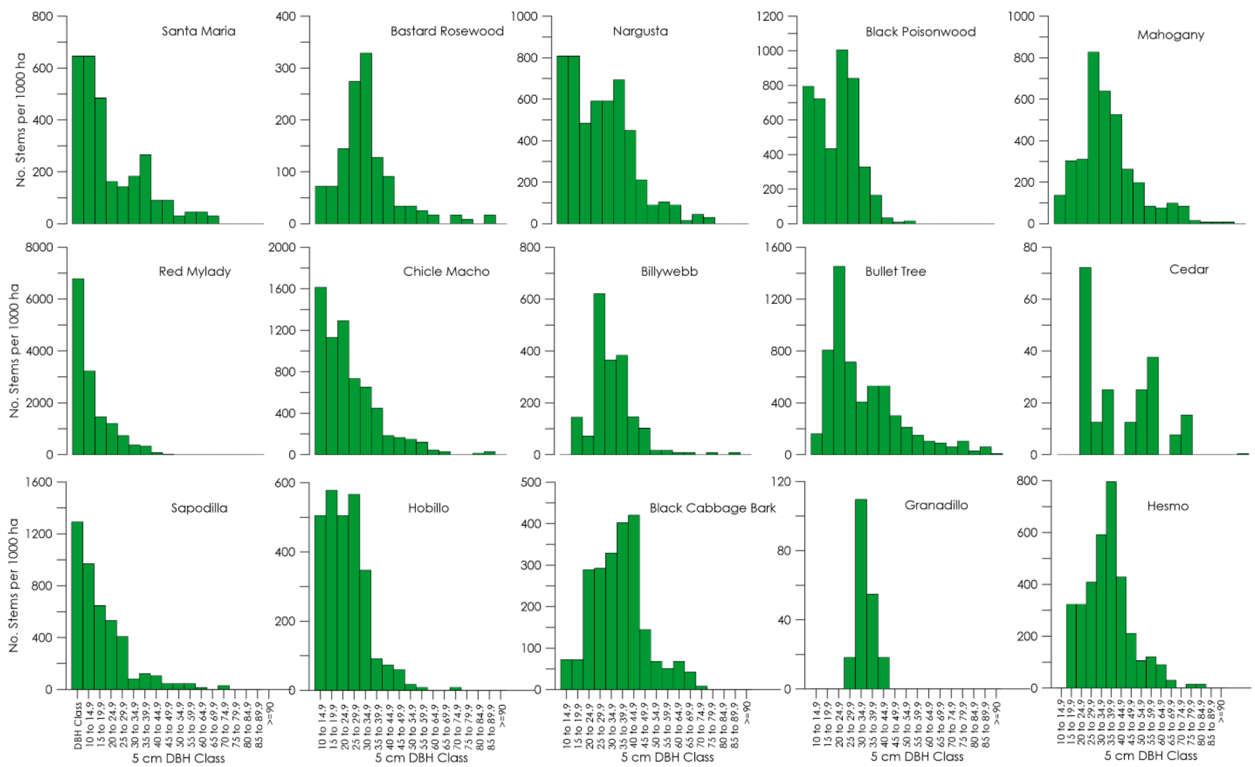


Figure 18. Commercial species diameter distribution at the landscape level.

Graphs represent the population in the average 1,000 ha logging compartment.

Management of Mahogany and Cedar should therefore aim to support a healthy population of large seed bearing trees, which are more sturdier and better able to survive hurricanes, distributed more-or-less evenly across the forest, while trees in the mid-size diameter classes are sought for timber. No expectation should be made on replacement of stocking through regeneration in the absence of disturbance. The strategy should be to determine a yield that the present population can sustain without prejudicing the ability of the future population to regenerate following a large-scale disturbance in sufficient quantity to replenish or increase its population size. The yield should therefore be determined as sustainable if at least one additional harvest is possible from the mid-size diameter classes at the next felling cycle. The length of the felling cycle should be roughly half of the rotation age of the species, which evidence suggests is around 80 years.

Based on research in FORMNET-B and data collected in the forest inventory of the current forest management area, unlike Mahogany, it appears that most secondary hardwoods are 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, should be maintained. Despite this, the size and structure of the pre-commercial population will never-the-less determine the size of the harvest and the cutting cycle. And, 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. Harmonization of the cutting cycles between primary and secondary hardwoods will therefore be a necessary challenge of this new silviculture system.

One way to do this is 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.

Besides the numerical safeguards on sustainability there must also be spatial safeguards. The larger the annual cutting area, the greater the need to ensure that large seed bearing trees are evenly distributed. The harvest, however, must be proportional to the spatial distribution of mid-sized trees so as to leave an evenly distributed residual population. The overall objective is to leave a population of trees that is more resilient to hurricanes, and better able to take advantage of the space created by the opening of the forest canopy.

In Belize logging is allowed in only a fraction of the forest in any given year. And since hurricane disturbance is the primary driver of recruitment of timber species, one of the aims of silviculture has to be to prepare a resilient forest which is able to regenerate after hurricanes. The below decision tree shown in Fig. 19 demonstrates the considerations leading to the selection of a silvicultural system for the current forest management area.

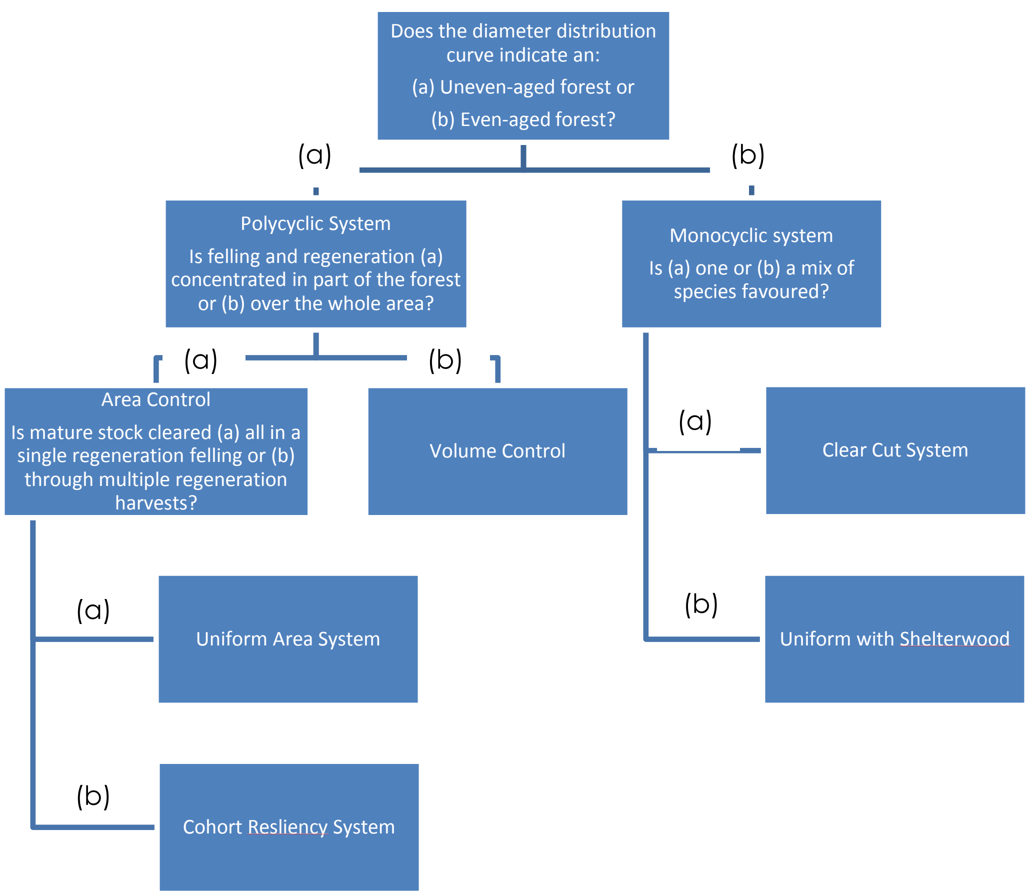


Figure 19. Silvicultural decision tree for natural broadleaf forests

The logical silvicultural system suitable for the forest area is referred to here as the "Cohort Resiliency (CoRe) System" which is a polycyclic selective area/volume hybrid control system. The cycle length is 40 years, which is roughly half the time to maturity for a typical Mahogany tree. This system aims to maintain forest structure through careful selection of harvest trees, while maintaining harvest levels over consecutive felling cycles until the last cycle when the stand is readied for natural regeneration following hurricane disturbance. The concept of the CoRe System is to leave a forest with sufficient trees and adequate structure to ensure biodiversity conservation and species recruitment in the event of a large-scale disturbance. The features of this CoRe System and the timing of interventions are described below.

Silvicultural Interventions (Treatments)

A *silvicultural treatment* is a planned programme of silvicultural interventions that can be implemented during the entire or partial cycle of a stand. Silvicultural interventions should be planned in accordance with the management objectives of the forest. Silvicultural interventions are necessary to address the relative depletion of some commercial tree species caused by past logging, 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. The planned treatments for the forest in the current management area are:

1. **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;

2. **Regeneration treatments** - retention and management of sufficient seed trees and growing stock of commercially valuable species to induce regeneration at the next hurricane disturbance. Natural regeneration will be relied upon;
3. **Stand-tending treatments** - liberation thinning from climbers to favour growth of future crop trees of commercial value.

These treatments will involve designating trees in the stand into functional groups:

a) **Future** - Any tree of a marketable species that is between the minimum diameter inventoried (MDI) and the minimum cutting diameter (MCD);
b) **Crop** - Any tree of a marketable 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 marketable 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 maturity size, 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.

A primary consideration of the CoRe silvicultural system is the size of trees to be cut. This is commonly defined as the minimum cutting diameter, because only trees larger than this diameter are considered merchantable. A merchantable tree is one that is of sufficient size and stem quality that it can be harvested and manufactured into wood products. For example, merchantability can be described as when a tree will provide at least one 5-metre log to a 30 cm top diameter. Most trees 45 cm DBH and larger are assumed to meet this requirement, but in some species wood quality improves through the deposition of exudates in the heartwood at larger stem sizes. Another consideration for choosing a minimum cutting diameter is the size at which trees between to slowdown in growth, though this consideration is more relevant for monocyclic systems. In any case, most species, including Mahogany, tend to slow in growth rate around 40 to 50 cm DBH. For the purposes of estimating yield, only trees above the minimum merchantable tree size are considered.

Additionally, another important consideration of the CoRe System is the need to preserve forest structure, particularly the emergent canopy comprising the largest of trees. Therefore, a Maximum Cutting Diameter (MaxCD) is prescribed for all species. This is usually 90 cm for most species such as Mahogany and Cedar, or is lessened to 60 cm in the case of species which do not generally attain large tree status. Table 8 below shows the MinCDs and MaxCDs in use on the RBCMA.

Table 8. Minimum and maximum cutting diameters for different species.

Species	MinCD	MaxCD
Barbajolote	45	90
Bastard rosewood	45	90
Billy webb	45	90
Bullet tree	45	90
Cabbage bark (black)	45	90
Chico zapote	45	90
Granadillo	45	90
Hobillo	45	90
Mahogany	50	90
Mylady (red)	45	60
Nargusta	45	90
Poison wood (black)	45	60
Salmwood	45	60
Santa Maria	45	90
Sapodilla	45	90
Yemeri	45	90

Timing of Silvicultural Operations

Silvicultural operations are procedures that aim to achieve stand-specific objectives by using silvicultural treatments. Silvicultural operations involve decisions on timing, manpower, machinery and other equipment, techniques, work organization and human resources, as well as considerations of operational cost and investment.

The following timeline will be followed in the implementation of the Cohort Resiliency System in the current forest management area:

Liberation will be combined with the stock survey to minimize costs of re-entry into the forest and consist of crews cutting ground-dwelling 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. No thinning is envisioned in this natural forest.

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.

Residual logging damaged caused when trees are broken, scraped or uprooted during road construction, felling and skidding increases mortality associated with logging and intensifies the release of carbon dioxide. Both of these negative side-effects of logging must be reduced to preserve the integrity of the forest and its various biotic and abiotic components.

Reduced impact logging (RIL) methods will be utilized during the stock survey, felling, skidding and hauling in order to minimize logging damage in the annual harvesting block. The RIL methods will follow the national code for timber harvesting distributed by the Forest Department. Contractors will be required to adhere to this code during the logging operations.

A primary action to minimize logging damage will be the cutting of lianas and vines during the pre-harvest stock survey. Since the pre-harvest stock survey is usually done about six months to a year before the logging operation, lianas and vines would have died and weakened by the time trees are felled. This reduces damages caused when felled trees pull down or snap branches off other tied-up or connected trees. To assess the effectiveness of RIL methods, and consequently to adjust where necessary, an assessment of damage will be made following the close of the logging coupe through a post-harvest assessment.

In the improved silvicultural system, regeneration of timber stocks will be approached proactively through the preparation of the stand during logging. Unless through minor planting interventions in barquadiers, lines or roads, natural regeneration will be relied upon to replace timber stocks through the life of the stand. Regeneration is a long-term process and the expectation is not for post-logging regeneration to form the next harvest, rather post-logging regeneration should be sufficient to replace advanced regeneration killed during logging or enhance the levels of advanced regeneration where it is lacking. Where regeneration does not naturally occur under modest levels of disturbance, such as by logging or blow downs, the plan is to prepare the stand to regenerate following large-scaled disturbances such as hurricanes. This last point relates particularly to Mahogany and Cedar which are light-demanding climax species.

A major problem in open-canopy regeneration mechanisms, such as in gaps or large areas opened up by hurricanes, is the burdening influence of lianas and vines on young saplings. The growth of young saplings is quickly suppressed by faster growing lianas and vines which entangle the crown of these small saplings forming a shade blanket extending from one to the next. Simply planting or allowing for natural regeneration does not guarantee that saplings will grow to large trees in the future. In the Chiqiubul following hurricane Hattie, there was ample natural Mahogany regeneration, but in a subsequent inventory it was determined that the regeneration was suppressed under a mat of vines and lianas. A large scale program was initiated in the decade following the hurricane to release these saplings from vine suppression. This activity undoubtedly has led to the high levels of large tree stocking currently observed in the Chiquibul forest.

Tending of regeneration will be carried out on a prescriptive basis depending on the observations made during the stock survey, or on general observations throughout the management area. This may be intensified following any future hurricane disturbances or in large gaps where vine influence may be overwhelming gap-phase regeneration.

Mahogany is the economic keystone species in timber operations and its marketability drives the economic viability of the logging operation. If an area of forest does not have sufficient numbers of large Mahogany trees to justify logging, it may well be skipped. However, if it is well stocked with another sought after species such as Black Cabbage Bark; it may be logged in conjunction with another compartment that is well stocked with Mahogany. These are all management considerations made on an annual basis. A logging regime should be flexible enough to allow for selection of multiple compartments in an effort to balance the variation in stocking of different timber species while maintaining integrity of the forest.

As a consideration, a block of forest logged as a unit should be large enough to contain a population of trees that can be considered as ecologically distinct from adjacent blocks of more or less the same size. A new management approach involves the consideration of each compartment or block of adjacent compartments, once logged together, as its own management unit, with prescriptions unique to the forest contained within it, and a yield and MCDs calculated to match the size of the population. Already ecological data derived from the national permanent sample plot network (FORMNET-B) supports this concept.

There is mounting evidence from FORMNET-B (Cho *et al*., 2013) and from nationwide forest inventories which suggest primary timber species, Mahogany and Cedar, do not recruit under an intact canopy but rather they require large-scale and very rare disturbances to recruit in numbers necessary to replace stocking in the upper diameter classes removed through logging. Such large scale disturbances come in the form of periodic hurricanes, often followed by fire. Management of Mahogany and Cedar should therefore aim to support a healthy population of large seed bearing trees, which are more sturdier and better able to survive hurricanes, distributed more-or-less evenly across the forest, where patchiness allows, while trees in the mid- to upper-size diameter classes are sought after for timber. No expectation should be made on replacement of stocking through seeding in the absence of disturbance. The strategy should be to determine a yield that the present population can sustain without prejudicing the ability of the future population to regenerate following a large-scale disturbance in sufficient quantity to replenish or increase its size. The yield should therefore be determined as sustainable if at least one additional harvest is possible from the mid- to upper-size diameter classes within a period of time equal to the cutting cycle decided for the forest. Forty years is used as the cutting cycle length for the RBCMA because it: (i) allows for replacement of the harvest if pre-commercial size classes were saturated; (ii) permits other abiotic and biotic elements of the forest to recover after logging; (iii) and is consistent with a full area control system of harvest. However, it does not allow for the optimization of economic benefits from the forest considering natural mortality rate and induced mortality due to disturbances. A shorter cutting cycle of say 25 years would be better at affording economic benefits from the forest. Ideally, however, the cutting cycle ought to vary with compartment depending on stocking.

One potential complication of this is that it may lead to confusion as to the length of the cutting cycle used in a given block. Hypothetically speaking, if the population size and structure were the same in all logging compartments then all compartments would support the same cutting cycle length. However, in Belize's forests, under natural setting, populations in compartments would be heterogeneous due to spatial variation in the distribution of species. One way to achieve similar cutting cycles across compartments is therefore to vary the area of the cutting compartment to account for spatial distribution and to attain equal-sized populations. This is called volume control, and is practiced in temperate, even-aged, single-species, coniferous forests where the population structure is easily known at the landscape level. A simple timber cruise in a given area of even-aged coniferous forest can inform the size of the compartment needed to achieve a desired volume. This is not easily done in tropical, uneven-aged, mixed-species hardwood forests where stocking of different species may be patchy across the landscape. On one hand, increasing the size of a compartment may achieve a desired stocking of Mahogany, but on the other hand it may lead to a larger population of a secondary species that is not desired, leading to suboptimal use of the timber resource. It would be an inordinately expensive and perhaps impossible undertaking to stock survey several compartments consecutively until a desired population size is encountered for each species. Therefore, given the new data on Mahogany growth and variable population size from compartment to compartment, a hybrid system of volume control with a set cutting cycle is the more suitable management system for RBCMA's forests.

Based on research in FORMNET-B and data collected in forest inventories across the country, unlike Mahogany, it appears that most secondary hardwoods are 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, should be maintained. Despite this, the size and structure of the pre-commercial population will never-the-less determine the size of the harvest and the cutting cycle. And, 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. Harmonization of the cutting cycles between primary and secondary hardwoods will therefore be a necessary challenge of this new forest management system. One way to do this is 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.

Besides the numerical safeguards on sustainability there must also be spatial safeguards. The larger the annual cutting area, the greater the need to ensure that large seed bearing trees are evenly distributed, where possible, given inherent patchiness. The harvest, however, must be proportional to the spatial distribution of mid-sized trees so as to leave an evenly distributed residual population. The overall objective is to leave a population of trees that is more resilient to hurricanes, and better able to take advantage of the space created by the opening of the forest canopy after catastrophic disturbance.

4.4.1.3 Yield and Production

Paramount to this new silvicultural system is the data-driven realization that hurricanes are the primary agent of stand initiation in Belize's forests and that at the time of a hurricane the old ecological regime ends and a new one begins. What this means is that all populations of all species are affected to a certain extent and can be considered to be reset by hurricane disturbance. The process of resetting a population of trees involves primarily taking out some of the old stock so that space is made for new individuals. A flurry of regeneration therefore occurs after hurricanes, be it from advanced regeneration (saplings existing before the hurricane) or open-canopy regeneration which occur from seeds which germinate in the high light environment following hurricane disturbance. Species can be classed into either of the preceding two groups: Mahogany falling into the latter. Based on a decade of forest inventories, we know that Mahogany does not occur as saplings under an intact canopy in sufficient numbers to replace stocking in the larger diameter classes. Regeneration is therefore periodic, following major hurricanes. The primary goal of the new silvicultural system is therefore to prepare the stand for the next stand initiation event.

The approach for estimating a yield for Mahogany and other species exhibiting even-aged population structures should not be aimed at determining a 'sustainable yield', according to its common definition. Instead the strategy should be to determine 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. 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 withstand annual mortality up to the next hurricane and still survive with sufficient intact stems to allow for regeneration and stand replacement. This theoretical minimum stem density can be termed the 'restocking threshold'. A population approaching this 'restocking threshold' can be termed the 'initiation stand'. With this consideration in mind, the life-line of a typical managed stand of Mahogany on the RBCMA can be described by:

1. Stand initiation in the high-light environment following a major hurricane
2. A series of intermediate pre-commercial liberation (can be combined with harvests)
3. One or more harvests, if stand is above the 'restocking threshold'
4. At final harvest, prepare the 'initiation stand'.

So what does the 'initiation stand' resemble and how do we determine the 'restocking threshold'? Larger Mahogany trees have more extensive root systems, bigger buttresses and more mass than smaller trees and may simply be too heavy to topple or break in strong winds. Large trees also are generally better seed producers. The size threshold here that defines 'large' is typically 50 cm DBH. Observations in logged forests following Hurricane Iris in 2001 and Richard in 2010 support this notion of 'large'. 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. However, data gathered elsewhere following Hurricane Richard in 2010 show that trees as small as 25 cm DBH also survive hurricane force winds in good numbers, and produce seeds subsequently. Consequently, 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. Recall here that the initiation stand is the stand after the final harvest, which will in theory be allowed time to grow before the next disturbance, allowing trees ≥25 cm DBH to achieve 'large' tree status. Contrary to this, but along the same reasoning, it can be argued that *all* the trees in the initiation stand can be chosen from those ≥25 cm DBH, since they will likely grow to be large trees at some point in the future. However, 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 exceptionally large trees ≥90 cm DBH, on account of their rarity, resilience and importance in maintaining upper canopy structure. All trees ≥90 cm should be protected from felling and form part of the initiation stand.

So what is an adequate population size for an initiation stand, *i.e.* what is the 'restocking threshold'? Previous observations and data collected in Belize and elsewhere have led other authors to conclude that a minimum of 10 large Mahogany trees 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. This is rather a large area to be seeded by a single tree. More reasonable seeding effort would be around 4 hectares for every tree, which means leaving 25 instead of 10 trees per square kilometre to restock an area after logging. However, annual mortality would have the effect of reducing the number of trees by a certain amount between the final harvest 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, 25 trees would be reduced to approximately 12, at 0.7 % yr^{-1} annual mortality. To achieve survivorship of 25 trees at the end of 100 years, the 'restocking threshold' should be 50 trees per square kilometre. At this 'restocking threshold' the re-seeding effort will be halved to 2 hectares for every tree immediately after logging.

Based on the above principles, the estimation of the yield for Mahogany will be highly dependent on the population size and structure in a given compartment, and less on the common principles governing the recuperation of yield over the cutting cycle. Mahogany yield will therefore be determined primarily by the re-stocking threshold, otherwise if ample stocking exists, then by the principles of sustained yield using the 'passage of time' model.

The adoption of a volume/area control hybrid as opposed to strict area control does away with the practice of harvesting equal-sized compartments in sequence from year to year based on a pre-defined order. Indeed there is no need to divide the forest area by the length of the cutting cycle to determine a compartment size. In fact, yield regulation and forest management becomes specific to an individual cutting compartment, once it is formed from the selection of adjacent 1 km^2 sub-compartments. In principle, the entire forest area can be considered as comprised of independent forest management units operating on management and silvicultural prescriptions customized to each respective compartment.

This approach makes allowances for greater flexibility to adjust the timber operation to accommodate fluctuating economic and market trends. For example, if in a given year Mahogany demand is down but supply is up, there is the option to forego logging for that year. A compartment would not have been skipped, since a compartment will only be formed from a group of 1 km^2 sub-compartments when it is first logged. If three years are skipped, there are no three compartments which must be logged when logging resumes. The compartments are only formed at the time of logging.

Stand Dynamics and Yield Modeling – Growth, Mortality and Recruitment

While a silvicultural system and estimates of population size and structure are requisite data for developing timber management prescriptions, estimates of growth, mortality and recruitment rates are needed for the modeling of timber yield. These are known as forest dynamics rates and can be estimated for individual species or groups of species, where individual sample size may be small.

The data used to determine species growth, mortality and recruitment rates come from the Forest Monitoring Network of Belize (FORMNET-B) (Cho *et al*. 2013). National averages are used as there are currently too few permanent sample plots in the RBCMA forest. National data on tree growth was gathered in plots in the Rio Bravo Conservation and Management Area, Chiquibul Forest Reserve and Columbia River Forest Reserve between 1992 and 2013. The data is stored in the National Permanent Sample Plot Database of Belize.

To deal with rare species, the national system for grouping species was used to analyze group mean rates for Prime, Elite and Select species. Growth was calculated as annualized increment or change in a tree's diameter over a length of time: $g = \frac{DBH_t - DBH_0}{t}$

Mortality was expressed as an instantaneous rate and was calculated using the exponential mortality coefficient equation of Sheil *et al*. (1995):

$$\lambda = \frac{\ln N_0 - \ln N_t}{t} \times 100$$

where λ is the exponential mortality coefficient (expressed as per cent per year), N_0 is the number of stems at the start of the census interval, N_t is the number of stems at the end of the census interval, and *t* is the census interval length (in years). Mortality rates were corrected for census interval length effects (Sheil and May, 1996) following the method proposed by Lewis *et al*. (2004), *i.e.* λ was standardized to one common census interval length by the equation:

$$\lambda_{corr} = \lambda \times t^{0.08}$$

where λ_{corr} is the mortality rate corrected for varying census length, λ is the uncorrected mortality rate, and *t* is time between censuses in years.

Central to the calculation of sustainable yield is the 'time of passage' model, one of the simplest and perhaps most widely applied models of forest growth and yield in the tropics. It is based on the concept of the time it takes for an average tree to grow through one size class and into the next, given the mean diameter increment of trees in a given size class. Time of passage was calculated for each size class in the different species groups using the following formula:

$$time\ of\ passage\ (years) = \frac{size\ class\ width\ (cm)}{increment\ (cm\ yr^{-1})}$$

Table 9 gives estimates of growth, mortality and time of passage for the three species groups. These figures are used in a growth and yield model described further below to estimate the sustainable yield of each species.

Table 9. Growth and mortality rates for the different species groups.

NB: Growth data were unavailable for Mahogany trees larger than 80 cm DBH, thus growth rates for Mahogany size classes above 80 cm were assumed to be the same as the rate for the class immediately below. Cumulative age for the different groups was calculated relative to the 25 – 29.9 cm DBH class.

Species Group	Parameter	←---Diameter class (cm)---→													
		25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	>90
Prime	Inc. (cm yr^{-1})	0.488	0.565	0.632	0.682	0.711	0.714	0.686	0.623	0.518	0.368	0.167	0.167	0.167	0.167
	Mort. (% yr^{-1})	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701	0.701
	Time of passage	10.3	8.8	7.9	7.3	7.0	6.9	7.3	8.0	9.6	13.6	29.9	29.9	29.9	29.9
	Cumulative Age	n.a.	19.1	27.0	34.3	41.4	48.4	55.6	63.7	73.3	86.9	116.9	146.8	176.7	206.7
Elite	Inc. (cm yr^{-1})	0.500	0.536	0.549	0.544	0.523	0.490	0.448	0.399	0.347	0.296	0.247	0.205	0.172	0.151
	Mort. (% yr^{-1})	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292	0.292
	Time of passage	9.9	9.3	9.1	9.2	9.5	10.2	11.2	12.5	14.4	16.9	20.2	24.4	29.1	33.1
	Cumulative Age	n.a.	19.3	28.4	37.6	47.2	57.4	68.5	81.1	95.5	112.4	132.6	157.1	186.2	219.2

Select	Inc. (cm yr^{-1})	0.366	0.388	0.398	0.398	0.389	0.372	0.349	0.323	0.294	0.263	0.232	0.203	0.178	0.157
	Mort. (% yr^{-1})	2.053	2.053	2.053	2.053	2.053	2.053	2.053	2.053	2.053	2.053	2.053	2.053	2.053	2.053
	Time of passage	13.6	12.9	12.5	12.5	12.8	13.4	14.3	15.5	17.0	19.0	21.5	24.6	28.1	31.9
	Cumulative Age	n.a.	26.5	39.1	51.6	64.5	77.9	92.2	107.7	124.7	143.7	165.2	189.8	217.9	249.8

The time of passage model allows the growth of a stand into the future to model the estimated yield. For example, given a population of 100 Mahogany trees with a hypothetical population structure 'A' (Fig. 23), an annual mortality of 0.7% and an arbitrary minimum cutting diameter of 60 cm, the time of passage model would suggest that in 20 years the population would resemble 'B', and that there would be an increase of 9 merchantable trees above the MCD resulting from growth over the period, but a loss 21 trees below MCD. These 9 trees would represent the yield, but one that cannot be achieved at every 20 year cutting cycle into perpetuity without recruitment. The new silvicultural system addresses the observed pervasive lack of recruitment of Mahogany.

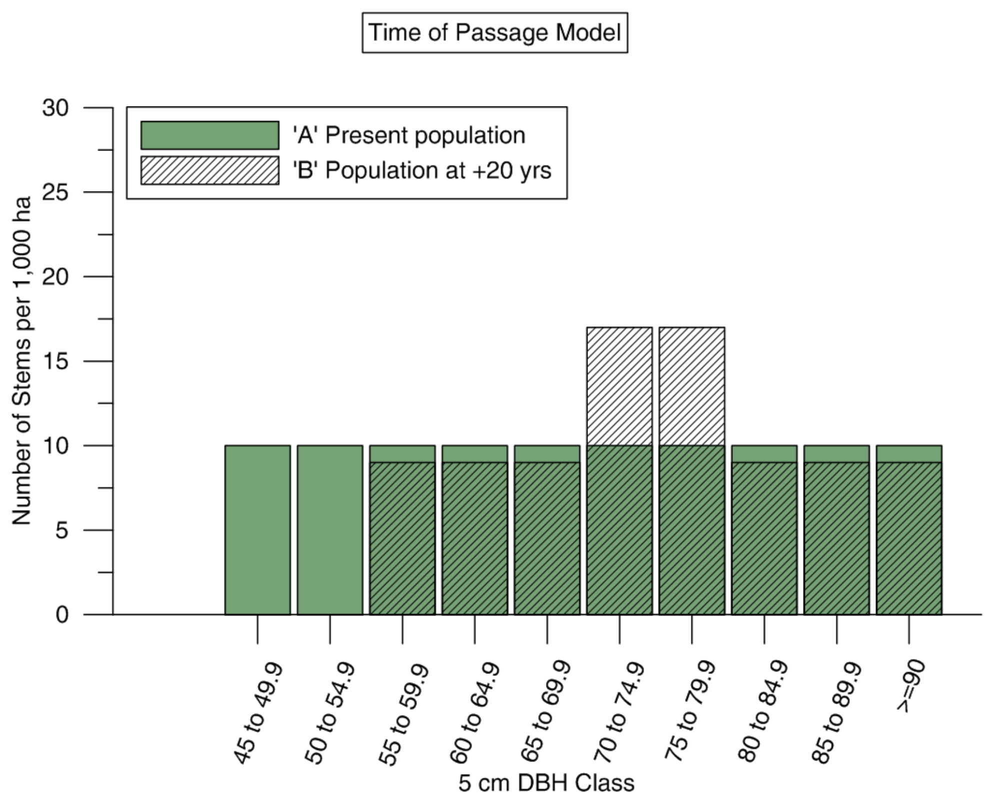


Figure 20. Time of passage model for Mahogany using a 20 year cutting cycle.

Green bars represent the population at present, while the diagonal shaded bars represent the future stand after mortality is accounted for. In order to sustain the original population size above MCD, the net off-take is nine trees.

Yield Calculation, Crop Selection and the Annual Allowable Cut

Yield calculation and selection is the science of determining *inter alia* which species and how many trees of each may be harvested, from where, and how often. This chapter describes a timber yield regulation system designed to be in synchrony with the silvicultural system in place and have minimum ecological impacts. This yield regulation system is designed to be in harmony with the natural turnover and disturbance mechanisms at work in the forests so as to ensure an optimal sustainable yield. Recall that each annual cutting compartment is taken as an individual management unit, thus, the yield is calculated at the level of the population of trees inside the compartment. This means the yield will vary from compartment to compartment as tree density varies across the landscape, but within each compartment the yield should be sustainable over multiple cutting cycles. To estimate the sustainable yield of a compartment, the population of trees in it must first be quantified through what is known as a stock survey. The process of calculating the yield, selecting the crop, and determining the annual allowable cut is described in this section.

The term yield actually has two meanings. It can refer to the total amount of timber (expressed as number of trees or volume of round or sawn wood) that can be harvested in one go at any time (usually in a monocyclic system), or it can refer to the amount that can be harvested continuously from the same stand of forest (in a polycyclic system). Yield and net growth, which refers to the net change in total amount of timber over some specified period of time, are essentially the same thing if after removal, the net growth can again be accumulated within the specified period of time (the cutting cycle). Generally, the amount of timber that a forest or stand can yield on a period basis is equal to the <u>net</u> growth that has accumulated between periods, this is known as accruement. The sustainable yield can be less than the accruement since deductions are often made to ensure the quality of future crops, preserve forest structure, induce regeneration, and maintain biological diversity. In some instances the sustainable yield can be greater than accruement, if for example, there is a hyper abundance 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 rates.

Understanding the volume and projected supply of timber from the management area over multiple cutting cycles provides the basis for demonstrating the economic benefits that will arise from sustainable management of the forest. This is essential to realise PfB's objective of growing high quality timber in the long term and making effective use of the forest resource.

The Cutting Cycle

One of the primary objectives of forest management is to provide a sustained yield of timber from a given block of forest over multiple cutting cycles, and to do this what is felled must be less than the periodic growth of the merchantable trees during the intervening period between cutting cycles. The determination of an appropriate cutting cycle length is therefore one of the key steps in developing a sustainable forest management system. The cutting cycle can be defined as the length of time over which an uneven-aged stand of trees is expected to replace the number or volume of trees that was harvested.

The difficulty with prescribing a cutting cycle for the RBCMA forest, however, is in part due to the fact that it is a mixed species forest. In reality, each species should be harvested according to its population structure, size and dynamics in each compartment – quite possibly leading to individualized cutting cycles per species. However, this can only lead to confusion in the long run and is therefore not desirable. Instead, one species has to act as a benchmark, from which its population structure and growth rate is used to determine a general cutting cycle length for all other species. Mahogany is the most valuable timber species and one of the most abundant, making it ideally suited as the benchmark species to use in the calculation of the cutting cycle length. The problem is that this species exhibits an even-aged population structure that is uncharacteristic of most of the other timber species. A reasonable approach, therefore, is to calculate a cutting cycle length based on Mahogany, and then investigate whether it is appropriate for the other species, or else adjust it accordingly.

Mahogany is thought to mature in 80 years, so the generally accepted cutting cycle is half this amount which is 40 years. This is the cutting cycle length that has been decided for the RBCMA.

Yield Calculation

To simplify the process of calculating yield in a multi-species uneven-aged forest, time of passage growth and yield models have been developed for each of the major species groups parameterized using the population dynamics estimates in Table 9. These models use as their input the population of trees from the stock survey.

The growth and yield model chosen for the calculation of stand yield takes the form of an "individual tree" model, which grows trees through time based on size-dependent growth rate applied in 5-year increments, and kills them off based on a cohort level mortality rate over the length of the cutting cycle. The model produces an estimated population at year 40, thereby allowing the estimation of accruement between the present and future populations. Accruement is calculated in terms of trees, as opposed to volume. The accruement is taken to be the estimated sustainable yield of the forest if, after removal through felling, the same accruement is achieved in another 40 years' time, *i.e.* over 2 cutting cycles. If the accruement cannot be maintained after harvest, the level of the harvest can 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. Thus, in the context of the determination of a sustainable yield, both the yield and the mature population structure must be sustained.

The yield model takes the form of an Excel spreadsheet with built in formulas governing growth rates, mortality rates, and other functions. Although this is an empirical growth and yield model, it makes no assumptions regarding the rate of in-growth due to regeneration. This is due to the pervasive lack of data regarding recruitment rates of timber species, especially Mahogany. However, it is not necessary since the silvicultural system calls for the maintenance of a vibrant stock of seed bearing trees after felling, and if this is not possible then felling should be discontinued for that particular species. After an amount of trees constituting the sustainable yield is determined, crop selection becomes the next major step in the yield selection process, and is described in the next section. The steps to using the yield model is described below in Table 10.

Table 10. Steps to using the yield model for broadleaf forests in Belize.

	Steps	What the model does
1	**Import population data from the stock survey:** In the sheet named <Annex II Trees> import Annex II formatted data for species X. Ensure that data are in the right columns. Make sure that the Fxn column is empty.	The model calculates seed tree suitability, stem volume and crown volume where appropriate.
2	**Set model parameters:** In the sheet named <Model parameters> specify the required parameters in the yellow boxes. Choose the appropriate	Based on the parameters entered, the model calculates required seed trees and restocking threshold. It then displays the growth model

	species group, set the cutting cycle, input the size the annual cutting compartment, and specify the MCD to be used.	coefficients as well as the mortality rates to be used in population modelling. The model then estimates the diameter of each tree at the specified cutting cycle. It then kills off trees based on the mortality rate in order to estimate a population at the specified cutting cycle. It subtracts the present from the future population to estimate accruement within merchantable size classes based on the specified MCD. The accruement is used as an indicative yield and the model then estimates how many trees can be cut from each diameter class to make up this indicative yield now and in the future.
3	**Seed tree selection:** Prior to yield selection, the required number of seed trees need to be designated. In the sheet named <Annex II Trees>, use the Seed Tree Suitability (STS) index to select the required number of seed trees that have an STS score of 65% or greater by entering "Seed" into the "Fxn" column for each.	The model checks that the required number of seed trees are selected.
4	**Set desired yield:** In the sheet named <Yield Analysis> examine	The model tries to determine a present indicative yield equal to

	accruement and indicative yield. To check if the indicative yield is a good starting point for crop selection, the future yield should not be more than half of the future residual stocking. If it is more than half, then enter a "User specified yield" in the yellow box that is less than the indicative yield. Continue to enter different iterations until the future yield is approximately half of the future residual stocking. Note the "Indicative yield" column is now called "User specified yield". Only here is it a criteria for the future yield to be not more than half of the future residual stocking. This is the starting point for crop selection, but after crop selection the same principle does not apply.	the accruement while respecting a maximum cutting intensity of 80%. The indicative yield may therefore be less than the accruement. If a "User specified yield" is entered, the model uses that instead of the accruement to estimate the present and future yield from each diameter class. The name of Column D then changes from "Indicative yield" to "User specified yield".
5	**Crop selection:** In the sheet named <Annex II Trees>, examine the "Indicative yield" or "User specified yield" column, whichever the case may be. Note the number of trees from each diameter class that comprises the yield. Now go to the sheet named <Annex II Trees> and select the corresponding number of crop trees from each diameter class	The model then calculates "Actual CI%" and "Actual Yield" which are based on what the user selects as the final "Crop" in the sheet named <Annex II Trees>. The model then kills of the trees selected as crop and grows the rest to the next cutting cycle. The model also kills of other trees based on the natural mortality rate. The model then

	by entering "Crop" into the "Fxn" column. Note that in some cases it may not be possible to find all the crop trees due to stem quality, etc.	attempts to cut the same number of trees comprising the present yield from the population at the next cutting cycle. It then calculates the residual stocking.
6	**Sustainability checks:** In the sheet named <Yield Analysis> check to make sure all values read "Yes" under the heading "Does the harvest meet all numerical criteria?". If not, adjust the crop selection until they do.	Here, the model checks that the restocking threshold is met at present and at the next felling cycle. It also checks that the required number of seed trees were selected. Finally, it checks whether the yield at the next felling cycle is more or less equal to the present yield.
7	**Classify the residual trees:** In the sheet named <Annex II Trees> designate all other trees as either Future, Reserve, Preserve, Salvage or Dead, as appropriate, in the "Fxn" column.	The model then calculates the harvest and residual volumes.

Crop Selection

The silvicultural system and 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. To do this, a number of rules have to be adhered to, which have been discussed in previous sections. Here, the rules are presented collectively to guide the selection of the crop.

1. Firstly, the yield model will determine the quantity of trees that can form the crop.
2. This quantum should not cause the residual population now and at the next cutting cycle to fall below 50 trees per square kilometre that are >=25 cm DBH for Mahogany and Cedar, or 20 trees per square kilometre in the case of other species.
3. The yield should be sustained at least twice.
4. Forest structure should be maintained or improved.
5. Species distribution should be maintained.
6. No tree >=90 cm can be felled.
7. At least 200 seed trees should be identified for Mahogany from above 40 cm DBH or 100 for other species. These should have a minimum seed tree suitability index of 70%. Seed trees need to be distributed proportionately to the observed distribution of the species, and need not be evenly distributed.
8. Crop trees can then be selected from the balance.
9. All trees in the population must be designated as one of either Future, Crop, Seed, Reserve, or Preserve.

One of the steps in crop selection is to establish the smallest tree to be counted as a contribution to growth of the merchantable class. This is commonly defined as the minimum size that is merchantable, because only merchantable trees constitute the yield. A merchantable tree is one that is of sufficient size and stem quality that it can be harvested and manufactured into products. For example, merchantability can be described as when a tree will provide at least one 5-metre log to a 30 cm top diameter. All trees 50 cm DBH and larger are assumed to meet this requirement. Therefore, to estimate growth (and yield), only trees above this minimum merchantable tree size are considered. There are some exceptions to the 50 cm merchantable tree size rule: these are Red Mylady, Black Poisonwood and Black Cabbage Bark, which do not frequently grow very large but can provide merchantable logs 45 cm DBH with sufficient length and strength to produce suitable products like beams and poles.

Annual Allowable Cut (of the Average Compartment)

Inputting in the model the stocking in the average 10 km^2 compartment based on the stand table, the average expected sustainable yield can be calculated for each species (Table 11).

For each timber species, the new growth into the merchantable class (≥ MCD and <90 cm DBH) over 40 years will represent the annual allowable cut (AAC), if the same level of new growth can be achieved at the next cutting cycle after a harvest. The use of cutting intensities can adjust the harvest to less than the accruement so as to balance the present and future yields. Since the input data represent the population in the average 1,000 ha logging unit, the annual allowable cut will be scaled to 1,000 ha at 40 years, and will be representative of the average compartment. The ACC was calculated in terms of trees, but figures for wood volume were produced based on the average volume of trees in different size classes. It is important to note that species which are unable to yield a harvest according to the AAC table can be locally abundant in one or more compartments, and may very well yield a sufficient harvest in some compartments encountered throughout the 5-year period.

Table 11. Expected annual allowable cut of commercial species on a 40 year cutting cycle for the average 10 km² harvesting block within the 2022-2026 quinquennial area.

Species	Variable	Number of stems per the average annual cutting compartment (1000 hectares)														Total	Residual Density (trees km²)
		25 to 29.9	30 to 34.9	35 to 39.9	40 to 44.9	45 to 49.9	50 to 54.9	55 to 59.9	60 to 64.9	65 to 69.9	70 to 74.9	75 to 79.9	80 to 84.9	85 to 89.9	≥90		
	Present Stocking	**352**	**352**	**198**	**308**	**242**	**48**	**40**	**71**	**32**	**16**	**24**	**8**	**8**	**0**	**1,697**	
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
Bastard Rosewood	Present Yield						36	30	54	24	12	18	6	6		**184**	151
MCD=50	AAC (m3)						41.5	40.0	92.8	47.6	23.3	49.4	17.7	20.8		**333**	
Elite	AAC (bdft)						7727	7507	17309	9080	4888	8607	3378	3468		**61,965**	
	Future Stocking	0	0	0	0	313	0	313	176	274	226	36	5	2	2	**1,347**	
	Future CI%						20%	20%	20%	20%	20%	20%	20%	20%		**20%**	114
	Future Yield						0	63	35	55	45	7	1	0		**206**	
	Present Stocking	**198**	**264**	**220**	**242**	**132**	**0**	**8**	**8**	**24**	**16**	**0**	**0**	**0**	**0**	**1,111**	
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
Billywebb	Present Yield						0	6	6	18	12	0	0	0		**42**	107
MCD=50	AAC (m3)						0.0	8.0	10.3	35.7	23.3	0.0	0.0	0.0		**77**	
Elite	AAC (bdft)						0	1501	1923	6810	4888	0	0	0		**15,122**	
	Future Stocking	0	0	0	0	176	0	235	196	215	117	12	0	0	0	**951**	
	Future CI%						10%	10%	10%	10%	10%	10%	10%	10%		**10%**	87
	Future Yield						0	24	20	22	12	1	0	0		**78**	
	Present Stocking	**220**	**418**	**330**	**308**	**198**	**48**	**32**	**8**	**8**	**8**	**0**	**0**	**0**	**0**	**1,576**	
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	150
Black Cabbage Bark	Present Yield						36	24	6	6	6	0	0	0		**77**	

MCD=45	AAC (m3)						41.5	32.0	10.3	11.9	11.7	0.0	0.0	0.0		**107**	
Elite	AAC (bdft)						7727	6006	1923	2270	2444	0	0	0		**20,370**	
	Future Stocking	0	0	0	0	196	0	372	294	274	187	12	0	0	0	**1,335**	111
	Future CI%						20%	20%	20%	20%	20%	20%	20%	20%		**20%**	
	Future Yield						0	74	59	55	37	2	0	0		**228**	
	Present Stocking	**2132**	**1758**	**1143**	**506**	**110**	**24**	**8**	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**5,689**	558
	Present CI%					75%	75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
Black Poisonwood	Present Yield					82	18	6	6	0	0	0	0	0		**112**	
MCD=45	AAC (m3)					77.2	20.8	8.0	10.3	0.0	0.0	0.0	0.0	0.0		**116**	
Elite	AAC (bdft)					14542	3863	1501	1923	0	0	0	0	0		**21,830**	
	Future Stocking	0	0	0	0	1897	0	1564	1017	450	103	4	0	0	0	**5,035**	403
	Future CI%					20%	20%	20%	20%	20%	20%	20%	20%	20%		**20%**	
	Future Yield					379	0	313	203	90	21	1	0	0		**1,007**	
	Present Stocking	**1748**	**1271**	**1245**	**1086**	**874**	**424**	**388**	**247**	**159**	**283**	**106**	**35**	**71**	**13**	**7,950**	667
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
Bullet Tree	Present Yield						318	291	185	119	212	79	26	53		**1,285**	
MCD=50	AAC (m3)						370.0	391.9	321.5	238.5	415.4	220.0	78.6	185.3		**2,221**	
Select	AAC (bdft)						68839	73573	59971	45504	87088	38340	15049	30899		**419,262**	
	Future Stocking	0	0	762	0	554	543	855	46	42	27	48	11	4	14	**2,907**	172
	Future CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
	Future Yield						407	641	35	32	20	36	9	3		**1,183**	
	Present Stocking	**12**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**12**	1
	Present CI%															**0%**	
Cedar	Present Yield							Too rare to harvest (in the average ACC)								**0**	
MCD=60	AAC (m3)															**0**	
Prime	AAC (bdft)															**0**	
	Future Stocking															**0**	0

	Future CI%															**0%**	
	Future Yield															**0**	
	Present Stocking	**185**	**185**	**132**	**79**	**106**	**35**	**0**	**18**	**18**	**18**	**0**	**0**	**0**	**0**	**777**	
	Present CI%															**0%**	78
Chicle Macho	Present Yield						Too rare to harvest (in the average ACC)									**0**	
MCD=50	AAC (m3)															**0**	
Elite	AAC (bdft)															**0**	
	Future Stocking															**0**	
	Future CI%															**0%**	0
	Future Yield															**0**	
	Present Stocking	**424**	**530**	**477**	**530**	**344**	**88**	**71**	**35**	**35**	**0**	**0**	**35**	**0**	**0**	**2,569**	
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	237
Hesmo	Present Yield						66	53	26	26	0	0	26	0		**199**	
MCD=50	AAC (m3)						77.1	71.2	45.9	53.0	0.0	0.0	78.6	0.0		**326**	
Elite	AAC (bdft)						14341	13377	8567	10112	0	0	15049	0		**61,446**	
	Future Stocking	0	0	0	0	377	0	471	424	471	326	32	0	8	0	**2,109**	
	Future CI%						40%	40%	40%	40%	40%	40%	40%	40%		**40%**	142
	Future Yield						0	188	170	188	130	13	0	3		**693**	
	Present Stocking	**264**	**198**	**66**	**110**	**22**	**8**	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**675**	
	Present CI%															**0%**	68
Hobillo	Present Yield						Too rare to harvest (in the average ACC)									**0**	
MCD=50	AAC (m3)															**0**	
Elite	AAC (bdft)															**0**	
	Future Stocking															**0**	
	Future CI%															**0%**	0
	Future Yield															**0**	
	Present Stocking	**398**	**234**	**234**	**199**	**293**	**178**	**188**	**129**	**79**	**129**	**50**	**59**	**30**	**10**	**2,211**	158

	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
Mahogany	Present Yield						134	141	97	59	97	37	45	22		**632**	
MCD=50	AAC (m3)						155.8	189.9	167.5	119.0	189.4	102.9	132.4	78.0		**1,135**	
Prime	AAC (bdft)						28975	35660	31253	22700	39712	17931	25337	13006		**214,575**	
	Future Stocking	0	0	0	0	301	177	177	177	150	255	99	9	11	13	**1,369**	95
	Future CI%						40%	40%	40%	40%	40%	40%	40%	40%		**40%**	
	Future Yield						71	71	71	60	102	40	4	5		**422**	
	Present Stocking	**1165**	**980**	**715**	**874**	**583**	**212**	**124**	**124**	**106**	**53**	**35**	**0**	**18**	**5**	**4,993**	
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
Nargusta	Present Yield						159	93	93	79	40	26	0	13		**503**	449
MCD=50	AAC (m3)						185.0	124.7	160.7	159.0	77.9	73.3	0.0	46.3		**827**	
Select	AAC (bdft)						34419	23410	29985	30336	16329	12780	0	7725		**154,984**	
	Future Stocking	0	0	508	0	427	312	635	23	14	14	17	4	0	4	**1,958**	
	Future CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	119
	Future Yield						234	477	17	10	10	13	3	0		**764**	
	Present Stocking	**1907**	**1457**	**795**	**371**	**238**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4,767**	
	Present CI%					75%	75%	75%	75%	75%	75%	75%	75%	75%		**75%**	459
Red Mylady	Present Yield					179	0	0	0	0	0	0	0	0		**179**	
MCD=45	AAC (m3)					167.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		**167**	
Select	AAC (bdft)					31540	0	0	0	0	0	0	0	0		**31,540**	
	Future Stocking	0	0	832	0	635	347	266	0	0	0	0	0	0	0	**2,079**	
	Future CI%					20%	20%	20%	20%	20%	20%	20%	20%	20%		**20%**	183
	Future Yield					127	69	53	0	0	0	0	0	0		**249**	
	Present Stocking	**1059**	**900**	**662**	**609**	**159**	**177**	**18**	**35**	**71**	**53**	**18**	**0**	**0**	**0**	**3,761**	
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	348
Santa Maria	Present Yield						132	13	26	53	40	13	0	0		**278**	
MCD=50	AAC (m3)						154.2	17.8	45.9	106.0	77.9	36.7	0.0	0.0		**438**	
Select	AAC (bdft)						28683	3344	8567	20224	16329	6390	0	0		**83,537**	

	Future Stocking	0	0	462	0	393	289	335	19	2	4	14	2	0	0	**1,519**	119
	Future CI%						50%	50%	50%	50%	50%	50%	50%	50%		**50%**	
	Future Yield						144	168	10	1	2	7	1	0		**332**	
	Present Stocking	**156 3**	**795**	**662**	**397**	**212**	**106**	**35**	**18**	**35**	**0**	**0**	**0**	**0**	**0**	**3,823**	368
	Present CI%						75%	75%	75%	75%	75%	75%	75%	75%		**75%**	
Sapodilla	Present Yield						79	26	13	26	0	0	0	0		**146**	
MCD=50	AAC (m3)						92.5	35.6	23.0	53.0	0.0	0.0	0.0	0.0		**204**	
Select	AAC (bdft)						17210	6688	4284	10112	0	0	0	0		**38,294**	
	Future Stocking	0	0	682	0	347	289	266	11	4	2	4	0	0	0	**1,604**	132
	Future CI%						50%	50%	50%	50%	50%	50%	50%	50%		**50%**	
	Future Yield						144	133	6	2	1	2	0	0		**288**	

It must be cautioned that the above figures of sustainable yield are indicators of what may be achievable on average after all blocks are logged. Year to year the actual yield may vary substantially with spatial variation in species distribution. It may be safer to refer to the proportion of each species making up the total annual allowable cut as opposed to actual figures of board feet. Table 13 below presents the percentage of the annual allowable cut contributed by each species. Over the next 5-year period it can be expected that Bullet Tree will comprise the majority of the lumber available in the forest, contributing 37% of the estimated production. Mahogany is the next most voluminous species contributing around 19%, followed by Nargusta and Santa Maria.

Table 12. Summary of contribution to annual allowable cut by species.

Species	AAC (bdft)	% of total
Bastard Rosewood	61,965	6%
Billywebb	15,122	1%
Black Cabbage Bark	20,370	2%
Black Poisonwood	21,830	2%
Bullet Tree	419,262	37%
Cedar	0	0%
Chicle Macho	0	0%
Hesmo	61,446	5%
Hobillo	0	0%
Mahogany	214,575	19%
Nargusta	154,984	14%
Red Mylady	31,540	3%
Santa Maria	83,537	7%
Sapodilla	38,294	3%
TOTAL	**1,122,925**	**100%**

Proposed sequence of harvesting blocks 2022-2026

Since the area inventoried for the previous 5-year plan was approximately 10,000 hectares, half of the area (approximately 5,000 ha) was not included in the 2017-2021 management cycle and therefore will be carried over to this new quinquennial period. Additionally, several compartments within the 5,000 hectares slated for logging during 2017 to 2021 were ultimately not logged for a variety of reasons, including inclement weather. All these compartments that were inventoried but not slated for logging during 2017 to 2021 or were not logged, along with the compartments inventoried in this new quinquennial area, are now included in the pool of eligible compartments as options to choose from in developing the proposed sequence of harvesting for 2022-2026. The total area of the eligible pool of compartments is 12,131 hectares. Compartments comprising approximately 5,000 hectares will be selected for logging during 2022 to 2026.

To guide the process of selecting the sequence of harvesting blocks for 2022 to 2026, stratification based on Mahogany stocking will be used. Stratification is the process of arranging each potential harvesting block into different categories or strata based on a particular criterion or different criteria. In this case the stratum will be dependent upon the per hectare boardfeet stocking of Mahogany trees ≥50 cm DBH, which represents the productive sector of the population surveyed during the inventory. The more trees there are, the greater the likelihood of obtaining a high yield. Figure 16 shows the different per hectare stocking strata of Mahogany trees ≥50 cm DBH present within the 2022-2026 quinquennial area. There will be three strata corresponding to expected boardfootage of <222 bdft per hectare (low stocking), 222 – 769 bdft per hectare (medium stocking), and ≥770 bdft per hectare (high stocking), respectively.

Selecting from among compartments in the current quinquennial area and unlogged compartments from the previous management cycle, an annual sequence is proposed which could see more or less similar yields of Mahogany year to year over the next five years. Table 13 below shows the proposed sequence of blocks by year along with relevant details of each block. This is a proposed sequence, only, and is not intended to bind PfB to this order of blocks.

Rather it is a planning tool based on the need to optimize the market potential over the next five years.

Table 13. Proposed sequence of harvesting blocks 2022-2026.

Year	Zone	Compartment	Hectares	Yield Category
2022	West Botes	71	86	High
	West Botes	83	72	High
	West Botes	94	81	High
	West Botes	104	100	Medium
	West Botes	105	100	Medium
	East Botes	171	62	Medium
	Governor Creek	287	100	Medium
	East Marimba	355	100	Low
	West Marimba	361	98	Low
	West Marimba	389	98	Negligible
		Total	**897**	
2023	Governor Creek	270	24	Low
	Governor Creek	272	66	Low
	Governor Creek	273	98	Low
	Governor Creek	274	100	High
	Governor Creek	275	100	Medium
	Governor Creek	288	100	Low
	Governor Creek	289	100	Medium
	Governor Creek	290	100	Medium
	Governor Creek	291	80	Medium
	Governor Creek	308	100	Low
	Governor Creek	309	100	Medium
		Total	**968**	
2024	Governor Creek	311	100	Medium
	Governor Creek	312	100	High
	Governor Creek	328	100	Low
	Governor Creek	329	100	Low
	Governor Creek	346	47	Low
	West Marimba	378	100	Low
	West Marimba	379	100	Low

	West Marimba	390	100	Low
	West Marimba	391	100	Medium
	West Marimba	401	100	Low
	West Marimba	402	100	Medium
		Total	**1,047**	
2025	Governor Creek	276	100	Medium
	Governor Creek	292	100	High
	Governor Creek	310	100	Medium
	West Marimba	326	42	Low
	Governor Creek	327	88	Medium
	West Marimba	344	100	Low
	West Marimba	345	78	Low
	West Marimba	362	100	Low
	West Marimba	363	100	Low
	West Marimba	377	100	Negligible
		Total	**908**	
2026	West Botes	59	73	Low
	West Botes	67	15	Negligible
	West Botes	68	60	Low
	West Botes	69	100	Low
	West Botes	70	65	Medium
	West Botes	82	46	High
	West Botes	118	48	Low
	East Botes	191	39	Low
	East Botes	213	13	Low
	East Botes	214	84	Negligible
	East Botes	215	98	Negligible
	East Botes	252	83	Low
	Governor Creek	277	74	High
	Governor Creek	278	91	High
	Governor Creek	293	99	High
	Governor Creek	294	98	High
		Total	**1,092**	

4.4.1.4 Timber Harvesting Operations

The Annual Plan of Operations

Logging operations will be guided by an annual plan which specifies the yield, road operations, post-harvest prescriptions, and silvicultural management in the annual harvesting block. This annual plan of operations (APO) will be informed by the assessment performed during the pre-harvest stock survey. It will consist of general physical information about the annual harvesting block, timing of felling, skidding and hauling operations, harvestable volumes, silvicultural activities and roading operations. The most important component of the APO will be the yield tables of harvestable volumes. The format for the APO will be as per dictated by the Forest Department.

Reduced Impact Logging

Residual logging damaged caused when trees are broken, scraped or uprooted during road construction, felling and skidding increases mortality associated with logging and intensifies the release of carbon dioxide. Both of these negative side-effects of logging must be reduced to preserve the integrity of the forest and its various biotic and abiotic components.

Reduced impact logging (RIL) methods will be utilized during the stock survey, felling, skidding and hauling in order to minimize logging damage in the annual harvesting block. The RIL methods will follow the national code for timber harvesting distributed by the Forest Department. Machinery operators will be required to adhere to this code during the logging operations.

A primary action to minimize logging damage will be the cutting of lianas and vines during the pre-harvest stock survey. Since the pre-harvest stock survey is usually done about one year before the logging operation, lianas and vines would have died and weakened by the time trees are felled. This reduces damages caused when felled trees pull down or snap branches off other tied-up or connected trees. To assess the effectiveness of RIL methods, and consequently to adjust where necessary, an assessment of damage will be made following the close of the logging coupe by the Forest Department via the Post-harvest Audit system.

Type of machinery

The PfB contractor employs the use of rubber-wheeled skidders in hauling operations, D6 and D3 bulldozers in roading operations and rubber-wheeled front end loaders in log landing operations. Pole trucks are utilized in trucking operations. Backhoes are utilized in road maintenance operations at the close of the logging season, along with dump trucks and 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 are in good working order and the contractor continuously invests in parts and new equipment.

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 annual rainy season begins since the secondary extraction roads deteriorate quickly with the slightest of moisture.

Felling operations

Numerous felling crews are usually utilized to minimize the time spent felling trees. Felling typically begins 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 done where possible using the hinge technique, but often times lianas interrupt the planned felling direction.

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. Typically a tree is skidded no more than 1,000 m to the nearest barquadier, which are usually situated along a main extraction route.

Hauling operations

Hauling is done from barquadiers to the main mill site of purchasers. 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.

4.4.1.5 Processing Operations

PfB does not process any of its timber. Instead, it sells timber in the round to local workshops and timber manufacturers. As an FSC certified operation it has an interest in promoting the best use of its material and in buyers continuing through Chain-of-Custody certification. The certification differentiates PfB timber from other timber, maintains demand and gives down-stream marketing opportunities using the PfB ‘green’ credentials. In making sales agreements, PfB not only takes account of sales price but also of the economic benefit of maintaining a sustained flow of forest product and of highest end use within the local market. As an environmental NGO, these are considered gains in terms of fulfilling organizational aims. In general terms the approach supports both 'highest and best' use and local value-added processing.

The *Business Plan for sustainable timber extraction on the Rio Bravo Conservation and Management Area* that was developed as part of the EU funded *Integrated Forest Management Demonstration Project* describes below PfB's timber marketing strategy. The Rio Bravo forestry operations ensure that a regular supply of certified timber of a range of species enters the local Belize market. In doing so, the organisation achieves its organisational objectives and secures an income stream that, though modest, exceeds its targets. This can stand alone as a successful demonstration of natural resource management compatible with conservation objectives. It does, however, also create the opportunity to enhance PfB revenues by re-engaging with the certified timber market higher in the value-added chain. The second strand to PfB strategy, therefore, is to use its name and its contacts with the international NGO community and their networks in order to market certified timber products more effectively. Expansion of certified forest management is in fact a conservation strategy in itself, operating at a larger scale than the Rio Bravo.

In 2004 PfB was the only FSC certified timber producer in Belize. Since then several Belizean timber companies have initiated the process of becoming certified and at least two have recently achieved FSC certification. This growing interest in timber certification from the other forest managers is no doubt in part a result of the stimulation of a wider and clearly defined market in certified timber products and linked to a marked increase in certified sources from Petén and southern Mexico.

Several of the companies who purchase or have purchased timber from PfB have developed a wide range of value added products ranging from high quality flooring, panelling, decking, doors, and mouldings to very fine top end furniture. Non-traditional timber species especially those of the durable and heavier hardwood are increasingly utilized with growing market acceptance. Other forest products such as wood chips may be a possibility. These companies have also established and continue to expand export market niches.

4.4.2. Environmental Protection and Biodiversity Conservation Programme

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. Using the yield model, four species came out as too rare to harvest based on their population in the average annual cutting block. Three of these are exceptionally rare and will very likely not be harvestable in any of the annual blocks: Cedar, Barbajolote, and Granadillo. The fourth species, Hobillo, comprises only 1% of available production, and although a sustainable yield is possible, it is so small that the precautionary principle may be applied to prevent potential overharvesting.

In other forest management areas in Belize, it is these same species that also occur as too rare to harvest. There may be some recruitment limitation or high mortality mechanism at work in their population. These 'at risk' species may require protection from logging, through exclusion from harvest selection and through the prevention of logging-related damage and mortality.

Reducing the Carbon Footprint

Residual damage from 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 can be 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. Reduced-impact logging methods will be carried out in the annual harvesting block and branches and other residual material will be utilized by artisans to make long-lasting furniture and other wood products.

Quarries

Marl pits are of environmental concern as they can be a source of sedimentation for nearby water courses if not properly located and managed. There are 9 very small marl pits along major roads on the RBCMA (Fig. 21). The area of all marl pits on the RBCMA combined is 0.5 hectares, which is a miniscule part of the entire landscape.

None of the marl pits are located immediately next to perennial waterways. Indeed, marl is only found in the higher well-drained areas where hillocks are located as protrusions above the clayey sediments typical to the lower lying areas of the RBCMA. The marl pits are seldom used, and provide material when needed for road works. The pits themselves are less of a cause for concern than the roads which they are used to build.

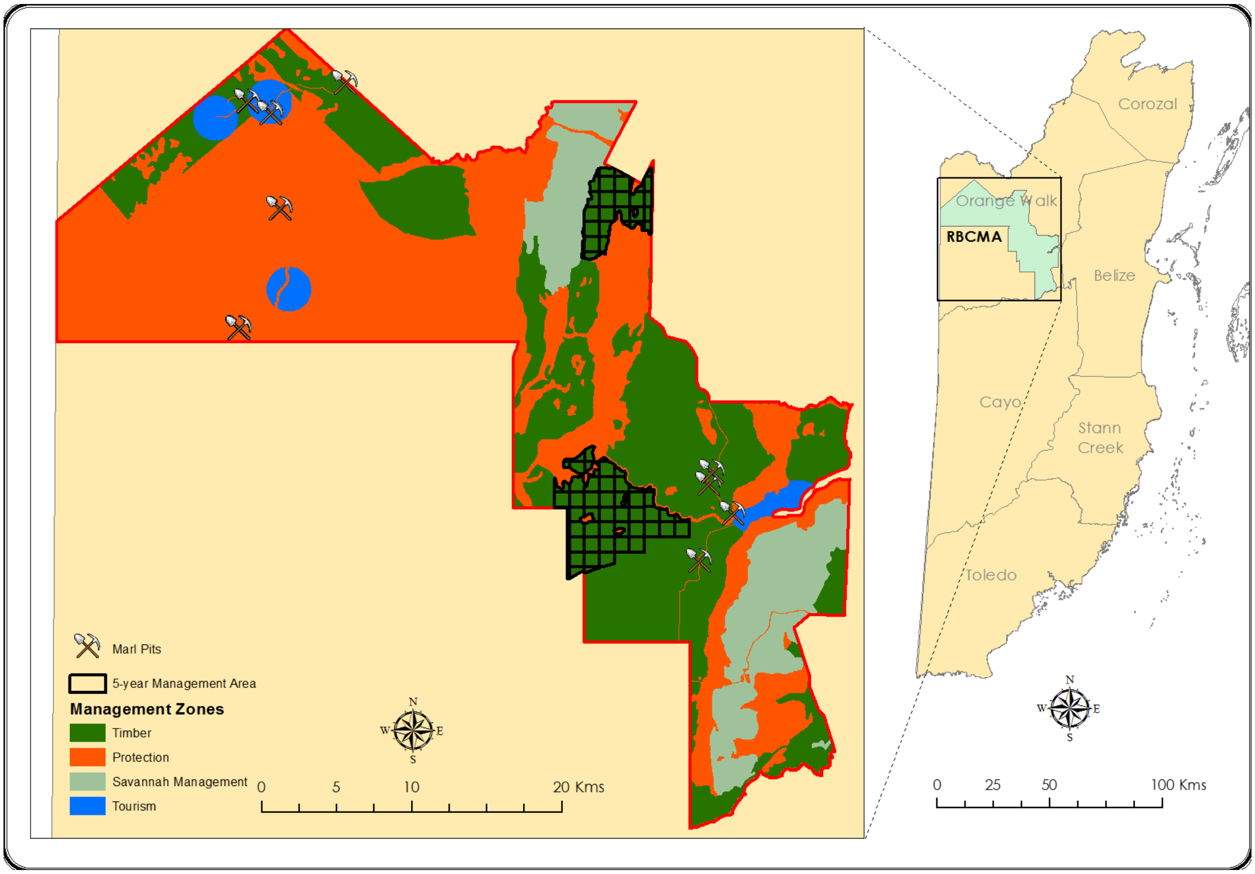


Figure 21. ***Location of marl pits on the RBCMA.***

Buffer Zones

Buffer zones in which logging impacts will be minimized or non-existent have been put in place around waterways, lagoons, roads, recreational sites, fragile soils, communities and High Conservation Value Forests (HCVF). The standard buffer zone width of 100 metres is used for all buffers around sensitive vegetation and soils. The intent is to exclude logging impacts in order to preserve the integrity of sensitive areas and forests. Buffer zones are also instituted in annual cutting compartments based on the mapping performed during the pre-harvest stock survey.

Soil and Water Conservation

The conservation of fragile soils and water bodies will be achieved mainly through the use of buffer zones around the escarpment areas, lagoons and rivers. These buffer zones extend for 100 metres on either side of sensitive areas to ensure logging impacts are excluded from stream banks and steep slopes. In addition, operational safeguards will be put in place during logging to ensure impacts from equipment use are minimized. For example, rubber-wheeled skidders which have higher floatation rating than tracked skidders will be used during skidding to minimize soil impacts. Skidding distance will also be minimized through skid trail planning using high resolution topographic data.

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.

4.4.3 Forest Protection and Security Programme

The general objectives of the security and vigilance plan are to protect the integrity of the natural and archaeological resources in the FMU.

More specific objectives are:

- To detect and impede all illegal activities within the FMU including unauthorized logging, hunting, and looting of archaeological sites.
- To seek the collaboration and support of adjacent land owners and communities for security and vigilance activities.
- To build mutual collaboration and support with law enforcement authorities in ensuring that appropriate judicial sanctions are expedited.

Security and vigilance for the FMU are incorporated in the following comprehensive strategies that within the RBCMA Management Plan (Edition V) 2006-2010 are considered adequate to address the threats to the conservation targets including the broadleaf forest formations:

• Protection: - involving boundary marking, surveillance through patrols and legal action wherever appropriate, in order to address direct threats arising from unauthorized activity.

• Managed resource use – to enhance the relevance of the area for the local economy and augment its reputation as a key site through delivery of concrete benefits, giving the basis for a constituency of support for the area. This also acts as a form of passive protection by occupying the ground and visibly demonstrating an active presence. The tourism, hardwood timber and savannah management programs fall under this category.

• Outreach and education – to engage with neighboring land owners and communities to improve resource management and protection of natural habitat in the wider landscape. Aims here are to preserve the forest bloc in which the RBCMA is embedded and to maintain some reasonable degree of biological connectivity in the wider landscape. Promoting visits by local people to the area to obtain first-hand experience is a key part of this area of activity.

• Research – to obtain and disseminate information on the area and activities on it, reinforcing awareness of its importance and building up the constituency of support.

Vigilance over the FMU is the sole responsibility of PfB. The PfB rangers are tasked with all protection activities including protecting against illegal logging and the looting of archaeological sites while the road entrances are all permanently manned with gate-houses. The rangers also provide manpower in the advent of fires. Ranger patrols therefore target the most vulnerable/resource rich areas and the pine savannas to protect the Yellow-headed parrots. PfB's forestry crew may also be called upon to assist with patrolling on an emergency basis only and will become directly involved after evidence of illegal logging is detected through collection of GPS and timber volume data. Given the extent, complete interdiction of illicit activity is not possible over the entire area but is held down to tolerable levels and the area is classed one of the best-protected in the country.

While some of PfB's rangers are special constables with powers of arrest and dealing with illegal activities on the RBCMA, law enforcement is also the responsibility of the Forest Department in dealing with forest offences as well as other government authorities who have the responsibility to enforce pertinent legislation and regulations related to resource use and protection. A standard protocol and written format should be developed together with the Forest Department to report any activity or situation that requires action by the Forest Department or any other pertinent law enforcement agency. The objective is to enhance good communication and to provide the necessary documentation for follow up action by both the law enforcement agency and PfB. This format should include among other things: date the report was made, date the offense or activity under investigation was discovered, nature of the offense or activity which may constitute an offense, names and or addresses of perpetrators if possible, vehicle license number if applicable, where the offense occurred, extent of damage or impact, name of person reporting the offense or unwanted activity, request for mitigation or preventive measures, to whom the matter was reported (name, post or rank, station). These reports should be incorporated into the forest management information system of PfB for follow up, review, and planning purposes. The use of GIS applications should facilitate the georeferencing of incidents for future threat analysis.

PfB also provides support to the Forest Department in the prosecution of offences committed in the license area by assisting with securing evidence or providing testimony that may be required in a case. However, where it is provided for under the law, PfB also exercise its rights to make a complaint and to bring civil suit against those parties that engage in illegal resource use on its property. The vigorous legal pursuit of those persons found to be engaged in illegal resource activities within the FMU is a very critical element in the development of a credible deterrence to illegal and unwanted activities. Security and vigilance needs to commence with public awareness and education which will hopefully contribute significantly to prevention and will also act as a vehicle to promote the involvement of local authorities and the community as a whole in detecting and reporting illegal or unwanted activities that act in deterrence to the sustained forest management of the FMU.

Local tip-offs are becoming more important as more community members become actively involved and develop interests in good management of the area. Timber theft is followed up confiscation and legal action, with increasing success. Therefore public appreciation for the objectives of the sustained forest management plan, the forest rules and other pertinent legislation as it applies to the FMU as well as the role of PfB as the primary stakeholder in ensuring protection of the FMU must also be an integral part of the overall public and community crosscutting outreach program. The strategies developed by PfB to address the identified threats to the broadleaf forest and other conservation targets integrate the above considerations. Obviously the Forest Department and other law enforcement agencies must also be an active partner in this endeavor as well as authorities within the communities.

Boundary demarcation and maintenance especially in areas where the risk of trespass is high should be carried out on an annual basis and should be included as an activity in each APO. On the ground, signage is an important tool for reinforcing public awareness and education as well as assisting in projecting a management presence. Signs should be placed at appropriate points along public roads, explaining that the area is under long term sustained forest management (This may also be a strategic vehicle to inform the public that PfB's FMU is certified by NepCon and confirms to the FSC principles and criteria); an important prevention message (fire, milpa, and hunting) may be incorporated into this sign. Similar signs should be placed at other strategic locations. Other signs with prevention or forest management awareness messages will also be erected. Signage is a gradual process that should be developed in stages commencing with those that are of critical importance and progressing to providing specific on the ground information to adjoining landowners and communities and the general public. The construction of signs can also provide a mechanism for providing direct economic benefit to communities in or adjacent to FMU. It is an activity that should form part of the APO whether it is for new signs or for maintenance of those already erected. Regular patrols at least once a month during the wet season and twice a month during the dry season should be carried out particularly in those areas of high risk for arson, illegal logging, illegal harvesting of forest produce and/ or minerals, illegal settlements and/or agriculture, and illegal hunting. Vigilance will also form part of other activities which require monitoring such as detection of insect attacks, wildfires, resource assessments, and all the daily forest operations which require ingress into the FMU or a particular compartment. Therefore all forestry workers at all levels of responsibility should be trained to look for signs of unwanted activities and to whom and how to report any unwanted activity if found. All personnel should be encouraged to use maps as a standard tool not only for vigilance and security but for all forest management activities that require geo-referencing.

Personnel involved in vigilance and security patrols will also have to be properly trained to avoid or defuse confrontational situations which may arise from contact with individuals involved in illegal activities. Community or local contacts should also be cultivated as a means of obtaining valuable information. Cooperative or collaborative relationships with other agencies or organizations involved with security and vigilance in or adjacent to the FMU should be developed. It is also important that PfB develop collaboration with Gallon Jug Industries and Maya Forest Trust under a cooperative agreement in planning and carrying out protection activities. All activities connected with security and vigilance should form a recurrent element of the APO.

The RBCMA benefits from a strong ranger force but is never-the-less vulnerable to illegal logging and hunting from neighbouring communities, as well as escaped fires from adjacent agricultural areas. There have several recorded incursions into the RBCMA for timber resources although it is recognized that this is mainly isolated in the eastern border areas near specific communities.

Other than illegal incursions for timber and wildlife resources and the occasional escaped fire, there are not any other major threats to the RBCMA. Beetles and other forest pests do not affect broadleaf forest to any significant level warranting specific protection, nor are there any major outbreaks of pine bark beetle recorded in the northern pine savannahs.

Security and Vigilance Plan

The main threat to the forest resources in the RBCMA is the illegal felling of trees by trespassers. In recent years this threat has somewhat increased and has spread into the Reserve along the eastern boundary. Because of the sensitivity of the situation with respect to good community relations, the matter is dealt with carefully and internally by PfB.

As a measure to reduce the temptation to enter to poach trees, PfB plans to carry out pre-emptive felling of compartments along the eastern 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. In terms of vigilance, PfB and its employees continually record and report the movements of illegal loggers to the authorities.

Based on information gathered during the pre-harvest inventory, a more detailed security and vigilance plan will be elaborated in the Annual Plan of Operations.

Integrated pest management plan

There are few records of large scale attacks of insect pests to tropical broadleaved forests and where these have occurred, it has been limited to one species or group of species. Seedlings and saplings are most vulnerable especially to leaf cutting ants. A normal insect attack does not commonly result in tree mortality but may result in a decline in growth, form and timber quality. No insect pests of significant economic concern have been identified for the broadleaf forests in northern Belize with the exception of the mahogany shoot borer, *Hypsipilla grandella* Zimmerman which has been identified as an endemic that is responsible for the formation of multiple shoot leaders in saplings and poles of the Meliacea family. So far no wide scale treatment has been developed. It is generally ignored in natural forests and is of greater concern in plantations of Mahogany. Wood borers primarily of the order Coleoptera tend to affect heavier timbered species more commonly after they have been logged.

Nevertheless, there is the need for training at the field level to monitor for any changes in forest appearance that may be attributed to an insect pest, rapid action to control and isolate outbreaks, and the silvicultural interventions necessary to develop healthy stands which are less predisposed to insect attacks. Therefore forest monitoring for any signs of threats to forest health by insect pests in broadleaf forests should also form part of the forest monitoring activities in the APO's. Monitoring can be done at different levels including during forest management related operations, resource protection patrols, annual or periodic over flights by light aircraft, analysis of recent satellite imagery, etc.

Under normal conditions in the forest, there is a natural equilibrium between trees, insects that affect trees and other plants, predators and parasites. The ecosystem is in equilibrium but can be broken by natural causes or human activity. The damage caused by Hurricane Richard is one event that has altered the natural equilibrium in a portion of the RBCMA and in the FMU. Therefore special monitoring attention will have to be given to the hurricane affected area in particular where the canopy has been severely affected and there is a high accumulation of dead biomass.

Pest control is very difficult in natural forests, because the most economic form of control applicable would consist in eliminating trees or their affected parts, as compared to the cost of chemical or biological control. All of these methods have significant potential environmental consequences. Therefore efforts should be focused on maintaining forest health and vigor. Where it is appropriate simple practices like removing weak, moribund, or dead trees and silvicultural treatments that favor young growing trees of economic or ecological importance should be implemented. Initially these treatments may be applied at an experimental or pilot scale and then applied on a larger scale as experience and an evaluation of results permit.

A national strategic approach is described in the National Forest Health and Management Plan which forms part of a regional forest health effort. Collaborative relationships should be established and maintained with local and regional institutions that carry out research on relevant regional forest pests in order to keep current on developments and applications related to forest conditions in the northern broadleaf forests of Belize.

Included in any Integrated Pest management (IPM) program should be measures to ensure that forest management activities do not unduly impact on beneficial predator habitat. The effects of climate change on the population dynamics of insect pests and diseases is a factor that must also be considered in any IPM program. As with insects, in the tropical broadleaf forest there is an ecological equilibrium between pathogens, antagonistic organisms and the forest. Disruptions to this equilibrium can cause a severe attack of a disease. Trees are susceptible to disease during their whole life span but are much more vulnerable during their juvenile and senile stages.

Most forestry diseases are caused by fungi that could be initiated by bad harvesting practices, changes in humidity and/or temperature and insects. The principal way of controlling diseases is by mechanical control, in which the affected trees should be felled and burned.

There are no major pests known to be active inside the RBCMA forest at this time. However, this could change from year to year especially considering the shifting weather patterns currently being experienced across Belize. To this end, PfB through its bush crew, will 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. A more detailed integrated pest management plan will be elaborated in the Annual Plan of Operations as may be required to address a particular pest outbreak.

Fire management

Wildfires have been identified as the most serious single threat to the broadleaf forest and the pine savannas of the RBCMA. While pine savannas are fire dependent ecosystems where fire is essential and species have evolved adaptations to respond positively to fire, the broadleaf forests are fire sensitive ecosystems where species lack adaptations to respond to fire and even low intensity fire can cause high mortality.

Therefore, the primary aim of fire management is to keep fire out of the FMU. Most wildfire ignitions do not normally occur within the FMU but start either on the pine savannahs or agricultural land adjoining the RBCMA from where it penetrates into the broadleaf forest. Fire use is a firmly embedded part of the land management culture of many of the surrounding inhabitants of the RBCMA who use fire for land clearing, removing unwanted debris or vegetation, chasing away unwanted wildlife such as snakes and ticks, and attracting game species such as deer who feed on the young grass shoots that develop on the savannas shortly after it is burnt. The outbreak of fires in the 2011 fire season in the broadleaf forest areas affected by Hurricane Richard and that have not had a history of fire point to an elevated fire risk that will continue for several years.

Therefore, a forest fire management plan will have to be devised for the FMU that addresses fire management considerations both within the FMU and the surrounding lands. The three main axes of any realistic and effective fire management program are:

1. fire prevention,

2. law enforcement,

3. adequate organizational fire management capacity.

A continuous educational and sensitization campaign is necessary. This is a medium term to long term process which must change deeply ingrained cultural practices and perceptions which have been manifest for decades. The objective should be to promote the wise use of fire as a land management tool that combines fire science and conservation principles with traditional and indigenous knowledge. It must have the strong support of not only PfB but all stakeholders including local communities, NGO's, and Government agencies that can influence behavioral changes in the indiscriminate use of fire. The financial support required is very substantial and may very well only be achievable with external support from the relevant international agencies.

Present legislation related to the negligent use or deliberate use of fire appears to have an urban focus. Arson and damages to natural resources due to the negligent use of fire in Belize continue to remain unpunished. There is a need for specific legislation related to forest fires caused by deliberate or negligent human actions.

An efficient fire management organization which has both the training and the tools to carry out its function is required. Efficient early detection and an effective rapid response have to be the key to avoiding major conflagrations. While most of this will be the responsibility of PfB, other stakeholders such as adjacent land owners, local communities, and Forest Department participation will also be required in these activities.

A fire map of the areas with the highest fire risk due to fuel composition or loading as well as likelihood of ignition due to proximity of sources of ignition has been prepared. The RBCMA Management Plan (Edition V) 2006-2010 identifies the savannah and fire management programme as the priority development area over the planning period. The objective is to maintain the present fire training programme but incorporate it within pine savannah management plans developed for 2500 ha on the Rancho Dolores and San Felipe savannahs. These plans include fire control and use as a management tool to maintain biodiversity (with special emphasis on the yellow-headed parrot) and promote pine stocking.

While fire management in the broadleaf forest benefits from the training and experience gained in the savannah and fire management programme, fire management in the broadleaf forest zone must be focused on prevention (primarily through good community relations) and suppression. The use of fire in the broadleaf forest as a silvicultural tool to promote regeneration of permanent light demanders such as mahogany is at present not an option. The present capacity both in equipment and skills needs to be maintained and built upon. Training will be required periodically to address both staff and worker turnover and to keep the fire management team current. The general guideline is to contain the fire within as restricted an area as possible.

The suppression of fires in broadleaf forest is notoriously difficult and dangerous. Extensive areas will be burnt if an outbreak is not detected early and takes hold. Hurricane Richard has altered the fuel composition in about 12,658 ha of broadleaf forest and 6,067 of pine savannah. The wind thrown trees on the ground in the broadleaf areas affected by Hurricane Richard have dramatically increased the fuel loading to the level of a giant milpa prior to burning. Leaves and small branches in the crowns of wind thrown trees will have dried out sufficiently by the middle of the dry season to be able to carry a fire and ignite the heavier fuels composed of larger branches and limbs. The absence of a canopy layer will facilitate the reduction of moisture content in heavier fuel as a result of increased desiccation from sun and wind. In the dry season fuel and atmospheric conditions may be favorable for a high intensity "hot fire" and extreme fire behavior. Therefore for the next three years or more the fire hazard in the hurricane affected area will be very much higher than in the broadleaf forest not affected by hurricane force winds. All precautions related to reducing the risks of fires need to be taken. Strict measures must be imposed on personal habits e.g. smoking, use of cooking fires, and the use of equipment that may inadvertently cause fires, e.g. motorized equipment without mufflers or leaking fuel. Very clear guidelines preferably both written and orally must be provided to all personnel entering or working in high hazard areas including contractors. However, a high degree of vigilance needs to be exercised continuously during the periods of high fire hazard along the boundaries of the property to guard against the encroachment of wildland fires originating from uncontrolled agricultural fires.

Effective fire management requires considerable resources often beyond the capacity of any one land manager or land owner. Wildland fire equipment is expensive. Fire detection, communication, training, and planning can be developed into a cooperative programme which also provides for mutual support and assistance in fire suppression when requested by members of the cooperative. There are many successful examples of fire management cooperative agreements in other countries where wildfires are a perennial problem. The RBCMA, Maya Forest Trust, and Gallon Jug Industries share common boundaries and their land management activities include the sustained forest management of the broadleaved forest. The three properties have been affected by Hurricane Richard to the extent where the fire hazard in their respective FMU's will be of considerable concern during the dry season. PfB should therefore examine the feasibility of developing a cooperative or at least a collaborative approach to fire management that will be mutually beneficial to all parties involved and that could with time also involve other neighbors and stakeholders.

PfB is one of the few forest managers that have a strategy outline for the rehabilitation of areas affected by wildfires. Wilson emphasizes that the rehabilitation of those broadleaf areas affected by a wildfire should focus on promoting regeneration and conserving what remains of the standing resource. Recently burnt areas therefore need special management prescriptions.

Planning guidelines are:

• Undertake a preliminary survey of fire impacts on the standing stock and any permanent sample plots in the area. A local plan is then developed for the area that supersedes any existing schedules. The following elements should be included.

• Establish an inventory transect (Protocol C) in each compartment affected, marking it as a permanent plot with 5-yearly re-measurements. The aim here is to track post-fire mortality regeneration and mortality.

• Undertake a stock survey (Protocol A, but including an assessment of form – i.e. 'marketability'). This assesses impacts on the standing stock and is especially useful if the area has already been surveyed. If the compartment has already been covered by an inventory cruise this step is unnecessary.

• Re-measure any permanent study or demonstration plots in the area. These will give useful 'before and after' information.

• Use the opportunity to locate and clean any trails serving the compartment.

• Avoid any over-enthusiastic salvage operations. Surviving trees are precious seed sources at this stage – this extends to damaged and dying trees where the stress may stimulate prolific flowering and seeding. This is a more important function than any revenue likely to be generated. Furthermore, any activity likely to crush the newly established seedlings must be avoided.

• The area will constitute a dense thicket with vigorous growth of vines until the forest begins to reconstitute itself. Every two years (starting the year after the fire) the area must be systematically covered to i) liberate all surviving trees of good form and commercial species; ii) clean all seedlings of commercial species that can be located. This process must be repeated until the saplings are out of severe competition.

• Re-organize the extraction schedule for the compartment. Truck-passes may be used to gain access to the hinterland but logging should not be considered for at least 20 years to allow the newly-established age cohort of light-demanding species time to develop to a size where they can easily be protected during operations. Consideration should be given to replanting in those areas where the density of desired regeneration is low and seed trees are few. An area in the Chiquibul Forest Reserve that was burnt by a wildfire in 1974 continues to experience a very low regeneration density.

The broadleaf areas of the RBCMA is currently under low risk for fire, having recovered much of the green vegetation following Hurricane Richard. The canopy is closed and logging disturbance affects a small fraction of the area, inputting minimal debris to the forest floor. However, vigilance is important especially during severe dry seasons. To this end, the company and its bush crew will practice safe fire handling at campsites by clearing to mineral soil a minimum of 12 feet around any camp fires. No fires will be allowed away from established campsites.

To handle potential fires the savannah areas, the bush crew have received fire training in the past and continually build upon their skills through annual prescribe fire exercises available to them.

4.4.4. Social Responsibility Programme

Social impacts attributable to forestry operations (and indeed to RBCMA management as a whole) are believed to be neutral to positive. This is based on formal consultations made with local stakeholders (community and industry representatives) in developing the management principles for the forestry programme in 1996, backed by continuing informal and formal contacts through the outreach programme.

The PfB does, however, have a responsibility to contribute to the socio-economic development of the general region and its performance in this area should be assessed. Part of the exploration of the potential for payment for environmental services must therefore include a Total Economic Evaluation (TEV) to act as a baseline and to identify suitable indicators to monitor trends. The design of this programme (to be undertaken during the lifetime of this plan given prevailing economic realities) is an expert task for a socio-economist but should provide the following data:

- Number of jobs directly created by RBCMA management activity including geographical location and job level including confirmation and quantification of impact in neighboring villages.

- Number of jobs maintained indirectly by RBCMA management activity including those from forestry activity.

- Assessment of beneficial impact of PfB's education, outreach and training programs on local communities and the economy in general.

- Assessment of the level of restriction to traditionally used resources consequent to PfB management practices being introduced including an identification of those resources, their value, their users, and the rationale for restricting their use. It should also include an assessment of the opportunity cost incurred by the management regime.

- Assess the degree of environmental goods and services maintained by PfB management, the values attributed to them, the beneficiaries, and mode of benefit.

The objective is not only to assess delivery of environmental and socio-economic benefits but also to track them to assess how they are distributed and to identify actions that will optimize gains, reduce loss and promote equitable distribution within the constraints of good resource management. Once the base-line is established, re-assessment against set indicators becomes a standard exercise in future revisions.

4.4.5. Staff and Health and Safety Programme

Apart from the first-aid training mandatory for all staff, PfB maintains first-aid equipment both at the field stations and in the field with the crews. Full communications exist through radio coverage over all of the RBCMA with VHF link to its Belize City headquarters. Telephone communications also exist at the field stations. PfB maintains and emergency evacuation procedure involving either taking injured parties out to the nearest hospital or, in extreme emergencies, calling in helicopter evacuation services.

Specialized safety equipment is retained for all forestry activities involving a degree of risk. Forestry crews are issued with hardhats, steel-toe boots and snake-chaps, but it is often left up to the discretion of the user when this equipment is to be used. However, fellers are required to be equipped with goggles and protective gloves and leggings against chainsaw accidents at all times. There are no national averages for comparison but the safety record has been good so far. Although rare, accidents do happen, but in all cases so far serious injury has been prevented by the safety equipment. The emergency evacuation has had to be used for a snake bite within the last two years but proved effective. Given the number of people – staff and tourists – in the area, however, vigilance must be maintained at all times.

Employee safety is paramount for efficient execution of forest management throughout all operations. Contractors are responsible for the safety of their employees during logging operations and will be required by the forest manager to abide by all national laws regarding occupational safety hazards. The forest manager will be responsible for the safety of all its own employees. Safety equipment and clothing will be used at all times and fire hazard equipment and fire extinguishers will be available in all work sites.

Safe equipment handling and use, such as during the felling of trees with chainsaws, will be required of contractors, and to this end, contractors and their employees will be required to participate in periodic trainings to ensure a high level of safety at all times.

4.4.6. Other Management Programs

The harvesting of non-timber products is not contemplated under this SFMP nor is PfB planning to do so in the near future.

It is increasingly recognized that natural and planted forests provide a wide range of benefits, other than timber, to local communities and to society in general. Forest conservation through SFM in the FMU will contribute to:

- Regulate water flows; reducing the risk of flooding and consequent damage and economic loses to nearby human populations, infrastructure and agricultural activities.
- Maintain water quality for the benefit of human and wildlife health, particularly for the conservation and reproduction of freshwater and marine organisms.
- Control soil erosion, which benefits agriculture and ecosystem productivity.
- Oxygen production and carbon dioxide fixation, which alleviate atmospheric warming and air pollution.
- Biodiversity conservation, increasing the options for medicinal products and NTFP development, and genetic improvement of cultivated organisms.
- Enhance scenic beauty for the benefit of ecotourism activities.
- Provide off site opportunities for alternative livelihoods based on the sustainable use of natural resources.

It is inherent in its overall management objectives for the RBCMA and indeed it's one of PfB's core reason for existence to make every effort to maintain these positive values though the effective application of the SFMP; and the development or use of market mechanisms involving such values.

Tourism is well-developed on the RBCMA and is supported by a Tourism Development Programme based in Belize City. Tourism and tourism-related activity (gift sales, agency work) is the principal source of self-generated income for PfB, accounting for over 50% of annual income. The management zoning described in section 4.3 includes a description of the tourism zone. The designated tourism zones do not extend into the timber production zone.

4.5 Financial Sustainability and Administration

4.5.1. Staffing

Programme for Belize hires two types of staff: permanent and project-related. These are supplemented on an as-needed basis by local and international consultants, interns, and temporary personnel. Each field station has a station manager, maintenance staff and resident naturalists. Hillbank also has a staff forester and forest management crew of three persons supplemented by five seasonal workers. The ranger force consists of eight men, usually based at Hillbank and the gate houses. Senior staff members are based at Belize City and include the Executive Director, Administrative Officer and Technical Coordinator. Support staff at headquarters include tourism staff, administrative assistants and accounts personnel.

Conditions of employment for permanent and project-related staff follow national norms plus benefits including: full medical insurance for themselves and their families; boarding and lodging for field staff while based at Hillbank or La Milpa; and field clothing. Project-related personnel are employed for the duration of the project only. The terms for local and international consultants are per their individual contracts, which also follows national norms. Temporary personnel are employed according to the labour laws and national norms which includes social security coverage, above minimum wages, and boarding and lodging while based in the field. All staff have recourse to the labour laws governing rights and means of conflict resolution.

Recruitment for field staff members is usually performed preferentially within local communities abutting the RBCMA. Recruitment for permanent, project-related, or consultants is usually performed preferentially within Belize, but in cases where international consultants are hired, they work with a formal local or staff counter-part to assist in the transfer of skills and knowledge.

Permanent staff possess expertise in business management, economics, forestry, ecology, tourism, protected areas and general maintenance.

Training is a priority area for PfB at all levels. It is PfB's policy that all forestry staff must have adequate expertise to understand and execute management and operational plans, especially considering the recent high rate of staff turnover. PfB accomplishes its training agenda by taking advantage of nationally organized training events by the Forest Department and other bodies. PfB also organizes its own training exercises intermittently to boost skill levels among its field staff, by relying on local consultants. Trainings have taken place for all of PfB field staff at one time or the other in the following areas: tree identification; stock survey; directional felling; first aid (every two years); forest navigation (every two years); patrolling and enforcement (every two years); and fire control.

At a higher level, all staff members regularly attend training courses and seminars organized at the national or regional level on various aspects of natural resource management, human resource management, and protected areas management. There is also a program of encouraging the involvement of locals in research programs led by international scientists taking place in the RBCMA.

4.5.2. Five Year Plan and Budget

Table 14 offers a general idea of the activities to be carried out during the next five-year planning period on commencing timber harvesting operations. Specific tasks in each area of action will be presented in the APO activity timetable.

Table 14. Five year plan and budget

Activity	Cost / yr ($1000)	2022		2023		2024		2025		2026	
		I	II	I	II	I	II	I	II	I	II
Stock Survey	30		■		■		■		■		■
Preparation of APO	10		■		■		■		■		■
Road construction and maintenance	22	■		■		■		■		■	
Implementation of timber harvesting operations	60	■		■		■		■		■	
Post harvest treatments	10		■		■		■		■		■
Implementation of fire control program	15	■		■		■		■		■	
Implementation of resource protection and vigilance plan	30	■	■	■	■	■	■	■	■	■	■
Implementation of monitoring plan	10	■	■	■	■	■	■	■	■	■	■
Implementation of integrated pest management plan	5		■		■		■		■		■
Implementation of research activities	10			■	■	■	■	■	■	■	■
Training of PfB staff and contractors	5		■		■		■				
Community outreach	8		■		■		■		■		■
Midterm review of SFMP	5					■					

In the table above it is assumed that the stock survey and the APO for the 2022 cutting coupe will have been completed in 2021. In the new quinquennial planning period, the stock survey and APO for 2023 would have been done in the first year (2022). The APO of course guides the implementation of annual activities within the management area. It is recommended that subsequent APOs are prepared during the last semester of every year in order to allow enough time for approval and adjustments before its implementation at the start of the following year. Stock survey work should be carried out during the drier months of the last semester in each year.

Implementation of harvesting operations include skid trail planning and design, felling, skidding, hauling and all the tracking procedures that are integral to the chain of custody process.

Simultaneously, fire management and forest protection activities should start. These include assessment of fire risks post Hurricane Richard and the prevention, pre-suppression and suppression activities that need to be implemented. Pest management activities should start a semester later during the rainy season when fire management tasks have freed resources and pest activity is higher.

Another important early activity will be training of personnel through short applied courses on RIL and safety methods, such as directional felling, forest roads, skidding techniques, first aid, environmental considerations, fire management, pest management, PSP establishment and measurement, etc. depending on the need for refresher courses and PfB personnel/contractor turnover.

Community outreach with regards to identifying and ameliorating any perceived areas of conflict or concern as well as raising awareness of the benefits of sustained timber management may be incorporated into PfB's Outreach Programme. Seeking community involvement would start also a semester later to take advantage of the increased resource availability as a result of the decreased logging intensity brought about by the rainy season. Community outreach also involves community integration into fire management, forest protection and pest control activities.

Research projects often require a lengthy period to become implemented. Funding and research partners have to be sourced. Hence, it is judged that a period of 1 to 2 years is needed to implement new research activities.

Looking for research cooperation would commence a year later once experience and control has been gained on implementation of operational activities, and resources can be more easily dedicated to developmental initiatives. By this time, it is expected that actual implementation of community participatory activities will take place.

Review of the SFMP is deemed essential rather shortly after implementation of the plan. This is so, because it is during this phase when significant discrepancies between written plans and execution of operations arise, such as feasibility and efficiency of proposed compartments and procedures. Unforeseen events and disasters may also impact on the implementation of the plan. The passage of Hurricane Richard over the RBCMA requires that the normal schedule for the implementation of activities be modified at the start of the planning period giving priority to the implementation of post hurricane operations including the salvage of hurricane damaged timber trees in those areas of the quinquennial management area severely affected by Hurricane Richard.

Those management activities that are required in the hurricane salvage area are described in the Annual Salvage Operation Plan (ASOP) that will be prepared for each year of salvage operations. This ASOP effectively replaces the APO for areas under normal SFM. It should be noted that salvage logging is carried out under a Forest Permit for a hurricane salvage area and therefore is implemented under a distinct legal authorization from that which officially sanctions the SFMP. It should be also pointed out that while criteria for the selection of trees to be felled in salvage areas will be completely distinct from that utilized in a normal SFM harvesting operation, most of the principles of reduced impact logging will apply as well as the environmental safeguards which need to be observed in an SFM operation.

Therefore, adjustments to the SFMP should be timely allowing a review that involves the experiential perspective of those involved in guiding and supervising its implementation. Under normal circumstances the plan should be reviewed at the end of the first two years of operations. Afterwards, it is not considered necessary until the end of the five-year period.

4.5.3. Plan for Review and Updating of the Management Plan

The management plan is updated every five years. This is the fourth update since the first management plan of 2006 to 2010. Each management plan is preceded and guided by a forest inventory of the quinquennial area, which is carried out in the final year of the outgoing management plan.

During the life of the management plan, at the midterm point, a review will be undertaken to assess the success of achieving the objectives, at least in terms of executing the planned actions on the ground in the forest and with respect to staff capacity building. This will be undertaken by PfB itself and will consist of a field assessment, staff survey, and financial assessment.

5. MONITORING

Monitoring overall, is a disciplined effort depending heavily on strict procedures and a proper data management. While there is some experience and tradition with monitoring forest management on the RBCMA, its incorporation as a routine activity is still progressive in the measure that training in monitoring is realized and its benefits appreciated.

Careful attention must be given to ensuring that no aspect of monitoring is overlooked. Therefore a monitoring plan document needs to be developed that defines what should be monitored, gives indication of how these parameters should be monitored, justifies why they should be monitored, identifies who should monitor them, specifies a timeframe for monitoring, and indicates the best ways to synthesize findings of monitoring so that it feeds back into management in order to achieve optimum efficacy in monitoring and improvements to management over time. An outline of a comprehensive monitoring plan that should also satisfy forest certification requirements is provided in Annex II. The development of a permanent system of registers that allows the FME to compile information on all aspects of forest management operations including production and costs, in addition to documenting problems or obstacles to their execution will facilitate the monitoring of management operations. Therefore the development of a forest information system is a basic first step in developing effective monitoring.

A logging operation generates a wide array of impacts, some of which are negative and others positive. Both types of impacts need to be known in order to execute adaptive management which may seek to reduce the negatives and increase the positives. Negative impacts may include excessive tree mortality, soil compaction, siltation, drainage clogging, and disturbance to wildlife habitat, to name a few. Positive impacts can include the stimulation of regeneration, enhanced growth increment, increased wildlife and bird species, and reduction in competition among trees, to name a few. Some impacts can be observed over the short term and others over the longer term. Short term impacts may include tree damage and mortality, soil compaction or drainage clogging.

Beyond the need to monitor the impacts to the forest caused by logging, there are administrative and legal aspects of the logging operation that need to be monitored for compliance with regulations and laws. For example, the felling of trees need to adhere to what was approved in the management plan in terms of numbers, species and location of trees. One way to do this is to tag each individual tree felled so that its movement may be tracked out of the forest and onto the sawmill production line.

Tree Identification Numbers

Each tree in the forest will carry an identification number relating to its location in the compartment and its sequence of encounter along a given transect, so that its stump can be easily found when the log has been removed from the forest. This number will be placed on the tree following the stock survey, and tags bearing the number will be placed on both ends of the log at the time it is felled. The tag will remain on the log during skidding and hauling and will be recorded at the mill site along with the dimensions of the log. The idea is to execute a chain of custody for each log so that its movement can be tracked and the lumber it produces can be traced back to the tree in the forest.

The Chain of Custody

PfB's chain of custody (CoC) is a mechanism for tracking material from the forest to the final sawn product to ensure that the wood can be traced back to a tree in the forest. This is in conformity with FSC certification. The CoC also affords the company the ability to estimate its conversion efficiency over time and to estimate the quality of wood coming from each tree over time.

The CoC begins in the forest where each tree is individually numbered and a tag placed on the tree during the stock survey. When the tree is felled the same number is applied to both the ends of the log. Records are kept as to which log is skidded to which barquadier and from there further records are kept as to which truck hauls which log. When the log arrives at the purchaser's sawmill, duplicate records indicate which truck hauled the log and when it arrived. Logs coming from the operation must be kept separate from logs originating from other felling operations. When the log is about to be milled, its dimensions are recorded along with its tag number and number of bucked logs. During milling the number and sizes of boards coming off each bucked log is recorded and pinned to the individual log bearing the unique number. If wood quality is also recorded, the data on log size, board volume and lumber quality will provide important decision making information to the forest and mill managers.

The Post-harvest Assessment

Adaptive management is to be strived for at all times because it allows for improvement based on weaknesses and strengths learned from past experiences. For management to be adaptive, there must be an assessment of performance following each annual operation. This assessment takes the form of a post-harvest assessment (PHA) to be performed between 3 and 6 months after the close of logging operations. The PHA is usually conducted by the Forest Department in conjunction with PfB staff. A report should be written up at the end of each PHA in order to synthesize the findings and allow for adaptive management going forward into the next operational year. The methodology for conducting PHAs is as described below.

Materials: 50 metre tape, Soil Compaction Tester, Compass, GPS unit, Stock Maps, Field Sheets, Clipboard, Notepad

General Method: The post-harvest assessment methodology calls for two 20 metre wide sampling transects to be positioned in the compartment running east to west for the entire extent of the compartment to match the prevailing direction of skid trails. This is expected to provide a sample area of 4 hectares. Within these transects all stumps encountered would represent a felling site and the damage to residual trees and the size of the felling gap will be measured.

The process of deciding where transects should be located should be unbiased, meaning that two numbers should be chosen from 1 to 10 out of a hat. These two numbers will represent a 100 metre east to west line; for example, a random number of 2 would mean that one transect would be placed along the 200 metre line. However, a complication to this method is that protected sites such as bajos can be traversed by the transects. Since these protected sites were deemed outside of the felling area and since they would not be included in any calculation of felling intensity, they should be avoided. In such instances, transects will be re-directed around protected sites where possible.

For each compartment, the width of the main access road will be measured at 5 points spaced 50 metres apart. Measurements should be taken on a representative stretch of road. General observations will be made about the extent of rutting and the general condition of the main access road as well as skid roads. Neither regeneration nor compaction will be assessed on main access roads since these are often permanent roads.

Specific Methods: (i) Barquadiers - Half of all barquadiers will be assessed for damage to residual stems and the other half for regeneration. All barquadiers will be measured for size and tested for a compaction layer. The lengths of two perpendicular lines dissecting the barquadier (configured as a cross) whose four ends were oriented to the four cardinal points (E-W and N-S) will be measured to determine barquadier size. Barquadier area will be determined by calculating the area of an ellipse, in the GIS, having the same dimensions as those of the measured barquadier.

Residual damage will be measured for stems of all species >=20cm within a 3 metre zone of forest at the perimeter of the barquadier. Residual means that the stems were not intended to be knocked over as part of the clearing of the barquadier. The extent of the damage to each residual tree will be described qualitatively as Crown Off, Half Crown, Stem Scrape, Root Scrape, Branch Off, Branches Off, Leaned, Pushed Over, Dead or None.

Regeneration will be counted within a 1-metre strip along the entire length of the measurement line oriented E-W. The E-W line was chosen since it might be possible to expect the spatial variation in regeneration to be due to the prevailing wind direction and to the path of the sun across the sky. The number of seedlings

(≤1 metre in height) of each species occurring inside the transect will be recorded. Originally the 1-metre wide strip was to extend beyond the edge of the barquadier by 20 metres at both ends (East and West end) so that a comparison could be made with regeneration occurring inside the forest surrounding the barquadier, but a comparison would be confounded by the edge effect present around the perimeter of the barquadier caused by higher light penetration than is typical in a patch of closed forest as well by the immense amount of coarse woody debris at the perimeter of barquadiers.

(ii) Felling Gaps - For each tree encountered along sample transects, felling gap size will be measured. Gap length will be measured in the direction from the stump to the crown of the tree using a 50 metre tape. Gap width will be measured perpendicular to gap length at the widest point (since an ellipse would be used to calculate gap area). Gap perimeter will be determined based on the edge of the crowns of residual trees bordering the gap. Felling gap area will be calculated later based on an ellipse with parameters corresponding to the length and width of the gap.

Residual tree damage will be assessed for each gap encountered along the transects. All stems ≥20 cm DBH within the gap itself and within a 1-metre buffer at the perimeter of gaps will be assessed for damage. The extent of the damage to each residual tree will be described qualitatively as Crown Off, Half Crown, Stem Scrape, Root Scrape, Branch Off, Branches Off, Leaned, Pushed Over, Dead or None.

Regeneration will not be assessed in felling gaps as this would be too costly and timely. The scientific consensus is that gaps do promote the regeneration of shade intolerant species but that, although a flurry of new regeneration occur in gaps immediately after creation, gaps are typically dominated by species present under the canopy before the gap was created. These pre-existing stems would be in a better position (height-wise) to take advantage of the increased sunlight. Thus, the assessment of regeneration in gaps would not provide an accurate representation of *new* regeneration created by the logging event. The results would be misleading as they would show that logging encouraged the regeneration of species which were already regenerating under the canopy. For a more useful assessment of gap phase regeneration, the species succeeding to the canopy should be determined, but this is only possible several years after the gap was created. Furthermore, it has been found that RIL logging does not promote any more regeneration in felling gaps than does conventional logging (Kukkonen *et al*. 2008). In fact, the same study found that regeneration in natural gaps was typically more than in felling gaps.

(iii) Skid Trails - Damage will be assessed along 100 metres of two skid trails, the first encountered on the first transect and the first encountered on the second transect. All trees >=20 cm DBH within a 1-metre buffer on both sides of the skid road will be assessed for damage. The extent of the damage to each residual tree will be described qualitatively as Crown Off, Half Crown, Stem Scrape, Root Scrape, Branch Off, Branches Off, Leaned, Pushed Over, Dead or None. Skid trail width will be measured at 0 metres, 50 metres and 100 metres along the same length of the skid road assessed for damage.

Regeneration will be counted inside a 1x10-metre strip in the centre of the skid trail at the beginning of the 100 metre section used to assess damage.

5.1. Forest Cover

Monitoring forest cover requires examination at two spatial scales: landscape and stand level.

Forest cover can be monitored “remotely” using over flights and remote sensing. Given the importance of the broadleaf forest as for biodiversity conservation, constant monitoring should be carried out using over flights and remote sensing in order to identify threats due to encroachment and/or infringements from the outside. Updated satellite imagery should be used to monitor forest condition in critical regions.

Monitoring at the stand level is undertaken using Permanent Sample Plots (PSPs). 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. Monitoring plots should be placed in both logged and unlogged forest in forest types that are under management. Research in other tropical forests suggests that a minimum of four monitoring plots at the scale of a hectare are needed to generate reliable averages. Research in Belize on the FORMNET-B network suggests that such plots should be monitored for a minimum of five years to produce reliable averages. Plots to be established on the RBCMA will follow the methodology used in FORMNET-B, the national forest monitoring network, in order to add to the larger dataset on forest dynamics in Belize. Two PSPs were established in June 2016 in the timber extraction zone as per the spatial distribution and location in Fig. 22.

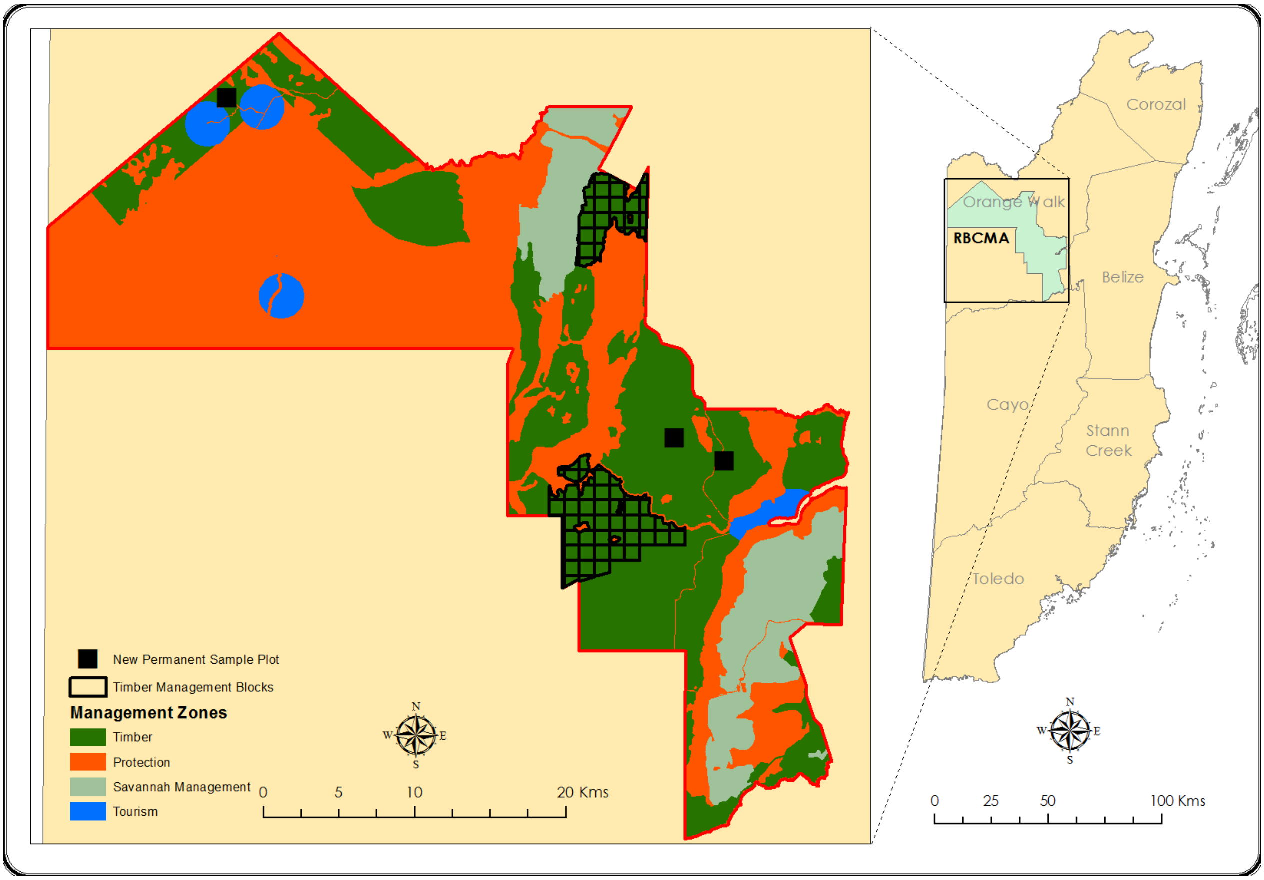


Figure 22. Location of new permanent sample plots on the RBCMA.

The methodology for establishing and monitoring the permanent sample plots is the standard system used in FORMNET-B, which is described in the next section.

PSP Material and Method

Materials: Ladder, Diameter tapes, Densiometer, Nails (100mm), GPS receiver, Tree tags, Hammer, Emulsion paint, Tying wire, Clinometer, 50 m tapes, 20m drag ropes, Compass, Field sheets, Flagging tape, Marker, PSP map, Data sheets from last census.

Plot layout: Each plot will be 100 metres by 100 metres oriented due north, and divided into 25 quadrats each 20 metres by 20 metres. At all corners of quadrats a marker post will be placed. The perimeter of the plot will be opened by machete on the outside only. The perimeter and internal quadrat lines will be rechecked and distances should be within ±0.4 m otherwise they will be re-measured.

Borderline Trees: Trees on the perimeter of the plot are of major concern compared to trees on the perimeter of internal quadrats. A compass sighting from a 20 m marker on the plot perimeter which is within 20 m of the tree has to confirm that greater than 50% of the roots and buttress lies within the plot. A tree on the perimeter which is not included in the plot will be slashed with an X on the side of the bole facing into the plot to indicate that it should not be measured.

Method of working: In each plot, tree measurement will begin in the north-west quadrat and then proceed south and then north again, in a zigzag fashion. In each quadrat a systematic approach will be used to avoid missing any trees. In quadrats enumerated heading south, work will begin in the north-west corner and proceed clockwise. Tags on trees near to internal quadrat lines will always be placed on the side of the bole facing the quadrat line. Once the north-west starting point is reached, the quadrat will be walked diagonally through the centre to inspect for missed trees. The next quadrat will be enumerated starting in the north-east corner heading in a clock-wise direction. Once the starting point is reached, the quadrat will again be walked diagonally through the centre to inspect for missed trees. The next quadrat will then be enumerated starting again from the north-west corner. Once the southern boundary of the plot has been reach, work will begin in the next column starting from the south-west corner of the adjacent quadrat. The same systematic method will be observed heading north but this time in an anti-clockwise direction within quadrats.

Tree location: Location of trees will be recorded within each quadrat as x,y coordinates, i.e. eastings and northings - the perpendicular distance in metres from the nearest westerly internal quadrat line (x) and the nearest southerly internal quadrat line (y), respectively. The reference point will therefore always lie at the southwest corner post of each quadrat, and since the plot is aligned with true bearings, tree coordinates will be aligned with true bearings and hence with the UTM grid system. Two parallel 20 m tapes originating from the westerly boundary will be laid out on the ground along the north and south boundaries of each quadrat. Similarly, two parallel 20 m tapes originating from the southerly boundary will be laid out along the east and west boundaries. Using this system, x,y coordinate measurers can move about on parallel quadrat perimeters to obtain the most advantageous point of measurement and be within 10 m of any given tree. From perpendicular boundaries, a compass will be used to sight to the geometric centre of the base of each tree using the magnetic bearing adjusted to true bearings. This will produce the x,y coordinates to within 10 cm.

Tree identification: During measurement, trees will be identified down to the species level wherever possible. Indigenous knowledge will be used to identify trees by common names and botanical samples will be obtained for each tree identified in this manner. Trees which are neither identifiable to species or to common name, will be classed as unknowns and numbered sequentially, and botanical samples collected. All botanical samples collected will be photographed and labeled by plot, e.g. plot x, unknown 1,...i. Voucher specimens consisting of foliage, flowers and fruits, where possible, will be prepared for later identification at a reputable herbarium. However, photographs of bark, leaves, flowers and fruits along with a short description of all lesser known and unknown species will be compiled in a manual and used in the field to aid in maintaining consistency in identification. By this manner, the total number of taxonomically different trees (i.e. species) can be determined reliably and efficiently.

Measurement of diameter: Diameter measurements will be made using fiberglass tapes and recorded to the nearest 1 mm for all trees ≥10 cm at 1.3 m above the soil in all quadrats. For saplings ≥1 cm but less than 10 cm in quadrats 1, 13 and 25, a small caliper will be used to take perpendicular measurements, the average of which will be recorded as the diameter. If the reading appears to be exactly halfway between the graduations, then it will be rounded up. A stick carefully measured and marked at 1.3 m in length will be used in the field to measure the point of measurement (p.o.m). The height of 1.3 m will always be measured on the uphill side of vertical trees on slopes. The height of 1.3 m will always be measured along the side lowest to the ground for any non-vertical tree, be it on a slope or not. For vertical trees not on slopes but where the surrounding ground is uneven (a common situation), the height to the p.o.m. will be measured from the highest point around the tree as long as it is measured from soil. For trees where it is not possible to reliably measure diameter at 1.3 m, e.g. buttressed or stilted roots, the p.o.m. will be moved from 1.3 m above the ground to 0.5 m above the convergence of the buttress or stilts. The height to the new p.o.m. will be recorded on the field sheet. The use of a ladder will assist with making measurements on buttressed and stilted trees. Where tall buttresses occur and the use of the ladder does not allow measurement at the p.o.m., the diameter will be estimated by reaching with tall poles to place the diameter tape perpendicular to the main axis of the stem and readings will be taken from two perpendicular positions. The distance away from the tape will be measured. Such measurements will be coded and corrected for parallax error during data post-processing following the methodology in Phillips et al. (2009). Otherwise a laser caliper will be used. Paint will be applied to the p.o.m using a paint brush on a pole and the tree will be tagged at 1.3 m from the ground. Where trees are fluted at the base, the procedure is the same as for buttressed trees. Where fluting extends along the entire stem, the diameter is measured at 1.3 m and a fluting code recorded on the field sheet. Where the tree forks below 1.3 m, each stem is measured and tagged individually. Where the fork lies at exactly 1.3 m, the stems are measured and tagged individually and the new p.o.m.'s are taken immediately above where the stem divides. Multiple stems will each be given a code on the field sheet to indicate that they belong to the same root system.

Where the fork occurs above 1.3 m, one p.o.m. will be marked and one measurement taken and the tree will be coded accordingly. Where there is a defect at 1.3 m, the diameter is measured immediately above the defect, given that defects normally spread downward, and the height to the new p.o.m. recorded. The height to the new p.o.m. and reason for moving the p.o.m. are always recorded on the field sheet. Before diameter is recorded any loose bark or moss will be brushed away and the p.o.m. will be marked with chalk or timber crayon. Climbers will not be cut away and the diameter tape must be passed under climbers to be in direct contact with the tree. The diameter tape will be placed perpendicular to the main axis of the stem so that its lower side coincides with the chalk mark and additional chalk marks will be made along the lower side of the tape to mark the exact location of measurement. Once the diameter is recorded the tape will be removed and a band painted around the tree with the top edge coinciding exactly with the chalk marks. Painting will be done carefully and accurately, perpendicular to the bole so that the upper margin of the painted band is exactly at the p.o.m. For stems <10 cm the four points of contact of the caliper will be painted with a dot.

Tagging trees: All measured trees will be numbered with an individual aluminium tag. As far as possible, trees will be numbered consecutively throughout each plot as per the method of working. For trees ≥5 cm diameter the tags will be nailed into the stem 30 cm above the p.o.m. using 100 mm nails driven into the stem at 45° from vertical. For saplings less than 5 cm in diameter the tags will be tied around the stem with tying wire. In addition to the painted band, a vertical strip of paint will be placed on each sapling to help with future re-location. Newly issued tags will not possess a number already present in the plot. Deciduous trees may appear dead to the untrained eye; therefore, careful checks will be made to confirm if the cambium beneath the tree bark is still live and it will be tagged.

Tree height: Crown point height for all trees, defined as the height to the first major live branch, will be measured to the nearest 0.1 m using a laser rangefinder. Total tree height to the top of the crown will also be measured for all trees.

Crown position: Crown position will be assessed for every tree measured. The methodology follows the five-point system developed by Dawkins and illustrated in Bird (1998). For ease of reference the classification system is presented in section 8.4.

Crown form: Crown form will be recorded for all trees measured. The five-point system developed by Dawkins and illustrated in Bird (1998) will be used. For ease of reference the classification system is presented in section 8.4.

Climber presence: Each tree measured will also be coded for the degree of strangulation by climbers. The codes presented in Bird (1998) following Synnott (1979) will be used. For ease of reference the classification system is presented in section 8.4.

Palms: Only palms ≥10 cm diameter at 1.3 m will be enumerated. In a given hectare of forest, palms ≤10 cm in diameter can be too abundant to measure in any reasonable amount of time. All palms ≥10 cm diameter will be measured, mapped and tagged. Where the p.o.m. is obstructed by the presence of fronds no diameter will be recorded. Individuals will be assessed as immature if fronds emerge from the stem below 5 m (Bird 1998). Individuals where fronds emerge from the stem above 5 m will be classed as mature and diameter recorded in the standard manner.

Missing, dead or damaged trees: If a tree has died, the reason will be determined and recorded. The tree will be measured for diameter according to the standard method. The cause of death or disappearance will be coded according Table 15. These codes are neither similar to Bird (1998) nor Phillips et al. (2009) but were redesigned to be applicable to hurricane impacted forests. For example, additional codes relating to hurricane damage or mortality have been added. Any tree died broken or broken but not dead will be measured to the height at which the breakage occurred.

Table 15. Codes for dead or missing trees.

Code	Description (more than one code may apply)
DT	Dead tree
DA	Died alone
DG	Died in a group
DS	Dead standing with branches intact
F	Felled naturally (uprooted)
FH	Felled by hurricane
FA	Felled (anthropogenic)
KB	Killed standing (broken) by natural tree fall, branch fall, or liana weight
KBH	Killed standing (broken) by hurricane (tree fall or wind snap)
KF	Killed by fire
KI	Killed standing by liana competition
KL	Killed by lightning
KR	Killed during road building or log extraction
KS	Killed standing by strangler
KU	Killed by unknown
KW	Killed by weight of liana (use in combination with F or KB)
V	Vanished
VP	Vanished but presumably due to poor mapping
X	Caused death of other tree by natural fall or hurricane fall

Adapted from Bird (1998) and Phillips *et al.* (2009)

Tree description: Each tree which is measured will also be assessed for a variety of additional characteristics such as alive or dead, physical condition, defects, phenotypic manifestations, and damage. The list of codes and corresponding description for live trees is presented in Table 16.

Table 16. Codes for living tree condition.

Code	Description (more than one code may apply)

AF	Alive fallen
AH	Alive with rot in stem (hole)
AR	Alive partially rotten (no hole)
AS	Alive with strangler fig
BC	Broken top >1.3 m, but with coppice crown
BS	Broken <1.3 m
BT	Broken top > 1.3 m, no crown present
BU	Buttressed tree
CD	Crown defoliated by insect or other cause
DB	De-barked, bark has been lost over part of the stem
DC	Damage in crown caused by other falling trees or branches
DS	Damage on stem due to falling tree
DU	Diameter measurement unreliable
FA	Major fork above p.o.m., but below half tree height
FB	Major fork below p.o.m.
FD	Fire damage present on tree bole
FL	Fluted bole
FU	Fungus present on tree bole
L	Lightning damage
LA	Liana
LS	Leaves shed (deciduous)
LT	Leaning tree and/or supported by other trees
N	New tree
N	Near death, declining
PC	Palm fronds cut
PI	Immature palm. Fronds emerge from stem below 5 m
PM	Mature palm. Fronds emerge from stem above 5 m
R	Resprout
S	Is a strangler
SS	Stem slashed for chicle collection
ST	Stilt roots
TB	Termites present on bole or roots
TC	Termites present in crown
TF	Tree in fruit
TS	Too small now (<10 cm or <1cm) due to damage or shrinkage
TW	Tree in flower
US	Very bad bole form with no utilization value

Adapted from Bird (1998) and Phillips *et al.* (2009)

Site codes: The bio-physical conditions within each quadrat will be described using the system of codes detailed in Bird (1998) and presented in Table 17.

Table 17. *Quadrat site codes.*

Code	Description
CT	Climber tangle on top of pole-sized re-growth
DW	Dry watercourse
FI	Recent fire
FL	Recent flooding evident
GA	Natural gap formed by tree fall
LO	Past logging evident
RK	Rocky outcrops
RS	River or stream
SW	Occurrence of swamp conditions
TI	Ground dwelling termite mound present
TP	Truck-o-pass
TS	Tree stumps
WT	Windthrow

Adapted from Bird (1998)

Slope and Slope Position: The slope of each quadrat will be measured with a clinometer and two pegs 1.3 m in height. The slope position at the centre of each quadrat will also be recorded. Five positions will be recognized: hill top, upper slope, mid-slope, lower slope, and valley bottom.

Aspect: The aspect of each quadrat will be assessed and recorded according to eight directions based on the four cardinal points.

Canopy openness: The canopy openness in each quadrat will be measured using a spherical crown densiometer (convex model A, Forestry Suppliers Inc.). This equipment measures the percentage of overhead space not occupied by canopy using a series of dots on a concave mirror. Four readings will be taken according to the four cardinal points and averaged to produce one reading.

Vine cover: The percentage of each quadrat covered by vines up to a height of 5 m will be visually estimated.

Re-sprouting: On standing, but broken trees with coppiced crowns, or fallen trees, the parent stem and all re-sprouts ≥10 cm diameter at 1.3 m will be enumerated. For all re-sprouts on fallen or standing trees, the p.o.m. will be taken at 1.3 m from where the re-sprout is attached to the parent stem (Phillips et al. 2009), this measurement following any curve in the re-sprouted stem. For fallen new parent trees the p.o.m will be taken horizontally from the base of the stem while for fallen old parent trees the original p.o.m will be used. Re-sprouts will be counted as separate individuals if they emerge at any point along a standing or leaning parent stem whose original canopy is alive. If the parent canopy is dead, multiple re-sprouts will be counted as multiple individual stems. This criterion of dead/live parent canopy is not discussed in Bird (1998) or Phillips et al. (2009), but is considered relevant in the context of hurricane damaged forest.

Fallen live trees: Fallen trees will be checked carefully to determine if they are still alive, as with standing deciduous trees. Fallen live trees will be enumerated as per standard procedure.

Liana measurements: Each liana stem that is ≥10 cm diameter at any point along its stem within 2.5 m vertical distance from the ground will be measured and tagged (Phillips et al. 2009). Diameter will be recorded at 1.3 m along the stem from the principal rooting point. Liana stems which share the same root system will be counted as multiple stems (i.e. forking) if they fork within 2.5 m vertical distance above the ground. All p.o.m.'s on a liana will be painted and the tag will be placed at 1.6 m vertically above the ground. For each liana stem, the tag number of the tree whose crown is most affected by the liana crown will be recorded. If the host tree is outside the plot it will not be recorded. Elliptical lianas will be measured by taking the diameter at the widest and narrowest axis and later converted to a round diameter.

Strangler lianas: Strangler lianas will be issued a separate tag from the host tree. Loose and separate lianas will be enumerated as per standard procedure. At advanced stages of liana parasitism, the entire bole of the tree can be engulfed with little or no portions visible. This presents a problem for measuring the liana as the shape of the stem will not allow diameter to be measured. To deal with this problem, first an estimate will be made of the percentage of bole surface covered by the liana. Second the thickness of the liana will be measured, where possible, at the p.o.m. If the entire surface of the bole is engulfed at the p.o.m. liana thickness will be estimated from the mean liana thickness. Third, the diameter of the parasitic complex will be measured and p.o.m. determined as per standard procedure. During volume calculation a correction will be applied to account for the volume of the tree bole and the un-covered space on the exterior of the tree bole. Volume will first be calculated using the diameter of the parasitic complex, and subtracted from this will be the volume calculated from the diameter of the host tree which will be determined by subtracting '2 x liana width'. The difference will be the total volume of the liana outer shell and this will then be corrected by multiplying by the decimal percent of bole covered by liana.

Strangled live trees: In some cases trees may be strangled by multiple stems of the same liana and in extreme cases the liana stems may merge into each other forming a blob covering most if not the entire surface of the stem. If the tree is still alive, it will be impossible to lift the liana stems to accurately measure tree diameter. In cases where the tree bole is still visible, the diameter of the tree will be estimated by holding the tape (on standard side) perpendicular to the main axis stem at the p.o.m and readings taken from two perpendicular positions. The tree will be painted and tagged in the standard manner. Such measurements will be coded and later corrected for parallax error during data post-processing. In cases where the liana stem has entirely engulfed the tree at the p.o.m., tree diameter will be estimated and coded as unreliable.

Quality control: One of the 25 quadrats in each plot will be selected at random and re-measured after the plot has been enumerated. This will act as a control on the consistency of the measurements taken.

Re-measurement Frequency

Permanent sample plots should be remeasured annually to detect growth, recruitment and mortality which operate on a similar temporal scale. For example, the dry season often induces mortality related to drought stress and this can be detected after several months as the trees senesce, and the mortality signal is ideally detectable until the following year. For logistical ease, remeasurements should take place at the start of the dry season. The plots will be remeasured at the same time annually in order to standardize the temporal resolution of the data and make analysis less troublesome.

Reporting

A general report on the findings from the permanent sample plot should be made at the end of five years, when sufficient time has elapsed and data has been collected to formulate concrete and generalizable conclusions. This five year reporting period will also coincide with the revision of the management plan, allow for adaptive management.

5.2. Wildlife

While monitoring the results (outputs) of forest management inputs is important to forest management, the effects of forest management on the biodiversity of the RBCMA must also be measured as management runs the risk of becoming ineffective when it cannot be measured. Research and monitoring are closely linked. Based on the RBCMA HCV assessment a concise set of monitoring efforts is suggested that will allow for some measure of management effectiveness assessment at a later stage. Important in this aspect are the Biodiversity Zones and buffers which will allow for future monitoring of changes in the forest by providing an example of the forest in its undisturbed state, against which changes can be compared.

There are several levels of monitoring and special attention should be given to the critical species listed earlier. But specific cases such as monitoring of the logging impacts on the bird population of the RBCMA are of interest. Birds, especially neotropical migrants of global concern, should be of particular interest as their presence can be used as an indicator of forest health.

More specific Biodiversity monitoring efforts are the following:

- Biodiversity studies must be implemented so as to update the status of endangered species. This can be done at the species level in-house and/or through the engagement of research institutions and universities.
- Encourage independent research (Local and foreign universities) to carry out research (such as migratory bird research) in both logged and un-logged compartments
- Maintain a network of wildlife cameras that automatically record wildlife activities. Cameras should be placed in both the protection forest as well as in the logged area, in order to compare changes and impacts.
- Following the recommendations of the previous FMP, under any circumstances reassessment of the impacts of forest management interventions on biodiversity should be undertaken during this planning period.

5.3. Water Quality

Water quality testing to monitor sedimentation and eutrophication of forest interior streams and major water bodies must be carried out in conjunction with main disturbance activities such as the creation of roads.

6. RESEARCH

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.

The geographic juxtaposition of the RBCMA both within the context of the Maya Forest and the Northern Biological Corridors, its management objectives and its management programs and infrastructure are all conducive to developing the RBCMA as a centre for research. The strategy therefore that is enunciated in the RBCMA Management Plan (Edition V) 2006-2010: is to maintain the present opportunistic approach to research programs, with particular emphasis on those that support priority management areas (i.e. ecotourism, hardwood timber and savannah management, aquatic systems), but also to institute small-scale but regular monitoring programs by PfB field staff – i.e. promote a greater degree of self involvement in preparation for a more wide-ranging development effort in the future.

Timber Management Research

Wilson (2006) provides a description of the timber management research programme on the RBCMA:

The research programme of the RBCMA combining forest ecology and management alongside operations has played an important role in developing the present forest management regime. Several of the research activities were conceived as long-term programs and must be maintained to obtain their benefits. The permanent plots are especially important and priorities are:

• Maintenance of the FPMP permanent sample plots. These are designed to give accurate data on recruitment, growth and mortality and should be re-measured at 5-year intervals. Two PSP's (21 & 22) were measured in 2011 with the technical supervision of a Belizean PhD candidate and it is expected that data from these plots will be analyzed as part of his dissertation.

• Reiteration of the full stock survey in 100 ha compartments conducted early in the experimental phase. These were first measured 16 years ago and should now yield good growth and mortality data with large samples of commercial species in the critical 30-100+ size ranges. This act alone will allow vastly improved modelling for projections of yield and allowable cut, of immediate use in stand management and financial planning.

• Re-location and re-measurement of the CATIE liberation-thinning demonstration plots. The liberation approach proposed here as a routine operation is based on this technique. Measurement of the results of the demonstration therefore also has an immediate bearing on operations. The original data needs to be repatriated.

• Maintenance of observations on regeneration of mahogany and other species in the patch cuts and seed shadows. If necessary, PfB should maintain routine observations in collaboration with the University of Belize. The seed-shadows in particular have a direct and immediate bearing on operational planning.

• Promotion of research into the ecological and stand dynamics of a broader range of important hardwood species. Work to date has centered on mahogany. It should now be expanded to cover the other key hardwoods that make up the forest resource including, in approximate order of importance, billy webb, black cabbage bark, chicle macho, nargusta and bullet tree.

The passage of Hurricane Richard (2010) and Hurricane Earl (2016) over the RBCMA has drastically altered important ecological conditions of light, horizontal and vertical forest structure, species distribution etc. This obviously impacts research sites in the hurricane affected area of the RBCMA and opens up the opportunity for new research on post hurricane forest dynamics. A complete review of ongoing research and research sites and the possibilities for new research should be carried out. This may very well be a good time for PfB to re-evaluate its forest ecology and forest management research.

Biodiversity Research

The RBCMA is well-suited as a base for research and both field stations at Hill Bank and La Milpa host several visiting research and survey projects each year. As a result the ecological characteristics and dynamics of the area are perhaps the best known in the country. The most important multi-year efforts undertaken in partnership with international institutions and underlying present management programs include:

- *Faunal research* has taken place over time, one of the more recent studies is from Virginia Tech and involves various types of Jaguar research evaluating camera's, trapping and scatological research.

- *Avifaunal surveys (from 1989):* These were undertaken in partnership with Manomet Observatory for the Conservation Sciences and later with The Nature Conservancy, starting with an emphasis on neotropical migrants and expanding to include the distribution and status of the avifauna as a whole. Subsequent studies have concentrated on species of special conservation concern, notably the Yellow-headed Parrot. The Harpy eagle re-introduction work (in partnership with the Peregrine Fund and Belize Zoo) is a continuation of this programme.

- *Archaeological Programme (from 1989):* Two parallel programs on the La Milpa site and on the archaeological landscape of the RBCMA, conducted by the Universities of Boston and Texas.

- *Broad-leaved forest ecological dynamics (from 1989):* Studies began in partnership with Manomet Observatory and were expanded in partnership with Duke University and the UK-funded Forest Management and Planning Project. They have included detailed vegetation mapping, forest phenology, monitoring and experimentation on recruitment, growth and mortality, and logging impacts on biodiversity indicator groups.

- *Carbon sequestration (from 1995):* These studies are linked to the Carbon Sequestration Pilot Project and undertaken with The Nature Conservancy and Winrock International. The programme includes assessment and monitoring of biomass in different vegetation types, tracking of land use trends in north-west Belize and development of techniques for biomass assessment at different scales.

- *Pine savannah management (from 2001):* Initiated by studies on savannah vegetation and ecology with the Royal Botanical Gardens (Edinburgh) and continued in conjunction with The Nature Conservancy Fire Management Programme and the Carbon Sequestration Programme.

- *The Freshwater Programme (from 2004):* Monitoring of water quality indicators in the New River Lagoon and its tributaries, in conjunction with The Nature Conservancy.

Cooperation with research organizations

PfB as indicated previously in this section has continuously developed through the years close collaboration with national, regional, and international research organizations. At the national level the development a natural resource management faculty in the University of Belize the national university and its Environmental Research Institute plus the establishment of a private university, Galen University, expands the scope for collaboration in research at the national level. At the regional level, the increasing involvement of CATIE in forestry projects in Belize also widens the scope for collaboration between this prestigious regional institution with which PfB has collaborated in the past. Within the Caribbean opportunities to establish research links with regional institutions such as CERMES especially in the area of freshwater management and carbon sequestration could be a spin off from the yearly scheduled visits facilitated through the Caribbean Climate Change Centre. At the international level, PfB has successfully attracted the cooperation of various North American universities and well known organizations. Although for the most part the present series of collaboration has run their course, new partnerships should be promoted.

7. Information Management System

Fact documentation and record keeping is a key aspect in SFM. Oftentimes, documentation is the unique way of proving the execution of specific actions, such as conflict resolution events, stakeholders' agreements, etc. FME performance is improved and SFM evaluation costs are greatly reduced when archived records exist. Furthermore, efficient operations monitoring is only feasible when activity records and documents exist and are properly managed.

Records and documents can be managed through an information management system; which is a set of procedures and algorithms that analyse and summarize information in order achieve a better understanding of the events and processes related to such records.

Information systems greatly improve decision making in enterprise and resource management, and operations execution. Accounting is an example of a basic information system that is implemented in nearly all business undertakings. Management information systems linked to GIS are even more powerful, particularly as an aid to carry out complex forest management tasks. However, information systems are expensive and may be rather inaccessible to small companies. Fortunately, sophisticated information systems are not required to achieve SFM. A simple but reliable management information system including the main aspects of the management operations should suffice. Such management information system should include the following records:

- Daily or weekly tree felling and adjustments to stock surveys.
- Daily or weekly log skidding volumes and trips.
- Daily or weekly log hauling volumes and trips.
- Post harvesting assessments
- Logging yard inventories.
- Yearly production report by compartment.
- Costs register.
- Timber salvage volume register.
- Silvicultural treatment register.
- Wildfire register.
- Community agreements/resolution conflict register.
- Accidents register
- Road construction and maintenance register
- Results of monitoring interventions and processes

It is important that the forest information system is linked to the monitoring system.

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9. ANNEXES

ANNEX I. JOB CONTROL DOCUMENT

PROGRAMME FOR BELIZE FOREST INVENTORY

INVENTORY DATE: May - June 2021

LOCATION: Rio Bravo Conservation and Management Area

PURPOSE: The purpose of this inventory is to collect sample data necessary to evaluate the stocking of commercial timber species, footprint of past logging, and the feasibility of maintaining a sustainable harvest regime into the future.

CRUISE: Quarter hectare plots will be sampled throughout the area under investigation. The dimensions of each plot will be 125 metres by 20 metres oriented lengthwise in an East to West direction. Each plot will be comprised of 10 subplots each 10 metres by 25 metres. Plots will be distributed across the forest following a random location model with constraints for minimum distance between plots of 250 metres.

TEAMS: There will be 4 persons to a team and 1 team leader. The team leader is responsible for accurate data recording and for making sure the protocol is followed at every stage. The other team members will each be assigned a role: tree measurer, assistant tree measurer, linesman, assistant linesman. Their duties will be to accurately measure each tree, assist with the measurement of each tree, clear the central transect line, and assist with clearing the central transect line, respectively.

I. PLOT LAYOUT AND SAMPLING DESIGN

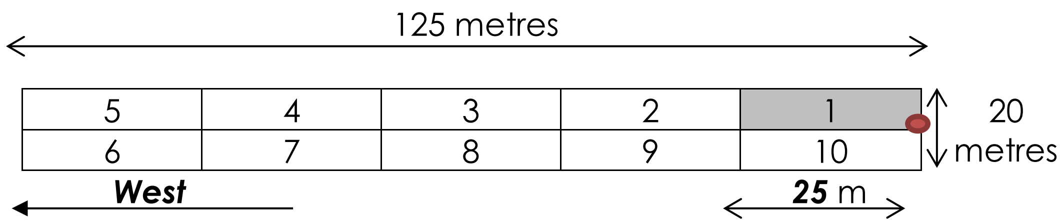


Figure AI.1. *The plot/subplot layout used in the inventory. The red dot indicates the starting point. All Mahogany trees ≥10 cm DBH are sampled in the entire plot. For all other species, including palms, trees ≥10 cm DBH are sampled in subplot 1 only. In all other subplots, trees ≥25 cm DBH of all other species, including cohune and other palms, are sampled. All logged stumps of any species and all old truck-o-passes are recorded in the entire plot.*

a. **Plot monumentation**: The beginning of each plot should be located using GPS receivers and coordinates provided. The provided coordinates are for the eastern end of the plot at the start of the central transect. At the starting point a thick post should be driven into the ground to 1.3 metres in height. This post should be flagged with fluorescent flagging tape leaving a 25 cm tail hanging down on two sides of the post. The plot number should be written on the flagging tape. A 10 metre rope should be stretched due north of the starting point so that the team may become oriented with the plot dimensions. The same should be done due south of the starting post.

Figure AI.2. Establishing the plot monumentation.

b. **Central transect**: From this starting point, a line heading due west should be cleared and posts erected and flagged at 25 metre intervals along the line, and labeled with the distance from the starting point. Between these main posts there may be additional posts erected and flagged minimally but not labeled with distances.

Figure AI.3. Establishing the central transect.

c. **Subplots:** Each 25 metre by 10 metre section of the plot constitutes a subplot labeled as per Fig. AI.1. There will be 10 such subplots each being 1/40th of a hectare. Trees will be tallied by subplot in which the trees are located.

d. **Trees to look for in the subplots**: All Mahogany trees ≥10 cm DBH are sampled in the entire plot. For all other species, including palms, trees ≥10 cm DBH are sampled in subplot 1 only. In all other subplots, trees ≥25 cm DBH of all other species, including cohune and other palms, are sampled. All logged stumps of any species and all old truck-o-passes are recorded in the entire plot.

e. **Data to record**: The species of all trees and palms should be recorded where known. Where species is unknown it should be recorded as such. Special note should be made to record the names of species used for fence posts. The DBH at 1.3 m of all trees should be recorded to the nearest 0.1 cm (Fig A1.4). The height to the first major branch should be recorded for all trees to the nearest 0.5 metre using a laser rangefinder or visually if none is available. However, for all palm trees, the total height to the top of the highest frond should be recorded to the nearest 1 metre using a laser rangefinder or visually if none is available. For palm trees without a definite stem at 1.3 m, the number of fronds should be recorded in place of diameter with the word "fronds" following the number. For trees ≥25 cm DBH of timber value, the log grade should also be recorded (see section on Log Grades). Stumps which are the result of recent logging <50 years should simply be recorded as "Stump" with no diameter measurement. The presence of old truck-o-passes should be recorded per subplot at the bottom of the field sheet.

Figure AI.4. Enumerating a tree.

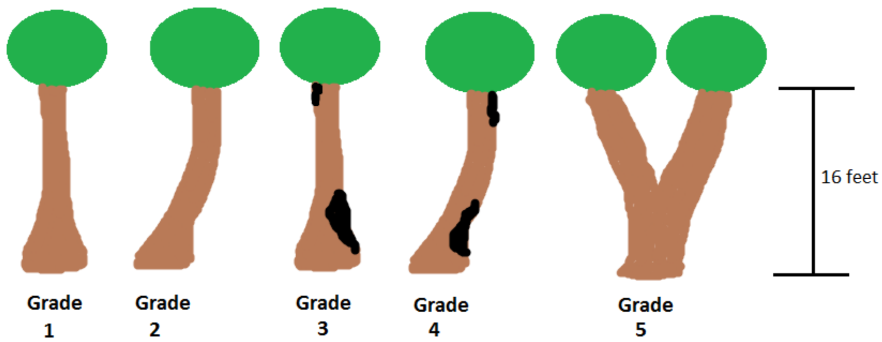
f. **Log Grades:**

Grade 1 – Straight – No major deviations or defects in the first 16 ft log.

Grade 2 – Curved – Typically a long curve deflecting more than 3 inches in the first 16 ft log.

Grade 3 – Defected – A large defect in the form of a hollow, rot or other damage affecting 25% or more of the first 16 ft log.

Grade 4 – Curve and Defected – a combination of a long curve and a defect affecting 25% or more of the first 16ft log.
Grade 5 – Forked below 16 feet – A large fork on the first 16ft log. Other defects may be present.



g. **Edge trees:** Trees whose middle point falls exactly on the perimeter of the plot as measured from the centre line are included in the tally.

h. **Dead trees**: No clearly dead trees (snags, standing dead, broken dead) will be recorded.

i. **Species names:** A detailed species list is to be provided and includes the English, Spanish, Maya, and scientific names for the different species to be tallied. Prior to any data collections, a single name should be selected for each species to be used throughout the data collection process.

II. EQUIPMENT

Four 50 m transect tapes
Two DBH tapes
Two clipboard
Two 10 m yellow ropes
Two laser rangefinders
Ample flagging tape
Two GPS receivers
Machetes

ANNEX II. Outline of Monitoring Plan for the 2022 - 2016 Timber Management Area in the RBCMA

	Tier three	Consists primarily of office checks concerning regulatory, legal, financial, corporate and social obligations under the long-term forest license which seek to satisfy government requirements.				
	Tier two	Consists of on-ground monitoring activities at the scale of the management unit, i.e. the entire property. Since the ecological and social effects of logging operations can sometimes manifest themselves a few years after logging has been completed, the frequency and intensity of monitoring activities within tier two can take place every two to three years.				
	Tier one	Consists of on-ground monitoring activities at the scale of the annual harvest coupe (also known as the Annual Cutting Compartment or ACC). The frequency of monitoring at the level of this tier should be annually, in order to detect immediate impacts or deficiencies resulting from the logging operations.				
Tier	3.	Legal, financial, regulatory, corporate, & social obligations				
ME No.	**Monitoring Element**	**Acceptable Limits/Indicators**	MOV	OVI /Criteria	Feedback Action	Schedule
1.	Land Tenure	Land tenure should always be secure and unchallenged.	All land title documents	1. Land tenure valid 2. Official .shp file of boundary (including any legal adjustments)	Technical Coordinator	Every 5 years
2.	Long term forest license	The long-term forest license (LTFL) should always be valid and presentable at a moments notice.	Check PfB's main office and Hill Bank Field Station for filed up to date copy.	Return identical valid and presentable copies of the LTFL	Technical Coordinator	Every 5 years
3.	Security Bond	A valid and presentable security bond covering the long-term forest license should always be in existence.	Check with PfB main office and/or Forest Department.	1. Date of expiration of security bond 2. Valid for $20,000	Technical Coordinator /Accountant	Annually
4.	Cutting permit	A valid and presentable cutting permit should be in existence at all times during which felling is occurring.	Check with PfB main office and Hill Bank Field Station. District Forest Officer should also have a copy.	Valid copies of the cutting permits, with receipts for the $500 BZD fee attached.	Technical Coordinator /Forester	Annually at the start of the year
5.	Annual Plan of Operation	1. An FD approved and presentable annual plan of operations (APO) should be available at all times during logging operations. 2. PfB's staff must also	Check with PfB main office and Hill Bank Field Station.	1. Valid copy of an APO to cover the year's forestry operations is available. 2. PfB's forestry staff verbally	Technical Coordinator /Forester	Annually before start of logging season

		fully understand the contents of the APO.		quizzed on the contents of the APO via a staff meeting prior to the start of logging operations.		
6.	Environmental Impact Assessment	**These are not presently required by FD.**				
7.	Environmental Compliance Plan	**These are not presently required by FD.**				
8.	National developments in the forest sector	All managerial staff should be aware of at least one recent (within the past year) national development in the forest sector.	Web searches or checks with the Forest Officer responsible for Forest Resource Planning and Management.		Technical Coordinator /Forester	At least every trimester.
9.	Regional developments in the forest sector	All managerial staff should be aware of at least one recent (within the past year) regional development in the forest sector.	Web searches or checks with the Chief Forest Officer or Deputy CFO.		Technical Coordinator / Forester	At least once every 4months.
10.	International developments in the forest sector	All managerial staff should be aware of at least one recent (within the past year) international development in the forest sector	Web searches or checks with the Chief Forest Officer or Deputy CFO.		Technical Coordinator /Forester	At least once every 6 months
11.	Additional Monitoring Elements					

Monitoring Element	Acceptable limits	How	When	**Who**
Employee Relations	Employees satisfied	Meeting with employees / signed surveys	Quarterly	Technical Coordinator
Social Security	Social Security paid	Checks with Social Security office	Monthly	Accountant
Qualified forester	Qualified forester on staff/contract	Interview with Forester	Annually	Technical Coordinator
Training	Employees given adequate annual training	Meeting with employees / signed surveys	Annually	Technical Coordinator
Laws available	Paper copies of relevant laws available	Checks at main office/ Hill Bank F.S. for availability of paper copies of relevant	Annually	Technical Coordinator

				laws		
		Employee Safety	Safety equipment & procedures in effect	Meeting with employees	Annually	Technical Coordinator
		Royalties	Royalties paid in full	Checks with PfB Accountant, FD HQ	Monthly	Accountant
Tier	2.	Management effectiveness, social and ecological impacts				
ME No.	**Monitoring Element**	**Acceptable Limits/Indicators**	MOV	OVI /Criteria	Feedback Action	Schedule
	Management Effectiveness					
12.	Production quality of the APO	The APO should always be produced according to national standards as determined by a qualified forester with 10 years of experience in the field of forestry in Belize.	APO signed by the practicing forester	APO approved by FD	Technical Coordinator or Forester	Annually
13.	Staff training	Following the training schedule, staff should be well-trained in carrying out their different roles	1. Training schedule 2. Training reports	1. No. of staff trained 2. Copies of training certificates	Technical Coordinator/Forester	Annually
14.	Chain of custody	There should always be an efficient, up-to-date and accurate chain of custody in effect.	Spot checks at 3 different legs of the chain of custody.	Documented Control System in place	Technical Coordinator/Forester	Weekly during logging operations
15.	Biological and Resource Security	The property should be free from ongoing illegal logging and invasive species.	Patrols in area susceptible to or historically affected including known routes open only to footed or hoofed traffic.	1. Patrol schedules and reports including maps 2. Documented action taken to address issues	Technical Coordinator Forester/	At least five times per year
16.	Safety preparedness	Safety preparedness and awareness should always be at a visibly high level.	Unannounced spot checks to see if personal protective safety equipment and other safety gear are being used and safety precautions are being observed.	1. Safety code known to all. 2. Checklist for and documentation of any infraction and corrective measures	Safety Officer	Weekly

17.	Community Relations	A third party report on the most recent community consultation/outreach activities must be in existence and presentable at all times.	1. Simplified community outreach strategy and action plan 2. Latest third party report available at the Hill Bank Field Station and B.C. office.	3. Documented response to issues arising	Technical Coordinator or Forester	Semi-annually
18.	Forest Management Costs (Internal Rate of Return)	The internal rate of return (IRR) of PfB's logging operation should be no less than 10%.	All costs and incomes associated with the logging operation calculated and documented on a monthly basis	Utilization of a suitable formula to calculate IRR	Technical Coordinator /Accountant	Quarterly
	Social Impacts					
19.	Employee ratio from neighboring communities	The ratio of employees from neighboring communities to those from elsewhere should always be 1 or greater	Check PfB's employment records	Relevant details recorded in employment records for both permanent and casual employees	Technical Coordinator	At the end of the calendar year
20.	Income injection to nearby communities	There should always be a positive and significant income injection into nearby communities.	Tallying of the value of equipment time, assistance or monies given to communities in the form of salaries, donations, or loans.	1.Signed standard forms that certify the type of assistance provided 2. Audit of value of income injection	Technical Coordinator or Accountant	Annually
	Ecological Impacts					
21.	Forest dynamics and species composition	Forest dynamics and species composition should always reflect a natural state of affairs, that is to say that logging should not be causing undue negative changes	Collection of data from permanent sample plots positioned in both unlogged and logged forests by trained personnel.	Analysis and comparison of data between logged and unlogged plots.	Qualified forest ecologist/biometrician	Every 2 to 3 years

		to these parameters.				
22.	High conservation value forests	Identified HCVFs should never be impacted by logging or other detrimental activity.	Site visits to HCVFs when the logging coupe is in the general location of the HCVF.	1. HCVFs should be clearly defined on the ground and on maps. 2. Field ledger to record any visible infractions into the buffer area or the HCVF area. 3. Monitoring report	Technical Coordinator/Forester	Weekly during logging operations
23.	Forest Pests	The forest should always be free from **severe** pest outbreaks, both natural and foreign.	Spot checks at the barquadiers, annual logging coupe and throughout the property.	Field ledger used to record the presence of any unusual tree death or log degradation	Forester	Bi-annually
24.	Rare, threatened and endangered species	Rare threatened or endangered species (RTEs) should not decline in status.	Spot checks to sites of known RTE habitation.	Field ledger used to record any observations of RTE presence	Field ecologist or Forester	Every year or two
Tier	1.	Operational effectiveness, and local ecological impacts				
	Ecological impacts					
ME No.	**Monitoring Element**	**Acceptable Limits/Indicators**	MOV	OVI /Criteria	Feedback Action	Schedule
25.	Logging Damage	Logging damage should be kept to a minimum	Sampling using transects within which all trees 20 cm or above are assessed for damage.	Results of sampling protocol	3rd party suitably qualified forest ecologist	Annually at the close of forest operations
26.	Felling intensity	Felling intensity should be kept to around 8 trees per hectare or below.	Monitoring using the 3 phase approach.	Analysis of transect sampling of tree stumps	3rd party suitably qualified forest ecologist	Annually at the close of the logging season.

27.	Canopy opening	Canopy opening should be no greater than 10% of the area of the ACC.	transect sampling to determine mean felling gap size, mean skid road width, mean barquadier size, and mean extraction road width.	Analysis of transect sampling	3rd party forest ecologist	Annually at the close of the logging season
28.	Stream-size zone integrity	Stream-side zones should never be impacted by falling trees or logging machinery.	Spot checks of at least 30 randomly selected sites along streams.	Field ledger used to record infractions	1. Forester 2. Forest ecologist	1. During logging season 2. At close of logging season
29.	Regeneration	Barquadiers and skid trails should encourage the regeneration of light loving species.	Random sampling of barquadiers and skid trails to count and determine the species regenerating in the openings.	Analysis of sampling	3rd party suitably qualified forest ecologist	3 to 6 months after the close of the logging season
30.	Seed tree retention	Minimum of 10 seed trees per km^2 to remain for all harvestable species.	Random checks to determine the existence of marked seed trees according to the stock map.	Field ledger noting condition of each seed tree checked.	3rd party forest ecologist	Annually at the close of the logging season.
31.	Road construction	Main extraction routes should be no wider than 5 metres. Skid roads should be no wider than 3.6 metres. Skid road intensity should be no more than 200m per hectare.	Random sampling along stretches of skid and extraction roads.	Sampling results	3rd party forest ecologist	Annually at close of logging season.
32.	Barquadier construction	Barquedier area should not exceed 2,400 square metres. Barquadiers should not be larger than 40x60 metres	Counting and inspection of barquadiers, and the sampling of barquedier widths	1. No. of barquadiers 2. Sampling results	3rd party forest ecologist	Annually at the close of the logging season
33.	Tree marking	All harvestable and seed trees should be marked	Random sampling using transects.	Sampling results	3rd party suitably qualified forester	Annually at the close of the

		with paint or some other suitable method.				logging season
34.	Compartment closing	The ACC should be 'closed' once all logs and branches (if applicable) are extracted.	Spot checks to examine if barriers or markers are placed at the main entrances to the compartments.	Presence or absence of markers	Forester	Annually at close of logging operation for the ACC
	Operational discipline					
35.	Reduced Impact Logging	Reduced Impact Logging (RIL) techniques such as directional felling and skidding with a winch should be observed at all times.	Spot check different aspects of the logging operation such as felling, skidding, and stream crossing.	1. Field ledger used to record infractions 2. RIL Code for Belize	Forester	Biweekly at unannounced times during logging operations.
36.	Branch Harvesting	Branch harvesting should not involve the felling of any additional trees be it for branches or to clear access to branches.	Random, unannounced checks at branch harvesting sites.	Field ledger used to record infractions.	Forester	Randomly Selected days comprising 3 or more per week during branch harvesting operations.
37.	Stock survey	The stock survey should be carried out according to national standards.	Spot checks to observe the practices of the stock survey team	Field ledger used to record any infractions	Technical Coordinator/Forester	Weekly during the stock survey
Monitoring Feedback Protocol		All monitoring exercises should involve a documented report which is filed electronically and, if possible, in paper format.				