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Comparative study of broadleaf forest in the Rio Bravo Conservation and Management Area, Belize: with an emphasis on the impacts of forest Management

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DEDICATION

To my wife Maria.
To my daughter Shannellie.
To my son Shamir.

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RESUMEN

Este estudio tuvo como propósito, validar enfoques para establecer los impactos en la estructura y composición del rodal en bosque latífoliados en el Área de Manejo y Conservación de Río Bravo en el noroeste de Belice, basado en el manejo forestal y la variabilidad natural del bosque en estudio. Para determinar los impactos en los indicadores antes mencionados, los niveles de cambio fueron determinados como aceptables e inaceptables en bosques intervenidos con respecto a bosques no intervenidos, siguiendo los procedimientos descritos por Finegan y otros (2004), y a la misma vez la validación era realizada de la guía.

El muestreo de los indicadores se realizó en tres bosques aprovechados y en sus respectivos sitios de referencia. La evaluación de la densidad del rodal, área basal y abundancia de las palmas para individuos $\geq$ 10 cm de dap se llevo a cabo en parcelas temporales de 50 m x 20 m. Para la apertura del dosel y la estructura vertical se utilizaron parcelas temporales de 10 m x 10 m.

Se encontraron diferencias entre los bosque manejados y no manejados para la densidad del rodal y para algunas clases díamétricas. Mientras que para el área basal no con respecto al total por bosque, solo en algunas clases diamétricas se dieron diferencias. Sin embargo, se considera que esta diferencia se debe a cambios provocados por el manejo o por cambios antes del manejo o por la alta variabilidad natural.

Para el indicador de apertura del dosel fue menor en bosques no aprovechados-implica niveles bajos de luz, con un sotobosque menos denso y un dosel más cerrado. Mientras que para bosques manejados se presentaron mayor apertura de dosel- mayor entrada de luz al suelo, con un sotobosque más denso y un dosel superior más abiertos.

Una herramienta práctica para demostrar el nivel de impacto causado por el manejo es el uso de umbrales y activadores. Sin embargo, para indicadores que por su naturaleza presentan una variación natural muy alta (la composición y densidad de las palmas), el uso de los desvíos estándar son muy altos para la determinación de umbrales para su establecimiento. Entonces aspectos como la variación natural y la sensibilidad de medición de algunos indicadores es importante considerar para el uso de este enfoque.

El nivel de impacto estimado para los indicadores como la apertura de dosel y estructura vertical en los primero estratos fueron considerados como aceptable al implementar el enfoque de umbrales y activadores de la guía.

<u>Palabras claves:</u> indicadores, monitoreo, umbrales y activadores.

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SUMMARY

The purpose of this study was to validate approaches to establish the impacts on the structure and composition of the forest stand in broadleaf forest in the Rio Bravo Conservation and Management Area, in northwest Belize, based on forest management and natural variability of the forest studied. To determine the impacts on the indicators mentioned the levels of changes were determined as acceptable or unacceptable in a logged forest with respect to an unlogged following approach and procedure of the Monitoring Guide described by Finegan *et al.* (2004) and at the same time validation was being carried out of the Guide.

Indicators were sampled in three managed forest sites with their respective reference sites. Evaluation of tree abundance, basal area and the abundance of palms for individuals ≥ 10 cm DBH were measure in temporary plots of 20 m x 50 m, canopy openness and vertical were evaluated in 10 m x 10 m plots.

Differences were found between the forests for tree abundance with respect to total per forest and for some vegetation classes. No differences were found in basal area with respect to the total per forest, however, some differences were found in some diameter classes. Such differences found in those indicators could be attributed to a response to forest management, previous intervention or to their high natural variability.

For indicators of canopy openness and vertical structure of the forest stand, significant difference were found between forest in the lower strata probably because harvesting did affect the canopy opening of the forest under management and this possibly contributed to regeneration of the understorey.

A practical tool to demonstrate the level of impacts by management intervention is the use of thresholds and triggers. Nevertheless, indicators with a high natural variation such as the abundance and composition of palms, its standard deviation were too high to accurately calculate their thresholds according to the established methodology. Hence, aspects such as natural variation and the measurability of some indicators are important to consider in the use of this approach.

The level of impact estimated for the indicators on canopy openness and vertical structure of the two strata were considered to be within acceptable limits when the application of the threshold and trigger approach proposed by the Monitoring Guide were applied.

Keywords: indicators, monitoring, thresholds and triggers.

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ACRONYMS AND ABBREVIATIONS

CI – Confidence interval
CV - Coefficient of variation
dbh – diameter breast height
FSC – Forest Stewardship Council
HCVF - High Conservation Value Forest
PG – Punta Gorda
PfB – Programme for Belize
RBCMA – Rio Bravo Conservation and Management Area
WB – West Botes
WM – West Marimba

1 INTRODUCTION

Global awareness of the multiple benefits provided by the forest ecosystem has increased while global forest coverage has continued to decrease and loss of biodiversity, through degradation and removal of forests and other natural ecosystems is one of today's most worrying environmental problems (Higman *et al.* 1999). Increasing demands for products and services from tropical forest require solutions that conserve biodiversity while responding to human needs (Lugo 1995).

Furthermore, growing public awareness of forest destruction and degradation has led consumers to demand that their purchases of wood and other forest products will not contribute to this destruction but rather help to secure forest resources for the future. In response to these demands, certification and self-certification programs of wood products have proliferated in the marketplace (FSC 2003).

Certification is a means of confirming that the forest and its management conform to a particular standard and appears to be a useful tool for promoting conservation of biodiversity and other environmental values within production forests (Nussbaum and Simula 2005). In all cases the process of certification are initiated voluntarily by forest owners and managers, who request the services of a certification organization. The goal of Forest Stewardship Council is to promote environmentally responsible, socially beneficial and economically viable management of the world's forests, by establishing a worldwide standard of recognized and respected Principles of FSC (FSC 2003).

The FSC's Principles and Criteria (P&C) apply to all tropical, temperate and boreal forests, the scale and intensity of forest management operations, the uniqueness of the affected resources, and the relative ecological fragility of the forest will be considered in all certification assessments.

Many of the natural forest in the Neotropics are considered by the Forest Stewardship Council as High Conservation Value forest (HCVF) and to meet the requirements for certification, management activities in such forests shall maintain or enhance the attributes which define such forests (Finegan *et al*. 2004).

The area of the present study is located in the Rio Bravo Conservation Management Area. It is a site of national and regional importance for biodiversity conservation (Smartwood

2005). The Rio Bravo Conservation Management Area joins directly on to the Maya Biosphere Reserve via the Rio Azul National Park, itself linking to the Calakmul Biosphere Reserve in Mexico. The Rio Bravo therefore constitutes the Belizean portion of the largest conservation area, and the largest remaining tract of forest, in Central America, and one of the most important in the American tropics (World Bank Report 1996).

The RBCMA is managed by Programme for Belize under the terms of formal Memorandum of Understanding (MoU) with the Government of Belize (GOB). In the Planning Guidelines for Timber Extraction – 2004, it contains a subsection of Research and Monitoring, with a general approach based on the precautionary principle to counter – balance the incompleteness of information. The body of research undertaken on RBCMA and findings are from work elsewhere in the region which provides the insight upon which timber operations are carried out.

Timber harvesting is only one activity amongst the array constituting the RBCMA forest regime and is a means of achieving the forest conservation by which PfB measure its success. The objective is to minimize impact upon environmental and biodiversity of the forest (Guidelines Timber Extraction 2004).

This study aims to validate approaches to identifying the impacts of forest management in the biodiversity of broadleaf forest of the Rio Bravo Conservation and Management Area, Belize by means of ecological monitoring indicators of structure and composition of forest stand which where selected from the Monitoring Guide (Finegan *et al*. 2004) and at the same time evaluating the Monitoring Guide.

In this way, it is hoped to contribute towards designing and implementation of management practices derived from an understanding of the ecological processes which sustain forest resources and ecosystems and to provide guidelines to foster an integrated approach for sustainable forest management and conservation in Belize.

1.1 Objectives of Study

1.1.1 General Objectives

- To contribute guidelines towards of forest management sustainability and conservation of biodiversity in the Rio Bravo Conservation and Management Area (RBCMA).
- To contribute to the development of practical monitoring tool through the validation of procedures and approaches describe in the Ecological Monitoring Guide by Finegan *et* al. (2004).

1.1.2 Specific Objectives

- To identify the effects of selective logging on the structure and composition of the forest stand (coarse filter).
- To determine the response between the different indicators and level of changes caused by intervention applying the procedures and approach proposed in the Monitoring Guide.
- To determine if the changes caused on the forest by intervention are within acceptable or unacceptable limits for the different indicators according to the Monitoring Guide.

1.2 Hypothesis

- The forest management does not cause significant changes on the indicators of the forest structure and composition.
- The impact of logging does not cause any significant changes in the structure and composition of the forest stand.
- With respect to the Guide Ecological Monitoring, the forest management does not cause any unacceptable changes on the forest of RBCMA.

2 JUSTIFICATION

Forest management impacts and their effects on biodiversity depend large on harvest intensity, planning and extraction operations as well as post – harvest interventions (Johns 1997). Efforts to conserve biodiversity and reverse current tropical deforestation rates are primarily focused on conservation, sustainable production, and improved practices on forest management (Lindenmeyer *et al*. 2000).

Increasing demands for products and services from tropical forest require solutions that conserve biodiversity while responding to human needs (Lugo 1995). One important mechanism is timber certification, which is gaining currency in both consumer and producer countries- in consumer countries because of irreparable loss of tropical forest and in producer countries because of desire to maintain access to wide range of markets (Bennett 2000).

If timber certification is to be a useful tool in promoting the sustainability of tropical forest logging, certification standards must be expanded to include the effects of logging on biodiversity and the ecology of the forest (Bennett 2000). Nevertheless, ecological monitoring in the tropical forests has been a weak aspect in the process of certification because the guidelines are normally very generally as to serve as adequate guidelines (Finegan *et al.* 2004). Ecological monitoring has the potential to provide timely information on changes in the biota and when properly designed, to identify appropriate responses to reverse undesired trends (Sparrow *et al.* 1994).

This study attempts to identify the impact of management on the structure and composition of the forest stand, the structure of the forest is altered by logging and such impacts of tropical forestry have received little attention (Mason 1996).

The study was carried out in the Rio Bravo Conservation and Management Area forest, an area of biologically and culturally significant Mayan forest region of northwest Belize. Rio Bravo reserve is home to endangered animals, contains forest cover types protected nowhere else in Belize, and is under imminent and demonstrable threat of conversion to agriculture. The Rio Bravo Carbon Sequestration Pilot Project include addressing protection of ecosystems and biodiversity, improving local environmental quality, and creating economic opportunities for local people (Kuhn 1999).

With all the initiatives of taken in Belize towards the protection, conservation and rational use of the valuable natural resources there is a need of a monitoring component mechanism that will reflect the goals of conservation in forest management programme. The use of indicators as a tool for ecological monitoring can serve as a guide to achieve sustainable forest management in Belize.

3 LITERATURE REVIEW

3.1 Sustainable forest management

Sustainable Forest Management is one of the *"Forest Principles"* foundations as agreed on the United Nations Conference on Environment and Development (UNCED) for the conservation and sustainable development of all types of forest (Swanson 1997). Sustainable forest management is the process of managing forest to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services, without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social effects (ITTO 1998), it makes up the main way to attain the goals of forest conservation and use (FAO 2002).

There is an increasing pressure world- wide for improvement in the quality of forest management. Concern about environmental and social issues associated with – such as effects on biodiversity, climate change, desertification, flooding, and conflicts over use rights and sustainable development generally- has led to for improving forest management practices (ITTO 1998).

Sustainable forest management standards have double function, to enable the detection of trends and problems in particular local situations, and to report on forest management performance in a credible way to the national and international community (Pedroni and De Camino 2000).

Since forests are not only a valuable source of timber but also provide a wide range of non-timber forest products (NTFPs) as well as major environmental services, the principle of sustainable management is to harvest natural forest resource (including NTFPs) without compromising its social and ecological value (Sist et. al 1998)

Sustainability of forest management is an integral measure in the maintenance of production, and the ecological and socioeconomic functions of forest systems and should consider both the fulfillment of sound forest practices as well as the impacts and results of forest management, providing key information for the identification of aspects of negative impacts that can be improved or modified within a system of adaptive management (Finegan and McGinley 2002). In forest management there is a need to know the potential effects of different types of treatments on diversity over time to design environmentally sound management practices. It is important to address diversity at the stand level because the stand is the basic unit of management, and the effects of management disturbances are directly expressed at this level (Roberts and Gilliam 1995).

3.2 Criteria and indicator

Evaluation of sustainability of forest management can be achieved through the implementation of practical and scientifically founded principles, criteria and indicators and (in specific cases) verifiers. These evaluate the inputs, processes and results of forest management. These sets of PCI&V should be tested and validated through application and practice, and count with the necessary tools for their implementation (i.e. documentation on their justification, their conceptual bases and guides for its application) (McGinley and Finegan 2001).

Criteria and indicators (C&I) provide a framework for describing, monitoring, and evaluating progress towards the goal of sustainable forest management. By measuring and monitoring indicators, trends toward specific goals and objectives can be more effectively determined, and become a basis for judging if progress toward sustainable forest management is occurring (Cook and O'Laughlin 1999). Criteria and indicators were identified, in order to make the new and much more comprehensive concept of sustainable forest management amenable to planning, monitoring and assessment at the national level as well as for the individual forest management unit. The selection and use of suitable criteria and indicators are thus one of the keys to progress in the practice of sustainable forest management. At the forest management unit level, criteria and indicators are used to assess compliance with performance-based certification standards (Poschen 2000).

The selection of indicators is a balance and compromise between what is practical and what is possible, seeking indicators that are simple and credible, cost effective, inclusive rather than exclusive(Szaro 1998). The proposed indicators of the coarse filter- structure and composition of the forest stand of the Monitoring Guide (Finegan *et al*. 2004), are ones that are directly related to impacts after management and in addition have the potential in significant monitoring and it is practical to be used (Finegan *et al*. 2004).

3.3 Certification

The global concern about the damage effects of tropical timber harvesting has resulted in a search for ways to ensure more sustainable production. One important mechanism is timber certification (Bennett 2001). Forest certification was promoted as an effective system for ensuring sustainable management forest and to improve market access for wood products (Agyeman *et al.* 1998). Certification has two main goals: to promote the ecological, economic and social of forestry in the world, and to promote the sustainability of markets that pay the price products deserve (Bruening 1996). Hence, forest certification is a procedure whereby an assurance is given that a forest is managed in accordance with agreed ecological, economic and social criteria. A label informs the consumers that the products they buy come from a certified forest. Thus, forest certification is a market instrument, which provides an incentive for sustainable forest management as it links producers and consumers in their responsible use of forest resources (GTZ 2003).

The FSC has the most widely and possibly highest standards for timber certification. If timber certification is to be a useful tool in promoting sustainability of tropical forest logging, certification standards must be expanded to include the effects of logging on the biodiversity and ecology of the forest. Indeed, this approach can even improved our scientific understanding if we can work with managers to try different logging protocols in the manner to adaptive management (Bennett 2001).

The FSC principle and criteria are designed to apply to tropical, temperate, and boreal forest as well as to plantations (Cauley *et al.* 2001) and FSC Principles and Criteria – Principle 9:- Maintenance of High Conservation Value Forests, require for the precautionary approach to HCVF management is a direct mechanism for the conservation of these forests (FSC2000). These forests have one or more characteristics: areas that are in or contain rare, threatened or endangered ecosystems, provide basic services of nature in critical situations (Jennings et al 2002 in Finegan *et al.* 2004). Most of the Neotropic forests tend to fall under the definition of High Conservation Value forest, due to their biodiversity attributes (Finegan *et al.* 2004).

Rio Bravo Conservation and Management Area is the only area that is certified in Belize and certification is applied to management of the whole forest – rather than management of the timber zone alone using the – Smartwood Generic Guidelines for Assessing Forest Management. RBCMA most comply with FSC standard, continue forest management performance and comply with conditions and recommendations to maintain certification (Smartwood 2005). Nevertheless, ecological monitoring is important since it can identify the condition of the forest due to management activity and determine if it acceptable or unacceptable.

3.4 Ecological monitoring

Ecological monitoring is an important tool in evaluating the quality of forest management, and a prerequisite for achieving good forest management. Ecological monitoring is a key element on adaptive management, and this as well is an important consideration of the Forest Stewardship Council for forest management (Finegan *et al.* 2004) Monitoring is an important component in any plan to manage natural resource for conservation or sustainable use. The complexity of the systems to be managed, however, often makes the selection of appropriate indicators extremely challenging because the suite of indicators must encompass sufficient breath to provide the information for feedback on varied fronts without being too cumbersome or expensive to monitor effectively (Kremen *et al.* 1998).

Ecological monitoring has the potential to provide timely information on changes in the biota and when properly designed, to identify appropriate responses to reverse undesired trends. Monitoring focuses on temporal changes in the biota and should be used by resource managers to evaluate success of their policies in meeting conservation needs (Sparrow *et al.* 1994).

It is essential provide practical information and guidelines for establishing monitoring programs that are pertinent to real conservation issues facing tropical reserve managers. Therefore it is important to develop a simple, inexpensive, easily monitoring scheme- that can produce reliable information to guide management (Sparrow et al 1994).

Plants can make excellent indicators species for integrated conservation and development programs because monitoring them provides information simultaneously on both ecological and socioeconomic changes. In addition, monitoring useful species is necessary for establishing management plans for their sustainable use (Kremen *et al.* 1998).

To obtain a reliable program of monitoring, it must be consider that the indicators are measurable variables that will allow evaluating or monitoring entities or environmental attributes related to such variables (Pielou 1995). Therefore, the present study uses the coarse filter base on the structure and composition of the forest stand (Finegan et al. 2004) because the characteristics are well defined in any forest; it is related directly to forest management and indicates quality of habitat for certain organism. If operational activities are unacceptable, indirectly the ecological integrity for some species at a lower level are affected and such changes can be detected by monitoring the structure and composition of forest stand (Finegan *et al.* 2004).

3.5 Logging impact

It is critical to recognize that forest interventions of all types, from harvesting of fruits for home consumption to clearcutting for timber, all have impacts on forests that need to be understood and often deserve mitigation (Peters 1996). Nevertheless, logging is often the most damaging and generally the most financially lucrative of such forest interventions (Pearce *et al*. 1999). In general, forest modification and clearance have negative impacts on biodiversity (Bawa and Seidler 1998).

Timber harvesting typically results in heavy damage to forest canopies and is often accompanied by road building, which provides access to hunters and colonists. A number of studies are concordant in showing that destruction of more than 50% of the canopy adversely impacts wildlife, especially large frugivorous species that comprise much of the biomass. Far more than in temperate forests, large birds and mammals play crucial roles as seed dispersers. If these animals are decimated, either by timber-harvesting practices that destroy their food resource and/or by the depredations of hunters, the regeneration of numerous species will be adversely affected (Lugo and Lowe 1995)

One potentially sustainable and economically viable us of tropical forest is selective logging (Lewis 2001). As selective logging regimes are devised and implemented throughout the humid tropics, it is becoming increasingly important to understand their effects on rainforest plants and animals (Boyle and Sayer 1995). Even highly selective logging can result in severe damage to a forest. For example, harvesting only 3% of trees in west Malaysian dipterocarp forest resulted in the destruction of 51% of the stand, with damage extending over all taxa and size classes of trees (Johns 1988). Damage to the stand and canopy loss is generally related to the number of stems harvested per hectare but can also be strongly influenced by the nature of the logging operations (Ghazoul and Hellier 2001).

Logging affects the landscape component of biodiversity by changing land forms and ecosystem types across large geographic areas. These changes in the habitat mosaic alter species distribution, forest turnover rates, and hyrodrologic process. Logging activities may directly and indirectly affect the identity, distribution, and proportion of habitat types in tropical forest. The ecosystem component of biodiversity is somewhat more sensitive to logging impacts than the landscape component in part because management activities are usually implemented at this scale. In contrast to the landscape component, most ecosystem-level impacts are a direct consequence of logging activities (Putz *et al.* 2000).

For the community component of biodiversity, logging affects composition by changing (often purposefully) the relative abundance of species and guilds inhabiting forest stand. The most obvious species level impact of logging is the abundance and age/size distribution of harvested and damaged trees. Depending on the intensity of logging and the care with which is carried out, the reproduction, growth and survival of a great number of species can be adversely affected. Their populations are often left greatly depleted, especially in the larger size classes of reproductive individuals when management is based solely on minimum diameter felling rules (Putz *et al.* 2000).

The impact of human activity in forest management is mainly through the alteration that occurs through the modification of vegetation structures and composition as a result of endless number of activities related to management (Mason 1996). Many forests have defined structural characteristics such as basal area, density of the stand and height of canopy. Also, the structural characteristics are bound to management operations in a clear and direct form (harvesting of timber removes trees of certain sizes, causes damage whose density varies between class sizes in a predictable form, reducing therefore the density of stand and basal area, among other variables (Finegan *et al.* 2004).

It is nonetheless important to evaluate the impact of different timber extraction methods and the effects of forest management of biological diversity and functional integrity (Koop *et al.* 1995).

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4 ARTICLE I. EFFECTS OF SELECTIVE LOGGING ON THE STRUCTURE AND COMPOSITION OF THE TROPICAL HUMID FOREST OF THE RIO BRAVO CONSERVATION AND MANAGEMENT AREA (RBCMA) – BELIZE.

4.1 Introduction

Since forest are not only a valuable source of timber but also provide a wide range of non-timber products as well as major environmental services, the principle of sustainable forest management is to harvest the natural resource without compromising its ecological value (Sist *et al.* 1998). The concerns about the effects of logging on biodiversity and sustainability have strongly influenced forest management (Bergeron and Harvey 1997), therefore ecology provides the foundation for forest management (Sheil and Heist 2000).

Selective timber extraction is often proposed as a sustainable, low- impact alternative to clear-cut logging (Sekercioglu 2002), since this type of extraction can reduce damage to the remaining stand (Ghazoul and Hellier 2000), by improving harvesting practices (Pinard and Putz 1996). Silvicultural treatments are "sometimes carried out" in the tropics, they're not commonly applied. It is applied to manipulate the composition and structure of forests with the purpose of producing timber and other forest products. Although the effects of such treatments on tree, mortality, and regeneration are well studied, these effects are poorly understood from a more comprehensive ecosystem perspective (Crow *et al*. 2002) Forest management must be ecologically sound since any form of management of forest will produce ecological impacts. The key to it all is stability of yields, a stability that must rest on ecologically sound management (Wadsworth 1983). The understanding of the effects of selective logging is required now if the tropical forest are to be sustainable as recommended by the World Conservation Strategy (IUCN 1991).

In view of the inherent values of tropical forest, significant efforts have raised to curb destructive trends through development, implementation, monitoring and regulation of forest management practices (Prabhu *et al*. 1996). The research herein presented was to determine impacts of selective logging on broadleaf upland forest of the RBCMA based on five indicators of structure and composition that were proposed for the monitoring of impacts of timber harvesting by Finegan *et al*. (2004), density and basal area of the forest stand, canopy openness of the understorey, vertical structure of the forest and abundance and composition of palms.

4.2 Materials and methods

4.2.1 Study site

4.2.1.1 Rio Bravo Conservation and Management Area

The study was conducted in the forest of the Hill Bank Field Station located on the Rio Bravo Conservation and Management Area **(**RBCMA) during the months of January (late) to July 2006. The area lies in Orange Walk District, north- western Belize (17°36´N, 88°42´W), adjacent to the northeast of the Petén region Guatemala and southeastern Mexico (Figure 1). The area is in the subtropical moist forest life zone of the Holdridge Life Zone System (Hartshorn *et al*. 1984). Annual rainfall is 1500mm/ yr. However, rainfall in the dry and wet seasons can vary annually. Daytime temperature averages about 24° C and at night can be as 10° C during the months of November to January. From April to September the temperature averages about 26° C and the hottest period months are April and May with maximum temperature exceeding 32°C (Whitman *et al.* 1998).

The principal topographical features consist of a series of terraces developed over geological time, resulting in several distinct escarpments which run northeast- southwest through Rio Bravo. These escarpments break up Rio Bravo's generally flat or rolling terrain with low hills and occasional small swamps (Harcourt and Sayer 1996). Drainage is impeded in certain areas by the heavy soils which overlay calcareous bed-rock (Bird 1998).

The RBCMA was created by Programme for Belize (PFB), an Environmental Non-Governmental Organization – (NGO) established with the express purpose of acquiring as much land as possible for conservation purposes and dedicated to promoting wise use of the nation's natural resources. Some 2830 km² of land in north- western Belize came to the market after the break-up of much larger holding and as it was feared that the area would be totally cleared for agriculture. PFB begun the purchasing of such lands. Land was purchased with funding from foundations, bilateral aid agencies, commercial sponsors and through a sponsorship scheme and private donations – this area constitutes the Rio Bravo Conservation and Management Area (RBCMA).

The RBCMA is a site of national and regional importance for biodiversity conservation. It is the second largest conservation area in Belize and is an important part of the national protected area network conserving examples of natural habitats that are poorly or not represented at other sites (Smartwood 2005). It also represents populations of a range of species of national and international conservation concern. It is an extension of the largest tract of remaining forests in Mesoamerica and is part of the Selva Maya Priority Area of the Mesoamerican Biological Corridor that connects Belize to rest of the region. Over 75% of the area is strictly protected, managed for natural resource conservation and recreation (Smartwood 2005). For all their high conservation value, Programme for Belize (RBCMA Management Plan 2000) sought timber certification for RBCMA.

Figure 1 Map of Belize and the location of the study site (PfB 2005).

4.2.1.2 Forest PG, WB and WM

RBCMA covers 103,700 hectares (Smartwood Report 2005) in the northwest Belize, and is managed for conservation, research and economic activities consistent with the protection of biological diversity (Brokaw and Mallory 1993). The forests of northern Belize are similar to those covering Guatemala's northern Petén and Mexico's Yucatán Pennisula

(Pennington and Sarukan 1968). Characteristic species include *Swietenia macrophylla, Manilkara zapota, Brosimum alicastrum, Pimenta dioica, Manilkara chicle, Drypetes brownii, Pseudolmedia spuria, Dialium guianense, Orbignya cohune and Terminalia amazonia* (Hartshorn et al. 1984). Much of the forest has been selectively cut for the extraction of *Swietenia macrophylla, Cedrela odorata* and other hardwoods (Conservation of the Tropical Forest 1992).

The Timber Extraction Zone (TEZ) of the RBCMA covers 24,039 ha is and divided into eight management areas – Punta Gorda , North Duck Ridge, South Duck Ridge, East Marimba, West Marimba, East Botes, West Botes and Governor Creek. Each area is composed of various numbered compartments for management purposes (Planning Guidelines - RBCMA 2004). Three management areas were selected for the study and these are Punta Gorda, West Botes and West Marimba were considered to be the same type of forest- upland /*Attalea cohune* forest. (Mr. Mena-PFB Forester personal commu.). Within those management areas, there were subdivisions referred as to compartments. Logged and unlogged compartments were identified on respective management areas.

- ***Upland forest***

The broadleaf upland forests are the most extensive vegetation type in the RBCMA and constitute the matrix vegetation covering over 69,000 ha or over 66% of its total extent of the upland forest. They range from dry to mesic (moist) variants according to local topography, and considerable areas are transitional with the wetter seasonal thickets or ‘‘bajos’’. On deeper, moist but well-drained soils, cohune palm *Attalea cohune* tends to become dominant. More usually, however, no species dominates outright although a small group, usually less than ten species, tends to constitute more than 50% of the larger trees in any given area. The species concerned vary from place to place around HillBank, in generally mesic conditions, they consist of *Terminalia amazonia, Acacia usumacintensis, Swietenia macrophylla, Brosimum alicastrum, Vitex gaumeri, Spondias mombin and Acosimum panamense*. Other characteristic species include *Manilkara zapota and Manilkara chicle* (RCBMA Management Plan 2000).

- ***Attalea cohune forest.***

These forests occur on rich, well-drained soil in upland that often supports such palm. Cohune palm forest often occurs at the base of slopes, where pattern of deposition and drainage seem to produce suitable conditions. The cohune palm is a canopy dominant, but there are many other tree species most that are common in upland forest. A change from level ground with much cohune to slope with no cohune is abrupt in places (Brokaw and Mallory 1993)

4.2.1.3 Timber harvesting

Detailed information on timber harvesting was not available. The information for the three sites was obtained from http://www.rainforest-alliance.org/programs/forestry/smartwood/.

The first harvest was in PG in 1997 with 100 hectares being harvested in that site. The next two harvests were in 1998 and 1999, with an increase in area harvested 365 and 333 hectares for WB and WM respectively. In 1998, 18 different species were harvested (Smartwood 2005).

The area had past selective logging regime where the primary target was *Swietenia macrophylla* but other hardwoods such as *Cedrela odorata*, *Calophyllum brasiliense* were also exploited.

Timber harvesting in the sites is projected on a 40 year felling cycle with a polycyclic system approach. Areas considered physically unsuited for extraction due to slope or soil condition (wetness) are excluded from the Timber Extraction Zone. The harvesting of timber is selective and the criteria for the selection of trees are minimum cutting diameter (>55 cm dbh for *Swietenia macrophylla* and >45 cm dbh for all other species) and local commercial market -plywood core stock- (RBCMA management plan 2000). Species that were harvested for the period 1997-1999 are listed Annex 1.

4.2.2 Methodology

4.2.2.1 General

RBCMA covers 103,700 hectares (Smartwood Report 2005) in the northwest Belize, and is managed for conservation, research and economic activities consistent with the protection of biological diversity (Brokaw and Mallory 1993). The forests of northern Belize are similar to those covering Guatemala's northern Petén and Mexico's Yucatán Pennisula (Pennington and Sarukan 1968). Characteristic species include *Swietenia macrophylla, Manilkara zapota, Brosimum alicastrum, Pimenta dioica, Manilkara chicle, Drypetes brownii, Pseudolmedia spuria, Dialium guianense, Orbignya cohune and Terminalia amazonia* (Hartshorn et al. 1984). Much of the forest has been selectively cut for the extraction of *Swietenia macrophylla, Cedrela odorata* and other hardwoods (Conservation of the Tropical Forest 1992).

Three management areas were selected for the study and these are PG, WB and WM. The sites were considered to be the same type of forest- upland /*Attalea cohune* forest. (Mr. Mena-PFB Forester personal commu.). Within those management areas, there were subdivisions refer as compartments. Logged and unlogged compartments were identified on respective management areas.

The three sites PG, WB and WM were harvested in different years. PG was harvested in 1997 and WB and WM were harvested in 1998 and 1999 respectively. The present sampling of this study was carried out 7-9 years after logging.

First a ground trekking was carried out in the three sites. This was considered important for the stratification purposes of sampling. In PG and WM it was observed the presence of the same vegetation and topography, with no apparent difference in the structure and composition of the sites. WB was considered to have a vegetation of upland forest and PG and WM, a vegetation of upland/cohune forest. (PfB Forester personal commu.). During the ground trekking areas that were identified as different due to edaphic conditions were noted and where not taken in consideration for the study. A map of the Timber Extraction Zone was available at all times for reference of the zone.

Five indicators were chosen from the coarse filter (stand structure and composition) of the Monitoring Guide (Finegan *et al*. 2004), for evaluation. These were abundance of trees, basal area, and canopy openness of the understorey, vertical structure and composition and density of palms. These indicators were used for the evaluation and comparison between logged and unlogged sites. The approach for the measuring all the indicators were obtained from the Monitoring Guide (Finegan *et al.* 2004). Data were collected for each indicator on the study sites.

4.2.2.2 Sampling

Three transects were placed in each of the logged and unlogged forest in PG, WB, and WM, which were separated by 1000m and on each transect, three temporary plots of 20 m x 50 m were placed at 300 m of each other. Also along the transect sampling points were placed at every 50 m and imagined as being in the center of a temporary plot of 10 m x 10m.

In the temporary plots of 20 m x 50 m, the indicators of total density and basal area, density and composition of palms were measured while in the sampling points, canopy openness and vertical structure were measured.

On the respective compartments, where the temporary plots were established, the procedures and approach of the Monitoring Guide (Finegan *et al*. 2004) were applied. The management areas were distantly apart - km - from each other but the compartments (logged and unlogged) were approximately 1000m apart. The size of each compartment was approximately 150 hectares. For this study, compartments: logged and unlogged will be referred as sites: logged and unlogged.

4.2.3 Evaluation of indicators of the structure and composition of forest stand

4.2.3.1 Density and basal area: total and by size class

For these indicators the temporary plots of 20m x 50m in logged and unlogged were used. Within the plots, all live individual ≥10 cm dbh were recorded. The trees were counted; the stem diameter at breast height was measured with diameter tape at 1.3m above ground level. The trees were identified with their respective genus/species name or common name by a PfB forester; trees that weren't identified were indicated as "unknown". With this information the total number of trees and basal area per hectare and their diameter class distributions were obtained.

4.2.3.2 Canopy openness of the understorey

Measurements were carried out on the sampling points at every 50m along transect for the canopy openness of the understorey. A spherical densiometer (with a concave mirror) was used and four measurements were taken i.e. each measurement at a cardinal point. A mean was obtained for the four measurements at each sampling point and then multiplied by 1.04 to obtain the percentage canopy openness of the understorey.

4.2.3.3 Vertical structure of the forest

For the evaluation of this indicator, the sampling points were considered as the centre of imaginary temporary plots 10 m x 10 m for estimation of percentage vegetation covers in four different height strata; from the understorey to the upper canopy: a) 0-2 m, b) 2-9 m, c) 10-20 m, and d) 20-30 m as proposed by Thiollay (1992). A scale of 0, 1, 2, or 3 was used for the estimation of vegetation cover. A value of 0 was assigned when the percentage of vegetation cover was 0; 1 when vegetation cover was 1-33; 2 for 34-66 and 3 when vegetation cover was > 67% respectively.

From these measurements a mean value index of foliage cover for each stratum for each site was obtained. The estimations of vegetation covers were evaluated only in four strata (<30 m) (and not > 30 m as recommended by Thiollay 1992); because of the maximum height of the forest which was considered to be in an average between 20-30m.

4.2.3.4 Composition and abundance of palms

The composition and abundance of palms were evaluated in the temporary plots of 20m x 50m in logged and unlogged sites. All palms ≥10 cm dbh were recorded. The palms were counted; the diameters at breast height were measured with diameter tape at 1.3m above ground level. The palms were identified with their respective genus/species name or common name.

4.2.4 Data Analysis

A descriptive comparison was made with the information obtained of the structure and composition of the forest sites using the indicators measured.

A two way analysis of variance (ANOVA) for each variable was made using Complete Random Design with a factorial arrangement, of two factors: three sites (P.G, W.B and W.M) and two managements regime (logged and unlogged). The model used was: $Y_{ijk} = \mu + S_i + T_j + ST_{ij} + \varepsilon_{ijk}$

where:

Y_{ijk} = value of the response variable

μ = overall mean of the response of the variable

S_i = Site effect

T_j = Management effect

ST_{ij} = Site x management interaction

ε_{ijk} = Independent random error

The temporary plots 20 m x 50 m were the sampling units for the indicators: total density and total basal area per hectare, the number of individuals and basal area by diametric classes and abundance of palms. For the indicators of canopy openness and vertical structure of the forest stand the sampling points along transect were the units of sampling.

Where ANOVA showed significant differences between factors (site or treatment), Duncan's Multiple Range Test was preformed in order to determine pairwise differences between means. Variables that have a treatment effect, the data for all the sites were taken together for the calculation of the treatment mean.

Statistical analyses were carried out using SAS version 8e. (SAS) and Infostat (Infostat 2005). For all statistical tests, α = 0.05 was used.

4.3 Results and Discussion

Table 1 shows summary of the analysis of variance for the five indicators of the structure and composition of the forest stand: density and basal area – total and by size class, canopy openness of the understorey, vertical structure of the forest stand and composition and abundance of palms.

Taking into account the two factors contemplated by the design, *site* and *treatment*, plus the *interaction* between these two factors, a total of six outcomes of the statistical analysis were found.

The first outcome was of no significant effects of site or treatment, nor a significant interaction between the two. This outcome was found in six cases. Four of these cases concerned large trees: their abundance/ha in the diameter classes >= 50 cm and their basal area in the same diameter classes. As these are diameter classes in which trees are cut, it may seem surprising that there was no treatment effect, although the small numbers of trees in these size-classes, their patchy distribution in the forest and the probably patchy distribution of harvesting, may all have increased the variability of the data and therefore reduced the statistical power of the study (Ghazoul and Hellier 2000, Finegan et al. 2004). The other two cases concerned vegetation cover at heights >= 9 m.

The second and third outcomes corresponded to variables for which a site effect was found, or a site effect plus a significant interaction, but no treatment effect. A significant site effect was found for ten of the twenty response variables, including the key structural variables, tree numbers and stand basal area. It is therefore clear that important variation in forest stand characteristics exists among the areas of the RBCMA that are designated for timber harvesting, and that evaluations of management impacts should be carried out on a site-by-site basis, as was done in the present study (see article II). However, as the detection of site effects was not an objective of the present study, no further data are presented on site effects in this thesis.

The fourth, fifth and sixth outcomes were those in which a significant treatment effects was found, this usually occurring with a significant site effect and often with a significant interaction as well. Significant treatment effects are now analysed in more detail.

Table 1. Summary of the analysis of variance for the five indicators of the structure and composition of the forest stand. Pr values are shown for main effects (site and treatment) and interactions (boldface types indicate Pr < 0.05).

Indicator	Site	Treatment	Interaction
Total abundance of trees per hectare	**0.0017**	**0.0073**	**0.0032**
Diameter class abundance per hectare 10-19	**<0.0001**	**0.0032**	**0.0023**
Diameter class abundance per hectare 20-29	**0.0146**	0.8427	**0.0045**
Diameter class abundance per hectare 30-39	**0.0029**	0.0643	**0.0305**
Diameter class abundance per hectare 40-49	**<0.0001**	**0.0176**	0.3527
Diameter class abundance per hectare50-59	0.3733	0.8216	0.4636
Diameter class abundance per hectare>60	0.1800	0.1009	0.6887
Total basal area per hectare	**0.0449**	0.0616	0.6048
Diameter class basal area per hectare 10-19	<0.0001	**0.0096**	**0.0120**
Diameter class basal area per hectare 20-29	0.0441	0.9659	**0.0059**
Diameter class basal area per hectare 30-39	0.0007	0.0987	**0.0266**
Diameter class basal area per hectare 40-49	**<0.0001**	**0.0124**	0.3542
Diameter class basal area per hectare 50-59	0.3302	0.7601	0.5068
Diameter class basal area per hectare > 60	0.1851	0.0736	0.5806
Openness of understorey	**0.0001**	**0.0001**	**<0.0046**
Vegetation cover strata 0- 2m	**0.0046**	**0.0428**	0.4784
Vegetation cover strata 2-9m	**0.0293**	0.0709	0.4777
Vegetation cover strata 9-20m	0.1003	0.8841	0.0525
Vegetation cover strata 20-30m	0.9092	0.7632	0.1082
Palms abundance per hectare	0.0819	**0.0288**	**<0.0001**

4.3.1 Indicators for the structure and composition of the forest stand for treatments

4.3.1.1 Total abundance of trees and by size class

There were significant differences for treatments for the total number of trees (Fig.2). The unlogged resulted with a higher mean values than the logged. The difference could be that management caused a significant reduction in the number of trees harvested or regeneration was slow after harvesting.

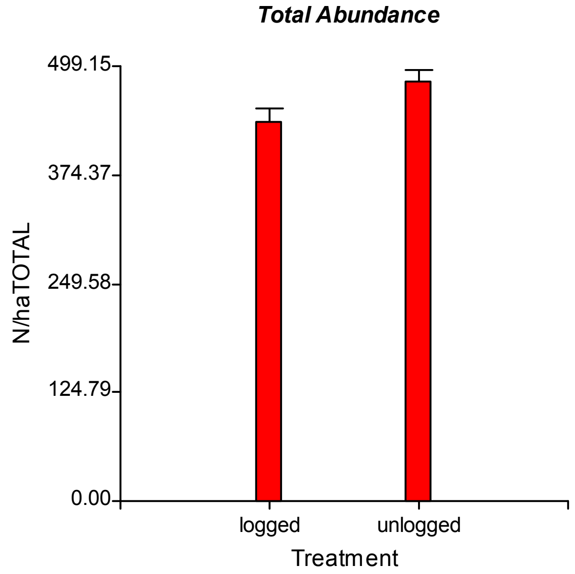

Figure 2. Total abundance of trees per hectare for both treatments: logged and unlogged. Vertical bars- 1 standard error.

Figure 4 shows the density of trees for the diameter class 10 -19; the unlogged has a higher mean value of the number of individuals to that of the logged. Harvesting decreases tree density (Crow *et al.* 2002). It could be that in the logged, the number of trees where reduced as a result of harvesting.

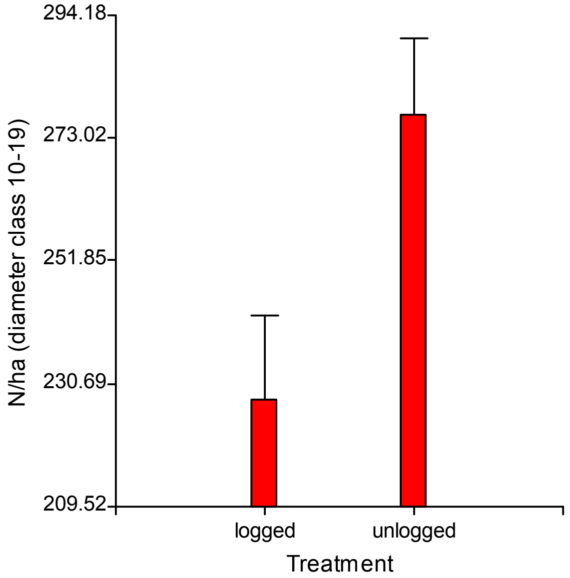

Figure 3. Density of trees per hectare for the diameter class 10-19 for both treatment: logged and unlogged. Vertical bars- 1 standard error.

Again in the diameter class 40-49, there was only difference between treatments Figure 5. The logged had a lower mean value; this could probably be due to selective logging which removes trees in this diameter class since the minimal diameter limit was 45 cm.

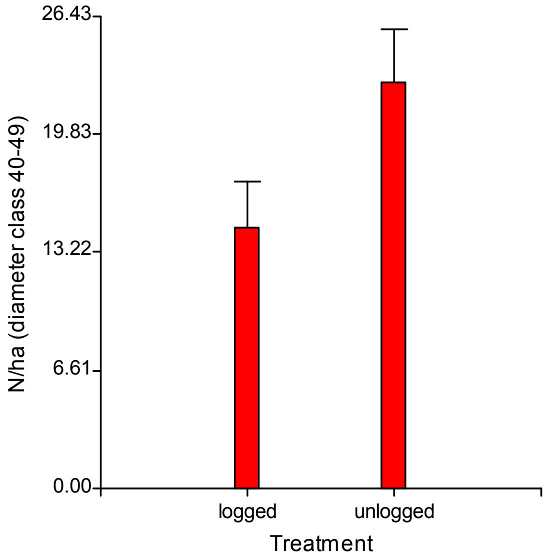

Figure 4 . Density of trees for diameter class 40-49 for both treatments: logged and unlogged. Vertical bar- 1 standard error.

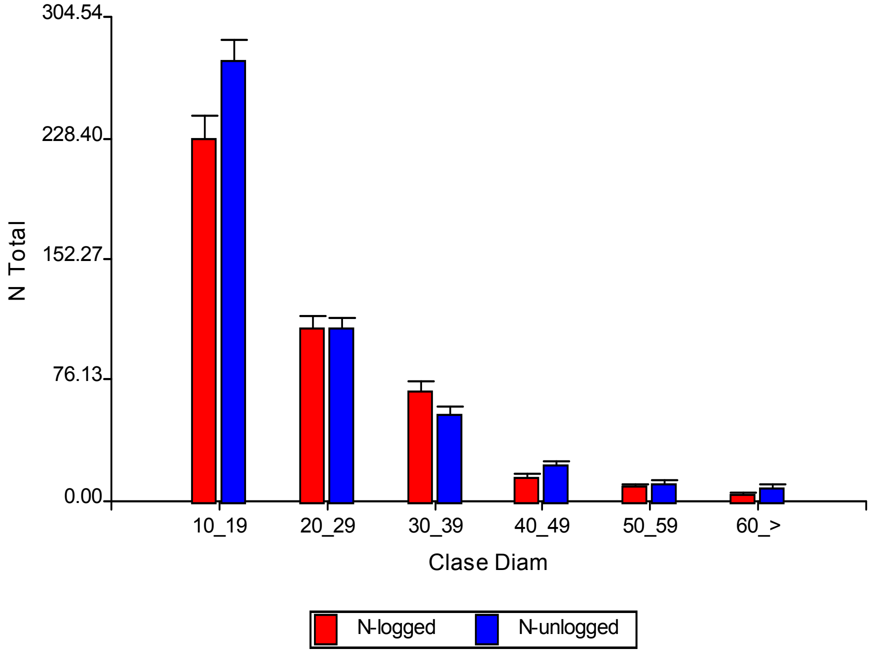

Figure 5. Abundance of tree per hectare for treatment for the different diameter classes. Grey bars-logged stands, Blacks bars- unlogged. Vertical bars- 1 standard error.

4.3.1.2 Basal area

The total basal area in the three sites ranges from 21.5 to 26.5 m²/ha in unlogged and from 19.5 to 23.9 m²/ha for logged. For the total basal area there were no significant differences between treatments (Figure 6), there was almost a statistically significant effect (P = 0.06).

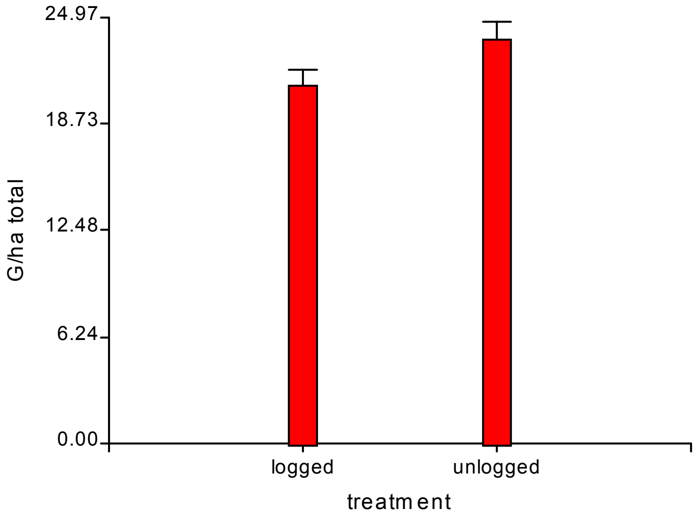

Figure 6 . Total basal area per hectare for both treatments logged and unlogged.Vertical bars- 1 standard error.

For the diameter class 10-19, there was significant difference between treatments. During the removable of harvestable timber trees there is high damage involve i.e. trees injured or killed (Sist et al 1998), to the remaining small trees (John 1988) as a result a decline in the number of trees after logging (Primack and Lee 1991) as a result a lower basal area for the treatment logged for this diameter class.

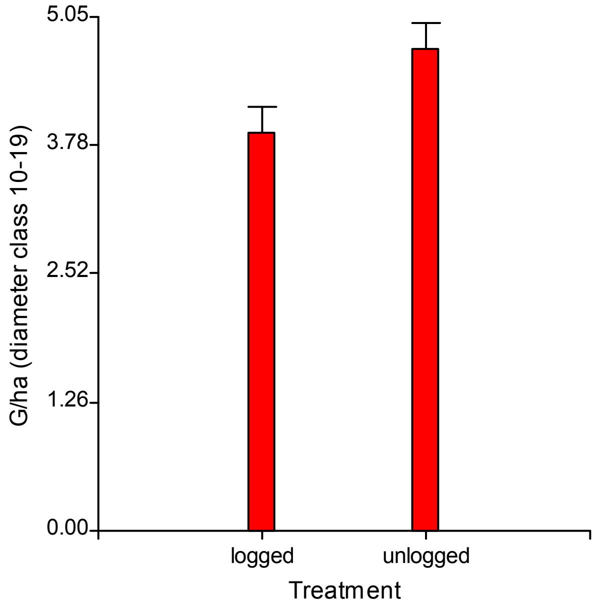

Figure 7. Basal area per hectare for diameter class 10-19 for both treatment: logged and unlogged. Vertical bars- 1 standard error.

As a result of extractions of timber there a significant difference between the logged and the unlogged for the diameter class 40-49. There was a low basal area in the logged area for the diameter class; it can be assumed that a lower number of trees and that during timber harvesting the number of trees removed were higher in this diameter class for hence contributing to such result.

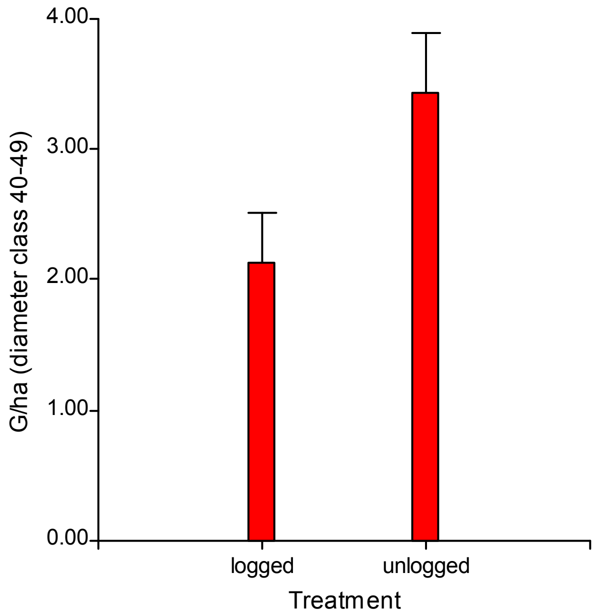

Figure 8 Basal area per hectare for diameter class 40-49 for both treatments: logged and unlogged. Vertical bars- 1 standard error.

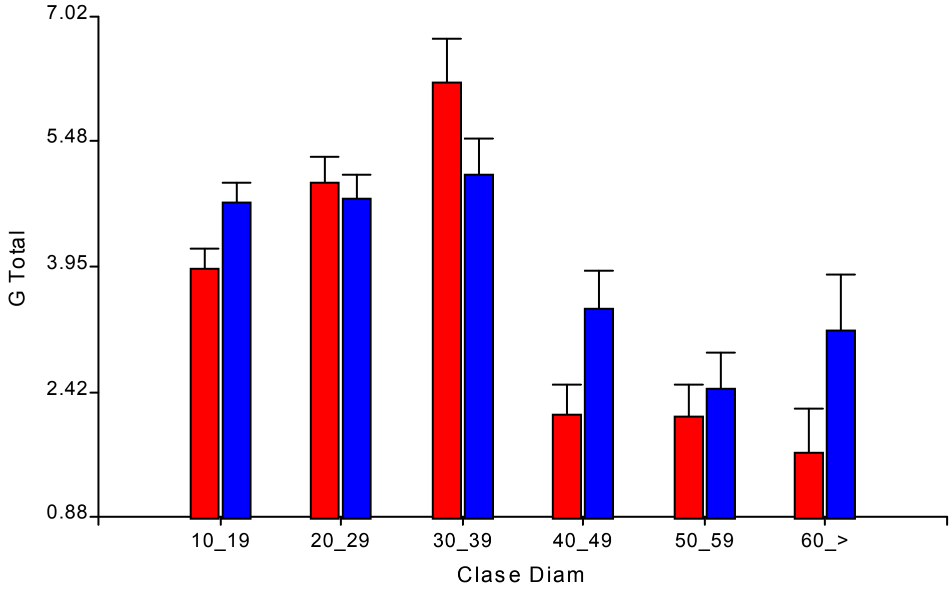

Figure 9. Basal area per hectare for treatments in the different diameter classes. Grey bars – logged stands; Blacks bars - unlogged stands; Vertical bars – 1 standard error.

4.3.1.3 Canopy openness of the understorey

There was greater canopy openness for the logged than the unlogged. The felling of trees during extraction of timber causes the opening of the canopy. As a consequence the amount of light that reaches the forest floor thus stimulates regeneration of species promoting a denser understorey. Recent logged forests have open canopies and understories. Selective logging reduces forest basal area and opens the canopy allowing more light to reach the forest floor. The understorey becomes hotter, drier and its vegetation more denser (Manson 1996). It is, however worth noting that these differences persist in the forest of RBCMA, 7-9 years after logging. The results are similar as those obtain by Ordoñez (Finegan *et al.* 2005), where the logged site had a greater canopy openness than the reference site.

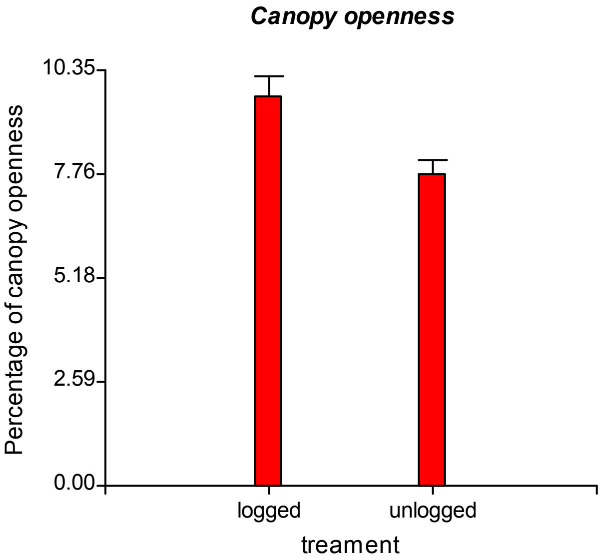

Figure 10. Canopy openness for treatment logged and unlogged. Vertical bars- 1 standard error.

4.3.1.4 Vertical Structure of the forest stands (foliage cover)

Figure 11 shows stratum 0-2m, there was greater foliage cover in the logged treatment. As assumed the management regime had an impact on the canopy openness which resulted in the lower stratum of the vertical structure to have a denser understorey as more vegetation cover. This result agrees with results obtained from canopy openness in which the logged sites had a higher canopy opening than the unlogged thus allowing light to reach the forest floor and as a result regeneration to occur. The mean for both treatments are almost similar but due to the intensity of evaluation it was able to determine such difference.

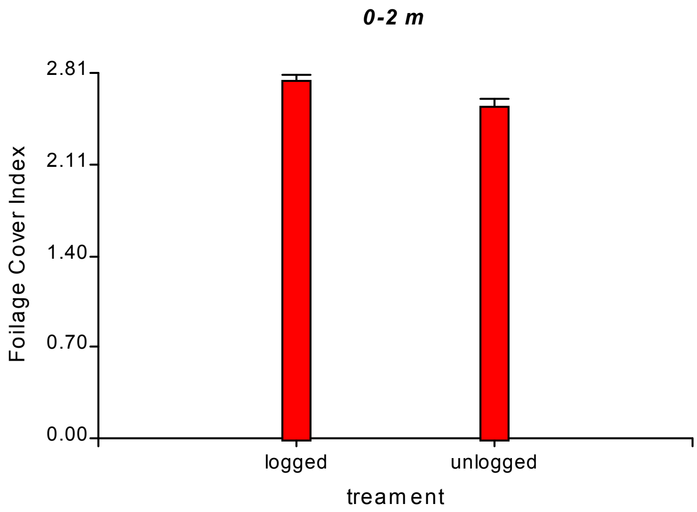

Figure 11. Vertical structure : 0-2m for both treatments logged and unlogged. Vertical bars 1 standard error.

The sum of the coefficients of variation of the five strata is a mean value for structural variability of the forest (Thiollay 1992); in this study four strata were taken in consideration. In Annex 2, the values of the structural variability are shown, for treatments in the three sites. The results show that there were no significant differences. After logging the vegetation structure of a logged forest is damaged and this would create heterogeneity, because of uneven distribution of harvest trees (Thiollay 1992). It is possible that this did not happened in the logged sites, probably because the management do not altered the forest developments processes, resulting in forest that are more uniform (i.e., less spatial heterogeneity) in their structure and composition (Crow et al. 2002).

4.3.1.5 The composition and abundance of palm trees

For the density of palms ≥ 10 cm dbh for the species *Attalea cohune* there was difference where the logged treatment had more of this species than the unlogged treatment (Fig. 13) and for the palm species *Sabal mauritiiformis* there was no difference between the two treatments Figure 13

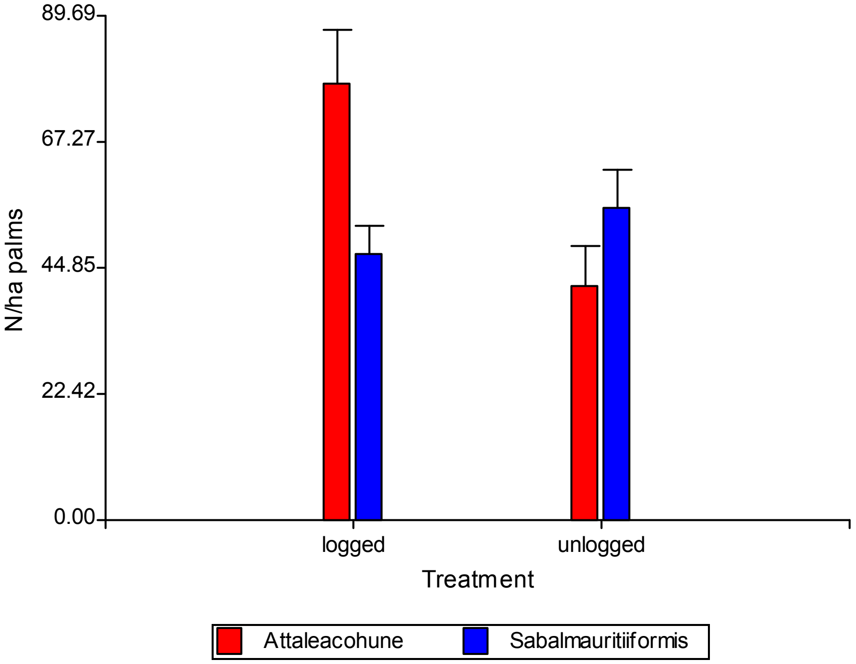

Figure 12. Density of palm per hectare for Attalea cohune and Sabal mauritiiformis. Vertical bars-1 standard error.

The harvesting of timber did not have an impact statistically on the total abundance of palms ≥ 10 cm dbh per hectare Figure 13.

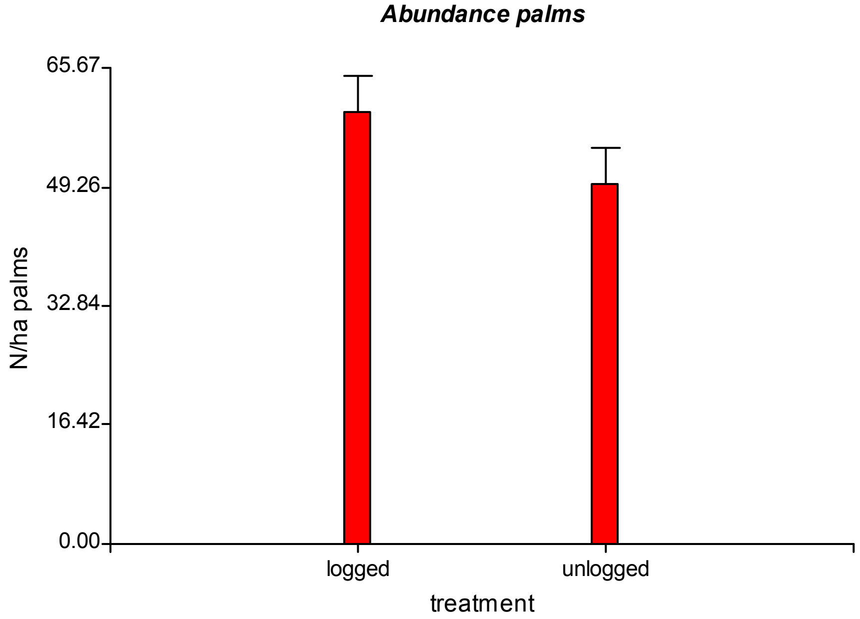

Figure 13. Total density of palms per hectare of the two species combined.Vertical bars-1 standard error.

4.3.2 Indicator for the structure and composition of the forest stand in sites

4.3.2.1 Total abundance of trees and by size class

Table 2 shows the mean number of trees, total and by diameter classes per hectare in the two treatments and three sites respectively.

In the two upper classes was where the agglomerations of most of the trees were: P.G 73%, W.B 87 % and W.M 66%. The classic reversed – *J* (negatively exponential) distribution in which the number of trees declines with the increasing size class, a stand structure results over time that can be characterized as reversed J-shaped of tree diameters with many small trees and a few large trees (Crow *et al*. 2002).

*Table 2. Total and diameter classes for the abundance of trees per hectare of sites for each treatment. Mean value of total and diametric classes and standard error (**μ± e**). Different letters between sites indicates significant differences.*

Diameter class (cm)	LOGGED				UNLOGGED			
	PG (*μ± e*)	**WB** (*μ± e*)	**WM** (*μ± e*)	**Pr>F**	**PG** (*μ± e*)	**WB** (*μ± e*)	**WM** (*μ± e*)	**Pr>F**
10-19	191 ± 15.89 **b**	309 ±10.94 **a**	173 ± 29.70 **b**	<.0001	313 ± 20.42 **a**	290 ± 17.08 **a**	213 ± 25.77 **b**	0.0071
20-29	104 ± 10.98 **b**	142 ±7.60 **a**	72 ±8.0 **c**	<.0001	99 ± 11.44 **a**	110± 10.69 **a**	117 ±10.44 **a**	0.5550
30-39	90 ± 11.31 **a**	41 ± 4.36 **b**	74 ± 7.18 **a**	0.0007	55 ± 11.70 **a**	47 ± 4.41 **a**	65 ± 8.72 **a**	0.3424
40-49	7 ± 2.14 **b**	9 ±3.48 **b**	31 ± 5.46 **a**	0.0001	21 ± 4.51 **b**	15 ± 2.90 **b**	36± 7.63 **a**	0.017
50-59	6 ± 2.89 **a**	11 ± 3.72 **a**	11 ± 1.79 **a**	0.4198	10 ± 3.01 **a**	10±2.92 **a**	13± 5.17 **a**	0.8145
> 60	2 ± 1.54 **b**	4 ±1.40 **ab**	9 ±3.48 **a**	0.0854	9± 4.99 **a**	6± 1.86 **a**	9±2.33 **a**	0.8214
Total	**402 ± 24.90** **b**	**517 ± 13.11** **a**	**370 ±31.51** **b**	**0.0002**	**508 ±23.18** **a**	**480± 23.46** **a**	**453 ±19.72** **a**	**0.2889**

Within sites there were statistical differences for the total abundance in the logged where WB had the highest density followed by PG and finally and WM. This could indicate that probably management reduced the number of tree in these two latter sites. The densities of trees were consistently lower in selective logged areas to that of unlogged areas results obtained by Chapman and Chapman (1997).

For the diameter class 10-19, of the three sites that were harvested for timber WB had a larger number of individuals in this diameter class. This could be the result of harvesting where WB was probably favored and regeneration took place a short time after harvesting.

PG and WM were statistically similar in the logged sites while in the unlogged PG and WB were statistically similar.

In the diameter classes: 20-29, for the sites that were harvested WB had the greatest number of trees, followed by PG and WM respectively. With respect to this, it is possible that regeneration occurred in WB a short time after harvesting hence having a larger number of trees than the other two sites. It could probably be that selective logging created disturbance producing a local increase in tree density as few large trees were replaced with more small trees (Denslow 1995).

PG, WB and WM were statistically different within the logged sites in this same diameter class.

In the logged sites in the diameter class 30-39 PG and WM presented a greater number of than in WB. It could be assumed that for WB the number of trees damaged during extraction of timber for this diameter class was greater than in the two other sites.

For the diameter class 40-49 WM had the highest density of tree than PG and WB. This could be that in these two sites more trees were harvested than WM.

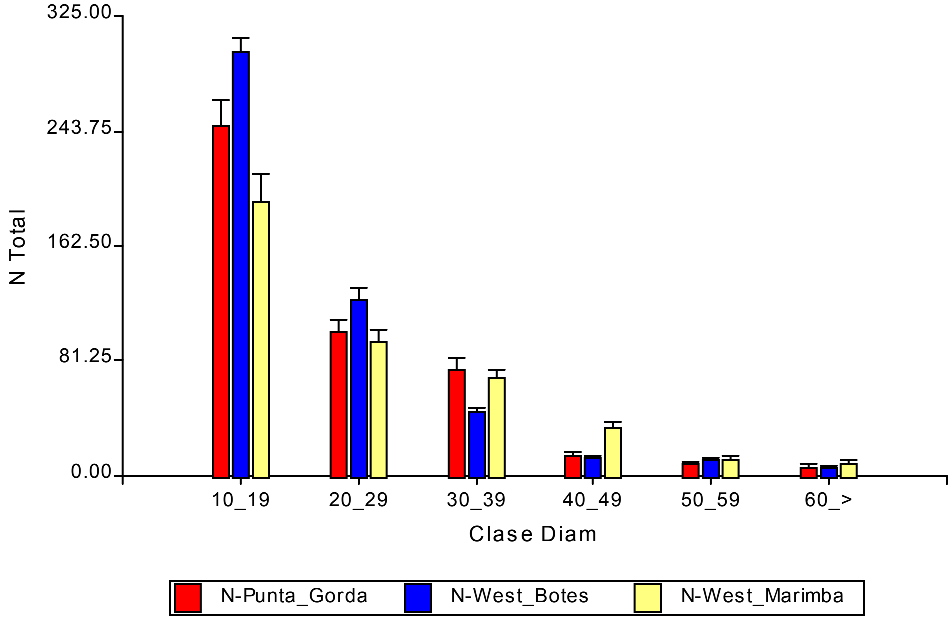

Figure 14. Abundance of trees per hectare for the different diameter classes of each site. Vertical bars- standard error.

4.3.2.2 Basal area

The total basal areas ranged from 19.5 to 23.9 m²/ha where extraction of timber was carried out and 21.5 to 26.5 m²/ha in the reference sites (Table 3). There were no significant statistical differences in sites for the total basal area.

*Table 3. Mean value for the basal area, total and the diameter classes per hectare for sites for each treatment. Mean value and standard error (**µ**± **e**). Duncan's Test. Different letters between sites indicates significant difference.*

	LOGGED				UNLOGGED			
Diameter class (cm)	**PG** (*µ*± *e*)	**WB** (*µ*± *e*)	**WM** (*µ*± *e*)	**Pr>F**	**PG** (*µ*± *e*)	**WB** (*µ*± *e*)	**WM** (*µ*± *e*)	**Pr>F**
10-19	3.3 ± 0.25 **b**	5.2 ± 0.23 **a**	2.8 ± 0.49 **b**	<.0001	5.3 ± 0.38 **a**	5.0 ± 0.37 **a**	3.6 ± 0.48 **b**	0.0203
20-29	5.0 ± 0.54 **a**	6.3 ± 0.36 **a**	3.3 ± 0.44 **b**	0.0007	4.5 ± 0.54	4.8 ± 0.50	5.1 ± 0.47 **a**	0.7419
30-39	7.9 ± 0.97 **a**	3.6 ± 0.38 **b**	7.1 ± 0.68 **a**	0.0003	5.1 ± 1.05	4.4 ± 0.37	6.1 ± 0.78	0.2801
40-49	1.1 ± 0.31 **b**	1.4 ± 0.53 **b**	4.5 ± 0.75 **a**	0.0001	3.2 ± 0.70 **ab**	2.4 ± 0.46 **b**	5.3 ± 1.12 **a**	0.0306
50-59	1.3 ± 0.60	2.6 ± 0.82	2.5 ± 0.45	0.3111	2.2 ± 0.68	2.3 ± 0.67	2.9 ± 1.15	0.8206
> 60	0.7 ± 0.53 **b**	1.2 ± 0.43 **b**	3.6 ± 1.56 **a**	0.0550	3.6 ± 1.83	2.7 ± 0.75	3.4 ± 0.92	0.8390
Total	**19.5 ± 1.55**	**20 ± 0.89**	**23.9±** 2.27	**0.1444**	**24 ± 2.42**	**21.5 ± 1.32**	**26.5 ± 1.85**	**0.1930**

In the diameter class 10-19 there were significant differences within sites in the different treatments. In WB where harvesting occurred had the highest mean value in basal area for this class. This could be attributed to the greater number of trees in this particular diameter class which contributes to a higher basal area with respect to the two other sites (see table 2).

In this same diameter class WM had the lowest basal area for site that does not had intervention, it could be considered that of three sites WM had the lowest number of trees hence contributing to lower basal area in this diameter.

For the diameter class 20-29, 30-39 and 40-49, significant differences were resulted only were harvesting were carried out and for the latter diameter class there was also difference in the site without intervention.

In the diameter class 20-29 WM showed the lowest basal area of the three sites were harvesting had taken place. It can be assumed again that the lower number of trees in this particular diameter class contributed for WM having a lower basal area.

With respect to the diameter class 30-39 WB had the lowest mean value of the three sites were timber was extracted. The display of WB correlates with the density of tree of that site, being the lowest to that of the other two sites.

Finally for the diameter class 40-49 WM is the site with the highest mean value of basal area. Since WM have a greater number of trees in this particular diameter class probably this contributed for that site to have the highest value or it could be can be considered that the number of trees harvested was less in WM.

In this same diameter class but for sites where there were no management regime WB and WM were statistically similar to PG but they are different statistically to one another.

For the upper classes 50-59 and > 60 there were no significant difference in sites within and between treatments respectively.

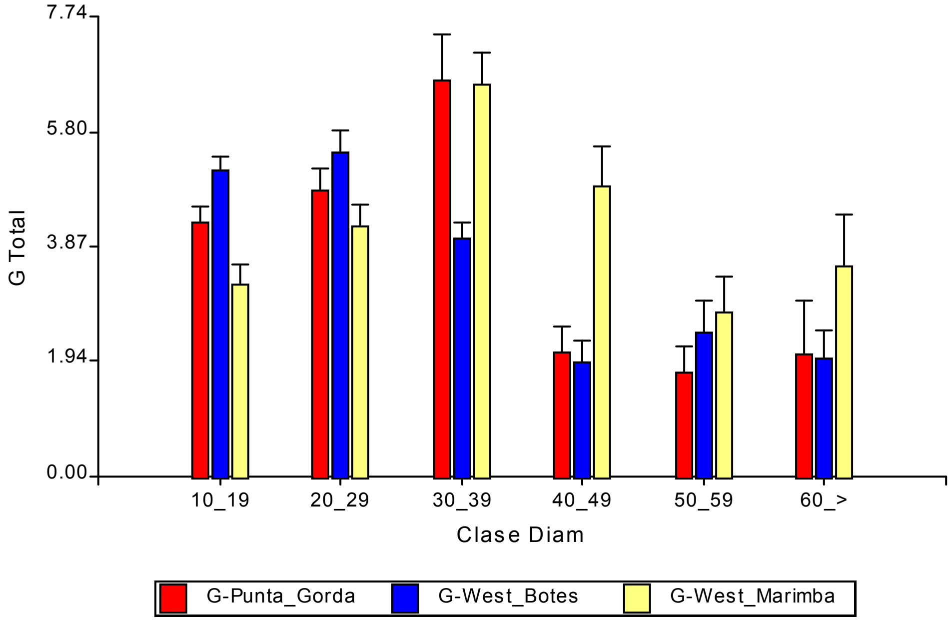

Figure 15. Basal area of tree per hectare for the different diameter classes of each site.Vertical bars – 1 standard error.

4.3.2.3 Canopy openness of understorey

The three sites with management regime showed: PG > WB > WM with respect to canopy openness of the understorey in table 4 - (the canopy openness is greater in PG and continues in descending order- WB and WM).

Selective logging would create more gaps; there is a change in the microclimate which contributes to regeneration of the forest which is characterized by dense undergrowth (Thiollay 1992), as a consequence of more light reaching the forest floor (Denslow 1995). Hence it can be assumed that logging had an impact on the sites where timber was extracted.

Similar results were similar as those obtained by Ordoñez (2005) for this particular indicator were management tends to lead to greater canopy openness than the unlogged sites.

*Table 4. Canopy openness of the understorey for treatments within sites of study. Mean value of canopy openness and standard error (**μ**± **e**). Duncan's Multiple Range Test. Different letters between sites indicates significant difference.*

Sites	**Canopy openness**		
	Logged (μ± e)	**Unlogged (μ± e)**	**Pr>F**
PG	13.8 ± 0.45	9.8 ± 0.53	0.0049
WB	8.9 ± 0.23	7.3 ± 1.4	0.0383
WM	6.4 ± 0.43	5.8 ± 0.13	0.1896

4.3.2.4 Vertical Structure of forest Stand (Foliage cover)

For the strata 0-2 m, 2-9 m, and 9-20 m there were significant difference for logged and unlogged the sites Figure 16 a- 16c.

For strata 0-2m (Figure 16a) where timber was extracted WB and WM have a greater foliage cover than PG. This differences could be as a result of intervention where harvesting had a greater impact in these two sites, canopy openness results and more light reached the forest floor that could contribute to regeneration and hence a denser vegetation cover.

In figure 16b and figure 17c shows strata 2-9m and 9-20 m respectively for the three sites under management having significant difference. It can be assumed as a consequent of management the impacts were differently in these sites. WM had a higher foliage cover than WB and in turn WB had a higher vegetation cover than PG for the respective strata. This probably suggests that harvesting reduced the number of trees allowing gaps to be formed and as a result more light reached the forest floor which could stimulate regeneration and consequently a denser lower vegetation cover.

For the sites that were unlogged for the strata 0-2m, 2-9m and 9-20m (Figure 16a-16c) it was PG that had a less dense vegetation cover. Probably it could be that there were fewer gaps on this site or more trees allowing less light to reach the different strata hence less vegetation cover.

For the structural variability there were no significant differences in sites within treatment and also no significant differences between treatments.

The sum of the five coefficients of variability is a mean value for structural variability of the forest (Thiollay 1992). In annex 2, it shows that the sites in both logged and unlogged have similar structural variability. After logging the vegetation structure of a logged forest is damaged and this would create heterogeneity, because of uneven distribution of harvest trees (Thiollay 1992). It is possible that this did not happened in the logged sites, probably because the management techniques do alters forest developments processes, resulting in forest that are more uniform (i.e., less spatial heterogeneity) in their structure and composition (Crow *et al.* 2002).

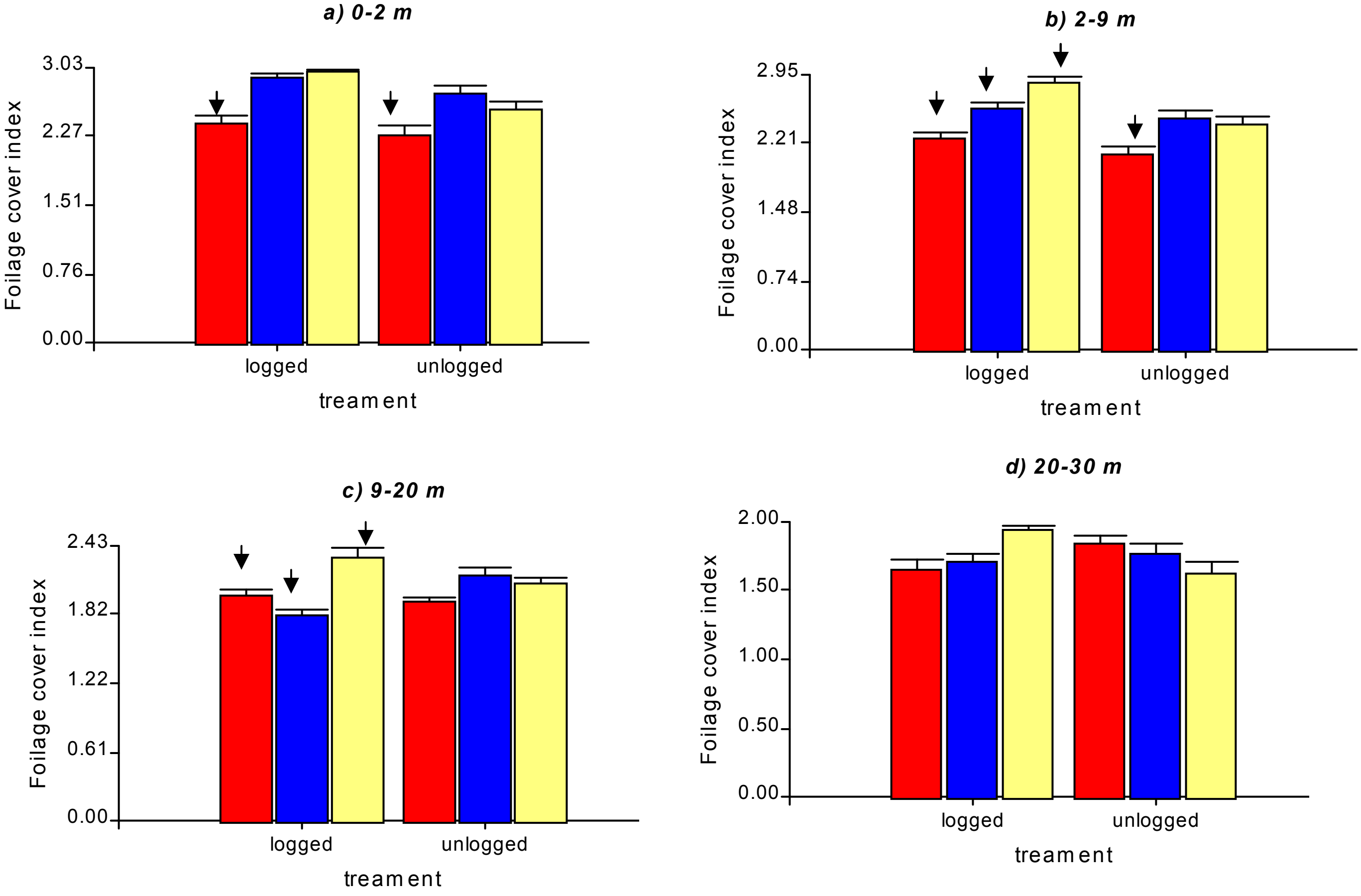

Figure 16. Vertical structure for strata for foliage cover index in the sites. ↓ Means significant differences. Grey bars- PG, Black bar s- WB, Open bars - WM and vertical bars- 1 standard error.

4.3.2.5 The abundance and composition of palms.

For sites that were logged and those without management there were no differences statistically in the total abundance of palms ≥ 10 cm dbh within sites. Similarly, there were no differences for the abundance of individual palm species ≥ cm dbh.

*Table 5. Abundance of palm in the three sites of study: PG, WB and WM for treatments. Mean value of abundance and standard error (**μ**± **e**). Duncan's Multiple Range Test. Different letters between sites indicates significant difference.*

Palm species	LOGGED				UNLOGGED			
	PG (*μ*± *e*)	**WB** (*μ*± *e*)	**WM** (*μ*± *e*)	**Pr>F**	**PG** (*μ*± *e*)	**WB** (*μ*± *e*)	**WM** (*μ*± *e*)	**Pr>F**
Attalea cohune	90 ± 2.7	-	58 ± 0.0	0.0934	65 ± 17.5	31 ± 0.0	38 ± 9.7	0.3960
Sabal mauritiiformis	41 ± 14.0	54 ± 8.0	37 ± 0.0	0.5920	33 ± 18.5	63 ± 6.1	57± 14.9	0.4295
Total	**68 ± 12.1**	**54± 8.0**	**47± 10.5**	**0.4296**	**53 ± 14.1**	**53 ± 11.3**	**47 ± 7.3**	**0.9334**

4.4 Conclusions

The forest sites displayed some structural differences probably as a response to the management and to the silvicultural treatment applied. Nevertheless, natural variation, difference in time of intervention, among others factors must be considered**.** According to the results obtained there were changes in logged areas for the indicator of total abundance of trees and density of trees for diameter classes 10-19 and 40-49 where the unlogged treatment had a higher density than that for the logged which could probably be as a result of management.

For the total basal area there was no significant difference between treatments. While for the basal area for the diameter classes 10-19 and 40-49, the unlogged had a higher basal area than the logged.

For the indicator of canopy openness, the treatment logged have a greater canopy openness than the unlogged, it could be probably be the result of harvesting activities that lead to more gaps for the logged.

Also for the vertical structure of the forest stand the logged (strata 0-2m) had a higher vegetation cover than the unlogged which was expected as the logged resulted with a higher canopy openness.

For the abundance and composition of palms, for the total abundance of palms there was no significant difference. For the palms species separately there was difference for *Attalea cohune* were the logged had a higher density than the unlogged. In the case of the *Sabal mauritiiformis* there was no difference. The composition of palm, two species were present: *Attalea cohune and Sabal mauritiiformis.*

The areas of the RBCMA have variation in the forest stand therefore it is recommended that evaluations of management impacts be carried out on each of the sites.

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5 ARTICLE II. EVALUATION OF A METHODOLOGY FOR ECOLOGICAL MONITORING OF FOREST MANAGEMENT IN BROADLEAF FOREST OF THE RBCMA- BELIZE.

5.1 Introduction

Forest certification was introduced to address concerns of deforestation and forest degradation especially in the tropics (Ramesteiner and Simula 2003). Also forest certification shows that forestry practices are conducted with no negative impacts on the forest (Murillo *et al.*1999). Forest certification constitutes one of the main mechanisms available to promote the use of sustainable forest practice (Finegan *et al.* 2004).

Tropical forests are considered among the most valuable ecosystems in the world – ecologically and biologically for providing important environmental services such as carbon sequestration, water and soil protection and climate regulation (Colfer *et al.* 1997).

In view of the inherent value of tropical forest and persisting threats of deforestation (Prabhu *et al.* 1996), most of the natural forest of the Neotropics tend to be categorize by definition of Forest Stewardship Council (FSC) as High Conservation Value Forest (HCVF) (Finegan et al 2004). The FSC Principle 9: Maintenance of High Conservation Value Forest, states that management activities in HCVF shall maintain or enhance the attributes, which define such forest (Colfer *et al.* 1997) .One important mechanism for this is certification, a useful tool in promoting the sustainability of tropical forest logging. Certification standards must be expanded to include the effects of logging on the biodiversity and ecology of the forest. (Bennett 2000). Within this context, monitoring becomes essential to determine the actual condition of the forest and the level of change caused by forest management and recovery, even more when these are occurring in HCVF in relation to its biodiversity.

The demands for sustainability have resulted in various initiatives to define guidelines for sustainable forest management at global, regional, national and forest management unit (FMU) levels (Higman *et al.* 1999), which can be used to measure and monitor forest management practices. However, there has been growing realization that goals of sustainability largely rest on actions carried out at the local or forest (FMU) scale (Wright 2003).

Sustainable forest management (SFM) can no longer neglect the importance of ecological aspect of forest management. Regarding scale and detail of SFM standards, the potential impact is likely to increase as the standards become more specific and detailed both geographical and scale and in content. Forest Management Unit (FMUs), as defined in certification initiatives, concerns the administrative unit, which decides upon, and subsequently executes activities in relation to forest management. Considering that SFM certification is designed to act as an incentive therefore FMUs is more effective for inducing changes in forest management than the scales (regional and national), as it addresses the forest operations directly (Rametsteiner 1999).

Finegan et *al*. (2004) propose the use of a coarse filter base on the structure and composition of the forest stand. Such characteristics are well defined in any forest; they are related directly to forest management and indicate the quality of habitat for certain organisms. Also if operational activities contribute to unacceptable changes at this level, indirectly the ecological integrity for some species at a lower level are affected and such changes can be detected by monitoring the structure and composition of forest stand (Finegan *et al.* 2004).

A key aspect of the monitoring approach proposed in the Guide was the establishment of thresholds of change in order to be a useful ecological monitoring tool. A threshold is a value of variable that is being monitored that indicates that an unacceptable degree of change has occurred or probably could occur according to the available data and this could indicate the need of adjustment in the management activities (Finegan *et al*. 2004).

The Monitoring Guide (Finegan *et al.* 2004) was applied at sites in broadleaf forest of RBCMA in Belize. The method used for the harvesting of timber is selective. RBCMA has been certified by Smartwood (Smartwood Report- PfB 2005). Certification was applied to management of the whole forest – i.e. the entire RBCMA – rather than the management of the timber zone (Planning Guidelines for Timber Extraction RBCMA 2004). In order to evaluate the approach of the Guide five indicators of the coarse filter (stand and composition) where selected it. By means of evaluating the indicators, levels of changes where detected in the logged site with respect to the unlogged site. The level of changes where determined if it were within acceptable limits or that of unacceptable. Recommendations were made for the adaptation of procedures in the Guide to specific conditions of the RBCMA.

5.2 Materials and methods

5.2.1 Study site

5.2.1.1 Rio Bravo Conservation and Management Area

The study was conducted in the forest of the Hill Bank Field Station located on the RBCMA during the months of January (late) to July 2006. The area lies in Orange Walk District, north- western Belize (17°36´N, 88°42´W), adjacent to the northeastern of the Petén region Guatemala and southeastern Mexico (Figure 18). The area is in the subtropical moist life zone of the Holdridge Life Zone System (Hartshorn et al. 1984). Annual rainfall is 1500mm/ yr. However, rainfall in the dry and wet seasons can vary annually Daytime temperature probably average about 24° C and at night can be as 10° C during the months of November to January. From April to September daytime average about 26° C and the hottest period, April and May with maximum temperature exceeding 32° C (Whitman et al. 1998).

The principal topographical features consist of a series of terraces developed over geological time, resulting in several distinct escarpments which run northeast- southwest through Rio Bravo. These escarpments break up Rio Bravo's generally flat or rolling terrain with low hills and occasional small swamps (Harcourt and Sayer 1996). Drainage is impeded in certain areas by the heavy soils which overlay calcareous bed-rock (Bird 1998).

The RBCMA was created by Programme for Belize (PFB) is an Environmental Non-Governmental Organization – (NGO) established with the express purpose of acquiring as much land as possible for conservation purposes and dedicated to promoting wise use of the nation's natural resources. Some 2830 sq. km of land in north- western Belize came to the market after the break-up of much larger holding and as it was feared that the area would be totally cleared for agriculture, PFB begun the purchasing of such lands. Land was purchased with funding from foundations, bilateral aid agencies, commercial sponsors and through a sponsorship scheme and private donations – this area constitutes the Rio Bravo Conservation and Management Area (RBCMA). RBCMA covers 103,700 hectares (Smartwood Report 2005) in the northwest Belize, Central America and is manage for conservation, research and economic activities consistent with the protection of biological diversity (Brokaw and Mallory 1993).

The tri – national Petén region is the largest tropical broadleaf forest remaining in Central America (Bridgewater 1999) and the region is rich in biological resources and archeological sites (World Resources Institute 2001). RBCMA contains healthy populations of a wide range of species that are becoming rare in Central America (Burton). The carbon sequestration project in Belize's Rio Bravo Conservation and Management Area plays an important role in the mitigation of global climate change (Kuhn 1999). Taking into account the aspect of national and international importance, the RBCMA fulfills the ecological attributes of High Conservation Value Forest (HCVF) 1, 2, and 3 proposed by FSC (Table 6).

Table 6. High conservation value forest.

HCVF1	Forest area with significant concentration at global, national or regional level , of values of biodiversity (e.g. endemic, endangered, sanctuary)	RBCMA an important site for faunal communities characteristic of the area, including those species that are listed as threatened by IUCN (Groombridge 1993).
HCVF2	Forest area which contains relevant landscape at a global, national o regional, which forms part o include the unit of management, where it exist viable population of the majority – or entirely – of species which occur naturally with a natural pattern of distribution and abundance.	At the landscape level, the upland forest system is still part of the most extensive tract of forest in Central America (Bridgewater 1999).
HCVF3	Forest area which are categorized or contain rare ecosystems, endangered or in risk.	RBCMA forms an important part of the protected network, incorporating critical habitats for conservation and vegetation types poorly represented in the national system (RBCMA Management Plan 2000).

Figure 17. Map of Belize and the location of the study site (PfB 2005).

5.2.2 Forest Sites - PG WB and WM

RBCMA covers 103,700 hectares (Smartwood Report 2005) in northwest Belize and is managed for conservation, research and economic activities consistent with the protection of biological diversity (Brokaw and Mallory 1993). The forests of northern Belize are similar to those covering Guatemala's northern Petén and Mexico's Yucatan Pennisula (Pennington and Sarukan 1968). Characteristic species include *Swietenia macrophylla, Manilkara zapota, Brosuim alicastrum, Pimenta dioica, Manilkara chicle, Drypetes brownii, Pseudomelia spuria, Dialium guianense, Orbignya cohune and Terminalia amazonia* (Hartshorn et al. 1984). Much of the forest has been selectively cut for *Swietenia macrophylla, cedrela odorata* and other hardwoods (Harcourt and Sayer 1996).

The Timber Extraction Zone (TEZ) of the RBCMA covers 24,039 ha and is divided into eight management areas – Punta Gorda, North Duck Ridge, South Duck Ridge, East Marimba, West Marimba, East Botes, West Botes and Governor Creek. Each area is composed of various numbered compartments for management purposes (Planning Guidelines – RBCMA 2004).

Three management areas were selected to carry out the study and these are Punta Gorda, West Botes and West Marimba were considered to be the same type of forest- upland /*Attalea cohune* forest. (Mr. Mena-PFB Forester personal commu.). Within those management areas, there were subdivisions referred as to compartments. Logged and unlogged compartments were identified on respective management areas

5.2.2.1 Upland forest

The broadleaf upland forests are the most extensive vegetation type in the RBCMA and constitute the matrix vegetation covering over 69,000 ha or over 66% of its total area. They range from dry to mesic (moist) variants according to local topography, and considerable areas are transitional with the wetter seasonal thickets or ‘‘bajos’’. On deeper, moist but well-drained soils, cohune palm *Attalea cohune* tends to become dominant. More usually, however, no species dominates outright although a small group, usually less than ten species, tends to constitute more than 50% of the larger trees in any given area. The species concerned vary from place to place around HillBank, in generally mesic conditions, they consist of *Terminalia amazonia, Acacia usumacintensis, Swietenia macrophylla, Brosimum alicastrum, Vitex gaumeri, Spondias mombin and Acosimum panamense*. Other characteristic species include *Manilkara zapota and Manilkara chicle* (RCBMA Management Plan 2000).

5.2.2.2 Attalea cohune forest.

These forests occur on rich, well-drained soil in upland that often supports this palm. Cohune palm forest occurs at the base of slopes, where pattern of deposition and drainage seem to produce suitable conditions. The cohune palm is a canopy dominant, but there are many other tree species most that are common in upland forest. A change from level ground with much cohune to slope with no cohune is abrupt in places (Brokaw and Mallory 1993).

5.2.3 Timber harvesting

Detailed information on timber harvesting was not available. The information for the three sites presented here was obtained from http://www.rainforest-alliance.org/programs/forestry/smartwood/ since none could be provided by PfB.

The first harvest was in Punta Gorda in 1997 with 100 hectares being harvested in that site. The next two harvests were in 1998 and 1999, with an increase in area harvested to 365 and 333 hectares for WB and WM respectively. In 1998, 18 different species were harvested (Smartwood 2005).

The area had past selective logging regime where the primary target was *Swietenia macrophylla* but other hardwoods such as *Cedrela odorata*, *Calophyllum brasiliense* were also exploited.

Timber harvesting in the sites follows a a 40 year felling cycle with polycyclic silvicultural system. Areas considered physically unsuited for extraction due to slope or soil condition (wetness) are excluded from the Timber Extraction Zone. The harvesting of timber is selective and the criteria for the selection of trees are a minimal cut diameter (>55 cm dbh for *Swietenia macrophylla* and >45 cm dbh for all other species) and local commercial market (plywood core stock) (RBCMA Management Plan 2000). Species that were harvested for the period 1997-1999 are listed Annex 1.

Information on management activities at the sites was not available for this study. Hence the impacts on the logged sites are evaluated with the values of the reference sites assuming that these values are characteristics of the logged site prior to management.

5.2.4 Methodology

5.2.4.1 General

The methodology was to determine the impact of management and to evaluate procedures and approach of an Ecological Monitoring Guide elaborated by Finegan *et al.* (2004), with the intention to aid in sustainable forest management and certification. The sampling design was based on the approach of the Monitoring Guide (Finegan et al. 2004); also other research works related to this one were reviewed such as Ordoñez (2003). At the same time with the purpose of collaborating with the validation of the Monitoring Guide, to support efforts for forest certification and sustainable forest management.

Three sites were selected for this study: Punta Gorda, West Botes and West Marimba.

First a ground trekking was carried out in the three sites. This was considered important for the stratification purposes of the sites of study. In PG and WM it was observed the presence of the same vegetation and topography, with no apparent difference in the structure and composition of the sites. WB was considered to have a vegetation of upland forest and PG and WM a vegetation of upland/cohune forest. (PfB Forester personal commu.). During the ground trekking areas that were identified as different due to edaphic conditions were noted and where not taken in consideration for the study. A map of the Timber Extraction Zone was available at all times for reference of the zone.

Five indicators were chosen from the coarse filter (stand structure and composition) of the Monitoring Guide. These were density of trees, basal area, canopy openness of the understorey, vertical structure and composition and density of palms. The approach for the evaluation indicators was obtained from the Monitoring Guide. Data were collected for each work site of study areas.

5.2.4.2 Sampling

Three transects were placed in each of logged and unlogged forest – PG, WB, and WM, i.e. (logged and unlogged) which were separated by 1000m and on each transect, three temporary plots of 20 m x 50 m were placed at 300 m of each other. Also along transect sampling points were placed at every 50 m and imagine being in the center of a temporary plot of 10 m x 10 m.

In the temporary plots of 20 m x 50 m, the indicators of total density and basal area, density and composition of palms were measured while in the sampling points, canopy openness and vertical structure were measured.

On the respective compartments, where the temporary plots were established, the procedures and approach of the Monitoring Guide (Finegan et. al 2004) were applied. The management areas were distantly apart - km - from each other and the compartments (logged and unlogged) were approximately apart 1000 m. The size of each compartment was approximately 150 hectares. For this study, compartments: logged and unlogged will be referred as sites: logged and unlogged.

5.2.4.3 Evaluation of indicators of the structure and composition of forest stand

- ***Density and basal area: total and by size class***

For these indicators the temporary plots of 20m x 50m in logged and unlogged sites were used. Within the plots, all live individual $\geq$10 cm dbh were recorded. The trees were counted; the stem diameter at breast height was measured with diameter tape at 1.3m above ground level. The trees were identified with their respective genus/species name or common name by a PfB forester; trees that weren't identified were indicated as "unknown". With this information the total number of trees and basal area per hectare, and their diameter class distributions were obtained.

- ***Canopy openness of the understorey***

Measurements were carried out at the sampling points at every 50m along each transect for the canopy openness of the understorey. A spherical densiometer (with a concave mirror) was used and four measurements were taken i.e. each measurement at a cardinal point. A mean was obtained for the four measurements at each sampling point and then multiplied by 1.04 to obtain the percentage canopy openness of the understorey.

- ***Vertical structure of the forest***

For the evaluation of this indicator, the sampling points were considered as the centre of imaginary temporary plots of 10 m x 10 m for estimation of percentage vegetation covers on four different height strata; from the understorey to the upper canopy: a) 0-2 m, b) 2-9 m, c) 10-20 m, and d) 20-30 m as proposed by Thiollay (1992). A scale of 0, 1, 2, or 3 was used for the estimation of vegetation cover. A value of 0 was assigned when the percentage of vegetation cover was 0; 1 when vegetation cover was 1-33; 2 for 34-66 and 3 when vegetation cover was > 67% respectively.

From these measurements a mean value index of foliage cover for each stratum for each site was obtained for both managed and reference areas. The estimations of vegetation covers were evaluated only in four strata (<30 m) (and not > 30 m as recommended by Thiollay 1992); because of the maximum height of the forest which was considered to be in an average between 20-30m.

- ***Composition and abundance of palms***

The composition and abundance of palms were evaluated in the temporary plots of 20m x 50m in logged and unlogged sites. All palms ≥10 cm dbh were recorded. The palms were counted; the diameters at breast height were measured with diameter tape at 1.3m above ground level. The palms were identified with their respective genus/species name or common name.

5.2.4.4 Determining the thresholds from the variation on the reference sites

The Monitoring Guide (Finegan *et al.* 2004), determines the thresholds as the change of variation observed in the values of indicators in the manage sites compared to those of the reference sites using the standard deviation as a means of variation. The Monitoring Guide defines a threshold as the value of a monitoring variable that indicates that a certain change has occurred.

The data obtained from the reference site where used to determine the thresholds in the following way:

Low Change threshold is one standard deviation from the mean value of the indicator in the reference site. Two standard deviations are considered as a **Moderate Change threshold**. A **High Change threshold** is one which exceeds three standard deviations (Finegan *et al*. 2004).

Therefore:

$$T = x \pm y\ (s)$$

Where: T is the value of threshold, x is the estimated value of the indicator (or mean of the estimated values in various sites) in the manage site before intervention (or of the reference site), y is the constant of the threshold of change and s is the standard deviation of the values of the estimates in the reference sites. The constant of the threshold of change, when $y = 1$ determines low change threshold, 2 for moderate change threshold and 3 for high change thresholds.

It is important to consider the mean value of the indicator in the reference site where the product of the constant of the threshold of change and the standard deviation is added or subtracted to it. This is as a result of impacts brought about by management, which can cause the values on the indicators to increase or decrease.

For the indicators: stand density and diameter classes 10-19 and 20-29, total basal area, and abundance of palms the thresholds were established below the reference value since the values of such indicators will tend to decrease immediately after harvesting. For canopy openness and vegetation cover in lower strata of the understorey 0 –2 m, and 2-9 m the thresholds were placed above the reference value since these values increases as large trees are remove and regeneration occurs as the result of harvesting.

5.2.4.5 Establishing the values of the triggers

The Monitoring Guide (Finegan *et al.* 2004) proposes the selection of a trigger, which is the value of the threshold that indicates that it is necessary to modify the management activities as a response to the changes caused by logging. The selection of a threshold to be used as a trigger is base on five interrelated factors. These are: the conservation objectives, the need for precaution, the conservation importance, monitoring intensity and natural variation. The value of the threshold can vary from low to high according to the characteristics of each indicator, the objectives of conservation and management as well as the natural variation of the study sites (Finegan *et al*. 2004).

Principle 9 of FSC refers to the maintenance of High Conservation Value Forest (HCVF) and according to the guide for the identification of these forests there are six types of HCVF (Jennings *et al*. 2002). RBCMA fulfills the ecological attributes of HCVF 1, 2and 3. HCVF1: Forest area with significant concentration at global, national or regional level, of values of biodiversity (e.g. endemic, endangered, sanctuary). RBCMA an important site for faunal communities characteristic of the area, including those species that are listed as threatened by IUCN (Groombridge 1993). HCVF2: Forest area which contains relevant landscape at a global, national o regional, which forms part o include the unit of management, where it exist viable population of the majority – or entirely – of species which occur naturally with a natural pattern of distribution and abundance. At the landscape level, the upland forest system is still part of the most extensive tract of forest in Central America (Bridgewater 1999). HCVF3: Forest area which are categorized or contain rare ecosystems, endangered or in risk. RBCMA forms an important part of the protected network, incorporating critical habitats for conservation and vegetation types poorly represented in the national system (RBCMA Management Plan 2000). Considering RBCMA as a High Conservation Value Forest according to (HCVF1, HCVF2 and HCVF3), and taking suggested criterias by (Finegan *et al.* 2004) the triggers were established as Low change thresholds.

To compare the logged sites with the reference sites, the mean value of the estimates for each indicator on the logged site and its 95% interval of confidence (as a means of evaluating), is compared with the established value of the trigger to determine the level of changes caused by management (Finegan *et al*. 2004). In this way, if it overlaps with the value of the trigger, then it could be that management activities are causing impacts on the resources in an unacceptable manner. For such reasons there is a need to make changes on the management plan.

The approaches of the Monitoring Guide were applied only to the indicators with a Coefficient of variation less than 40% in the reference area.

5.3 Results and discussion

5.3.1 Evaluation of Indicators according to Approach of Monitoring Guide

Table 7. Indicators showing values of coefficient variation > 40% that could not be used in each of the sites PG, WB and WM.

Indicator	PG	WB	WM
Abundance of trees diameter class (cm)	C.V	C.V	C.V
30-39	72	-	42
40-49	75	73	67
50-59	104	113	125
> 60	108	108	82
Basal area diameter class (cm)			
20-29	41	41	-
30-39	71	-	41
40-49	75	76	67
50-59	107	113	124
>60		109	86
Canopy openness	47	58	-
Vegetation cover strata 20-30 m	-	-	44
Palm abundance	**105**	**47**	**42**

For the above mentioned indicators the Monitoring Guide was not applicable due to high variation of the indicators. Therefore the use of the standard deviation to determine the threshold of change became an excluding factor for these indicators.

The following indicators with a coefficient of variation less than 40% were the ones that the approaches of the Monitoring Guide were applicable:

PG: total abundance, abundance by diameter class (10-19 and 20-29), total basal area, and the vegetation cover stratum: 0- 2 m, 2-9m, and 10-20 m and 20-30m

WB: Total abundance, abundance by diameter classes (10-19, 20-29 and 30-39), total basal area, and the entire vegetation cover height range: 0- 2 m, 10-9m, and 9-20 m and 20-30m

WM: total abundance, abundance by diameter classes (10-19, 20-29 and 30-39), total basal area, canopy openness the vegetation cover stratum 0-2m, 2-9m, and 10m – 20m.

5.3.1.1 Indicators of forest stand structure

As for the total tree density, (Fig. 18 a – c) the 95% confidence interval of the logged site overlaps with the trigger established for PG and WM (Fig. 18a, c) but not in WB (Fig 18b). Generally as a consequence of timber harvesting the number of trees per hectare are reduced. Even though only a small number of trees in a selectively logged area are removed a large amount of trees are destroyed (Sekercioglu 2002), therefore harvesting decrease tree density (Crow *et al.* 2002).

By the criteria established by Finegan *et al.* (2004) this indicates that the impact caused by logging was unacceptable in PG and WM. The lack of an impact on tree numbers in WB could be as the result of the low intensity of logging that have prevented increase of natural disturbance and made it possible for the forest to revert to that of unlogged forest (Sekercioglu 2002). It is also possible, but uncertain, that a greater number of residual trees were left, moreover forest stand following logging will further influence in structure as this characteristically change during stand development (Reich *et al.* 2001). This contributes for the value of the logged site to be within acceptable range .Nevertheless, it is not certain how much the value for this indicator decreased in the logged site after the harvesting since there wasn′t information prior to harvesting.

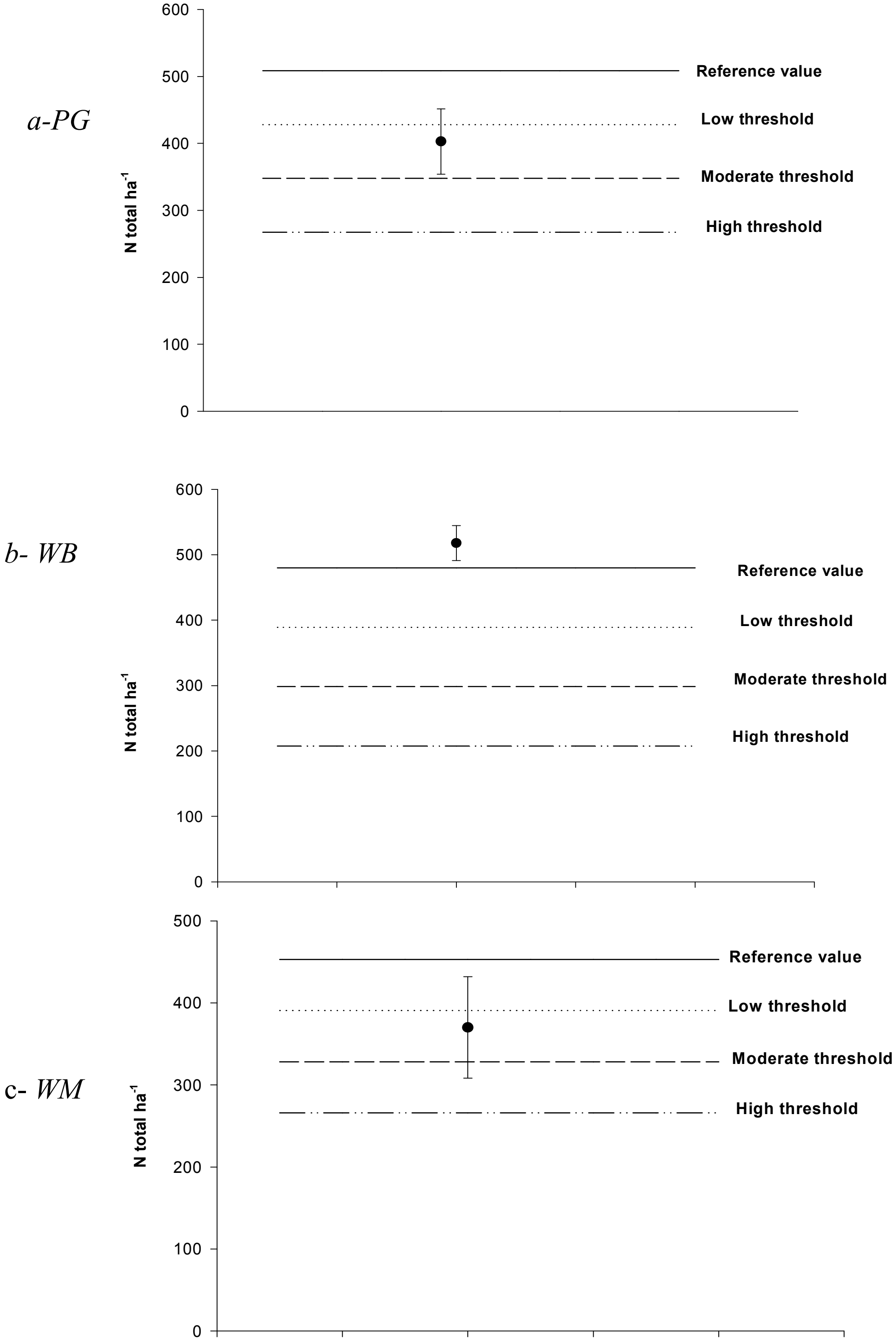


Figure 18 a (P G), b (WB) and c (WM). Evaluation of change for the indicator of total abundance of trees per hectare for broadleaf forest - RBCMA, Belize. Dots-mean and vertical bars-confidence interval.

5.3.1.2 Impacts on tree numbers by diameter classes

In the 10-19 cm dbh, (Fig. 19 a - c), the confidence intervals for the managed areas overlapped the selected trigger in PG and WM but not in WB. During the removable of harvestable timber trees there is high damage involve i.e. trees injured or killed (Sist et al 1998), to the remaining small trees (John 1988) as a result a decline in the number of trees after logging (Primack and Lee 1991). In WB, the structure of the forest is not greatly altered and the growing stock gradually recovers and tends to become similar to the unlogged forest because of the recovery after selective logging (Pelisser et al 1998).

In (Fig. 19 d – f), shows 20- 29 cm dbh, where there was only unacceptable change in WM. Nevertheless, it is not certain how much the value for this indicator decreased in the logged sites for PG and WB after the harvesting since there wasn′t information prior to harvesting.

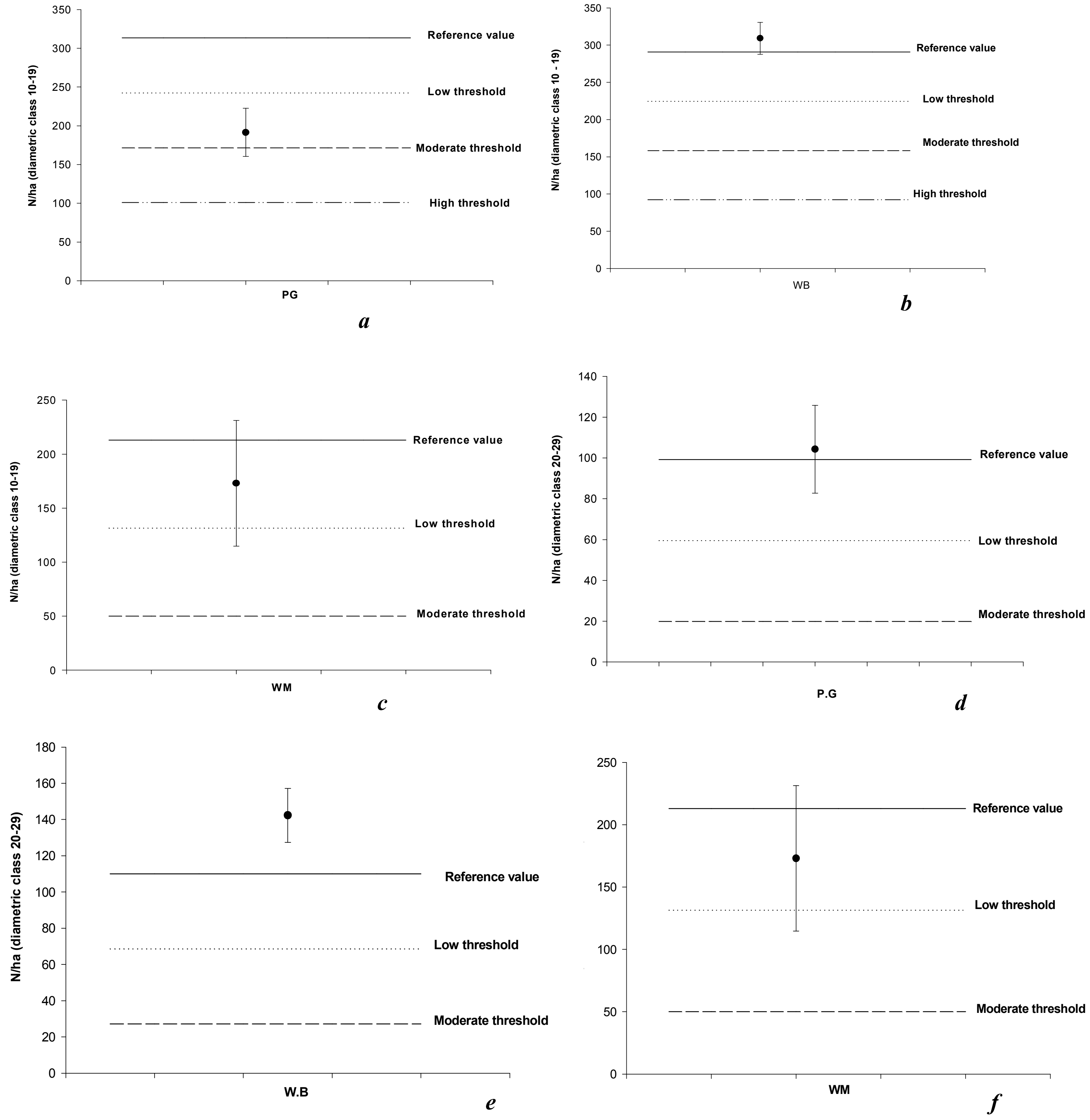


Figure 19. a - c and 19 d – f. Threshold of change for the indicator abundance of trees per hectare for diameter class 10-19 cm- dbh and 20-29 cm-dbh . a/d- Punta Gorda , b/e – West Botes and c/f – West Marimba. Dots- mean and vertical bars-confidence interval.

Figure (20 a and b) represents 30-39 cm dbh for WB and WM. In both cases the mean value and confidence interval does not overlap with trigger. An increase growth rates are frequently observed in residual trees following selective logging (Jonkers 1987) and so this diameter class was favored resulting in a mean value above the reference one. The impact of management is within acceptable limits and there is no need to modify the management plan. Also in WM, the logged areas do not overlapped with the low change threshold, therefore the impact was considered as acceptable. But it is not know how much impact was caused by management since the mean of the logged is above the reference value.

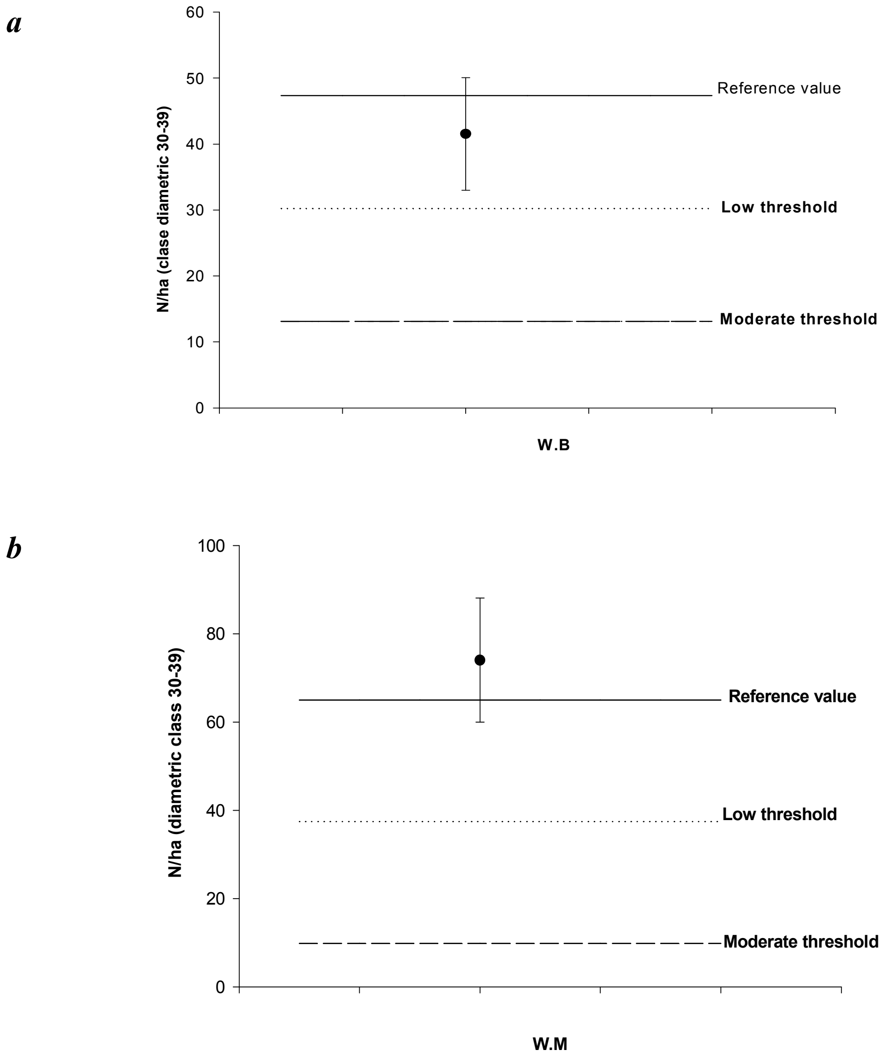
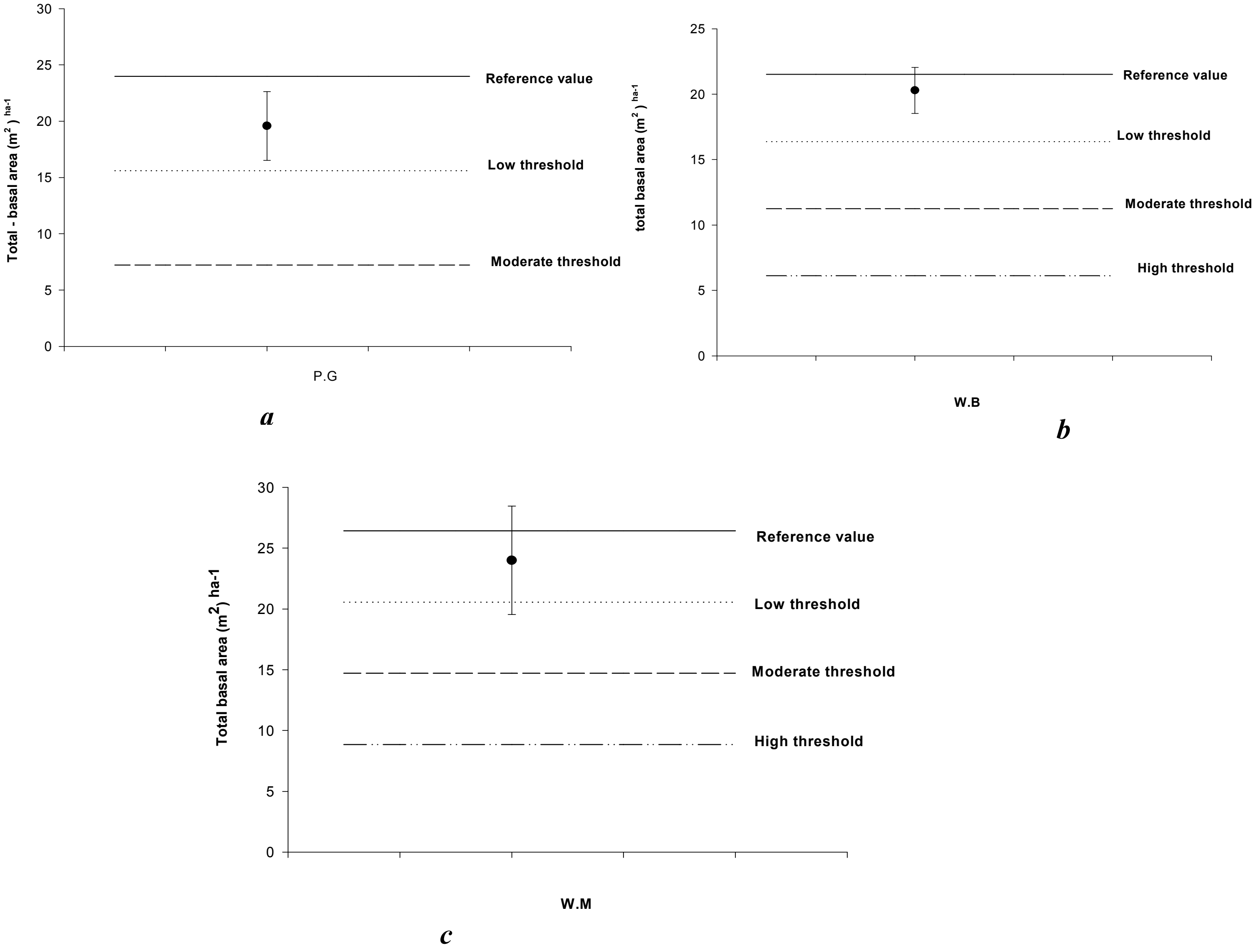


Figure 20. Evaluation of change for the indicator of abundance of trees per hectare for diameter class 30-39 cm –dbh. a- West Botes and b- West Marimba. Dot- mean and vertical bars-confidence interval.

5.3.2 *Total basal area*

For the total basal area, the 95 % confidence interval of the logged areas there was only an overlapped in WM and hence the only unacceptable change for this indicator (Fig. 21 a - c). The recovery of basal area after logging occurs by the growth of remaining trees and new recruitment (Ghazoul and Hellier 2000), which could had occurred in PG and WB. The impacts caused by management activities in these sites can be considered to be within an acceptable change.



a

b

c

Figure 21. a-c. Threshold of change for the total basal area per hecatre. a- PG, b- WB and c- WM. Dot-mean and vertical bars-confidence interval.

5.3.3 Canopy openness of the understory

In figure 22 the mean value and the interval of confidence at 95 % do not overlap with the established trigger and therefore the impact was considered as acceptable.

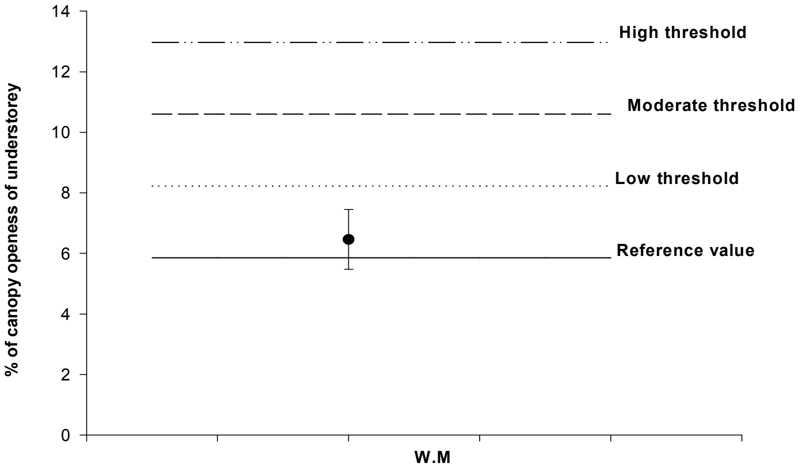


Figure 22. Evaluation of change for the indicator of canopy openness, for WM - RBCMA, Belize. Dot-mean and vertical bars-confidence interval.

Timber harvesting decreases tree density and as a result, creates gaps in the canopy (Crow *et al*. 2002); selective logging tends to eliminate the largest tree (Thiollay 1992).

5.3.4 Vertical structure

5.3.4.1 Punta Gorda

For the 2m– 9m, figure 23a. strata the mean value and the confidence of interval at 95% does not overlaps with the established trigger. Timber harvesting decreases tree density and as a result, creates gaps in the canopy (Crow et. al 2002), when selective logging tends to eliminate the largest tree (Thiollay 1992), this allows more light to reach the forest floor and the understorey becomes denser (Mason 1996). Management impacts were considered to be within acceptable limits.

The figure 23b. strata 10m-20m, the mean and the interval of confidence at 95% of the logged do not overlap with the trigger. Selective logging tends to eliminate the largest tree

(Thiollay 1992), this allows more light to reach the forest floor and the understorey becomes denser (Mason 1996). The management impacts were considered to be within acceptable limits.

For the strata 20m – 30 m, figure 23c. The mean and the confidence of interval at 95% of the logged do not overlap with the established trigger. When logging takes place a large proportion of the mature forest is degraded (Thiollay 1992). This allows more light to reach the forest floor and the understorey becomes denser (Mason 1996). The mean and the confidence of interval do not overlap with the established trigger hence management is considered as acceptable.

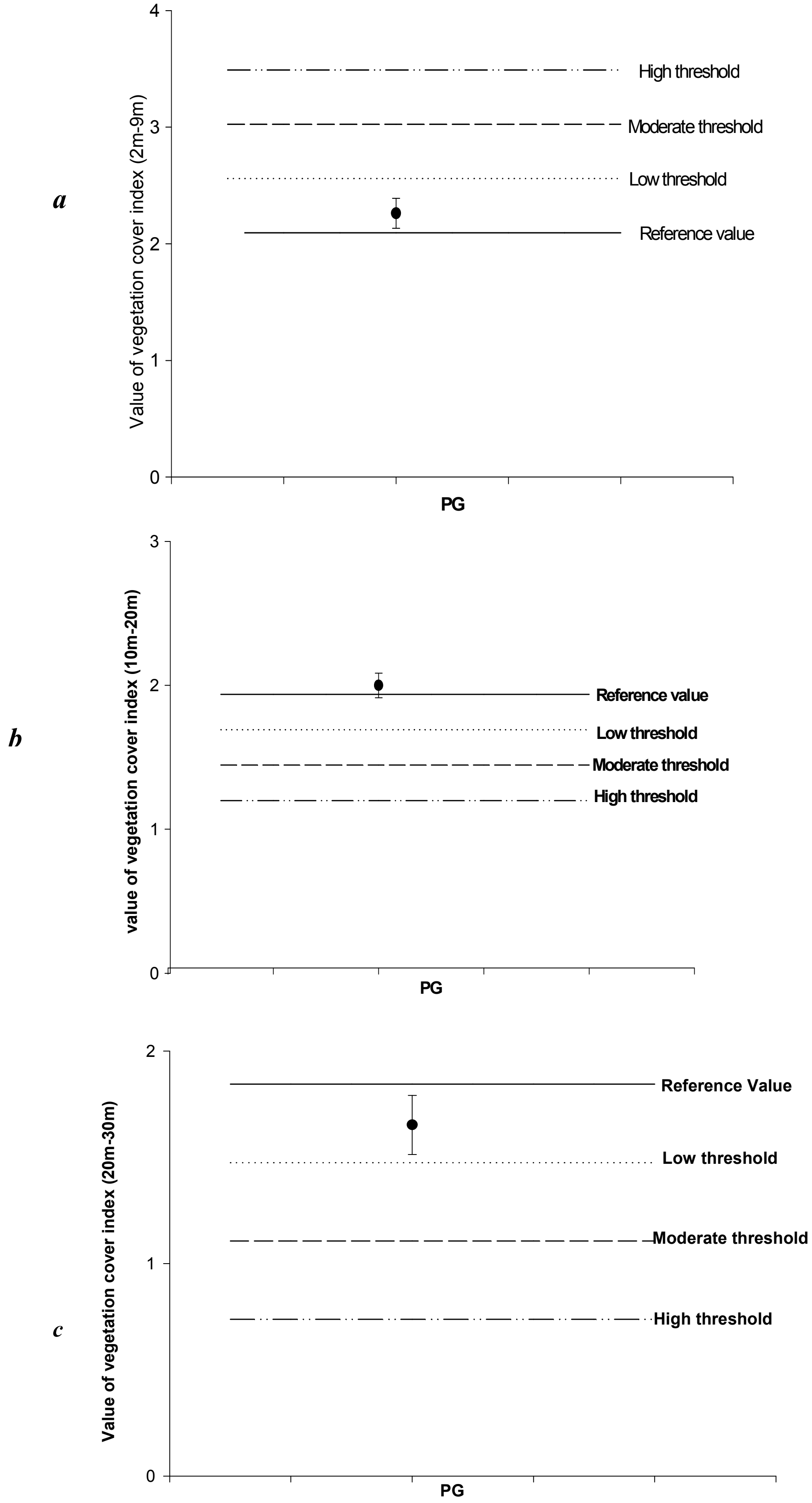


Figure 23. Evaluation of change for the vertical structure indicator for strata for broadleaf forest PG-RBCMA, Belize: a) 2m-9m, b) 10m-20m, and c) 20m-30m. Dots-means and vertical bars-confidence interval.

5.3.4.2 West Botes

For 0m-2m strata (figure 24a) the mean and the confidence of interval 95 % of the logged do not overlap with the established trigger. Timber harvesting decreases tree density and as a result, creates gaps in the canopy (Crow *et al.* 2002), selective logging tends to eliminate the largest tree (Thiollay 1992), this allows more light to reach the forest floor and the understorey becomes denser (Mason 1996).

For strata 2m -9m, figure 24b shows that the impact of the management regime can be considered to be within acceptable changes. The threshold do not overlaps with the established trigger. Timber harvesting decreases tree density and as a result, creates gaps in the canopy (Crow *et al.* 2002), selective logging tends to eliminate the largest tree (Thiollay 1992), this allows more light to reach the forest floor and the understorey becomes denser (Mason 1996)

In figure 24c. for strata 10 m – 20m, the threshold overlaps with the trigger. Therefore the impacts of management activities were within unacceptable limits. During the removable of harvestable timber trees there is high damage involve i.e. trees injured or killed (Sist et al 1998), to the remaining small trees (John 1988) as a result a decline in the number of trees after logging (Primack and Lee 1991).

In figure 24d for the strata 20m -30m the mean value and the interval of coefficient at 95% of the logged forest does not overlap with the established threshold. Impact of management is considered to be within acceptable limits.

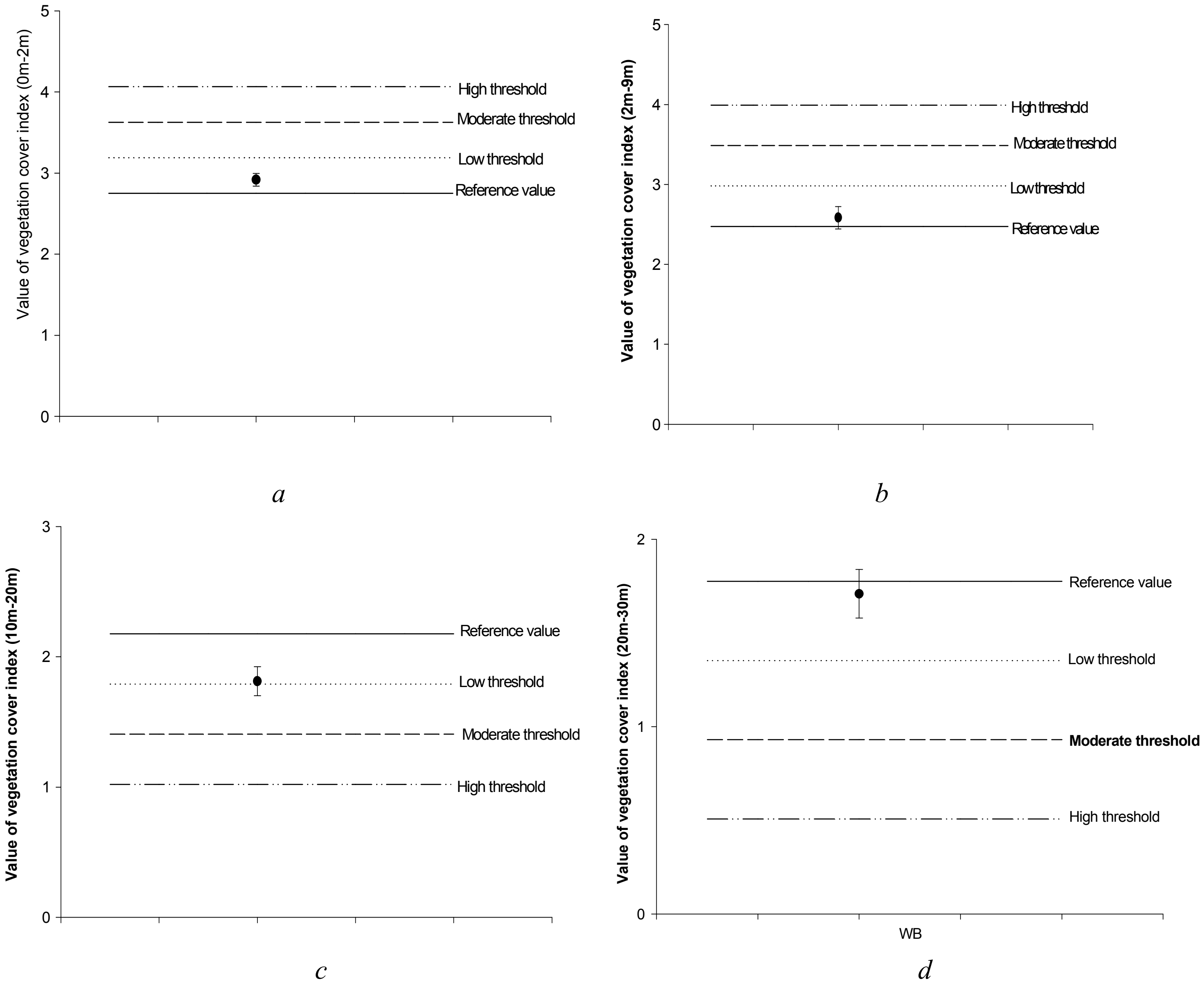


Figure 24. Evaluation of change for the vertical structure indicator for strata for broadleaf forest PG-RBCMA, Belize: a) 2m-9m, b) 10m-20m, and c) 20m-30m. Dots-means and vertical bars-confidence interval.

5.3.4.3 West Marimba

For the strata 0m- 2m, (figure 25a) the threshold does not overlap with the established trigger. The mean and the confidence of interval 95 % of the logged do not overlaps with the established trigger. Timber harvesting decreases tree density and as a result, creates gaps in the canopy (Crow et. al 2002), selective logging tends to eliminate the largest tree (Thiollay 1992), this allows more light to reach the forest floor and the understorey becomes denser (Mason 1996). The impacts of management's activities are within acceptable limits.

For the stratum 2m-9m, (figure 25b) shows that the mean and the interval of coefficient at 95% for the logged site does overlaps with the established trigger, the impacts of management activities are within unacceptable changes. Damage intensity depends mainly on biophysical factors such as the height of the tree (Sist et al 1998) and for this class it was unfavorable.

Strata 10m – 20m (figure 25c) it is observed that the mean value and the confidence of interval at 95% do not overlap with the trigger. The structure of the forest is not greatly altered and the growing stock gradually recovers and tends to become similar to the unlogged forest because of the recovery after selective logging (Pelisser et al 1998).

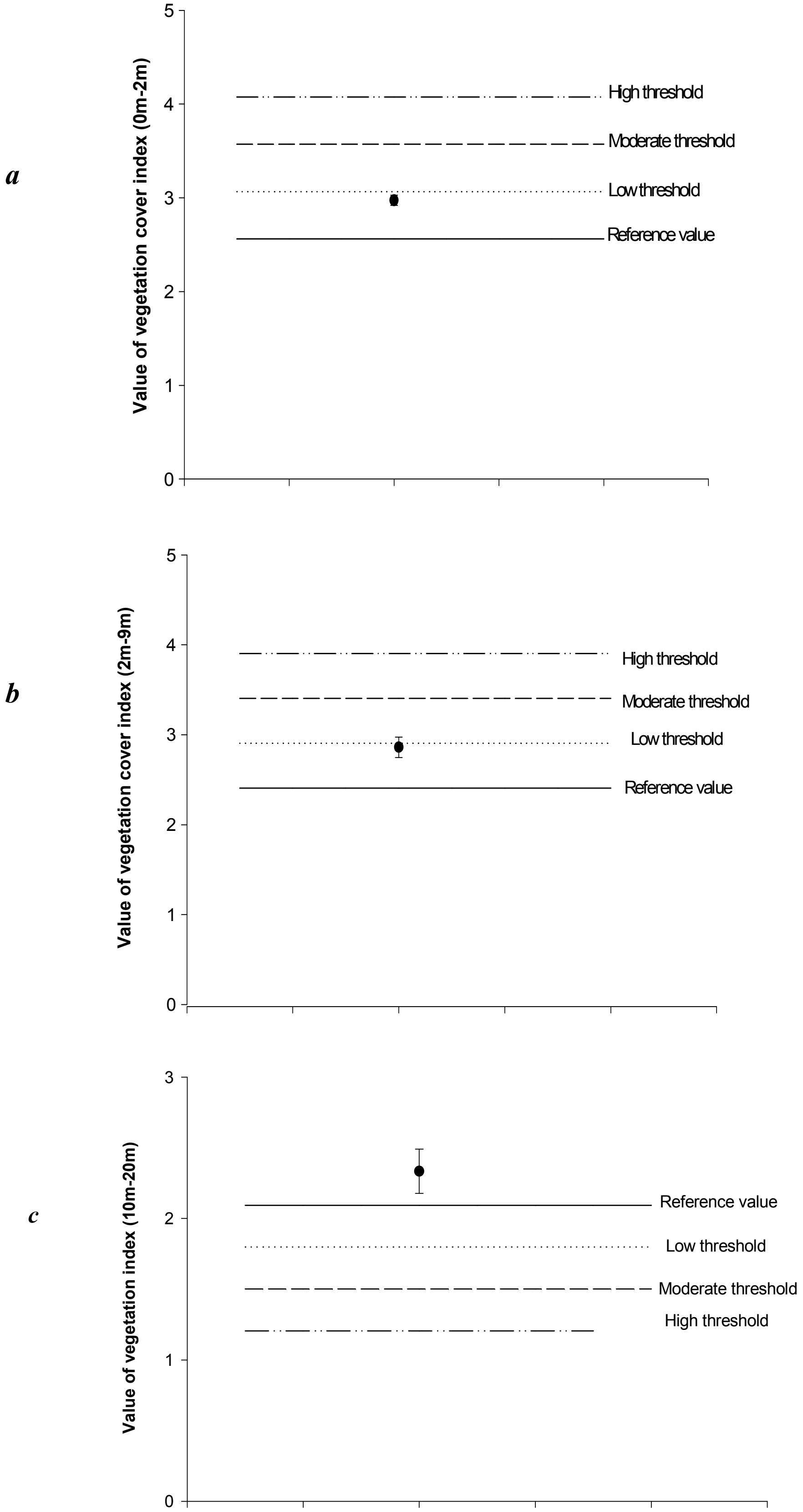


Figure 25. Evaluation of change for the vertical structure indicator for strata for broadleaf forest WM RBCMA, Belize: a) 0m-2m, b) 2m-9m, c) 10m-20m. Dots-mean and vertical bars-confidence interval.

5.3.5 Composition and abundance of palms

The palms are also recognized as an important element of the structure and composition of high value for the fauna, since their fruits constitute an important source of food for many animals of the forest such as birds, monkeys among others. The palms are also one of the principal components of the forest stand and of the understorey of the tropical humid forest (Finegan *et al.* 2004). The ecological importance of the palms makes the setting of the threshold below the mean of the reference value. This is because of the felling of trees during harvesting reduces or affects the palm causing a reduction in their population.

In PG and WM, the most abundant palm species was *Attalea cohune* while in WB, the most abundant species was *Sabal mauritiiformis*.

Possibly the variations could be attributed to the characteristics of the species. More problematic is variability within sites due topography or edaphic conditions which can give rise to different forest formations on local scales (Ghazoul and Hellier 2000); this by nature could lead to the formation of more of a particular species in a site and not as a direct response of management activities.

Similar results were obtained from pervious work carried out in Nicaragua by Ordoñez in 2003. It seems that the palms tend to have a large natural variation and their distribution tend to be related with edaphic conditions. But the role that the palms have in the diet of forest animals makes them an important composition of the forest stand.

5.4 Conclusions

The statistical approach proposed in the Monitoring Guide for the use of thresholds of change and triggers are very useful since this could indicate the need to do certain adjustments on the management regime. This could contribute to the goal of ecological sustainability which infers the conservation of certain key functions and parameters of the ecological system.

The variability of values in terms of standard deviation of a particular indicator is important since in natural undisturbed forest (unlogged) would determine its utility in assessing impacts. Clearly, indicators that generate a set of highly variable results under similar condition are of little value for the assessing impacts. For example, indicators such as the palm abundance (cv105%) and the upper diametric classes of abundance of trees (cv 104%) which by nature presents a high natural variation can not be used for evaluating.

Hence, natural variation and measurability that some indicators have are important to be considered in the use of this approach and therefore it is possible that the approach would not be applicable to all indicators.

For structure and composition of the forest in PG and WB most of the indicators were within acceptable limits while for WM most of the indicators were within unacceptable limits (Annex 5). Therefore again it is recommended that evaluation and monitoring be carried out on each site.

It is important to consider the area of reference when monitoring to established thresholds and also to determine which indicators cannot be used because of its natural variation. Therefore it is necessary to select and identify area of reference and intervene to have similar condition other wise wrong decisions can be taken.

The Monitoring Guide approach served as a useful tool for monitoring since it is based on relatively simple and reliable indicators that indicate the conditions of the forest due to the influence of forest management. This Guide is very useful since it can be easily made for adaptations to specific conditions of the site being monitored in this case RBCMA. Additionally the Monitoring Guide provides essential guidelines for monitoring which is an essential component for the sustainable forest management and for certification.

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6 ANNEX

Annex 1 List of species harvested and minimal cut diameter cut in PG, WB, and WM.

#	Common Name	Scientific name	Minimal diameter cut (MDC)
1	Mahogany	*Swietenia macrophylla*	55
2	Black Cabbage Bark	*Lonchorpus castilloi*	45
3	W. Rosewood	*Dalbergia Stevenson*	45
4	Nargusta	*Terminalia amazonia*	45
5	Belly Webb	*Sweetia panamensis*	45
6	Bullet Tree	*Bucida buceras*	45
7	Bread Nut	*Brosimum alicastrum*	45
8	Zapote Macho	*Manilkara chicle*	45
9	Jesmo	*Lysiloma acapulcense*	45
10	Mexican cedar	*Cederla odorata*	55
11	Jobillo	*Astronium graveolus*	45
12	Santa Maria	*Calophyllum brasilencis*	45
13	Cortes	*Tabebuya Chrysantha*	45
14	Vatairea lundelli	*Vatairea lundelli*	45
15	Yakex	-	45
16	Male Bullhoof	-	45
17	Female Bullhoof	-	45

Annex 2 Vertical structure of vegetation coverage in the four strata for treatments: logged and unlogged for the three sites of study. Mean value of coverage and standard error (***μ***± ***e***).

Strata (m)	**Mean foliage cover index**								
	PG			**WB**			**WM**		
	Logged ***u***± ***e***	Unlogged ***u***± ***e***	**Pr>F**	Logged ***u***± ***e***	Unloggd ***u***± ***e***	**Pr>F**	logged ***u***± ***e***	Unlogged ***u***± ***e***	**Pr>f**
0-2	2.4± 0.07 **a**	2.2 ± 0.01 **a**	0.3272	2.9 ± 0.04 **a**	2.7 ± 0.06 **b**	0.0335	2.9 ± 0.02 **a**	2.5 ± 0.08 **b**	<.0001
2-9	2.3± 0.06 **a**	2.0 ± 0.08 **a**	0.1131	2.6 ± 0.04 **a**	2.4 ± 0.07 **a**	0.3159	2.8 ± 0.05 **a**	2.4 ± 0.08 **b**	<.0001
9-20	2.0 ± 0.04 **a**	1.9 ± 0.04 **a**	0.3319	1.8 ± 0.05 **b**	2.1 ± 0.06 **a**	<.0001	2.3 ± 0.07 **a**	2.0 ± 0.05 **b**	0.0171
20-30	1.6 ± 0.07 **a**	1.8 ± 0.06 **a**	0.0619	1.7 ± 0.05 **a**	1.7 ± 0.06 **a**	0.4842	1.9 ± 0.03 **a**	1.6 ± 0.08 **b**	0.0009
Structural variability	115.8 a	109.9 a	0.9965	104.1 a	101.8 a	0.5399	64.0 a	113.4 a	0.0845

Annex 3a Thresholds of change for each indicator in logged site P.G. Indicators (a) with less than 40% application of protocols of the Monitoring Guide. (b) could not be applied

Indicator	Trigger	Unlogged site CV-P.G	Application of protocols of Monitoring Guide
Total abundance of trees per hectare	Low threshold	15	a
Diameter class abundance 10-19	Low threshold	22	a
Diameter class abundance 20-29	Low threshold	39	a
Diameter class abundance 30-39	Do not apply	72	b
Diameter class abundance 40-49	Do not apply	75	b
Diameter class abundance 50-59	Do not apply	104	b
Diameter class abundance >60	Do not apply	188	b
Total basal area per hectare	Low threshold	34	a
Diameter class basal area 10-19	Low threshold	25	a
Diameter class basal area 20-29	Do not apply	41	b
Diameter class basal area 30-39	Do not apply	71	b
Diameter class basal area 40-49	Do not apply	75	b
Diameter class basal area 50-59	Do not apply	107	b
Openess of understorey	Do not apply	47	b
Vegetation cover strata 0-2m	Low threshold	28	a
Vegetation cover starta 2-9m	Low threshold	22	a
Vegetation cover strata 9-20m	Low threshold	13	a
Vegetation cover strata 20-30m	Low threshold	20	a
Palms abundance per hectare	Do not apply	105	b

Annex 3b Thresholds of change for each indicator in unlogged site W. B . Indicators (a) with less than 40% application of protocols of the Monitoring Guide. (b) could not be applied

Indicator	Trigger	Unlogged site C.V - W.B	Application of protocols of Monitoring Guide
Total abundance of trees per hectare	Low threshold	19	a
Diameter class abundance 10-19	Low threshold	23	a
Diameter class abundance 20-29	Low threshold	38	a
Diameter class abundance 30-39	Low threshold	36	a
Diameter class abundance 40-49	Do not apply	73	b
Diameter class abundance 50-59	Do not apply	113	b
Diameter class abundance >60	Do not apply	108	b
Total basal area per hectare	Low threshold	23	a
Diameter class basal area 10-19	Low threshold	28	a
Diameter class basal area 20-29	Do not apply	41	b
Diameter class basal area 30-39	Low threshold	33	a
Diameter class basal area 40-49	Do not apply	76	b
Diameter class basal area 50-59	Do not apply	113	b
Diameter class basal area > 60	Do not apply	109	b
Openess of understorey	Do not apply	58	b
Vegetation cover strata 0-2m	Low threshold	16	a
Vegetation cover starta 2-9m	Low threshold	20	a
Vegetation cover strata 9-20m	Low threshold	18	a
Vegetation cover strata 20-30m	Low threshold	23	a
Palms abundance per hectare	Do not apply	47	b

Annex 3c. Thresholds of change for each indicador in unlogged site W. M. Indicators (a) with less than 40% application of protocols of the Monitoring Guide. (b) could not be applied

Indicator	Trigger	unlogged site C.V – W. .M	Application of protocols of Monitoring Guide
Total abundance of trees per hectare	Low threshold	14	a
Diameter class abundance 10-19	Low threshold	38	a
Diameter class abundance 20-29	Low threshold	28	a
Diameter class abundance 30-39	Do not apply	42	b
Diameter class abundance 40-49	Do not apply	67	b
Diameter class abundance 50-59	Do not apply	125	b
Diameter class abundance >60	Do not apply	82	b
Total basal area per hectare	Low threshold	22	a
Diameter classbasal area 10-19	Do not apply	42	b
Diameter class basal area 20-29	Low threshold	28	a
Diameter class basal area 30-39	Do not apply	41	b
Diameter class basal area 40-49	Do not apply	67	b
Diameter class basal area 50-59	Do not apply	124	b
Diameter class basal area > 60	Do not apply	86	b
Openess of understorey	Do not apply	40	b
Vegetation cover strata 0-2m	Low threshold	25	a
Vegetation cover starta 2-9m	Low threshold	26	a
Vegetation cover strata 9-20m	Low threshold	19	a
Vegetation cover strata 20-30m	Do not apply	44	b
Palms abundance per hectare	Do not apply	42	b

Annex 4a . Summary of impact of management regime and mean values ± standard Deviation for each indicator for P.G logged.

Indicator	Mean value of unlogged P.G	Mean value of logged P.G	Impact of management regime
Total abundance of trees per hectare	508.3 ± 80.3	402.8 ± 93.2	Do not apply
Diameter class abundance per hectare10-19	313 ± 70.7	191.4 ± 59.4	Do not apply
Diameter class abundance per hectare 20-29	99.1 ± 39.6	104.3 ± 41	Do not apply
Diameter class abundance per hectare 30-39	55.8 ± 40.5	90.7 ± 42.3	Do not apply
Diameter class abundance per hectare 40-49	20.8 ± 15.4	7.9 ± 8.0	Do not apply
Diameter class abundance per hectare 50-59	10 ± 10.44	6.4 ± 10.8	Do not apply
Diameter class abundance per hectare >60	9.1 ± 17.2	2.1 ± 5.7	Do not apply
Total basal area per hectare	23.9 ± 8.3	19.5 ± 5.8	No
Diametric class basal area per hectare 10-19	5.2 ± 1.3	3.3 ± 0.9	Do not apply
Diameter class basal area per hectare 20-29	4.5 ± 1.8	5.0 ± 2.0	Do not apply
Diameter class basal area per hectare 30-39	5.1 ± 3.6	7.9 ± 3.6	Do not apply
Diameter class basal area per hectare 40-49	3.2 ± 2.4	1.1 ± 1.2	Do not apply
Diametric class basal area per hectare 50-59	2.2 ± 2.3	1.3 ± 2.2	Do not apply
Diameter class basal area per hectare > 60	3.5 ± 6.3	0.7 ± 1.9	Do not apply
Openness of understorey	9.7 ± 4.7	1 1.4 ± 2.9	No
Vegetation cover strata 0-2m	2.2 ± 0.6	2.4 ± 0.5	No
Vegetation cover strata 2-9m	2.1 ± 0.5	2.3 ± 0.4	No
Vegetation cover strata 9-20m	1.9 ± 0.2	2.0 ± 0.3	No
Vegetation cover strata 20-30m	1.8 ± 0.4	1.7 ± 0.5	Do not apply
Palms abundance per hectare	64 ± 49.2	135 ± 75.3	Do not apply

Annex 4b Summary of impact of management regime and mean value ± standard deviation for each indicator for W. B logged.

Indicator	Mean value of unlogged W.B	Mean value of logged W.B	Impact of management regime
Total abundance of trees per hectare	480 ± 90.9	517 ± 47.3	Do not apply
Diameter class abundance per hectare 10-19	290 ± 66.1	309.2 ± 39.4	Do not apply
Diameter class abundance per hectare 20-29	110 ± 41.4	142.3 ± 27.4	Do not apply
Diameter class abundance per hectare 30-39	47.3 ± 17.1	41.5 ± 15.7	Do not apply
Diameter class abundance per hectare 40-49	15.3 ± 11.3	9.2 ± 12.5	Do not apply
Diameter class abundance per hectare50-59	10 ± 11.3	11.5 ± 13.5	Do not apply
Diameter class abundance per hectare>60	6.6 ± 7.2	3.8 ± 5.1	Do not apply
Total basal area per hectare	21.5 ± 5.1	20.3 ± 3.2	No
Diameter class basal area per hectare 10-19	5.0 ± 1.4	5.2 ± 0.9	Do not apply
Diameter class basal area per hectare 20-29	4.7 ± 1.9	6.2 ± 1.3	Do not apply
Diameter class basal area per hectare 30-39	4.3 ± 1.4	3.6 ± 1.4	Do not apply
Diameter class basal area per hectare 40-49	2.4 ± 1.8	1.4 ± 1.9	Do not apply
Diameter class basal area per hectare 50-59	2.3 ± 2.6	2.6 ± 2.9	Do not apply
Diameter class basal area per hectare > 60	2.6 ± 2.9	1.2 ± 1.5	Do not apply
Openness of understorey	7.3 ± 4.3	8.8 ± 5.5	No
Vegetation cover strata 0-2m	2.7 ± 0.4	2.9 ± 0.3	No
Vegetation cover strata 2-9m	2.5 ± 0.5	2.6 ± 0.5	No
Vegetation cover strata 9-0m	2.2 ± 0.4	1.8 ± 0.4	No
Vegetation cover strata 20-30m	1.8 ± 0.4	1.7 ± 0.5	Do not apply
Palms abundance per hectare	75.3 ± 35.4	56.2 ± 32.5	Do not apply

Annex 4c. Summary of impact of management regime and mean value ± standard deviation for each indicator for W. M logged**.**

Indicator	Mean value of unlogged W..M	Mean value of logged W..M	Impact of management regime
Total abundance of trees per hectare	453 ± 62.4	370 ± 99.6	Do not apply
Diameter class abundance per hectare 10-19	213 ± 81.5	173 ± 93.9	Do not apply
Diameter class abundance per hectare 20-29	117 ± 33.0	72 ± 25.3	Do not apply
Diametric class abundance per hectare 30-39	65 ± 27.5	74 ± 22.7	Do not apply
Diameter class abundance per hectare 40-49	36 ± 24.1	31 ± 17.3	Do not apply
Diameter class abundance per hectare 50-59	13 ± 16.3	11 ± 5.7	Do not apply
Diameter class abundance per hectare >60	9 ± 7.3	9.0 ± 11	Do not apply
Total basal area per hectare	26.4 ± 5.8	23.9 ± 7.1	No
Diameter class basal area per hectare 10-19	3.5 ± 1.5	2.8 ± 1.6	Do not apply
Diameter class basal area per hectare 20-29	5.1 ± 1.4	3.3 ± 1.4	Do not apply
Diameter class basal area per hectare 30-39	6 ± 2.4	7.1 ± 2.2	Do not apply
Diameter class basal area per hectare 40-49	5.2 ± 3.5	4.5 ± 2.4	Do not apply
Diameter class basal area per hectare 50-59	2.9 ± 3.6	5.6 ± 1.4	Do not apply
Diameter class basal area per hectare > 60	3.3 ± 2.9	3.7 ± 4.9	Do not apply
Openness of understorey	5.8 ± 2.4	6.5 ± 2.9	No
Vegetation cover strata 0-2m	2.6 ± 0.5	2.9 ± 0.2	No
Vegetation cover strata 2-9m	2.4 ± 0.5	2.9 ± 0.4	No
Vegetation cover strata 9-20m	2.1 ± 0.3	2.3 ± 0.5	No
Vegetation cover strata 20-30m	1.6 ± 0.5	1.9 ± 0.2	Do not apply
Palms abundance per hectare	97 ± 40.8	95 ± 34.3	Do not apply

Annex 5. Summary of application of approach Monitoring Guide.

Indicator	Punta Gorda	West Botes	West Marimba
Total abundance of trees per hectare	Unacceptable	Acceptable	Unacceptable
Diametric class abundance per hectare10-19	Unacceptable	Acceptable	Unacceptable
Diametric class abundance per hectare 20-29	Acceptable	Acceptable	Unacceptable
Diametric class abundance per hectare 30-39	-	Acceptable	Acceptable
Total basal area per hectare	Acceptable	Acceptable	unacceptable
Openness of understorey	-	-	Acceptable
Vegetation cover strata 0-2m	-	Acceptable	Acceptable
Vegetation cover strata 2-9m	Acceptable	Acceptable	Unacceptable
Vegetation cover strata 10-20m	Acceptable	Unacceptable	Acceptable
Vegetation cover strata 20-30m	Acceptable	acceptable	-
Palms abundance per hectare	-	-	-
Total	7	9	9
Acceptable	5	7	4