ASSESSMENT OF CHANGES IN LAND COVER AND FOREST COMPOSITION AND STRUCTURE IN OKONGO COMMUNITY FOREST, NAMIBIA

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Thesis submitted in partial fulfilment of the requirements for the degree of Master of Natural Resources Management at the Namibia University of Science and Technology

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JANUARY 2020

Declaration

I, Agnes Shikomba, hereby declare that the work contained in the thesis entitled: Assessment of changes in land cover and forest composition in Okongo Community Forest, Namibia is my original work and that I have not previously in its entirety or part submitted it at any university or higher education institution for the award of a degree.

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List of Acronyms

AOI	-	Area of Interest
BAIPL	-	*Baikiaea plurijuga*
BURAF	-	*Burkea africana*
BA	-	basal area
CFs	-	Community Forests
CO_2	-	Carbon Dioxide
CBRM	-	Community–Based Natural Resource Management
COMCO	-	*Combretum collinum*
COMAA	-	*Combretum apiculatum*
COMPS	-	*Combretum psidioides* (psidioides)
COMZE	-	*Combretum zeyheri*
DBH	-	Diameter at Breast Height (1.3 m)
DoF	-	Directorate of Forestry
DED	-	German Development Service
EIS	-	Environmental Information Services
ETM+	-	Enhanced Thematic Mapper sensor
FAO	-	Food Agricultural Organisation
GPS	-	Global Positioning Information Systems
GIS	-	Geographic Information Systems
GNP	-	Gross National Product
GDP	-	Gross Domestic Products
GUICO	-	*Guibourtia coleosperma*
K	-	Potassium
KfW	-	German Development Bank
MAWF	-	Ministry of Agriculture Water and Forestry
MET	-	Ministry of Environment and Tourisms
Mg	-	Magnesium
N	-	Nitrogen
NACSO	-	Namibian Association of Community Based Natural Resource Management Support Organisation
NAFOLA	-	Namibia's Forested Lands
NIR	-	near-infrared
NTFPs	-	Non-Timber Forest Products
N$	-	Namibian Dollar
OLI	-	Operational Land Imager
P	-	Phosphorus
PTEAN	-	*Pterocarpus angolensis*
PRA	-	Participatory Rural Appraisal
QGIS	-	Quantum Geographical Information System

SASSCAL-		Southern African Science Service Centre for Climate Change and Adaptive Land Management
SFM	-	Sustainable Forest Management
SOC	-	Soil Organic Carbon
TIRS	-	Thermal Infrared Sensor
TERSE	-	*Terminalia sericea*
TA	-	Traditional Authority
TAC	-	Total allowable cut
US$	-	United States of American Dollar
WWF	-	World Wide Fund for Nature

Acknowledgements

Appreciation goes to the GIZ-Bush Control and Biomass Utilization project for funding the study and the Directorate of Forestry for entrusting me to be amongst the beneficiaries of De-bushing funds. Furthermore, I would like to acknowledge the following people and institutions for their contribution to the successful completion of this study:

- Dr. Vera De Cauwer (Namibia University of Science and Technology), my supervisor for her support and guidance she gave me over the past two years on this study. I thank her for the love, patience and the help she gave me on how to use GIS.
- My co-supervisor, Dr. Jonathan Kamwi (Namibia University of Science and Technology) for mentorship and encouragement that helped me to complete this study and help me how to use FRAGSTAST.
- Dr. Ben Strohbach, the programme coordinator (Namibia University of Science and Technology) for always sharing relevant information that contributed to my study and for always keeping his office door open.
- The fellow students of the Department of Agriculture and Natural Resources for their motivation and support whenever this was required.
- The colleagues of the Directorate of Forestry in particular at the Forest National Inventory team for their assistance on retrieving inventory data from the forestry inventory database.
- I would like to thank my extended family, specifically, my aunt, Ms Victoria Igonda Nangombe Petruttis and her beloved husband, Mr Manfred Petruttis for their support and encouragement during my studies.
- To my mother, Ms Lundovika Toopeka Nangombe who has been praying for my success and achievement. Her encouragement helped me to achieve my goals.
- To my siblings, thank you for helping me to complete my study. You are always the best!

Dedication

This project is dedicated to my mother, Ms. Lundovika Nangombe Toopeka and my greatest aunty Ms. Victoria Igonda Nangombe Petruttis. It is a special dedication to them because of the support they gave me when I was working on this project.

Abstract

Land cover refers to the observed vegetation, structures, or other features that cover the land such as closed forests, open forest, woodland, grasslands, bushland, and settlements. Land cover change is one of the serious threats to the forests and woodlands of Namibia, and it is mainly triggered by forest resource utilization and conversion to agriculture by local communities. As one of the mechanisms to control land cover change, Namibia introduced the Community Forests (CF) programme for local communities to own, manage and use forest resources sustainably. Therefore, this study assessed changes in land cover in Okongo Community Forest (CF) in Namibia for the period 2003 – 2017 by comparing the Okongo CF with the areas outside Okongo CF. The study also monitored major changes (trends) in forest composition of Okongo CF since it was gazetted. The study area is situated in the Okongo constituency in the eastern part of Ohangwena region and includes Okongo CF, Omufitu Wekuta CF, within Okongo Conservancy. The study area was divided into five sub-areas - Okongo CF, Omufitu Wekuta CF, the central buffer zone, the buffer east and the buffer west to compare the land cover change. The study adopted a mixed approach by analysing land cover on satellite images (2003 Landsat 7 satellite imagery and 2017 Landsat 8 satellite imagery) and forest inventory data for 2000 and 2015 derived from the National Forest Inventory database. The satellite image data collected were analysed quantitatively using a GIS and FRAGSTATS technology for landscape metric calculations. The inventory data were entered and organised in Excel. Trees were placed in diameter at breast height (DBH) classes and the stem density, mean DBH, and basal area of all measured trees were determined. DBH distribution was studied for the timber species such as *P. angolensis, B. plurijuga, B. africana and G. coleosperma*, as well as stem densities and basal area per ha.

The main land cover changes that occurred for the period 2003 – 2017 between Okongo CF and areas outside Okongo CF include a decrease of forest/shrubs land in three of the five sub-areas: the buffer west (-4.7%), Omufitu Wekuta CF (-4.6%), and the central buffer zone (-6.9%). Forest cover remained close to the same in Okongo CF (0.2 %) and the eastern buffer (-0.01%). An increase in bare land was found in the buffer east of the study area (260.1%) and Omufitu Wekuta CF (557.7%). However, the Okongo CF showed more declined in bare land (-98.1%) than other parts of the study area. About 0.67% of the study area was converted to settlements area and this includes part of Okongo, Omufitu Wekuta CF and the central buffer zone. As for human activities, it is agriculture that showed an increase in all areas with much increase experienced in the buffer west (77.3%), Omufitu Wekuta CF (85.1%) and the central buffer zone (113.1%) of the study area. The study found that the eastern part of the study area (includes Okongo CF and the

buffer east) shows hardly change in forest/shrubs cover and agriculture. The FRAGSTATS analysis of landscape metrics for landscape structure and patterns Spatio-temporal fluctuations showed that patch density generally increased for nearly all land cover classes except for bare soil (80 ha). Largest patch index decreased for forest/shrubland (94.2%) as compared to other land uses and the interspersion and juxtaposition index (IJI) decreased for forests/shrubs land (15%) and bare land (1%) while it increased in agriculture land (9%).

The study found that the mean DBH of all measured tree species in 2000 inventory was significantly higher than the mean DBH of 2015 inventory (p-value = 0.003). There were no significant differences in the distribution of frequencies of timber tree species between the 2000 and 2015 inventories (U=44.5, p=0.684). This study found a significantly lower count of 250 stems per hectare for the 2000 inventory as compared to the 2015 inventory with 300 stems per hectare (p-value = 0.021). The study found that the mean DBH of timber species (*P. angolensis, B. plurijuga, B. africana and G. coleosperma*) in 2000 and 2015 was not significantly different (p=0.875). There was no significant difference between the basal cover of 2000 and 2015 inventory (p-value = 0.737).

It is concluded that the Okongo CF experienced a positive and favourable decrease in bare land class and area converted to bare land in comparison with the other parts of the study area. The study also concluded that there is a favourable increase in an area that was converted to forest/shrubs land compared to Omufitu Wekuta CF, the buffer west and the central buffer zone. Another small patch of an area of the Okongo CF was converted to agricultural land and settlements whereas the remainder of the area remains forest/shrubs land. This suggests that there has been sustainable land use management in Okongo CF since its gazettement in 2006. Considering the effects of changes in areas outside Okongo CF, it was recommended that the Government must consider extending strategies employed in Okongo CF to Omufitu Wekuta CF to realise positive gains, introducing indigenous forests plantations and educating people to increase awareness on the importance of conserving forests.

Keywords: Community forest, Forest composition, Land cover, Patch density, Tree inventory, Woodland.

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background

Land cover is defined as the 'observed (bio) physical cover on the earth's surface' (Di Gregorio 2005). According to Adepoju (2007), land cover refers to the vegetation, structures, or other features that cover the land such as closed forests, open forest, woodland, grasslands, bushland, and settlements. When considering land cover in a very pure and strict sense it should be restricted to describe vegetation and man-made features (Mannion 2002). Mannion (2002) additionally states that it is also describing the components that are characterizing the earth surface. These components comprise plants as units of vegetation or ecosystem soils, sediments, water and the built environment. Land cover is dynamic, which means changes is occurring constantly on a temporal and spatial as a consequence of natural stimuli (Mannion 2002).

Timely and precise information on land cover changes of earth's surface is extremely important for understanding relationships and interactions between human and natural phenomena for better management of natural resources and in decision making (Yesmin *et al.* 2014). Land cover change is a widespread process that is driven by human activities and natural phenomena (Kamwi *et al.* 2017b). Human drivers are mainly agricultural activities, the increasing of population densities and hence settlement areas, and illegal logging. Changes of land cover have serious environmental, economic and social impacts on rural livelihoods in most parts of the sub-Saharan African region (Maitima *et al.* 2010).

Forests cover nearly one-third of the world's land area. They provide vital environmental services such as soil and water protection, regulate the climate and preserve biodiversity, produce valuable raw materials and food, and sustain the livelihoods of millions of people (Karpatne *et al.* 2012). Namibia's vegetation types are divided into savannas (64%), desert (16%) and woodlands (20%). Namibia's forests consist of over four hundred species of plants of which 10% are woody species. Forest and woodlands together cover 20% with forests alone covering less than 10 % of Namibia's total land area of approximately 823,680 km^2 with timber resources confined and patchily distributed in the Northern regions (Mogaka 2001, Mendelsohn and Obeid 2005). The increase in population density in the northern part of Namibia is causing pressure on land and other natural resources because more people are using forest resources, especially firewood, poles and droppers for fencing and household construction (Kuvare *et al.* 2008). Namibia had a total woodlands area of 12.4 million ha in 1990, this was about 15% of the total land area (Erkkilä 2001). Furthermore, it was estimated that these woodland forests disappeared at a rate of 43 000 ha per year. Ten years later, forests accounted for

9.8% of the total land area (Watts 2003). Woodland savannah area decreased in north-eastern Namibia from 90% in 1975 to 83% in 2014 and then increased to 86% in 2014, while agricultural land increased from 6% to 12% between 1975 and 2014 (Wingate *et al.* 2016). Furthermore, the study found that for all regions apart from the Zambezi Region, agriculture is the third-largest contributor to the land cover transition. The study also found that most land cover changes occur in the communal area followed by state-protected land. Another study by (Wingate *et al.* 2016) on "Mapping Decadal Land Cover Changes in the Woodlands of North-Eastern Namibia" found that more woodland was cleared in Kavango communal areas where 26140 ha were cleared in 1943, then 72100 ha (1.48%) in 1972 and 194550 ha in 1996 (3.99%). A total of 122440 ha of communal land was cleared for crop production in the Kavango Region from 1943-1996 (Erkkilä 2001). Furthermore, land clearing along the Okavango River is still ongoing and is caused by factors such as new access routes and drilling boreholes by the government (Pröpper *et al.* 2010) .

Community Forestry (CF) is one of the programmes of the Directorate of Forestry (DoF) and is a component of Namibia's Community-Based Natural Resource Management Programme (CBNRM) (NACSO 2015). It aims at supporting and empowering local communities through transferring rights to manage forest resources and to benefit from related income and employment opportunities. The programme contributes to Namibia's national development objectives of poverty reduction, employment creation, economic empowerment and enhanced environmental and ecological sustainability as outlined in Article 95 (1) of the Constitution, Namibia's Vision 2030 and the National Development Plan III (MAWF 2012). CF in northern Namibia is threatened by the reduction of forest cover affecting habitats, carbon sinks capacities, and hydrological and nutrients cycles (Schick *et al.* 2014).

Uncontrolled fire is declining tree regeneration, killing older and larger trees and this leads to the loss of valuable vegetation in the area (Schick *et al.* 2014). The MET (2007) stated that 'renewable resources must be used sustainably for the benefit of present and future Namibian generations. The community involvement in natural resources management and sharing benefits arising from the use of the resource must be promoted'. Additionally, MET said that any activity that is causing damage to the environment must be reduced and controlled. Information on the land cover helps in monitoring land dynamics resulting from fires and the changing demands in forest resources (Adepoju 2007), and aids sustainable forest management. Deforestation and changes in forest composition directly drive land cover change. This study will be assessing the change in land cover and forest composition of the Okongo CF since it was gazetted. It will also examine where the land cover changes are most prevalent (hotspots) over the period 2003-2017. The information regarding vegetation cover change is essential for the communities benefiting from community forest resources as well as the DoF. Depending on the extent and causes of the changes, management can develop plans and strategies to address land cover change within the community forest. If the change is caused by overharvesting, management can formulate restrictions on harvesting and if it concerns uncontrolled fire, the development of fire management plans/strategies should be introduced. This study is also looking at the impact of the existing management plan for Okongo and extract lessons relevant for community forest resource management.

1.2 Problem Statement

Land cover change is one of the serious threats to the forests and woodlands of Namibia, and it is mainly triggered by forest resources utilization and conversion to agriculture by local communities. To tackle the challenge of land cover change and forest ownership and management, the Directorate of Forestry (DoF) introduced the programme of Community Forests (CF). One of the aims of the CF programme of Namibia is that local communities sustainably use forest resources. For this reason, each CF has a forest management plan that should ensure sustainable forest resources use. Considering the relatively recent start of the CF programme, it is however not known whether CFs actually succeed in Sustainable Forest Management (SFM) and hence in protecting land cover and forest composition. Okongo CF was declared among the first CFs, with implementation starting in 2000 and gazetting as a CF in 2006 (Mulofwa *et al.* 2002) and lessons can be learned from its early experience under community management. This research seeks to assess whether the declaration of Okongo CF has managed to protect the forest cover and composition.

1.3 Objectives of the Study

This research study aims to evaluate how the declaration of community forests can influence land cover and forest composition with a case study in one of the oldest CF's of Namibia, Okongo.

The research objectives are:

1.3.1 To compare land cover changes for the period 2003 – 2017 between Okongo CF and areas outside Okongo CF, especially the remaining part of the Okongo conservancy, which includes Omufitu Wekuta CF (declared in 2013);

1.3.2 To identify and assess areas where the land cover changes are most prevalent (hotspots) and examine the Spatio-temporal changes in landscape composition and configuration between 2003 and 2017 in Okongo CF and areas outside Okongo CF;

1.3.3 To monitor major changes (trends) in forest composition of Okongo CF since it was gazetted.

1.4 Research questions

1.4.1 How does land cover changes for the period 2003 – 2017 in Okongo CF compare with areas outside Okongo CF, especially the remaining part of the Okongo conservancy, which includes Omufitu Wekuta CF (declared in 2013)?

1.4.2 Where are land cover changes most prevalent (hotspots) in Okongo CF and what are the Spatio-temporal changes in landscape composition and configuration between 2003 and 2017 in Okongo CF and areas outside Okongo CF?

1.4.3 What are the changes in species and structural composition for 2000 and 2015?

1.5 Limitation of the research

In May 2000, the main source of GPS error was selective availability and this added errors to the GPS accuracy. This refers to deliberate errors induced by the U.S. Department of Defence which restricted high potential accuracy to those authorized by the U.S. military. So, a possible limitation to this study is the accuracy of the Global Positioning Information System (GPS) since the GPS error was 50 meters of error horizontally and 100 meters vertically to the GPS signals during 2000 when the initial inventory was conducted. The study was also delayed due to some financial constraints, so it could not be accomplished on time.

1.6 Significance/Justification of the research

Vegetation provides a vital role in environmental protection and rehabilitation. It contributes to water catchment management, carbon sequestration and storage, nutrient cycling, improve soil fertility, erosion management and landscape protection, promotion of agricultural production, animal habitat and maintenance of ecological and ecosystem processes' (FAO 2014a). However, changes in land cover often concern a reduction in vegetation, contributing to the higher emission of carbon dioxide (CO_2) in the atmosphere (UNDP/GEF 2014). The higher carbon emission increases the environmental temperature which can cause the reduction of forest cover and extinction of some species. According to MAWF (n.d.), the forest is a vital natural resource in Namibia that provides wood and non-wood forest products (NWFP) to communities. Without forests, large areas in Namibia would become degraded and local communities in those areas would suffer in various ways.

According to Barnes *et al.* (2010), Namibia's forest use directly contributed approximately N$ 1 billion (US$ 160 million)to the Gross National Product (GNP), some 3 % of GNP. Namibian's standing forest was estimated to have a capital value of N$ 19 billion (US$ 304 million) as it was compared with values for minerals, wildlife and fish. Apart from that, the Namibian rural population is also benefiting from direct values derived from the use of natural shrubland and woodland resources in the form of firewood, droppers and poles for construction of homesteads and fences. The other forest plants products are non-timber forest products (NTFPs), most of which are harvested for home consumption by rural households. These include plant products for craft production (carving, basket-making), plant fruits, plant products for medicine and cosmetics and grass for thatching.

The study will allow evaluating the sustainability of forest resources use and the rate of land cover change in a CF since its gazetting. This information can assist in fine-tuning the community forestry programme where needed, thereby contributing to Namibia's Forested Lands (NAFOLA) projects overall objective to reduce pressure on natural resources from competing for land uses in the wider landscape (MAWF n.d.). The output of this study could be used as resource material for schools and universities to educate students about land cover changes and their effects on forests and other landscapes.

1.7 Thesis outline

The thesis is composed of six chapters as outlined below

Chapter 1: General Introduction – Introduces the study, gives a brief background of the study and outlines the research objectives and the research questions. The chapter also provides limitations of the research and the significance of the research.

Chapter 2: Literature review – It reviews the literature related to the research study as a secondary research based on published data on the research topic. The chapter also reviews the findings of similar research studies.

Chapter 3: Methods – The chapter describes and explains the research approach, the research design and the methods employed to collect primary data from the field.

Chapter 4: Results and Discussions – The chapter presents, and interprets the results of the analysed primary data and discuss the results of the study by linking them to the literature review where applicable.

Chapter 5: Conclusion – The last chapter concludes the research study based on the findings of the primary research and the literature reviewed. The chapter also gives recommendations for future action based on gaps identified on conclusions.

CHAPTER 2: LITERATURE REVIEW

2.1 Importance of forests and woodlands in northern Namibia

Forests and woodlands play important roles in the livelihoods and local cultures of many societies, especially in developing countries where direct dependence of poor households on natural resources is high (Fotso 1998, Flower and Rooyen 2001). The woody vegetation is used as fuel and poles for construction of houses, fences and livestock pens. The Non-Timber Forest Products (NTFPs) include mushrooms, wild leaves, resin-exuding plants bark and roots for traditional medicine, fruits, seeds, and leaves grasses and are used as animal forage (Gundy 2003). As compared to woody vegetation, some of the important NTFPs that are used in other countries are such as fruits (Zambia, Swaziland, and Mozambique), medicinal plants (Zambia, South Africa, Mozambique, Zimbabwe and Malawi), mushrooms (Zambia, Malawi) and roots and tubers (Mozambique, Zambia) (Sola 2011) are similar to those that are used by the local communities in Namibia.

Woodlands provide shade that allows animals to use less water to cool themselves and to expend less energy in producing metabolic water and panting. However, in the absence of shade, many animals would die if they were exposed to high temperatures for a long period because proteins break down under conditions of extreme heat (Mendelsohn and Obeid 2005). The woody plants themselves add a diversity of species and then create conditions that enable diverse other species to live there as well, thus why forests and woodlands are said to be major contributors to biodiversity (Mendelsohn and Obeid 2005). Forest provides habitats for many other living organisms, and this is where they find water, food, and place to nest, sleep or hide.

2.1.1 Socio-economic importance of forests and forest industries

An estimate of about 1.6 billion people of the world's population relies on forest resources for their livelihood (FAO 2014a). Also, the forest products industry alone is a major source of economic growth and employment, with global forest products traded internationally in the order of US$ 255 billion in 2011. However, 40 % of this value is generated in developing countries, where forest-based employment provides forty-nine million jobs (FAO 2014a). Furthermore, the forest sector is a major provider of rural employment in many countries, especially in many African countries. The World Bank has estimated that about one billion people worldwide depend on drugs derived from forest plants for their medicinal needs (FAO 2014a). In various African countries, fuelwood is the major source of energy. Harvesting of NTFPs from forests provides income-earning opportunities for women in particular. Trees have an extremely important role in supporting agricultural production by providing shelter, shade, soil structure and fertility improvement, declining erosion and alleviating floods, and providing materials such as fencing, processing equipment and tools. Forests also have an essential role in mitigating poverty in times of hardship and crop failure, for example by providing fuelwood when other fuels are inaccessible (FAO 2014a).

In Namibia, the forest sector is only measured for its contribution to the commercial timber industry excluding all other values. Therefore, its economic contribution is not fully reflected in the calculation of the Gross Domestic Products (GDP) (Kojwang 2000). Namibia's forests provide browse and grazing for livestock farming and are important to the tourism industry since they create valuable territories for game animals. The most economic trees species that can be sold in the urban areas are *Pterocarpus angolensis, Baikiaea plurijuga, Burkea africana* and *Guibourtia coleosperma*. NTFP's are also an important food and income for the population. The NWFPs play an important role in day to day life for many rural communities in Namibia. They received considerable interest from various stakeholders, due to their economic and nutrition values. They are also globally recognised for their contribution to improving rural livelihood by providing food, nutrition and medicine, and by generating employment, revenues and foreign exchange earnings. Today there are several NWFPs traded in informal as well as informal markets include fruits and their by-products. The NWFPs such as marula oils for food and cosmetic and devils' claw for medicine have gained access to the international market. NTFP include fruits from *Schinziophyton rautanenii* (Omanghete), *Strychnos cocculoides* (Omauni), *Ziziphus mucronata* (Omukekete), *Ximenia spp* (Oshipeke), *Strychnos pungens* (Omupwaka), and *Vangueria infausta* (Eembu). The Omanghete nuts can be eaten raw or smashed as a sauce to be eaten with porridge. Omukekete bears the fruits that are used for brewing ovambo liquor (Ombike). The Omauni fruits are eaten unprocessed and are the most preferred forest product for the indigenous people. Eenmheke, the fruits of Oshipeke, are used to make soft drinks and can also be eaten mixed with milk (DRFN 1997). Additionally, thatching grasses are used for the construction and renovation of huts. The forestry sectors social input relies on fuelwood and NWFPs contribution, which are the focal origin of domestic energy for the majority of people and an important source of food security and income generation (FAO 2013).

2.1.2 Environmental values of forests

Forests and woodlands have a spiritual role in some other areas as sanctuaries for traditional worshipers. They also increase the attractive beauty of rural landscapes; contribute to the reduction of soil/wind erosion and in regulating air pollution in the urban area. Forests conserve biodiversity by providing habitats for many plant and animal species. They protect watershed as well as watercourses and this is contributing to water quality and quantity. The forests and woodlands of Namibia contribute to desertification control by preventing soil losses that are resulting from wind and water erosion (FAO 2013).

2.2 Forest in Namibia

Namibia has different vegetation types that include woodlands and forests. (Sola 2011) described Namibia's vegetation types as mopane savannah, semi-desert and savannah transition and dwarf shrubs savannah (Parviainen 2012). According to (FAO 2000), the woodland refers to the land that has a canopy cover from 5-10% that is capable to the extent a height of five meters. FAO defined forest as land covered by trees with a canopy cover of more than 10 % and higher than 5 m (FAO 2000). However, according to (FAO 2000) definition, the forest in Namibia can only be found in the northeast of the country that has a higher annual rainfall (Figure 1). They include forests in the Zambezi, Kavango, eastern Ohangwena regions, as well as the hills around Tsumeb, Otavi and Grootfontein. Namibia is a semi-arid country, 40 % of the country is covered by desert and shrubland, 50% of the country is covered by woodland and approximately 10% is forest (Mendelsohn and Obeid 2005). Woodlands and shrubs occupy most of the area south and west of the forested land. Desert and shrubland cover the south-western region of Namibia (Figure 1).

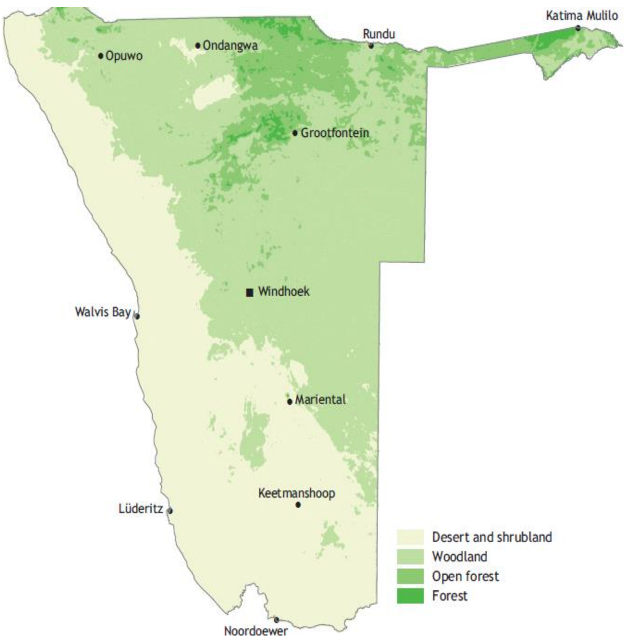

Figure 1:Forest and woodland coverage in Namibia (Mendelsohn and Obeid 2005)

2.3 Forest cover change and drivers of change

The world's total forest area is just over 4 billion hectares, with the five most forest-rich countries (the Russian Federation, Brazil, Canada, the United States of America and China) accounting for more than half of the total forest area(FAO 2014a). Loss of forest cover will almost certainly continue to be a problem while the world's population continues to increase (FAO 2014a). Furthermore, the rate of loss of forest cover is mainly from the conversion of tropical forest to agricultural land. Clearing land for agriculture mainly affects the topsoil (Elberling *et al.* 2003). Other studies found that clearing land for agricultural activities results in a loss of soil nutrients such as Nitrogen, Potassium, Phosphorus and Magnesium (N, P, K, and Mg), decrease in soil fertility and loss of concentrations and stocks of soil organic carbon (SOC). However, about thirteen million hectares of forest were converted to other uses each year between 2000 and 2010, compared with sixteen million hectares per year in the 1990s. Most forest losses in the period 2000-2010 occurred in the regions and countries with more biodiversity-rich tropical forests. Globally, Africa is the second region with the largest loss of forests of 3.4 million hectares annually after South America which has a loss of 4 million hectares. For example, forest cover in Ethiopia has diminished with more than 50 % in the twentieth century (FAO 2014a).

During 1990 to 2000 it was estimated that dry forest and woodland countries in sub-Saharan Africa lost nearly 5 million hectares of forest cover annually in 2000 (FAO 2005). The causes of woodland cover degradation and loss in semi-arid Africa are overgrazing, agricultural expansion and overexploitation of forest resources (Kigomo 2003). The large areas of dry forest of southern Africa have now been reduced to wooded grassland or secondary grassland with scattered forest trees after destruction by humans and fire (Chidumayo and Gumbo 2010). Namibian forests and woodlands have reduced rapidly in the past decades, specifically in the northern parts of the country (Erkkilä and Siiskonen 1992).

Major threats to forests in Namibia include the expansion of land for agriculture, the cutting of wood for fuel and domestic use, clearing for infrastructure development, forest fires, selective logging through timber concessions and unlicensed curio carving and habitat destruction by elephants (Ruppel and Ruppel-Schlichting 2013). Namibian forests and woodlands have reduced rapidly in the past decades, specifically in the northern parts of the country (Graz 2004). The per cent of land covered by forests in Namibia has reduced from 8.8% in 2010 to 8.4% in 2019 (FAO 2014). This is 15% less than the percentage reported by FAO in 1990 (FAO 1990, FAO 2014b) However, the current estimates may not be correct as these results were based on extrapolations of old data. The difference in definitions of what is considered a forest can cause misinterpretations. For example, the vegetation maps (derived from SPOT) include savannah classes, defined as areas with more than 10% bush cover and trees of 2m to 5m in height. In the FAO reports for Namibia, 35% of these classes are converted to the forest without indicating the reasons (De Cauwer 2015). Kamwi *et al.* (2017b) found that in the communal areas of the Zambezi region forest land declined in 1984-1991 and increased in 1991-2000 and 2000-2010. Kamwi *et al.* (2018) further state that in the Zambezi region, the shrubland increased between the yea 1984-1991 and 1991-2000 and declined from2000 to 2010. Crops/grassland became greater than before during 1984-1991 and decreased from 1991 to 2000 and 2000-2010.

2.3.1 Forest Fires

Fire is one of the main driving forces of the land cover changes. According to Bowman and Artaxo (2009) fire is a biogeochemical agent influencing forests and woodland structure and carbon cycling. According to a study done by Giardina *et al.* (2000), it is found that fire does have a severe impact on nutrient cycling; specifically, carbon and nitrogen are lost to the atmosphere. However, one-third of the global gross carbon dioxide emissions released by fires are attributed to fires of African savannah (FAO 2007). Additionally, fire has a profound impact on species composition and vegetation structure. Furthermore, fire is one of the main problems that the woodland managers in Southern Africa deal with. African savannahs account for more than half of the annual burned area (Mouillot and Field 2005). According to a study done by Furley *et al.* (2008), in Miombo woodlands, several long-term fire experiments have shown fire to be of critical importance in determining woody cover. These long-term plot-scale experiments have shown that, under annual burning, Miombo woodland is converted to grassland and in the absence of fire, miombo starts to form closed-canopy forest (Furley *et al.* 2008). Hundreds of trees are lost each year due to forest fires in various portions of the country. This happens due to extreme warm summers and milder winters. Fires, whether caused by man or nature, result in huge loss of forest cover. It is recorded that about 14% of the land area in the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) focus countries is burned annually (Revermann *et al.* 2018). It is found that countries with the largest forest cover such as Angola and Zambia have recorded with 27% to 24% of the land area burned from 2003 to 2012. The area burned in Namibia, Botswana and South Africa were lower, ranging between 7 % and 4 % (FAO 2015). A study in the Kavango-Zambezi Trans-frontier Conservation Area found that the area burned annually in Angola, Zambia and Namibia was higher in comparisons with Botswana and Zimbabwe where effective fire management takes place (Pricope and Binford 2012).

2.3.2 Fuelwood harvesting

According to FAO (2007), more than 90% of the trees cut in Africa were burnt as firewood. Cline-Cole (1994) found that the harvesting of fuelwood obstructs forest protection and gradually changes the forests cover. Similarly, too many other countries in the developing world, Namibia is finding it challenging to supply steadfast electricity to its population across the nation. Communal people are mostly dependent on firewood for energy. In Namibia, about 80 % of rural households rely on firewood as their main source of energy (EEP 2012). Therefore, most of the little trees are killed and harvested for fuel. This high reliance on firewood for energy contributes to the increased deforestation. Together with fuelwood, vegetation cover is removed for many other uses such as fencing, as well as building homes. One estimate suggests that about 316,000 cubic metres of wood may be used each year for fencing and construction in northern Namibia (EEP 2012). Additionally, over-harvesting for domestic use or commercial trade in charcoal significantly degrades forests.

2.3.3 Clearing land for agriculture

Agricultural activities are one of the major factors contributing to deforestation. Communal people are transforming forests into cropland mostly for subsistence. Once the forest is cleared for cropland, the soils can become a large source of carbon emission, depending on how farmers manage the land. However, due to growing demand for food products, a larger amount of trees are cut down to grow crops (Oldeland *et al.* 2010). Almost 60% of Namibia's population lives in rural areas and 48% of these are directly dependent on environmental natural resources (Watts 2003).

Due to the increased population density the demand for agricultural land, firewood, housing, and carving is high and resulted in chopping of trees of various species. According to Mendelsohn (2009) , the rise in immigration from Angola during its civil wars from 1961 to 2002 has had a main impact on land uses in the Kavango regions. It caused large areas of communal land being cleared for agricultural crop production. During the Namibian liberation war in 1943, all land cleared for cultivation was along a narrow band near the Okavango River. In 1972, dispersed fields had been cleared along many of the omurambas. Land clearing for cultivation then became more widespread and stretched further throughout 1972-1996. The areas cleared for cultivation shows that about 3, 6 % was cleared each year between 1943 and 1972 and 4,2 % of new land was cleared each year from 1972 to 1996 (Mendelsohn 2009).

2.3.4 Global climate change

It is recognised that climate change is a global concern. Climate change is complex and caused by an intricate interplay amongst various factors most of which are not restricted to national boundaries. For instance, deforestation of tropical rain forest decreases the carbon sink, thus reducing the capacity of trees to absorb carbon dioxide emissions from the atmosphere which leads to global warming. This contributes to the melting of ice at the poles with a resultant rise in sea levels (Barnard 2002). Climate refers to the long-term average weather conditions for a region. In the past centuries, the climate of the earth has varied significantly in terms of average weather conditions. Such significant variations in climatic conditions are referred to as 'climate change' (Barnard 2002). There is scientific evidence that human activities have contributed significantly to climate change. This has been mainly through the use of fossil fuels and change in land use patterns due to increases in the global human population. One consequence of climate change is the observed increase in global temperature (global warming) during the last 200 years (Topfer and Hunter 2002).

Concerning changes in precipitation, an average of a 25 % decrease in rainfall has occurred over the African Sahel over the past 30 years. A reduction in precipitation has occurred over the twentieth century, particularly after the 1960s, in the subtropics and the tropics from Africa to Indonesia (IPCC 2001). As a consequence, trees may experience limited water availability for a certain period which may result in stressed trees and mortality. In the dry environment of Southern Africa, drought is the more frequently found trees stressor. Across large areas of Southern Africa, temperatures are increasing, whereas rainfall is declining. Besides, reduced rainfall may lead to the decline of vegetation cover in the most vulnerable environments in the case of a prolonged drought period (Erkkilä and Siiskonen 1992).

2.3.5 Browsing and Grazing

Large numbers of large and small livestock domestic animals are causing high browsing and grazing pressures on vegetation cover. Studies found that vegetation cover declined as a result of relatively higher livestock densities than the environmental carrying capacity (Kramer *et al.* 1997).

2.3.6 Infrastructural development

Development of infrastructure is often accompanied by destruction of flora and fauna and their ecosystems, thus disturbing their reproduction processes. Infrastructure development threatening biodiversity can be electricity grid lines, schools and clinics, business centres and major roads and railways (Timberlake and Chidumayo 2011).

2.3.7 Population density and growth

Areas with high population densities that greater than 10 persons/km^2 are threatened by human pressure (Timberlake and Chidumayo 2011). The population density of Namibia has increased over the past years from 1.7 in 1991 to 2.2 in 2001 and 2.6 persons/km^2 as a result of the growth of the population. At the regional level, Ohangwena and Oshana are the most densely populated regions with 22.9 and 20.4 (Namibia Statistics Agency Namibia 2011). However, the demand for and use of natural resources and environmental services is highest in highly populated areas. This will result in overexploitation of forest resources.

2.3.8 Rising poverty

Namibia was recorded with more unemployed people especially these that are lives in rural areas (Namibia Statistics Agency Namibia 2011). Due to the lack of sufficient income, people start to use and overuse every resource available to make a living (Timberlake and Chidumayo 2011). As the people become poorer, they abolish the resources faster. They tend to mismanage the natural resources because they do not have anything to provide for their families and individual livelihood. Poor people harvest natural resources to meet their basic needs such as agricultural production and wild plants for their medicine. All people regardless of wealth status depend on natural resources; the concern with poor people is that they are using the resources directly (Pinstrup-Andersen and Pandya-Lorch 1995).

2.4 Environmental and socio-economic impacts of land cover changes

2.4.1 Loss of Biodiversity

Overexploitation of plant resources is a growing threat to biodiversity in forests and woodland countries in sub-Saharan Africa. Approximately 90 % of tree species on the CITES list are threatened by overexploitation and eleven per cent are threatened by habitat loss (Shackleton 2006). Other plant species such as *Walburgia salutaris* in Zimbabwe and *Albizia brevifolia* in Namibia are now threatened (Shackleton 2006).

2.4.2 Soil erosion

Additionally, forest and woodlands play a significant role in soil structure. They decrease soil erosion when the roots alleviate the ground by holding and binding soil particles. Whenever the vegetation is removed, it will result in increased surface flows, the soil becomes exposed and there will be reduced water in the soil for plant growth (Mendelsohn and Obeid 2005).

2.4.3 Poor soil fertility and agricultural production

Land cover changes lead to environmental degradation and this result to force people to move to other regions in search of better living conditions. The degradation occurs in an area where the people overburden environmental resources. Other research studies demonstrate that species invasions by non-native plants, animals and diseases may occur more readily in areas exposed by land cover changes, especially in closeness to human settlements (Meyer *et al.* 1994). Trees add considerable qualities of nutrients to soil commonly in a form of humus or compost, but in their absence soil nutrients will be declined (Mendelsohn and Obeid 2005). The major zone of crop agriculture in sub-Saharan is in the dry forests and woodlands, much of which is rain-fed and is therefore vulnerable to climate variability. The climate of the dry forest and woodland regions are characterized by frequent droughts and occasional floods that frequently cause crop failure. However, this results in the reduction of agricultural productivities (Chidumayo and Gumbo 2010).

2.5 Drivers of changes in forest composition

Forest composition refers to species and structural composition of a landscape. It can also refer to forest communities at the stand or landscape level whose canopies may be dominated by a single tree species or contain a mixture of species (De Cauwer 2015). The woodlands of Namibia are open *Burkea* forests and are part of the Miombo Eco-region of the World Wide Fund for Nature (WWF) classification (Burke 2002, Timberlake and Chidumayo 2011). Towards the southern part, the woodland is intermixed with *Acacia* species. The woodlands are distinguished by a few canopy species, mostly *B. africana*, *B. plurijuga* and *P. angolensis* (De Cauwer *et al.* 2016). So, clearing for agricultural purposes and expansion of fences, forest fire, and reduction of annual rainfall are the major threats to the natural forest composition in Namibia. About 90 % of the *Acacia erioloba - S. rautanenii* community in the Okavango river valley has already been cleared for agriculture (Strohbach 2013).

2.5.1 Climate change

Drought and high temperature with low humidity easily result in forest fires, especially in the savannah woodlands. The combination of spatial and temporal fluctuations in patterns of temperature, rainfall, wind, solar radiation along with the rise in land-use pressure in southern Africa, may lead to increased desertification (Millennium Ecosystem Assessment 2005).

In Namibia, rainfall declines are expected to be greatest in the north-west and central regions (Midgley *et al.* 2005). Even if rainfall changes little from present levels, the water balance will become drier because temperature increases will cause higher evaporation rates; and this is likely to cause severe water shortage (Barnard 2002). Changes in rainfall and temperatures will result in significant changes in vegetation structure and functions in several areas in Namibia.

2.5.2 Logging

Logging roads are made to gain access to forested land; however, the process of land clearing causes changes in forest composition and structure. This can be attributed to the use of heavy machinery which causes soil compaction which leads to poor vegetation growth (Unanaonwi and Amonum 2014).

2.6 Consequences of forest cover change

A reduction in forest cover may cause changes in weather patterns and turn may lead to climatic change. It affects the weather pattern which leads to climate variability for the geographic regions of the world. It changes the biophysical, biogeochemical cycles and energy exchange processes both at local, regional and global scales (Shackleton 2006). Southern Africa is endowed with woodland resources which sustained millions of people for centuries, particularly rural peasants. Most woodlands occurring in communal areas are under increasing pressure (Chidumayo 2002) due to human population expansion.

In central Namibia, logging and other factors such as fires and overgrazing have contributed to a bush encroachment problem. The spread of invader bush species has reduced the grazing capacity of the pasture lands intensely and caused serious losses for livestock farmers (Graz 2004). Similarly, in the northern regions, deforestation has caused a shortage of fuelwood and building material as well as soil erosion. There have been rising concerns about woodland and forest degradation caused by various factors including unsustainable harvesting practices by resource users. The impact of changes on the vegetation cover can result in long-term and irreversible degradation such as soil erosion, changes in soil structure, a decrease in palatable and nutritious plant species, a loss of biodiversity, bush and shrub encroachment, and a loss of quality and quantity of forage (Abel and Blaikie 1990). Since numerous of the organisms depend on trees, they would simply get extinct when forest areas are converted to something else. However, more effects are observed when undisturbed lands are converted to more intensive uses including crop field, livestock grazing, selective tree harvest and even fire prevention (Ellis and Pontius 2006).

2.7 The long-term impacts of land cover changes

2.7.1 Scarcity in food, medicine and income

Forest encompasses a multitude of plant species and their roles in livelihood are manifest in many practices which comprise food supply, income resources, education, medicines and energy (Tee 2007). According to (FAO 2010), 90% of poor people that are dwelling in rural areas rely on forest vegetation for subsistence and income. In the local markets, women are active in the sale of fresh and dry forest food products. Medicinal plants from forest vegetation is used to treat various sicknesses like cough, headache, flu, diarrhoea, stomach ache, and skin rashes. The United Nations through the Food and Agriculture Organisation (FAO) is giving attention to the role of forest vegetation in food security due to the understanding of the reliance of rural people on trees and forest to meet essential needs such as food and income (FAO 1991). Forests play a very large role in poverty and hunger eradication and its current changes will bring severe consequences if unchecked.

2.7.2 Loss of biodiversity

Changes in forest cover will result in changes in flora and fauna populations of the forest ecosystem. Wild animals depend on the natural forest for shelter and food and when the forest cover declines, it will lead to relocation, loss and complete species extinction. Exposure of the forest soil due to changes in forest cover will lead to the death of millions of soil micro-organisms that play major roles in the biogeochemical cycles that support all forms of life on earth (Unanaonwi and Amonum 2014).

2.8 Sustainable Forest Management

There have been growing concerns on woodland and forest deforestation and degradation caused by various factors including unsustainable harvesting practices by resource users (Mapaure and Ndeinoma 2011). As a result, the need for sustainable use of natural resources has been placed high on the priorities of most governments as the world faces increasing human population which puts pressure on limited natural resources (Nkem *et al.* 2008). In Namibia, numerous woodland parts are managed by local communities under the Community Based Natural Resource Management Program. This programs targets to support and empower local communities by giving them rights to control and use forest resources.

Sustainable Forest Management (SFM) is the multipurpose management of a forest to ensure that its capacity to provide goods and services is not diminished over time. 'SFM of both natural and planted forests and for timber and non-timber products is essential to achieving sustainable and is a critical means to eradicate poverty, significantly reduce deforestation, stop the loss of forest biodiversity and land and resource degradation, improve food security and access to safe drinking water and affordable energy (FAO 2014). SFM is of major importance for its role in maintaining biological diversity and global ecological functions while enabling adequate use of the products derived from forests to meet growing demand (FAO 2014a).

In Africa and Europe, forest management strategies were more targeted to wood production in the past. State ownership of forests in which the people were kept out of the forest was a principal feature of forest management programmes in the southern part of Tanzania (Raphael and Swai 2009). However, many people from rural households, especially in Africa, derive a wide range of products for their subsistence from the rich and various vegetation types (Chirwa *et al.* 2008). SFM involves multi-scale initiatives. At the national level, it involves a clear definition of the national objectives of forest management, the establishment and support of national institutions for the implementation of SFM, the establishment of supportive policies, the monitoring of forests and forest activities, and the establishment of a favourable forest business environment (ATO/ITTO 2003). The establishment of policies that favour SFM requires measures to facilitate access to forest resources (Arnold 1998). SFM requires that forestry operations contribute to the improvement of the economic and social well-being of workers and the local population in forest concessions.

2.9 Community forests

Community participation and benefit-sharing has been adopted in most forest policies in dry forest and woodland countries and is a strong part of the SFM. After the Earth Summit in Rio de Janeiro in Brazil in 1992, the international pressure for sustainable natural resources management leads to the recognition of the role of local communities in natural resources management and revision of policies in many countries (Jumbe and Angelsen 2007). According to a study done by (Phiri and Morgenroth 2017), the government of Zambia initiated participatory forest management in which communities should be involved. This was expected to have a positive impact on the quality of forest resources and improve the livelihoods of local communities over time (Murali *et al.* 2003). Many community forestry programs were and continue to be implemented around the world. It seems that these approaches enjoy worldwide popularity. They started to develop after the 1970s when researchers and policymakers realized that conventional centralized management practices were not the right approach for tackling environmental protection issues involving local people (Schusser 2013).

In Namibia, the DoF under the Ministry of Agriculture Water and Forestry (MAWF) in collaboration with German Development Service (DED) and the German Development Bank (KfW) started a community forestry programme in 1996 (Mbapaha n.d.). A CF is an area in the communal lands of Namibia for which indigenous communities are given rights to manage forests (CFN 2008), woodlands and other types of natural vegetation according to the provisions of the Forest Act No. 12 of 2001. Communities are legalised to manage and utilize natural resources in agreement with the requirements of the Forest Act. If communities are strongly and economically competent to get themselves involved in SFM, this would promote encouraging economic benefits from conserving forest which results in a reduction of degradation (Mogaka 2001). Involving communities in decision making and benefits sharing is very vital in combating poverty at the community level (Bhattarai and Dhungana 2005). It is assumed that forests can be better managed when forest users are involved in making and adapting rules that include appropriate management strategies, monitoring impacts, and resolving the conflicts that arise from the management of natural resources (Ostrom 1999).

According to MAWF (n.d.), a CF is managed and guided by sustainability principles, ensuring that the forest resources are not depleted but are sustainably utilized. CF pursues to bring areas of forest lands under the governance of the community residence with aims to combat deforestation(Bhattarai and Dhungana 2005). However, a CF in conservancy areas does not only provide additional employment and income opportunities but also protects game habitats and landscapes to tourism to sustain income from tourism. In such areas, the co-operation of the conservancy and CF support organizations, unified management structures and joint management plans reduce costs and mitigate resource use conflicts.

The Okongo CF was among the first CF's in Namibia that was established in the early 1996s. Before 2005, Namibia had only seven CFs. About 13 CFs were officially registered in 2006 in the Government Gazette of the Republic of Namibia (Parviainen 2012). By 2013, the total number of the gazetted CF had increased up to 32 (Table 1), and then from 2018-2019, the number of registered community forest rose to 42 (Table 1).

Table 1: Namibia's community forest reserves (Source:(NACSO 2015)

No.	Name of the Community Forest	Region	Registration Date	Total area covered in km^2
1	Bukalo	Zambezi	Feb-06	53
2	Hans Kanyinga	Kavango-East	Feb-06	277
3	Kwandu	Zambezi	Feb-06	212
4	Lubuta	Zambezi	Feb-06	171
5	Masida	Zambezi	Feb-06	197
6	Mbeyo	Kavango-West	Feb-06	410
7	Mkata	Otjozondjupa	Feb-06	865
8	Ncamagoro	Kavango-West	Feb-06	263
9	Ncaute	Kavango-East	Feb-06	118
10	Ncumcara	Kavango-West	Feb-06	152
11	Okongo	Ohangwena	Feb-06	765
12	Sikanjabuka	Zambezi	Feb-06	54
13	Uukolonkadhi	Omusati	Feb-06	848
14	Cuma	Kavango-East	Mar-13	116
15	George Mukoya	Kavango-East	Mar-13	486
16	Gewatjinga	Kavango-East	Mar-13	341
17	Kahenge	Kavango-West	Mar-13	267
18	Katope	Kavango-West	Mar-13	638
19	Likwaterera	Kavango-East	Mar-13	138
20	Marienfluss	Kunene	Mar-13	3034
21	MuduvaNyangana	Kavango-East	Mar-13	615
22	NyaeNyae	Otjozondjupa	Mar-13	8992
23	Ohepi	Oshikoto	Mar-13	30
24	Okondjombo	Kunene	Mar-13	1644
25	OmufituWekuta	Ohangwena	Mar-13	270
26	Orupembe	Kunene	Mar-13	3565
27	Oshaampula	Oshikoto	Mar-13	7
28	Otjiu-West	Kunene	Mar-13	1100
29	Puros	Kunene	Mar-13	3562
30	Sachona	Zambezi	Mar-13	122
31	Sanitatas	Kunene	Mar-13	1446
32	Zilitene	Zambezi	Mar-13	81
33	Ehi-Rovipuka	Kunene	Oct-18	222,014
34	N#aJagna	Otjozondjupa	18-Oct	630289
35	Odjou	Otjozondjupa	Oct-18	876280
36	Otjituuo	Otjozondjupa	Oct-18	876280
37	African wilddog	Otjozondjupa	Oct-18	473224
38	Otjombinde	Omaheke	Oct-18	5,891
39	OmurambaUaMbinda	Omaheke	Oct-18	3,824
40	Eiseb	Omaheke	Oct-18	6,625
41	Otshiku-ShiIthilonde	Oshana/Omusati	Oct-18	87836
42	Omundaungilo	Ohangwena	Oct-18	23210
43	Epukiro	Omaheke	Feb-19	10927
Total				**3246909**

CHAPTER 3: Research Methodology

3.1 Conceptual Framework

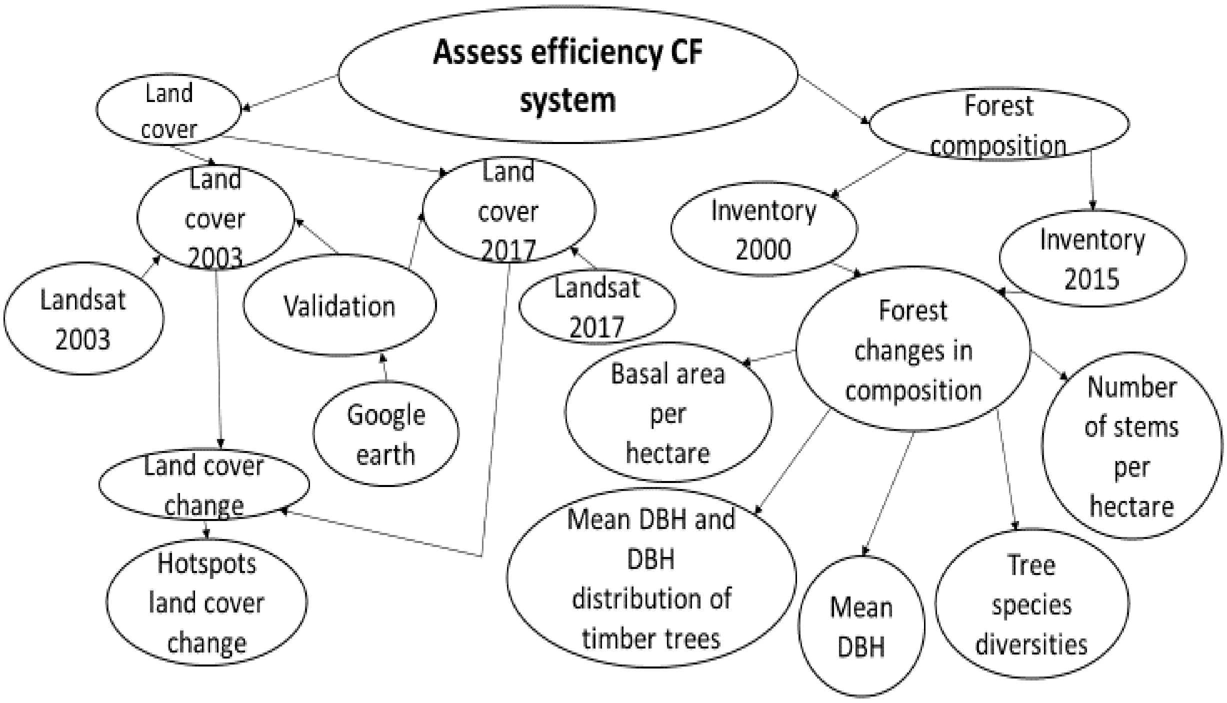

Figure 2: Conceptual framework of the study

The conceptual framework in Figure 2 shows the main concepts covered in the assessment of the efficiency of the community forest system. The main variables assessed are land cover and forest composition. The land cover is assessed by analysing and comparing the Landsat images of 2003 and 2017 while the forest composition is assessed by analysing and comparing the forest inventory data of the year 2000 and the year 2015. The outcomes or results of the land cover analysis are land cover change and hotspots of land cover change while the outcomes or results of forest composition analysis are forest composition changes in terms of mean DBH, DBH distribution of timber trees, species diversity, number of stems per hectare and basal area.

3.2 General Description of the study area

Okongo CF is located in the northern part of Namibia, in the Okongo constituency in the eastern part of Ohangwena region (figure 3). Okongo CF is bordered to the north by Angola and to the east by the Kavango West region. The Okongo CF is within the boundaries of the Okongo conservancy. The forest area for Okongo CF excluding the veterinary quarantine camp is 55,918 ha. The veterinary quarantine camp is 19,640 ha. The total area including the veterinary camp is 75,518 ha. The quarantine portion is fenced off and it is used by cattle farmers to isolate their livestock before they are sold. The reason is to improve the marketing of the livestock from the Northern Communal farmers(Mulofwa *et al.* 2002). The CF was gazetted on the 14th February 2006 (MAWF, n.d.), and it benefits the population of 21,321 people as estimated in 2009 (MET 2009). The Okongo CF falls in the communal land tenure system involving 20 villages as follows: contiguous to the CF are Oshushu, Omauni West, Oshalande, Kumininenge and those that are inside the CF are amongst others Omauni East, Oshimanamwene, Otutunda, Eloolo, Omwandi, Okanyandi, Ombonyola, Okatope I, Okatope II, Ohiki, Okanaimanya, Ekofya, Ombumbuma, Emanya, Okashalandona and Oshikome. The name Okongo derives from Oshiwambo word meaning ‘a place or forest for hunting’(Mulofwa *et al.* 2002). It is written in the by-laws and regulations of Okongo and Omufitu Wekuta CFs that no expansion of existing crop fields or fences is allowed as this would lead to deforestation and subsequent degradation of forest resources.

Omufitu Wekuta CF forms part of the Okongo conservancy, based at the western side. Omufitu Wekuta CF covers 29,197 ha with a total population of 5060 during the gazettement and it was gazetted on the 8th March 2013 (MAWF 2013) . Inside of the Omufitu Wekuta CF there are 15 villages: Onehanga A, Onehanga B, Onghwiyu 1, Onghwiyu 2, Oshushu, Okalukulwena, Olukulalakula, Oshamukweni, Omufimba, Oshalumbu, Ombambi, Onekuta, Eposha, Okanghalulwena and Omungete.

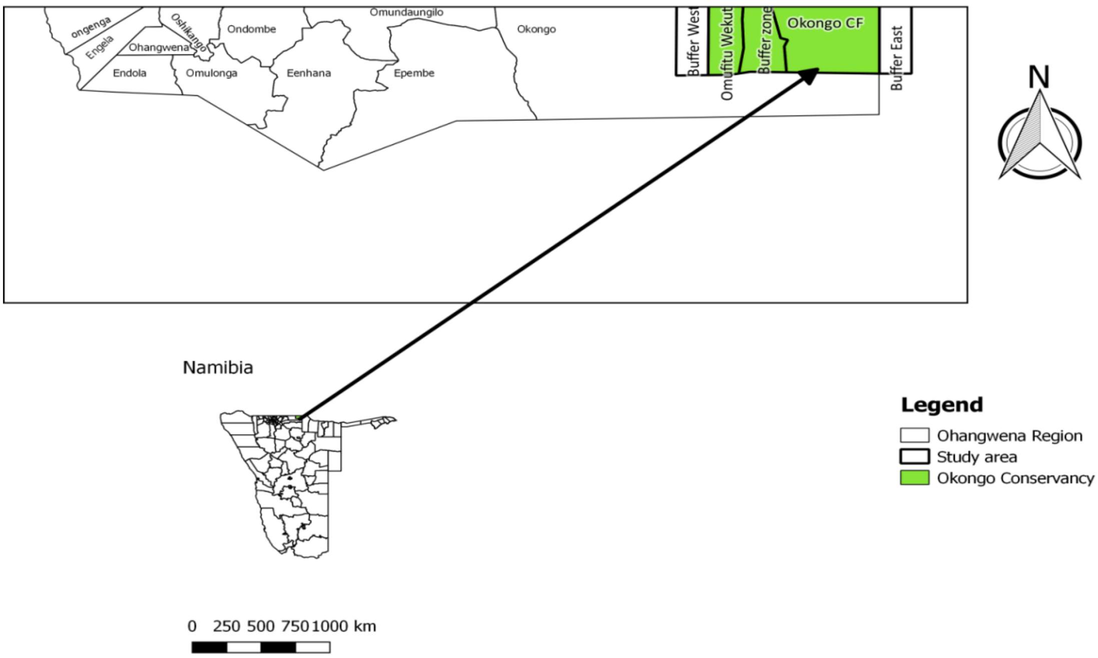

Figure 3: Location of Okongo CF, the study area in the Ohangwena region of northern Namibia (Own compilation, data sources: Government gazette coordinates (modified by De Cauwer).

The study area was divided into five polygons to compare the land cover change: Okongo CF, Omufitu Wekuta CF, central buffer zone (the area between Okongo and Omufitu Wekuta CF), the buffer east and the buffer west (Figure 3). A buffer distance of 10 km from the east and west side of the CF's was considered as a base of comparison for land cover changes. The northern and southern sides of the study area were not assessed. The north side falls within the boundaries of Angola while the southern part falls on the other side of the Okongo to Rundu tar road. Due to different land tenure systems, their data are considered incomparable for this study.

3.2.1 Climate and soil

According to MAWF (2014), the rainfall in this area mostly falls in the summer months from October through March, ranging from 500 mm to 550 mm. During the winter from May through August, there is little or no rain and no surface water to sustain vegetation. The average winter temperatures are just below 20 °C and summer temperature around 28 °C. The maximum temperature reaches around 35 °C in summer and recorded average minimum temperatures are around 8 °C in winter. The Okongo CF is situated at an altitude of 1000 m, and has very little variation in topography. Frost occurs annually, mainly between June and August, and can be severe to exotic tree species such as *Carica papaya*, *Psidium guajava* and *Kigelia africana*. The vegetation type of Okongo and Omufitu Wekuta CF is savannah and woodland according to (Giess 1971) classification. The Okongo CF soil ranges from sandy loam to loamy clay and the soil is deep (up to 150 m) and it has poor water retention capacity (MAWF 2010b). The soil type of the Omufitu Wekuta CF is generally homogenous. Loamy soils, representing 97%, while sandy soils represented 3% of the area measured (MAWF 2010a).

3.2.2 Vegetation of Okongo and Omufitu Wekuta Community Forests

According to Angombe *et al.* (2000), there is a distinct tree layer in a considerable part of the Okongo CF with medium timber potential. Most of the Okongo CF (76%) is classified as forest according to Food Agricultural Organisation (FAO) classification. The woody vegetation is concentrated in the tree layer. Less than 10% of the Okongo CF is classified as bushland or shrubland, five per cent of the Okongo CF is classified as grassland or bare land (Angombe *et al.* 2000). Shrubland occurs around the Omauni village and south of the CF. The north and east parts of the Okongo CF consist of mature woodland. The Okongo CF is part of the *B. plurijuga* woodland ecosystem in southern Africa. *B. plurijuga (Omupapa), P. angolensis (Omuuva), Combretum collinum (Omupupwaheke), B. africana (Omutundugu), Terminalia sericea (Omwoolo)* and *S. rautanenii (Omunghete)* are the six dominating tree species. *Baphia massaiensis* and *Bauhinia petersiana* are the most dominating shrubs in the study area (Angombe *et al.* 2000). The shrubland has only a few larger trees, mainly consisting of *T. sericea,* *B. massaiensis, Crotongra tissimus, Ozoroa insignis, Ximenia caffra, Ximenia americana* and *C. collinum*. Around pans *Z. mucronata* is conspicuous while along roads and boreholes *Dichrostachys cinerea, Acacia karroo* and other *Acacia* shrubs (Omano) become more common (DRFN 1997). The forest has some plants species with medicinal value while other species are edible (Angombe *et al.* 2000). Grasses are plentiful and in the northern, less disturbed forest areas the grasses were up to 2m high (DRFN 1997). A total of 40 diverse woody species were recorded in Omufitu Wekuta CF, with as most abundant *B. plurijuga* (Omupanda), *C. collinum* (Omupupwaheke), *B. africana* (Omutundungu), *D. cinerea* (Ongete), *T. sericea* (Omwoolo) and *P. angolensis* (Omuuva). In total, 136 forest products are collected in Omufitu Wekuta CF whereby 25 are used for construction, 17 for extraction, 29 are used as food products, 39 for medicine, 26 are used differently. This information was collected through the Participatory Rural Appraisal (PRA) survey in Omufitu Wekuta whereby the most important forest products were identified and ranked. The 22 forest products that are considered as the most important ones are listed in table 2.

Among the most important forest products, 9 tree species have a high abundance in Omufitu Wekuta CF and these are *X. americana* (Eemheke), *Grewia spp* (Eeshe), *S. rautanenii* (Omanghete), *Vangueria infausta* (Omumbu), *Boscia albitrunca* (Omunghudi), *C. collinum* (Omupupwaheke), *S. cocculoides* (Omuuni), *Berchemia discolour* (Omuve) and *Gymnosporia senegalensis* (Oshingondwe). Forest products with low abundance are *Croton gratissimus* (Ombango), *Acacia erioloba* (Omoonde), *Spirostachys africana* (Omuhongo), *Z. mucronata (Omukekete), Lonchocarpus nelsii (Omupanda), B. plurijuga (Omupapa), Securidaca longipedunculata* (Omutiwongobe), *P. angolensis* (Omuuva) and *D. cinerea* (Ongete) (MAWF 2010a).

Table 2: The most important forest products and their uses in Omufitu Wekuta CF (MAWF 2010a)

No	Oshiwambo name's	Latin name's	Use
1	Oshimbu/Omumbu	*Vangueria infausta*	Medicine, Edible (Fruits)
2	Eeshe	*Grewia spp.*	Extracted (dry gin), Edible (fruits)
3	Emeke	*Ximenia americana*	Extracted edible (fruits)
4	Omanghete	*Schinziophyton rautanenii*	Extracted (oil, dry gin), Edible (soup)
5	Omauni	*Strychnos cocculoides*	Edible fruits, extracted
6	Ombango	*Croton gratissimus*	Construction (fencing, droppers, firewood), medicine
7	Omoonde	*Acacia erioloba*	Construction (poles, handle, pestle, fuelwood)
8	Omuhongo	*Spirostachys africana*	Medicine
9	Omukekete	*Ziziphus mucronata*	Construction, edible (fruits), Extracted (dry gin)
10	Omunghudi	*Boscia albitrunca*	Medicine
11	Omupanda	*Lonchocarpus nelsii*	Construction (oxen york, pestle, firewood, furniture)
12	Omupapa	*Baikiaea plurijuga*	Construction
13	Omupupwaheke	*Combretum collinum*	Medicine, Construction and firewood
14	Omupwaka	*Strychnos pungens*	Edible (fruits)
15	Omutiwongohe	*Securidaca longepedunculata*	Medicine
16	Omuuva	*Pterocarpus angolensis*	Extracted (cosmetic powder), construction
17	Omuve	*Berchemia discolor*	Extracted (dye, dry gin), edible (fruits), construction
18	Omuwe	*Ochna pulchra*	Extracted (lo, lotion, dye, traditional pipe)
19	Omwoolo	*Terminalia sericea*	Poles, droppers, firewood, fibre and medicine
20	Ongete	*Dichrostachys cinerea*	Construction (poles, handle), firewood
21	Oshikoxo	*N/A*	Medicine
22	Oshingondwe	*Gymnosporia senegalensis*	Medicine, construction

3.3 Data collection

The data collection was divided into two parts, namely collecting data from satellite images and collecting of forest inventory data from the National Forest Inventory (NFI) database, Directorate of Forestry within the Ministry of Agriculture, Water and Forestry (MAWF) in Namibia.

3.3.1 Satellite images

For this study, cloud-free scenes of Landsat 7 Enhanced Thematic Mapper sensor (ETM+) (WRS path 179, row 72) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) were downloaded for Okongo CF and the remaining part of the conservancy. The ETM+ instrument is an eight bands multispectral scanning radiometer capable of providing medium resolution image information of the Earth's surface. The approximate scene size is 170 km north-south by 183 km east-west. A standard full scene is normally centred on the intersection between a Path and Row (the actual image centre can vary by up to 100m). Each band requires 50MB (uncompressed), and Band 8 requires 200MB (U.S.Geological Survey (USGS) 2015). Landsat 8 sensors collect data jointly to provide coincident images of the same surface areas. The Landsat used in this study was obtained from landsat.gsfc.NASA.gov. Landsat 7 captures visible (reflected light) bands in the spectrum of green, red, near-infrared (NIR) with 30m spatial resolution in colour imagery (Table 4). Landsat 8 sensor collects image data for shortwave spectral, near-infrared and thermal infrared bands over a 190 km swath with a 30 m spatial resolution (Table 3).

Table 3: Landsat 7 and Landsat 8 designations

Landsat 7 ETM + Spectral bands	Resolution (metres)	Wavelength (µm)	Landsat 8OLI & TIRS Spectral bands	Resolution (metres)	Wavelength (µm)
Band 2	30m Green	0.52- 0.601	Band 2	30m Green	0.553 - 0.590
Band 3	30m Red Near infrared	0.63 – 0.69	Band 3	30m Red Near infrared	0.636 – 0.673
Band 4	30m	0.76 - 0.90	Band 5	30m	0.851 - 0.879

For this study, Landsat 7 satellite imagery (dated 07 March 2003) and Landsat 8 satellite imagery (dated 06 April 2017) were used for comparison purposes. These images were taken at the end of the rainy season. During this period the woody vegetation is still green and the visibility of vegetation is higher due to the presence of a chemical compound in leaves called chlorophyll. Chlorophyll strongly absorbs radiation in the red but reflects green wavelengths. However, vegetation leaves appear greenest in summer when chlorophyll content is at its maximum. Additionally, images taken at the end of summer contain less cloud cover; while soil moisture content and vegetation moisture is lower(Kamwi *et al.* 2017). FAO (1996) states that images taken at the end of the rainy season are optimal for detecting woody plant vegetation. To display the Landsat images in colour, bands 4-3-2 of Landsat 7 and bands 5-4-3 of Landsat 8 were combined (Table 3). Different band combinations were used to identify different features on the ground. The shapefiles representing the boundaries of Okongo CF, Omufitu Wekuta CF and the area between Okongo and Omufitu Wekuta CF were placed in Quantum Geographical Information System (QGIS) together with the LANDSAT images. The LANDSAT images were loaded into QGIS for digitising. Three shapefiles were created (land cover 2003, land cover 2017 and study area). In areas where the resolution was not high enough to study land cover, Google Earth images with a resolution of 1.5 x 1.5 m were used.

In addition to satellite imagery, registered community forest data in GIS format were acquired from the Environmental Information Service (EIS) website (www.the-eis.com) which is home to conservation-related GIS data for Namibia which is compiled from different sources. However, the Okongo and Omufitu Wekuta CF data were re-digitised according to the gazetted boundaries. This data shows boundaries of registered community forests and these vector data were analysed in a GIS to come up with Area of Interest (AOI) which is the Okongo CF.

3.3.2 Satellite image classification

This is a process of grouping pixels into meaningful classes. For land cover classification, it concerns the process of assigning land cover classes to pixels. The Landsat images that were used in this study (Table 3) were independently classified into five land cover classes namely, forest/shrubland, crop/agricultural land, settlements, water body, and other lands (Table 4).

Table 4: Description of land use and land cover classes (Source: Anderson 1976, Cowardin *et al.* 1979)

Land cover class	**General description**
Forest and shrub	Areas with closed and open canopy forests (with 20% or more crown cover) and wooded landscapes with trees higher than 3 m. Shrubland is an area with a combined cover of shrubs, bushes and occasional trees.
Agricultural	Areas which are mainly used for the production of food with isolated bushes and trees
Settlements	Land covered by buildings and other man-made structures. Usually contains sparse vegetation cover and relicts of secondary forest.
Water body	An area which is covered by surface water. It can be lakes, reservoirs, stream, rivers or swamps
Bare soil	Areas which are mostly bare in nature
Other land	Areas not classified as forest/shrubland, crop/agricultural land, waterbody, bare soil and settlements. For example, sand mining, rocky areas or pans.

The classification of the Landsat images of 2003 and 2017 was done through visual/manual interpretation. Manual classification is an operative method of classifying land cover especially when the analyst is familiar with the area being classified. It relies on the analyst to employ visual cues such as tone, texture, shape, pattern and relationship to other objects to identify the different land cover classes. Manual classification is more subjective since it relies on the researcher's interpretation (Horning 2004). This method is only able to incorporate 3 bands of data from a satellite image since the interpretation uses a colour image comprised of three bands, in this study red, green and NIR bands.

The author studied the image on the computer screen and classified the image by creating polygons around areas that are identified as a particular land cover type.

3.3.3 Identification of most prevalent land covers change

A hotspot map was created from X and Y coordinates/points that are indicating where the changes or no changes have occurred over the period. A hotspot is an area that has a higher concentration of events compared to the expected number given a random distribution of events. Hotspot detection evolved from the study point distributions or spatial arrangements of points in space (Chakravorty 1995).

3.3.4 Forest inventory

Forest inventory is defined as the systematic collection of data on the forest for assessment or analysis (Asrat and Tesfaye 2013). The forest inventory data help to generate the required information based on the forest resources within a specific area of interest. There is forest inventory data that was collected by DoF before (2000) and after (2015) the gazetting of the Okongo CF (Angombe *et al.* 2000, MAWF 2017).

The sampling method used in Okongo CF inventory for 2000 and 2015 was systematic sampling to ensure that each unit has an equal chance of inclusion in the sample. A total number of 60 plots were sampled and each plot is represented by a unique number (Figure 4).

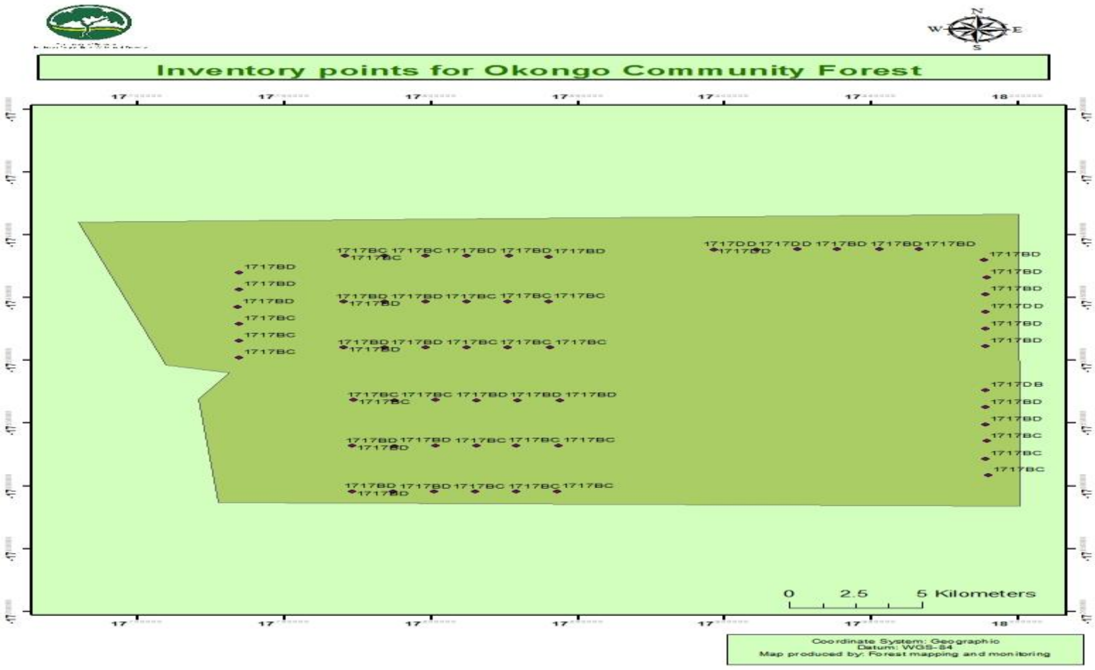

Figure 4: Map showing sampled plots in Okongo CF (MAWF 2017)

i. Sample plot design

The sample design by the MAWF was different for the two inventories; the sample plots for the 2000 inventory were divided into three concentric circles while for 2015, the plots were divided into two concentric circles (Figure 5). Circular plots are preferred to be better than other plots such as square plots since they avoid the skewness of the boundary lines by obstacles (Kuru *et al.* 2015). Circular plots are considered to be more suitable for dry forest since the vegetation is open and they are easier to set up than rectangular plots (Müller and Nyambe 2015). The concentric sample plots are used because of the spatial distribution of trees in Namibian forests (Ministry of Environment and Tourism (MET) n.d.). Therefore, to get a good number of big-sized trees, the plot size should be bigger, however, for small-sized trees; the tree density might be large hence plot sizes should be smaller because smaller plots are more efficient than larger plots in areas of high tree density (Kohl *et al.* 2006).

For the 2000 inventory, all trees ranging from 5-20 cm DBH were measured within a 10m radius, medium-size trees larger than 20 cm DBH were measured within a 20m radius and big trees with a DBH > 45 cm were measured within a 30 m radius. For the 2015 inventory, in the 20 m radius plot, any woody vegetation with a diameter at breast height (DBH) greater ≥ 10 cm was measured and classified as a big tree and measured. In the 10 m radius plot, all woody plants with a DBH of ≥5 cm were measured and classified as saplings (MAWF 2010b).

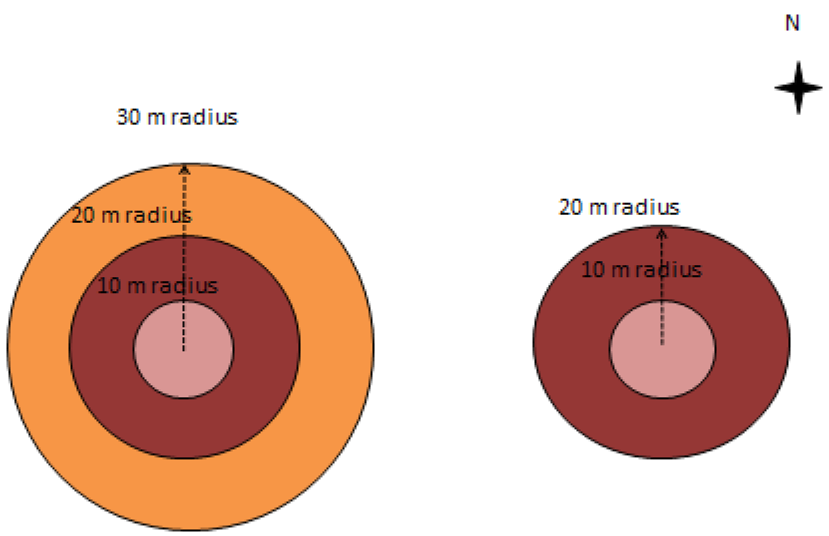

Figure 5: Plot design with three and two concentric circles (MAWF, 2010b)

ii. Finding the sample point

Each sample point representing the plot centre is unique. The NFI provided maps, waypoints and sample plots to be measured. These waypoints and coordinates were loaded into the GPS that was used to locate sample plots in the field (See coordinates in Appendix A and B). The waypoints are unique numbers referring to sample plot name/number (MET 2000, MAWF 2010b).

iii. Collecting data

In all 60 plots, tree inventory data was collected and recorded on field inventory sheets. A measuring tape was used to measure the sample plots radius (MAWF 2010b, MET 2000).

iv. Diameter measurements

Stem diameter of each tree was measured at the standardized height of 1.3 m above ground level (DBH). The height of 1.3 metres was measured first using a ruler stick from the ground level at the base of the tree stem. At the measured and marked 1.3m height of the stem, the stem diameter was measured by using a diameter tape.

In some cases, abnormalities of branching or forking of stems occur before the standard height of 1.3m. When the tree is forking below 1.3 m, then all stems were measured at 1.3 m as separate stems (Figure 6). However, they were recorded as one tree with different logs. If a tree is forking above 1.3m, then it should be considered as one log.

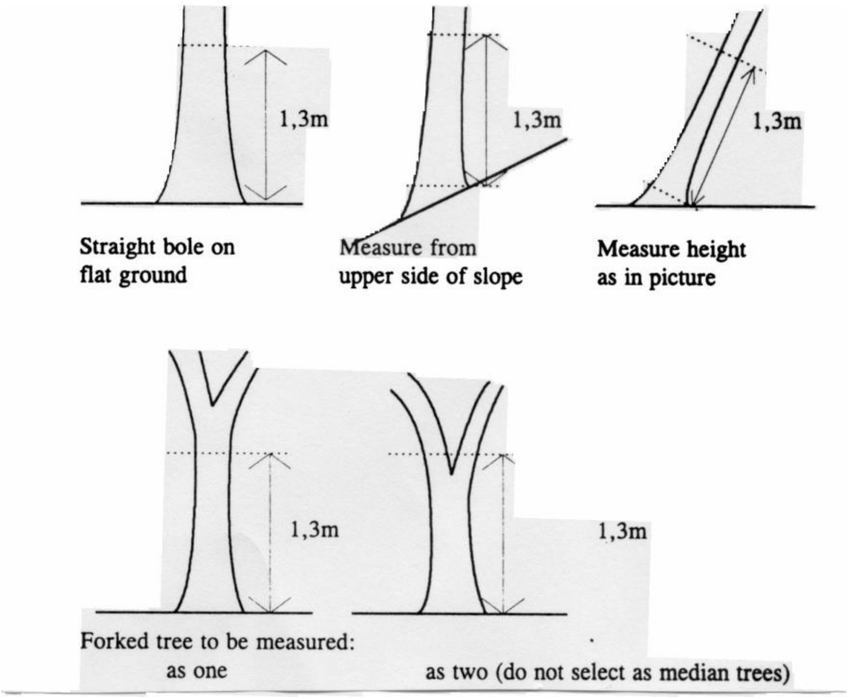

Figure 6: Method to measure the DBH in various situations (The tree Register 2014)

3.4 Data analysis

The data analysis was divided into three parts, namely detecting land cover changes, identifying hotspots of land cover change and detecting changes in forest composition.

3.4.1 Detecting land cover change

Detecting land cover change was done through the image classification process. Image classification allows for imagery from different years to be compared to see changes that have taken place over the years. Image classification makes it possible to look at land cover from global and local scales. Change detection is defined as a process of classifying changes in the state of land cover by observing them at different times. This process was accomplished with the use of geoprocessing tools in QGIS. The areas of the land cover classes of 2003 and 2017 were calculated in QGIS and summed up for five polygons representing the different parts of the study area (Okongo CF, Omufitu Wekuta CF, the central buffer zone, buffer east and buffer west. The area covered by each class was calculated as follows:

Formula: $\%\ of\ land\ covered\ per\ class = \left(\frac{Total\ land\ cover\ per\ class}{Total\ land\ covered\ by\ all\ classes\ per\ polygon}\right) * 100\%$

3.4.2 Land cover validation

Land cover validation is a process of assessing the classification accuracy of the land cover map (Shi *et al.* 2015). Concerning this study, the land cover maps were compared by using Google Earth images that can provide sufficient details for that specific period.

3.4.3 Detecting change in forest structure and species composition

The inventory data were entered and organised in Excel. Trees were placed in DBH classes and then converted to the number of stems per ha, basal area (BA) per ha, mean DBH, diameter distribution and mean diameter of the larger timber trees such as *P. angolensis, B. plurijuga, B. africana and G. coleosperma*. The size and class distribution for the tree species in Okongo CF was analysed by allocating the diameters into 9 diameter classes with 5 cm intervals. DBH classification gives an idea of the forest structure and the survival of the individual tree from the smaller size class to medium and bigger class (Backéus *et al.* 2006).

3.4.3.1 Basal area (BA)

BA of an individual tree is the over bark cross-sectional area of the stem at breast height (1.3m). BA also measures the overall level of competition for resources between trees in the stand and it is frequently used to determine whether a stand should be thinned (Timber Measurement Manual 1999). The BA was calculated per tree from the DBH by using the following formula: $G = \frac{\pi(DBH)2}{4}$ for all tree species per plot, whereby G is basal area in meter squared (m^2), and DBH is the diameter at breast height (m). The BA of all measured trees were summed up for each plot and converted to BA per ha by multiplying with an expansion factor.

The expansion factor converts the number of trees per plot to the number of trees per hectare. The expansion factors (table 5) were used to upscale DBH classes from plot level to a hectare based on the respective plot radii of 10m, 20m and 30m.

Table 5: The expansion factors used for the different plot radius

2000 DBH class (cm)	2015 DBH class (cm)	Plot radius (m)	Plot area (m^2)	Expansion factor of 2000 and 2015
5-20	5-9.9	10	314.16	31.83
20-45	≥10	20	1256.64	7.958
≥45	NA	30	2827.43	3.537

3.4.3.2 Mean diameter

The mean DBH is defined as the average DBH within the measured plot. The mean DBH was calculated as follows:

$$\text{Mean DBH} = \frac{\text{DBH per tree} * \text{expansion factor}}{\text{Number of stems per hectare}}$$

3.4.3.3 Species composition

Tree species composition is defined as the identity of all the species that make up a community (Hamilton 2005). Therefore, the total number of all tree species including timber species were identified and computed to determine species richness. The species composition was further analysed through the abundance, measured as stems per hectare, of the most common tree species with minimum DBH of 5 cm. The difference between the previous (2000) and recent (2015) inventories were tested for significance with the paired t-test for normally distributed data (De Cauwer *et al.* 2016). The t-test is a statistical test that is used to determine if there is a significant difference between the mean or average scores of two groups.

3.4.3.4 Diameter class distribution of timber species

The diameter distribution for timber tree species within the study area was analysed by allocating the 10 diameters classes with 5 cm intervals. The tree species that are considered as timber species are *P. angolensis, B. plurijuga, B. africana and G. coleosperma.* The non-parametric test (Mann-Witney U-test was used to determine if the two datasets of timber species are significantly different.

3.4.4 Determining hotspots of land cover change

The classified land cover was analysed to provide information regarding how patterns of land cover change over the time. Hotspot analysis normally uses vectors to categorize positions of statistically significant hot spots and cold spots in the data set by combining points of appearance into study area polygons. The analysis grouped features when similar hot or cold spot are found in the area of interest. Hotspot analysis was carried out using QGIS tools whereby the classified land cover of 2003 and 2017 was overlaid, and to produce the change detection map. The differences between the two shapefiles were detected using the different tools with the image analysis. The new shapefile was created which shows the hotspot changes between the two layers (2003 and 2017). According to Voss (1988), land cover hotspots can be perceived at three levels: high rates of land cover change which are observed at present or have been observed in the recent past, areas where land cover changes are likely to occur shortly and the severity of the impact of the change. For this study, the hotspot analysis was done to identify the locations of the hotspot, cold spots and where there is no change in the study area.

3.4.4.1 Programme used

To understand the relationship between landscape structure and landscape function with landscape metrics, it is necessary to quantify structural characteristics for sustainable planning and, at the same time, to determine landscape changes over time. In this analysis, FRAGSTATS technology version 4.1 was used to compute the landscape metrics. This programme computes many different metrics on each patch in a thematic map, each category in a thematic map, and the whole landscape, such as space, compactness, connectivity, and distance to the nearest neighbour (McGarigal and Marks 1995). Then, metric values are interpreted differently at different classification rates. To calculate and control broad landscape characteristics databases, it is necessary to define and measure landscape complexity. Depending on the classification categories, components that characterize landscape characteristics have different levels of importance (Farina 2012).

3.4.4.2 Landscape class metrics selection

Environmental metrics are essential tools to identify the formation of landscapes and the transformation of landscapes. It also helps us to understand landscape changes from various points of view such as imagery, biodiversity, and ethnicity (McGarigal and Marks 1995). Landscape metrics are more dynamic objects, with the main challenge being to investigate and quantify spatial variants in landscape pattern metrics (McGarigal 2002). By using landscape metrics, the variation of the landscape configuration and composition in space over time can be explained. For this study, landscape metrics were used to differentiate the study area's landscape structures over the various periods to recognize the spatial-temporal arrangements and structure of land cover change. There are different landscape metrics available, but due to the similarity between several of them, caution must be exercised in selecting exact metrics (McGarigal 2002). Nevertheless, landscape metric choice is determined by the research objectives and the area's spatial characteristics (Kamwi *et al.* 2017a). Taking these aspects into account, three landscape class metrics the Largest Patch Index (LPI), Patch Density (PD), and Interspersion and Juxtaposition Index (IJI), were selected to calculate and examine the landscape structure and patterns Spatio-temporal fluctuations. First, the classified land cover shapefiles of 2003 and 2017 were rasterized into tiff format for FRAGSTATS. Landscape metrics were calculated to measure the arrangement and configuration of land cover in Okongo CF and area outside the CF.

The metrics used in this analysis were chosen so they can describe characteristics at different levels and also be evaluated objectively to determine the nature of the landscape. Also, to identify unwanted negative trend according to sustainable land management considering the negative consequences such as increased runoff, accelerated soil erosion, loss of soil fertility and desertification. Such landscape metrics are believed to be the most powerful indices capable of defining and measuring the spatial characteristics of the landscape pattern (Riitters *et al.* 1995). These landscape metrics symbolize the spatial arrangement of the entire landscape mosaic in the study area and have been more roughly interpreted as indices of landscape heterogeneity as they measure the entire landscape configuration. Also, the metrics identified in this analysis were quantitatively assessed in the study area. So, to analyze landscape metrics in FRAGSTATS, the numerical data is obtained related to landscape structure and is normally produced from classified images. The metrics are described in Table 6 and metrics values were calculated using 8*8 m cell neighbourhood rule in FRASTAT software for each land cover.

Table 6: Class metrics and descriptions (Neel and Cushman 2004)

Name of metrics	**Function of the metrics**	**Additional information to the study**
Largest Patch Index (LPI) $$\mathbf{LPI} = \frac{\mathbf{max}(\mathbf{a_{ij}})}{\mathbf{A}}(\mathbf{100})$$	LPI quantifies the percentage of the total landscape area covered by the largest patch of a particular class.	It will allow the study to identify which specific land cover class is occupying a less or large portion over a specific period. This approach will enable the study to tell which land cover class is more dominant compared to others.
Patch Density (PD) PD $=\frac{ni}{A}$ $(10{,}000)(100)$	Refers to the number of patches per unit area. According to (McGarigal 2002), PD indicates the number of patches per 100 hectares.	Measure of the fragmentation in the study area.
Interspersion and Juxtaposition Index $$\mathrm{JI} = -\sum_{k=1}^{m'} \frac{\left(\left(\frac{e_{ik}}{\sum_{k=1}^{m'} eik}\right) In\left(\frac{eik}{\sum_{k=1}^{m'} eik}\right)\right)}{In(m'-1)}(100)$$	At the class level, interspersion is a measure of the relative interspersion of each class.	It will help the study to measure how the patch types are interspersed/spread or scattered. Higher values result from landscapes in which the patch types are well interspersed, whereas lower values characterize landscapes in which the patch types are poorly interspersed.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results of the study are presented and discussed regarding the aim of the study, which was to evaluate how the declaration of community forests can influence land cover and forest composition with a case study in one of the oldest CF's, Okongo. The three objectives of the study were:

1. Compare land cover changes for the period 2003 – 2017 between Okongo CF and areas outside Okongo CF, especially the remaining part of the Okongo conservancy, which includes Omufitu Wekuta CF (declared in 2013);
2. Identify and assess areas where the land cover changes are most prevalent (hotspots) and examine the Spatio-temporal changes in landscape composition and configuration between 2003 and 2017 in Okongo CF and areas outside Okongo CF;
3. Monitor major changes (trends) in forest composition of Okongo CF since gazettement

The results are presented according to two main variables studied: that include land cover changes and forest composition changes.

4.2 Land cover changes

The results presented in this section address the first two objectives of the study meant to compare land cover changes for the period 2003 – 2017 between Okongo CF and areas outside Okongo CF, and to identify and assess areas where the land cover changes are most prevalent (hotspots). The results are from the land cover assessed and analysed by comparing the Landsat images of 2003 and 2017. Therefore, the results are presented in two sub-sections that include classified land cover and hotspots for land cover changes.

4.2.1 Classified land cover

The land cover in Okongo CF and areas outside the CF in 2003 and 2017 is shown in Figure 7 and Figure 8 respectively. The classified land cover of 2003 and 2017 was used to calculate the changes in the land cover classes for the entire study area (Table 7). Over the whole study area during 2003 and 2017, the land cover class that changed most was forest/shrubs land. In 2003, a large patch of bare land was identified in Okongo CF in the central area of the CF (Figure 7). This could be due to the clear-cutting of trees and burning of bushes in the study area. However, it then disappeared in 2017 (Figure 8) and this may indicate that the conversion of forest land into agricultural activities was minimized. The classified land cover of 2017 (Figure 8) shows water that was not classified in 2003. The sudden water land that occurred in 2017 could be due to the amount of rainfall received during the rainy season in 2017 and the water body has increased as more land is covered with water than in 2003. About 63.55 mm of rainfall was recorded in Okongo in the Ohangwena region towards the end of March in 2017 before the Landsat image was taken (Okongo Monthly Climate Averages 2017).

A patch of other land was classified in 2017 in the north-eastern part of the study area and this is an area that is covered by features that can be sand mining or rocky. However, this patch was not there in 2003 and this may have occurred between 2004 and 2005 before the gazetting of the CF and there is no clear evidence of what is this patch is representing. A small patch of settlement class is observed in the central part of the study area (between the buffer zone and Okongo CF) in 2003 and it has become larger in 2017 (Figure 8). A patch of settlement can also be found western part (in Omufitu Wekuta CF) of the study area. This could be an office area for the CF, settlements, health clinic, school buildings and water point for the residents that are residing within or in areas that are surrounding the CF (personal communication)

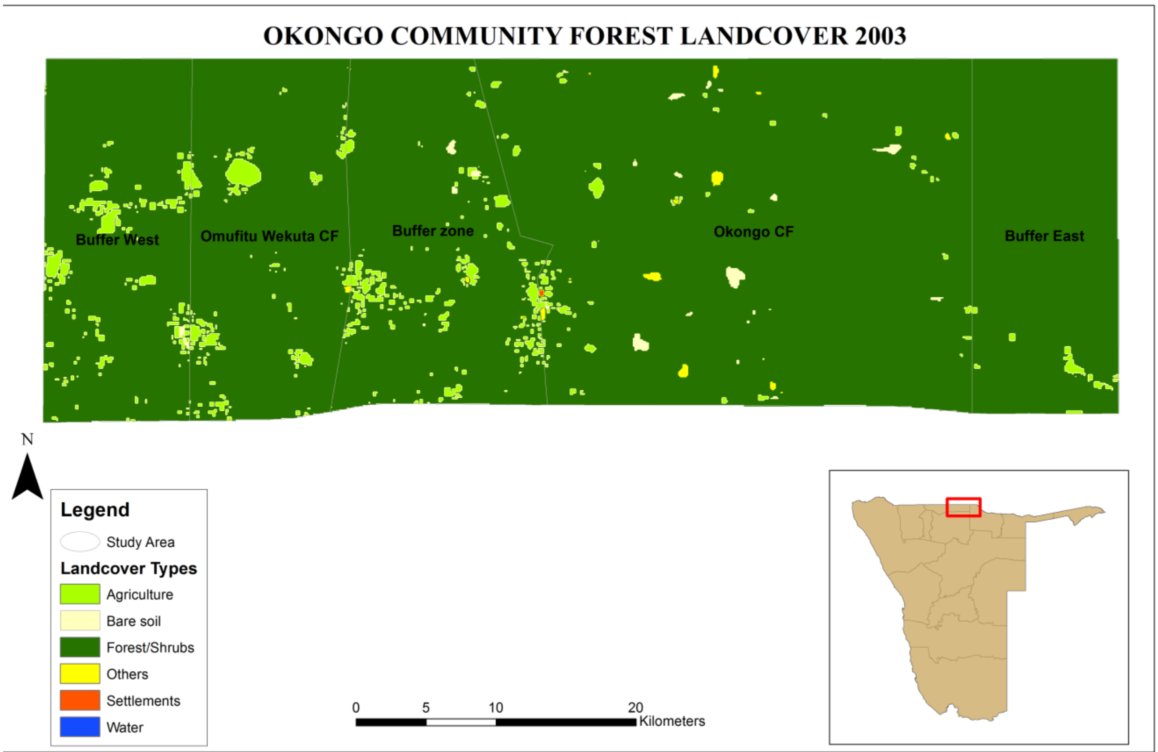

Figure 7 Classified land cover of 2003

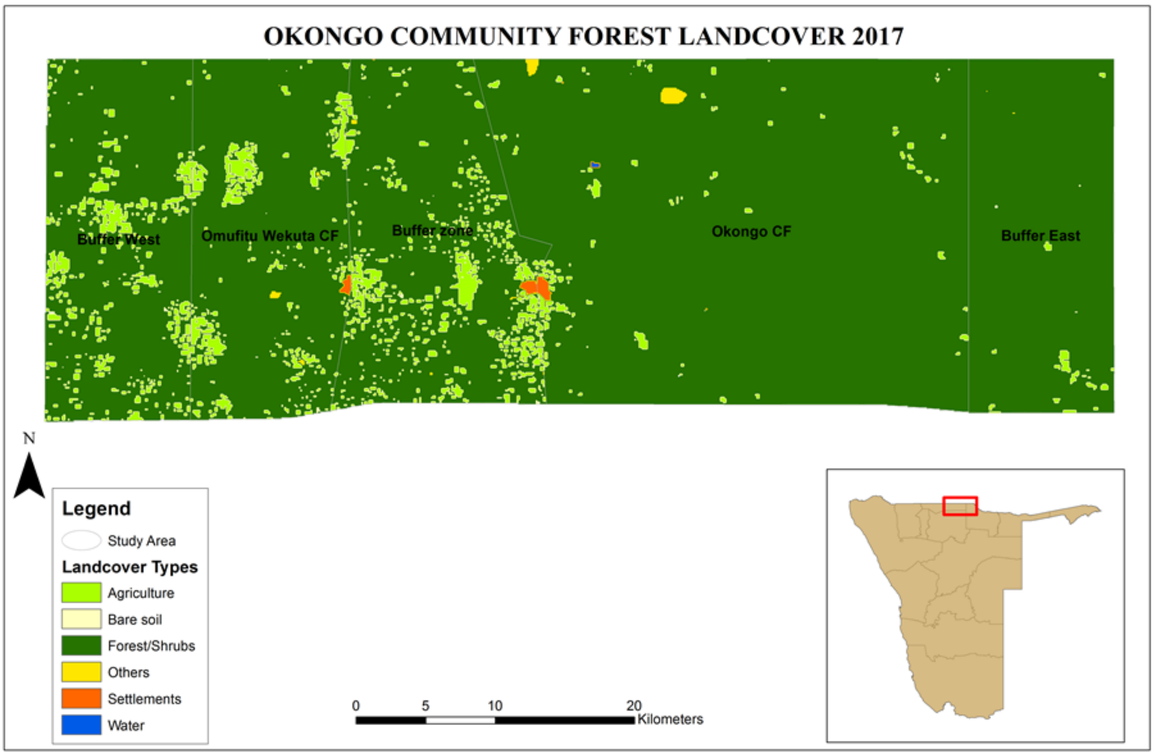

Figure 8 Classified land cover of 2017

4.2.2 Land cover within five parts -Okongo CF, Omufitu Wekuta CF, buffer zone, buffer west and buffer east - of the study area.

Table 7: Land cover changes for 2003 and 2017 (in %)

	2003	2017	Change in ha	Change in % compared to sub-area	Change in % compared to the class in 2003
	Sum and size of the class in ha				
Buffer West	**25809.1**	**25815.6**			
Agriculture	1521.6	2698.1	1176.5	4.56	77.3
Bare soil	51.9	21.4	-30.5	-0.12	-58.7
Forest/shrubs	24235.6	23096.1	-1139.5	-4.41	-4.7
Omufitu Wekuta CF	**27089.8**	**27102.9**			
Agriculture	1244.8	2304.1	1059.2	3.91	85.1
Bare soil	5.0	32.7	27.7	0.10	557.7
Forest/shrubs	25818.3	24642.2	-1176.1	-4.34	-4.6
Others	21.7	55.7	34.0	0.13	156.9
Settlements		68.3	68.3	0.25	NEW
Central buffer zone	**29216.4**	**29214.1**			
Agriculture	1637.7	3489.9	1852.2	6.34	113.1
Bare soil	96.6	48.4	-48.2	-0.16	-49.9
Forest/shrubs	27461.6	25553.0	-1908.6	-6.53	-6.9
Others	19.8	38.5	18.6	0.06	93.9
Settlements		83.4	83.4	0.29	NEW
Water	0.7	0.8	0.1	0.00	20.2
Okongo CF	**76531.4**	**76556.4**			
Agriculture	714.7	931.6	216.9	0.28	30.4
Bare soil	485.3	9.1	-476.3	-0.62	-98.1
Forest/shrubs	75026.2	75189.2	163.0	0.21	0.2
Others	287.4	290.3	3.0	0.00	1.0
Settlements	17.4	115.0	97.7	0.13	562.9
Water	0.5	21.2	20.7	0.03	4520.4
Buffer East	**25288.7**	**25288.7**			
Agriculture	240.8	251.1	10.3	0.04	4.3
Bare soil	1.8	6.5	4.7	0.02	260.1
Forest/shrubs	25046.1	25026.4	-19.7	-0.08	-0.01
Others		4.7	4.7	0.02	NEW

The results show that there is a decrease of the forest/shrubs land cover class in all areas except in Okongo CF and the buffer east. On the other hand, bare soil also decreased in some areas that include buffer west, central buffer zone and Okongo CF. The highest increase in bare soil was in the eastern and Omufitu Wekuta CF. As for human activities, it is agriculture that showed an increase in most areas with much increase experienced in the buffer west (77.3%), Omufitu Wekuta CF (85.1%) and the central buffer zone (113.1%). Settlements showed changes only in Okongo CF (562.9%). Also, the results showed that settlements were not found in some parts of the study area (especially in Omufitu Wekuta CF and in the central buffer zone) during 2003 (Table 7). Hence, this indicates that those developments were established after 2003. Therefore, the results showed that settlements cover an area of 0.67% of the study area.

The land cover changes in the table indicate that it is mainly agriculture, bare soil and forest/shrubs that changed over the period between 2003 and 2017. The central buffer zone showed a large area that was converted to agricultural land (6.34%) than any other parts of the study area, followed by the buffer west (4.56%) and Omufitu Wekuta CF (3.91%). The Okongo CF (0.28%) and the buffer east (0.04%) showed a small area that has been converted to agricultural land. Bare soil decreased (-0.62 %) in Okongo CF, (-0.16%) in the central buffer zone, (-0.12%) in the buffer west and showed a slight increase in the buffer east (0.02%) and Omufitu Wekuta CF (0.10%). Based on these results, the study showed that Okongo CF has the highest decline in bare land class (-98.1%) in the entire study area. Also, the most decrease in forest/shrubs area can be found in the western parts of the study area which includes the central buffer zone (-6.53%), the buffer west (-4.41%), Omufitu Wekuta CF (-4.34%) and with a slight change in the buffer east (-0.08). It was also found that an area of forest/shrubs (0.21%) was restored in Okongo CF. It can be attributed to the clearing of land for agriculture that reduced forest/shrubs at the same time increasing bare soil. This study found that there is an increase in agriculture land in the study area in 2003 and 2017 while there is a loss on forest/shrubs land. This shows that agriculture remained the highest source of the livelihood for the people lives in the western part of the study area. It is noticeable that the eastern part of the study area (includes Okongo CF and the buffer east) shows hardly change in forest cover and agriculture. This cannot only be due to the gazetting of Okongo CF; it can be as a result of fewer people that live in the area hence the minimal disturbance. This finding is supported by (Baetcke 2018) who found that the increase in forest and shrub cover was predominantly found in the eastern part of the Okongo CF.

The study also showed that forest/shrubs land increased from 75026.17 ha in 2003 to 75189.15 ha in 2017 (see Appendix G). A recent study done by (Baetcke 2018) in the same area showed that forest cover increased from 9,057 ha in 2006 to 15,034 ha in 2016 while bare soils increased from 3,510 ha in 2006 to 5,061 ha in 2016. But this study found that bare soil was recorded with 485.33 ha in 2003 and declined to 9.08 in 2017 (see Appendix G). Grassland was found experienced less change whereby in 1996 it covered 28,285 ha but increased by 1,285 ha in 2006 and showed a loss of 8,277 ha in the time until 2016. 21,293 ha of the study area was covered by grassland in 2016 (Baetcke 2018).

Similarly on other study done in the four administrative regions (Ohangwena, Caprivi, Kavango and Oshikoto) has found a high loss in woodland cover (-8 %) and this was accompanied by agricultural expansion (5.71%) (Wingate *et al.* 2016). The conversion of forest/shrubs land to agriculture shows non-sustainable forest management practices. Other issues include an increase in competition for grazing land and forest resources especially in the commonage areas (Wingate *et al.* 2016). The changes in the study area of Okongo are also similar to changes in Kavango East Region. A recent study in Kavango East region (Muhoko 2018) has found that the most dominant land cover was forest land, bushland and cropland. Similarly, this study has found that forest/shrubs land and agriculture were more dominant in the study area. A decline in forest land was observed in the Kavango East region whereby the decreasing started in 1990 (57.6%), 2000 (55.6%), 2009 (54.9%), 2016 (54.2%). Cropland areas occupied more than doubled from 2.9 % in 1990 to 6.1 % in 2016 (Muhoko 2018).

Forest/shrubs land can provide habitat for animals, increasing edge effects and connectivity between forest patches (Kamwi *et al.* 2017a). Forest/shrubs land are also important for biodiversity conservation, wild fauna, timber and non-timber products and carbon storage (Kamwi *et al.* 2017). So, the Government of Namibia has developed a forest policy in 1991 within the Ministry of Agriculture, Water and Forestry to provide a legal framework on sustainable forest management. Forest protection activities such as law enforcement and forest fire management were introduced by the DoF. The legal timber harvest in Okongo CF is carried after each forest resources inventory. The DoF within MAWF calculates an annual allowable cut based on forest inventory which is binding for 5 years or longer. The allowable cut is a guide that is used to regulate the harvest of timber and poles in a natural forest. The DoF determine the quantity of forest produce for which a licence may be issued in any CF and the maximum quantity of forest produce which may be harvested under section 24 (3) (Forest Act 2001). Legal harvesting in Namibia is controlled in community forests but illegal harvesting is still being practised.

4.2.3 Hotspots for land cover changes

Hotspots were characterized as areas with a higher concentration of changes compared to the entire study area. The hotspots of the study area are shown in Figure 9.

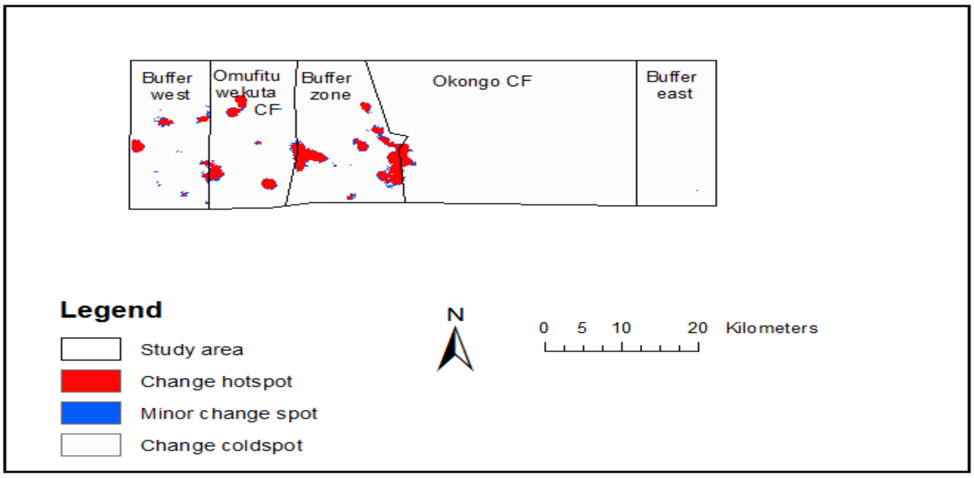

Figure 9: Hotspot detection in Okongo CF and areas outside Okongo CF

The results show that changes (both minor and major hotspots) are concentrated in the west of the study area which includes the western buffer zone, Omufitu Wekuta CF, the central buffer zone and a small portion at the western part of Okongo CF while the eastern buffer zone had no changes. Therefore, it can be noted that major hotspots of land cover changes are both in unprotected areas (western buffer zones and central buffer zones) and protected areas (Omufitu Wekuta and Okongo CF) (Figure 9). The hotspots of land cover change are more expanding in Okongo CF and this indicates that new development took place in the CF as carpentry trees workshop, health clinic and the police station office (personal communication). The existence of hot spots of prevalent land cover changes can be attributed to human activities that include clearing land for agriculture, clearing land for settlement, and cutting down trees for timber and firewood. Land clearing for cultivation converting woodland for farming practices and household construction is a common practice in the north and north-eastern Namibia where almost 60% of Namibia's population lives in rural areas (Watts 2003) (Mendelsohn 2009). This is also the case with some parts of the study areas especially from central to the western parts where the rural communities depend on agriculture as their source of living. Few hotspots for land cover changes in the Okongo CF can be a result of effective protection of forests and good forest management.

4.2.4 Patch density (PD)

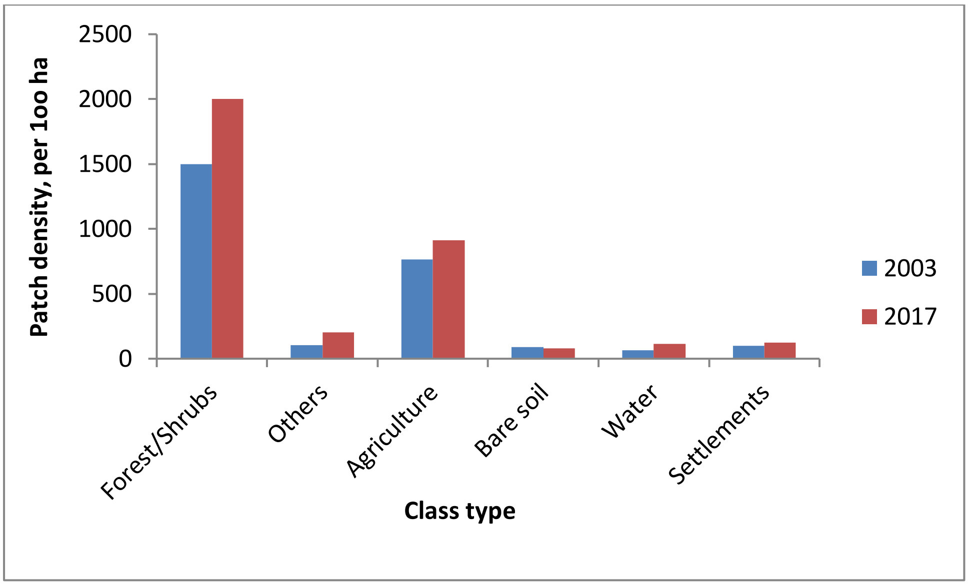

Figure 10: Patch density in the study area

The results shown in Figure 10 indicate that the patch density generally increased for nearly all land use and land cover classes except for bare soil. This is an unwanted negative trend according to sustainable land management considering the negative consequences such as increased runoff, accelerated soil erosion, loss of soil fertility and desertification. PD for forest/shrubs was recorded in 2003 (1500 ha) and increased in 2017 (2001 ha). A class with a greater density of patches indicate that it is subdivided into many patches and thus could be considered more fragmented in the study area. Similarly to this study, PD was also increasing in communal areas during 1984 - 1991 and 1991 - 2000 in the Zambezi region (Kamwi *et al.* 2017a). The increase in PD period is caused by human interference in demands of forest resources, and social developments. Additionally, the results showed that the agriculture class has a higher number of patches per ha in 2017 (914) than in 2003 (763). However, this can be a result of increasing the expansion of agricultural practice such as cultivation and expansion of fencing in the study area. The agricultural practice was found contributing to the loss of biodiversity, habitat destruction, and displacement of wild animals. The rise shows further destruction over this period giving increase to isolated landscape patches which might lead to affect ecological processes through the loss of connectivity. For the rural communities that are based in the study area, fragmentation is a great concern since it creates a natural imbalance in the relationship of the distribution of natural resources in which they depend (Gaespenu and Associates 1996). Besides, forest fragmentation disturbs the dynamic forces of species and material in the landscape and this may also contribute to the extinction of most valuable species (Forman 1995).

4.2.5 Largest patch index (LPI)

The LPI calculates the percentages of total landscape area comprised of the largest patch. The patch analysis (LPI) in the study area showed a decrease in the forest/shrubs class in 2017 in comparison with 2003 (Table 8). Based on the results, the decrease in LPI indicates that there is a reduction in forest/shrubs and this could be a result of deforestation. Other classes such as agriculture, settlements, water, bare soil, and others cover the small area during 2003 and 2017. These results show that the LPI (forest/shrubs) has a greater dominance as it represents more percentages of the total area during 2003. This greater dominance of forest/shrubs in 2003 could be due to the lower numbers of human population density that may cut trees for their households and fences in the study area and do national and international wood marketing. For instance, whereas agricultural land has reduced, forest/shrubs land increased during 2003 and 2017. The decrease in LPI is not in the Ohangwena region of Namibia alone. A study in the Zambezi region on land use also found that LPI decreased in the communal area of Zambezi region during the 1984-1991 and 1991-2000 (4.9 % to 2.3 %) then had a greater increase in 1991-2000 and 2000-2010 from 2.3% to 12.6% (Kamwi *et al.* 2017a).

Table 8: Largest patch index in the study area

Largest Patch Index, %		
Class type	**2003**	**2017**
Forest/Shrubs	96.5336	94.2277
Others	0.0365	0.2432
Agriculture	0.2034	0.0045
Bare soil	0.0714	0.0113
Water	0.0006	0.0917
Settlements	0.032	0.1081

4.2.6 Interspersion and juxtaposition index (IJI)

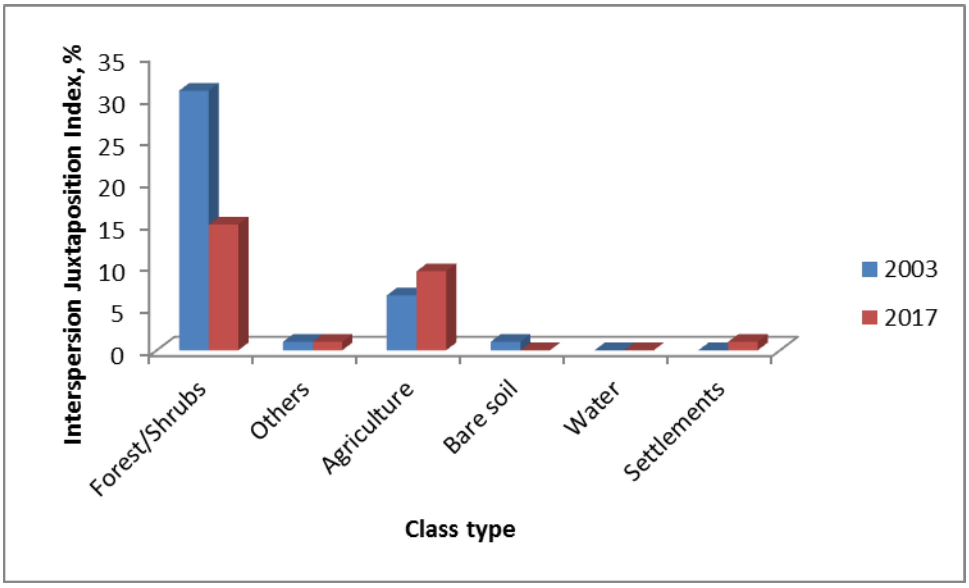

Figure 11: Interspersion and juxtaposition index in the study area

The results shown in Figure 11 above indicates that the IJI decreased for forests/shrubs and bare soil with a more considerable decrease for forests/shrubs. The increase in IJI is high in agriculture with a slight increase in settlements.

The arrangements of landscape patches in the Okongo CF and the area outside the CF were evaluated using the IJI landscape metric. IJI approaches 0 when adjacencies are unevenly distributed, IJI = 100 if all patch types are equally next to all other patch types. It is observed that there was less uniformity arrangement of the landscape during 2017. That means the patches were not regularly distributed in the study area. However, for 2003, IJI was higher for forest/shrubs than in 2017 and thus indicates a more uniform spatial distribution of the land cover types, especially for forest/shrubs land. The decrease in IJI indicates that the adjacencies of patches were more slightly distributed in the landscape and is attributed to the decrease in PD. Kamwi *et al.* (2017a), found a decrease in IJI from 1984-1991 and 1991-2000 in the Zambezi region and these results indicated a less uniform configuration in a study area. However, IJI started increasing in the communal area from 1991-2000 to 2000-2010 and this indicating the more uniform spatial distribution of the land use land cover.

The less uniformity arrangement of the landscape patches in 2017 indicates that there is fragmentation in the study area. This occurs as human activities have forced their way through forests, leaving behind small patches and contributing to the decline and loss of species diversity (Noss 1994). This results in a decrease in the number of resources and shelter areas available to fauna and therefore leads to the reduction in the number of individuals that can be hosted (Schmiegelow and Mönkkönen 2002). Therefore, forest protection should be strictly applied in the study area to eliminate subdivision of forest patches. This negative consequence of forest fragmentation can be done by preventing invasive species from colonizing the forest land. When the invasive species increase in population, they can alter the structure and species composition of the ecosystem by replacing the native species. To avoid this, a balance between timber harvesting and sustainable use of forestry products should be maintained. Over-exploitation of forest resources should not be done in both communal and protected areas. A study by Oldeland *et al.* (2010), reveals that land-use practices affect the amount and spatial pattern of woodland habitats, which affect the ecological function and future development of that specific habitat.

4.3 Changes in forest composition

This section presents the results of the analysis of forest composition changes in Okongo CF. This addresses the last and third objective of the study meant to monitor major changes (trends) in both species and structural composition of Okongo CF since gazettement. The results are from the analysis of forest inventory data for the year 2000 and year 2015 derived from the Ministry of Agriculture, Water and Forestry in Namibia. The results of forest composition changes analysis presented in this section include analysis of the mean DBH, DBH distribution of timber tree species, stems densities, mean DBH of timber tree species, basal area per hectare and Species composition.

4.3.1 Mean DBH

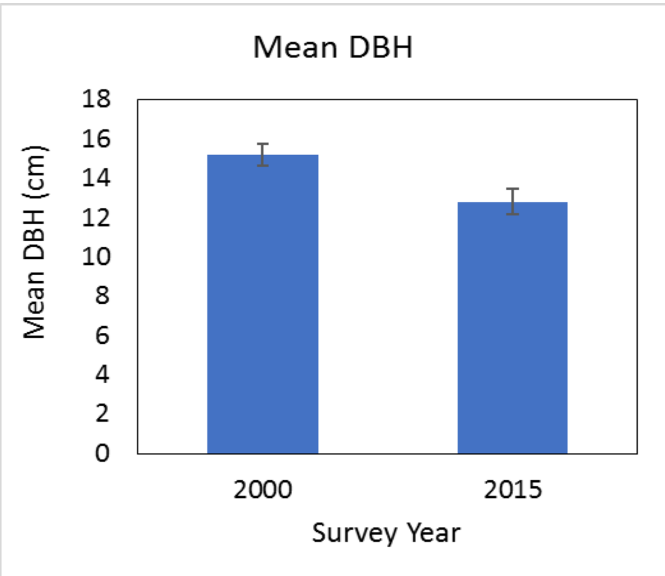

Figure 12: The mean DBH measured in the 2000 and 2015 inventory

Figure 12 shows that the mean DBH of 15 cm for all measured tree species in 2000 was significantly higher than the mean DBH of 13 cm in 2015 (Paired t-test; df = 59; T-value = 3.05; p-value = 0.003). DBH is an important growth parameter often used for the estimation of the productivity of forests (Sumida *et al.* 2013). A significant decrease in mean DBH indicates changes in forest structure. A decrease of mean DBH may indicate a decrease in tree size whereby large trees have been harvested leaving younger trees. The changes of trees mean DBH in the study area may have occurred due to the reduction of rainfall patterns over the years, fire frequency and changes in environmental temperature. An increase of temperature under climate change might increase evapotranspiration and reduce soil moisture which further limiting plant growth (Yang *et al.* 2003). A study by Yang *et al.* (2006) found that the warmer temperature is a major factor in reducing trees DBH. Increased in temperature is however primarily associated with a negative effect on tree growth because it can increase respiration rates .Hébert *et al.* (2016) found a significant increase in DBH growth for different trees species with a low number of trees per hectare, due to a better tree crown development. So, the higher number of trees per ha has a negative impact on DBH growth of the tree. That means fewer trees per ha accelerates diameter growth of individual trees. Trees with a greater height advantage than their neighbours exhibited more radial growth than individuals of lower stature and likely also exerted a greater competitive effect on their neighbours. Trees growing near many competitors of larger DBH showed reduced growth relative to trees under less competitive conditions (Wright *et al.* 2018).

4.3.2 Diameter distribution for timber species

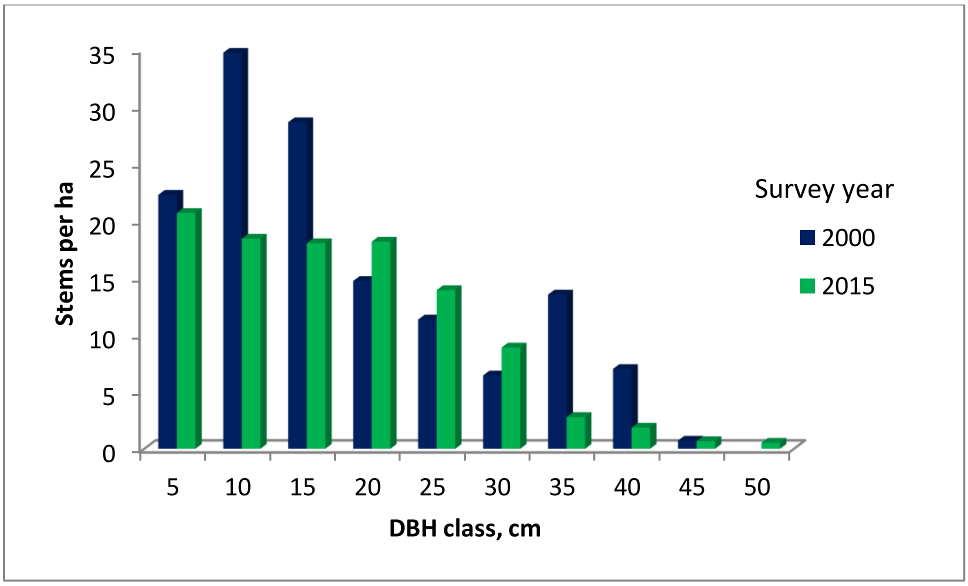

Figure 13: DBH class distribution of timber tree species for the year 2000 and 2015 inventory results

The results show an increase in the number of stems per ha within medium DBH classes of 20cm to 30cm only while the rest experienced a decrease in the number of stems per ha. Those that experienced a decrease in stems per ha include those with a DBH of 5cm to 15cm and a DBH of 35cm to 45cm. The results suggest a high number of tree species at medium DBH of 20cm to 30cm and lower number of tree species at smaller DBH and at larger DBH. The decrease in the number of stems per ha for DBH class 10cm and 15 cm can be as a result of an uncontrolled forest fire and over-harvesting of smaller trees in the study area that can be used for poles and droppers. A reduction in the number of stems per ha from 40 cm - 45 cm diameter class was recorded and this is the size of stems whereby people would largely cut. Also, forests near human habitations are highly degraded by firewood collection and cattle grazing, this may lead to poor plant diversity in the area (Jayakumar and Nair 2013). This way, local people are also disturbing the forest floor and contributing greatly towards biodiversity loss. Additionally, all changes in the number of trees per ha can be due to timber harvesting. It can also be as a result of a clear cut that may destroy younger trees or due to the establishment of fire cutlines, access roads and settlements in the CF. The decrease in the number of stems per ha can also occur due to some environmental factors. A study by (De Cauwer *et al.* 2016c) in patterns of forest composition and their long term environmental drivers in the tropical dry forest transition zone of southern Africa has specified that abiotic factors appeared to have more effects on forest composition than anthropogenic factors.

The data did not fit a normal distribution and an equivalent non-parametric test (Mann-Witney U test was carried out. The test results (U=44.5, p=0.684) indicate that there was no significant difference in the distribution of frequencies across the 2000 and 2015 inventories since the p-value is 0.684 above the alpha risk of 5 per cent (0.05). According to Buthmann. (2019), if the p-value is below the usually agreed alpha risk of 5 per cent (0.05), the null hypothesis can be rejected and at least one significant difference can be assumed. A recent study by Kabajani (2016) on an assessment of the natural regeneration of valuable woody species in the Kavango regions of north-eastern Namibia found that the DBH distribution of timber species are highly concentrated on smaller and medium DBH classes than in the larger diameter classes (Kabajani 2016). This is similar to the results of this study.

The desired diameter distribution from the timber management point of view is one where the bulk of the stems are in the lower diameter classes, and the number of stems gradually decreasing as the diameter gets bigger (MET 2000). The bulk of the stems are observed in the small and medium diameter classes and there are few timber tree species within the harvestable DBH of 45 cm. With this preferred distribution, there is continuously going to be trees reaching into the mature stages and allowing the continuous harvest of timber. If the actual diameter distribution deviates from the desired one, it is bound to affect short or long term management decisions (MET 2000). Timber trees are picked based on diameter class, and it is specified that only trees with a diameter from 45 cm may be picked lawfully (Van Holsbeeck *et al.* 2016). Van Holsbeeck *et al.* (2016) found that timber species are slow-growing and mature at around 100 years and above hence it is vital to have regulations to ensure sustainable utilization of the timber species and other woody species. In Zambia trees of more than 30 cm diameter were reported to be severely harvested. However, the results showed that there is no individual record in the DBH classes between 50 cm-54.99 cm in 2015. This could be an indication that the stems of such size DBH classes have been harvested for their timber values. It is essential to ensure that some larger stems are remaining when harvesting take place. Keeping different tree species of different ages and size will provide a diversity of habitat features for wildlife. Also, bigger trees provide more food resources and nesting opportunities and produce more nectars, foliage and fruits than younger trees. Additionally, the deep roots of bigger trees are able to tap into deep seated nutrients and recycle them at the soil surface as litter, pollen and other materials. This is some of the aspects to be considered by forests management when deciding on the total allowable cuts (TAC).

4.3.3 Stem densities

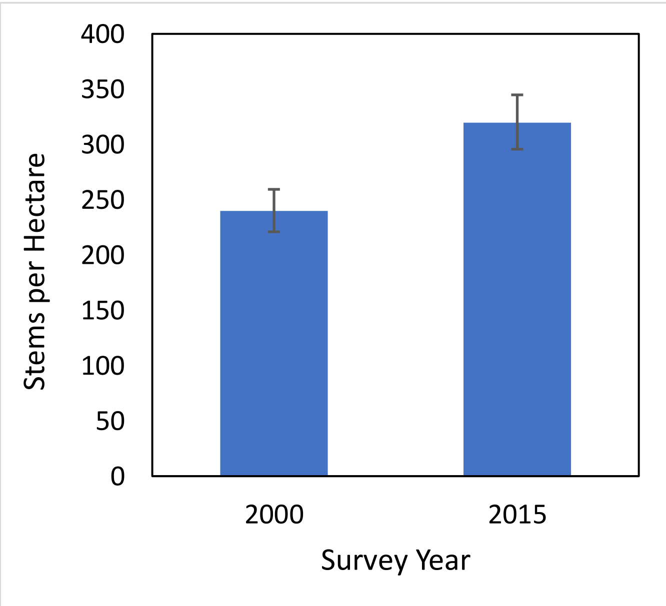

Figure 14: Stem densities for the year 2000 and 2015

The study found a low count of stems per hectare of 250 in 2000 inventory as compared to 2015 inventory with 300 stems per hectare. The numbers of stems per hectare measures stand density. A Paired t-test was carried out to find out if there is a difference in stems per hectare between 2000 and 2015. The results of the t-test (Paired t-test; df = 59; T-value = 2.37; p-value = 0.021) showed that there is a significant different of stems per hectare in 2000 and 2015 inventory. However, the number of stems per hectare was increased in 2015 than in 2000. The increase in numbers of stems per hectare can indicate that there were bigger trees that can produce sufficient numbers of seeds. Additionally, the higher number of trees per ha in 2015 indicates that most of the tree species were at the regeneration phases during the 2000 inventory.

4.3.4 Comparison between the mean DBH of timber tree species

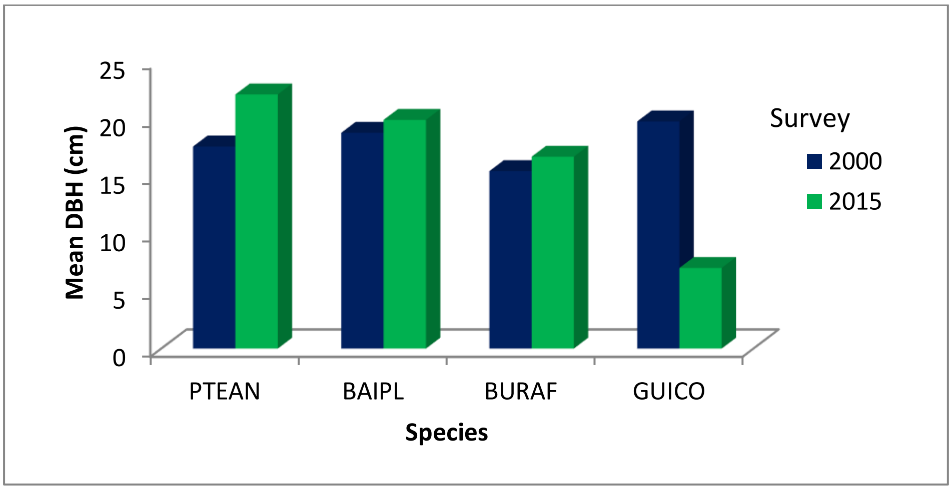

Figure 15: Mean DBH per ha of timber tree species for 2000 and 2015 inventory.

The results show a general trend of increase of mean DBH for *P. angolensis* (PTEAN) (18 cm to 22cm), *B. plurijuga* (BAIPL) (19 cm to 20 cm) and *B. africana* (BURAF) (15cm to 17cm) while only *G. coleosperma* showed a large decrease in mean DBH (20cm to 7cm). Increase in mean DBH for *P. angolensis*, *B. plurijuga* and *B. africana* may indicate low demand for exploitation hence they are not much harvested while a decrease in mean DBH for *G. coleosperma* may indicate a high rate of harvesting of large trees leaving less harvestable small trees. Additionally, it can also be a lack of regeneration of *P. angolensis*, *B. plurijuga* and *B. africana* in the study area.

To find out whether there is a difference in mean DBH between the year 2000 and 2015, the mean DBH of all timber tree species of the two datasets were statistically compared. Also, the statistical test was not done per each timber species. However, the results showed that the mean DBH of timber tree species for 2000 and 2015 inventories were not normally distributed (see appendix A). Therefore, the Wilcoxon test was used to test for the normal distribution of all timber species and the results indicated that the mean DBH of timber in 2000 was not significantly different in 2015 (Wilcoxon test; z=-0. 365 p=0.875).

Generally, the changes in mean DBH for selected tree species have indicated that the decrease of mean DBH for the *G. coleosperma* species due to harvesting of mature trees leaving the smaller ones dominating the forest. Therefore, this suggests that large and mature *G. coleosperma* species have been highly exploited.

4.3.5 Basal area per hectare

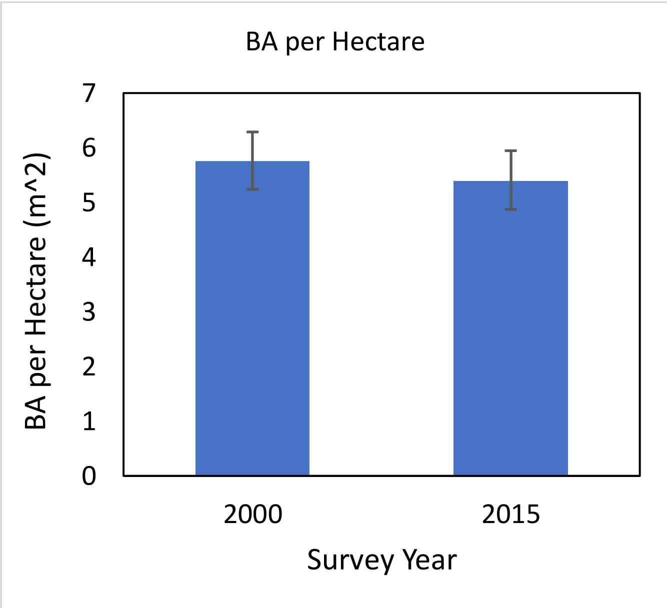

Figure 16: Basal area per hectare for measured trees in 2000 and 2015

Basal area is a useful parameter for forest managers to describe the area occupied by tree stems. As with the tree count estimates, the BA gives estimates per hectare for all tree species in the Okongo CF and are presented in figure 16. There is no significant difference between the BA of 2000 and 2015 inventory (BA per hectare; paired t-test: df = 59; T-value = 0.33; p-value = 0.737). The results show a very slight, but non-significant decrease of basal cover from 5.7 m^2. ha in 2000 to 5.3 m^2. ha in 2015. This suggests that despite a significant decrease in mean DBH and a significant increase in stem density, the basal area did not change. So, what has been removed has been replaced. This means that there is a sufficient number of small trees in the forest that substitute the bigger DBH class.

The BA of 2000 and 2015 tells how the forest area is occupied and this will assist in making timber harvest decisions. A greater BA markedly decreases ground cover and slows timber growth (Steve 2020). Also, a higher BA may lead to a decrease in tree growth and vigour from the increased competition for crown space, nutrients and moisture. Based on the results, it is promising that the sunlight will hit the ground that promotes the growth of grasses, forbs and shrubs that provide important food and cover for some species of wildlife. The results showed that no thinning is required in the CF since the BA is not too higher, the spacing between tree species remain constant and this is avoiding competition. The study also found that the BA has no negative impact on tree growth. There are no larger trees that can be at a competitive advantage over smaller trees. When small trees shaded by taller neighbours they grow slowly as a consequence, while larger trees will less be affected by shading.

4.3.6 Species composition

The study also ran an analysis of species composition across the two inventory years (2000 and 2015) and the results show that not all the same tree species were recorded in each year. In total there were 29 species recorded in 2000, and 32 species recorded in 2015, with a total of 43 species recorded over the two years (Appendix D and E). However, there were 10 species recorded in 2015 that were absent in 2000, and 8 species recorded in 2000 that were not present in 2015 (*See table 9*) and about 20 tree species recorded in both years (Appendix F).

Table 9: Total number of trees absent in 2000 and 2015

Species absent in 2000	Species absent in 2015
Combretum apiculatum	*Combretum psidioides (psidioides)*
Spirostachys africana	*Ozoroa schinzii*
Philenoptera nelsii	*Ozoroa paniculosa*
Berchemia discolor	*Ozoroa longipes*
Strychnos spinosa	*Combretum engleri*
Commiphora africana	*Diplorhynchus condylocarpon*
Commiphora glaucescens	*Ochna cinnabarina*
Acacia melliferas ubsp.detinens	*Pavetta zeyheri*
Baphia massaiensis	
Combretum imberbe	

It is unclear why so many trees species are not recorded in both inventory years. One of the likely reasons is bush encroachment. Other explanations may include bush encroachments and at times a human error of omission or misidentification during the time of the survey. For example, this study found that there were no individual records of *C. apiculatum* in 2000 which were recorded in 2015 (Table 9). The study also found that *Combretum psidiodes* was a fairly common species in 2000 but there were no individual records in 2015 (Table 9). All trees that are not recorded in both 2000 and 2015 they are distributed in the study area according to tree atlas of Namibia (Curtis and Mannheimer 2005).

There is also a change in the stem densities of the most common tree species present in the two years of recording (Table 10). For example, *B. plurijuga*, the most common species in 2000, is the third most

common species in 2015 but has half the number of stems per hectare compared to 2000 (t-test on log-transformed data: d.f. = 118; t= 2.31; p = 0.022). Similarly, *P. angolensis* had half the number of stems per hectare in 2015 as in 2000 (24 compared to 40) but values did not differ statistically (df = 118; t-value = 1.35; p = 0.178).
In contrast, *C. collinum* and *T. sericea* increased in abundances since 2000, approximately doubling by 2015 (df = 118; Cc t-value = 2.09; p=0.039; Test statistics t-value = 2.25; p=0.027). This means there is a significant difference in abundance of *C. collinum* and *T. sericea* tree species of 2015 inventory in comparison with 2000 inventory.

Another study has found that *T. sericea* is the pioneer tree species that grow faster in comparison with *B. plurijuga, P. angolensis* and *B. africana* (Van Holsbeeck *et al.* 2016) and this study is also supporting it based on the tree abundances in the study area (Table 10). Other studies stated the highest % in species composition were *P. angolensis* found in the Okongo and Katope CF (Nott 2014) while recorded second highest in 2000 and 7th in 2015 inventories. *G. coleosperma* has a low tolerance for fire (Burke 2006) and this may be one of the contributors to the decline in stem density in the study area. Forest fire and expansion of land for agricultural practises have been previously found as a major threat (Mendelsohn and Obeid 2005). However, the results of this study can support it since the tree species have a good record in composition. However, it is concluded that the distribution of *P. angolensis* can decline due to climate changes as a result of the reduction of rainfall and changes in seasonal temperature (De Cauwer *et al.* 2014).

Also, of note is the large and significant increase in stems per hectare seen for *Combretum zeyheri* from 7 in 2000 to 26 in 2015 (d.f. = 118; Cc t-value = 2.39; p=0.018).

Table 10: Stem density in Okongo CF in number of stems per hectare

Species Name	Species per hectare		Stems per Hectare	Rank in year	
	2000	2015	Mean across years	2000	2015
Baikiaea plurijuga	60	28	44	1	3
Combretum collinum	24	52	38	5	1
Terminalia sericea	25	43	34	4	2
Pterocarpus angolensis	40	24	32	2	7
Burkea africana	28	28	28	3	4
Combretum zeyheri	7	26	17	11	6
Erythrophleum africanum	13	14	14	6	8
Combretum apiculatum	0	28	14	NA	5
Lonchocarpus nelsii	10	4	7	7	16
Guibourtia coleosperma	8	7	7	10	10
Schinziophyton rautanenii	10	15	13	8	19
Combretum psidioides	8	0	4	9	NA

The trends shown are more likely to be the result of differences in means DBH in 2000 and 2015 inventories. Those that are on high demand for construction, wood carving and firewood may decrease significantly while those on low demand may increase.

CHAPTER 5: CONCLUSION

5.1 Introduction

This study aims to assess changes in land cover and forest composition in Okongo CF in Namibia. The study was guided by the following objectives:

- To compare land cover changes for the period 2003 – 2017 between Okongo CF and areas outside Okongo CF, especially the remaining part of the Okongo conservancy, which includes Omufitu Wekuta CF (declared in 2013);
- To identify and assess areas where the land cover changes are most prevalent (hotspots) and examine the Spatio-temporal changes in landscape composition and configuration between 2003 and 2017 in Okongo CF and areas outside Okongo CF;
- To monitor major changes (trends) in forest composition of Okongo CF since it was gazetted.

The study was achieved through a literature review as a secondary study and a primary study involving the collection and analysis of both primary and secondary data. Considering the literature reviewed in Chapter 2 and the results of analysed data in chapter 4, this chapter concludes the research study and gives recommendations for future action.

5.2 Conclusions

The study concludes that it is mainly agriculture, bare soil and forest/shrubs that changed over the period between 2003 and 2017. The central buffer zone showed a large area that was converted to agricultural land (6.34%) than any other parts of the study area, followed by buffer west (4.56%) and Omufitu Wekuta CF (3.91%). The Okongo CF and the buffer east had a small area that was converted to agricultural land. Also, bare land decreased (-0.62 %) in Okongo CF, (-0.16%) in the central buffer zone, (-0.12%) in buffer west and showed a slightly increased in the buffer east (0.02%) and Omufitu Wekuta CF (0.10%). However, this study concludes that Okongo CF has experienced more declined in bare land class (-98.1%) compared to other parts of the study area. The study further concludes that there is an utmost decrease in forest/shrubs area in the central buffer zone (-6.53%), buffer west (-4.41%), Omufitu Wekuta CF (-4.34%) with a slight change in the buffer east (-0.08). It is also concluded that an area of forest/shrubs (0.21%) was restored in Okongo CF.

The study also concludes that 0.67% of the study area was converted to settlements. It can be attributed to the clearing of land for agriculture that reduced forest/shrubs at the same time increasing bare soil. Additionally, the study concludes that the eastern part of the study area (includes Okongo CF and the buffer east) shows hardly change in forest/shrubs cover and agriculture. This cannot only be due to the gazetting of Okongo CF; it can be as a result of fewer people that live in the area hence the minimal disturbance.

The main driving forces of land cover changes are the increasing population density, socio-economic factors such as competition for space in the study area due to increasing demand for land for agriculture and increasing demand for forest products for firewood and timber for construction. Furthermore, it can be concluded that minor and major hotspots areas for changes in land cover are concentrated in the western part of the study area. This study also concludes that the hotspots of land cover change are more expanding in Okongo CF. The existence of hot spots of land cover changes can be attributed to human activities that include clearing land for agriculture, clearing land for settlements, and cutting down trees for timber and firewood. PD for forest/shrubs class was recorded in 2003 (1500 ha) and increased in 2017 (2001 ha). Additionally, it is concluded that the agriculture class has a higher number of patches per ha in 2017 (914) than in 2003 (763). Largest patch index has a greater dominance as it represents more percentages of the total area during 2003 (96.5%).

The forest inventory data was used to compare forest structure and species composition in 2000 and 2015 and from the results, it can be concluded that the mean DBH of all measured tree species in 2000 inventory was significantly higher than the mean DBH of 2015 inventory (p-value = 0.003). The study also concludes that there were no significant differences in the distribution of frequencies of timber tree species across the 2000 and 2015 inventories (p=0.684). The stem density increased from 2000 (250) to 2015 (300) (p-value = 0.021). It is however concluded that the BA of 2000 and 2015 did not significantly change (p-value = 0.737), hence a shift to smaller DBH classes has taken place. There is a general trend of increase of mean DBH for *P. angolensis* (18 cm to 22cm), *B. plurijuga* (19 cm to 20 cm) and *B. africana* (15cm to 17cm) while only the *G. coleosperma* showed a decrease in mean DBH (20cm to 7cm). The Wilcoxon test was used to test for the normal distribution of all timber species and the results indicated that the mean DBH of timber in 2000 was not significantly different in 2015 (Wilcoxon test; z=-0. 365 p=0.875). Furthermore, not all the same tree species were recorded in each year. In total there were 29 species recorded in 2000, and 32 species recorded in 2015, with a total of 43 species recorded over the two years. There is a change in the stem densities of the most common tree species present in the two years of recording. *B. plurijuga*, the most common species in 2000, is the third most common species in 2015 but has half the number of stems per hectare compared to 2000 ($p = 0.022$). *P. angolensis* had half the number of stems per hectare in 2015 as in 2000 (24 compared to 40) but values did not differ statistically ($p = 0.178$). *C. collinum* and *T. sericea* increased in abundances since 2000, approximately doubling by 2015 ($p=0.039$; $p=0.027$). A large and significant increase in stems per hectare was seen for *Combretum zeyheri* from 7 in 2000 to 26 in 2015 ($p=0.018$).

It is concluded that the major changes (trends) in forest composition of Okongo CF since gazettement is that, both of the bare land class and area converted to bare land had decreased drastically compared to the other parts such as the buffer west, Omufitu Wekuta CF, the central buffer zone and the buffer east of the study area. The study also concluded that there is a remarkable increase in forest/shrubs class and the area converted to forest/shrubs in Okongo CF than in Omufitu Wekuta CF, the buffer west and the central buffer zone. Additionally, it is also concluded that only a small area of the Okongo CF was converted to agricultural land, while the large part of the area remains forest/shrubs land.

5.3 Recommendations

Considering the results in chapter 4 and the conclusions in the above section in this chapter, the following is recommended:

- MAWF through its DoF should extend strategies employed in Okongo CF to Omufitu Wekuta CF to realise positive gains achieved in Okongo CF since its gazettement. However, this may be difficult to be implemented because of the higher population density around Omufitu Wekuta CF and more land is already converted into agricultural land.
- Indigenous forests plantations can be proposed and implemented in hotspot areas of the study area including the West buffer zone, Omufitu Wekuta CF, Central buffer zone and Okongo CF as an alternative to natural forests since Namibia lacks alternative sources of timber tree species.
- Educating people living in the communal areas around Okongo must be introduced to increase awareness to people on the importance of conserving forests and the negative effects of illegal harvesting, veldt fires and over-exploitation of forest products for timber and firewood. Such efforts for mass education of local people must be in local languages for effective communication.

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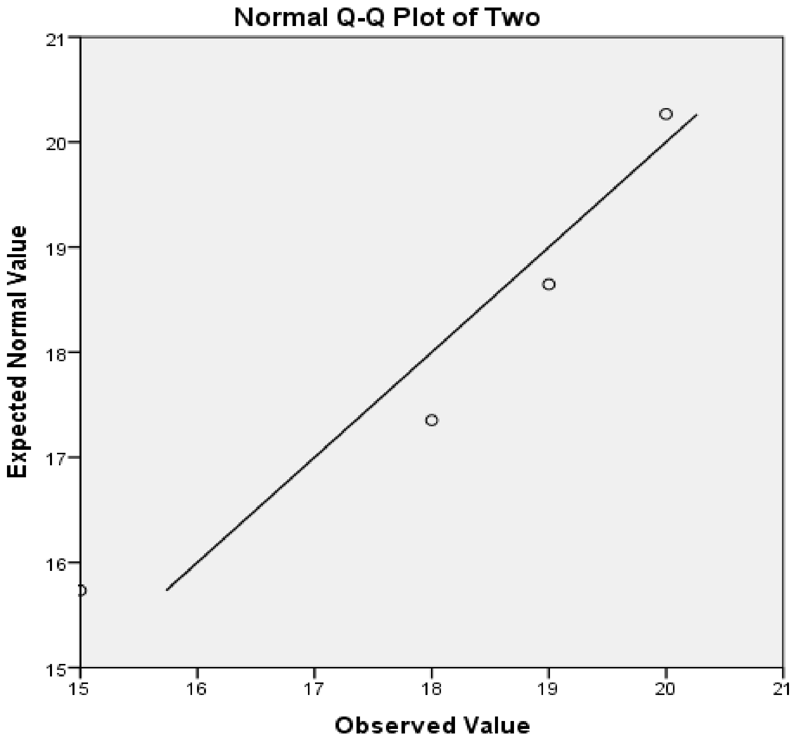
APPENDICES

Appendix A: The Q-Q plot for normally distribution between mean DBH of timber tree species



Q-Q plot normal distribution for the mean DBH of timber tree species for 2000 and 2015 inventories.

Appendix B: Coordinates of 2015 inventory

2015		
Plot No	Latitude	Longitude
1	-17.4979	17.7348
2	-17.4842	17.7348
3	-17.47099	17.73489
4	-17.4575	17.7346
5	-17.4436	17.7349
6	-17.4299	17.7347
7	-17.48861	17.98869
8	-17.4749	17.9886
9	-17.40119	17.9887
10	-17.4475	17.9886
11	-17.4338	17.98881
12	-17.42	17.9883
13	-17.41172	17.89622
14	-17.4117	17.9105
15	-17.4116	17.9246
16	-17.4116	17.9383
17	-17.4116	17.9525
18	-17.4115	17.9662
19	-17.4168	17.7707
20	-17.41681	17.7844
21	-17.4169	17.79841
22	-17.4169	17.8124
23	-17.4169	17.8264
24	-17.4176	17.8403
25	-17.45319	17.77056
26	-17.4534	17.78423
27	-17.4533	17.7984
28	-17.4534	17.8122
29	-17.45312	17.8263
30	-17.4532	17.84021
31	-17.4899	17.7704
32	-17.4899	17.7845
33	-17.4898	17.7482
34	-17.4899	17.8124
35	-17.4899	17.8263
36	-17.4898	17.8406
37	-17.5317	71.7738
38	-17.5318	17.7878
39	-17.5316	17.8018
40	-17.5318	17.8156
41	-17.5319	17.8296
42	-17.5318	17.8439
43	-17.5681	17.7735

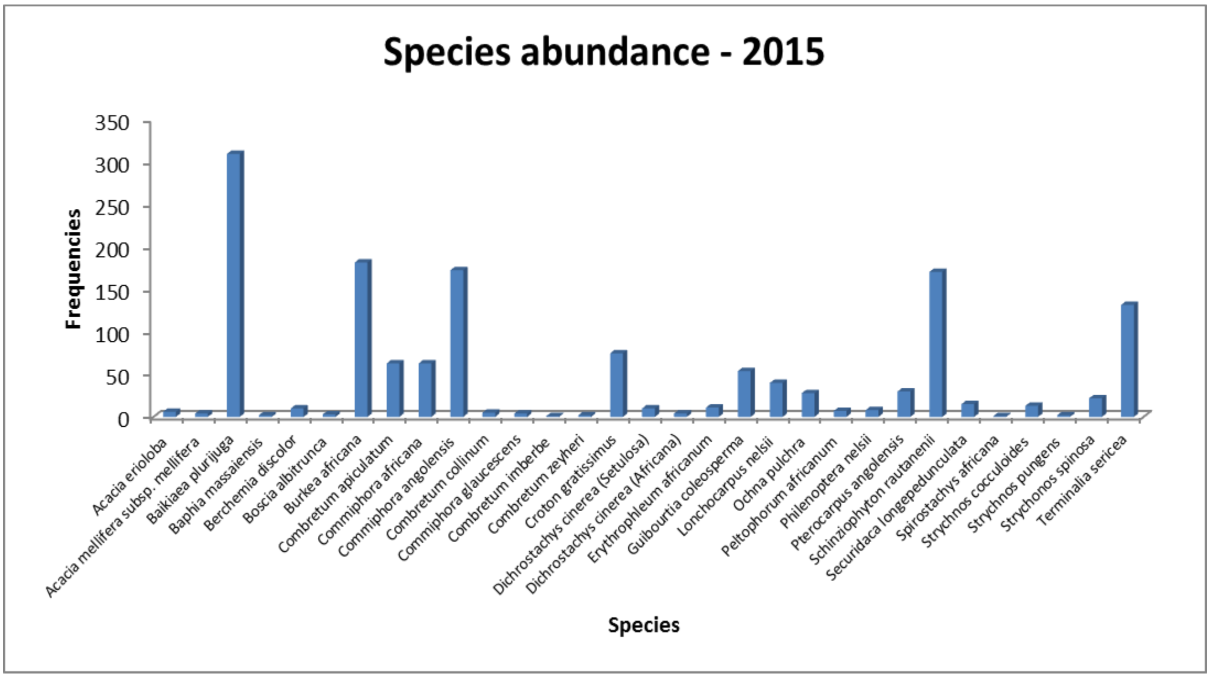
44	-17.5683	17.7878
45	-17.5681	17.8016
46	-17.5682	17.8156
47	-17.5681	17.8291
48	-17.5681	17.8435
49	-17.6045	17.7733
50	-17.6046	17.7871
51	-17.6047	17.8011
52	-17.6047	17.8152
53	-17.6047	17.8291
54	-17.6046	17.8431
55	-17.5915	17.9894
56	-17.5684	17.9887
57	-17.5644	17.9888
58	-17.551	17.9887
59	-17.5374	17.9886
60	-17.5236	17.9886

Appendix C: Coordinates of 2000 inventory

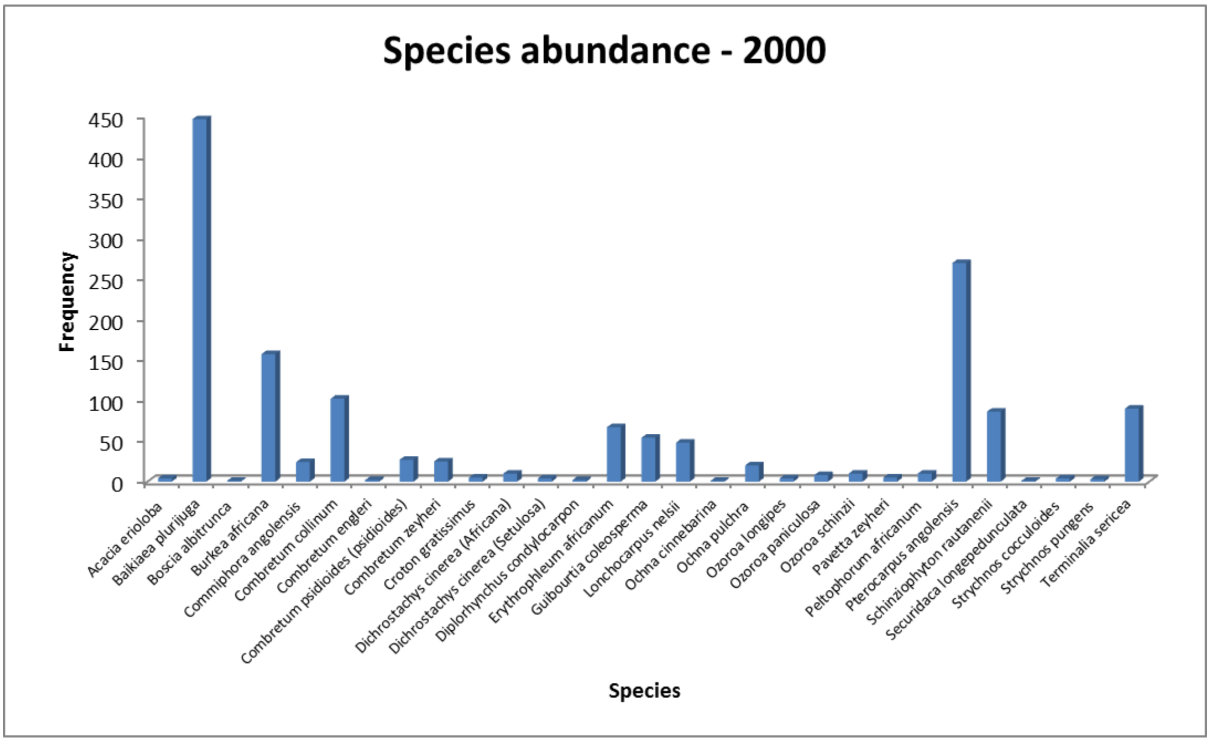
2000		
Plot No	Latitude	Longitude
1	-17.4979	17.7348
2	-17.4842	17.7348
3	-17.471	17.7349
4	-17.4575	17.7346
5	-17.4436	17.7349
6	-17.4299	17.7347
7	-17.4886	17.9887
8	-17.4749	17.9886
9	-17.4612	17.9887
10	-17.4475	17.9886
11	-17.4338	17.9888
12	-17.42	17.9883
13	-17.4117	17.8962
14	-17.4117	17.9105
15	-17.4116	17.9246
16	-17.4116	17.9383
17	-17.4116	17.9525
18	-17.4115	17.9662
19	-17.4168	17.7707
20	-17.4168	17.7844
21	-17.4169	17.7984
22	-17.4169	17.8124
23	-17.4169	17.8264
24	-17.4176	17.8403
25	-17.4532	17.7706
26	-17.4534	17.7843
27	-17.4533	17.7984
28	-17.4534	17.8122
29	-17.4532	17.8263
30	-17.4532	17.8402
31	-17.4899	17.7704
32	-17.4899	17.7845
33	-17.4898	17.7982
34	-17.4899	17.8124
35	-17.4899	17.8263
36	-17.4898	17.8406
37	-17.5317	17.7738
38	-17.5318	17.7878
39	-17.5316	17.8018
40	-17.5318	17.8156

41	-17.5319	17.8296
42	-17.5318	17.8439
43	-17.5681	17.7735
44	-17.5683	17.7878
45	-17.5681	17.8016
46	-17.5682	17.8156
47	-17.5681	17.8291
48	-17.5681	17.8435
49	-17.6045	17.7733
50	-17.6046	17.7871
51	-17.6047	17.8011
52	-17.6047	17.8152
53	-17.6047	17.8291
54	-17.6046	17.8431
55	-17.5915	17.9894
56	-17.5784	17.9887
57	-17.5644	17.9888
58	-17.551	17.9887
59	-17.5374	17.9886
60	-17.5236	17.9886

Appendix D: Trees abundance in 2015



Appendix E: Trees abundance in 2000



Appendix F: Tree species recorded in 2000 and 2015 inventories

Tree species across years (2000 and 2015)
Acacia erioloba
Baikiaea plurijuga
Boscia albitrunca
Burkea Africana
Commiphora angolensis
Combretum collinum
Combretum zeyheri
Croton gratissimus
Dichrostachys cinerea (Africana)
Dichrostachys cinerea (Setulosa)
Erythrophleum africanum
Guibourtia coleosperma
Lonchocarpus nelsii
Ochna pulchra
Peltophorum africanum
Pterocarpus angolensis
Schinziophyton rautanenii
Securidaca longepedunculata
Strychnos cocculoides
Strychnos pungens
Terminalia sericea

Appendix G: Size of class in Ha for Okongo CF 2003-2017

Class	**Year**	**Size of Class in HA**	**Class**	**Year**	**Size of Class in HA**
Agriculture	2003	714.6755994	Agriculture	2017	931.5827859
Bare soil	2003	485.3392196	Bare soil	2017	9.086000571
Forest/shrubs	2003	75026.17065	Forest/shrubs	2017	75189.15111
Others	2003	287.392268	Others	2017	290.3477657
Water	2003	0.458661232	Water	2017	21.19194056
Settlements	2003	17.35507181	Settlements	2017	115.0421247