Faculty of Bioscience Engineering

Academic year 2015 – 2016

Assessment of fire damage on the forest population near Hamoye, Kavango, Namibia

Maarten Schelstraete

Promoter: Prof. Dr. Ir. Jan Mertens

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Master thesis proposed to achieve the degree of Master of Science in Bioscience Technology: Agriculture and Horticulture

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Foreword

Writing a thesis is a serious task that asks a lot of time and energy. The support that I received to write the thesis helped me to acquire the result below. I want to use this foreword to thank all the people that helped me with the realization of this dissertation.

Firstly I want to thank my promoter Prof. Dr. Ir. Jan Mertens, he gave me the opportunity to go to Namibia for my thesis. I want to thank him for the advice and help he offered me during the writing of my thesis. Also the help with the statistical analysis was helpful.
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The Future Okavango project made it possible for me to do the fieldwork in Namibia. I want to thank the project for the financial support of the fieldwork. Also the Directorate of Forestry (DoF) and Namibian University of Science and Technology (NUST) have my appreciation. The DoF provided me with accommodation and the opportunity to use an office, thank you. NUST provided a 4x4 that could be used during the fieldwork and the university also provided the material to do the fieldwork and arranged my study permit, thank you.

Miya Kabajani a student at NUST helped me with the fieldwork, she taught me the species of the woodlands and showed me around in Kavango and Windhoek. Thank you Miya for helping me!
I would like to thank all the employees of the forestry station of Hamoye for the support and help during my stay. They also helped me with fieldwork during the absence of Miya.

Last but not least, I want to thank my parents, family, friends and girlfriend for the support, trust, patience and believe.

Abstract

The dry forests and woodlands of the northern Kalahari are of great importance for the local inhabitants of the eastern Kavango, Namibia. But large areas of these forests are burned down annually by forest fires. These forest fires occur naturally in these forests, but the frequency altered. More frequent fires result in less time for vegetation to regrow. The wood production is important in these forests, this study aims to (1) determine if there is a short term variation in tree composition and tree growth in State and Community forest, (2) if young and old trees are more susceptible to the impact of forest fires and if the fire frequency has a negative impact on the basal area and diameter distribution (3) determine the number of fires that affected the sample sites in the last 15 years. In two different forests, Community and State forest, plots were sampled. In each forest 33 plots were sampled. The data of 2015 was compared with the data collected in 2014 by a group of students. The results show that there is no change in stem number, basal area and standing stock on short term. There is an effect of the forest fire on the condition of the trees. The damage inflicted by fire rose significantly. No change in diameter composition was found. This study found no evidence that the forest fires decreased the basal area on short term. Burned area products and LANDSAT images showed that the forests knew forest fires every two years in the last 15 years. The plots in Community forest knew a higher average fire frequency, although it wasn't proven significantly. Only State forest had a single period of four years without forest fires.

Keywords: Forest fire; woodlands; vegetation; fire frequency

Samenvatting

De droge bossen en woodlands van de noordelijke Kalahari zijn van heel groot belang voor de lokale bevolking van de oostelijke Kavango, Namibië. Maar grote oppervlakten van deze wouden branden jaarlijks af door bosbranden. Deze bosbranden zijn onderdeel van de wouden en komen natuurlijk voor, maar de frequentie van de branden is te hoog. De hoge frequentie aan branden zorgen ervoor dat er minder tijd is voor de vegetatie om zich te herstellen. Houtproductie is belangrijk in deze wouden, deze studie tracht antwoorden te vinden op volgende vragen: (1) bepalen of er een variatie is in de samenstelling en groei van de bomen in State en Community forest, (2) of jonge en oude bomen gevoeliger zijn voor de impact van bosbranden en of de bosbrandfrequentie een negatieve impact heeft op stamoppervlak en diameter verdeling van de bomen, (3) het aantal branden bepalen dat de laatste 15 jaar in de plots gewoed hebben. In twee verschillende bossen, Community en State forest, zijn er gegevens vergaard in plots. In elk bos is er data verzameld van 33 plots. De gegevens van 2015 zijn vergeleken met de gegevens die verzameld zijn door een groep studenten in 2014. De resultaten geven aan dat er geen verandering is in stamnummer, stamoppervlak en houtvoorraad op korte termijn. Er is een effect gevonden van de bosbranden op de conditie van de bomen. Schade aan de bomen door brand steeg significant. Verandering in diameter samenstelling werd echter niet gevonden. De studie vond geen bewijs voor een daling in stamoppervlak door bosbranden op korte termijn. Burned area products en LANDSAT beeldden tonen ons dat de bossen zijn getroffen door bosbranden elke twee jaar in de laatste 15 jaar. De plots in Community forest kenden een hoger gemiddelde brand frequentie maar dit werd niet significant bevonden. Enkel State forest kende een periode van vier opeenvolgende jaren zonder bosbranden.

Sleutelwoorden: Bosbranden; woodlands; vegetatie; brand frequentie

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Abbreviations

ANOVA	Analysis of variance
BA:	Basal area (m^2)
CBH:	Circumference at breast height
CF:	Community forest
DBH:	Diameter at breast height
DoF:	Directorate of Forestry
DRC:	Democratic Republic of Congo
FAO:	Food and agriculture organization of the United Nations
FIRMS	Fire Information for Resource Management System
GNP:	Gross National product
GPS:	Global positioning system
MODIS:	Moderate-resolution Imaging Spectroradiometer
NTFP:	Non-timber forest products
SF:	State Forest
TFO:	The Future Okavango project
WAMIS:	Wide area monitoring information system

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1 Introduction

Namibia is known to have the driest climate of sub-Saharan Africa. The mean annual rainfall in Namibia is 270 mm. There is a big difference in rainfall in the country, the western parts an coastal zone of Namibia only receive a mean of 20 mm a year and at the end of the eastern Caprivi strip a mean of 700 mm rain can occur. 70% of the country is arid to semi-arid, meaning an annual rainfall ranging from 100 to 500 mm. During summer there is a wet season that stretches from November to March. In the wet season there is a high variation in rainfall all over the country, with drought condition as consequence (Sweet & Burke, 2006).

The dry forests and woodlands of the northern Kalahari (Giess, 1998) are of great importance for the local inhabitants of the eastern Kavango, Namibia. This strong dependency on the natural environment led to severe deforestation and land degradation along the Kavango River valley (Hofmeyr, 2004). The farmers make use of the destructive “slash-and-burn” to fertilize their fields, but soon these burned fields are abandoned, because the crop yield deteriorates with time. This forces the farmers to move and clear new lands (Mendelsohn & el Obeid, 2005). Most of the time land clearing is done with fire and these controlled fires are mostly left unattained, which causes the fire to spread into the forest and start uncontrollable and destructive forest fires (Frost, 1999).

Every year 34% of the Kavango region burns (Mendelsohn & el Obeid, 2005), mostly started by farmers to stimulate the fresh growth of grass for cattle, or clearing land for crop producing. This unnatural frequency of forest fires causes the trees to die. Seedling establishment becomes limited, the growth is decreased, nutrients are lost and cause reduction of soil fertility (Mendelsohn & el Obeid, 2005; Geldenhuys, 1977).

1.1 Problem statement

The Namibian woodlands are frequently affected by forest fires. In the Caprivi and Kavango regions, 28% to 51% of the land area burned annually during fire seasons in a period from 1989 to 2002 (Siljander, 2009). The woodlands are of great importance for the people living near it. Not only the resources that can be used directly (e.g. fire wood and fruits), but also the resources that provide indirect benefits (e.g. adding nutrients to the soil, tourism, the forest that provides a place for bees to produce honey, …) are very important for local economy and the survival for the local people (Mendelsohn & el Obeid, 2005). With fires destroying these forests on a frequent basis and the fact that the forests do not get enough time to regenerate, a very valuable ecosystem service could be gone lost. Since it is not known what the impact of fires is on the vegetation in the Hamoye State forest and Ncaute Community forest this study was conducted.

1.2 Aims and objectives of the study

The study aims to assess the short-term damage caused by forest fires on the forest population. This by resampling the sample plots during a period of July 2015 until August 2015 that were sampled by a group of students (University of Göttingen, Namibian University of Science and Technology (former Ploytechnic of Namibia) and the University of Stellenbosch) in 2014. And comparing the collected tree data of 2014 with 2015. A study of satellite images will be conducted to assess the fire frequency that affected the sample plots in a period from 2001 until 2015. These aims were accomplished by following these objectives:

- Is there a short term variation in tree composition and tree growth in State and Community forest.
- Are young and old trees more susceptible to the impact of forest fires?
- Determine if fire frequency has a negative impact on the basal area and does it affect the diameter distribution.
- Determine how many fires have affected the sample sites in the last 15 years and the seasons in which the fires took place.

2 Literature review

2.1 Importance of woodlands in Northern Namibia

2.1.1 Socio-economic aspect of the woodlands

It is estimated that 68% of the population of Namibia is supported by communal land (Ministry of Agriculture, Water and Forestry and Directorate of Forestry, 2005). in northern Namibia most of the land is communal land. Most of the poor households live in the forested communal areas in the north of Namibia. These households are depending on the resources the forest and land gives them. The communal land is important for an income. The non-forested land is used for growing crops such as millet and maize. Forested land provides the inhabitants with forest resources such as: fire wood, construction timber, food, medicine, crafts, materials and fodder. These resources are a part of the daily used product and therefore the woodlands are very important for the population (Barnes et al., 2010) (Björkman, 1991) (Barnes et al., 2005).

The communal forest is used very intensively, fire wood is collected as a main energy resource. Up to 20% of the produced energy in Namibia, is produced by fire wood. Which is slightly higher than the global average of 14% (Mendelsohn & el Obeid, 2005).The wood is gathered near the villages by the people when needed and they can collect as much as they need for living. The wood is used mainly for cooking. Because Namibia has cold winters, fire wood is also used to heat up the houses. For constructing houses and fencing of the cattle, wood is also collected out of the forest. Most of the wood collected out of the forest is for direct use, sometimes wood is sold in the bigger cities.

The economic interesting species that can be sold in the urban areas are *Pterocarpus angolensis*, *Baikiaea plurijuga*, *Burkea africana* and *Guibourtia coleosperma.* Although there is no commercial harvesting in northern Namibia, a lot of small scale harvesting is done by the local inhabitants for earning some money.
Non-timber forest products (NTFP's) are also an important food and income for the population. NTFP include fruits (eg. *Strychnos* fruits), nuts from the Manketti tree (*Schinziophyton rautanenii*), plant products for medicine and cosmetics, plants for carvings and making of baskets and thatch for constructing roofs (Björkman, 1991).
The grass and plants in the forest are also browsed by cattle, the large herds of cattle are send into the forest for browsing and then returned to their fenced area by nightfall (Barnes et al., 2010).

In 2005 Barnes et al. estimated a forest resource use of N$ 1.2 billion, in terms of the gross output. With a direct contribution of N$ 1 billion (N$ 1 = €0.056, exchange rate 2015) to the gross national product (GNP). This represents 3% of the GNP. This in comparison to agriculture 6.8%, fishing 5%, mining 6.8% and 6% tourism. This lower input must be taken relative, because only 10% of Namibia is forested. Barnes et al. (2010) included the total direct and indirect costs (eg. Transport), and had found that the GNP was at 1.8 billion. Fuel wood is with a value of N$610 million the highest forest resource value, NTFP's (N$ 283 million) and pole wood (N$ 157 million) complete the total GNP.

Namibia's standing forest assets (natural capital stock) was estimated at a value of N$ 19 billion. Which is a significant large amount in comparison to the manufactured capital stock (N$ 86 billion).

The northern regions of Namibia have a high contribution to the GNP, because the north has the highest density of forest. Kavango region contributes N$ 148.2 million to the GNP, other northern regions such as Ohangwena and Omusati contribute even more. This underlines the importance of the northern forested regions (Barnes et al., 2005).

Volumes of woody resources in Namibia range from 24 m^3 per hectare in the forests and 5 m^3 per hectare in other wooded lands. The total volume is estimated 166 million m^3 in forests and 43 million m^3 in other wooded land (FAO, 2015).

2.1.2 Forest in Namibia

According to the FAO (Food and Agriculture Organization of the United Nations) forest is defined as land that is covered by trees with a canopy cover greater than 10% and trees should be higher than 5 meters. A forest should have a minimum size of 0.5 hectares, plantations and young indigenous trees stands that have the opportunity to grow old are also seen as forest (FAO, 2000). Woodland is defined by the FAO as land that has a canopy cover from 5-10% that are able to reach a height of five meters (FAO, 2000).

Namibia is a very dry country, 40% of the country is covered by dessert and shrubland. 50 % of Namibia is covered by woodland and approximately 10% is forest (Mendelsohn & el Obeid, 2005).

These forests are mostly found in the north-east of Namibia. Woodlands cover most of the area south and west of the forested land. Shrubland and desserts are found in the most western and southern parts of the country (Figure 1).

As seen in Figure 1, woodland covers most of the southwestern part of Namibia.

The denser forests occur in the north-east of Namibia, which has a higher annual rainfall. The Zambezi region, Kavango East and West regions, Eastern Ohangwena and the hills around Tsumeb, Otavi and Grootfontein (Geldenhuys C. J., 1996).

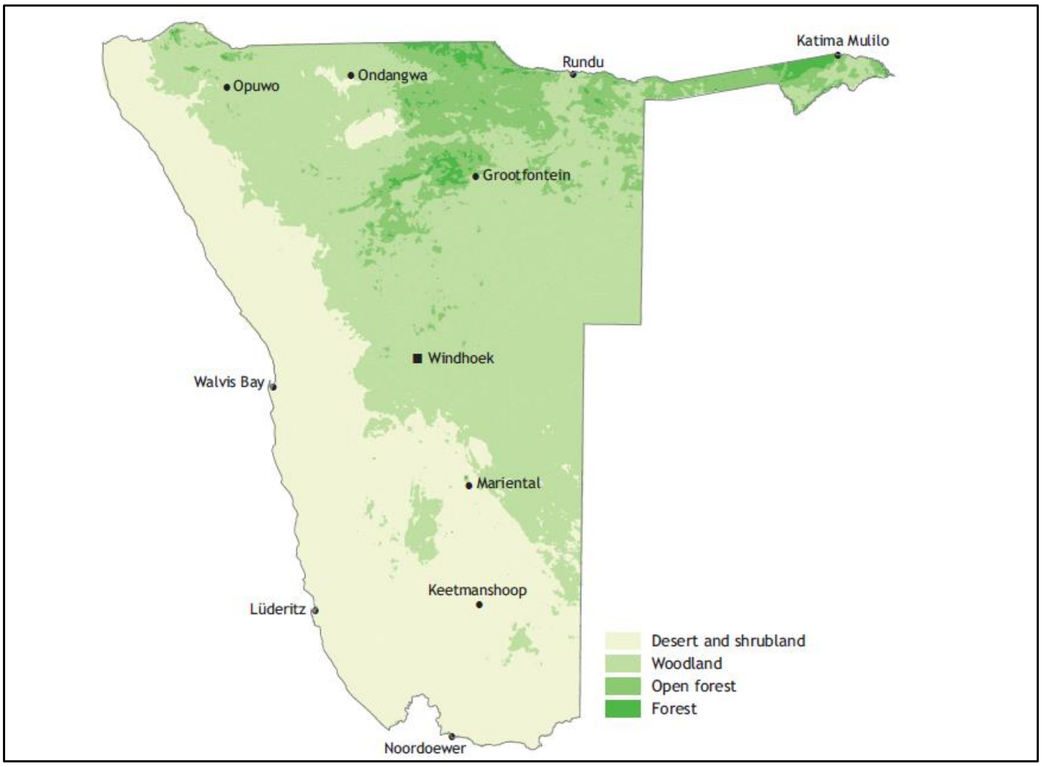

Figure 1: Forest, woodland, shrubland and dessert coverage in Namibia. (Mendelsohn & el Obeid, 2005)

The use and management of the forests in Namibia changed through the decades. The management of forests was strongly influenced by German and South African influences. The Germans lacked interests in the woodland or forest resources. First the Germans had two strategies to supply wood for the developing of infrastructure; importation of wood and cultivation of suitable timber species. The South Africans focused more on the commercial harvesting of timber species in the north of Namibia. The harvest of timber increased substantially after the Second World War with a peak in the late sixties. Other than the commercial focus, the South African mandate was characterized by a minimal presence of forestry administration. The mandate lacked measures to supervise or control harvesting, because there was little or no knowledge in forestry.

After the independence of Namibia in 1990, the community based management of the forests was an important change. Most commercial harvest of timber stopped and forests became protected state forests or forests managed by the surrounding inhabitants, the community forests. (Mendelsohn & el Obeid, 2005).

2.1.3 Community and State forests

The State forests are protected by the Republic of Namibia, this is written in the Forest act of 2001 (Republic of Namibia, 2001). The State forests are protected by the Directorate of Forestry and they aim to preserve and protect the biodiversity. At the moment there is a no touch policy for the State forests. No harvesting, grazing and collection of Non-timber forest products are allowed. A forest management plan is needed to declare the forest as State forest.

The first Community forests were established in the early 2000s in collaboration with the German Development Services (DED). In 2006 the first Community forests were recognized by the Republic of Namibia as Community forests. This was done to ensure the sustainable and correct use of the forest resources and to make sure that the communities derived the benefits from the forests to improve their livelihood (Benkenstein et al., 2014).

The Forest Act (2001) states that a community forest can be established through a written agreement between the minister responsible for forestry and the representatives of those who have rights over the relevant area of communal land. The local representatives are required to set up a management authority to organise governance and day-today forest management activities in the community forest. The Forest Act further gives the community the right to manage and use the forest products and other natural resources, and to graze livestock (Benkenstein et al., 2014). The exploitation of the resources must be based on a management plan and must be developed by the community in collaboration with the Directorate of Forestry (DoF)

2.2 The dry forests and woodlands of the northern Kalahari

2.2.1 Vegetation of the Kavango region

The Kavango region is bordered by the Kavango river in the North. In the river valley, alluvial deposits created a relatively fertile soil compared to the nutrient poor surrounding Kalahari sand plateau to the south (Mendelsohn & el Obeid, 2005). The climate of the region is a transition between a sub- tropical steppe and subtropical (sub)humid climate. The vegetation is mainly limited by rainfall, climate, temperature and frost. Temperature is a limiting factor for the vegetation growth. In Namibia temperatures often vary 20°C between minimum and maximum temperatures, plants need to cope with these seasonal and daily fluctuations in temperatures. The hot temperatures cause higher evapotranspiration, which limits the plants in growth. And the freezing temperatures kill the plants, especially the younger seedlings and small trees. Older and bigger trees are more resistant against the temperature fluctuations (Mendelsohn & el Obeid, 2005). Because the rainfall in Namibia is very unpredictable, often all the rain falls in two or three months and the rest of the year is very dry and hot, vegetation needs to adapt to grow in very dry circumstances (Burke , 2006). Trees that store water in roots, stem or succulent leaves and trees that have deep roots to reach the ground water are common strategies to survive in the dry climate. Another strategy of the trees is dropping leaves in dry season (May until October), when there is no rainfall at all. In Namibia the trees are sparsely distributed, small in size and have very slow growth rates. This is mainly a consequence of the variable and low rainfall. The soils in the Kavango region retain little water. Water is lost through seepage and evapotranspiration (Mendelsohn & el Obeid, 2005).

The nutrient poor Kalahari basin that covers the entire Kavango region, is since its existence a catchment for erosion products. Today it bears the most extensive sheet of Aeolian sand in the world (Partridge, 1997).

Giess (1998) classified the vegetation in the eastern and western Kavango region as “Dry Forests and Woodlands of the northern Kalahari”, or the Zambezian *Baikiaea* woodlands (Vetter, 2015).

The area were the study was conducted, is characterized by flat landscape that is called the Kalahari sand plateau. The sand plateau is dissected by several north and east flowing omiramba (dry rivers). The vegetation associated with this landscape and type of nutrient poor Aeolian soils are *Pterocarpus angolensis* and *Schinziophyton rautanenii* woodlands. Along these types of woodlands patches of *Baikiaea plurijuga* and *Burkea africana* woodlands occur on these landscapes. The shrublayer of these woodlands are mainly dominated by *Terminalia sericea, Baphia massaiensis, Bauhinia petersiana* and *Combretum* species (Burke A. , 2002). These types of woodland have a tree cover of around 28% (Strohbach & Petersen, 2007).
The Omiramba are a precious source of underground water in these types of vegetation. Human activities are mainly situated round these Omiramba (Burke, 2002).

In a recent article Strohbach (2013) identified eleven associations in the Kavango region. According to his classification, this study is conducted in the *Pterocarpus angolensis*–*Guibourtia coleosperma* association of the Kavango Woodlands (Figure 2). A total of 145 plant species have been observed in this association, with on average 43.9 species per 1000 m². This association is bound to the Kalahari sand plateau with typical Arenosols (Soil that consists mostly out of sand, without formation of soil horizonts) that are very low in nutrients and organic carbon (Strohbach & Petersen, 2007).

Figure 2: Typical vegetation of the Kavango woodlands. With *Pterocarpus angolensis, Burkea africana, Baikiaea plurijuga* and *Guibourtia coleosperma* as the dominating trees.

2.2.2 Woodland species

2.2.2.1 Pterocarpus angolensis

P. angolensis or kiaat is an important species of the dry woodland savanna of northern Namibia. *P. angolensis* is leguminous tree of the *Fabaceae* family. The genus *Pterocarpus* has about 100 species according to Dyer (1975), four of these species occur in northern and eastern parts of southern Africa. It is a small to medium-sized deciduous tree (leaves dropped during winter, June-August) with a cylindrical bole and a thin-foliaged spreading crown (Groome et al., 1957).

P. angolensis occurs in the dry woodland savanna of southern Africa. It occurs in Zambia, Malawi, Mozambique, Tanzania, Angola, Namibia, Botswana, South Africa, Zimbabwe and Swaziland (Vermeulen, 1990). In Namibia, Kiaat only occurs in the northern and north-eastern regions. *P. angolensis* grows together with *Burkea africana* and *Terminalia sericea*. In the Kavango region it may be found growing with *Guibourtia coleosperma* and *Schinziophyton rautanenii*. The different species occur together but since *P. angolensis* does not bear competition, it is probable that *P. angolensis* established before the other species (Graz, 2004).

The species can tolerate forest fires and can tolerate fire temperatures between 400°C and 450°C. This allows *P. angolensis* to compete with other less fire resistant species. After a fire, the tree benefits from the nutritious ash and the lack of competition for water with the surrounding vegetation (Vermeulen, 1990).

Kiaat provides a very valuable timber used for carpentry and carving. The heartwood is reddish to reddish- brown. The sapwood is pale yellow to white. Freshly exploited trees seem to bleed, the red gummy sap contains 77% tannin and is a defence mechanism against insects. The bleeding gives the tree another popular name, “bloodwood” (Vermeulen, 1990). Commercial exploitation is controlled, but it is uncertain how much volume is exploited illegally. The species is slow growing, therefore conservation measures must be taken to insure sustainable use of the species (Graz, 2004).

Description of phenology

P. angolensis is a medium sized tree with a short trunk and flat topped crown (Figure 3). The tree reaches heights between 10 and 12 meters, higher heights are recorded up to 20 m (Orpen, 1982). Although Groome et al. (1957) recorded tees in Zambia of 30 meters. Tree growth and ultimate tree size are depended on environmental factors, with the final height directly related to the productivity of the site. Size and height are also strongly genetically controlled (Vermeulen, 1990). Von Breitenbach (1973) found that the tree reaches its full crown diameter in its third to fourth decade.

Kiaat is a deciduous tree, during winter (June-August) leaves are dropped in Namibia.

The leaves are compound, 5-9 pairs of leaflets sub opposite to alternate plus a terminal one (Orwa et al., 2015). The young leaves often are densely, silky-pubescent (von Breitenbach, 1973). First rains will initiate leaf flush, and mostly the flowers are already produced before the first rains (Childes, 1989) (Vermeulen, 1990).

Figure 3: ***Pterocarpus angolensis*** **in Hamoye State Forest (Picture taken by M. Schelstraete).**

At the start of the dry season leaves are repelled, probably because of moisture stress (Childes, 1989).

Flowers of *P. angolensis* are orange to yellow and occur in large, branched sprays about 10 to 20 cm long. Flowers can occur from August to December. The flowers are pollinated by insects (Vermeulen, 1990).

The fruit of the kiaat three is a bristled pod surrounded by an orbicular, lobed wing. The pods contain one seed, although this can vary. Sometimes two or three seeds are found in the pod (Vermeulen, 1990). The wing of the pod provides the pod the ability to travel up to 3 km from the mother tree by wind (Groome et al., 1957). While the bristles are meant to spread by the aid of animals, the bristles stick to the fur and are transported by the animal (epizoochoric dispersal) (Graz, 2004). The fruit can therefore be dispersed by a combination of mechanisms. The dispersal by wind in the first place, then the seed can stick into the fur of an animal and the wings can also provide the pod the ability to roll over the ground (Graz, 2004).

Although the tree has enough mechanisms for dispersal of the seeds, it is known that the seeds often do not travel more than 30 meters from the parent tree (Vermeulen, 1990). Most of the fruits are thus deposited around the mother tree (von Breitenbach, 1973).

The pods are mostly dispersed at the end of the dry season or beginning of the wet season. Mostly wind is the reason for detachment of the seeds, but rain can cause detachment in rain season as well (Groome et al., 1957) (Vermeulen, 1990).

The heartwood is reddish to reddish- brown. The sapwood is pale yellow to white. The shift from heartwood to sapwood is very sharp, which is exploited by the carving industry to create contrasts of white and reddish colours. Freshly exploited trees seem to bleed, the red gummy sap contains 77% tannin and is a defence mechanism against insects. The bleeding gives the tree another popular name, “bloodwood” (Vermeulen, 1990).

Distribution

P. angolensis occurs in dry woodland savanna of southern Africa. It occurs in Zambia, Malawi, Mozambique, Tanzania, Angola, Namibia, Botswana, South Africa, Zimbabwe and Swaziland (Vermeulen, 1990). In Namibia, Kiaat only occurs in the northern and north-eastern regions (Figure 4).

P. angolensis grows together with *Burkea africana* and *Terminalia sericea*. In the Kavango region it may be found growing with *Guibourtia coleosperma* and *Schinziophyton rautanenii*. The different species occur together but since *P. angolensis* does not bear competition, it is probable that *P. angolensis* established before the other species (Graz, 2004).

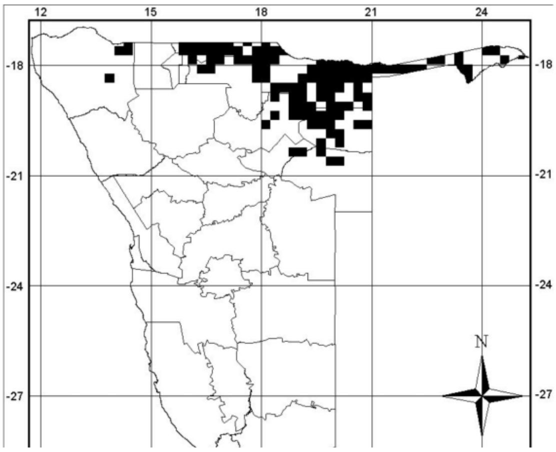

Figure 4: Distribution of *Pterocarpus angolensis* in Northern Namibia (Curtis & Mannheimer, 2005)

Growth conditions

Since its distribution is linked with the type of soil, it mostly occurs on deep sands. And it prefers well-drained soils with a sandy or loamy texture.

The tree grows in areas where the wet and dry seasons are well-defined, it can bear rainfall as low as 400 mm per year (Curtis & Mannheimer, 2005). In Namibia rainfall is sometimes less, but it can survive in the northern regions even though the mean precipitation is slightly less (Vermeulen, 1990). The rooting strategy of Kiaat is described by von Breitenbach (1973) and Vermeulen (1990), and indicates that the roots rather rely on precipitation than a permanent subterranean water supply.

P. angolensis is a light demanding species, it can bear moderate shade but growth will likely stagnate if there is a shortage of light (Vermeulen, 1990; Groome et al., 1957). In very shady condition it may survive as suffrutex (low growing woody shrub that dies back and resprouts e.g. after fire or winter) and form a permanent shoot once conditions improve (Boaler & Sciwale, 1966).

Frost affects younger plants in growth, and causes die-back of the plant. Periodic frost damage may also occur on the older trees, causing die-back of the top leaves and branches (Groome et al., 1957). Forest fires also play an important role in the lifecycle of the tree, following chapters will explain why.

From germination to adult tree

When the pods are released from the tree, germination can start. But there are a couple of factors that influence germination. Firstly fire is very important for the germination, but is not necessary for successful germination (Vander Heyden, 2014) . Fire removes the bristles and wings and makes sure the seed is in contact with the ground. That is not always the case without fire, because seeds often get stuck in grasses and shrubs. Fire makes sure that the seed makes contact with the ground (van Daalen, 1991). When the bristles and wing is removed by fire, the hard and tough pod remains. This hard pod appears to be opened by repeated wetting and drying in the later part of the rainy season (von Breitenbach, 1973). Groome et al. (1975) suggests that termites also help in freeing the seeds from the pods, but Vermeulen (1990) states that the termites only remove the bristles and wings and do not open the pod.

It has been found that fire enhances the germination under natural conditions (Geldenhuys, 1975), but fire frequency and intensity should not be too high. Intense fires reduce the viability of the seeds, and 'cool' fires (When dry biomass is very low and burns very fast, a cool fire can occur. Biomass is not sufficient to induce an intense and hot fire.) have little influence on germination (van Daalen, 1991).
Once the seeds are germinated, seedlings are subjected to a high degree of mortality. The mortality may be caused by fire, nutrient deficiencies, damage by animals, intra- and interspecific competition (Vermeulen, 1990) and drought (Groome, Lees, & Wigg, 1957).
During the establishment phase, the seedling develops a taproot. The taproot reaches a length of 45 to 90cm in the first growing season (von Breitenbach, 1973).

Quickly after establishing the seedling enters the suffrutex stage. This stage is characterized by a yearly die-back of the produced shoots in the growing season. The shoots only reach a height between one to three meters, and die back in dry season, which is a very effective way of protecting the taproot against the dry season fires. This period mostly lasts for a couple of years, 10 years is a good estimation (von Breitenbach, 1973). Although this period can be stretched by high fire frequencies.

During the annual die back, the plant can store enough nutrients and water to produce and sustain a permanent shoot which can survive the dry season (Vermeulen, 1990).
The roots of the tree will grow over an area greater than the canopy in the upper 30 to 60 cm of the soil and will rely mostly on precipitation, which could be read in paragraph 0. The tree also sends roots called 'sinkers' to a greater depth of 2 meters (Vermeulen, 1990).
At an age of 90-100 years the tree will have reached its maximum height and a crown diameter of 10-12 meters with a stem diameter of 50-60 cm (Takawira-Nyenya, 2005). The tree grow

slowly with an yearly average increment of 3.5 mm (Therell et al., 2007). The tree can be harvested at a minimum diameter at breast height (DBH) of 45 cm (Graz, 2004).

Use of *P. angolensis*
Kiaat is used for different kinds of purposes. Every part of the tree is used. It is a source of income, a medicine and a dye. The wood is used for construction, carpentry, furniture manufacturing, parquet and veneer. Wood carvings of the species are popular in Namibia and South Africa. Due to its durability, the wood is often used for boats, doors and windows. From the heartwood of the roots, a dye is produced. This dye is used for painting the fibres of baskets. The dye has a great cultural importance for the Ovambo people, where it is used as decoration of the skin. When the bark is damaged, a red resin appears. This red gummy is used as a powerful astringent to treat diarrhoea, heavy menstruation, nose bleeding, headache, stomach-ache, schistosomiasis, sores and skin problems. The root is believed to cure malaria, Blackwater fever and gonorrhoea. In South Africa the seed ash is applied on wounds and psoriasis. Leafy twigs are used as fodder and the flowers are an import source of nectar for bees to produce honey (Takawira-Nyenya, 2005) (Vermeulen, 1990).

Fire resistance of *P. angolensis*
The suffrutex stage dies back every time a fire occurs, the taproot survives underground (Vermeulen, 1990). Only when the suffrutex stage can go into the sapling stage, the tree can benefit from its fire tolerance. The saplings can tolerate fire temperatures between 400°C and 450°C. This allows *P. angolensis* to compete with other less fire resistant species. After a fire, the tree benefits from the nutritious ash and the lack of competition for water with the surrounding vegetation (Vermeulen, 1990).

Kiaats fire resistance allows him to colonize open areas. In such areas the herbaceous vegetation development is favoured. Which leads to a higher fire frequency and intensity and leading to a growth advantage for *P. angolensis* to other species. After the fire there is more available water and nutrients (Vermeulen, 1990).

Even though *P. angolensis* has a high fire resistance, high frequencies and intensive fires will also damage the resistant bark. When the bark is damaged and cambium is affected by fire, the fire will enter the trunk and cause the tree to die (Graz, 2004).

2.2.2.2 Baikiaea plurijuga

B. plurijuga or Zambezi teak is a tree from the *Fabaceae* family. It occurs in Angola, Botswana, Namibia (more specific north-eastern Namibia), Zambia and Zimbabwe where it grows on deep Kalahari sands. It prefers an annual rainfall of 600-1000 mm (Joker & Jepsen, 2015). Burke (2006) found that the Zambezi teak does not occur in areas where the rainfall is lower than 300 mm per year. The tree is deciduous although it is rarely seen without any leaves. Childes (1989) has found that after the leaves fall, new leaves reappear quickly after the fall of the old leaves. Mendelsohn (2005) writes that the tree is evergreen. The tree can grow up to 27 meters tall and is deeprooting (Childes, 1989). The wood is heavy, fine-grained, strong and durable. It has a red-brown colour and is rated as one of the world’s finest commercial timbers. The wood is resistant to termites and borers and therefore it is used as fencing wood in rural areas. It is used as firewood because it produces very hot coals. Locally the bark is used in medicine and for tanning leather. *B. plurijuga* has a large, dense, spreading crown and the bark is smooth and pale. The bark of older trees become fissured and cracked (Joker & Jepsen, 2015). Seeds are scattered from June to September and germinate readily. But seedling survival in the first year is very low as a result of inadequate water, browsing and fire (Mendelsohn & el Obeid, 2005). The Zambezi teak's tolerance against fire is low, and cannot withstand intensive fires (Childes, 1989).

2.2.2.3 Burkea africana

B. africana or Wild Syringa is the most abundant and eye-catching large tree that grows on Kalahari sands in the north-eastern woodlands. It has a wide distribution, it occurs on the dry savanna's of Nigeria to South Africa. It belongs to the *Fabaceae* family and is a deciduous tree growing up to 20 meters tall. It has a characteristic long, thin trunk, which divides into several large branches that supports a loose canopy. The wood is pale yellow to reddish-brown, hard and heavy. But it is often damaged by woodborers and therefore less wanted. The wood is thus not used very often. It is sometimes used to build huts and it is suited to use as firewood (Mendelsohn & el Obeid, 2005). *B. africana* is reported to be fire tolerant, but it can postpone flowering after severe fire damage and start flowering when the environment is more suitable for flowering (Burke, 2006). Seedlings will compete better against other species under canopy cover. It doesn't need light to germinate, which gives the tree an advantage above Kiaat that needs light to grow (Mendelsohn & el Obeid, 2005).

Figure 5: *Burkea africana* in Hamoye state forest. The species sheds its leaves very late in winter. (Photo: M. Schelstraete, 2015)

2.2.2.4 Schinziophyton rautanenii

Schinziophyton rautanenii or Manketti, Mongongo or Mangetti is an indigenous, deciduous tree in Angola, Botswana, DRC (Democratic Republic of Congo), Malawi, Mozambique, Namibia, Transvaal (Region) in South Africa, Tanzania, Zambia and Zimbabwe (Rønne & Jøker, 2006). The Mangetti belongs to the family *Euphorbiaceae*. The tree is considered a fast growing tree (Peters, 1987). In 1952 the tree was declared a protected species, probably because of its socio-economic importance (Erkkilä & Siiskonen, 1992).

S. rautanenii grows to a height of 7-12 metres (Lee, 1973) although a tree of 24 metres was reported by Palmer & Pitman (1972). The stem of the tree can reach a diameter of one meter. The tree often grows in a cluster of neighbouring trees. The cluster can count up to five trees (Peters, 1987). In dense forest the crown tends to grow flatter, while isolated trees can grow round crowns (Mendelsohn & el Obeid, 2005). The isolated trees in Zambia had a shorter bole and many branches and the fruit yield was much higher (Graz, 2002).

Figure 6: *Schinziophyton rautanenii.* With the typical round crown and large trunk. (Photo taken in Hamoye State Forest (M. Schelstraete, 2015))

Mangetti is always found on deep Kalahari sands (Palmer & Pitman, 1972), which are poor in nutrients and low in organic matter. The species tolerates drought and occurs in a wide rainfall range and variability. With annual rainfall ranging from 200 to 1000 mm (Graz, 2002). The tree grows in regions where the maximum daily temperatures often exceed 30°C, it tolerates light winter frost (Peters, 1987).

In September-October, before the first rains, leaves begin to sprout. In May, when the dry season is beginning, the leaves are shed (Peters, 1987). The species has male and female trees (dioecious species), the ratio of male and female trees is more or less 1:1 (Lee, 1973). Flowering starts in early summer before the first rains fall (Palmer & Pitman, 1972).

The fruit ripens after falling on the ground in April or May. First the fruit is yellow, when the fruit is ripe it has a reddish brown colour. By August the fruits are ripe. The Manketti nuts are very important in Namibian local and rural economies. The nuts are used for food, they also serve as a unit of exchange and the shells of the nuts are used as fuel for cooking. Out of the nuts oil is extracted, the remaining pulp is used as food. Lee (1973) found that the consumption of the nuts is depended on the season and ranges from 5-10% to 90% of the total dietary intake of local people. The fruit can also be used to produce a strong alcoholic drink (Graz, 2002).

The wood of *S. rautanenii* is yellowish, light and soft. Despite its lightweight the wood is rather strong (Graz, 2002). Because of the weight, the wood is used frequently. The wood is used for canoes, boxes, tools and carvings. But despite its lightweight which makes it easy to use, it is susceptible to insects and fungi (Rønne & Jøker, 2006).

Seedling establishment is best, when seedlings are protected against fire. Fire kills of most seedlings (Geldenhuys, 1977). Older trees are often seen with fire scars on their trunks, this can indicate that trees may cope with a certain amount of fire damage. But no conclusions can be drawn on long-term effects of fire (Graz, 2002).

2.3 Forest fires

2.3.1 Forest fires in Southern Africa

Fire has a double role in the world's vegetation. First, in certain ecosystms, natural fires are in some ecosystems essential to maintain dynamics, biodiversity and productivity. Fire is an important determinant of vegetation community structure (Bond & Van Wilgen, 1996). Fires increase open space and thus diminishing the competition for light, water and nutrients between plants. Some plant species need fire to induce germination and stimulate flowering (Bond, 1998).

The negative side of the wildfires is the destruction of millions of hectares of forest, woodlands and other vegetation each year. This is causes the loss of human and animal lives, economic damage (destroyed resources and the cost of suppression), environmental damage and an impact on society (FAO, 2007). The fire causes the loss of nutrients of the African ecosystems. The nutrients get dispersed by aerosols and they affect the climate and enrich the oceans with minerals. These aerosols contribute to the rich marine life at the western coast of Africa (Vickery et al., 2013). and a significant source of greenhouse gas emissions (Patra et al., 2005). In 2000 it was estimated that fire affected 350 million hectares globally (FAO, 2007). In Sub-Saharan Africa 2.3 million km² was burned in 2000, this is 64 percent of the global total. The African vegetation is known to be affected by fire frequently. In 2000 the continent also had the highest number of fires (54 percent) globally (FAO, 2007). In Namibia the Caprivi and the Kavango region are most affected by fire, 28% to 51% of the land area is burned annually during a period from 1989 to 2002 (Siljander, 2009). An average of 34% of the Kavango region burned each year from 2000 until 2005, the Caprivi region had a higher yearly burned area of 43%. The more southern parts of Namibia burn less frequent, due to less rainfall. These more arid parts of Namibia will only burn after a wetter rainy season, which induces more growth and thus a higher biomass per hectare. These high numbers of fire and area destroyed by fire are mainly because of the distinctive wet and dry seasons, which favours regular vegetation fires. In the wet seasons, vegetation grows and fuel sources build up. During dry season the drought leads to ideal conditions for burning (FAO, 2007).

2.3.2 Causes of forest fires

At the end of the rainy season when the vegetation starts to dry, lightning can be a significant ignition source. But in most cases fire is started by people (Chidumayo, 1995; Stellmes, et al., 2013; Frost, 1999). The environment of Africa has always been shaped by human impact. Early human beings used fire to clear vegetation for hunt, now fire is used for several causes. Slash-and-burn is a commonly used method to clear agricultural sites or remove crop residues. These planned fires are often left unattended and spread very often (FAO, 2007). Higher population levels are also associated with higher number of fires occurring in the area (Keeley et al., 1999). But on the same time the higher population level results in intensified land use, reduced fuel loads (grazing, collection of fuelwood and felling of trees for timber), and fragmentation, which leads to a reduced spread of fire (Frost, 1999). At the end of the dry season the grasses are very dry and rarely browsed by cattle, and farmers try to burn patches of land in a controlled way to induce fresh grass growth. This fresh grass is a good source of nutrition for the cattle and attracts grazing wildlife that can be hunted. The new growth flushes of the grasses are induced by the sudden release of nutrients from the burned dry parts. But very often the fire spreads and a wildfire is started (Mendelsohn & el Obeid, 2005). Especially during the windy months between August and September, fires tend to spread and burn thousands of square kilometres of woodland.

2.3.2.1 Human influence

Human population can influence fire regimes directly, by altering the ignition frequency, and indirectly, by reducing fuels and fragmenting the landscape. Thus an increase in population could be a cause for increase of fire frequencies, but also a decrease of the extent of fire because of the fragmentation of the landscape. Farmers clear their land with fire, but commercial farmers prepare fire breaks to suppress unplanned fires. On communal land, fire management is inconsistent, fires are lit for a variety of reasons and it is not common to suppress actively burning fires (Mendelsohn, 2002). A management tool that is often used, is the early-season burning in communal areas to diminish the fuel loads for later fires (Frost, 1999). Archibald et al. (2008) found that population density always had a negative effect on burnt area. On the other hand, Archibald et al. (2008) state that increasing human population up to 10 people per square km are associated with more fire activity. But when the densities are higher than 10 people per square km, less fires occur. If climatic conditions are excluded from factors that influence burned area, road density, grazing, fraction of transformed land (cultivated/urban) and population density are identified as the four most important predictors of burnt area according to Archibald et al. (2008). Higher population density resulted in less area being burnt, probably because of the fragmentation of the landscape and through cultivation, grazing, fuel-wood collection, roads and possibly by suppressing of fires by people (Saunders et al., 1991).

2.3.3 Drivers of forest fires

Understanding the dynamics of fire is a hard task, because there is a big variation in factors that influence the fire regime and frequency. The fraction of landscapes that burn varies greatly. Understanding this variation is not simple, because forest fires are influenced by different factors. These factors often have an antagonistic influence. For example, rain influences growth. Generally the growth of biomass increases with rainfall. The higher the biomass per hectare, the higher the damage will be of the forest fire. With higher rainfall, the fuel moisture is higher leading to vegetation that is less susceptible for fire (Scholes et al., 1996). Every factor has antagonistic effects, which makes it very difficult to interpret and understand the factors and interactions between the factors of forest fires (Archibald et al., 2008).

Most of the fires in southern Africa are surface fires fuelled by grass and litter. After a fire, with sufficient rainfall, grasses and shrubs regenerate rather quickly and can provide new fuel after a few weeks of dry weather (Stott, 2000). Figure 7 shows the theoretical understanding of the drivers of fire in southern Africa. Soil fertility and rainfall positively affect fuel load production, however tree cover and high grazing pressure will reduce fuel loads (Trollope, 1984) (Van Wilgen & Scholes, 1997). The length of the dry season will determine the time that fuel is dry enough for ignition and determine the fuel moisture (Spessa et al., 2005). Lightning frequencies an human population densities variations will affect ignition frequencies (Keeley et al., 1999). Land management is likely to affect both ignition and suppression of forest fires (Frost, 1999). Fuel continuity is impacted by both landscape morphology (highly dissected, variable landscapes won’t be affected by large fires easily) (Dickson, et al., 2006; Russell-Smith et al., 2007), and by human activities. Roads and transformation of land through cultivation and urban expansion may break up the lanscape and prevent fire spread (Archibald et al., 2008). Removal of fuel for building, domestic cooking and heating puposes, may also reduce fire spread (Frost, 1999). The factors illustrated in Figure 7 vary spatially. Burned area will thus not be controlled by the same combination of factors in all circumstances.

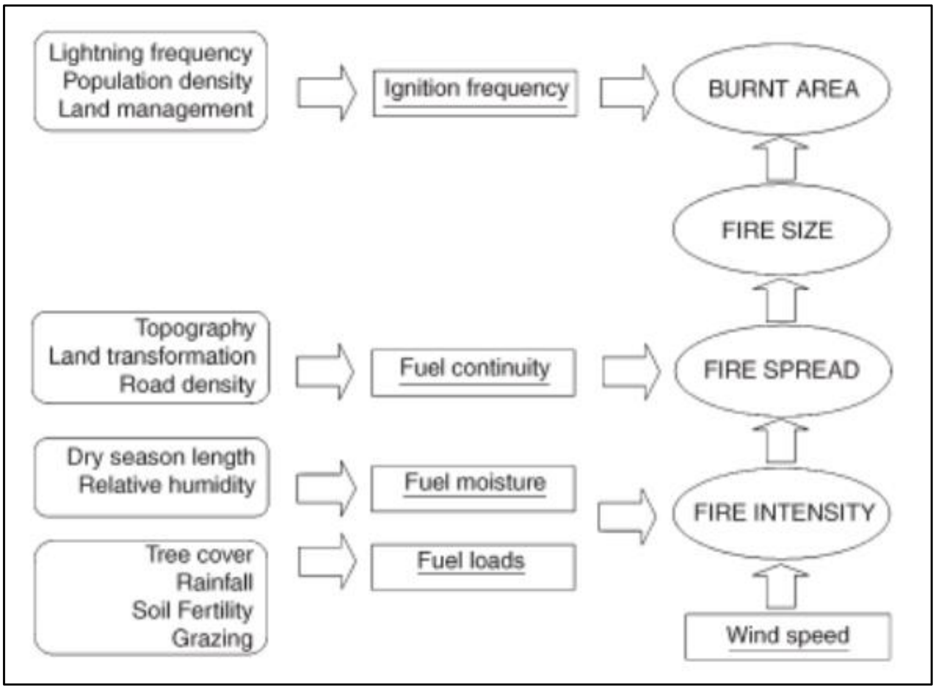

Figure 7: Theoretical model of factors affecting burnt area. Upper case text are components of fire regime. Underlined items are direct drivers of fire. Text on the left are the indirect drivers of fire, which are measurable. Many of these factors interact with each other, population density is correlated with grazing density, tree cover and soil fertility (Archibald et al., 2008).

2.3.3.1 Influence of fuel and weather conditions

For a fire to start, three conditions must be met: ignition event, flammable fuel and the weather conditions must be suitable (Stott, 2000) (Van Wilgen & Scholes, 1997). Archibald et al. (2008) found that tree cover is an important driver for fire spreading. When tree cover exceeds 40%, the burned area declines rapidly. This decline is related to a decrease in grass growth as tree density increases. To exceed the 40% tree cover an average annual rainfall of at least 800 mm is needed (Archibald et al., 2008). Large fires are thought to be caused by extreme weather conditions (Moritz, 2003) (McArthur, 2004) (Bessie & Johnson, 1995), in particular, periods of hot days combined with dry winds are thought to benefit the fire spreading. The annual rainfall greatly determines the fire intensity and frequency. High annual rainfall (more than 1000 mm) and low annual rainfall (less than 300 mm) burn less. Between these annual rainfalls, conditions are suitable for forest fires (Archibald et al., 2008). And if there is a dry season that is as little as 2.5 months, fuel can be dry enough to start forest fires (Stott, 2000). Lightning frequency in fire season came out as one of the least important predictors(Archibald et al., 2008).

2.3.4 Impact on vegetation

Forest fires always have an impact on the vegetation, but not only forest fires have an influence on the forest dynamics. Herbivory, frost and other disturbance agents also have an impact on the vegetation. It is known that fire has always shaped the current African vegetation (Van Wilgen & Scholes, 1997). Fire favours the grass component of the woodlands over the woody component (Bond & Van Wilgen, 1996). Joubert et al. (2012) found that fire killed off seedlings and about half of the saplings of woody vegetation. In frequent forest fires, seedlings and saplings have difficulties to settle and grow into big trees. Grasses are less prone to fire and thus they recover quicker than the woody vegetation.

According to Prior et al. (2009) an increase in frequency or severity of fires is likely to change the tree density and basal area of savannas. The effects on the woodland vegetation of long-term burning seem to be very variable. But in the different studies it can be seen that fire always have a marked effect on the vegetation.

For example, Trapnell (1959), Scholes and Walker (1993) found that complete protection of fire resulted in an increase in woody canopy height and biomass. Chidumayo (1988) recorded a lower species diversity in fire-protected plots in the Copperbelt area, Zambia. Kennedy and Potgieter (2003) recorded significant differences in tree height, canopy diameter, mean stem circumference and number of stems with different fire seasons in *C. mopane* woodland in South Africa. Tainton et al. (1993) found that dry season fires in *C. apiculatum* savanna in South Africa led to short, open, extensively coppiced shrub vegetation while wet season fires produced taller and closed vegetation.

Govender et al. (2006) found no effect of fire on woody species composition, but high impacts on the structure of woody communities in Kruger National Park. Shackleton and Scholes (2000) found reduced woody plant height, increased number of stems per plant and increased plant density in vegetation that was affected by high fire frequencies. Van Wyk (1971) found that the frequency of burning over a period of 42 years had no effect on woody plant density in the Kruger National Park.

All these studies give different effects, this proves the varying effect of fire on vegetation. When the effect of fire needs to be studied, many factors need to be taken into account (Gandiwa & Kativu, 2009).

Geldenhuys (1977) found that annual burning has a statistically significant influence on various components of the vegetation. Though he added, that it should be considered carefully that annual burning has a significant influence. Some of the effects of fire are difficult to establish and to interpret due to the complex relationships between various components. These components are for example, fire sensitivity of the species, soil properties, site differences, early or late fire, rooting strategy of the plant, climatic factors, … The list can be completed by many other factors that can be taken into account. This proves the complexity of the impact of fire on vegetation.

Geldenhuys (1977) also stated that fire application on an annual basis, if the fuel levels are relatively low, do not produce detrimental effects on the vegetation. The complete protection from fires is thus only beneficial to fire sensitive species e.g. *Baikiaea plurijuga, Commiphora spp., Ochna pulchra* and *Guibourtia coleosperma.* If the vegetation does not contain fire sensitive species, burning should be applied in the early dry season, that is as soon as possible after the rainy season. Early dry season fires have less impact on the vegetation, because the vegetation is not yet dry enough to produce the very hot and destructive fires. These early dry season fires are less hot and wont spread as wide as late dry season fires. This management strategy can lead to a lower fuel level, protecting the vegetation from severe late season fires (Geldenhuys, 1977). Late dry season fires are hotter and spread easier, because at the end of the dry season most of the biomass is very dry. Fires are then more destructive and will destroy young seedlings and damage older trees. Geldenhuys (1996) stated that late dry-season fires should be prevented, because of the serious impact on vegetation. Most of the species growing in woodlands can withstand small fires. Geldenhuys (1996) suggests to use fire as a controlled management tool to prevent late dry-season fire and apply fire in early dry season to control the biomass accumulation of grasses and shrubs. In early dry season vegetation still contains moisture, this causes a patchier fire and less likely to spread over a great distance. This type of fire is also easier to control. Depending on which trees are wanted, fire can be applied in early dry season every two to five years.

Fires mostly occur in late dry season because of agricultural practices. Farmers destroy the crop residues by fire at the end of the dry season, to prepare the field for the new growing season. Often the clearing of the crop residues is an opportunity for the fire to spread to the neighbouring forests with late season fires as a consequence (Le Page et al., 2010).

3 Material and methods

3.1 Situating study area

This study was conducted in two neighbouring forests with different management types. Hamoye State Forest (SF) is protected by the state to preserve the ecosystem and the biological diversity (Republic of Namibia, 2001) and to do research (the forest is based next to an research station of the Directorate of Forestry). Ncaute Community forest (CF) is managed and can be used by the surrounding community. In community forests it is allowed to gather natural resources by the community for living. State forest is protected and it is not allowed to gather resources in these types of forests, only the Directorate of Forestry (DoF) has the mandate to manage these forests (Republic of Namibia, 2001). This concept was introduced 18 years ago and is common all over Namibia.

Ncaute community forest stretches over an area of 12,000 hectares (Kanime, 2010), while Hamoye state forest covers an area of approximately 1,000 hectares (Shoopala, 2008). Soil samples were taken in both forests and the results of the analysis gave away that the soils in both forests didn't differ a lot. pH, conductivity and organic carbon were for all the samples more or less equal. A pH of six, conductivity between 2 and 3 mS/m and the organic carbon (Walkey Black) is around 0,5 % m/m C. Both forests are situated 30 km south of Rundu in the Kavango Region.

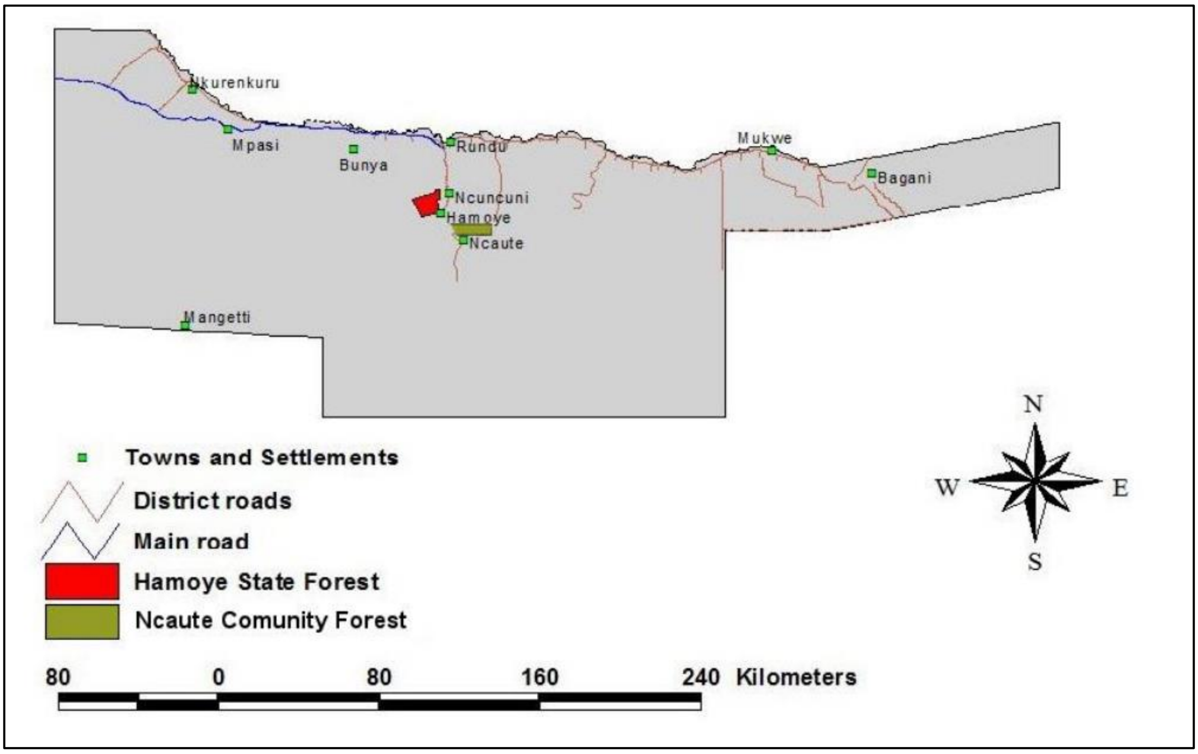

Figure 8: Location of Hamoye State Forest (SF) and Ncaute Community Forest (CF) within the Kavango regions of northern Namibia (Schulz, 2015).

Figure 8 shows the location of both forests in the Kavango Region.
A forest research center of the Directorate of Forestry (DoF) is situated at the border of the State forest. The forests have an average annual temperature of 22.1°C and a mean annual precipitation of 542 mm. Figure 9 gives an annual average climate diagram. The forests are growing on Kalahari sands, characterized with Ferralic Arensols (Muhoko & Kamwi, 2014). Ferralic Arensols are mineral soils with a relatively low CEC. The soils don't have diagnostic horizons and are a result of deposited sand particles out of the Kalahari dessert (FAO, 2016). The landscape is uniform with a predominantly plain topography. And has an average elevation of 1103 m above sea level (Muhoko & Kamwi, 2014).

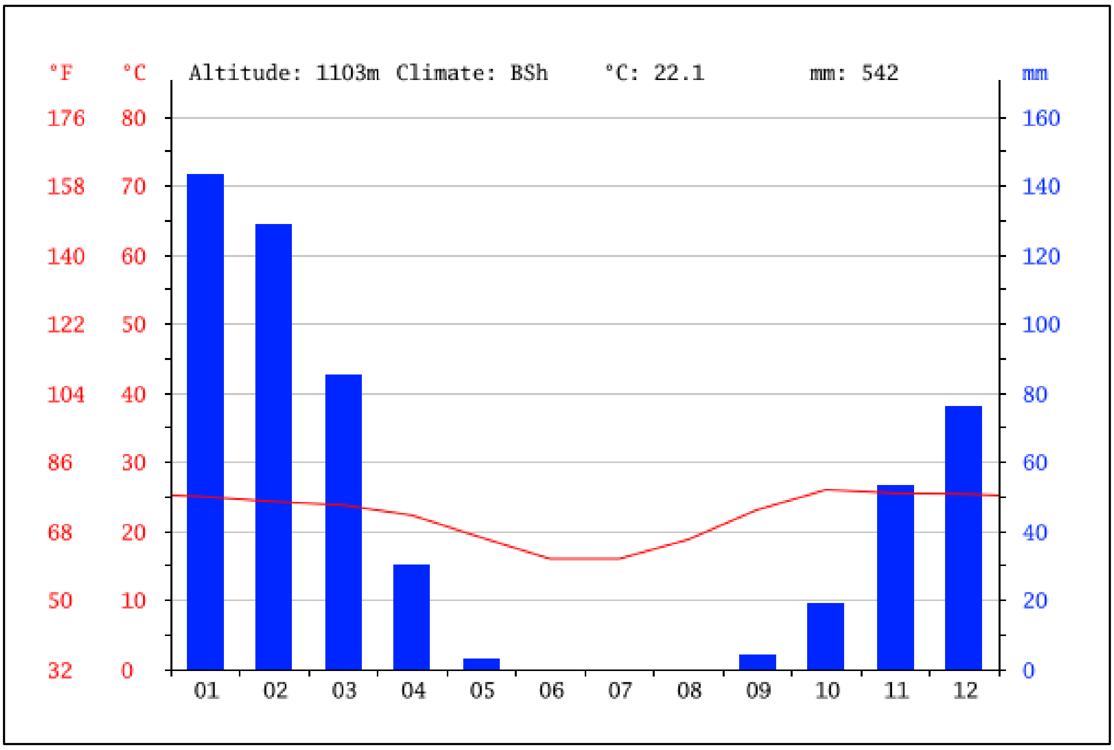

Figure 9: Climate diagram of Ncaute, this is a village close to Ncaute Community forest and Hamoye State forest. The diagram shows an average annual precipitation in blue bars and average annual temperature red line. (Climate-Data.org, 2016)

3.2 Forest inventory

3.2.1 Plot design

For this forest inventory, the same plots were used as a forest inventory performed in 2014 by a group of students of the Polytechnic (now Namibia University of Science and Technology) and Göttingen and Stellenbosch Universities. In both SF and CF, 33 plots were marked. Making a total of 66 plots. The inventory used a transect based sample design. The plots were placed along a transect at an increasing distance of 200 m, 600 m and 1000 m away from fire breaks or roads. The plot sites were selected beforehand in GIS by the Polytechnic. This organization of the plots is not at random. The fact that the plots are not spread all over the forest and are situated closer to roads may influence the results and cause bias. But it was considered that this outweighed the facts that otherwise significantly less data would be gathered and that this would be safer for car, equipment and researchers (De Cauwer, 2013). The plot design is based on concentric sample plots (Figure 10). The radius of the biggest circle is 30 meters, in this circle all trees with a CBH greater than 141 cm (DBH>44.9 cm) were included in the inventory. The second concentric circle had a radius of 20 m, in this circle al trees with a CBH between 62.8 cm and 141 cm (DBH from 20-44.9 cm) were included in the inventory. The smallest concentric circle has a radius of 10 m, in this circle all trees with a CBH between 15.7 and 62.8 cm (DBH of 5-20 cm) were included in the inventory. A smaller circle of 10 meters in diameter was used to make an inventory of the woody regeneration. These are all woody species with a DBH smaller than 5 cm (Burke et al., 1996).

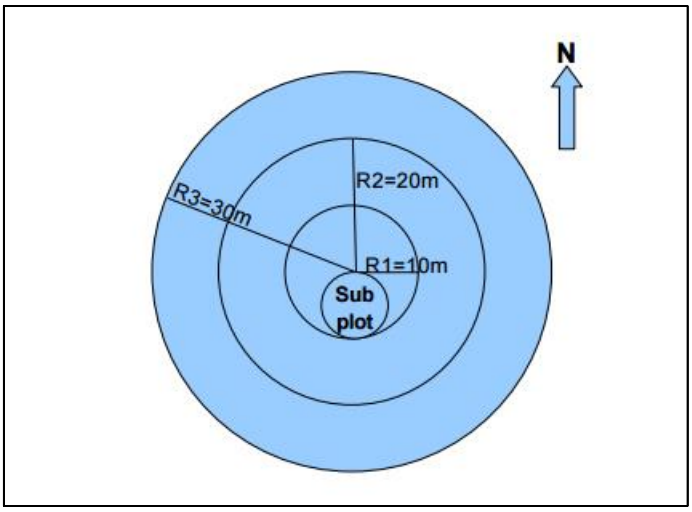

Figure 10: Plot design with three concentric circles and a smaller subplot with a diameter of 10 m. (De Cauwer, 2013)

3.2.2 Collecting data

In all 66 plots data of the trees were collected and noted down on TFO field inventory sheets. data was collected the same way as the group of students did it in 2014. This will make it possible to compare data. The method used was based on the forest inventory method of the Namibian Directorate of Forestry (Burke et al., 1996) but slightly adapted by the TFO project.

3.2.2.1 Finding the plot center

In each plot A GPS was used to find the plot center. The GPS gave us an indication of where the plot center was, but there is always an error of a couple of meters. The Garmin GPSMap 64 that was used as GPS has an error of +/- 3.65 meters (Garmin, 2014). The data of 2014 was needed to find the exact location of the plot center.

To make sure the same trees were sampled as the student team did in 2014, the exact same plot center needed to be found. Since the plots weren't permanently marked, the center of the plot was found by using the data of the trees the students collected in 2014. The most useful data to figure out where the plot center was localized, were tree species, azimuth, distance of the tree to the plot center and DBH (measured at 1.3 m above the ground)of the tree.

For every tree in the plot the distance from the center to the tree was measured. The distance alone is not enough to find the exact center of the plots. The azimuth of the trees were also collected. Together with the azimuth and the distance of the tree from the center, the center of the plot could be found to do the measurements in 2015.

In state forest, metal bars were hammered into the soil, to mark the plot centers permanently. This makes it possible to do more frequent data collections in the plots. This wasn't done in Community forest, because the iron bars probably would be stolen.

3.2.2.2 Tree sampling in the plots

In the plots the individual trees were sampled. All the trees with a DBH greater than 5 cm (CBH (circumference at breast height) greater than 15.7 cm) were measured individually. First the species of the tree was determined. This was done with the help of Miya Kabajani, a student from the Namibian University of Science and Technology (NUST). She knew the species very well. With the help of "Le Roux and Müller's Field Guide to the Trees and Shrubs of Namibia" trees were determined as the correct species (Mannheimer & Curtis, 2009).

Diameter measurements

The CBH (circumference at breast height) was always measured 1.3 meters above the ground with a tape measurer of 30 m. When the tree is growing on a slope or has grown crooked, the shortest distance from the ground to 1.3 meters was taken as the point to take the CBH. When the tree has a multiple stem under 1.3 meters, all separate stems were measured at 1.3 meters as separate stems (Figure 11). When there was a fork in the tree at 1.3 meters or there was an abnormal swelling at 1.3 meters, the smallest measurement directly below the fork or swelling should be recorded.

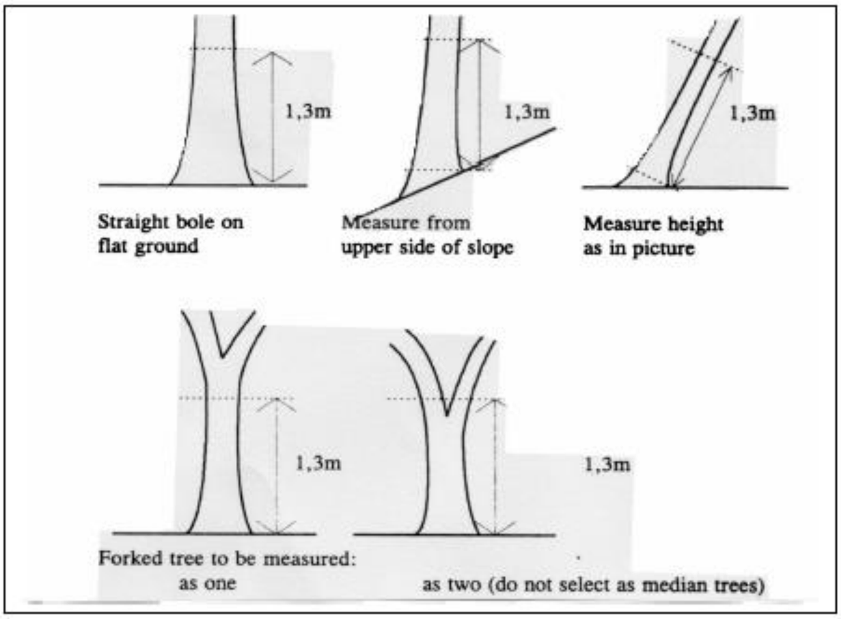

Figure 11: Method to measure the CBH of the trees in different circumstances (The Tree Register, 2014)

The CBH is practical to measure in the field, but DBH is preferred to work with and to interpret results. A simple calculation is needed to calculate the DBH out of the CBH:

$$DBH = \frac{CBH}{\pi}$$

Height measurements

The height of every tree was measured with a laser vertex (Haglöf Vertex Laser VL400). The vertex has an accuracy of ±0.4 m at distance <100 m when measuring the height of a tree (Haglöf Sweden AB, 2016). The laservertex needs a transponder on the tree as a reference point to make the height measurement. The transponder is placed at breast height on the tree (1.3 m). At a distance (HD) from the transponder the distance is measured and then the laservertex is pointed to the top of the tree and the vertex can then calculate the height of the tree (Figure 12). Heights of the trees were measured from the center of the plot. When the tree was too close to the center of the plot to see the top of the tree, a distance from the tree was taken until the top of the tree was visible through the laservertex.

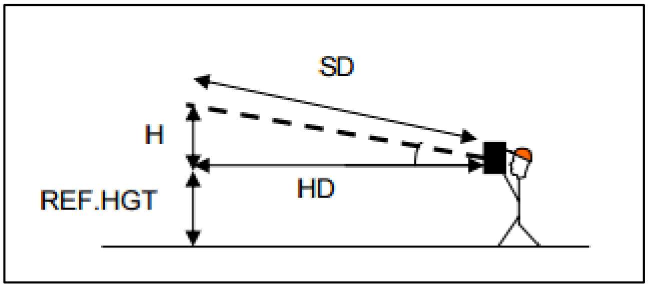

Figure 12: The working principles of the laservertex. REF.HGT= The height were the transponder is placed on the trunk (1.3 m), HD= The distance from where the height is measured to the tree, SD = Distance from the laservertex to the top of the tree, H+REF.HGT= Total height of the tree. (Haglöf Sweden AB, 2016)

Damage condition of the tree

The trees were inspected separately to identify the damage that was inflicted by the forest fires. The damage on the trees was classified into classes from 0 to 4.

- 0 = No damage or influence was noticed on the tree
- 1 = Mild damages are observed, not affecting the tees vitality
- 2 = Moderate damages are observed, decreasing the vitality of the tree
- 3 = Serious damages are observed, seriously affecting several trees
- 4 = Fatal damages are observed, several trees are dying or dead

(De Cauwer, s.a.) based on (Burke et al., 1996)

The condition of the tree was only classified for trees that had a DBH more than 5 cm (CBH > 15.7 cm).

3.2.2.3 Basal area

Out of the DBH, basal area was calculated. In Excel the basal area was calculated for every tree, with following formula.

$$BA = \frac{d^2 * \pi}{4}$$

The formula gives the basal area of every separate tree. To convert the total basal area of all the trees per plot to a basal area per hectare, a few calculations needed to be done in excel.
Basal area is the common term used to describe the average amount of an area (here in hectare) occupied by tree stems. It is defined as the total cross-sectional area of all stems in a stand measured at breast height, and expressed as per unit of land area (in this study square meter per hectare).

Firstly the plot is divided into three concentric circles where different diameter classes where measured.

- The first concentric circle of 10 meters in radius contains all the trees with a DBH greater than 5 cm in diameter.
- The second concentric circle of 20 meters in radius contains all the trees with a DBH greater than 20 cm in diameter.
- The third concentric circle of 30 meters in radius only contains trees with diameters greater than 44.9 cm.

In every concentric circle the basal area of the trees, that belong to the diameter class, where summed up and then converted to basal area per hectare. The basal areas per hectare of the three diameter classes where summed to calculate the total basal area per hectare for every plot.

3.3 Determination of fire frequency per plot

3.3.1 Determining the fire frequency per plot

There are two MODIS fire products available: MODIS thermal anomalies active fire detection (MOD14A2 and MYD14A2), referred as MODIS fire hot spots data with 1 km pixel size and MODIS burned area product (MCD45A1) with a 500m pixel size (Siljander, 2009). To determine how many fires occurred in the plots, burned area products and LANDSAT images were used. Landsat satellites have continuously acquired spacebased images of the Earth’s land surface. These detailed images have a pixel resolution on 30 x 30 meters (U.S. Geological Survey (USGS) , 2015). Active fire product was used as a verification.

The Burned area product shapefile was placed in QGIS together with the LANDSAT images. The burned area shapefiles were downloaded from the WAMIS website and the LANDSAT images were collected from Stellmes, M., et al. (2015).

The LANDSAT images were adjusted in QGIS to make the burned area visible. Band 5 [1230-1250 nm] and 7 [2105-2155 nm] were used in the RGB configuration in QGIS and then the fire scars were visible on the LANDSAT images. With the help of the burned area products the fire scars could be seen on the LANDSAT images. When a plot was in a burned fire scar and was in the burned area shapefile, the plot was affected by fire. When the LANDSAT image indicated a burned scar and the burned area shapefile did not, the LANDSAT image was taken as correct. Since the resolution of the LANDSAT image is higher (30 m x 30 m per pixel). This was done checked for every month with the available monthly burned area shapefiles and the LANDSAT images (every eight days a LANDSAT image is taken).

Marion Stellmes (2013) already did this fire scar monitoring for a period from January 2001 until December 2012. She collected the data in an Excel file that had the information on when a plot was inflicted by a fire, and by how many times.
The data was completed until July 2015 with the help of new downloaded burned area from the WAMIS website and LANDSAT images.
For all the 66 plots the number of fires that affected the plots were registered in an Excel file per month. During a period of January 2001 until July 2015. After the fire monitoring was done, it was known how many fires affected each plot.

Figure 13 is a LANDSAT image of the State forest in Hamoye, with the 33 plots projected as blue dots. The figure shows the state forest without the impacts of forest fires. The vegetation is not affected, thus the vegetation is responsible for most of the reflection of the light. This is why there are no fire scars to be seen in Figure 13. January is not known as a fire season month, since January is in rainy season. LANDSAT images that are taken out of the fire season are used as a reference for the images that show the burned scars to verify if there was a fire in the plots.

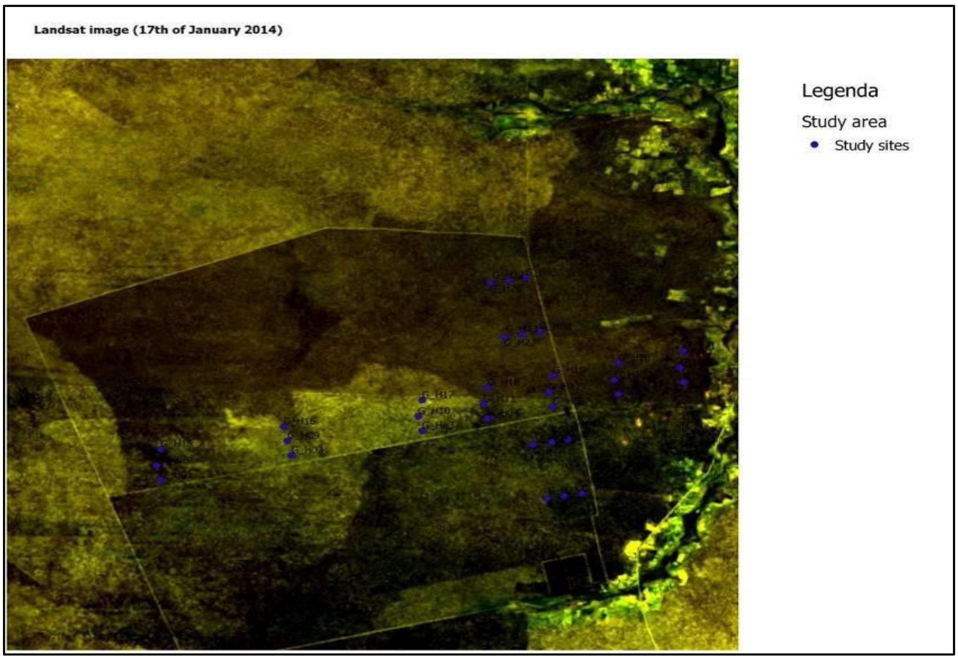

Figure 13: This LANDSAT image is from the 17th of January 2014. Here no fire scars are visible. The dark green and black parts are vegetation, yellow parts are the result of reflected light on the earth's surface (sand). The blue dots are the plots in State forest (Hamoye)

Figure 14 shows a LANDSAT images of 30th of September 2014, this is after a forest fire in State forest (Hamoye). In Figure 14 it is clearly visible that the yellow area is a scar that is caused by a forest fire. The overlaying transparent burned area shapefile follows the fire scar more or less, since the burned area shapefile has a resolution of 500 m it is not perfectly following the LANDSAT image. This is why the two data files were used to see which plots were affected by fire. Bands 5 and 7 were used in the RGB configuration in QGIS. This shows the fire scars more precisely and this configuration is also used to determine all the forest fires in the plots. The yellow color represents the bare burned soil and the green represents the vegetation that is not harmed by the forest fire.

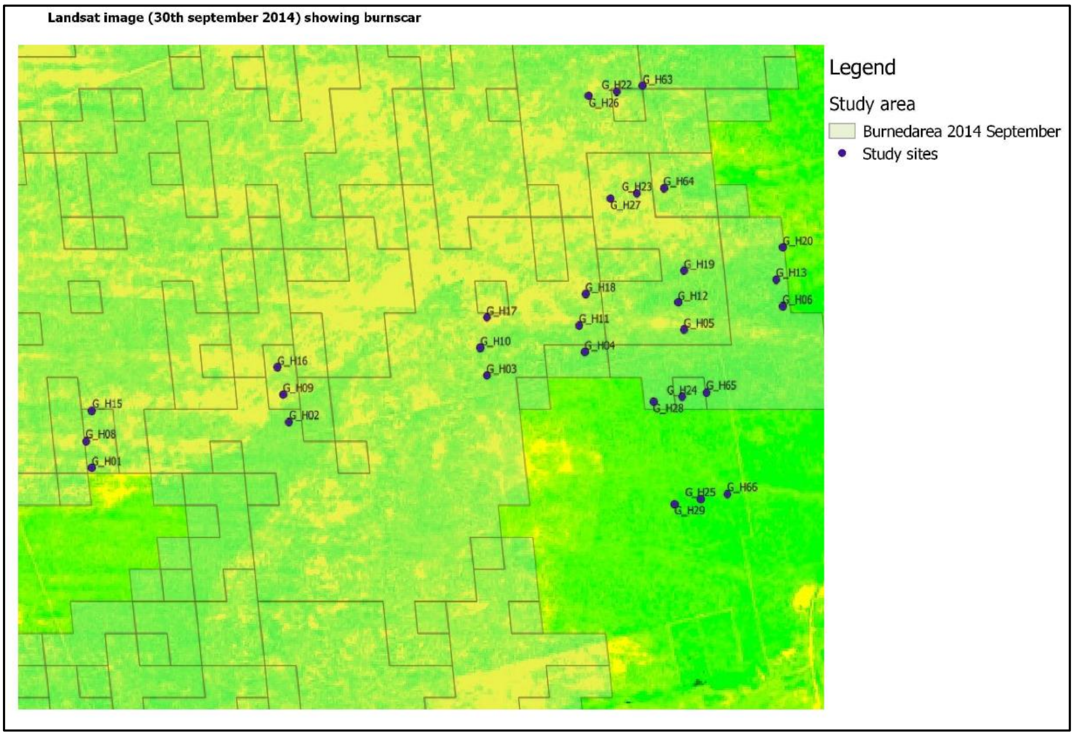

Figure 14: LANDSAT image showing the burn scars in State Forest in September 2014. Here the yellow parts give away the fire scar in September 2014. The burned area product is here projected as a transparent layer. The green parts are vegetation not affected by fire. Here Band 5 [1230-1250 nm] and 7 [2105-2155 nm] of the LANDSAT image are used to make the fire scars visible. The blue dots are the plots in State forest (Hamoye).

3.3.2 MODIS

MODIS stands for Moderate-resolution Imaging Spectroradiometer. It is a key instrument onboard of the Terra and Aqua satellites that detects a wide spectral range of electromagnetic energy. Each satellite makes a complete electromagnetic picture of the globe every two days (WAMIS, 2016). Two interesting products are derived from the electromagnetic pictures.

Burned area shapefiles are a pre-processed product compiled and distributed by the University of Maryland. The product is based on the MCD45 product and provides information at a spatial resolution of about 500 m. This product gives a shapefile on a monthly basis of fire occurrence

(Stellmes, et al., 2013). The burned area is derived from data that depends on the reflectance of electromagnetic radiation. To detect the burned area the near infrared and longer wavelength is used, because they are generally insensitive to smoke aerosols emitted from vegetation fires (Kaufman & Remmer, 1994). These waves are analyzed by an algorithm. The product detects the wavelengths that indicate a burned scar, black open spaces. This detection is only possible during daytime, a burned area is detected if the observed and predicted value differs significantly and if the nature of change matches the characteristics of burning (Justice, et al., 2006).

Burned area products are also susceptible to mistakes, burned area will sometimes be missed because of less reflective soils, flooding, vegetation removal or shadows. Although the algorithm has several test to avoid these false observations (Roy et al., 2005).

LANDSAT satellite images have a better resolution of 30x30m, tis makes it possible to see the fire scars on the land by using the correct bands of the sattelite images. Band 5 [1230-1250 nm] and 7 [2105-2155 nm] prove to have a good indication for monitoring fire scars (Justice, et al., 2006).

The Active fire product and burned area product. The Active fire product depends on the detection of thermal heat and thus the detection of the hottest center of a forest fire. The MODIS sensors onboard Terra and Aqua (those are both satellites) capture the earth’s surface of a given location on average every two days (Justice, et al., 2006). An algorithm filters out the errors, made by clouds, smoke or sun glints and smaller fires (Giglio, et al., 2003). After filtering, only the hottest centers of forest fires are projected as poly points in a shape file that can be downloaded from the NASA website. These poly points can be downloaded as FIRMS (Fire Information for Resource Management System). FIRMS can be requested at the site as shape files or comma-separated text files, that can be converted in any GIS software to a shapefile.

Active fire products are depending on the fact that it is only detected when the satellite can detect thermal heat that is big enough. Clouds and smoke will prevent de satellite to detect the hotspot of the fire. Short duration of fires will also not be detected. This is why active fire data is sometimes inadequate to map burned area (Giglio et al., 2003) (Pereira, 2003).

3.4 Statistical analysis

For the statistical analysis, the data was prepared in Microsoft Excel and then imported into IBM SPSS Statistics 22. For all the tests a significance level of 5% was used.

The number of stems in 2014 was 830 trees in total, in 2015 a total of 843 trees were measured. There is only a difference of 13 trees. In a few plots a couple of trees were neglected by the students of Gottingen. These were mistakes that occur and for the further comparison of the data the missing trees were deleted out of the data in 2015. No further analysis was conducted because of the small difference in stem number.

The measured diameters at breast height in 2014 and 2015 were compared, to see if there is a change in diameter composition of the forest. To compare the DBH of all the trees, only the

trees that were already sampled in 2014 were compared with the same sampled trees of 2015. First the normality of the dataset was tested. The data was then compared with a paired samples t-test.
The diameter at breast height (data 2014 and 2015) was checked for normality and then statistically tested with a paired samples t-test. The data of State forest and Community forest were tested separately and a significance level of 5% was used.
A difference in height between 2014 and 2015 was also tested with an paired samples t-test. The data proved to be distributed normally.
To compare the damage classes of the trees, an non-parametric test (Wilcoxon Signed Ranks Test) was used, because the data was not distributed normally.

The difference in fire frequencies in SF and CF was tested with a non-parametric test (Mann-Whitney U-test), because the data was not distributed normally.

The BA/ha was tested for State Forest and Community forest. It was tested on normality and then the impact of the fire frequency and the location on the BA/ha was tested with a Two-way ANOVA test. When the frequency of fires is divided into classes from one to eight, with class one being one fire in State Forest (Hamoye), class two being two fires in State forest (Hamoye) until class eight being four fires in Community forest (Ncaute). A one-way ANOVA can be done. A One-way ANOVA was used to test the impact of fire frequency on the basal area. A Tukey HSD test was used to see if there was a difference in BA/ha.

4 Results

4.1 Comparison individual tree data 2014 with data 2015

The DBH of 2014 and 2015 proved to be divided normally. No significant difference was found between the DBH of 2014 and the DBH of 2015 (paired samples t-test). This was the case for the entire dataset, and for the two forests separately (p value of 0.159).

In SF the DBH didn’t change significantly., the mean DBH of 2014 showed no significant difference to the DBH of 2015 (p-value of 0.173).
The same was done for the CF. The DBH of 2014 showed no significant difference to the DBH of 2015 (p-value of 0.318).
Since the DBH hasn’t changed significantly we can conclude that the BA hasn’t changed significantly either. In one year the fire had no significant impact on the BA and the diameter at breast height.

Height on the other hand did change. The mean height in 2014 was 9.11 meters, in 2015 the mean observed height was 9.2 meters. This is a minor rise in height, but the paired samples t-test showed that the average heights changed significantly (p-value less than 0.05).

Next to these measurements, damage that was inflicted by the fire was estimated. Figure 15 shows the evolution of damage class in the different diameter classes of the measured trees in CF and SF. The data of the difference in damage wasn’t normally distributed (p-value less than 0.05), a non-parametric test (Wilcoxon Signed Ranks Test) proved that there is a significant damage increase of 0.5 in comparison with the damage of 2014 (p-value less than 0.05).

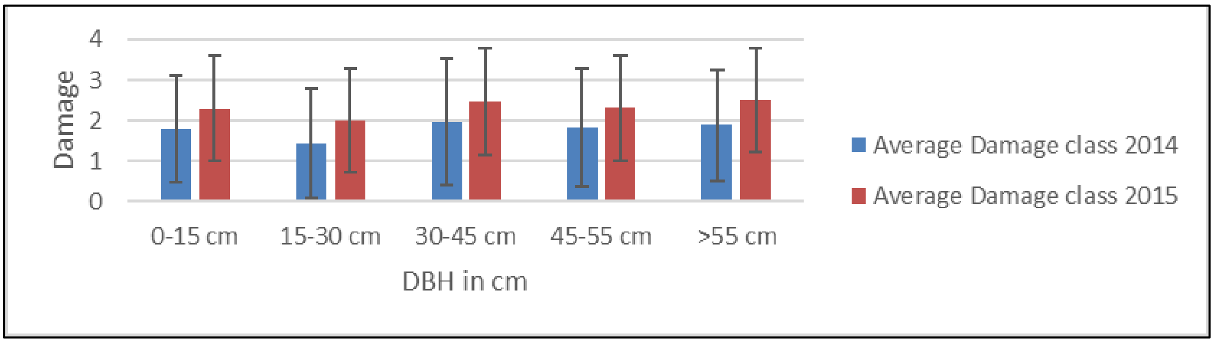

Figure 15: This graph shows the average observed damage of the trees in 2014 (blue bars) and 2015 (red bars). The damage class in this graph is linked with diameter classes. Standard deviation is given per bar.

4.2 Fire frequency in State forest and Community forest

Most of the fires occurred in the late dry season. From August until October 65% of the total fires occurred in the plots in a period of 14 years. In the month July the vegetation is also very susceptible for forest fire, the biomass is then dry enough. In July 21% of forest fires occurred (Figure 16).

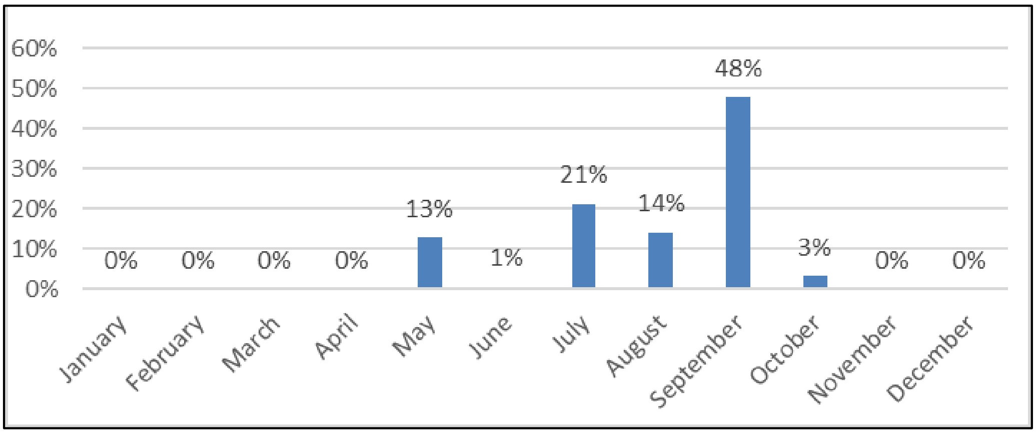

Figure 16 Shows an overview of the months that had the most percentage of fires in a period of 14 years. Most of the fires occured in the late dry season, 65 percent of the forest fires occured in the late dry season (August-Ocotober).

In Figure 17, an average number of fires per plot in community forest (CF) and state forest (SF) is given (Figure 17) over a period of 14 years (from January 2001 until July 2015). The average number of fires is a result of the burned area analysis. This graph shows the average number of fires that affected a plot in SF (blue bars) and in CF (red bars). September has the highest average number of fires per plot in state forest, with almost 2 fires in a period of 14 years. In community forest, July is the month with the highest number of fires per plot.

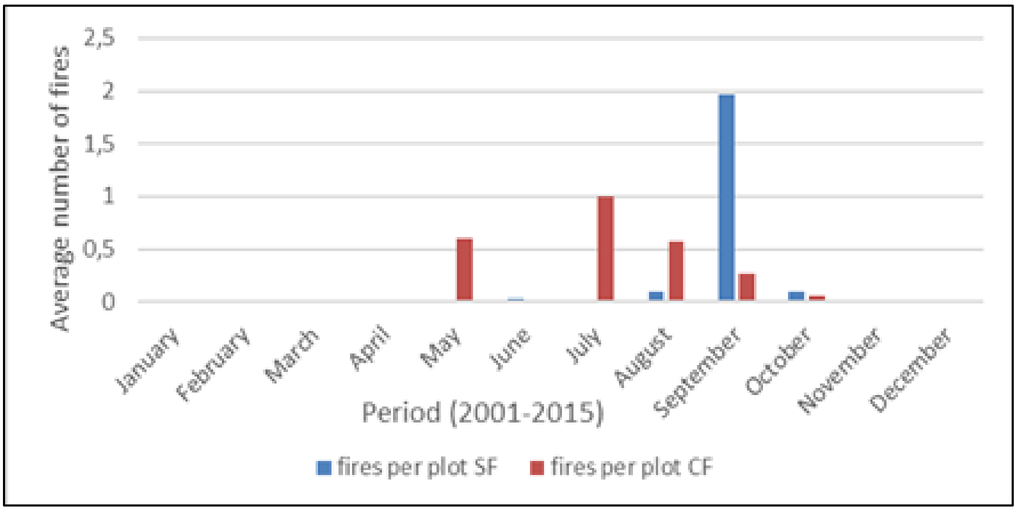

Figure 17: An overview of the average number of fires per plot in State Forest (blue bars) and Community Forest (red bars) in the period from January 2001 until July 2015. The graph shows a concentration of forest fires in September for State forest. While the forest fires in Community forest are occurring from July until September.

In both CF and SF all plots were affected by at least one fire in the past 14 years. The maximum number of fires a plot had to endure is four fires. Community Forest plots were affected by nine more forest fires then State Forest plots. In total 83 fires affected the plots in CF and 72 fires affected the plots in SF.

Figure 18 shows the number of plots that were affected by fire per year. The blue bars represent the plots that were affected by fire in State forest and the red bars represent the plots that were affected by fire in Community forest.

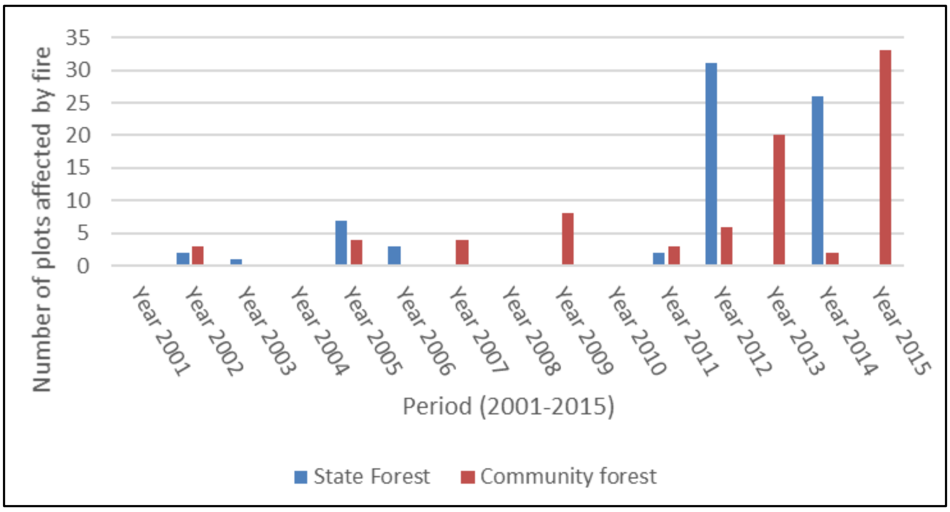

Figure 18: This graph shows the number of plots that were affected by fire in State forest (blue bars) and Community forest (red bars) per year.

Figure 19 shows us the difference in fire frequencies in SF and CF. An average of 2.5 forest fires affected the plots in Community forest, while the state forest plots were affected by an average of 2.18 forest fires in a period of 14 years. The average is thus slightly higher in community forest, but it was not proven that there was a significant difference in average number of fires. The average number of fires per plot in CF and SF were not normally distributed (p-value less than 0.05), Mann-Whitney U-test gave away that there was no significant difference in average number of fires per plot in CF an SF (p-value of 0.071).

The graphs seem to show that most of the plots in Community forest are affected by a higher fire frequency. While most of the plots in State forest are affected by lower fire frequency (Figure 19).

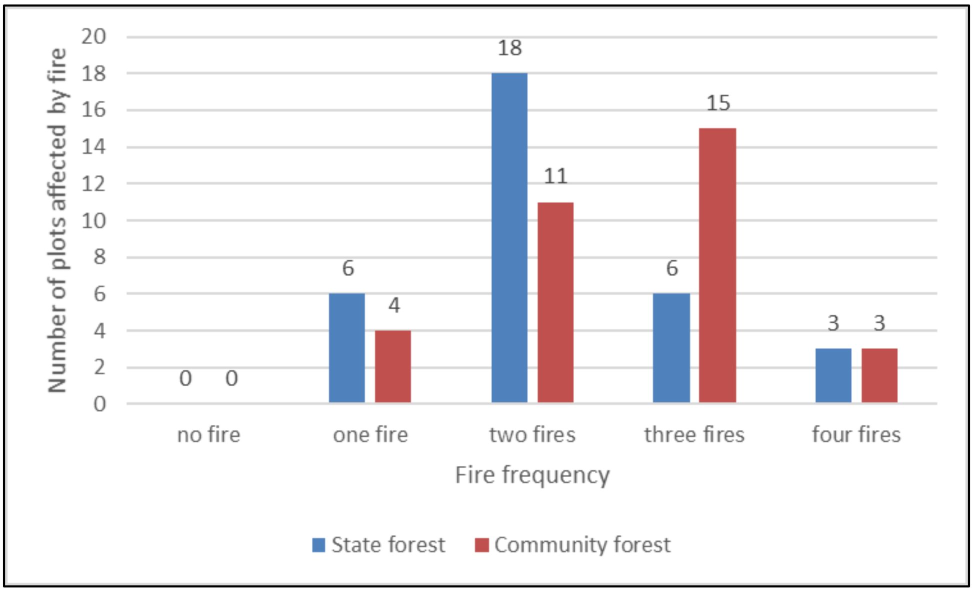

Figure 19: Number of plots that are affected by different fire frequencies in Community forest and State forest, ranging from one fire in 14 years to 4 fires per plot in 14 years. With an average fire frequency of 2.5 forest fires per plot in Community forest and an average fire frequency of 2.18 in State forest.

4.3 Impact of fire frequency on basal area

The average calculated BA/ha in State forest (Hamoye) is 7.39 m²/ha. The average BA/ha in Community forest (Ncaute) is 3.52 m²/ha. State forest has double the amount of BA. The BA is normally distributed, Shapiro-Wilkinson gave a p-value of 0.5 for State forest and 0.104 as p-value for Community forest. It can thus be concluded that the BA is normally distributed. The BA is significantly higher in State forest, there was a significant difference (p-value of 0.018). The number of fires does not seem to have a significant impact on the BA. With a p-value of 0.7 it cannot be stated that the number of fires has a significant impact on BA. The interaction location (CF or SF) and number of fires is also not significant (p-value of 0.269).

In State forest (Hamoye) BA for the different fire frequencies doesn’t differ a lot. But in Community forest (Ncaute), BA is very low (1.8 m²/ha) in the low fire frequencies and rather high (6.48 m²/ha) in the high (four fires) fire frequency.

A one-way ANOVA gives a significant difference between groups of mean BA/ha (p-value smaller than 0.05). The Tukey HSD test shows that only the plots with one fire in Community forest differ significantly from the plots with one, two and four fires in State forest. The rest of the classes do not differ significantly from each other (Figure 20).

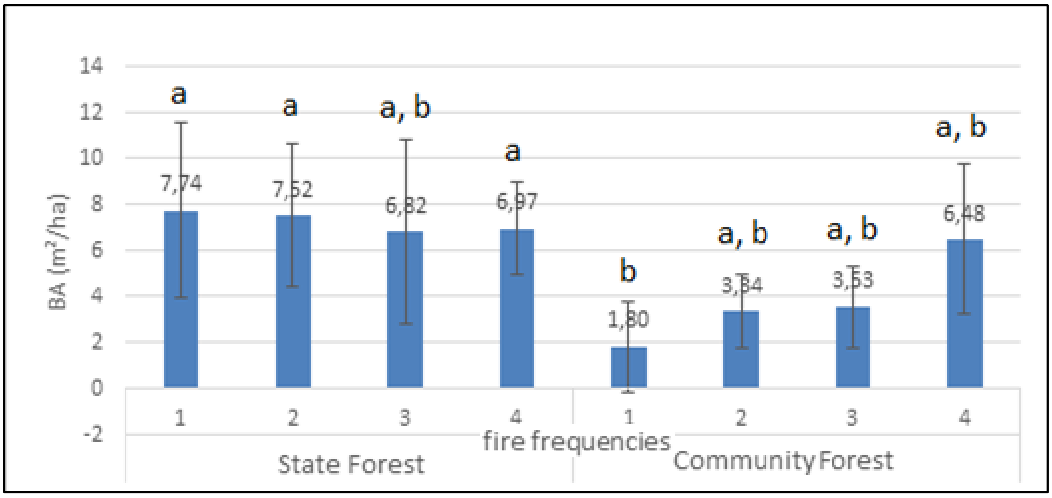

Figure 20: Gives the mean BA/ha in State Forest (Hamoye) and Community Forest (Ncaute) in different fire frequencies. The variations are present for every fire frequency. The results of the Tukey HSD test are marked with letter a and b, pointing on differences in mean BA/ha between the different classes.

The mean BA/ha in fFigure 20 doesn't take the different diameter classes into account. The three diameter classes were also tested with an two-way ANOVA. Similar results were retrieved as the two-way ANOVA from the total mean BA/ha. The BA in the two biggest diameter classes is significantly different in the two different locations (p-value greater than 0.05). More BA in SF (Hamoye) than CF (Ncaute). But there seems not to be a significant difference in BA for the smallest diameter class (DBH 5-20 cm), thus the BA for the smallest diameter class is equal in SF and CF (p-value smaller then 0.05). The mean BA/ha for the smallest diameter class is 1.57 m²/ha for SF and 1.15 m²/ha for CF (Figure 21). The figure below clearly shows the BA/ha difference in location. CF clearly has a lower BA/ha then SF. But the mean BA/ha in the smaller diameter class does not differ significantly.

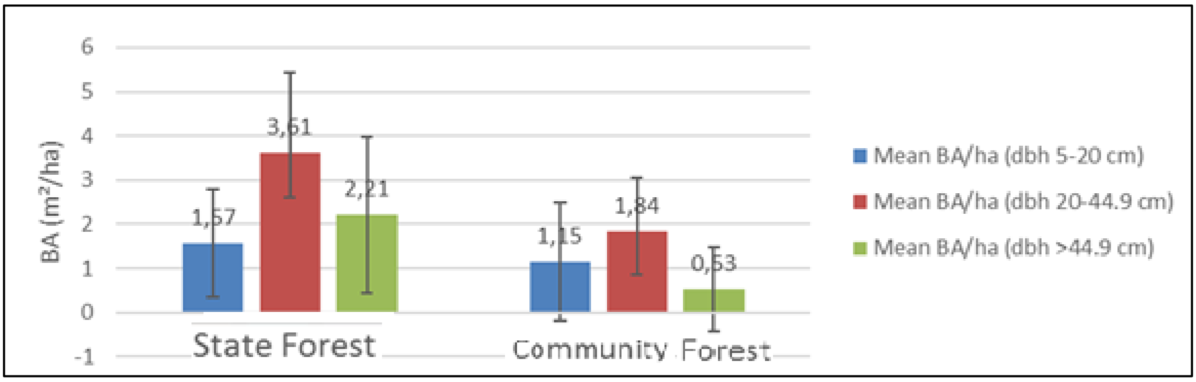

Figure 21: This graph shows the mean BA/ha for three different diameter classes in State Forest (Hamoye) an Community Forest (Ncaute). The blue bars give the mean BA/ha for the diameters ranging from 5 to 20 cm, the red bars show the mean BA/ha for the diameter class ranging from 20 to 44.9 cm and the green bars show the mean BA/ha for the diameter class with diameters greater than 44.9 cm.

For all three classes (DBH from 5 to 20 cm, DBH from 20 to 44.9 cm and DBH greater than 44.9 cm) fire frequency does not have a significant impact on the BA/ha (p-value greater than 0.05). The interaction between location of the forest and number of fires also does not have a significant impact on BA (p-value greater than 0.05) (Figure 22).

Figure 22 shows a high BA/ha in the smallest diameter class for the plots in Community forest (Ncaute) with a forest fire frequency of four fires in comparison with the other fire frequencies in Community forest. While this is not the case in State forest (Hamoye). Although the figure gives the intention that the forest fires cause a difference in BA/ha in the smallest diameter class, statistical analysis didn't found a difference in BA/ha with forest fire frequency as a random factor.

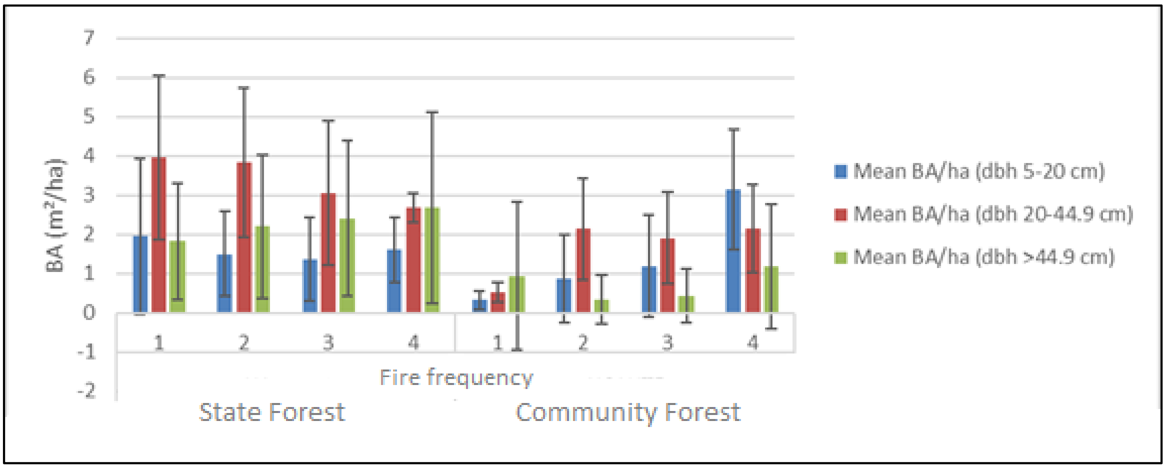

Figure 22: A graph showing the distribution and variation of the mean BA/ha in the three different concentric circles. The blue bars represent the mean BA/ha of trees with DBH ranging from 5 to 20 cm. Red bars represent the mean BA/ha of the trees with DBH ranging from 20 to 44.9 cm. The green bars represent the mean BA/ha of trees with DBH greater than 44.9 cm. The mean BA/ha are given for the two different forests, State Forest (Hamoye) and Community Forest (Ncaute) under the different fire frequencies.

4.4 Impact of fire frequency on four woodland species

Figure 23 shows the mean BA/ha for the smallest diameter class. We can see that *Burkea Africana* knows a raise in BA/ha with a rise in fire frequency in Community forest. In State forest, this is clearly not the case, although there is less BA/ha for *B. africana* in the highest fire frequency in state forest. We can see that *Baikiaea plurijuga* is absent in community forest, in the field no *B. plurijuga* were found. It seems that there is no regeneration of the species in Community forest. *Pterocarpus angolensis* also knows a raise in BA/ha with a rise in fire frequency, especially in Community forest the rise is clearly seen in the figure (Figure 23).

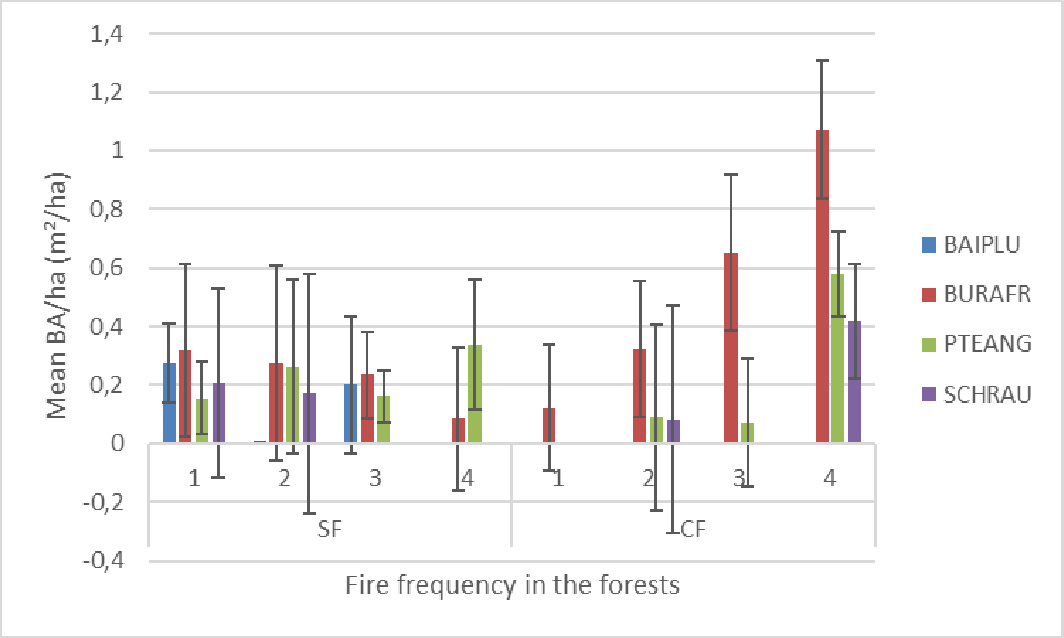

Figure 23: Shows the mean BA/ha for four woodland species in State forest (SF) and Community forest (CF) under different fire frequencies for the smallest diameter class (5-20 cm). ***Burkea africana*** **(BURAFR),** ***Baikiaea plurijuga*** **(BAIPLU),** ***Pterocarpus angolensis*** **(PTEANG) and** ***Schinziophyton rautanenii*** **(SCHRAU). Mind the raise in BA/ha in CF of BURAFR. Also PTEANG has more BA/ha in higher fire frequencies.**

Figure 24 and Figure 25 show the mean BA/ha of the middle and highest diameter classes (20-44,9 cm and more than 44,9 cm). These figures show that *B. africana* is dominant in the middle class. In the highest diameter class *B. plurijuga and S. rautanenii* are dominant in State forest. But *B. plurijuga* is not present in Community forest, there are no trees measured in this forest of *B. plurijuga*.

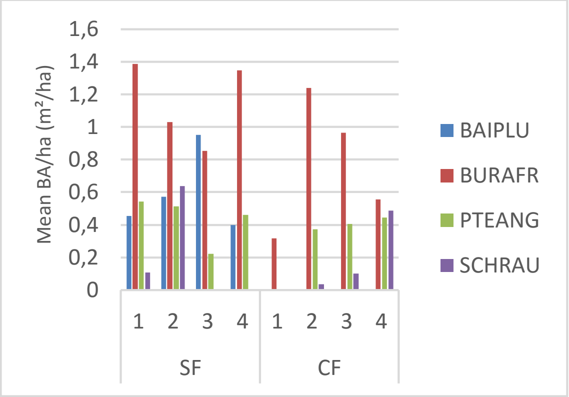

Figure 24: This figure shows the mean BA/ha for four woodland species in State forest (SF) and Community forest (CF) under different fire frequencies for the middle diameter class (20-44,9 cm). *Burkea africana* (BURAFR), *Baikiaea plurijuga* (BAIPLU), *Pterocarpus angolensis* (PTEANG) and *Schinziophyton rautanenii* (SCHRAU). Here again the dominance of *B. africana.* Again the absence of *B. plurijuga* in Community forest.

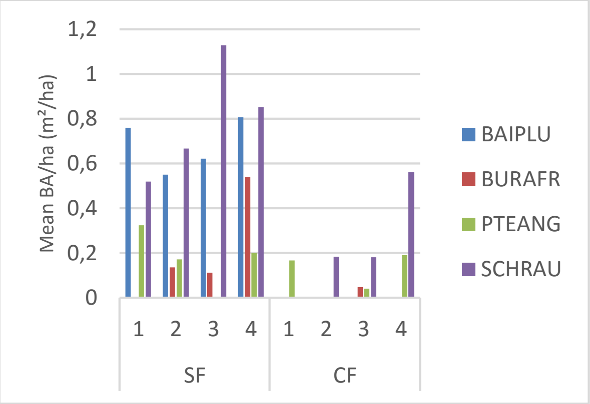

Figure 25: This figure shows the mean BA/ha for four woodland species in State forest (SF) and Community forest (CF) under different fire frequencies for the highest diameter class (> 44,9 cm). *Burkea africana* (BURAFR), *Baikiaea plurijuga* (BAIPLU), *Pterocarpus angolensis* (PTEANG) and *Schinziophyton rautanenii* (SCHRAU). In this graph we can see that *B. plurijga and S. rautanenii* are the dominant species in State forest. In the highest fire frequency, *B. africana* has a rather high BA/ha, this is probably because of its high fire resistance.

5 Discussion

5.1 Short term variation in tree composition and tree growth

The results show no significant change in stem number and diameter of the trees. That there is no change in stem number is probably because the fire does not have a severe impact on short term. The diameter class didn't change significantly, this is probably because the time in between measurements was rather short (10,5 months). The species that grow in the Namibian woodlands are known to grow rather slow. For example a *P. angolensis* reaches a harvestable diameter of 45 cm in 90 to 95 years (Graz, 2004).

The height measurements showed a significant change. The height in 2015 was significantly higher than 2014. But the height only changed with nine centimetres. This is a rather small growth, but it was proven significantly. We should be careful with interpreting these results, because the measurements of 2014 were done by a group of students of Göttingen and in 2015 the measurements were done by two persons. Mistakes in height measurements are easily made and maybe the wrong top of the tree was taken. So we should be careful with assuming that the height of the trees did change significantly. Vasilescu (2013) found that a Vertex III hypsometer had an error of 0.3 m for smaller trees (about 10 m height) and less than 0.2 m in case of taller trees (> 20 m) (Vasilescu, 2013).

Because stem number and diameter didn't change in one year we can assume that the basal area also didn't change significantly. Since the basal area didn't change significantly and the height only changed with nine centimetres, we can assume that the standing stock also didn't change significantly.

The diameter distribution in State forest and community forest did not change significantly. In between the two measurements 13 trees died, so no change in diameter distribution can be proved.

This short term comparison of data does not show a significant change in the growth of the trees. The diameter distribution was also not affected in the short period even though forest fires affected both forests in between measurements. The growth an diameter distribution probably didn't change because of the slow growth of the trees in these types of forests. Most tree species are resistant to forest fires and can withstand a forest fire. Multiple frequent fires are needed to kill trees and thus creating a change in diameter distribution (Gandiwa & Kativu, 2009).

Further studies could be focussing on long term effects of fire on the forest vegetation. If frequent collection of data can be done, the effects of fire on long term can be studied.

5.2 Susceptibility of trees to the impact of forest fires

Because both State forest and Community forest were affected by forest fires in between measurements, the effect of fire on the individual trees was measured with the help of damage classes. The results show a significant impact of the fire on the damage of the trees. The damage class rose with half a class in comparison to the year 2014. This shows that fire has an impact on the individual trees, but one fire is not enough to change the diameter distribution and the stem number. Probably multiple fires are needed to change the distribution and stem number, because most of the species are adapted to forest fires. Most of the species have thick bark and are in rest when fire season is at its highest (Childes, 1989).

It was not proven significantly that the middle diameter class trees were affected less than the lower and higher diameter class trees. All diameter classes seemed to rise evenly in damage. The seedling and sapling stage of the trees are most vulnerable for the fire damage. These small diameter trees are easily killed by fire and even though the trees resprout in the next growing season, frequent fires prevent the tree to grow into a large enough tree to escape the fire (Bond W. J., 2008). Ben-Shahar (1998) found that in forests with higher fire frequency, density of trees was lower and that there were more lower diameter class trees and smaller trees with height less than 3 meters. These trees were also more susceptible to fire damage than mature trees (Ben-Shahar, 1998). He also found that hence the fact that tall trees are more resistant to fire, in the *B. plurijuga* dominated woodlands, the tall trees declined significantly and had a lot of accumulated fire damage.

5.3 Impact of fire frequency on basal area of Community forest and State forest

The results show that fire does not have a significant impact on the basal area. The type of forest seems to be significant for the basal area. In State forest the basal area is significantly higher than the basal area in Community forest. This is because this type of forest is managed in a different way. State forest are managed in a no touch policy, while in community forests the community can harvest trees if this is regulated by management plans (Republic of Namibia, 2001). The human impact is probably the reason why the basal area in Community forest is significantly lower than in State forest. Since the Community can harvest trees in Community forests.

Figure 22 shows an increasing BA/ha of the small diameter trees with an increasing fire frequency in Community forest. This however is not statistically proven different. The fire frequency does not have an impact on the BA/ha. Only location is proven statistically influencing BA/ha. The BA/ha for State forest seems not to be influenced by fire frequency when we see Figure 20. This however is strange, since we would expect an decreasing BA/ha with an increasing fire frequency. The BA/ha in State forest seems to be staying constant with increasing fire frequency, but in Community forest Figure 20 shows that the BA/ha seems to increase with an increasing fire frequency. This however wasn’t proven statistically, only location seemed to have an impact on BA/ha, fire did not have an statistical impact on BA/ha.

Gandiwa and Kativu (2009) found in their research that with an increasing fire frequency BA/ha did indeed decrease, this is not the case in this study. BA/ha does not seem to be affected by increasing fire frequency. They also found that with an increasing fire frequency the woody plants with small diameters increased in number. The forests affected by higher fire frequency had more small diameter trees (shrubs) than the larger diameter trees (Gandiwa & Kativu, 2009). In community forest we also see an increase in the smallest diameter trees with an increasing fire frequency. Walters (2000) found that there was an increase of BA, because of the increase in basal coppicing or resprouting, with an increase of fire frequency. This can explain the increase in BA/ha in the small diameter class in Community forest. Kennedy and Potgieter (2003) also had these findings in their research.

Out of the results we cannot conclude that fire has an impact on BA/ha. This is rather odd, because it seems obvious that fire results in an decrease of BA/ha. Further collection of data would be important to see the evolution on long term on the BA/ha. Because this study was conducted on short term, the influence of forest fire on BA/ha was not proven. This is probably because the different trees species (e.g. *P. angolensis and B. africana*) (Vermeulen, 1990; Burke, 2006) are adapted to forest fires and they need multiple fires to get killed. This is why further collection of data, of the same plots, could possibly give more results on the effect of forest fires on BA/ha.

The data collection is also observational, the conditions in the different plots are not always the same. Maybe an experimental setup with controlled burnings in the different experimental plots with the same BA and biomass could generate interesting results.

B. africana is a fire resistant species, especially in Figure 23 we can see that in Community forest the average BA/ha of the small diameters of *B. africana* increases with an increasing frequency of fire. *B. africana* is also the most dominant species in the basal area with trees of the middle class diameter. This shows that the species is more resistant against forest fire (Burke, 2006) and it can grow in forests that are affected by forest fire. Also *P. angolensis* does well in fire affected forests (Vermeulen, 1990), but here the results are less clear.

Figure 23, Figure 24 and Figure 25 all show that *B. plurijuga* is missing in Community forest. Apparently *B. plurijuga* is not occurring in Community forest, we cannot say that this is a result of the species vulnerability to fire (Childes, 1989). Because it is occurring in fire affected plots in State forest. So the only explanation that seems plausible is again the impact of the human logging because of its good resistance against termites and its excellent durability (Joker & Jepsen, 2015).

S. rautanenii is prominent in the higher class diameters, larger trees are mostly left alone by people and even protected. Because the trees provide food that help the people survive (Erkkilä & Siiskonen, 1992). The species does also grow faster in comparison to the other tree species (Peters, 1987).

5.4 Fire frequency in State forest and Community forest

In both forests the number of fires that occurred in the period of 14 years was more or less the same. No statistical difference was found in number of fires. It seemed however that the fire frequency in state forest is more in the one and two fire classes, and community forest plots know a higher fire frequency in the plots. The average number of fires in the plots of Community forest and State forest do not differ significantly (p-value 0.071). An average of 2.5 fires was found in Community forest and 2.18 fires in State forest. The p-value does not differ a lot from the significance level of 0.05. With the fact that we can see that the plots in Community forest are mostly affected by higher fire frequencies (three and four fires in the period of 14 years). We can carefully state that there is indeed a higher fire frequency in Community forest. This is probably a result of the different management that allows the community to use the forest. This higher fire frequency could be an explanation for the lower basal area in Community forest. However the fact that the forest is managed in a different way is also an important factor for the lower basal area.

Most of the forest fires in State forest occur in the month September. This is at the end of the late-dry season and have the most destructive influence on the forest, because all the biomass is very dry and fire can spread easily (Siljander, 2009). In Community forest there is no specific month were most of the fires occur.

Figure 17 shows that fires occur mostly in the period from May until October. This is also what the literature states (Verlinden & Laamanen, 2006).

Figure 18 shows the number of plots affected by a fire in Community forest and State forest. Out of this figure we can conclude that Community forest knows a period of maximum two years before a forest fire reoccurred. From 2011 until 2015 the forest was affected by fire every year. In State forest, forest fires also do occur frequently. There is one period that the forest is not affected by forest fires for four years (2007-2010). The rest of the period also show a return of forest fire of maximum two years.

6 Conclusion

This study shows that there is almost no change in stem number, only 13 trees died in a period of 10.5 months. The basal area didn't change, since there was no significant growth in diameter of the trees. The height of the trees however did change significantly, an average increase of nine centimetres was found. This however should be interpreted carefully, because the measurements of the trees were done by two different teams and the laser vertex has an measuring error that can't be neglected. The nine centimetres increase in height is much, especially when we study the standing stock. We can thus conclude that there was no increase in standing stock. This was expected, since the trees are slow growing species. We also didn't find a change in diameter distribution, since most of the trees didn't grew in the 10.5 months period. Stem numbers, tree height, standing stock and change in diameter distribution didn't change in the short period of 10.5 months. To study the evolutions in these parameters a long term study will be needed, with yearly data collections of the same plots.

The short term effect of fire on the trees, was an increase of half a class in damage. This increase was proven significant. It can be concluded that the forest fires do have an impact on the individual trees. It was however not proven that there was a diameter class that suffered more from the forest fires. All diameter class showed an increase in damage.

Basal area per plot in Community forest is significantly lower than in State forest. With an average of 7.39 m^2/ha in State forest, State forest has more than double the amount of basal area than Community forest (with an average of 3.52 m^2/ha). The location has an significant impact on the basal area. The frequency of forest fires in the plots does not seem to have a significant impact on basal area. In state forest the average basal area per plot stays more or less constant with an increasing fire frequency. In Community forest the basal area increases with an increasing fire frequency. The reason of this increase is the increasing basal area of the small diameter class (dbh 5-20 cm) trees with an increasing fire frequency. This is probably an effect of the frequent fires, burnt down trees produce more small diameter coppices. Leading to an increase in basal area of small diameter trees.

Only the location is proven to be significant on the basal area, this is probably because of the human impact on the forest. In Community forest trees can be cut down when permission is granted. In State forest a “no touch policy” is the rule, the forest is protected to maintain the biodiversity.

The fire frequency does not have a significant impact on basal area, this is probably because the two data collections were done very shortly after each other. Again a more frequent data collection for a long period would give more insight in the evolution of the basal area and the impact of fire frequency on it.

B. africana seems to do well in the fire affected forests, in Community forest an increase in basal area in the smaller diameter classes is seen. The species also has the highest average basal area in CF and SF for the middle diameter class. This shows that the species is indeed an fire resistant species. *B. plurijuga* was not found in the plots of Community forest, this is probably not because of the forest fires. Because the species is found in State forest affected plots. The wood has interesting properties, such as termite resistance. This is probably why it is harvested a lot by people of the Community. In the largest diameter class, the average basal area of *S. rautanenii* is higher than the other species. This probably because of its interest as food provider and its rather fast growth in comparison to the other species.

With an average of 2.5 forest fires affecting the plots in Community forest, and an average of 2.18 fires affecting the plots in State forest no significant difference was found. We can however carefully state that there could be a difference in fire frequency, because the p-value (0.071) is not very far from the used significance level of 0.05. It seems that the plots in community forest are affected by higher fire frequency and the plots in State forest by lower fire frequency. With this we can presume that Community forest knows a higher fire frequency. This is probably because of the difference in management and the influence of the community. We can however conclude that in both forests the fires occur in the late dry season. In State forest fires occur especially in September. While the forest fires in Community forest mainly occur from July to October. Both Community forest and State forest are frequently affected by fires. In Community forest fires occur every two year. The last period from 2011 until 2015 Community forest burned annually. State forest was also affected by fire every two year, only in the period from 2007 until 2010 the forest was not affected by fire. These results show us that the forests are indeed frequently affected by forest fire and that the vegetation is under constant pressure.

Recommendations for further research, is the continuous collection of data to detect the evolution of the forest on long term. The collection of data on a yearly basis could give more insight in what the long term effect is of forest fires on the vegetation. 10.5 months in-between measurements is probably too short, because the slow growing vegetation and its fire resistance.

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