THE EFFECT OF BROWSING, FIRE AND PLANT COMPETITION ON THE REGENERATION OF TIMBER TREES AND OTHER WOODY SPECIES IN ONKUMBULA COMMUNITY FOREST OF NORTHERN NAMIBIA

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NAMIBIA UNIVERSITY OF SCIENCE AND TECHNOLOGY

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Declaration

I, *Monika Amutenya*, hereby declare that the work contained in the thesis entitled: *The effect of browsing, fire and plant competition on the regeneration of timber trees and other woody species in Onkumbula community forests of northern Namibia* is my own original work and that I have not previously in its entirety or in part submitted it at any university or higher education institution for the award of a degree.

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List of Acronyms

ANR – Assisted natural regeneration
BaiPlu – Baikiaea plurijuga
BurAfr – Burkea africana
CBNRM – Community based natural resource management
CD – Collar diameter
CD Diff. - Collar diameter difference
CF – Community Forest
DBH – Diameter at breast height
DoF – Directorate of Forestry
FMB – Forest Management Body
GLM – Generalised linear model
GPS – Global Positioning System
GuiCol – Guibourtia coleosperma
H_0- Null hypothesis
H_1- Alternative hypothesis
Ha – Hectares
Height Diff. - Height difference
MAWF – Ministry of agriculture, water and forestry
NACSO – Namibia Association of CBNRM support organisations
NAFOLA – Sustainable Management of Namibia Forested Land
PtrAng – Pterocarpus angolensis
SASSCAL – Southern African Science Service Centre for Climate Change and
NUST – Namibia University of Science and Technology

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Dedication

To my Husband, Heinrich Ndeutala Sheehama, for all your love and support

IN LOVING MEMORY OF

Gerlidis Tweifa-Oipa Gergolius Kakangwa "Mother" (1950 – 2010)

Paskalia Ndeshuuva Shambwangala "Grandmother" (1927 – 2018)

Abstract

Natural regeneration is an important component of forest dynamics, therefore the knowledge of the forest and requirements of different species are vital for proper planning of sustainable forest management. It is also important to understand how abiotic and biotic factors affect forest regeneration. This study looked at the effect of browsing, plant competition and fire on the regeneration of woody species in Onkumbula community forest in northern Namibia.

The study was divided into two experiments. Experiment 1 looked at the effect of browsing and plant competition on seedling density, seedling species richness, seedling growth and survival. Experiment 2 assessed the effects of fire on woody species regeneration density, species richness, mortality and shoot production. The study sites for Experiment 1 were set in three villages selected based on the last inventory for the community forests where high numbers of timber species were recorded. Three sites were selected; eight plots per study site were established. At each site, four subplots were fenced off to observe the effect of browsing protection on seedlings. A treatment of competition removal to observe the effect on seedlings was also applied. The effects of the treatments to seedlings were monitored between March 2018 and April 2019. In Experiment 2, ten plots were set in the burnt areas of the 2017/18 fire season and ten plots in the adjacent, not burned area and the effect of fire on woody species regeneration was observed five months after the fire.

According to the results, browsing protection did not affect seedling density ($p=0.116$) and species richness ($p=0.445$). However, browsing protection significantly improved the growth of seedlings both in height and diameter ($p<0.001$) but did not significantly improve seedlings survival ($p=0.591$). Plant competition removal did not significantly influence seedlings' species richness ($p=0.132$) or growth ($p=0.441$ for height growth and $p=0.307$ for collar diameter growth). The treatment did also not influence seedling survival ($p=0.838$). Burned plots recorded a significantly higher number of seedlings by 31% compared to unburned plots and recorded 8 species more compared to 5 species in the no-fire treatment. Shoot production in trees and saplings increased with fire, recording average shoots of 3.9 in saplings and 4.5 in trees. Fire significantly affected sapling survival with 36% of saplings recorded dead in the fire plots compared to 2% in the unburned plots. The results of this study will help in the proper management of tree regeneration in Namibia forests by providing more insight into the extent that natural regeneration is affected by external disturbances such as herbivory, fire and plant competition.

Keywords: density, species richness, natural regeneration, browsing, plant competition, fire

Chapter 1: General Introduction

1.1 Background

Forests are important natural resources that play a significant role in human life; humans have always relied on forest resources to meet basic needs. Forests purify the air by filtering particles and chemical substances, preserve catchments by preventing soil erosion and improve water quality and quantity (Mendelson and EI Obeid 2005). In addition, they stabilize soil and prevent erosion, provide products such as timber, medicine and are home to many of the world's most endangered wildlife species. In Namibia, direct use of forest resources is mainly from harvesting of wood for fuel and construction mostly by rural households as well as harvesting of non-wood forest produce for various uses (Siiskonen 1996). With the impact of climate change, these forest products and services are likely to decline in the future (Lucas and Manuel 2014). In the context of global change, changes in temperature, rainfall patterns, biogeochemical cycles and land use have already been recorded worldwide and are predicted to intensify in the future (Lucas and Manuel 2014). Namibia is classified as a semi-arid country with variable rainfall pattern; climatic changes may reduce the success of natural regeneration and hence require adjustments to silvicultural practices. *Pterocarpus angolensis, Baikiaea plurijuga, Guibourtia coleosperma* and *Burkea africana* are among Namibia's most important trees (Mendelsohn and El Obeid 2005) for their good timber and other wood products. This status is based on their economic, ecological as well as social values. The trees are also found in most of the savannah areas of eastern and southern African countries (Ncube and Mufandaedza 2013).

Land clearing for agriculture is considered one of the main causes of deforestation in Namibia (Ibrahima and Moses 2002). Large tracts of woodlands are cleared using traditional slash and burn methods, especially in the north and northeast of the country. Namibia's forest soils are generally poor and quickly lose fertility when crops are planted continuously. When this happens the land is abandoned and another area cleared. This practise is common in the two Kavango regions and Zambezi region. Slash and burn have been practised for centuries but it has now due to an increase in the human population - become unsustainable (Admin 2012). Due to an increase in demand for food and climate change, there has to be a substitute for this method and conservation agriculture is a better alternative. According to Namibia's reporting to FAO (2015), 8.9% or about 7,290,000 ha of forest land of Namibia is forested and between 1990 and 2010, Namibia lost an average of 73600 ha per year.

Timber harvesting is considered as another threat (Mendelsohn and El Obeid 2005). Timber tree species are being harvested at an alarming rate in Namibia since 2018 mostly for export to Asia. A live *P. angolensis* is sold at N$200.00 and dead at N$110.00 according to the government tariff for 2011. These prices have not changed to date and small scale farmers in Kavango and Zambezi regions continue to sell these trees at that low price. Even though timber harvesting for commercial purposes is restricted to classified forests such as community forests, incidences of illegal harvesting are still reported across the country and normally illegal harvesters do not follow authorized diameter classes required for harvesting. Immature trees are felled before they become fertile to produce seeds for the next generation which have probably contributed to the decline in the populations density for *P. angolensis* noted in southern Africa (Caro *et al.* 2005). The use of timber is restricted to a few species and this has caused an unsustainable utilization of these species (*P. angolensis, B. plurijuga and G. coleosperma).*

Considering the low number of seedlings that recruit into adults trees in Namibian forest's, especially from *P. angolensis* (Graz 2004), efforts have been devoted to propagating trees in nurseries but with little success (Ministry of Agriculture, Water and Forestry 2011, De Cauwer and Younan 2015). Attempts to grow the species commercially in plantations have also been unsuccessful (Graz 2004). Besides, natural regeneration of most timber trees remains a problem due to the failure of the seedlings to survive during establishment. This low survival rate has been attributed to several factors including adverse environmental and physical conditions of the woodlands that are characterized by long dry seasons, regular fire outbreaks and browsing by animals, competition from other trees mainly for light and delayed seed production (Caro *et al.* 2005). *P. angolensis* has also annual dieback of seedlings which makes it difficult for the tree to establish itself quickly (Graz 2004).

As forests provide many ecosystem services, their conservation is a priority. The main challenge is to facilitate the natural regeneration of most tree species (Gebremedhin 2013). Anthropogenic disturbances, mainly of livestock and tree harvesting influence the regeneration success of woody species and in turn determine the vegetation structure and composition of these forests. Livestock grazing either facilitates or hampers regeneration. It is well known that livestock can compact soil, exacerbate erosion, consume tree seeds and seedlings and browse saplings thereby hampering forest regeneration (Iraj Hassanzad 2016). It has been suggested that a light level of grazing can increase tree regeneration by removing competitive vegetation, reduce fire hazard and provide fertilization from manure. Large herbivores can also create patches of bare ground through grazing and trampling in so doing creating safe sites for seeds to germinate (Wassie *et al.* 2009). On the other hand, continuous and intensive grazing may cause tremendous damage to young trees. To control forest destruction by livestock, temporary or permanent livestock removal from forests to allow regeneration growth is vital (Iraj Hassanzad 2016). Households in communal areas of northern Namibia practice what is called continuous grazing pasture management (i.e. a pasture system in which livestock have unrestricted access to the pasture area throughout the grazing season) (Namibia Statistic Agency 2015). The Namibia Statistic Agency (2015) in the Census of Agriculture 2013/2014 report also indicates that 39% of households own livestock in Oshikoto region. This is a clear indication of the presence of a large number of domesticated herbivores in the forest in addition to wild animals. Tree regeneration is a critical step in sustaining tree species' existence in forests. Therefore an understanding of natural regeneration processes is of paramount importance to examine the build-up of future forest structure, composition and hence biodiversity conservation.

The other threats to forests and woodland species in Namibia are bush fires. Fires that occur more frequently have a major impact on the structure and composition of woodlands in northern Namibia. The most devastating effect of fire is by killing young trees and damaging older ones. Some species are more vulnerable than others posing a threat to the populations of less tolerant tree species (Zida 2007). Species also respond differently to different fire intensities. For example, *P. angolensis* is known to be fire tolerant after the sapling stage (Graz 2004, Mojeremane and Lumbile 2016) but unfortunately, most valued timber species are sensitive to fire. Apart from negative effects, fire is also an important tool in forest management. It clears areas for fresh vegetation to grow, recycles nutrients and stimulates the germination of some tree and shrub species. There are two main ways in which fire is thought to influence tree populations: by top-killing the tree, forcing it to re-sprout to survive; and by killing belowground organs, exterminating the organism (Ryan and Williams 2011). These effects are known to vary between diameter classes because as diameter increases, the thickness of protective bark increases proportionally (Odhiambo *et al.* 2014). Hence younger trees are more vulnerable to fire damage compared to older trees. Besides, trees need time to grow and when the fire frequency becomes too high; seedlings die before they have the chance to reach a more fire-resistant age (Zida 2007).

Ryan and Williams (2011) emphasized that fire is probably the most important disturbance to cause plant loss and plant regeneration simultaneously. Apart from accelerating the cracking of seed, fire also promotes the germination of some types of seeds and most importantly promotes the subsequent survival of seedlings by reducing competition for light, water and nutrients. When fire passes through the forest it also improves the contact between soil and any newly shed seed. A study by Chidumayo (2012) on the effects of seed burial and fire on seedlings and sapling recruitment, survival and growth revealed that the absence of fire in the forest decreases the diversity of the ecosystem. In the process, the long term fire exclusion will alter the stand structure by promoting the growth of woody species at the expense of grass and other herbaceous plants.

A study conducted in 2015 in the Okongo and Ncumcara community forests as well as Caprivi State forest looked at the natural regeneration potential for *P. angolensis* (Kayofa 2015). The study focused on assessing the main factors facilitating the development of *P. angolensis* seedlings through the suffrutex stage to the sapling stage in Namibia dry forests. The result showed the most important factors influencing the tree development from seedlings to sapling and sapling to bole tree stages are soil, water, soil fertility, plant competition, sunlight and fires. *P. angolensis* regeneration in these three dry forests appeared poor because the abundance of the seedling size class is lower than that of saplings and mature tree size classes. Kabajani (2016) conducted a study focusing on assessing the density of natural regeneration of woody species and further relate these densities to selected environmental and anthropogenic aspects such as fire frequency, vegetation cover and distances to roads, settlements and rivers in the Kavango Regions. The results show that an increase in distance to the settlements is linked to an increase in seedlings per hectare. The study found that the current trends of regeneration densities and population size structures are in most cases a result of disturbances. This study has demonstrated that regeneration of woody species is a complex aspect that is driven by several factors such as fire frequency, vegetation cover, human activities and water availability.

Mwansa (2018) investigated the impact of rainfall and fire treatment on the natural regeneration abilities of socio-economically important woody species of Namibia and Zambia. The result showed that short-term effect of fire in subsequent (2 – 3 years) maintained high species richness and diversity and above all supported the re-establishment of the tree species after a fire.

Considering that all these species (*P. angolensis, B. plurijuga, B. africana and G. coleosperma)* only regenerate naturally, assisted natural regeneration (ANR) may be the solution if the future survival of these species is to be guaranteed. It is a simple, low-cost forest restoration method that can effectively convert deforested lands to more productive forests (Shono *et al.* 2007). The method aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as competition, fire, browsing, and wood harvesting. ANR is important in forest management as it offers significant cost advantages by reducing the costs associated with propagating, raising, and planting seedlings. However, the first condition of assisted natural regeneration, sufficient regeneration, must be present so that their growth can be accelerated (Shono *et al.* 2007). A study was conducted in Kanovlei state forest between 2015 2017 on assisted natural regeneration (Mubita 2019). This study assessed whether propagation by direct seeding is a viable option to enhance the regeneration of tree species; *B. plurijuga*, *G. coleosperma* and *P. angolensis* compared to planting seedlings pre-grown in a nursery. The result showed that the assisted regeneration method had a significant effect on the establishment of the studied tree species in the wild. The study concluded that seeds need to be covered by soil to ensure both good germination and survival rate of seedlings. Seedling protection against small mammals is essential for any extra benefit to being gained from ensuring germination and survival when planting seedlings pre-grown in a nursery. Timing of direct seeding on the site is crucial for the development of seedlings.

1.2 Problem statement

P. angolensis, B. plurijuga and G. coleosperma are the most valuable timber tree species found in the forests of north-eastern Namibia which are part of Miombo woodlands in Southern Africa (De Cauwer 2016, Mojeremane and Lumbile 2016). These and other woody species have been and are still harvested intensively for timber and poles production while concerns have been raised about their natural regeneration capacity. A low survival rate has been recorded for amongst others *P. angolensis,* which is attributed to forest fire, harsh climate, browsing, annuals dieback of seedlings, competition from other plants and delayed seed production (Caro *et al.* 2005). *B. plurijuga* faces difficulties because flowering and fruiting are erratic, with good seeds being produced only once in three or four years (Chidumayo 2013) and the seeds providing a favourite food source to small wild animals (Van Langevelde *et al.* 2003).

Efforts devoted to nursery propagation of important timber species have not been very successful in Namibia (De Cauwer and Younan 2015, Mojeremane and Lumbile 2016). Other forest management methods need to be explored to assist in natural regeneration. Barriers to natural regeneration can be controlled or minimized by forest managers. For example, the introduction of early burning programs might prevent intense fire in the dry season and minimize damage to trees during the critical stage of their reproduction. Another method to increase regeneration and controlling forest destruction by livestock is the temporary or permanent livestock removal from forests to allow regeneration growth (Iraj Hassanzad 2016). Another important barrier to seedling and sapling survival and growth is the competition of grasses, shrubs and other trees, especially for light-demanding species such as *P. angolensis*. Removing competition during the juvenile phase can improve growth and hence survival chances (De Cauwer *et al.* 2017). These ANR methods are currently rarely implemented in the country, hence experience and case studies are lacking.

1.3 Significance/Contribution

Woodland studies have become an important area of study in Namibia as the country is faced with the challenge of finding the balance between resource uses and population increase (Ministry of Agriculture, Water and Forestry 2011). The Namibian government through the Forest Strategic Plan for 2011-2015 has called for more research on the natural regeneration of woody species that are commercially exploited, especially *P. angolensis, B. africana, G. coleosperma* and *B. plurijuga* (Ministry of Agriculture, Water and Forestry 2011). The knowledge of the forest and requirements of different species are essential for the proper planning of sustainable forest management. For effective management of Namibia's timber trees, there is a need to monitor whether the rate of timber extraction is sustainable under the current fire and browsing regime and for this; more information on tree regeneration and information on the main disturbances affecting tree regeneration is amongst others needed. To meet those requirements, up to date information on forest resources and natural regeneration potential in the forests is important to design proper management for the future improvements of forest stands. Data from this study will help the proper management of tree regeneration in northern Namibia forests and provide more insight into the extent that natural regeneration is affected by external disturbances such as mammal predation. For effective management of Namibia's timber trees and ensure the long-term survival of timber tree populations, there is a need to monitor natural regeneration dynamics. Testing the effect of browsing and fire exclusion and removal of plant competition on the regeneration of woody species may be used to promote regeneration of species in other areas of Namibia. It will also be demonstrated to the communities that natural tree regeneration needs to be and can be actively encouraged.

1.4 Research Objectives

The study aims to determine to what extent anthropogenic disturbances, especially fire and browsing by domestic animals, as well as natural disturbances, such as plant competition and browsing by wild mammals, can influence the regeneration of woody species in Onkumbula community forest in northern Namibia.

1.4.1 Specific objectives

Objective 1

To assess woody species regeneration in response to browsing.

1.1 How is the seedling species richness affected, in response to protection from browsing?

H_0: Protection from browsing does not affect seedling species richness.

H_1: Protection from browsing increases seedling species richness.

1.2 How is the seedling density affected, in response to protection from browsing?

H_0: Protection from browsing does not affect the seedling density

H_1: Protection from browsing increases the seedling density

1.3 How is the survival of seedlings affected, in response to protection from browsing?

H_0: Protection from browsing does not affect the survival of seedlings

H_1: Protection from browsing has a positive effect on the survival of seedlings

1.4 How is the growth of seedlings affected, in response to protection from browsing?

H_0: Protection from browsing does not affect the growth (collar diameter and height) of seedlings

H_1: Protection from browsing improves the growth (collar diameter and height) of seedlings

Objective 2

To assess woody species regeneration in response to plant competition.

Research questions

2.1 Is the seedlings' species richness influenced by plant competition?

H_0: Plant competition does not affect the seedling species richness.

H_1: Plant competition reduces seedling species richness.

2.2 Does the removal of plant competition affect the growth of seedlings?

H_0: Plant competition removal does not affect the growth (collar diameter and height) of seedlings.

H_1: Plant competition removal improves the growth (collar diameter and height) of seedlings

2.3 Does plant competition influence the survival of the seedlings in the study area?

H_0: Plant competition does not affect seedlings survival in the study sites

H_1: Plant competition reduces the chance of seedlings survival in the study sites

Objective 3

To assess woody species regeneration in response to fire.

3.1 Does fire influences seedlings species richness of woody species in the study area?

H_0: Fire does not affect seedling species richness in the study area

H_1: Fire increases seedling species richness in the study area

3.2 Does fire influences seedlings density of woody species in the study area?

H_0: Fire does no effect seedling density of woody species

H_1: Fire increases the seedling density of woody species

3.3 Does fire influence shoot production of trees and saplings in the study area?

H_0: Fire does not affect shoot production of trees and saplings

H_1: Fire increases tree and saplings shoot production

3.4 Does fire cause mortality of saplings in the study area?

H_0: Fire does not cause mortality of woody regeneration (saplings).

H_1: Fire causes mortality of woody regeneration (saplings).

1.5 Conceptual framework

Research studies are conducted to find solutions to problems in different fields, including forest management. Natural regeneration of Namibia's timber trees is of great concern. Regeneration is defined as the renewal of a forest by natural, artificial, or vegetative means including all the ecological processes that affect the seedling establishment, growth and mortality (Blanco et al. 2009). In this study, all young woody plants with a diameter at breast height (DBH) of <5 cm that is capable of becoming trees are regarded as regeneration. Good regeneration of trees means that there will continuously be a sufficient number of seedlings and saplings which in turn can enter the maturity stage. Regeneration plays a vital role in the renewal and maintenance of forest and woodland ecosystems. It is one of the most important indicators of a healthy forest ecosystem.

Timber species such *as P. angolensis*, *B. plurijuga* and *G. coleosperma* have limited regeneration in Namibia's forests. Forest regeneration is mostly affected by environmental factors such as light, soil moisture and anthropogenic factors such as herbivory and fire. In the situation when resources such as light, moisture and nutrients are in short supply, plants compete for these resources and the weaker ones die. This is when the significance of assisted natural regeneration comes in (Figure 1). The aim is to nurture already natural regenerated seedlings so that they can pass the seedling stage which is the most vulnerable stage of plant life. Forest managers can influence the dynamics of the natural regeneration process and prevent the loss of tree species through assisted regeneration, hence filling a knowledge gap on the ecological factors controlling regeneration and consequently develop best silvicultural options for natural regeneration (Mubita 2019).

Browsing also disturbs savannahs through both direct and indirect effects. While intense fires cause a decline in the cover of woody vegetation types by killing trees or reducing their sizes, browsing herbivores reduce woody vegetation such that trees are either killed or minimized in size. The combined effects of fire and browsing lead to the hypothesis that fire causes a decline in woody vegetation cover while browsers inhibit recovery (Van Langevelde et al. 2003). The combination of these anthropogenic and natural factors has become a threat to natural regeneration in Namibia's forests (Figure 1). In northern Namibia which is a communal area, the woodlands regenerate naturally and disturbances such as fire and browsing mostly by livestock are common. Livestock grazes uncontrollably in the rangeland and browsing mostly becomes an option during the dry season when the grass has depleted. This study is focusing on the extent to which these anthropogenic disturbances can influence the regeneration of trees and how the removal of plant competition influences seedlings growth and survival.

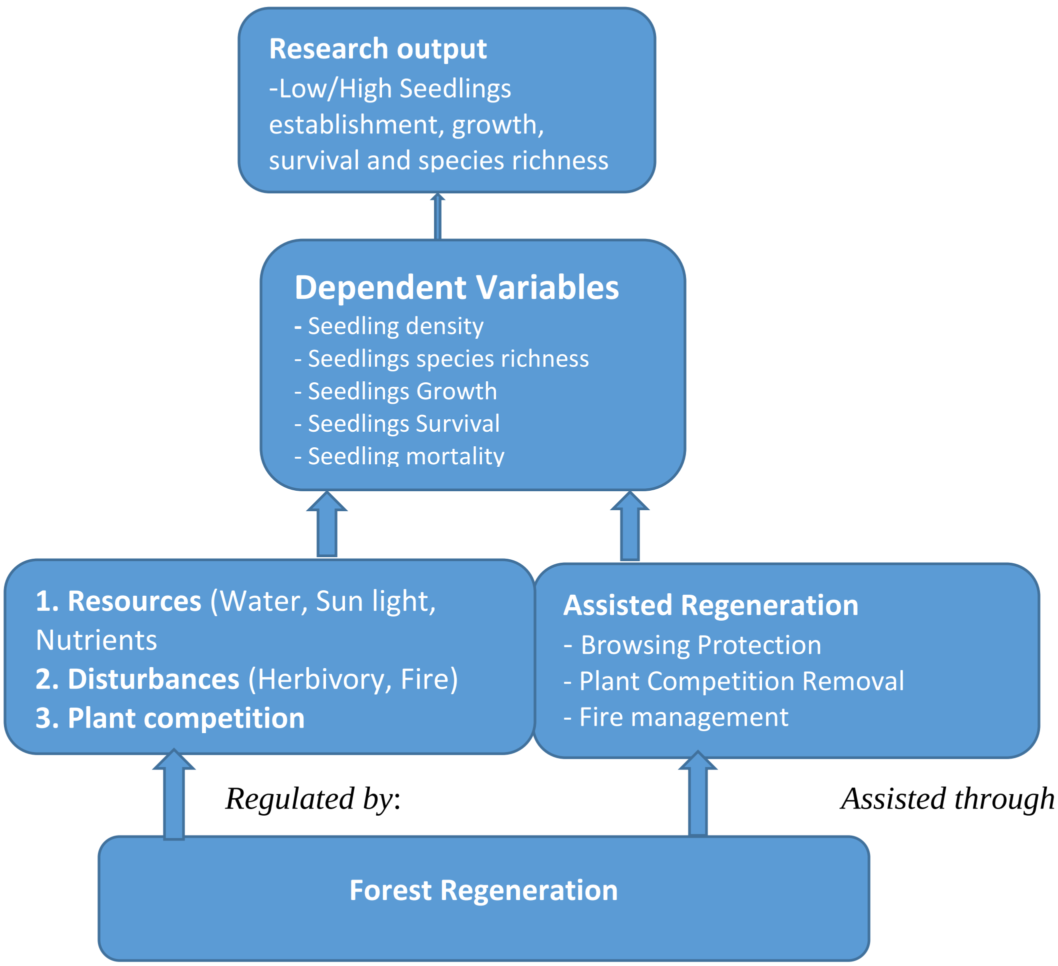

Figure 1: A flow chart showing how disturbances and resources influence forest regeneration.

Chapter 2: Literature Review

2.1 Focus tree species

2.1.1 *Pterocarpus angolensis*

P. angolensis is a leguminous tree which belongs to a genus comprised of about 100 species. Four of these species occur in the northern and eastern parts of southern Africa. *P. angolensis* is a well know species in southern Africa valued for its timber. It grows in the north-eastern parts of South Africa, Swaziland, Mozambique, Zimbabwe, Botswana, Namibia, Angola, Zambia, Malawi, south-eastern Democratic Republic of Congo and Tanzania (Geldenhuys 2013). The species only grow in natural mixed forest and is frequently co-dominant in the canopy layer (De Cauwer 2016). This tree species has many uses and is valued throughout Africa. Across its range, most mature trees are at risk from overexploitation for timber, causing the decline in its populations outside of protected areas and sometimes inside protected sites due to both legal and illegal logging activity.

The beautiful timber is easy to work and is used for furniture, implements and curios. The reddish-brown heartwood is resistant to borer insects and termite and also polishes well. The red sap is used traditionally as a dye and in some areas mixed with animal fat to make a cosmetic for faces and bodies. It is also believed to have magical properties for the curing of problems concerning blood, apparently because of its close resemblance to blood (Mojeremane and Lumbile 2016). While commercial exploitation is controlled, it needs strict monitoring due to increased demand for wood carving (Curtis and Mannheimer 2005). The tree is slow-growing and the percentage of young trees in the forest is a concern (Mojeremane and Lumbile 2016, Kayofa 2015).

The growth of the species is interesting in the sense that after germination the seedlings will continuously die-back in the dry season for some years before they grow into saplings, this stage is known as the suffrutex stage. This can continue for a period of up to 10 years although it may be prolonged by high fire frequencies before they eventually grow into saplings (Graz 2004). It is important to implement conservation measures to ensure sustainable utilization of the species (De Cauwer *et al.* 2017).

2.1.2 *Baikiaea plurijuga*

B. plurijuga (Zambezi teak) *is a s*emi-deciduous small to medium-sized tree up to 20 m tall and has a very deep root system. It is well adapted to dry sites on free-draining sandy soils with mean annual rainfall in the area of distribution is 350–1100 mm (Theilade *et al*. 2001). According to Plant resources of tropical Africa 2018, *B. plurijuga* occurs in Namibia, Zambia, southern Angola, northern Botswana and Zimbabwe. *B. plurijuga* is regarded as one of the most valuable timber trees in Namibia (Mendelson and El Obeid 2005). The wood is used for a variety of purposes including furniture and carvings. The sap is used for eye ointment and stomach upsets (Curtis and Mannheimer 2005). *B. plurijuga* is threatened by over-exploitation for timber, fencing as well as clearing for homesteads as well as agricultural fields and it is listed as near threatened in the IUCN red list. Natural regeneration is often poor and hampered by erratic seed production, long periods of drought, damage to the seedlings by wild animals and live stocks, competition with dense undergrowth, as well as fires. Seeds retain their viability for at least one year when stored at room temperature; in cold storage, they are still viable after 3 years (Theilade *et al*. 2001).

2.1.3 *Guibourtia coleosperma*

G. coleosperma is a tall tree with a spreading crown and loose branches, reddish to yellow-brown bark with rough black patches usually peeling off in small fragments. This tree is limited to Kalahari sands in the north, north-eastern Namibia where their range extends north into Angola, Zambia and Zimbabwe (Mendelson and El Obeid 2005). The flowering period is December to May and the leaves are evergreen. Seeds are edible but also used for cooking and cosmetics. The wood is used for canoes, construction timber and curved utensils (Curtis and Mannheimer 2005). *G. coleoperma* also is known as Rosewood has recently come into the spotlight when it was discovered that it is over-harvested in the two Kavango regions and the Zambezi for export to China (The Namibian 2018). Statistics indicate that the amount of rosewood (*G. coleosperma)* trade in Namibia has increased from 361m^3 in 2010 to 2326m^3 in 2014 (Wildlife trade monitoring network 2018).

2.1.4 *Burkea africana*

B. africana is a deciduous tree, small to medium-sized up to 20m tall. It is commonly found in the north and northeastern Namibia on sandy substrates. The tree is browsed by game including Springbok, Zebra and Eland. It is also a host to an edible caterpillar of the family Saturniidae during the rainy season (Curtis and Mannheimer 2005). The wood has numerous uses such as fuel wood and construction poles. The tree is difficult to cultivate, with poor germination and poor survival of seedlings although its recruitment in the wild is much better compared to other timber trees. Excessive fire may compromise the recruitment of the species by destroying the seeds and over-harvesting for poles and curios is also a growing concern (Curtis and Mannheimer 2005). *B. africana* is known to have an adaptation whereby it can resprout from its growing points in response to disturbance such as a fire. It was also found to be able to resprout from seedlings and saplings in response to fire

2.2 Factors affecting forest regeneration

2.2.1 Veld fire

Forest fires play a natural and beneficial role in the life-cycle of a forest ecosystem (Ncube and Mufandaedza 2013). Humans have used fire for thousands of years as a land management tool and it is one of the forces that have influenced plant communities over time. However, Ncube and Mufandaeza (2013) stated that frequent and large-scale fires, mainly caused by increased human activity negatively affect many forests around the world. Roughly 15% of Namibia's north-eastern regions burn every one to two years and most of the fires are man-made (Sheuyange *et al.* 2005). The loss of young trees slowly destroys the forest even if the bigger ones survive the fires. Fires in forests impact on the forest's composition, structure, regeneration and recovery potential. They also can affect wildlife, health, carbon stocks and emissions, and people's livelihood (Tesfaye *et al.* 2010, Ryan and Williams 2011).

A study conducted by Ryan and Wiliams (2011) in Mozambican Miombo indicates that above a fire return interval of 1 year, large stems can be sustained, but this is strongly dependent on fire intensity. Many experiments, in Miombo and elsewhere in the African savannah, have shown that early-season burning allows woody biomass to develop further compared to late-season burning (Tesfaye *et al.* 2010, N'Dri *et al.* 2018). Another experiment by Furley (2008) found a similar, but much more pronounced, pattern: low-intensity fires were about six times less destructive than the high-intensity fires.

A study conducted in Gwaai forest in the north-western part of Zimbabwe on the effects of fire on coppice shoot production and growth in a savannah woodland dominated by *P. angolensis* and *B. plurijuga* revealed that fire appears to stimulate coppice shoot production in a burnt than the unburnt areas (Ncube and Mufandaedza 2013). So it appears from this study that controlled fire is critical in sustainable forest management in terms of preserving *B. plurijuga* and *P. angolensis* species. The challenge is how much of the fire should be applied and timing of the burn. The study also showed an interaction between fire and stump size. The lower stump size classes showed a greater ability to recover from fire than the larger classes.

Fire is regarded as a germination stimulant for *P. angolensis* that can rupture the protective fruit to allow the water to enter thereby triggering the germination. The removal of grassy layer and wings and bristles of the fruit in the ecosystem by a cool fire can cause the seed to come into contact with the ground and enhance seed germination (Banda *et al.* 2006).

2.2.2 Browsing and grazing

Browsing restricts the regeneration of woody species in many areas around the world. Browsing is known to cause damage to young trees, shrubs and herbs, which alters both vegetation structure and composition and may delay woodland successional development (Čermák and Grundmann 2006). There are three main components to the structural changes caused by browsers: browsing on seedlings which limits stem density, browsing on leading shoots which limits height growth and browsing on side shoots which reduce foliage density (Van Langevelde *et al.* 2003, Zida 2007). The leading shoots and upper leaves are usually the most actively growing and nutritious parts of young trees and shrubs and are actively selected by browsers. As a result, height growth is usually sharply reduced by browsing. However, the loss of growth depends on the severity or frequency of browsing and may vary considerably between tree species, depending on the feeding selection by the browser or the ability of the trees to recover from damage (Robin 2001). Browsing has also a positive effect on trees by facilitating regeneration through nutrient cycling and dispersal of seeds (Van Langevelde *et al.* 2003). Wassie et al. (2009) suggested that a light level of grazing can increase tree regeneration by removing competitive vegetation; reduce fire hazard and providing fertilization from manure.

2.2.3 Plant competition

Negative and positive plant interactions play a vital role in regulating the composition and dynamics of plant communities (Dupuy and Chazdon 2006). The structuring influences of these interactions can be changed by external drivers such as climatic conditions or nutrient availability. Successful regeneration of species can only occur if the right amount of growing space and habitat conditions are available for the establishment and subsequent growth of seedlings (Gebremedhin 2013). Although many tree species need large canopy gaps to regenerate, seed germination and early seedling establishment are hindered in open areas, even for light-demanding species. Shaded sites become safe sites in water-stressed areas as the shade counteracts the water limitation in low rainfall periods and reduces seedling death by drought (Dupuy and Chazdon 2006). A study by Caro *et al.,* (2005) found that there was lower *P. angolensis* recruitment in protected areas where the grass cover was thick and parent tree canopy cover was abundant. This suggests that *P. angolensis* seedlings suffer from competition for light and edaphic resources. Another study by Mubita (2019) found that the sites with high vegetation cover were observed to have a lower number of seedlings compared to sites with less vegetation cover. This study observed that open canopy had a positive effect on seedling density, most probably because of increased resource and light availability. Vegetation cover influences the competition for nutrients, sunlight and ecological activities in the area and consequently individuals surviving over a period of time.

2.3 Assisted natural regeneration (ANR) concept

Due to the persistent physical, chemical, and biological barriers to forest regeneration, degraded areas may need human intervention to initiate recovery. ANR is the human protection and preservation of natural tree seedlings in forested areas by protecting and nurturing the mother trees and their young ones present in the area (Shono *et al.* 2007). ANR aims to accelerate, rather than replace natural succession processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition, and recurring disturbances such as fire, browsing, and wood harvesting. Seedlings are in particular protected from the undergrowth and extremely flammable materials (Shono *et al.* 2007). ANR combines fire prevention, ring-weeding (competition removal) of naturally-growing seedlings and saplings of pioneer trees. The most critical step in ANR is the protection of woody plants from fire for limited periods. Since ANR is often implemented by communities rather than individual farmers (Shono *et al.* 2007), groups are organized for fire control. At least a month before the dry season begins, there is a need to make plans and organize fire fighting crews. During the dry season, patrols are conducted in the ANR area to locate and suppress fires.

2.4 Background of forest management in Namibia

The formal forestry management started 126 years ago when the German government issued the first regulation to control the cutting of trees in 1894 but forestry remained a small sector (Mendelson and EI Obeid 2005). After gaining independence in 1990, Namibia started providing unique opportunities for environmental management to contribute to sustainable and economic development (Nikodemus and Hájek 2015). The policies were developed in the earliest 90s with the emphasis on how much wood could be obtained from Namibia's indigenous woodlands and plantations, the need for forestry to contribute to national and rural development and the role of forestry in contributing to the maintenance of biodiversity (Mendelson and EI Obeid 2005). The Directorate of Forestry released in 1996 the Namibia Forestry Strategic Plan. This document set the scene for the involvement of rural communities in forest management and the development of community forests. Another policy document was compiled and released in 2001 (Development Forestry Policy of Namibia). It declared the mission of the Directorate of Forestry which is to promote sustainable and participatory management of forest resources and other woody vegetation and to enhance socio-economic development and environmental stability. The last policy document developed was the Forest act in 2001 which was amended in 2005. The forest act requires for the parent ministry and the Directorate of forestry to embark on several activities example the declaration of five types of classified forest (state forests, regional forests, community forests, forest management areas and fire management areas).

Forestry Development Policy, the Forestry Strategic Plan and Forest Act of 2001 are therefore the main guiding documents for forestry management in Namibia. Most forests are found in the communal land in the Zambezi, Kavango regions and north-central Namibia (Oshana, Omusati, Oshikoto and Ohangwena regions) and they play an important role in the nutrition and economy of the local people. Communal land is state-owned and the traditional authorities are the custodian of communal land on behalf of the Government of Namibia. Forest resources are managed sustainably to meet the current and future needs, maintain and increase forest productivity potential level and using forest resources without damaging it the forest resilience. Sustainable management of forest resources is to ensure the security of supply and efficient utilization of forest raw materials. The utilization of the forest differs from one area to another example, in the Zambezi region trees in the forest are shared among the village members and there are distinct boundaries between villages. In the north-central area, the trees on the farm belong to an individual farmer while the trees in adjacent forests are shared among the farmers of the entire village (Mendelson *et al.* 2013).

2.4 .1 Community forestry in Namibia

Community forests play a vital role in Namibia's conservation goals, monitoring and effective implementation of community-based natural resource management (CBNRM). Community Forestry is one of the core programmes of the Directorate of Forestry under the Ministry of Agriculture Water and Forestry. The programme aims at empowering local communities by transferring rights to manage forest resources to benefit from income generation and employment opportunities (Ministry of agriculture, water and forestry 2015). The programme contributes to Namibia´s national development objectives of poverty reduction, employment creation, economic empowerment and enhanced environmental and ecological sustainability as outlined in Article 95(I) of the Namibian Constitution and the National Development Plans (Ministry of agriculture, water and forestry 2015). Specific provisions for the participation of local communities in forest management are made in the Namibian Forest Policy, the Forestry Strategic Plan and the Forest Act No. 12, 2001, Sec. 15 (and its 2005 amendment). It is believed that Community Forestry and CBNRM in general, have a great potential to help communities to gain better control of their resources. This will give them better opportunities to improve their lives, while simultaneously managing the forests and woodlands more sustainably. Community forestry program is a key element towards successful and sustainable management of communal land forest resources (Ministry of agriculture, water and forestry 2015). The community forests are in ten regions spread across the north of Namibia (the Zambezi, Kavango East and West, Ohangwena, Omusati, Oshikoto, Oshana, Otjozondjupa, Kunene and Omaheke). There are currently 37 registered and emerging community forests in Namibia, covering around 6% of the country. According to the Namibia Association of CBNRM Support Organization (NACSO), many of these forests overlap communal conservancies, in many cases by 100%, so the forest area outside of conservancies contributes only 0.4% of Namibia's land area.

Chapter 3: Methods

3.1 Study area

The study was conducted in Onkumbula community forest in northern Namibia (Figure 2). Onkumbula community forest is an emerging (not gazetted) community forest in the Okankolo constituency of Oshikoto region S 17.91679^0, E 16.99067^0. Plans are underway to have this area proclaimed as a community forest by 2020.

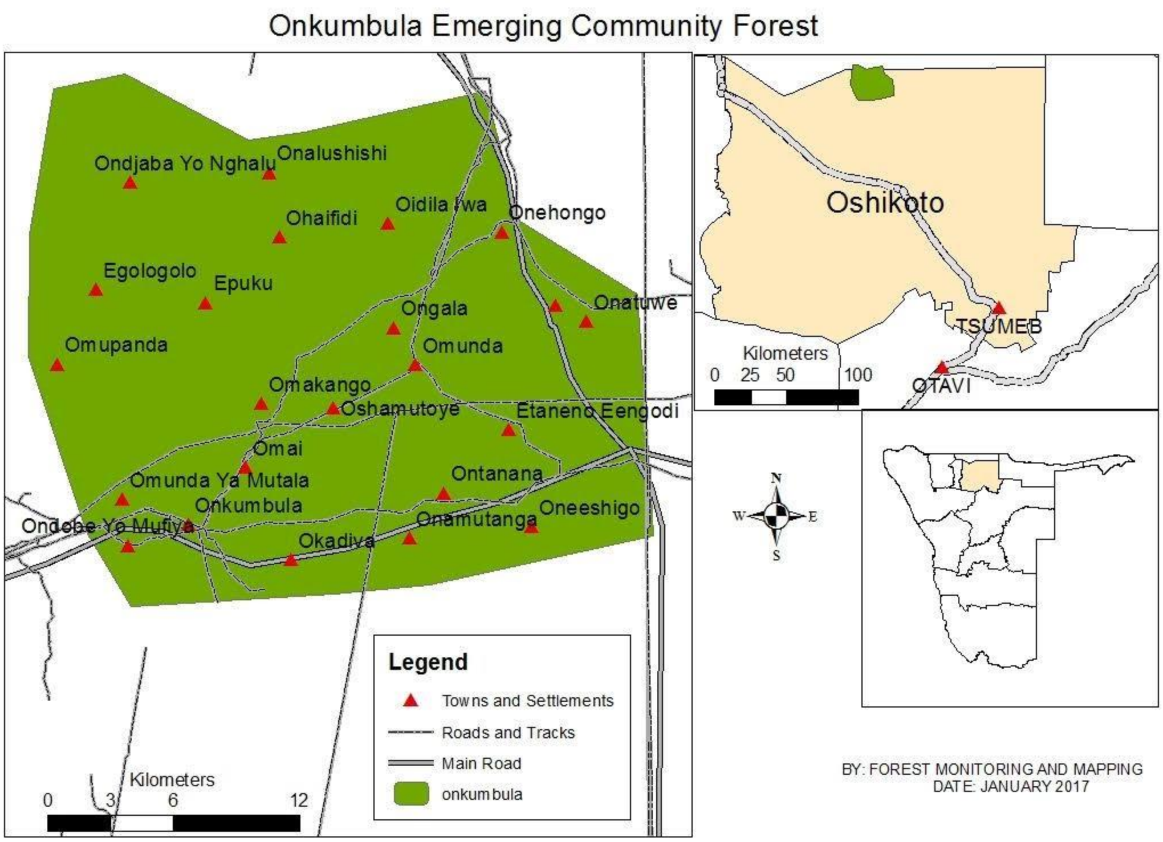

Figure 2: Location of Onkumbula Community Forest in Oshikoto region (Source: National Remote Sensing Centre, 2017)

3.1.1 Description of the community forest

Onkumbula Community Forest borders the northern part of Eengodi constituency to the south, Ohangwena region to the north and Ohepi Community Forest to the south-west. It covers an area of 56,103 ha and there are 22 villages within the community forest with a population of approximately 11,550 people (Ministry of Agriculture 2017). The community forest is managed by a committee called Forest Management Body (FMB) that is composed of 22 village representatives of which 6 are the executive members. Onkumbula Community Forest is a woodland area dominated by woody species that have high timber potential such as *Erythropheleum africanum, G. coleosperma, P. angolensis, B. africana, B. plurijuga* in association with other trees such as *C. collinum* and *T. sericea* among others.

3.1.2 Population

There are 11,550 inhabitants with about 1200 households with an average household size of 4.8 people (Namibia Statistic Agency 2015). 49% of the households are headed by females. The same report indicates that there are two ethnic groups: the Oshiwambo speaking people making up 98% of the inhabitants and San people (2%) found on some parts of the community forest. The inventory report which provided this information was compiled by NAFOLA project in 2017 when the inventory of the community forest was done as part of the milestone to get the CF officially registered.

3.1.3 Vegetation

Onkumbula Community Forest is a woodland area dominated by woody species that have high timber potential. According to the vegetation map for Oshikoto, it is located in the Baikiaea woodlands and Burkea woodland on sand vegetation types (figure 3). The forest inventory conducted by the Ministry of Agriculture Water and Forestry in 2017 was done in 99 plots which are set 2 km apart using a systematic sampling method (Figure 4). The data was analysed using the forest inventory database system (FIDS). The result indicates that out of 27 tree species recorded, 17% are *B. africana, 24% B. plurijuga*, 16% *P. angolensis* 5% of *G. coleosperma* and 38% other tree species. The results revealed that 39 % of the inventory forms recorded low regeneration, 36% medium and 18 % high respectively on the same sample plots. The main forest resources found in the community forest are woody resources from trees such as *P. angolensis, B. africana, B. plurijuga; G. coleosperma, E. africanum.* Other tree species are *C. collinum, T. sericea, A. erioloba and C. psidioides*. These are the common woody species that residents use to meet their daily needs. The area is dominated by deep sandy and sandy loam soil in some part.

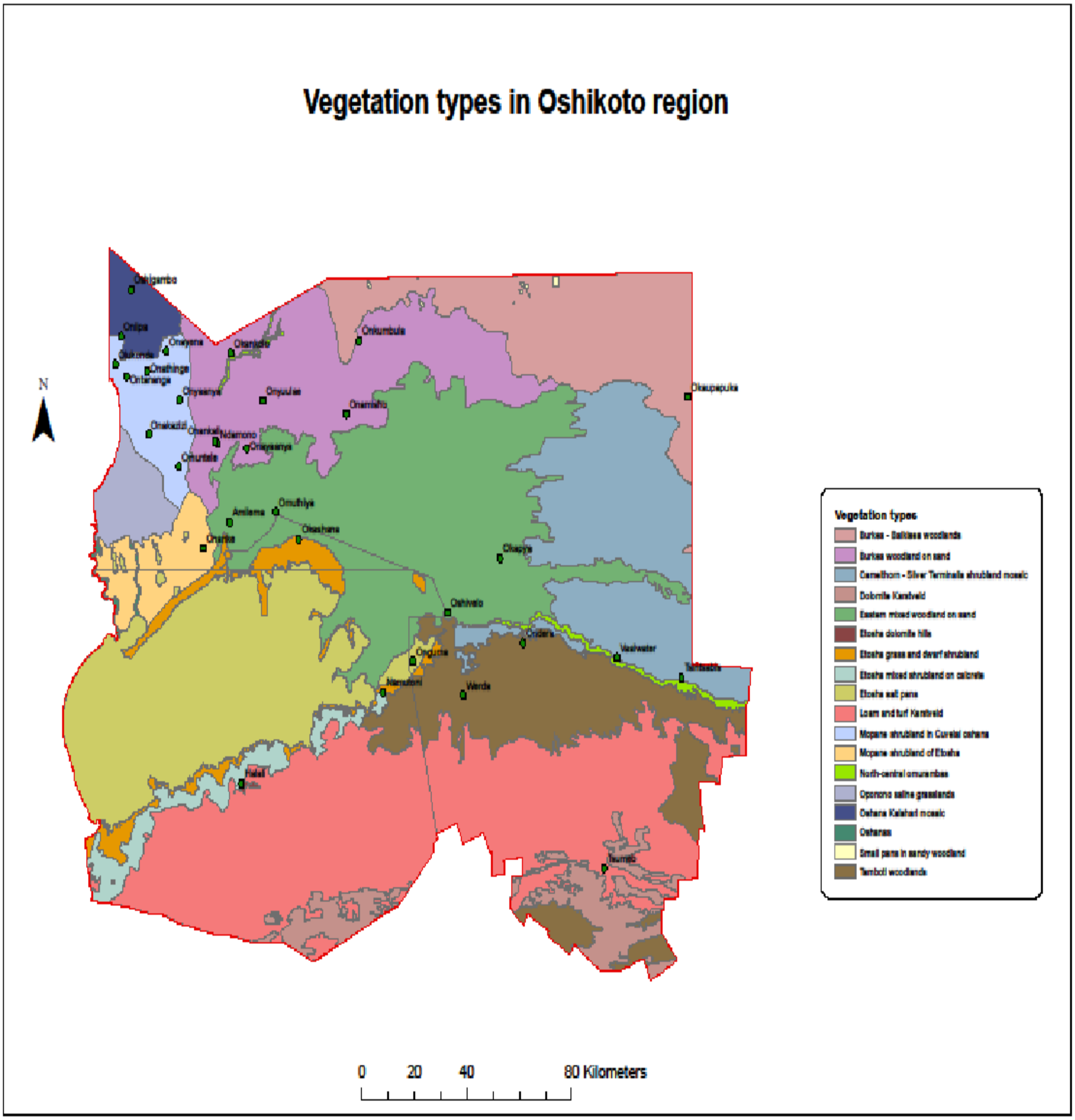

Figure 3: Vegetation map for Oshikoto Region (Source: MAWF National Remote Sensing Centre 2010)

3.1.4 Climate

The area receives rainfall ranging between 250 mm and 450 mm per annum with the dry season from May to October and a rainy season between November and April. In the 2017/18 rain season, the area only received an average rainfall of 21.8 mm between October 2017 and December 2018 (Figure 5). Cold months are sometimes associated with frost and hot months can record up to 39^{0}C.

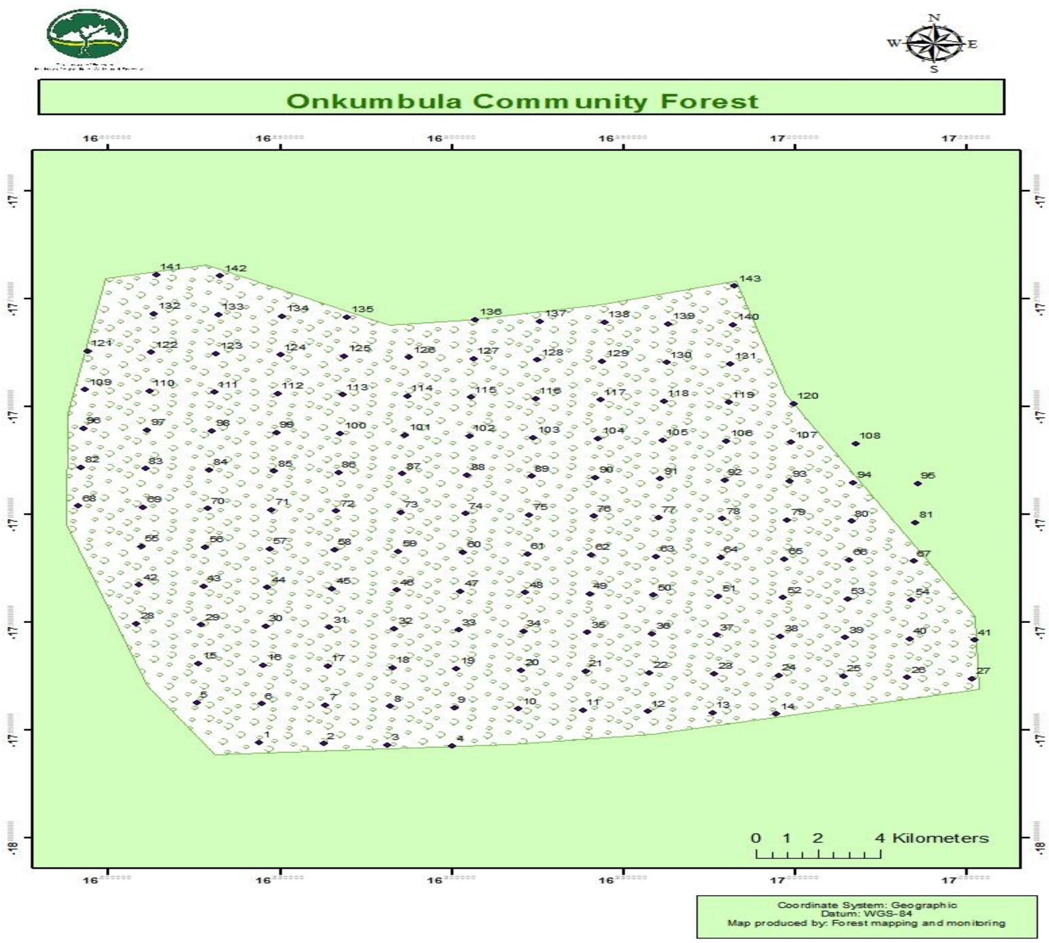

Figure 4: Distribution of sample plots on Onkumbula Community Forest (Source: MAWF National Remote Sensing Centre 2017)

3.1.5 Land use

The land-use system in the area is agro-pastoralism which involves growing crops, rearing of livestock and poultry. Livestock and crop production are equally important to the people of Onkumbula CF. They use livestock to plough their crop fields and sell the surplus to generate income. Crop production is the main source of food and income is generated from selling the surplus. Moreover, crop residues are a source of food for livestock as grass becomes scarce during the dry season.

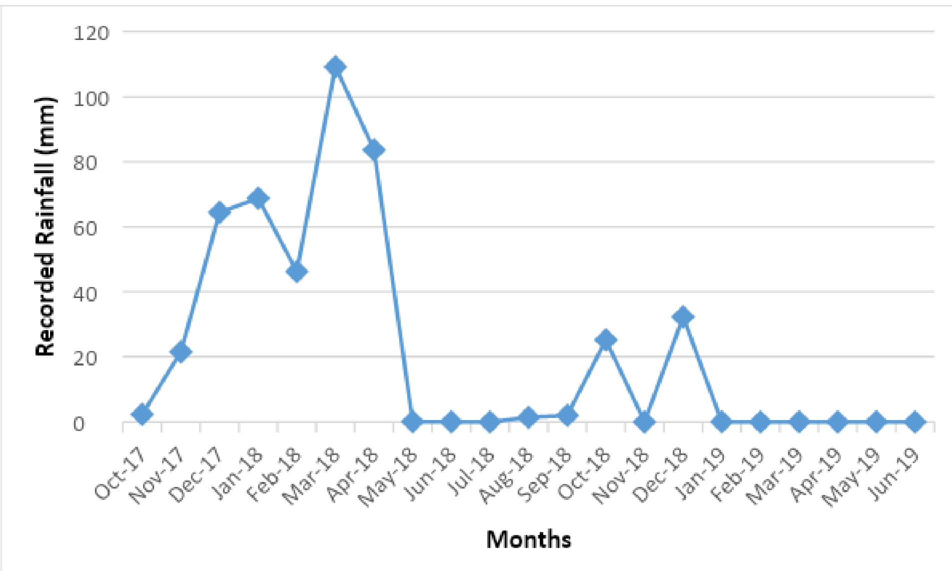

Figure 5: Rainfall data for Onkumbula Community Forest for 2017/18 rain season. (Source: SASSCAL weather net)

3.2 Experimental layout

The study was divided into two experiments and variables such as species richness, seedling density, seedling survival, seedling growth, shoot production and mortality were assessed. The study variables were assessed to address specific objectives (Table 1).

Table 1: An overview of the study variables per objective

Variables	**Effects of browsing and plant competition: Objectives 1 and 2**	**Effects of fire: Objective 3**
Seedlings species richness	X	X
Seedlings density	Only for objective 1	X
Seedlings survival	X	
Seedlings growth (height and diameter)	X	
Trees and saplings Shoot production		X
Saplings mortality		X

3.2.1 Experiment 1: Assessing the impact of browsing and plant competition on regeneration (seedlings)

Three experimental sites were established in three villages (Eengodi/site 1, Omtwewomedi/site 2, Onegongo/site3) in Onkumbula community forest (Figure 6). The villages are approximately 6 km apart from each other. Based on the last inventory results for the community forest conducted by the Directorate of Forestry in Ministry of Agriculture, Water and Forestry in 2017, a stone sampling method was used by throwing the stone behind one's back to determine the centre the blocks. The blocks were randomly set out in areas with a relatively high concentration of timber tree regeneration and presence of mother timber trees as indicated in the inventory report.

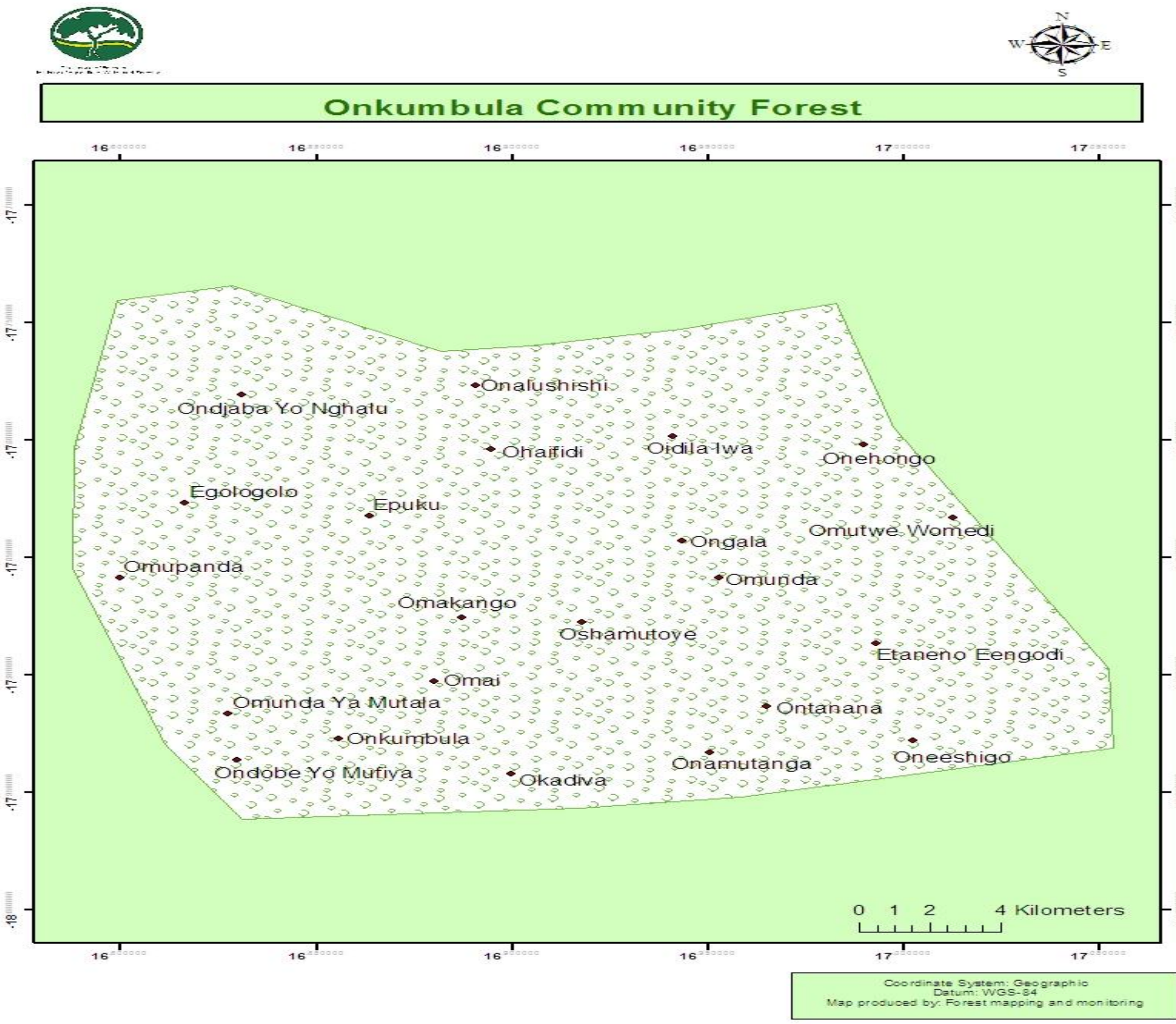

Figure 6: Map showing Villages in Onkumpula CF (Source: MAWF National Remote Sensing Centre 2017)

The block size is 80 m x 50 m which was divided into two plots of 20 m x 80 m separated by a 10 m buffer zone. Each plot was subdivided into four subplots of 20 m x 20 m were the treatments were applied (Figure 7). This will give a complete split-plot design (Gebremedhin, 2013). In each plot, two sub-plots were fenced off to protect the regeneration from disturbances by livestock giving the total of 4 fenced plots and 4 unfenced plots per site. The treatments are:

1. Removal of plant competition: removal of herbs and grasses within a radius of 50 cm for seedlings <150 cm height and removal of shrubs within a radius of 100 cm for seedlings (150 cm – 350 cm height).

2. Browsing protection for seedlings: erection of a 1.3 m height mesh wire around the subplot (Figure 8).

The treatments were applied in February 2018 and data recording started in March 2018. Originally, a third treatment was planned to observe the effect of fire on tree regeneration. Due to poor rainfall received in the area in the 2018 rainy season, the fire treatment could not be implemented. There was not sufficient fuel to conduct prescribed burning and observe the effect of fire on the regeneration. Therefore the fire treatment was laced in already burned areas caused by fires during 2017-18 fire season as explained in Experiment 2.

Inside each 20 m x 20 m subplots woody plants with height (10 cm - 350 cm) referred to as seedlings were tagged with iron tags marked with identification numbers to monitor their growth and survival for 12 months (March 2018 – April 2019). 21 seedlings were tagged per subplot (Figure 9) and their collar diameter using a digital calliper (Figure 10) and height were measured. In the same subplots, apart from the tagged seedlings the rest of the seedlings less than 150cm height were marked with plastic tags, recorded and counted after every three months noting new ones and mortality. The measurements of seedlings in each subplot (number, species, height and collar diameter) were recorded from the 2018 rainy season through the dry season up until the end of 2019 rainy season. The damages, as well as the cause of damages, were recorded. The presence of mother trees was also recorded by recording the numbers, species and measuring sizes. The seedlings with the height 10cm – 350 were counted to determine density and species richness

The study was focused on four species with socioeconomic values but limited regeneration, namely: *P. angolensis*, G*. coleosperma*, *B. africana* and *B. plurijuga.* The regeneration of all other woody vegetation was monitored as well because in some cases there was limited regeneration from the targeted species. The other woody species which were looked at include quicker growing pioneer species such as *T. sericea* and *C. collinum* which give a quicker response to management interventions.

To determine which of the 21 seedlings to tag in a plot, first the focus species where considered. In the absence of the focus species, preferences were also given to species preferred by livestock for browsing such as *T. sericea*, *C. collinum* and *Baphia massaiensis*. There was no maximum number to be tagged per species, rather it was attempted that all woody species in a plot are represented.

To measure how much competition was removed, the vegetation that was removed around seedlings per subplot was packed in bags (grass and herbs together and the other bag for woody plants) and weighed on a balance with an accuracy of 19m/2gm. The plant materials were placed in an oven for 48 hours and the weight recorded after every 12 hours to measure the dry weight.

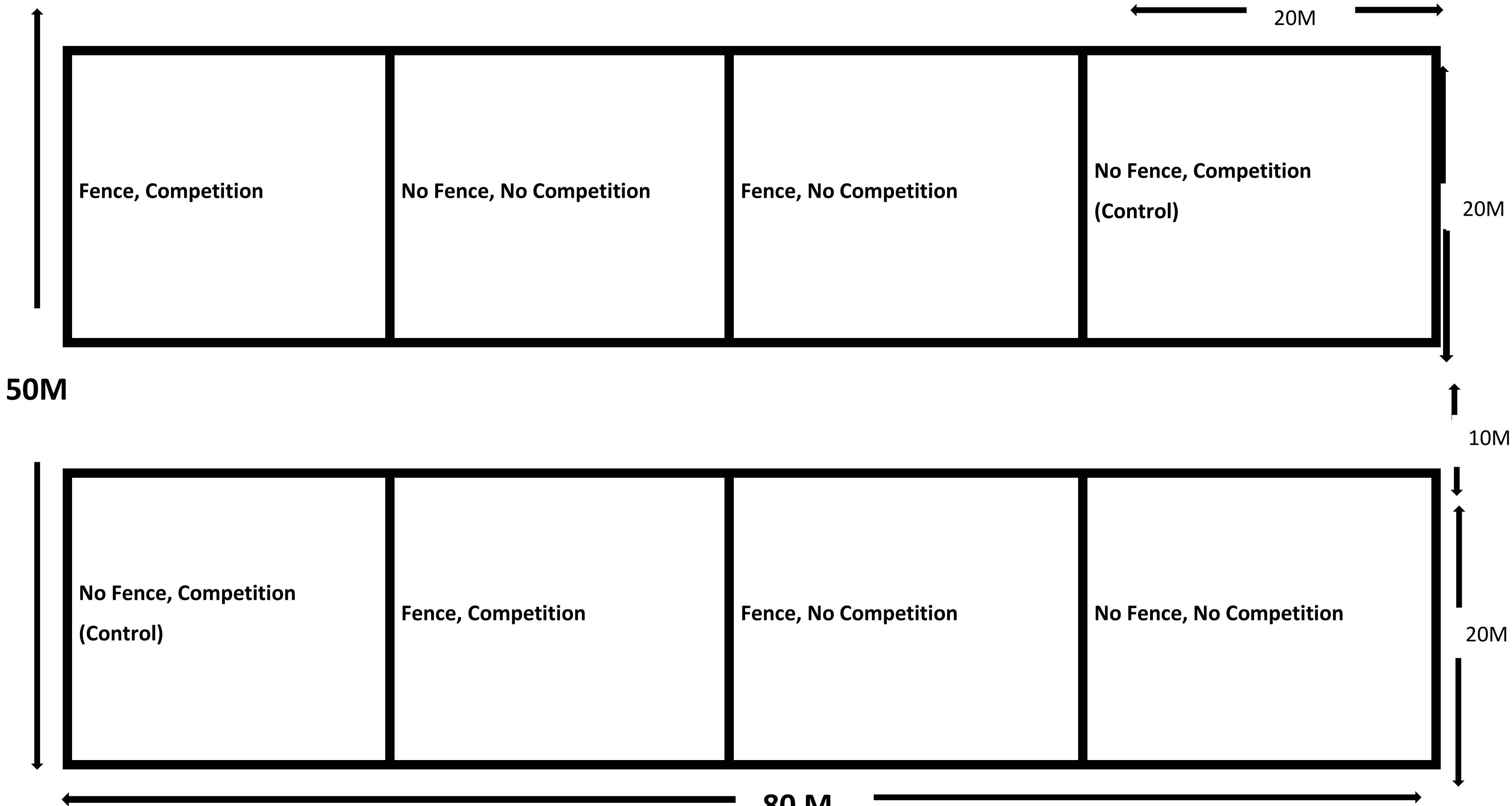

Figure 7: Experiment 1 layout per site

Key

Main plot: 80M x 50M

Sub plot: 80M x 20M

TREATMENTS

- Fence and Competition
- No Fence No Competition
- No Fence Competition
- Fence No competition

Figure 8: The 1.3 m high mesh wire used to protect seedlings from browsing.

*Figure 9**:** A tagged Seedling*

Figure 10: Measuring the CD of a seedling with a digital calliper

3.2.2 Experiment 2: Assessing the impact of fire on regeneration

A wildfire went through the northern side of the community forest in December 2017. This allowed to introducing Experiment 2 and studying the effect of the fire of the regeneration of woody species, especially since there was not sufficient fuel to do the planned prescribed burning in Experiment 1. The Remote Sensing department of the Ministry of Agriculture, Water and Forestry provided a map (Figure 11) of the fire scars of the 2017/18 fire season, the map allowed to select ten plots from the burned area and ten plots from the adjacent (not burned area) using a systematic sampling method. The two areas (burned and not burned) are separated by a 12 m wide fire break. All plots were circular with a 30m radius (Figure 12). The first plot was randomly selected and the remaining ones were laid along a transect with an interval of 50m on both sides of the fire break to give a total of 20 plots. The sample plots had a nested design with all trees with a DBH ≥ 10 cm measured within the 30 m radius and the regeneration of smaller trees (DBH ≤ 5cm-9.9 cm) measured within the radius of 10m. The trees were counted in numbers, classified in species, measured for height and DBH as well as recorded whether they are alive or dead. The saplings (woody plants with DBH 5-9.9 cm) were classified according to species, measured for the height and DBH and recorded dead/live, while seedlings (woody plants >150 cm in height and DBH <5 cm) were counted per species. The instruments used are: a ruler stick to measure the height (Figure 13 :), diameter tape to measure DBH, measuring tape to measure the distance and GPS to mark plots. Due to the absence of appropriate instruments to measure height such as a Suunto, a 4 m height rod was used to measure tree height. For the trees higher than 4 m height, it is estimated how many times the meter height rod fitted in the height of the tree. To further record the effects of fire on the vegetation, the number of shoots around the base of the trees and saplings were recorded and compared. The survey was done in May 2018, five months after the fire.

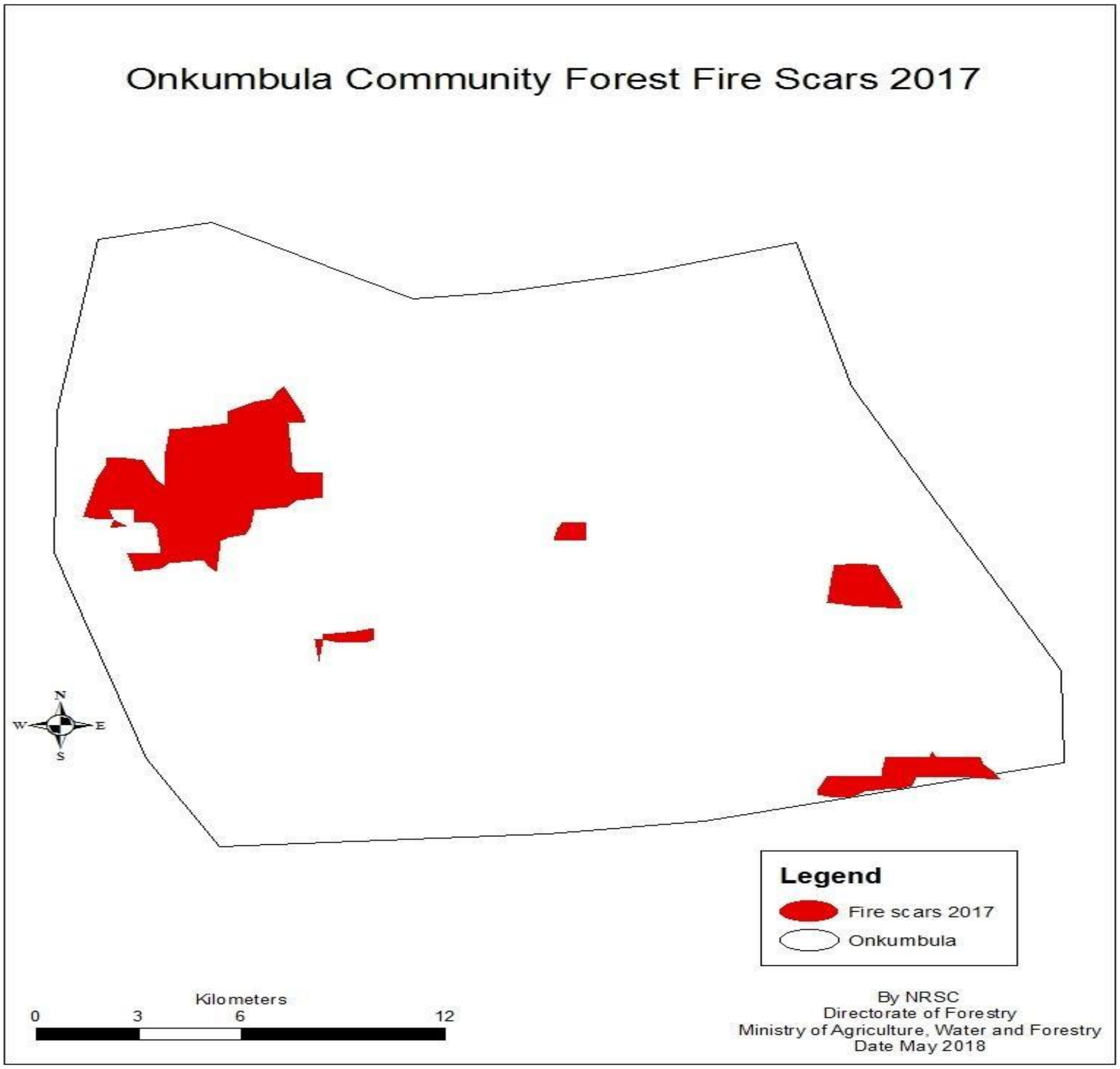

Figure 11: Okumbula Community Forest fire scars 2017 (Source: MAWF National Remote Sensing Centre)

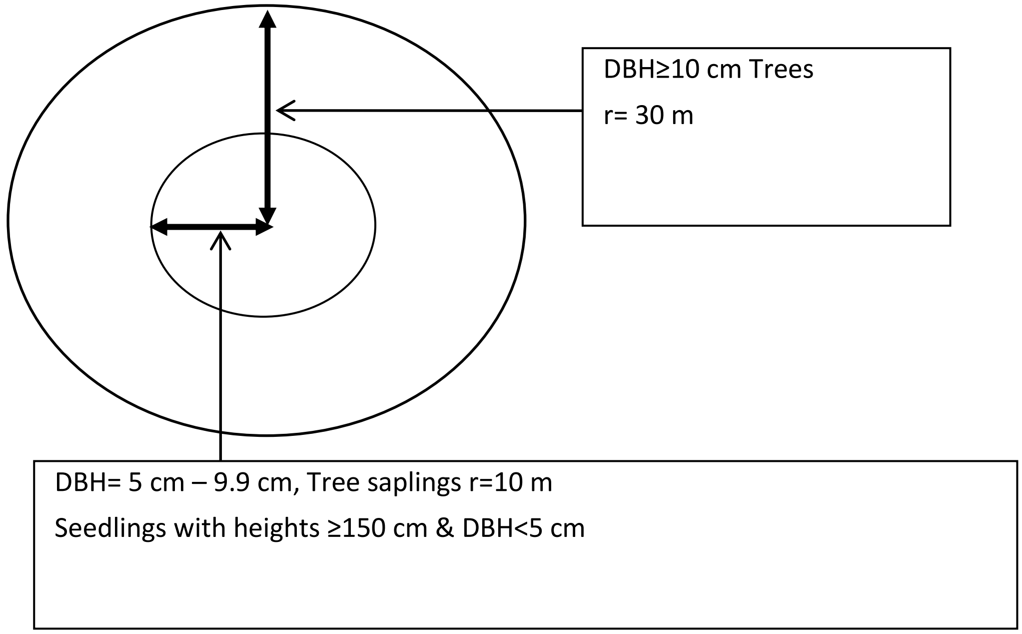

Figure 12: Plot design for Experiment 2

Figure 13: Measuring seedling height with a meter height rod. Note the previous height of the seedling before the fire

3.3 Data analysis

The data were analysed in a spreadsheet (with the production of graphs/charts) and with statistical software, R. Species richness or alpha diversity was determined by a total number of species recorded in each plot. The density of the seedlings in experiment 1 was obtained by using the number of individuals counted in each plot and then multiplied with an expansion factor of 25 to get density per plot, 4.167 for density per treatment and 3.125 for density per ha. The density of seedlings in experiment 2 was obtained by using the seedling counts per plot and multiply with an expansion factor of 31.8 to get density per ha. The pivot table was used to compile the average seedling species richness per site per recording period. Mortality rates were calculated based on the number of live seedlings recorded at the beginning of the recording period and the number of live seedlings at the end of the recording period (number of tagged seedlings measured in March 2018 – number of live tagged seedlings measured in April 19)/ number of tagged seedlings measured in March 2018) x 100. The growth of the surviving seedlings was analysed at the end of the recording period by computing the height and collar diameter difference between March 2018 and April 2019. A Shapiro Wilk's test was used to test the normality of the residuals of the linear regression model. In cases where the residuals of the model did not follow the assumptions of a normal distribution, a Kruskal – Wallis test was performed to test the effects of browsing, plant competition and fire on seedling density, seedlings species richness, seedling growth and survival as well as sapling mortality. The test was also done to evaluate the responses of the four focus species to browsing, plant competition and fire.

Chapter 4: Results

4.1 Seedling species richness

Seedlings species richness was counted for all seedlings (10cm – 350cm) in all the subplots. The result shows that species richness was slightly higher at the beginning of the recording period with site 3 recording the highest species richness (Table 2). In April 2019 (the end of recording period), the species richness remained unchanged at site 1, 2 and decreased with 25% at site 3 (Table 2). On average, Site 3 recorded more species in March 2018 and April 2019. The additional species found at site 3 are *Combretum psidioides* and *Erythrophleum africanum*. There is no significant difference in species richness between sites (p=0.097).

Table 2: Change in species richness per study site

Site	March 18	April 19	Difference	%
1	**6**	**6**	**0**	**0**
2	**5**	**5**	**0**	**0**
3	**8**	**6**	**-2**	**-25**
Average	**6**	**6**	**0**	**0**

4.1.1 Seedling species richness in response to browsing

The total effect of browsing protection did not affect species richness (Table 3). On average, there was no much difference in species recorded in fenced plots compared to unfenced plots between March 2018 and April 2019.

Table 3: Average species richness per treatment

Fence	Site 1	Site 2	Site 3	Average
Mar-18				
NO	6	6.3	7.3	**6.5**
YES	6.3	5.3	7.5	**6.3**
Average	**6.2**	**5.8**	**7.4**	**6.4**
Apr-19				
NO	5.8	5.5	6.5	**5.9**
YES	6.3	5	6	**5.8**
Average	**6.1**	**5.3**	**6.3**	**5.8**

A generalized linear model was used to test if there was an interaction between the two treatments with species richness being a response variable. The interaction between browsing protection (fence) and competition removal did not cause a significant effect on seedlings species richness (Table 4).

Table 4: Treatments interaction in relation to species richness

Effect	Estimate	Std. Error	t value	P value
Fence	-1.667e-01	6.876e-01	-0.242	0.810
CompRemoval	-9.167e-01	6.876e-01	-1.333	0.189
Fence:CompRemoval	-3.718e-15	9.725e-01	0.000	1.000

The residual of the linear model did not follow the assumption of a normal distribution, therefore, a Kruskal-Wallis test was done to test the effect of browsing on seedling species richness showing that the effect was not significant (p=0.445).

4.1.2 The seedlings species richness in response to plant competition

The biomass removed in subplots did not affect seedling species richness (Table 5). The total biomass removed was measured and converted to the nearest kilograms. The highest biomass removal was recorded at Site 2 which recorded a total dry weight of 7.3 kg, followed by Site 3 with 6.1 kg and lastly Site 1 with 3.3 kg.

Table 5: Biomass of plant competition removed

Site	Plot Number	Treatment	Total Dry weight (kg)
1	2	NoFenceNoComp	1.1
1	3	FenceNoComp	0.2
1	5	NoFenceNoComp	1
1	6	FenceNoComp	1
2	11	FenceNoComp	2.1
2	12	NoFenceNoComp	2.5
2	13	FenceNoComp	0.4
2	16	NoFenceNoComp	2.3
3	19	NoFenceNoComp	0.4
3	20	FenceNoComp	2.7
3	21	NoFenceNoComp	2.1
3	22	FenceNoComp	0.9

Competition removal slightly reduced average seedlings species richness across sites between March 2018 and April 2019. Site 3 recorded more richness in March 2018 with an average species richness of 7 and an average species richness of 6.5 in April 2019 (Table 6). Plots, where the competition was removed in March 2018, had less average species richness compared to those where completion was left intact. At the end of the recording period (April 2019), no difference in species richness was observed between treatments (YES vs NO competition removal). Overall, the species richness reduced across sites between March 2018 and April 2019 but this effect was not significant ($p=0.132$) as shown by the Kruskal-Wallis test. The interaction between treatments did not also influence the species richness (Table 4).

Table 6: Average species richness per study site in response to plant competition

Competition Removal	Site 1	Site 2	Site 3	Average
March 2018				
NO	6	5	8	**6.3**
YES	5	6	6	**5.7**
Average	**5.5**	**5.5**	**7**	**6**
Apr-19				
NO	6	4	7	**5.7**
YES	5	6	6	**5.7**
Average	**5.5**	**5**	**6.5**	

4.1.3 The seedlings species richness in response to fire

The fire had a significant positive influence on the species richness ($p<0.001$). The fire treatment recorded on average 8 species compared to 5 in the no-fire treatment (Table 7). The extra species recorded in the fire treatment are *Philenoptera nelsii, Combretum zeyheri and Acacia mellifera.*

Table 7: Species richness per treatment

Treatments	Average species richness
Fire	8
No Fire	5
Average	**6.5**

4.2 Seedling density

Seedling counts for all seedlings (10cm – 350cm) in all the subplots were recorded. The result shows that at the beginning of the experiment, the total seedling density of woody species for all sites was 745 seedlings per ha (Table 8). The relative increase in seedling density was highest for *Croton gratissimus* with an increase of 79.5% per ha, followed by *Ochna pulchra* with 43.9%, *B. plurijuga* with 19.7% and *Terminalia sericea* with 18.7% (Table 9).

Table 8: Changes in seedling density per ha for the three study sites for the period of March 2018 – April 2019

Site	Mar-18	Apr-19	Difference	
			Count per ha	%
1	531	606	**75**	**14.1**
2	1178	1571	**394**	**33.4**
3	525	453	**-72**	**-13.7**
Average	**745**	**877**	**132**	**17.8**

Seedling density increased with 18% to 877 seedlings per ha by April 2019, with most of the increase in site 2 (Table 8). Figure 14 shows that the increase commenced in December 2018 and remained slightly unchanged for the rest of the recording period.

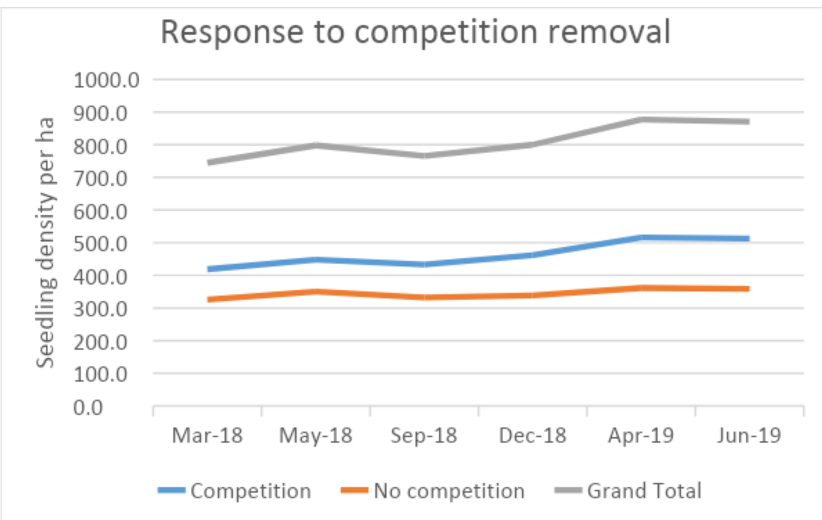

Figure 14: Evolution of seeding density over the year in response to plant competition

Table 9: Changes in seedling density for the most common species for the period of March 2018 – April 2019

Species	Mar-18	Apr-19	Difference	
			Count per ha	**%**
BaiPlu	950	1138	**188**	**19.7**
CroGra	122	219	**97**	**79.5**
OcnPul	141	203	**62**	**43.9**
TerSer	234	278	**44**	**18.7**

Two treatment sets were applied in Experiment 1: (1) browsing and protection from browsing, (2) removal of plant competition and no removal of competition. The effect of the removal of competition appears slightly larger than that of the fence protection against browsing (Table 10). However, the treatment of removing competition cannot be evaluated by the response variable seedling density as the treatment itself directly changed seedling density (Figure 14). Hence only the effect of the no browsing treatment will be evaluated for seedling density.

Table 10: Changes in seedling density per ha for the two treatments for the period of March 2018 – April 2019. Changes are expressed in % compared to March 2018. Treatments included fencing against browsing and removal of competition.

Effect	Competition	No Competition	Average
Browsing	21.4	0	**10.7**
No Browsing	24.7	19.7	**22.4**
Average	**23.1**	**9.9**	**16.5**

A generalized linear model was applied to test if there was an interaction between the two treatments. The interaction between treatments did not cause a significant difference in seedling density (p=0.354) (Table 11).

Table 11: The interaction between the two treatments, browsing and competition

Effect	Estimate	Standard Error	t-value	p-value
Fence	-0.436	18.766	-0.023	0.9815
Competition Removal	-31.25	19.286	-1.62	0.1073
Fence:Competition Removal	24.722	26.586	0.93	0.354

4.2.1 Seedling density in response to browsing

Average seedling density in response to browsing protection was 22.4 per ha compared to 10.7 per ha in response to browsing between March 2018 and April 2019 (Table 10). There was a 12% difference in seedling density between treatments (browsing and no browsing). A generalized linear model was applied to test if there was an interaction between the two treatments (browsing protection and competition removal). The interaction between treatments did not cause a significant difference in seedling density (p=0.354) (Table 11).

The residual of the model did not follow the assumption of a normal distribution, hence a Kruskal-Wallis test was performed to test the effect of browsing, showing that the effect of no browsing was not significant (p=0.116). The test was repeated to evaluate the response of browsing protection on the most important timber tree species. Browsing protection had no effect on any of those species, the p-value of *B. plurijuga* was 0.142, *B. africana* was p= 0.881, *G. coleosperma* was p=1 and *P. angolensis* p=0.543.

4.2.2 Seedling density in response to fire

A total of 759 seedlings were recorded in the fire treatment and 399 recorded in the no-fire treatment. These counts translated to 24136 seedlings per ha for the fire treatment and 12688 seedlings per ha for no fire treatment. The fire treatment had 31% more seedling density than the no fire treatment (Table 11).

Table 12: Seedling density for the fire experiment

Treatments	Density per ha
Fire	24136
No Fire	12688
Average	**18412**

The Kruskal-Wallis test was performed to test the effect of fire on seedling density, showing that the effect of fire was significant (p=0.0009). The test was repeated to evaluate the effect of fire on the study species. The fire did not have a significant effect on any of the species, for example, *B. africana* (p=0.2336). The other three species: *G. coleosperma*, *P. angolensis* and *B. plurijuga* had zero counts.

4.3 Seedlings survival

The seedlings survival was assessed for the 21 seedlings tagged per subplot to make it easier to compare the number of seedlings recorded at the beginning of the recording period and the number recorded at the end of the recording period.

4.3.1 Seedling survival in response to browsing

The average seedling counts decreased with 16% from March 2018 to April 2019 in plots open to browsing and 14% in plots protected from browsing (Table 13). A generalised linear model was applied to test if there was an interaction between treatments (browsing protection and competition removal). The interaction between treatments did not affect seedlings survival (p=0.705) (Table 14). The residuals of the model did not follow the assumption of a normal distribution hence a Kruskal Wallis test was performed to test the effect of browsing on seedlings survival, indicating that the effect of browsing protection was not significant (p=0.171). The number of seedlings measured at the beginning of the experiment (March 2018) was compared to the number measured at the end of the recording period (April 2019) and recorded in percentages.

Table 13: Seedling survival in response to browsing

Fence	Average counts for March 2018	Average counts for April 2019	Difference (%)
NO	19	16	-15.8
YES	21	18	-14.3
Average	**20**	**17**	

Table 14: Treatment interaction in relation to seedlings survival

Effects	Estimate	Std. Error	t value	p-value
Fence	-0.04461	0.08179	-0.545	0.59151
CompRemoval	0.01036	0.08179	0.127	0.90046
Fence:CompRemoval	-0.04436	0.11567	-0.384	0.70539

4.3.2 Seedling survival in response to plant competition

The average seedling counts decreased with 10.5% in plots where the competition was not removed and 14.3% in plots where the competition was removed between March 2018 and April 2019 (Table 15). Overall, competition removal did not significantly affect the survival of seedling (p=0.838) as shown by the Kruskal – Wallis test. The interaction between competition removal and fencing also did not have a significant influence on the survival of seedlings (Table 14).

Table 15: Seedling survival in response to plant competition

Competition Removal	Average Counts March 2018	Average Counts April 2019	% Difference
NO	19	17	-10.5
YES	21	18	-14.3
Average	**20**	**17.5**	

4.4 The species regeneration growth

The growth was assessed for 21 seedlings tagged per subplot and observes the difference in height and collar diameter growth between March 2018 and April 2019. A generalized linear model was applied to test if there was an interaction between the two treatments. The interaction between treatments did not cause a significant difference in seedlings' height growth (p=0.140) (Table 16). A Shapiro - Wilk test for normality was performed to see if the residuals of the model followed the assumption of a normal distribution which they did not (p<0.001).

Table 16: Treatment interaction in relation to height growth

Effects	Estimate	Std. Error	t value	p-value
Fence	12.116	3.432	3.530	0.000462 ***
Comp Removal	6.047	3.491	1.732	0.084035
Fence:CompRemoval	-7.037	4.760	-1.478	0.140051

The interaction between treatments also did not cause a significant difference in the growth of seedling collar diameter (p=0.280) (Table 17).

Table 17: Treatment interaction in relation to collar diameter growth

Effect	Estimate	Std. Error	t value	p value
Fence	2.2284	0.5209	4.278	2.35e-05***
Comp Removal	-0.8383	0.5299	-1.582	0.114
Fence:CompRemoval	0.7819	0.7819	1.082	0.280

4.4.1 Seedlings growth in response to browsing

The average height difference of 17.7cm and collar diameter difference of 4.3mm was recorded in plots protected from browsing compared to an average height difference of 7cm and collar diameter difference of 1.3mm in plots not protected (Table 15).

Table 18: Average growth in response to browsing between March 2018 and April 2019

Fence	Average of Height Difference (cm)	Average of Collar Diameter Difference (mm)
NO	7.0	1.3
YES	17.7	4.3
Average	**12.6**	**2.9**

A Kruskal – Wallis test was performed to test the effect of browsing on seedling growth indicating that the effect was significant (p<0.001) for height and (p<0.001) for collar diameter.

Fencing had a positive influence on the growth of *B. plurijuga* (p<0.001) both for height and collar diameter. Fencing did not influence the growth of *B. africana* (p=0.279). The other two species *P. angolensis* and *G. Coleosperma* had too small data set for analysis.

4.4.2 Seedlings growth in response to plant competition

Seedlings grow better when plant competition is removed (Table 19) but the effect of plant competition removal did not significantly affect the overall growth of seedlings both in height (p=0.441) and collar diameter (p=0.307) as shown by the Kruskal – Wallis test. With these data, we can accept the null hypothesis that plant competition removal does not improve the growth of the seedlings. The average seedling's growth between treatments (competition removal and no competition removal was not significantly different (Table 19).

Table 19: Table: Seedling average growth in response to plant competition

CompRemoval	Average Height Difference (cm)	Average Collar Diameter Difference (mm)
NO	11.6	2.6
YES	13.4	3.1
Average	**12.6**	**2.9**

4.5 Shoot production in response to fire

4.5.1 Trees and saplings shoot production in response to fire

The Kruskal-Wallis test was done to test the effect of fire on trees and saplings' shoot production, showing that the effect was significant (p<0.001) for both trees and saplings. The shoot production was high in the fire treatment showing an average of 3.9 shoots for saplings and 4.5 for trees (Table 20). Figures 15 and 16 show the average number of shoots per species for trees and saplings in each treatment. Overall, trees seem to produce more shoots after fire than saplings (Table 20). The target species were not well represented in this area therefore observations were done for other species with economic values especially those that are preferred by livestock in the dry season such as *C. collinum* and *T. sericea.*

Table 20: Average number of shoots per treatment

Treatment	Average of No. of Shoots for saplings	Average of No. of Shoots for trees
Fire	3.9	4.5
No Fire	1.2	1.2
Average	**2.5**	**3.0**

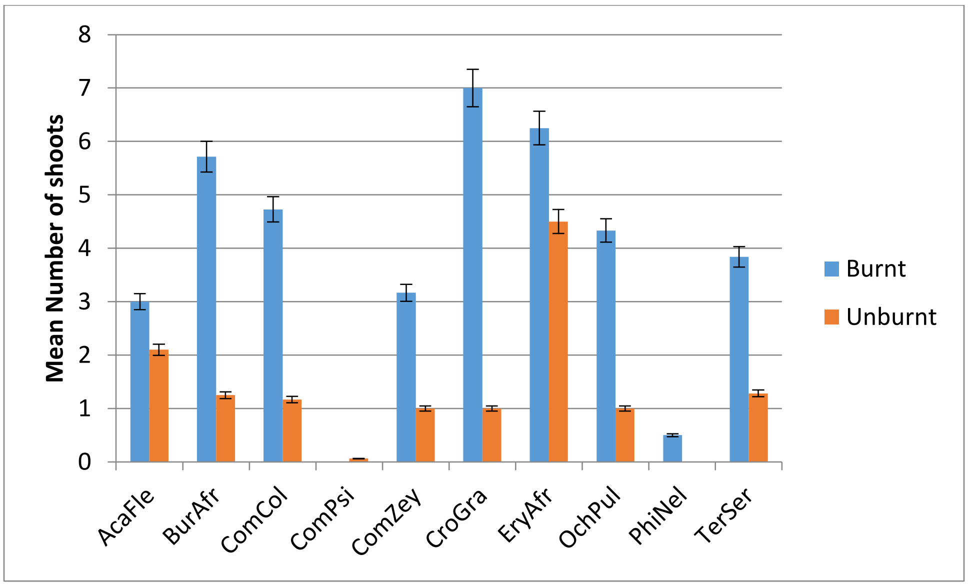

Figure 15: Saplings comparisons of shoots produced between burnt and unburnt area. Saplings (woody plants with DBH 5cm – 9.9cm)

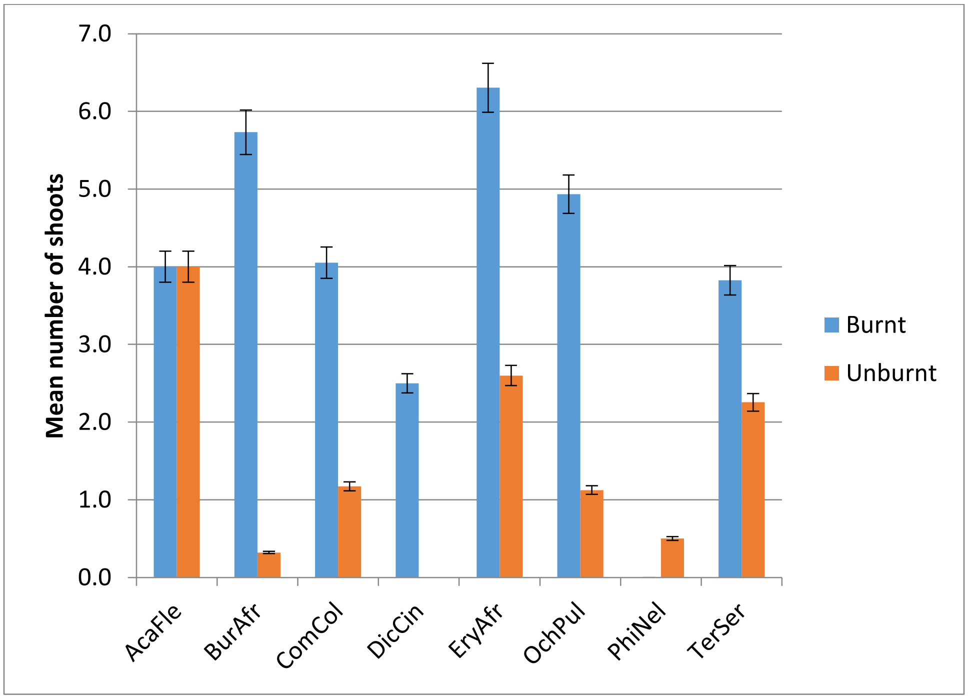

Figure 16: Trees Comparisons of shoots produced between burnt and unburnt area

4.6 The regeneration mortality in response to fire

The fire affected the mortality of saplings as shown by a Kruskal – Wallis test ($p<0.001$). More saplings were recorded dead in the fire treatment than in the no-fire treatment. 36% of the saplings recorded in the fire treatment are dead compared to the 2% in the other treatment (Table 21). *T. sericea* recorded 44 dead sapling counts in the fire treatment and 46 in the no fire. Other species recorded a high number of dead saplings in the fire treatment (Figure 17).

Table 21: Sapling counts per treatment

Treatment	Number of saplings measured	Number of saplings recorded dead	Number of saplings recorded per ha	Number of saplings dead per ha
Fire	96	35	3053	1113
No Fire	107	3	3403	96

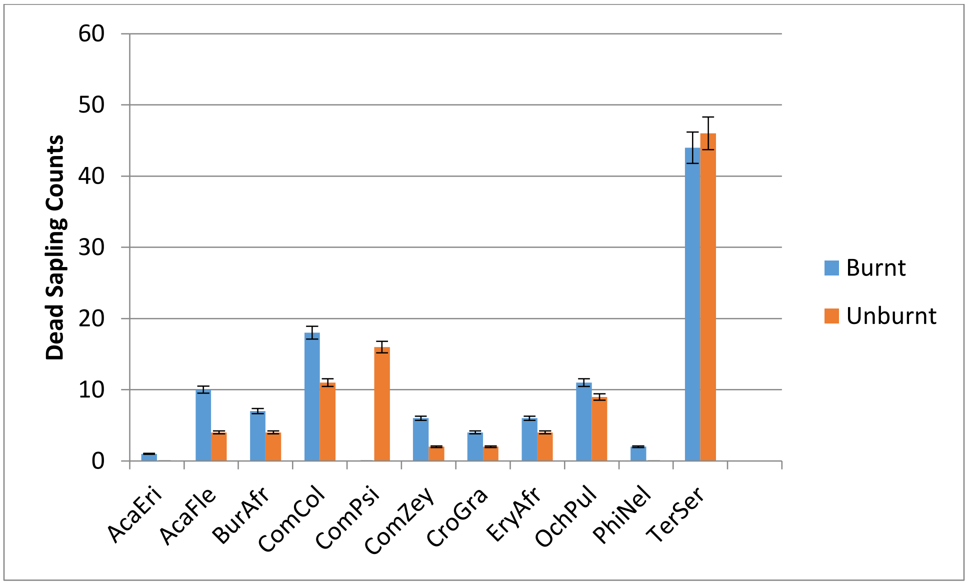

Figure 17: Sapling mortality in response to fire

Chapter 5: Discussion

The study focused on investigating the effects of anthropogenic and natural disturbances such as fire, herbivory and plant competition on the regeneration of woody species. The results of this study showed that disturbances affect forest regeneration in different ways. Some disturbances showed negative effects, some had both positive and negative effects such as forest fire. Forest regeneration reacts differently to disturbances and this reaction is also influenced by climatic factors.

5.1 The woody species regeneration species richness and density

5.1.1 Seedlings species richness and density in response to browsing

The results of this study show that exclusion from livestock did not influence woody species seedling richness and density contrary to other studies showing that browsing affects plant regeneration (Iraj Hassanzad 2016). The latter study showed that the removal of livestock from the forest led to a significant increase in the regeneration establishment in 9 years. Considering the amount of time this study was conducted and the severe drought experienced that year, it will be not wise to conclude that livestock exclusion does not affect seedling density in the forest. It is believed that even though livestock exclusion is supposed to cause significant differences in species richness and density, complex relationships between various components of the ecosystem may have complicated the effect of the treatment (protection from browsing) and the period is too short to observe meaningful results. The results indicate that the seedling density started increasing in the rainy season compared to the dry season. This indicates that the season also plays a big role in the establishment of seedlings in the forest. Seedlings increase during the wet season because seeds break dormancy and germinate when it is wet and conditions are more favourable for seedling establishment. A slight decrease in species richness (6.4 species to 5.8) could have been affected by low rainfall received in the area in the 2017/18 rain season (Figure 5). The area only received an average rainfall of 21.8 mm between October 2017 and December 2018. Different species have different water requirement. The drought period may have favoured some species and not others. The fact that the results of this study showed that there is no difference in species richness and density between fenced and not fenced plots indicates that the regeneration was affected by other factors probably climatic factors and not treatments and the study period could also not be sufficient enough to observe the effect of browsing protection. The treatment for fencing could also be more effective if sufficient seedlings are available to protect in the first place, concluding that drought periods and dry season may not be the best time to observe the effect of browsing protection.

A study by Sheuyange et al (2005) also supported these results indicating that grazing pressure alone did not influence plant species richness but the variability was more influenced by rainfall and fire.

Small rodents were also observed in some plots and caused damage to seedlings because the fence used did not prevent small herbivores from entering the plots. Herbivores may influence vegetation both directly through consumption of plant tissues and indirectly via their effects on nutrients cycling and soil disturbance (Hulme 1996). Since defoliation by grazers rarely kills the host plant, it is believed that the effect of herbivory is to reduce the competitiveness of the grazed plant rather than to cause mortality but these completely depends on the size of the plant and the intensity of browsing. Herbivores are known for uprooting small plants, therefore, causing a decrease in density of certain species. The impact of herbivores on vegetation diversity and density, therefore, depends on the degree to which they alter the resource requirements of the grazed individuals (Hulme 1996) and the effects of herbivores on plant diversity also differs with environments. Livestock grazing is considered to be of great ecological importance in terrestrial ecosystems if sustained at acceptable levels. Kikoti *et al.* (2015) conducted a study in Northern Slopes of Mount Kilimanjaro, Tanzania and found that species diversity of regenerants differed significantly among areas with different grazing intensity. Keeping the grazing intensity at low and moderate levels stimulated more plant growth and diversity as opposed to heavy grazing. A study by Zida in 2007 in the Sudanian savanna of Burkina Faso also indicated that a moderate level of grazing does not affect seedlings recruitment. Considering the livelihood system of Owambo people that everyone is a farmer (Siiskonen 1996), the presence of livestock in the forest remains a threat to regeneration. Farmers, therefore, need to be encouraged to practice light to moderate grazing to minimize the impact on forest regeneration. The seedling density can also be affected by the distance to settlements (kabajani 2016). However, the households set up in the study area are randomly distributed and one cannot say one area is more overpopulated than the other.

5.1.2 Seedlings species richness in response to plant competition

The result shows that there is no significant difference in seedling species richness ($p=0.132$) between plots where the competition was removed and that competition remained intact. The effect of plant competition on seedling density was not tested because it is concluded that the treatment itself affects the outcome of the experiment because some seedlings have to be removed during the treatment application. In a broader context, plant competition reduces species diversity in the sense that certain plant species out-compete others causing them to die and this reduces species diversity in the area leading to the dominance of certain species. Plant–plant interactions play a key role in regulating the composition of communities and ecosystems. Not only do they control the composition of plant communities, but they also have impacts that spread throughout ecosystems, for example through their effects on resource availability and habitat structure. Slight higher species richness at site 3 in response to plant competition could mean that even mother trees are diverse compared to the other two sites. Site 3 recorded a total of 11 species of mothers trees compared to 8 species recorded at site 2 and 6 recorded at site 1 respectively. The diversity of the mature stand is an indication that different species seeds are being dispersed in the area hence the population of seedlings will also be diverse. For this study, It is as well believed that there was no a sufficient amount of seedlings, grasses and herbs to cause a significant difference in competition removal vs no competition removal due to a severe drought experienced that year. The interaction between fencing and plant competition as well did not cause significant influence on species richness.

5.1.3 The seedlings species richness and density in response to fire

Forest fires have become common in Namibia forest and the damage depends on intensity and frequency. These fires can be anthropogenically caused by peoples or naturally caused by lightning. The result shows a single fire event has a significant influence on seedlings density and species richness. The fire treatment had a 31% higher seedling density per ha than no fire treatment. The fire did not cause a significant increase in seedling density of *B. africana* (p=0.2336). The rest of the study species recorded no data in the seedlings stage. The increase in seedlings species richness and density after a fire could be a result of breaking of dormancy of seeds by a single fire and an increase in sprouts. An increase in seedling density in burned plots suggests that a single fire event could be beneficial to the regeneration of trees. Higher nutrients availability, decrease in pathogen population and opening of mineral soils could also be the reasons for an increased number of seedlings. These data were collected five months after the fire has occurred and based on observation, it was a low fire intensity which swiped through the forest burning mostly the grass and herbaceous layer. Older fire history was not available, i.e. It is not clear when the area was burnt (before the event recorded here). The effect of fire depends on the intensity and frequency of burning. The result of this study is also supported by the study of Verma et al. (2017). The latter study also found an increased number of seedlings in burned patches compared to unburnt patches. Another supporting the findings of this study is by Ryan in 2011 which also indicated that low fire intensity improves forest regeneration. However, repeated burns reduce the species number of all live stems particularly if an area burns every year (Balch *et al.* 2013). In other studies, similar patterns were found indicating high regeneration density in low to moderately burned plots (Mwansa 2018).

5.2 The woody species regeneration growth and survival

5.2.1 Seedlings growth and survival in response to browsing

Herbivory is the main plant-animal interaction which has been investigated in rangeland ecosystems. The result shows livestock exclusion has a positive effect on the growth ($p<0.001$) but not on the survival of seedlings ($p=0.591$). The positive growth was detected in both height and collar diameter respectively. The hypothesis that protection from browsing does not increase the regeneration growth for seedlings is rejected. However, the results also indicate that livestock exclusion has no influence on the survival of seedlings in the study sites for one year. Herbivores, especially livestock are known to hinder seedling growth by consuming the terminal shoots with the apical cambium of the trees. The fact that no relationship between seedling survival and browsing was observed, indicates that herbivory inhibits growth but do not cause mortality in most cases. However, the study period may also be too short to conclude this with absolute certainty. Seedlings may be trampled by large herbivores and die at the same time. Seedling mortality can also be caused by rodents and some invertebrates as was observed in site 1. Some seedlings were completely dug out by small mammals negatively affecting the seedling survival. It can also be noted that because there was no knowledge of livestock in a plot or there was not sufficient proof that a certain plot was accessed by animals, these results may not be 100% certain about seedling survival in relation to browsing. A study by Wassie in the Ethiopian Church forest in (2009) indicated that in fenced plots more seeds germinated, seedling survival was higher and seedlings grew faster. In this case, a reduction in seedling survival could have been contributed by other disturbances and environmental factors. Plant response to herbivory depends on a range of interacting factors such as the frequency, magnitude, season of tissue removal, type of plant parts lost, levels of resource availability, competition and stage of the life cycle. An understanding of the plant-environment relationship is important for the success of rangeland restorations.

5.2.2 Seedlings growth and survival in response to plant competition

There was no significant increase in seedling growth in response to the removal of plant competition. The seedlings grew at the same rate in height and diameter in both treatments (competition removal and no competition removal). Therefore the hypothesis of plant competition removal does not improve the regeneration growth cannot be rejected. Plant competition removal also did not improve the survival of seedlings (p=0.838). Surprisingly, one would expect seedlings to grow better in conditions and survived longer with the reduction in plant competition which was not the case in this study. In general, nutrients, water and light are the three main resources that limit plant growth and are considered to be resources for which individual plants compete for. Plants compete for light, nutrients and water such that the biomass of an individual becomes smaller as the population density increases hence inhibit seed germination and seedlings growth. However, this depends on the stage of the seedling (newly germinated or established) and species. Newly germinated seedlings are more vulnerable because their roots are not yet well established compared to older seedlings and species respond differently to different conditions. Certain species are more shade tolerant than others and some are more light-demanding. This phenomenon applies to any given plant species in a given community. One might assume that due to a prolonged drought experienced in the area, the regeneration was not sufficient to cause any difference in the removal and no removal. Few individuals were removed in the treatment of competition removal which might not have caused any difference compared to plots where competition remained intact. Hypothetically, one can conclude that there was not enough regeneration in the forest to allow removal of sufficient competition to cause an impact.

5.2.3 Regeneration responses to fire

There was a significantly higher number of shoots produced for both saplings and trees in the fire treatment (Figure 15 and 16) (p<0.001). The results show that when plants are top killed by fire, they are forced to sprout from underground parts. However, in the case of trees, sprouting also happens after the disturbance even if the tree is not completely dead. Sprouting is a form of disturbance tolerance in plants and many species can sprout vegetatively after a substantial loss of biomass induced by environmental stress. The ability of woody species to sprout after a top kill by fire, particularly in savannah ecosystems, is due to the already established and functioning carbohydrate reserves stored in the roots. *T. sericea* is known for a high coppicing ability after the fire, the reason why it is one of Namibia's encroaching species (Siphiwe 2017). In this study, *T. sericea* also showed a high sprouting ability regardless of the treatment (Figure 15 and 16). This result is also supported by Jordaan (1995) where it has been found that the number of stems increases with fire. After a hot November fire in a *B. africana* savannah in Zambia, *T. sericea* had the greatest percentage of plants with basal regeneration shoots.). This finding is as well supported by a study by Chidumayo (2013) which showed a significant increase in shoots for *P. angolensis* and *B. plurijuga* in burned areas. Sprouting may occur from apical, epicormic and belowground buds which occurs in response to tissue loss through fire, herbivory, drought, insect attack and other disturbances (Zeppel *et al.* 2015). There are costs to resprouting which include lower seed production, higher allocation of biomass to roots and longer time to sexual maturity. In general, resprouting species have an extended root system and have a higher allocation to roots than shoots (Zeppel *et al.* 2015) and increased non-structural carbohydrate stores to support resprouting. A study by Ncube and Mufandaedza (2007) in Zimbabwe also showed that fire increases the number of coppice shoots produced by each stump for *B. plurijuga* and *P. angolensis.*

The fire significantly caused high mortality for saplings with 1113 saplings dead per ha. These figures include all saplings which are top killed and forced to sprout and those which could not pull through the fire. If the fire intensity was high enough to kill saplings, the damage to seedlings was likely to be even more only that this study did not account for seedling mortality. Tree mortality by fire has many implications for the future of the forest and the ecological goods and services they provide to society.

Chapter 6: Conclusion

This study focused on evaluating the effect of browsing protection, competition removal and fire on the woody species regeneration in Onkumbula community forest. Timber trees in Namibian forests are exploited and concerns of their natural regeneration capacity have been an issue of concern. Considering the low seedlings to saplings ratio in the forest especially for *P. angolensis* as confirmed by studies (Kayofa 2015, kabajani 2016), the future of these important species is in great danger. Efforts to propagate the seedlings in nurseries also did not yield much success. Assisted natural regeneration is an option being investigated to evaluate its impact in Namibia forests. This study aimed to investigate how the natural regeneration of woody species especially timber trees can be accelerated.

The result shows that browsing protection did not influence seedlings density and species richness in the study area over the study period. The same applies to the treatment of removal of plant competition which did not significantly affect seedling species richness. Even though there were differences observed in seedling counts between treatments, their impact was not statistically significant. It was also found out that browsing protection had a significant influence on seedlings growth ($p<0.001$) for height and ($p<0.001$) for collar diameter. Seedlings grew better indicating an average growth of 10.7 cm in height and 3 mm in diameter in plots protected from browsing. Fencing had a positive influence on the growth of *B. plurijuga* ($p<0.001$) both for height and collar diameter but did not have a significant effect on the growth of the other focus species. Besides, the four focus species did not record good regeneration and in some cases, data was not sufficient to analyze species. Browsing protection and competition removal do not have a significant effect on seedling survival. We conclude that the survival of seedlings may have been affected by other environmental factors of the ecosystem but not herbivory and competition removal during the study period.

The fire had a significant influence on seedlings density and species richness. More seedling counts and species per ha were recorded. The study results also showed that fire caused a significant increase in trees and saplings shoot production with the average shoots of 4.5 for trees and 3.9 for saplings ($p<0.001$). When vegetation is disturbed normally by environmental stress like fire, they are top killed or injured and sprout from roots. It is believed that species that can sprout stand a good chance of surviving harsh environmental conditions. The result also indicates that fire significantly causes the regeneration mortality with 31% more saplings dead in the fire treatment compared to the no-fire treatment.

Field-based woodland studies are required for forestry management in Namibia, as the knowledge of the forest and requirements for different species are essential for sustainable forest management. Up to date information on forest resources and natural forest, regeneration is important for future improvements of forest stands. To improve indigenous tree species regeneration in Namibia forests, controlling livestock pressure and fire management is necessary. The awareness of local people in this regard is therefore of paramount importance.

This study has shown that regeneration of woody species can be complex and it is driven by several factors. For this study, these factors appeared to be mainly fire and browsing by herbivores and not plant competition. It can therefore be concluded that the woody species regeneration needs proper management for the future existence of tree species and management methods include fire management and browsing management among other approaches. Despite the substantial efforts, further research is needed to reveal the true effects that cause a reduced regeneration of important timber species.

Chapter 7: Recommendations

For future studies, the following areas should be looked at:

- This study was conducted in one study area due to limited funds. It will be a good idea to replicate it in other community forests in northern Namibia.
- The study was conducted in a non-registered community forest, it will be best to compare the impacts of livestock browsing on tree regeneration in registered and non-registered community forests.
- A similar study to be conducted in years with sufficient rainfall and enough seedlings regeneration to assess the impact of plant competition removal on seedling growth and survival.
- This study was conducted in 12 months. It could be that the study period was not sufficient enough to observe the effects of browsing and plant competition. Therefore a similar study should be conducted for a longer period of three years or more and the fence should be high enough to restrict antelopes.
- More vegetation studies to be conducted in Oshikoto region as most of the studies are conducted in Kavango East, West and Zambezi region with few studies being done in Ohangwena region.

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Appendices

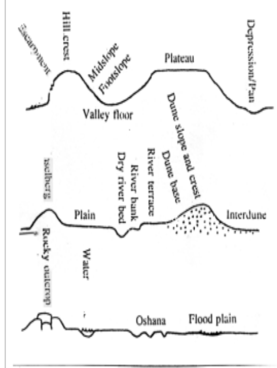
Appendix A: Stand disruption form

STAND INFORMATION

Block No	
Area	
Date	
Team	
Latitute	
Longitude	
Location Accuracy (m)	
Land type	
Land use	
Crown coverage trees	
Crown coverage shrubs	
Grass coverage	
Herb coverage	
Bare soil coverage	
Human influence (0 - 4)	
Domestic mammals (0 - 4)	
Damage by forest fire (0 - 4)	
Recent fire (Y/N)	
Main cause damage (0 - 10)	
Second cause damage	
PA nearby (Y/N)	
BP nearby (Y/N)	
BA nearby (Y/N)	
GC nearby (Y/N)	
Maximum tree height plot	
Remarks	

Land type

1 = Escarpment (steep, long ridge, extending over more than 10 km)
2 = Hill crest (top of a ridge)
3 = Mid slope
4 = Foot slope
5 = Valley floor
6 = Plateau
7 = Depression/Pan
8 = Inselberg (isolated mountain)
9 = Plain
10 = Dry river bed
11 = River bank (current)
12 = River/alluvial terrace (old bank)
13 = Dune base
14 = Dune slope and crest
15 = Interdune, (always sand, between dunes)
16 = Rocky outcrop
17 = Water course
19 = Flood plain
18 = Oshana



Land use

1 = Naturally vegetated land (including farmland used for grazing)
2 = Agro-silvopastoral (Agro-Forestry)
3 = Forestry (commercial tree production, plantation)
4 = Agriculture (crop production)
5 = Mining
6 = Bare soil

Cause damage

1 = Forest fire
2 = Mammals wild
3 = Mammals domestic
4 = Insect
5 = Human
6 = Frost
7 = Drought
8 = Erosion
9 = Storm
0 = Unknown
10=fungi

0 = No damage/influence
1 = Mild damages, not affecting the trees
2 = Moderate damages, decreasing vitality of trees
3 = Serious damages, seriously affecting several trees
4 = Fatal damages, several trees are dying or dead

Appendix B: Trees recording form

TREES

Study site:

Block number

Plot No.	**Species**	**No./specie**	**DBH**	**Alive**	**Dist (m)**	**Timb_q**	**l_log (m)**	**Crown_cl**	Phenol.	Height(m)	Damage	Cause_dam	Remarks

Alive

1 = Alive tree
2 = Standing dead tree
3 = Dead, lying
4 = Stump

5 = stump with coppice

Timber or pole quality

4 = Expected good
5 = Expected medium
6 = Expected poor

7 = no timber or pole quality

Crown class

1= Open crown
2 = Dominant
3 = Co-dominant
4 = Intermediate
5 = Overtopped

Phenology

L(eaves),Fl(owers),Fr(uits)

Damage : see sheet 1

Cause damage

1 = Forest fire
2 = Mammals wild
3 = Mammals domestic
4 = Insect
5 = Human
6 = Frost
7 = Drought
8 = Erosion
9 = Storm
0 = Unknown

10=fungi

Species names : list first three letters of genus and species, unless in cases where confusion can arise e.g. Combsp and Commsp.
unknown species are listed as Specx, but it is advised to take a picture and a leave sample to identify it afterwards.

Multiple stems : dbh and log length needs to be recorded for each stem.

Appendix C: Seedling measurement recording form

Namibia University of Science and Technology														
Department of Agriculture and Natural Resource Sciences														
Research Data collection form														
Study site: Onkumbula CF														
Block No.:														
	RECORDING PERIOD													
Plot No.	Treat ment	Species	Sapling /seedling tag No.	Dead /Live	Height: 0-150cm	Height: >150cm	CD	DBH	Damage/influence	Cause of damage	Remarks	1 = Alive tree 2 = Standing dead tree 3 = Dead, lying 4 = Stump		
									0 = No damage					
									1 = mild					
									2 = moderate			5=stump with coppice		
									3 = serious			1 = Forest fire 2 = Mammals wild 3 = Mammals domestic 4 = Insect 5 = Human 6 = Frost 7 = Drought 8 = Erosion 9 = Storm 0 = Unknown		
									4 = fatal					
												10=Fungi		

Appendix D: Regeneration form for Exp. 2

Regeneration sheet **Plot size** ________ m

Community Forest ______________________ Team leader ______________
Plot Nr. ______________________ Date ______________

Regeneration

	Species	Countings (tally)	Total
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

> 150 cm height and < 5cm diameter DBH, to be counted only

ONLY IF APPLICALBE!

Saplings

Nr.	Tree species	Diameter
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

bigger than 5 cm, smaller than 10 cm in diameter DBH, to be measured

Appendix E: Competition removal measurements

Site No.	Plot No.	Treatment	Plant type	Fresh Wheight (kg)	Initial dry Wheight (kg)	W. after 12 hrs (kg)	W. after 24 hrs (kg)
1	2	NoFenceNoComp	Grass and herbs	0.4	0.2	0.2	0.2
			Woody plants	3.6	1.8	1.2	0.9
1	3	FenceNoComp	Woody plants	1.3	0.5	0.3	0.2
			Grass and herbs	0	0	0.0	0
1	5	NoFenceNoComp	Woody plants	1.3	0.9	0.9	0.9
			Grass and herbs	0.2	0.1	0.1	0.1
1	6	FenceNoComp	Woody plants	1.5	1.1	1.1	1
2	3	FenceNoComp	Grass and herbs	0.1	0.1	0.1	0.1
			Woody plants	3.8	2.8	2.2	2
2	4	NoFenceNoComp	Grass and herbs	0	0	0.0	0
			Woody plants	4.7	3.1	2.8	2.5
2	5	FenceNoComp	Grass and herbs	0	0	0.0	0
			Woody plants	3.1	1.6	0.9	0.4
2	8	NoFenceNoComp	Grass and herbs	0	0	0.0	0
			Woody plants	7.8	3.7	2.7	2.3
3	5	NoFenceNoComp	Grass and herbs	0	0	0.0	0
			Woody plants	3.7		2.5	2.1
3	6	FenceNoComp	Grass and herbs	0	0	0.0	0
			Woody plants	2.7	1.5	1.2	0.9
3	3	NoFenceNoComp	Grass and herbs	0	0	0.0	0
			Woody plants	2.9	1.4	0.8	0.4
3	4	FenceNoComp	Grass and herbs	0	0	0.0	0
			Woody plants	6	3.5	3.1	2.7

Appendix F: Expansion factors used to convert seedling counts to density

The counts of the pivot were multiplied by the expansion factor depending on the area where it is applied to

Expansion factor used in experiment 1 to obtain seedling densities

Plot size	Height class	Plot area	Expansion factor per plot	Expansion factor per treatment	Expansion factor per site
20m x 20m	10cm - 350cm	400m^2	25	4.167	3.125

Expansion factor used in experiment 2 to obtain seedling densities

Plot radius	DBH class	Plot area	Expansion factor per treatment	Expansion factor per ha
10m	5-10cm	314.16m^2	3.18	31.8
30m	>10cm	2827.43m^2	0.35	3.537

Appendix G: Species counts per site for Experiment 1

Species	Sum of Counts Mar18	Sum of Counts May18	Sum of Counts Sep18	Sum of Counts Dec18	Sum of Counts Apr19	Sum of Counts Jun19	Grand Total
Site 1	**170**	**202**	**194**	**173**	**194**	**194**	1127
AcaEri	15	20	17	12	14	14	92
BurAfr	48	48	46	40	42	42	266
ComAng	2	2	1	1	1	1	8
ComCol	22	22	22	23	23	23	135
ComGla	2	2	2	2	2	2	12
Comzey	2	4	4	4	4	4	22
CroGra	3	8	8	7	10	10	46
DicCin	11	15	14	10	11	11	72
GreFla	1	5	5	5	5	5	26
OchPuc	1	4	4	4	6	6	25
OzoSch	1	1	1	1	1	1	6
PelAfr	1	5	5	5	6	6	28
PteAng	1	1	1	1	1	1	6
TerSer	57	62	61	55	65	65	365
XimAme	2	2	2	2	2	2	12
ZizMuc	1	1	1	1	1	1	6
Site 2	**377**	**414**	**399**	**453**	**503**	**501**	2647
AcaFle	3	3	2	2	2	2	14
BaiPlu	286	287	284	326	347	346	1876
BapMas	18	28	21	21	29	29	146
ComAng	1	1	1	1	1	1	6
ComCol	4	5	4	6	6	6	31
CroGra	35	45	45	52	56	56	289
GuiCol	2	2	1	1	1	0	7
OcnPuc	21	30	28	31	45	45	200
TerSer	7	13	13	13	16	16	78
Site 3	**168**	**150**	**142**	**142**	**145**	**141**	888
AcaEri	1	1	0	0	0	0	2
AcaFle	11	9	9	9	9	9	56
BaiPlu	18	17	17	17	17	16	102
BapMas	51	48	46	44	45	44	278
BauPet	2	2	1	0	0	0	5
ComCol	16	14	14	16	17	17	94
ComGla	1	1	1	1	1	1	6
ComPsi	3	3	2	2	2	2	14
CroGra	1	2	2	3	4	4	16
DicCin	4	5	5	5	5	3	27
EriAfr	12	12	12	12	12	12	72
GuiCol	8	7	6	5	5	5	36
OcnPuc	23	20	19	20	20	20	122
PteAng	6	0	0	0	0	0	6
TerSer	11	9	8	8	8	8	52
Grand Tot	**715**	**766**	**735**	**768**	**842**	**836**	4662

Appendix H: Seedling Species richness and counts per treatment for Experiment 2

Plot	Treatmen	TerSer	AcaEri	ComPsi	BurAfr	ComCol	CroGra	EryAfr	OcnPul	ComZey	PhiNel	AcaFle	SpeciesRichness	Totalcounts
1	Fire	45	6	0	3	4	0	6	2	11	0	1	8	78
2	Fire	45	3	6	1	5	17	7	5	0	0	5	9	94
3	Fire	19	0	3	10	0	5	18	9	3	1	2	9	70
4	Fire	9	7	0	13	12	1	0	9	1	3	0	8	55
5	Fire	16	2	1	5	12	0	11	13	8	0	3	10	71
6	Fire	25	0	0	4	12	2	0	7	4	0	6	7	60
7	Fire	12	5	0	5	8	0	5	21	0	0	0	6	56
8	Fire	35	3	2	0	15	0	23	11	0	1	2	9	92
9	Fire	13	10	0	1	22	0	0	4	0	0	14	6	64
10	Fire	48	15	0	27	11	8	2	6	0	0	2	8	119
11	NoFire	14	0	0	5	4	0	0	9	0	0	0	4	32
12	NoFire	3	0	6	0	11	0	0	12	0	0	2	5	34
13	NoFire	10	7	0	0	3	5	0	3	0	1	0	6	29
14	NoFire	11	0	1	0	4	0	3	24	0	0	0	5	43
15	NoFire	8	0	3	10	12	10	0	5	0	0	0	6	48
16	NoFire	8	0	1	7	9	0	0	7	0	0	0	5	32
17	NoFire	12	0	3	0	0	0	0	15	3	0	0	4	33
18	NoFire	9	0	2	4	8	0	0	9	0	0	0	5	32
19	NoFire	15	0	1	7	16	0	0	0	0	1	3	6	43
20	NoFire	17	0	0	0	10	0	28	6	0	0	12	5	73