

Effects of bush thinning on shoot resprouts and forage nutritive value of *Acacia mellifera* subsp. *detinens* in a semi-arid Camelthorn Savanna

Hivangere Hoveka

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NAMIBIA UNIVERSITY  
OF SCIENCE AND TECHNOLOGY

Supervisor: Dr Jonathan Kamwi

(Namibia University of Science and Technology)

Co-Supervisor: Mr Tendai Nzuma

(Namibia University of Science and Technology)

217089747

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## Declaration

I, *Hivangere Hoveka*, hereby declare that the work contained in the thesis entitled: *Effects of bush thinning on shoot resprouts and forage nutritive value of Acacia mellifera subsp. detinens in a semi-arid Camelthorn Savanna, Otjozondjupa Region, 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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## **Dedication**

I dedicate this thesis to Mr Riaan Zaaruka. This is for believing in me and encouraging me to keep going from the onset. Your push was what got me through this, I appreciate you.

## **Abstract**

Bush encroachment affects the most symbolic vegetation type in Namibia, the savanna which constitutes 64% of the land area. Savannas are event-driven and with proper management could return to their original state. Although bush control is seen as costly by most farmers, using the encroacher bush as livestock fodder could offer farmers an incentive to thin the bush, but little is known on using resprouts from the thinned bush as livestock fodder. This study determines the effects of bush thinning on shoot resprouts and forage nutritive value of *Acacia mellifera* subsp. *detinens* in a semi-arid camelthorn savanna. Resprouts were monitored for three different seasons, at different stump diameters and analysed for nutritive value in comparison to mature trees. Season of harvest did not have a significant effect on the number of resprouts however, more resprouts were seen when bush was thinned during the hot-wet season. Stump basal diameter did not have a significant effect on the number of resprouts although smaller trees with diameters in the range of 5cm-11cm showed more resprouts. Resprouts had a high nutritional value and were more palatable compared to mature trees.

**Keywords:** Bush thinning, bush encroachment, *Acacia mellifera* subsp. *detinens*, shoot, resprouts, forage nutritive value.

# CHAPTER 1

## GENERAL INTRODUCTION

### 1.1 Background

Savannas are the most symbolic vegetation type in Namibia, making up 64% of the land area (Brown, 1992; de Klerk, 2004). The importance of savannas cannot be overemphasised, they are important contributors to cattle and crop farming which form the basis for rural livelihoods and to the game and tourism sector (Grouzis & Akpo, 1997). The structure and productivity of savannas is influenced by primary and secondary determinants, primary determinants act as constraints for savanna ecosystems, these are soil moisture balance, light, temperature, soil nutrients and rainfall (Teague & Smit, 1992; Sankaran, Ratnam & Hanana, 2004; Joubert, 2014), secondary determinants modify primary determinants and they are fire (Fuhlendorf & Engle, 2001), herbivory, poor rangeland management practices and artificial water points (de Klerk, 2004). When there is a shift in the natural cycle of savannas a phenomenon known as bush encroachment occurs.

Over the years researchers have attempted to investigate the process and causes of bush encroachment, but there remains a poor understanding of what exactly causes bush encroachment (Ward, 2005). Models, theories and hypothesis have been developed and suggested to explain the causes of bush encroachment, which are; the State-and-Transition Model, Walter's Two-layer Model (de Klerk, 2004), Resource allocation model and Patch dynamic hypotheses.

The State-and-Transition Model states that bush encroachment is a reversible event depending on favourable management and environmental conditions since savannas are event-driven characterised by multiple complex factors such as fire suppression, inter-annual rainfall variability and exclusion of browsers (de Klerk, 2004). Among these factors, rainfall variability is assumed to be the major limiting factor for both grassy and woody plants (Walter, 1971). Walters's two-layer model states that over

utilisation of the grass layer for example by heavy grazing weakens its ability to absorb nutrients and water effectively, more water drains into the sub-soil and becomes available for woody plant growth (Wiegand, Ward & Saltz, 2005). Resource allocation model considers the mechanisms of plant coexistence, describing the role of competition and resources allocation on plant communities (Tilman, 1982). The model is based on resource availability  $R^*$  and states that a population can only be maintained if its growth is greater than its loss rate. Patch dynamic hypotheses state that savannas are patch dynamic systems which are spatial and temporal.

Bush thinning results in an immediate change in the competitiveness of the woody and herbaceous layers (Smit *et al.*, 1999) having both positive and negative effects. For farmers the positive effects include an increase in plant species diversity due to competitive release (de Klerk, 2004), groundwater recharge (Donaldson, 1969), increase in agricultural productivity and grass yield, increase in livestock carrying capacity, development of new economic value addition chains (de Klerk, 2004) creating employment opportunities and contributing to the country's economy. The negative effects can be explained by a reduction in biological diversity (de Klerk, 2004), the loss of soil nutrients (Hagos & Smit, 2005) and poor herbage quality (Nzehengwa, 2013), shortage of food for a variety of animals, displacement of animals, reduced livelihood for communities that depend on wood for income, construction material, fuelwood and medicine.

Early records show encroachment levels to have been 10 million hectares of grazing land, by 1999, the encroachment level had gone up to about 26 million hectares (de Klerk, 2004), In 2005 the figure stood at 45 million hectares (SAIEA, 2015). Bush encroachment is not a permanent phenomenon (Dougill, Thomas & Heathwaite, 1999), favorable management of savannas could restore it, to its grass-dominated state. Although many farmers are aware of the ways used to control bush encroachment, it is not easy to invest in fighting the bush especially in communal areas where there are shared resources. Chemical control, mechanical control, and biological control are the three methods used to clear encroacher bushes (de Klerk, 2004). The chemical control method uses chemicals in a localised

or broadcasted manner to kill woody plants, chemical means should be used carefully as there is a potential to poison water sources and non-targeted species. Mechanical control uses felling to control bush, this can be done with the use of axes, chainsaws, machetes and bulldozers. This method is selective and often not destructive, it has the potential to create job opportunities due to its labour-intensive nature. The biological control method uses controlled veld fires and grazing by game or goats to manage bushes. This method is more effective as aftercare where the bush has been thinned out (Trollope, 1974).

Bush based animal feed is seen by farmers as a solution to overcome drought and maintain their herds during the drought period. Farmers produce bush based animal feed to provide rations that ensure their animal survival and it is also seen as a viable business opportunity (Honsbein *et al.*, 2017). Wood consists of plant cell walls composed of cellulose, lignin and hemicellulose (Honsbein *et al.*, 2017). The high content of lignocellulosic biomass (source of fibre) in trees and bushes make them hard to digest, however, farmers can break down the strong wall structures by treating the wood fibres or by improving the digestibility of the fibres by adding supplements (Honsbein *et al.*, 2017). According to Rothauge (2014), it is advisable to use the small young bushes and resprouts which are more nutritious and less lignified when producing bush based animal fodder. The success of bush based animal fodder can be seen on Farm Langbeen of Anton Dresselhaus who managed to feed his livestock from 2011 to date, not only did his animals survive the dry years but they managed to experience a monthly growth rate of 1.2 kg. The feed is vital for cattle, sheep, goat and game. Anton Dresselhaus has managed to thin 150 hectares of land for bush based animal feed production. He estimates that over a period of five years the grazing capacity on this land has improved by up to 75% (Honsbein *et al.*, 2017).

## 1.2 Problem Statement

In Namibia, 45 million hectares of grazing land is bush encroached (SAIEA, 2015), by the dominant encroaching species *Acacia mellifera* subsp. *detinens* (synonym: *Senegalia mellifera* (Benth) and *Dichrostachys cinerea* (Joubert, 2014). Because of its encroaching nature and availability most farmers

clear *Acacia mellifera* subsp. *detinens* without fully understanding its potential, previously, mature *Acacia mellifera* has been used as fodder (Honsbein *et al.*, 2017, Boufennara *et al.*, 2012; Donaldson, 1969) but there is little information documented on using resprouts from *Acacia mellifera* subsp. *detinens* as fodder.

Resprouts harvested the correct time has a potential of not only being a source of fibre but of nutrients. Larger stems have more resprouts (Meyer *et al.*, 2005; Shackleton, 2001) which will serve as an incentive when harvesting resprouts for fodder. Resprouts from leguminous plants grow in an enriched soil through N-Fixation which improves herbage quality (Nzehengwa, 2013). A study by Rothauge (2014) suggested the use of regrowth for bush fodder as they have higher nutritional content, are easy to manage and contain less lignin than mature trees. Using resprouts is a solution to overcoming challenges restricting the use of encroacher bush as fodder.

This study will attempt to narrow these knowledge gaps by investigating the effects of bush thinning on shoot resprouts and forage nutritive value of *Acacia mellifera* subsp. *detinens* in a semi-arid Camelthorn savanna.

### 1.3 Study Objectives

#### 1.3.1 Overall Objective

The overall objective of the study is to develop an understanding of the effects of bush thinning on shoot resprouts and forage nutritive value of *Acacia mellifera* subsp. *detinens* in a semi-arid camelthorn savanna.

#### 1.3.2 Specific Objectives

- a) To determine the effects of season of harvest on the number of resprouts of *Acacia mellifera* subsp. *detinens*.

- b) To determine the effects of basal diameter on the number of resprouts of *Acacia mellifera* subsp. *detinens*.
- c) To compare the nutritional value of the resprouts of *Acacia mellifera* subsp. *detinens* as fodder versus mature *Acacia mellifera* subsp. *detinens* trees.

#### 1.4 Research Questions

- a) What is the effect of season of harvest on the number resprouts of *Acacia mellifera* subsp. *detinens*?
- b) What is the influence of stump basal diameter on the number of resprouts?
- c) Is resprouts of *Acacia mellifera* subsp. *detinens* more nutritious than mature *Acacia mellifera* subsp. *detinens*?

#### 1.5 Null Hypothesis

- a) Season of harvest does not have a significant influence on the resprouts of *Acacia mellifera* subsp. *detinens*.
- b) There is no significant difference between basal diameter and resprouts of *Acacia mellifera* subsp. *detinens*.
- c) Resprouts of *Acacia mellifera* subsp. *detinens* are not significant than mature *Acacia mellifera* subsp. *detinens* nutritionally.

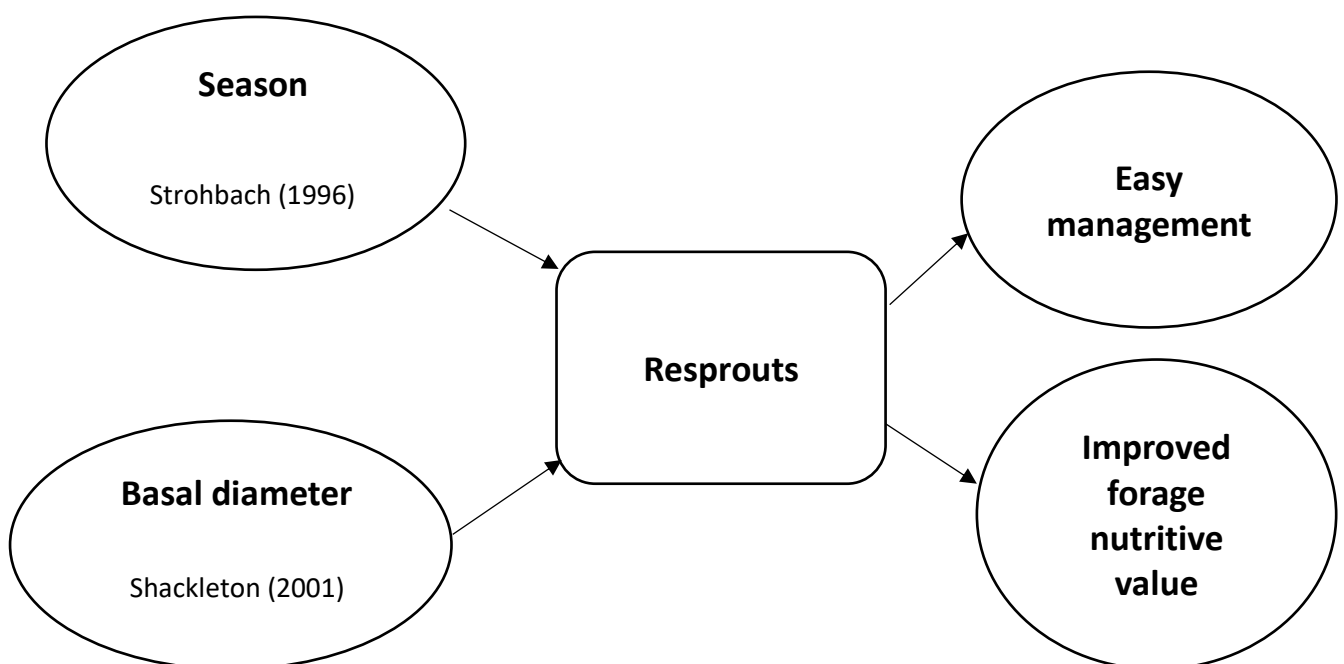
#### 1.6 Significance of the study

An improved understanding of the factors that affect resprouts and forage nutritive value (associated with nutrients, energy, protein, digestibility, fibre and minerals) of *Acacia mellifera* subsp. *detinens* can contribute to the sustainable management and utilization of this species as a fodder source especially in the dry months. Findings can be used to inform stakeholders on when to sustainably

harvest if they want to maximise forage nutritive value which will lead to better management of this species, shifting mindsets from seeing the bush as a problem but rather as an opportunity that can positively impact livelihoods. Furthermore, the study will attempt to meet the gap in knowledge on nutritional value of *Acacia mellifera* subsp. *detinens* resprouts for use as fodder.

## 1.7 Thesis outline

### 1.7.1 Conceptual Framework



**Figure 1:** Conceptual framework of the study (Source: Hivangere Hoveka).

The conceptual framework developed for this study considers two factors (season of harvest and basal diameter) that affect the resprouts from mechanically harvested *Acacia mellifera* subsp. *detinens*. These two factors influence the resprouts potential of the cut bush. Strohbach (1996) reported that after a disturbance in the rainy season, resprouts is at its lowest and mortality rate at its highest. Generally the bigger the basal diameter of the stem the more the resprouts and the bigger they are (Shackleton, 2002; Mlambo & Mapaure, 2006 and Cunningham & Detering, 2017). Although these two factors are explained individually they interact to create a suitable environment for resprouts.

Resprouts are easy to manage in comparison to mature bush thickets and improved forage nutritive value can be obtained from the resprouts which serves as an incentive for farmers to thin and use the resprouts as a renewable source of fodder.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Bush encroachment in Namibia

Savannas are communities or landscapes with a continuous grass layer and scattered trees that are defined by seasonal moisture availability patterns (Scholes & Archer, 1997; Johnson & Tothill, 1985). A phenomenon known as bush encroachment “the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass: bush ratio” has taken over productive savannas causing a decrease in biodiversity, a decrease in carrying capacity and concomitant economic losses. By 2004 an estimated N\$700 million per annum was lost to meat production, using the 2009 beef prices this figure went up to more than N\$1.6 billion per annum (de Klerk, 2004; Christian *et al.*, 2010).

This phenomenon is associated with various vegetation types namely the Dwarf Shrub Savanna, Camelthorn Savanna, Highland Savanna, Mixed Tree-and-Shrub Savanna, Mountain Savanna, and Thornbush Savanna. According to Joubert, Rothauge & Smit (2008) the main species causing the encroachment problem is *Acacia mellifera* subsp. *detinens* in Khomas region, *Dichrostachys cinerea* and *Colophospermum mopane* in the far Northern regions, *Rhigozum trichotomum* in the Southern regions, *Acacia mellifera* subsp. *detinens* and *Terminalia sericea* in the Eastern parts of Namibia and *Acacia reficiens* and *Acacia mellifera* subsp. *detinens* in the central northern parts of Namibia.

*Acacia mellifera* subsp. *detinens* and *Dichrostachys cinerea* are the most dominant bush thickening species due to their morphological and physiological attributes (Joubert, 2014). *Acacia mellifera* subsp. *detinens* produces secondary metabolites and forms mutualistic relationships with other organisms like ants which play an important role in plant defence against herbivory. The species is drought tolerant and has developed the ability to resprouts after forest fires, seeds have developed thick epidermis with a hard coat which acts as a barrier to external factors and protect the embryo

after seed production by inducing physical dormancy. Production of thorns is another survival attribute which increases the plant's fitness.

Trees have many effects on the biological, chemical and physical properties of soils (Miles, 1986). Plant growth and productivity are stimulated by minerals in the soil (Enkono, 2018). Soils have two types of nutrients needed for plant growth, these are macro nutrients (nitrogen, phosphorus, potassium, calcium, magnesium) and micro nutrient (iron, copper, manganese, zinc). The macro nutrients are crucial in plant production, photosynthesis, cell division, the formation of sugar and starch, translocation, enzyme activity, stomatal control, growth and function of root tips. Micro nutrients, although needed in small quantities, are crucial for plant growth and development. Acacias being legumes fix nitrogen into the soil and make it available for other plant forms through shedding their leaves and pods which decompose in the topsoil (McDonald *et al.*, 2011). They also act as a nutrient pump, pumping nutrients from within the deeper soil layers and outside their canopies and depositing these nutrients under their canopies (Ludwig *et al.*, 2004; Nzehengwa, 2013; Smit, 2004). Hagos & Smit (2005) in their study on soil enrichment by *Acacia mellifera* subsp. *detinens* in a semi-arid southern African savanna concluded that leguminous plants play an important role in soil enrichment, benefiting surrounding plants. Invader bushes maintain organic matter (any biological material that decomposes and becomes part of the soil), an important soil component which provides major soil energy and nutrient reserves and is a dominant source of Nitrogen, Phosphorus and Potassium in unfertilized soils (Smit, 2004). Soils with poor organic matter are more susceptible to soil erosion because organic matter holds soil particles together and increase the capacity of the soil to hold water (McCauley, Jones & Jacobsen, 2005).

According to Le Roux *et al.*, (2009), *Acacia mellifera* subsp. *detinens* is a deciduous shrub or single-stemmed tree (2-8m high) with a rounded crown, strongly curved thorns, creamy-white flowers, leaves are pinnately compound and spirally arranged. Many of the roots extend 8-15 m from the stem, parallel to the surface and at a depth of 25 cm.

## 2.2 Effect of season on resprouting

Several factors influence the survival and growth rate of resprouts from cut stems. According to Cunningham & Detering, (2017) season of harvest, species, method of harvest, size of tree harvested, rainfall, soil type and browsing impact are some of the factors that affect resprouts. Resprouting is a tool by which plants regenerate after partial or total defoliation (Bond & Midgley, 2001).

Plants harvested in the early dry season produce the highest regrowth of leaves (Adejumo, 1992). Adejumo's findings are supported by Strohbach (1996) who found that regrowth after harvesting largely depends on the species and season of cutting, his findings further suggested that fire girdling during the rainy season yield the lowest regrowth with the highest mortality rate and the method is more effective if done as near to the ground as possible.

*Acacia mellifera* has seasonal and regional variations in its annual cycle, flowering takes place between the cool-dry season and hot-dry season (Joubert, 2014) by using stored carbohydrates (Menke & Trlica, 1981). Fruiting takes place in the hot-wet season (Orwa *et al.*, 2009), thereafter photosynthates are transferred from the leaves to the roots (Van Niekerk & Kotze., 1977). Seeds germinate in the hot-wet season (Joubert, 2014). Therefore, plants growth is dictated by the season of treatment because it is related to their survival and coppicing abilities (Kahumba, 2010). The present study investigates the effects of season on the number of resprouts, does the time a farmer harvest have an effect on the resprouts that come back?

## 2.3 Effect of stump basal diameter on resprouting

When the above-ground biomass of bushes and shrubs is thinned or removed, the response is a production of new shoots which regrow using stored energy from their root system (Walter, 1971). Different studies show that an individuals size before a disturbance in woody plants can either have a positive or negative effect on its resprouting. A positive effect is seen in a study by Shackleton (2000) who examined the Influence of cutting height, stem size and surface area on the number of coppice

shoots produced for twelve savanna species and found a positive relationship between stem diameter and coppice shoots for eight out of the twelve species studies. The larger the stem diameter the more coppice shoots were observed due to a bigger surface area per stump and the ratio of the shoot to the root. Mencuccini *et al.*, (2005) used grafting shoots from donor trees which showed that the size of the recipient rather than the age of the donor trees had an effect on shoot growth rates suggesting that growth is strongly influenced by tree size. This relationship can further be explained due to the acquisition of more reserves in below-ground organs and more active underground buds (Konstantinidis, Tsiourlis & Xofis, 2006; Meyer *et al.*, 2005). MacDonald & Powell (1983) studied the relationships between stump sprouting and parent- tree diameter in sugar maple (*Acer sacharum* Marsh.) in the first year following clear-cutting and revealed a negative relationship between sprouts and size of tree at diameter at breast height. These results were explained by the concept of phase change from juvenile to adult phase (Solomon & Blum, 1967).

#### 2.4 Nutritive value of *Acacia mellifera* subsp. *detinens* resprouts compared to mature *Acacia mellifera* subsp. *detinens*

In order to derive maximum nutritional benefits from plant material, it is crucial to harvest them at an appropriate stage of maturity (Kökten *et al.*, 2012). Elseed *et al.*, (2002) assessed *Acacia mellifera* and *Acacia tortilis* amongst others, and noted that the time of harvesting has an influence on their potential value for the supplementation of energy or protein. Although livestock such as cattle and sheep are dominantly grazers they browse when grazing becomes scarce, making browse species more representative in their diets. *Acacia mellifera* subsp. *detinens* branches as an important supplement with nutritional value for cattle, moreover Moleele (1998) investigated cattle diet composition on free feeding cattle for three seasons and concluded that cattle browse even when the grass is abundant. They browse on green leaf material especially in the hot-wet season and switch to litter foraging (leaf & pods) during the cold-dry season, during the hot-dry season browsing decreased due to protein deficiency in the browse material. Effectiveness of bush can be compared to Lucerne

for small stock indicating the potential of bush as fodder (Aganga, Omphile & Baleseng, 2001; Stehn, 2008). The nutritional value is largely influenced by the size of the harvested material (less than 2cm), harvesting stage of plant material, very young, thin branches, leaves, shoots, fruit and seeds are more nutritious and contain less lignin (Rothauge, 2014; Kökten *et al.*, 2012). The viability of encroacher bush as a main component in animal feed production was tested by Honsbein *et al.* (2017) for six encroacher species including *Acacia mellifera*, the results found that the nutritional value of the bush decreased below maintenance level during the dry months, although in an acceptable range for bush fodder. The crude protein content was above maintenance level for ruminants during the summer months, overall digestibility and metabolisable energy was low due to fibre content in the bush. Bushes are generally high in protein content to increase the palatability, digestibility and nutrition content of the bush feed supplement addition is required (Tolsma, Ernst & Verwey, 1987).

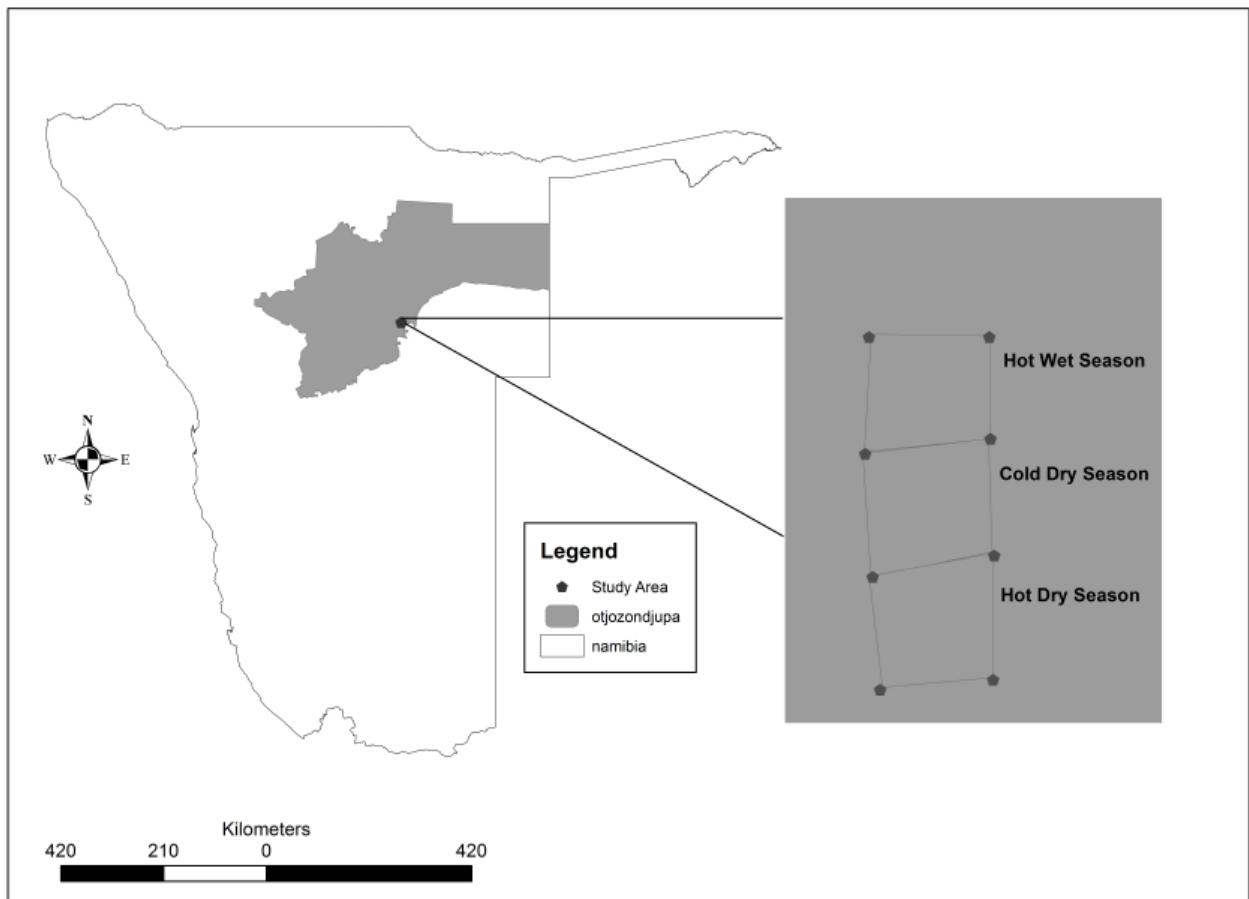
## CHAPTER 3

### METHODS

#### 3.1 Description of Study Area

##### 3.1.1 Location

The study was conducted in Okahitanda, a village 3 km east of Okondjatu in the African Wild Dog Conservancy and Community Forest. The study site is located between 20.98 °S and 18. 27°E (Figure 2) is a representative of the whole area.



**Figure 2:** Map of study area showing sampled plots in different seasons (Source: Forest Monitoring and Mapping, 2019).

### 3.1.2 Vegetation

The vegetation is indicative of camelthorn savanna dominated by *Acacia* species and *Terminalia sericea*. Acacias originate from the family Fabaceae subfamily Mimosoideae, this species is capable of fixing Nitrogen which is lacking in the Kalahari sands (Dougill *et al.*, 1998; Hagos & Smit, 2005). *Terminalia sericea* originates from the family Combretaceae, it is eaten by various animals and has many local uses such as poles for construction, domestic implements (spoons), furniture and traditional medicine (Mendelsohn & El Obeid, 2005). Other woody plants that occur commonly are *Grewia species*, *Albizia anthelmintica*, *Philenoptera nelsii*, *Ziziphus mucronata* and *Ozoroa paniculosa* among others. The non-woody plants include superb climax grasses such as *Schmidtia pappophoroides*, *Antheophora pubescens*, *Digitaria seriata*, *Brachiaria nigropedata*, *Panicum species*, and *Urochloa oligotricha* which are replaced by perennial *Aristida* species in the early stages of degradation and eventually by annual species such as *Schmidtia kalahariensis* and *Enneapogon cenchroides* (Rothauge, 2016).

### 3.1.3 Geology and soils

The area is part of the Kalahari sands group (Mendelsohn, 2002). The dominant rock types are sands and calcrete. Sands which are more dystrophic (whitish) are associated with *Terminalia sericea* whereas sands which are less dystrophic (reddish) are associated with *Acacia erioloba*. The calcrete is used by the locals as bricks to build houses and in its powdery form “zeolite” can be used to retain soil moisture (Rothauge, 2016).

### 3.1.4 Climate

The region has a semi-arid climate (evapotranspiration exceeds precipitation) with three seasons, namely a hot-dry season, hot-wet season and cold-dry season and receives an average annual rainfall of 400-450mm, mostly from November to April, with January and February being the wettest months (Mendelsohn & El Obeid, 2002). Much of the rainwater infiltrates into the soil where it becomes

available to deep-rooted trees and bushes. In the summer months the maximum temperatures range from 32°C to 34°C, while in the winter months the minimum temperatures range from 6°C and 8°C (Mendelsohn & El Obeid, 2002).

### 3.2 Experimental design

A quantitative research approach was used for this study. Using a purposive sampling method an area was chosen for sampling, this area was divided into three hectares each representing a different season. For each season the one hectare was divided into twenty-five smaller plots which were systematically sampled.

### 3.3 Sampling procedures

#### 3.3.1 Plot demarcation

For each season a hectare was demarcated and used for sampling. In order to make sampling easier, twenty-five smaller plots were demarcated within the hectare each measuring 20 × 20 m<sup>2</sup>, using a randomized table of number to avoid biasness, test plots were determined. In the test plots all *Acacia mellifera* subsp. *detinens* were mechanically harvested, the harvested bush was used to build a bush fence around the one hectare plot to deter animals from entering.

#### 3.3.2 Effect of season on resprouting

Seasons were classified according to Lindeques (1991) classification, namely hot-wet (November-April), cold-dry (May-July), and hot-dry (August-October). In each season, all *Acacia mellifera* subsp. *detinens* within the test plots were mechanically harvested with a skid steer (figure 3), a total of 367 trees were harvested, following harvesting, all *Acacia mellifera* subsp. *detinens* trees within the one hectare were marked to identify them during re-measurements. Cut stems (no defined length of cutting) were left undisturbed for three months, after the three months the number of resprouts were counted and recorded.



**Figure 3:** Skid steer used to thin *Acacia mellifera* subsp. *detinens*.

### 3.3.3 Effect of stump basal diameter on resprouting

The basal diameters of the 367 cut stems were measured (figure 4) with a measuring tape and recorded in each season.



**Figure 4:** Measurement of basal diameter.

The cut stems were then left undisturbed for three months. After the three months, the number of resprouts (figure 5) from the cut stems were counted and recorded.



**Figure 5:** Resprouts from the basal stem.

### 3.3.4 Nutritive value of *Acacia mellifera* subsp. *detinens* resprouts compared to mature *Acacia mellifera* subsp. *detinens*

In each season before the trees were cut, ten samples were collected from clearly marked mature *Acacia mellifera* subsp. *detinens* trees and placed in carefully labelled paper bags, stored at room temperature overnight and then transported to the Ministry of Agriculture, Water and Forestry laboratory where they were analysed as mature. After a full year, resprouts were collected from the same trees and placed in secure labelled paper bags and then stored at room temperature overnight and transported to the Ministry of Agriculture, Water and Forestry laboratory where they were analysed as resprouts.

#### 3.3.4.1 Moisture/Dry matter

An empty weighing vessel was dried with opened lid in an oven set at 105°Celsius for one hour and then cooled in a desiccator and weighed ( $W_1$ ). 2 g  $\pm$  0.001 g of a dry sample was weighed and then

grounded to pass a 1 mm sieve into the weighing vessel and weighed ( $W_2$ ). The sample was then dried in an open weighing vessel for five hours at 105°Celsius in a convection oven. The weighing vessel lid was placed in place and cooled in a desiccator, after cooling the weighing vessel was weighed with the dried sample ( $W_3$ ).

For calculations the following equation was used:

$$\text{Moisture (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where:

$W_1$  = dish (without lid)

$W_2$  = sample + dish

$W_3$  = sample + dish after drying

Dry matter (%) = 100 - moisture (%)

#### 3.3.4.2 Fat

About 2 g of the dry sample was weighed accurately to 0.001 g, grounded to pass a 1 mm sieve, onto a piece of filter paper. The filter paper was carefully folded to completely encapsulate the sample. The enclosed sample was placed in an extraction thimble where it was pushed far enough down the thimble so that it would intermittently be totally immersed in the petroleum ether. A firm cotton wool plug was inserted in the thimble to keep sample in place during extraction. A Soxhlet flask previously cleaned and dried at 105°Celsius was weighed and connected to the extraction apparatus, after filling the flask to about 2/3 of its capacity with petroleum ether the extraction thimble containing the sample was placed in the extractor and ensured that all the joints of the extraction apparatus seal properly. A heating mantle was switched on and temperature was adjusted to achieve a certain

condensation rate of the ether (the extraction period may vary from 4 hours - at condensation rate of 5-6 drops of ether per second, to 16 hours at condensation rate of 2-3 drops per second).

At the end of this period, the thimbles were removed and the ether was distilled into a collection tube for re-use. The flask was carefully removed from the heating mantle just prior to complete evaporation of the ether and placed in a cold, explosion-proof, oven which was then switched on and, from the time the oven reached 105°Celsius, the flask was left in for 1 hour before it was removed from the oven. The flask was then allowed to cool in a desiccator and weighed.

For calculations the following equation was used:

$$\text{Crude fat (\%)} = MFR \frac{MF}{m} \times 100$$

Where:

MF = Mass of the flask, in g

MFR = Mass of the flask with extracted residue, in g

m = Mass of the sample used, in g

#### 3.3.4.3 Crude fibre

About 1 g of dry sample was weighed to 0.001 g and grounded to pass a 1 mm sieve, it significantly into a previously marked crucible. The crucible was securely placed in a hot extraction unit with all the valves put in the closed position and the cooling water was turned on (flow should be 1-2 dm<sup>3</sup> per minute). Using a funnel, 150 cm<sup>3</sup> of preheated (ca 95°Celsius) sulphuric acid solution was added to each tube up to the first mark. 3 drops of *n*-octanol (antifoaming agent) were added to each tube, a cover was placed in front of the heating section, the heating element was turned on fully and brought to the boil, the heat was adjusted and allowed to boil for 30 minutes (ensuring that no solids adhere to the walls of condenser tubes). Following this procedure the heating element was turned off and

the water suction pump was started with the valve pressed to vacuum position, it was rinsed 3 times with about 30 cm<sup>3</sup> of hot distilled water each time (ensuring that all material have been rinsed off the walls of the condenser tubes). Ensuring that all valves were in the closed position, 150 cm<sup>3</sup> preheated (ca 95°Celsius) sodium hydroxide solution was added to each tube. 3 drops of *n*-octanol were added to each tube, brought to the boil and allowed to boil for 30 minutes. The heating element was then turned off, filtered by vacuum and rinsed 3 times using about 30 cm<sup>3</sup> of hot distilled water each time (ensuring that all material have been rinsed off the walls of the condenser tubes). About 20 cm<sup>3</sup> of acetone was then used to wash the heating element 3 times to remove traces of water. The main switch was switched off and water suction pump closed. All valves were pulled into the rest position and the crucibles were released with a safety hook and placed in the crucible holder. The crucibles were transferred to a drying oven (ensuring that no dirt adhered to the outside of the crucibles especially the bottom part) where they were dried overnight at 105°Celsius. After drying the crucibles were cooled in a desiccator for about 30 minutes and weighed. The crucible was then placed in a cool furnace and the temperature of the furnace adjusted to 500°Celsius. The samples were ashed at 500°Celsius for a minimum of 4 hours. The crucibles were allowed to cool slowly to below 250°Celsius before they were removed from the furnace and placed in a desiccator to cool for about 30 minutes, after cooling the crucibles were weighed.

For calculations the following equation was used:

$$\text{Crude fibre (\%)} = \frac{W_1 - W_2}{m} \times 100$$

Where:

$W_1$ = Mass of residue in the crucible after drying, in g

$W_2$ = Mass of residue in the crucible after ashing, in g

$m$  = Original sample mass, in g

#### 3.3.4.4 Ash/Organic matter

A pre-dried crucible previously marked with a heat resistant marker ( $W_1$ ) was weighed. About 2 g of a dry sample was accurately weighed to 0.001 g, grounded to pass a 1 mm sieve, into the crucible and recorded ( $W_2$ ). The crucible with its contents was placed in a cool muffle furnace. The temperature was set at 250°Celsius for one hour and then ashed at 550°Celsius for a minimum of 4 hours (until all traces of carbon have been removed), it was then cooled in a desiccator and weighed ( $W_3$ ).

For calculations the following equation was used:

$$\text{Ash (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where:

$W_1$  = mass of pre-dried crucible

$W_2$  = mass of sample + crucible

$W_3$  = mass of sample + crucible after ashing

Organic matter content is calculated as follows:

$$\text{Organic matter (OM) \%} = 100 - \text{Ash (DM) \%}$$

#### 3.3.4.5 Neutral detergent fibre

150 g of the *sodium lauryl sulphate* was dissolved in 2500 cm<sup>3</sup> distilled water and 50 cm<sup>3</sup> 2-ethoxyethanol was added to it. 93.05 g of *di-sodium-EDTA* and 34.05 g of *sodium borate decahydrate* was weighed in about 1000 cm<sup>3</sup> distilled water, heated and stirred until it dissolved. This solution was added to the sodium lauryl sulphate solution and stirred. 22.80 g of *disodium hydrogen phosphate*

was dissolved, separately in about 500 cm<sup>3</sup> distilled water, then it was added to the other ingredients making up to 5 dm<sup>3</sup>. The pH was checked that it was in the range of 6.9 to 7.1.

0.001 g was weighed accurately, about 1 gram of the sample, grounded to pass a 1 mm sieve, into the sintered glass crucibles (W<sub>1</sub>). Crucibles were placed in an extraction unit, the lever was pushed down all the way and caution was taken to make sure that all the crucibles fit snugly and that all the valves were in the CLOSED position. The cooling water was turned on, but not too much as the pressure is quite high. 50 cm<sup>3</sup> of cold neutral detergent solution (NDS) was added to each crucible which was checked for leakages and then the cover was fitted in front of the heating section and the heating element was set to "high". The solution was brought to the boil and allowed boiling for 30 minutes. The heating element was turned off. To each crucible, 50 cm<sup>3</sup> of cold NDS was added and brought to the boil. Extraction was terminated exactly one hour after the initial 50 cm<sup>3</sup> NDS started boiling, NDS was filtered out by suction (turned the valves down to the left) and washed with hot water (min. 95°Celsius) by soaking it for 2 minutes it was then filtered by vacuum. This process was repeated until all traces of foam disappeared. The suction pump, extraction unit and cooling water were switched off and turned all the valves set to the rest position. Crucibles were released with the safety hook. Dried overnight at 105° Celsius, cooled in a desiccator for 30 minutes and weighed (W<sub>2</sub>). After weighing they were ashed at 500°Celsius for a minimum of 4 hours. The furnace was allowed to cool to below 250°Celsius before the crucibles were removed and placed in a desiccator where they were allowed to cool then weighed (W<sub>3</sub>).

For calculations the following equation was used:

$$NDF(\%) = \frac{W_2 - W_3}{W_1} \times 100$$

Where:

W<sub>2</sub>= Residue in the crucible after drying, in g

$W_3$  = Residue in the crucible after ashing, in g

$W_1$  = Mass of the sample, in g

#### 3.3.4.6 Acid detergent fibre

100 g of *cetyl trimethyl ammonium bromide* was dissolved in 5 dm<sup>3</sup> of 0.5 M sulphuric acid. 0.001 g was weighed accurately, about 1 g of sample, grounded to pass a 1 mm sieve, into a large glass test tube and a 50 cm<sup>3</sup> pepsin-acid solution previously heated to 42-45° Celsius ( $W_1$ ) was added. It was ensured that the sample was completely dispersed and then it was placed in a water bath at 45°Celsius. The sample was mixed intermittently by swirling then incubated in a water bath for 24 hours. A clean, dry and weighed sintered glass crucibles were placed in the cold extraction unit of the apparatus and the incubated sample solution was quantitatively transferred from the test tubes to the crucibles and filtered by suction while rinsing with warm (50°Celsius) water. The crucibles with the lever pushed down all the way and fitted snugly were placed in the extraction unit and the machine was turned on. After all the valves were closed the condenser cooling water was then turned on. To each crucible 100 cm<sup>3</sup> of cold ADS was added, a cover was fitted in front of the heating section. The heating element was turned on high and the solution was brought to the boil. The heat was adjusted and the solution was left to boil for exactly 60 minutes at about 70-75°Celsius. After the 60 minutes, the ADF solution was filtered out by suction and washed 3 times with warm (50°Celsius) water. The solution was further rinsed twice with acetone, soaked for about 2 minutes, dried overnight at 105° Celsius, cooled in a desiccator for 30 minutes and weighed ( $W_2$ ). The solution was ashed at 500°Celsius for a minimum of 4 hours. The furnace was allowed to cool to below 250°Celsius before the crucibles were removed and placed in a desiccator for 30 minutes. The crucibles ( $W_3$ ) were then weighed.

For calculations the following equation was used:

$$ADF (\%) = \frac{W_2 - W_3}{W_1} \times 100$$

Where:

$W_1$ = Mass of the original sample, in g

$W_2$ = Mass of residue in the crucible after drying, in g

$W_3$ = Mass of residue in the crucible after ashing, in g

#### 3.3.4.7 Crude protein

Crude protein was determined by the combustion method as described by AOAC (2000) and according to the standardized analytical procedures of the Agri-Laboratory Association of Southern Africa (Palic *et al.*, 1998). Nitrogen was determined by total combustion of the sample at 950°Celsius in the presence of oxygen where nitrogen was converted to NO<sub>x</sub> gas (Dumas Principle). The NO<sub>x</sub> measured in a thermal conductivity cell was reduced to N<sub>2</sub>. Percent protein was calculated by multiplying the reported nitrogen by 6.25.

#### 3.3.4.8 Organic Matter Digestibility (OMD) and Metabolizable Energy (ME)

The Organic Matter Digestibility (OMD) and Metabolizable Energy (ME) of the feed were estimated using the In Vitro Gas Test according to the procedure of Menke *et al.*, 1979. A sample of about 230 g was ground to pass through a 1mm sieve, weighed and placed into glass syringes in duplicates. 30 ml of rumen liquor collected from a rumen fistulated donor ox and prepared into a rumen-buffer mixture was added into the syringes. The syringes were then incubated in an incubation apparatus maintained at 39°Celsius. The gas production readings were recorded after the first 8 hours of incubation, the clip opened and the piston moved back to 30 ml position. The final reading was taken at 24 hours after the incubation commenced. Gas production at 24 hours from a standard hay meal (GbH) and a concentrate standard (Gbc) was used as a correction factor.

The correction factor for hay meal (FH) is:

$$FH = \frac{44.43}{(Gbc - GbO)}$$

While that of concentrate mixture (FC) is:

$$FC = \frac{62.6}{(Gbc - GbO)}$$

The mean of these factors was then used for the correction of sample measurement

OMD was calculated using the following as follow:

$$\begin{aligned} \text{OMD (\%)} = & 14.88 + 0.889 \text{ gas production}(Gb) + 0.045 \text{ Crude protein} \left( XP; \frac{g}{kgDM} \right) \\ & + 0.065 \text{ Crude ash} \left( XA; \frac{g}{kgDM} \right) \end{aligned}$$

Similarly, Metabolisable Energy (ME) was calculated as follow:

$$\begin{aligned} \text{ME (MJ/kg)} = & 1.242 + 0.146 \text{ gas production}(Gb) + 0.045 \text{ Crude protein} \left( XP; \frac{g}{kgDM} \right) \\ & + 0.0224 \text{ Crude lipids} \left( XL; \frac{g}{kgDM} \right) \end{aligned}$$

#### 3.3.4.9 All elements

All elements were prepared by the dry ashing procedure which was performed by placing a sample in an open inert vessel and destroying the combustible (organic) portion of the sample by thermal decomposition using a muffle furnace. Typical ashing temperatures are 450 to 550 °Celsius. Magnesium nitrate was used as an ashing aid. The samples were charred prior to muffling.

### 3.3.4.10 Inductively coupled plasma (ICP) principle

For all the elements except Phosphorus, the ICP principle was used. The solution to be analyzed was conducted by a peristaltic pump through a nebulizer into a spray chamber. The produced aerosol was lead into an argon plasma. Plasma is the fourth state of matter, next to the solid, liquid and gaseous state. In the ICP-OES (Inductively coupled plasma - optical emission spectrometry) the plasma is generated at the end of a quartz torch by a cooled induction coil through which a high-frequency alternate current flows. As a consequence, an alternate magnetic field is induced which accelerated electrons into a circular trajectory. Due to collision between the argon atom and the electrons ionization occurs, giving rise to a stable plasma. The plasma is extremely hot, 6000-7000 Kelvins. In the induction zone it can even reach 10000 Kelvins. In the torch desolvation, atomization and ionization of the sample take place. Due to the thermic energy taken up by the electrons, they reach a higher "excited" state. When the electrons drop back to ground level energy is liberated as light (photons). Each element has its own characteristic emission spectrum that was measured with a spectrometer. The light intensity on the wavelength was measured and with the calibration calculated into a concentration.

**Table 1:** Wavelength at which elements were analysed.

<b>Element</b>	<b>Wavelength (nanometers)</b>
Ca	317.9
K	766.4
Na	589.5
Mg	279.5
Cu	324.7
Fe	259.9
Mn	257.6
Zn	213.8

### 3.3.4.11 Phosphorus

**Ammonium molybdate-ammonium metavanadate reagent.** Added 25 g of ammonium molybdate and 1.25 g of ammonium metavanadate was added to approximately 300 cm<sup>3</sup> of warm water to dissolve, cooled and diluted to 500 cm<sup>3</sup>.

**Hydrochloric acid, approximately 5 M.** 215 cm<sup>3</sup> of hydrochloric acid (36% mm-1) was diluted to 500 cm<sup>3</sup>.

**Phosphorus stock standard solution, 1 mg cm-3 of phosphorus.** Potassium dihydrogen orthophosphate was dried at 105°Celsius for 1 hour and cooled in a desiccator. 0.879 g of the dried salt was dissolved in water and 1 cm<sup>3</sup> of hydrochloric acid, 36% mm-1 added. The salt was diluted to 200 cm<sup>3</sup> and one drop of toluene was added to the solution.

**Phosphorus working standard solutions, 0-50 µg cm-3 of phosphorus.** On the day of use, 0, 1, 2, 3, 4 and 5 cm<sup>3</sup> of stock standard solutions was pipetted into 100 cm<sup>3</sup> volumetric flasks and made up to volume with water. This corresponded to a phosphorus concentration of 0, 10, 20, 30, 40 and 50 µg cm-3 1 respectively.

**Toluene.** 10 cm<sup>3</sup> of each phosphorus working standard solution was pipetted into a 50 cm<sup>3</sup> volumetric flask. To each flask 5 cm<sup>3</sup> of 5 M, hydrochloric acid was added and 5 cm<sup>3</sup> of ammonium (molybdate-ammonium metavanadate reagent) was diluted to 50 cm<sup>3</sup> and allowed to stand for 30 minutes. The absorbance in a 10 mm optical cell at 400 nm was measured. 10 cm<sup>3</sup> of the sample solution was transferred into a 50 cm<sup>3</sup> volumetric flask. 5 cm<sup>3</sup> of 5M hydrochloric acid and 5 cm<sup>3</sup> of ammonium molybdate-ammonium metavanadate reagent was added to the solution, diluted to 50 cm<sup>3</sup> and allow to stand for 30 minutes. The absorbance in a 10 mm optical cell at 400 nm was measured.

From the standard graph, the concentration (µg cm-3) of the sample and the blank was read.

For calculations the following equation was used:

$$P(\text{mg kg}^{-1}) = \frac{C \cdot g \cdot V \cdot 50}{10 \cdot m}$$

Where:

$C \cdot g$  = Difference between the sample and blank concentrations as read from the graph, in  $\mu\text{g cm}^{-3}$ .

$V$  = Total volume of the sample digest solution, (here  $100 \text{ cm}^3$ )

$m$  = Mass of the sample, in g

10 = Sample aliquot (here  $10 \text{ cm}^3$ )

50 = Dilution of sample aliquot ( $10 \text{ cm}^3$ ) to  $50 \text{ cm}^3$ .

**Note:**  $1 \mu\text{g g}^{-1} = 1 \text{ mg kg}^{-1}$

### 3.4 Data Analysis

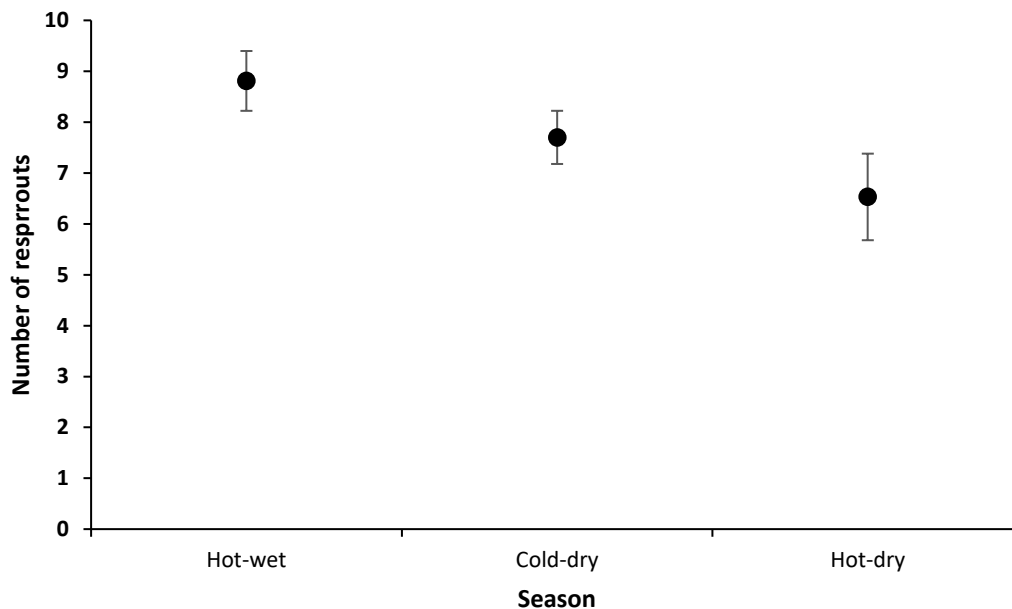
All statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS) version 25. To test for normality the Shapiro Wilk test was used. Shapiro-Wilk test has been demonstrated to be the most powerful test for all types of distribution and sample sizes (Razali & Wah, 2011). A One Way ANOVA test was used to test the effects of season of harvest and basal diameter on the number of resprouts of *Acacia mellifera* subsp. *detinens*, for basal diameter a Turkey post hoc test, was further used to separate the means. A Multivariate ANOVA test was used to compare the nutritional value of the resprouts of *Acacia mellifera* subsp. *detinens* as fodder versus mature *Acacia mellifera* subsp. *detinens* trees. Means were considered significance difference at  $P < 0.05$ .

## CHAPTER 4

### RESULTS

#### 4.1 Effect of season on resprouting

The number of resprouts was not significantly ( $p>0.05$ ) affected by season. Resprouts per stump were lower in hot-dry than in the hot-wet season (respectively,  $6.5 \pm 0.85$  and  $8.8 \pm 0.59$ ; mean  $\pm$  SE).

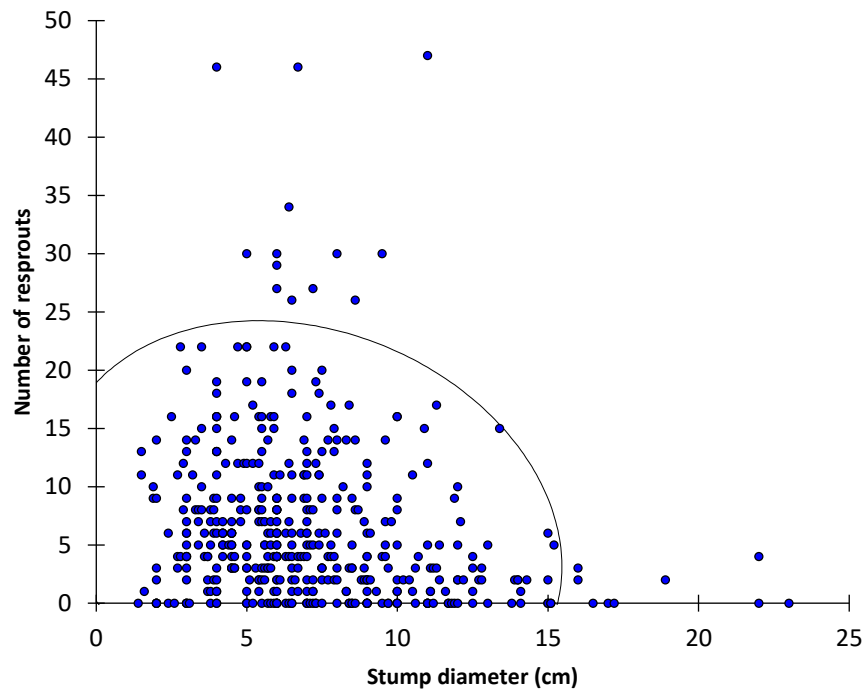


**Figure 6:** Mean ( $\pm$ SE) number of resprouts in the hot-wet, cold-dry and hot-dry season. Bars indicate standard error of the means.

The hot-wet season had the highest mean number of resprouts followed by cold-dry season and hot-dry season. Figure 6 shows that on average more resprouts grow in the first half of the year. The results show that the mean resprouts of *Acacia mellifera* subsp. *detinens* do not vary with the season of harvest (Figure 6).

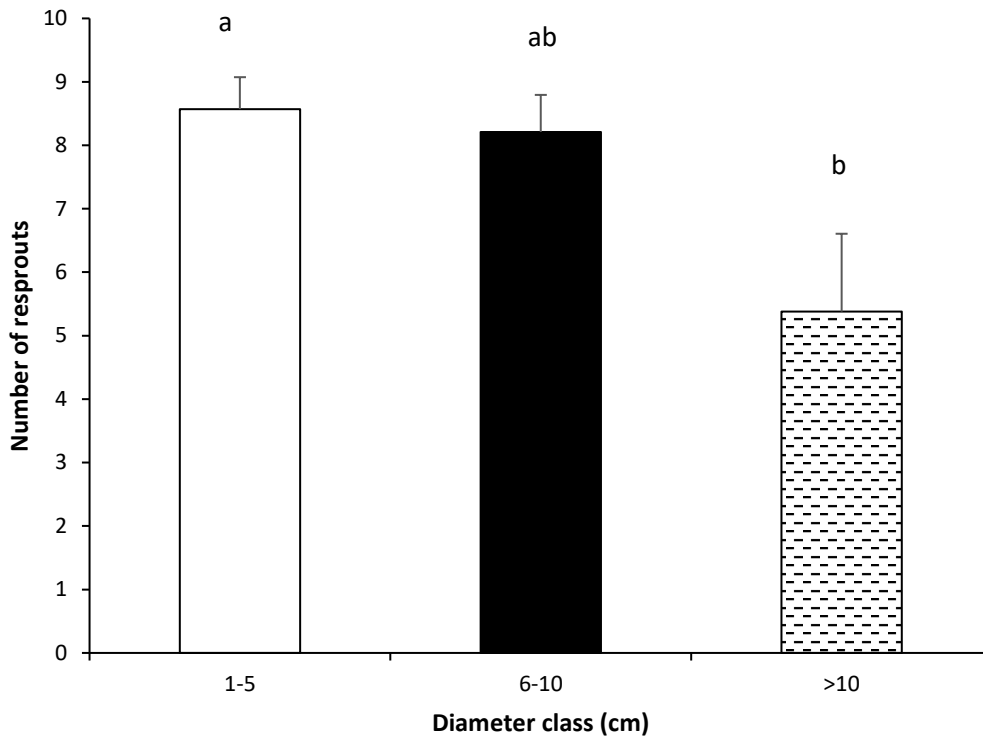
#### 4.2 Effect of stump basal diameter on resprouting

In this study, the basal diameter of species is ranging from 1.4 cm to 23 cm. Resprouting was high between diameters 5 cm and 11 cm.



**Figure 7:** Relationship between stump diameter (cm) and the number of resprouts.

The study found that the number of resprouts decreased with the basal diameter of stumps (Figure 7). The results also showed that 70 stumps below 15 cm had not resprouted during the three growing seasons.



**Figure 8:** Mean ( $\pm$ SE) number of resprouts in the diameter classes 1-5cm, 6-10cm and >10cm. Bars indicate standard errors of the means. Means with different letters are significantly different ( $p < 0.05$ ).

Diameter class 1-5cm had the highest mean number of resprouts followed by the diameter class 6-10 cm and the >10 cm diameter class having the least number of resprouts. The results in Figure 8 reveal that the smaller the basal diameter the more the number of resprouts.

The ANOVA results show that diameter class has no significant ( $p > 0.05$ ) effect on the mean number of resprouts. A post hoc test was further carried out to separate the means and there was a ( $p < 0.05$ ) significant mean difference between the diameter classes 1-5cm and >10cm.

#### 4.3 Nutritive value of *Acacia mellifera* subsp. *detinens* resprouts compared to mature *Acacia mellifera* subsp. *detinens*

The chemical composition of the *Acacia mellifera* subsp. *detinens* in resprouts and mature trees are presented in Table 2 and appendix 1. The CP ranged from 203 to 499 g/kg DM and was lowest in mature trees. The ADF and NDF content were lowest in resprouts and highest in mature trees.

Resprouts had the highest OMD concentration (78 g/kg DM) and mature trees the lowest (50 g/kg DM). For all the samples the ADF fraction was a large proportion of the NDF, which indicate a high content of cellulose and lignin and low levels of hemicellulose.

**Table 2:** Concentration of organic matter (OM (g/kg DM)), crude protein (CP (g/kg DM)), neutral detergent fibre (NDF (g/kg DM)), acid detergent fibre(ADF (g/kg DM)), organic matter digestibility (OMD (g/kg DM)), crude fibre (CF(g/kg DM)) and fat (g/kg DM) of *Acacia mellifera* subsp. *detinens* resprouts and mature trees.

	OM	CP	NDF	ADF	OMD	CF	Fat
Mature	917 <sup>a</sup>	203 <sup>a</sup>	665 <sup>a</sup>	365 <sup>a</sup>	462 <sup>a</sup>	319 <sup>a</sup>	58 <sup>a</sup>
Resprouts	852 <sup>b</sup>	499 <sup>b</sup>	406 <sup>b</sup>	274 <sup>b</sup>	837 <sup>b</sup>	237 <sup>b</sup>	22 <sup>b</sup>
SEM <sup>b</sup>	5.4	22.9	22.8	19.9	38.2	17.1	3.1

<sup>a</sup> Means with different letters within a column are significantly different (p<0.05).

<sup>b</sup> S.E.M.: standard error of the means.

The mineral concentration of acacia species resprouts and mature trees are presented in *Table 3*. Except for phosphorus, magnesium and copper, there were significant (p<0.05) differences among resprouts and mature trees. Mature trees were exceptionally high in calcium (14.7 g/kg DM), magnesium (0.2 g/kg DM) and copper (9.9 mg/kg DM).

**Table 3:** Concentration of macro (g/kg DM) and micro (mg/kg DM) elements in *Acacia mellifera* subsp. *detinens* resprouts and mature trees.

	Ca	P	K	Mg	Na	Cu	Fe	Mn	Zn
Mature	14.7 <sup>a</sup>	0.1 <sup>a</sup>	0.7 <sup>a</sup>	0.2 <sup>a</sup>	0.007 <sup>a</sup>	9.9 <sup>a</sup>	76.7 <sup>a</sup>	34.7 <sup>a</sup>	23.1 <sup>a</sup>
Resprouts	0.6 <sup>b</sup>	0.4 <sup>a</sup>	15.2 <sup>b</sup>	0.1 <sup>a</sup>	1.2 <sup>b</sup>	9.6 <sup>a</sup>	446.8 <sup>b</sup>	40.4 <sup>b</sup>	41.2 <sup>b</sup>
SEM	0.89	0.1	0.1	0.7	0.02	0.34	28.27	1.07	1.68

<sup>a</sup> Means with different letters within a column are significantly different ( $p < 0.05$ ).

<sup>b</sup> S.E.M.: standard error of the means.

## CHAPTER 5

### DISCUSSIONS

#### 5.1 Effect of season on resprouting

Woody plants play an important role in the diet of livestock in different seasons as seasons influence the type of food available for foraging as was confirmed by Katjiua & Ward (2006). The study confirms the hypothesis that the season of harvest does not have a significant influence on the resprouts of *Acacia mellifera* subsp. *detinens*, however the hot-wet season had the highest mean number of resprouts followed by cold-dry season and hot-dry season. Generally, there is more soil moisture available in the hot-wet season compared to the other two seasons encouraging regrowth, also resprouting is encouraged by the presence of photosynthates deposited during the hot wet season in the plant roots (Kambatuku, 2010; Van Niekerk & Kotze, 1977).

The study contradicts evidence by Strohbach (1996) who found that fire girdling of *Acacia mellifera* during the rainy season yielded the lowest regrowth and highest mortality rate. These results mean that harvesting in different seasons does have an influence although not significant on the resprouts. Depending on farmer's preferences this knowledge could be used to manage the bush either by encouraging resprouts by harvesting in the hot-wet season for value addition (e.g bush fodder) or suppressing resprouts by harvesting in the hot-dry season to reclaim rangeland.

#### 5.2 Effect of stump basal diameter on resprouting

Many woody species have the ability to resprouts after a disturbance. In line with the hypothesis that there is no significant difference between basal diameter and resprouts of *Acacia mellifera* subsp. *detinens*, the study found that the number of resprouts decreased with the basal diameter of stumps. Also, a significant mean difference was seen between the diameter classes 1-5 cm and >10 cm. This has huge implication on bush control in Namibia for farmers as well as policy makers if resprouts are

to be used because the study support harvesting of smaller trees (5cm-11cm) which are in the accepted range (<18cm) of trees to be harvested according to the license conditions for bush control in the Forest Regulation. These findings are supported by Khan & Tripathi (1986) and MacDonald & Powell (1983) who also found a negative relationship between stump diameter and resprouts, they linked this to the change in the physiology of trees with age (reduced vegetative reproduction, mortality of buds).

Ickes, Dewalt & Thomas (2003); Morrison & Renwick (2000); Shackleton (2001); Stocker (1999) in their studies found that in woody plants resprouting ability increases based on the size of the individual before it is disturbed, this contradicts the results from this study. They based their findings on the ability of larger individuals to accumulate more energy in dormant vegetative buds and greater surface area per stump/ greater root/shoot ratio.

### 5.3 Nutritive value of *Acacia mellifera* subsp. *detinens* resprouts compared to mature *Acacia mellifera* subsp. *detinens*

The results do not agree with the hypothesis that resprouts of *Acacia mellifera* subsp. *detinens* are not significant than mature *Acacia mellifera* subsp. *detinens* nutritionally. Resprouts have a higher crude protein range and organic matter digestibility, lower acid detergent fibre and neutral detergent fibre than mature trees. The chemical composition in this study is consistent with what has been reported in Abdulrazak, Ondiek and Orskov (2000) who concluded that *Acacia* species based on the moderate to high crude protein content have the potential to be used as livestock fodder. Abdulrazak, Ondiek and Orskov, (2000) findings are supported by Aganga, Omphile & Baleseng (2001) and Stehn (2008). The above results were seen because resprouts at this stage have not started depositing fibrous components which reduce forage quality (Newman, Lambert & Muir, 2006). A significant difference was also seen in the potassium, sodium, iron, manganese and zinc content of resprouts, which are all good determinants of forage quality (McDowell, 1985). These values are consistent with those reported by Topps (1992) and Norton (1994).

This study not only agrees with the conclusions from the previous studies but provides new insight into the importance of resprouts. The idea is to thin which opens rangelands for grass establishment, use the highly nutritive resprouts as a renewable source for fodder and kill the bush after repeated harvest from the same stump as plant roots reserves responsible for root maintenance aiding in resprouting get depleted (Schutz, Bond & Cramer, 2009). This is an effective way to control encroacher bush especially for farmers who view bush control as costly.

## CHAPTER 6

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Conclusions

Season of the harvest was not a significant factor to influence the number of resprouts. However, if the aim of thinning is to use the resprouts, it is advisable to thin during the hot-wet seasons as more resprouts are produced. For the same purpose, it is also advisable to thin smaller trees with diameters in the range of 5cm-11cm as they significantly produce more resprouts as compared to trees of basal diameter >10cm, the smaller the basal diameter the more the resprouts.

This study determined that *Acacia mellifera* subsp. *detinens* resprouts have good potential as a livestock diet as they are more nutritious and are more palatable than mature trees. In terms of rangeland management, continuous browsing by the livestock on resprouts when young will reduce the amount of coppices of *Acacia mellifera* subsp. *detinens*, which in turn can halt the encroachment of the species in semi-arid areas of Southern Africa.

This study contributes significantly to understanding the nutritional value of bush-encroacher resprouts as fodder. Further, the study raises awareness of the value of *Acacia mellifera* subsp. *detinens* as a potentially renewable resource that can freely be used by farmers especially in semi-arid to dry environments. This study has provided some of the first evidence to explain the importance of resprouts in animal nutrition. The results from the experiments revealed that resprouts have significant high forage nutritive value in terms of CP, NDF, ADF, OMD, K, Na, Fe, Mn, Zn content when compared to mature trees. These results are a gateway in unlocking the potential of expanding the diversification of bush encroacher species biomass in semi-arid environments.

## 6.2 Recommendations

For management and maximum utilisation of *Acacia mellifera* subsp. *detinens* as forage the following can be considered:

- The nutritional content of resprouts at different stages of growth, to determine the duration of rest between harvests.
- Strength of resprouts in meeting the nutritional intake for different livestock, to determine which livestock nutritional needs are met by using resprouts as fodder.
- Relationship between the herbaceous layer and thinned area with standing untreated basal stumps, to determine interspecific competition.
- Relationship between resprouts and transpiration rate, to determine the amount of water lost by resprouts compared to mature trees.
- Relationship between soil fertility and resprouts, to determine the effects of soil fertility on the number of resprouts.
- Thinning intensity (stumps thinned) guided by diameter of basal stumps, to determine intraspecific competition.

## REFERENCES

- Abdulrazak, S. A., Ondiek, J.K., Orskov, E. R. (2000) Nutritive evaluation of some Acacia tree leaves from Kenya. *Animal Feed Science and Technology*, 85(1–2), pp. 89–98.
- Adejumo, J. O. (1992) Effect of plant age and harvest date in the dry season on yield and quality of *Gliricidia sepium* in southern Nigeria. *Tropical Grasslands*, 26(1), pp. 21–24.
- Aganga, A. A., Omphile, U. J. and Baleseng, L. (2001) Performance of tswana goats fed *Acacia mellifera*, *Euclea undulata*, and *Peltophorum africanum* as a supplement to buffel grass. *Archivos de zootecnia*, 50(191), pp. 383–386.
- Bond, W. J. and Midgley, J. J. (2001) Ecology of sprouting in woody plants: the persistence niche. *Trends in ecology & evolution*, 16(1), pp. 45–51.
- Boufennara, S., Bouazza. L., Bodas, R., Bousseboua, H. and Lopez, S. (2012) Nutritive evaluation of foliage from fodder trees and shrubs characteristic of algerian arid and semi-arid areas. *Journal of Animal and Feed Sciences*, 21(3), pp. 521–536.
- Brown, C. (1992) Namibia's Green Plan. *Directorate of Environmental Affairs (DEA), Ministry of Environment and Tourism (MET). Government of Namibia.*
- Christian, C., van der Merwe, B., Bockmuehl, F., Mostert, A. and Klerk, N. (2010) The effect of bush encroachment on groundwater resources in Namibia: A desk top study. *Prepared for the Namibian Agronomic Board, Windhoek.*
- Cunningham, P. L. and Detering, F. (2017) Determining age , growth rate and regrowth for a few tree species causing bush thickening in north-central Namibia. *Namibian Journal of Environment*, 1 , pp. 72–76.
- Donaldson, C. H. (1969) *Bush encroachment with special reference to the blackthorn problem of the*

*Molopo area*. Department of Agricultural Technical Services.

Dougill, A. J., Heathwaite, A. L. and Thomas, D. S. G. (1998). Soil water movement and nutrient cycling in semi-arid rangeland: vegetation change and system resilience. *Hydrological Processes*, 12(3), pp. 443–459.

Dougill, A. J., Thomas, D. S. G. and Heathwaite, A. L. (1999) Environmental change in the Kalahari: integrated land degradation studies for nonequilibrium dryland environments. *Annals of the Association of American Geographers*, 89(3), pp. 420–442.

Elseed, F. A. M. A., Amin, A. E., Ati Abdel, A., Sekine, J., Hishinuma, M. and Hamana, K. (2002) Nutritive evaluation of some fodder tree species during the dry season in Central Sudan. *Asian-australasian journal of animal sciences*, 15(6), pp. 844–850.

Enkono, A. N. (2018) *The effect of bush clearing on soil properties, at Cheetah conservation fund farm in Otjozondjupa region, Namibia* (Doctoral dissertation, University of Namibia).

Fuhlendorf, S. D. and Engle, D. M. (2001) Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns: we propose a paradigm that enhances heterogeneity instead of homogeneity to promote biological diversity and wildlife habitat on rangelands grazed by lives. *BioScience*, 51(8), pp. 625–632.

Government of Namibia (2015) Forest Regulation: Forest Act 12 Of 2001. Section 22, 23/Regulations 12.

Grouzis, M. and Akpo, L.E. (1997) Influence of tree cover on herbaceous above-and below-ground phytomass in the Sahelian zone of Senegal. *Journal of Arid Environments*, 35(2), pp. 285–296.

Hagos, M. G. and Smit, G. N. (2005) Soil enrichment by *Acacia mellifera* subsp. *detinens* on nutrient poor sandy soil in a semi-arid southern African savanna. *Journal of Arid environment*, 61(1), pp. 47–

59.

Honsbein, D., Shiningavamwe, K., Iikela, J., de la Puerta Fernandez., M. (2017) Animal Feed from Namibian Encroacher Bush.

Ickes, K., Dewalt, S. J. and Thomas, S. C. (2003) Resprouting of woody saplings following stem snap by wild pigs in a Malaysian rain forest. *Journal of Ecology*, 91(2), pp.222-233.

Johnson, R. W. and Tohill, J. C. (1985) Definition and broad geographic outline of savanna lands. Canberra.

Joubert, D. F., Rothauge, A. and Smit, G. N. (2008) A conceptual model of vegetation dynamics in the semiarid Highland savanna of Namibia, with particular reference to bush thickening by *Acacia mellifera*. *Journal of Arid Environments*, 72(12), pp. 2201–2210.

Joubert, D. F. (2014) *The dynamics of bush thickening by Acacia mellifera in the highland savannas of Namibia* (Doctoral dissertation, University of the Free State).

Kahumba, A. (2010) *Comparison of the rehabilitative effects of mechanical and chemical methods of bush control on degraded highland savanna rangelands in Namibia* (Doctoral dissertation).

Kambatuku, J. R. (2010) *Ecophysiology of Encroaching Acacia mellifera in Intra-and Inter-specific Interactions* (Doctoral dissertation, University of KwaZulu-Natal, Pietermaritzburg).

Katjiua, M. L. J. and Ward, D. (2006) Cattle diet selection during the hot-dry season in a semi-arid region of Namibia. *African Journal of Range and Forage Science*, 23(1), pp. 59–67.

de Klerk, J. (2004) *Bush Encroachment in Namibia: Report on Phase 1 of the Bush Encroachment Research, Monitoring, and Management Project*. Ministry of Environment and Tourism, Directorate of Environmental Affairs.

Khan, M. L. and Tripathi, R. (1986) Tree Regeneration in a Disturbed Sub-Tropical Wet Hill Forest of

North-East India: Effect of Stump Diameter and Height on Sprouting of Four Tree Species. *Forest Ecology and Management*, 17(2-3), pp. 199–209.

Kökten, K., Kaplan, M., Hatipoğlu, R., Saruhan, V. and Çınar, S. (2012) Nutritive value of Mediterranean shrubs.

Konstantinidis, P., Tsiourlis, G. and Xofis, P. (2006) Effect of fire season, aspect and pre-fire plant size on the growth of *Arbutus unedo* L.(strawberry tree) resprouts. *Forest Ecology and Management*, 225(1–3), pp. 359–367.

Le Roux, P. J., Müller, M. A. N., C, B. and Mannheimer, C. (2009) *Le Roux and Müller's field guide to the trees & shrubs of Namibia*. Macmillan Education Namibia.

Lindeque, P. M. (1991) *Factors affecting the incidence of anthrax in the Etosha National Park, Namibia* (Doctoral dissertation, Council for National Academic Awards).

Ludwig, F., Van De Vijver, C. A. D. M., Kumar, L., Van De Koppel, J., De Ridder, N., Van Andel, J., Skidmore, A. K., Hearne, J. W., Stroosnijder, L. and Bond, W. J. (2004) The influence of savanna trees on nutrient, water and light availability and the understorey vegetation. *Plant Ecology* , 170(1), pp. 93–105.

MacDonald, J.E. and Powell, G.R. (1983) Relationships between stump sprouting and parent-tree diameter in sugar maple in the 1st year following clear-cutting. *Canadian Journal of Forest Research*, 13(3), pp.390-394.

McCauley, A., Jones, C. and Jacobsen, J. (2005) Basic soil properties, *Soil and water management module*, 1(1), pp. 1–12.

McDonald, P., Halgh, J. F. D., Morgan, C. A., Sinclair, L. A., Wilkinson, E. R. A.G. and Green, R. (2011) *Animal Nutrition*.

McDowell, L. R. (1985) Nutrient requirements of ruminants. In *Nutrition of grazing ruminants in warm climates*. Academic Press, Harcourt Brace Jovanovich Orlando, FL, pp. 21–36.

Mencuccini, M., Martínez-Vilalta, J., Vanderklein, D., Hamid, H. A., Korakaki, E., Lee, S. and Michiels, B. (2005) Size-mediated ageing reduces vigour in trees. *Ecology letters*, 8(11), pp. 1183–1190.

Mendelsohn, J. (2002) *Atlas of Namibia: a portrait of the land and its people*. New Africa Books (Pty) Ltd.

Mendelsohn, J. and El Obeid, S. (2002) *The communal lands in eastern Namibia*. Raison.

Mendelsohn, J. M. and El Obeid, S. (2005) *Forests and woodlands of Namibia*. Raison.

Menke, K.H., Raab, L., Salewski, A., Steingass, H., Fritz, D. and Schneider, W. (1979) The estimation of the digestibility and metabolizable energy content of ruminant feedingstuffs from the gas production when they are incubated with rumen liquor in vitro. *The Journal of Agricultural Science*, 93(1), pp. 217–222.

Menke, J. W. and Trlica, M. J. (1981) Carbohydrate reserve, phenology, and growth cycles of nine Colorado range species. *Journal of Range Management*, pp. 269–277.

Meyer, K. M., Ward, D., Moustakas, A. and Wiegand, K. (2005) Big is not better: Small *Acacia mellifera* shrubs are more vital after fire. *African Journal of Ecology*, 43(2), pp. 131–136.

Miles, J. (1986) What are the effects of trees on soils?

Mlambo, D. and Mapaure, I. (2006) Post-fire resprouting of *Colophospermum mopane* saplings in a southern African savanna. *Journal of Tropical Ecology*, 22(2), pp. 231–234.

Moleele, N. M. (1998) Encroacher woody plant browse as feed for cattle. Cattle diet composition for three seasons at Olifants Drift, south-east Botswana. *Journal of Arid Environments*, 40(3), pp. 255–268.

Morrison, D. A. and Renwick, J. A. (2000) Effects of variation in fire intensity on regeneration of co-occurring species of small trees in the Sydney region. *Australian Journal of Botany*, 48(1), pp.71-79.

Newman, Y. C., Lambert, B. and Muir, J. P. (2006) Defining Forage Quality: Nutritive Value of Southern Forages.

Norton, B. W. (1994) The nutritive value of tree legumes. *Forage tree legumes in tropical agriculture.*, pp.177-191.

Nzehengwa, J. (2013) *The influence of Acacia mellifera on soil fertility, herbage quality and composition on sandy soils in camelthorn savannas of Namibia* (Doctoral dissertation).

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. and Anthony, S. (2009) Agroforestry Database: a tree reference and selection guide version 4.0. *World Agroforestry Centre, Kenya*, 15.

Palic, D., Claassens, A.S., Loock, A. and Hattingh, D. (1998) Handbook of feeds and plant analysis. *Agricultural Laboratory Association of Southern Africa: Pretoria*.

Razali, N. M. and Wah, Y. B. (2011) Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests. *Journal of statistical modeling and analytics*, 2(1), pp. 21–33.

Rothauge, A. (2014) Baseline Assessment for the De-bushing Programme in Namibia. *Final Report Prepared for MAWF/GIZ De-bushing Project, Windhoek, MAWF/GIZ*.

Rothauge, A. (2016) REPORT: Dry Season Baseline Assessment 2015: Characteristics and Management of Woody Plants and Livestock in NAFOLA Hotspots.

SAIEA, S. A. I. for E. A. (2015) *Strategic environmental assessment of large-scale bush thinning and value addition activities in Namibia*.

Sankaran, M., Ratnam, J. and Hanan, N. P. (2004) Tree–grass coexistence in savannas revisited—insights from an examination of assumptions and mechanisms invoked in existing models. *Ecology letters*, 7(6),

pp. 480–490.

Scholes, R.J. and Archer, S.R. (1997) Tree-grass interactions in savannas. *Annual review of Ecology and Systematics*, 28(1), pp.517-544.

Shackleton, C. M. (2000) Stump size and the number of coppice shoots for selected savanna tree species. *South African Journal of Botany*, 66 (2), pp.124–127.

Shackleton, C. M. (2001) Managing regrowth of an indigenous savanna tree species (*Terminalia sericea*) for fuelwood : the influence of stump dimensions and post-harvest coppice pruning. *Biomass and Bioenergy*, 20(4), pp.261-270.

Shackleton, C. (2002) Nearest-neighbour analysis and the prevalence of woody plant competition in South African savannas. *Plant Ecology*, 158(1), pp. 65–76.

Schutz, A. E. ., Bond, W. J. and Cramer, M. D. (2009) Juggling carbon: allocation patterns of a dominant tree in a fire-prone savanna. *Oecologia*, 160(2), p.235.

Smit, B., Burton, I., Klein, R.J. and Street, R. (1999) The science of adaptation: a framework for assessment. *Mitigation and adaptation strategies for global change*, 4(3-4), pp.199-213.

Smit, G. N. (2004) An approach to tree thinning to structure southern African savannas' for long-term restoration from bush encroachment. *Journal of Environmental Management*, 71(2), pp. 179–191.

Solomon, D. S. and Blum, B. M. (1967) stump sprouting of four northern hardwoods. U.S. Department of Agriculture, Forest Service Research Paper.

Stehn, H. (2008) *Rangeland management*. Edited by M. Lochna. Windhoek: Joint Presidency Committee.

Stocker, R. K. (1999) Mechanical harvesting of *Melaleuca quinquenervia* in Lake Okeechobee, Florida. *Ecological Engineering*, 12(3-4), pp.373-386.

Strohbach, B.J. (1996). The effect of season and treatment on the survival rate and coppicing ability of five encroaching woody species. II: The effect of fire girdling. *Agricola*, 8, pp.61-65.

Teague, W. R. and Smit, G. N. (1992) Relations between woody and herbaceous components and the effects of bush-clearing in southern African savannas. *Journal of the Grassland Society of southern Africa*, 9(2), pp. 60–71.

Tilman, D. (1982) *Resource competition and community structure*. Princeton university press.

Tolsma, D. J., Ernst, W. H. O. and Verwey, R. A. (1987) Nutrients in soil and vegetation around two artificial waterpoints in eastern Botswana. *Journal of Applied Ecology*, pp. 991–1000.

Topps, J. H. (1992) Potential, composition and use of legume shrubs and trees as fodders for livestock in the tropics. *The Journal of Agricultural Science*, 118(1), pp. 1–8.

Trollope, W. S. W. (1974) Role of fire in preventing bush encroachment in the Eastern Cape. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa*, 9(1), pp. 67–72.

Van Niekerk, J. P. and Kotze, T. (1977) Chemical control of bush encroachment by means of aerial spraying. In *Proceedings of the National Weeds Conference of Southafrica*.

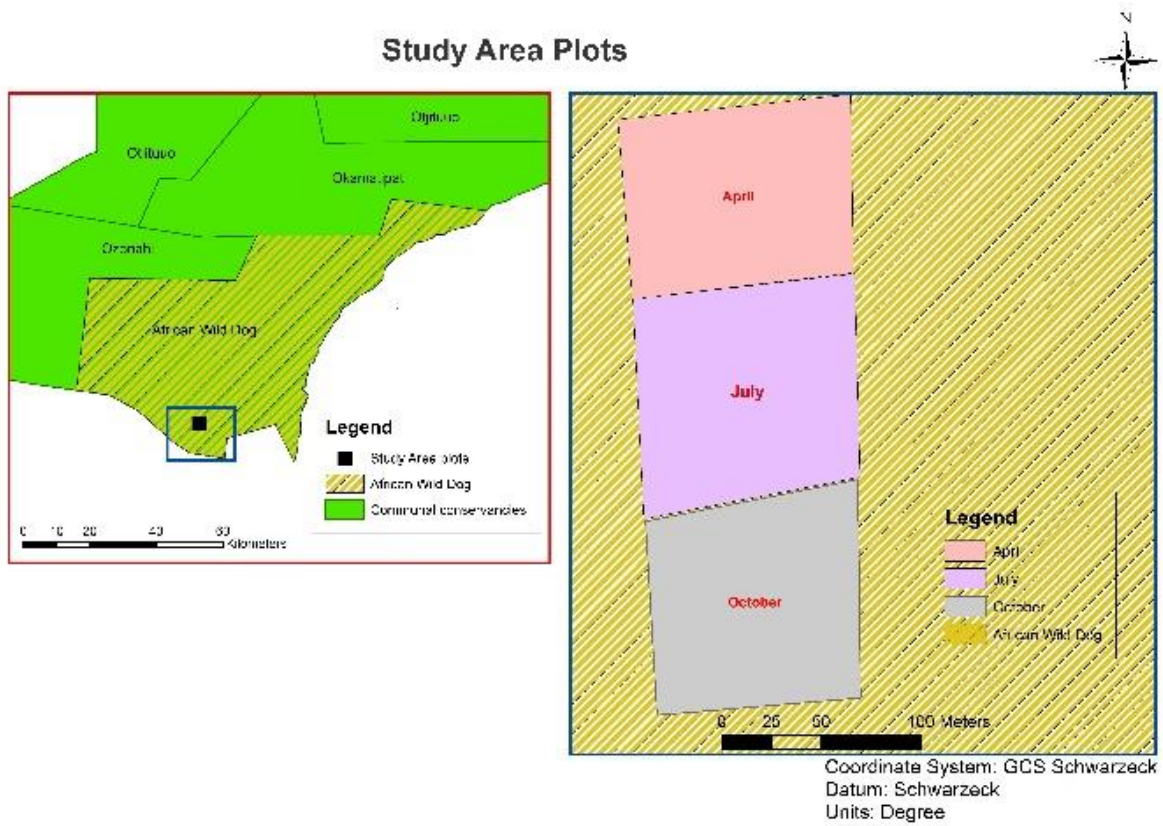
Walter, H. and Mueller-Dombois, D. (1971) *Ecology of tropical and subtropical vegetation*. Oliver & Boyd Edinburgh.

Ward, D. (2005) Do we understand the causes of bush encroachment in African savannas? *African Journal of Range and Forage Science*, 22(2), pp. 101–105.

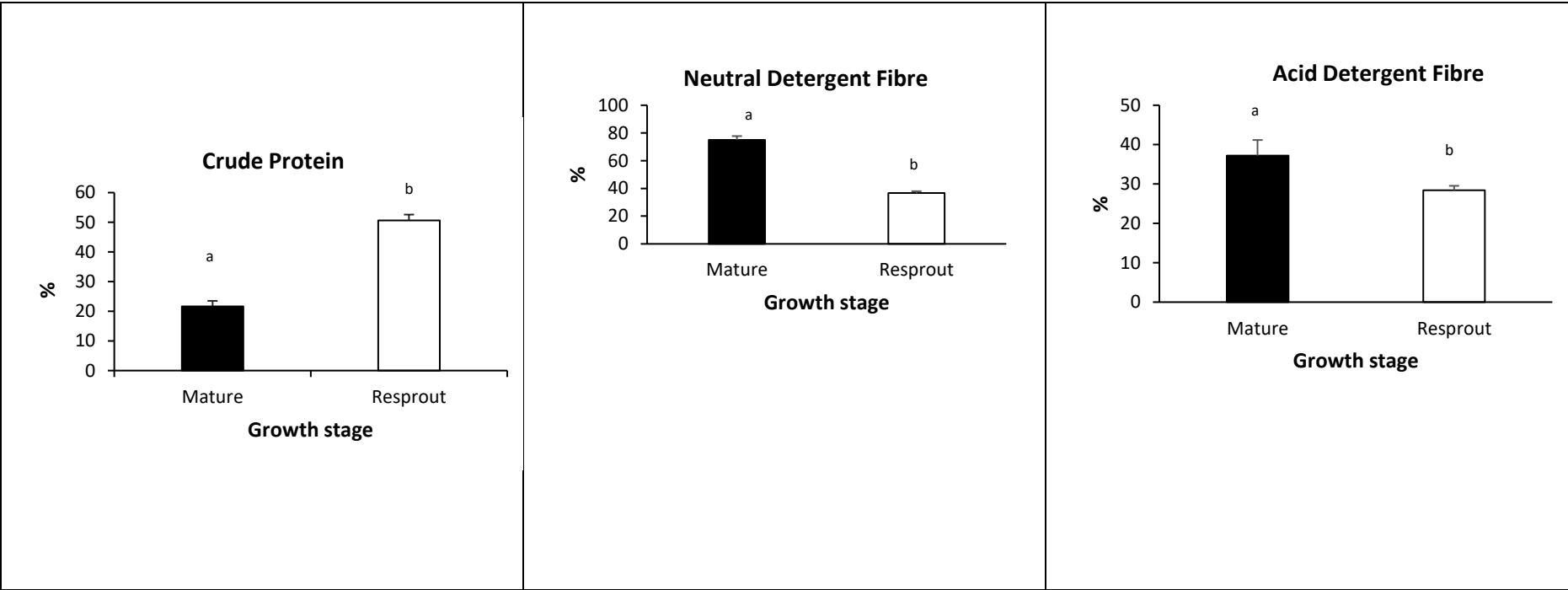
Wiegand K, W. D. and S. D. (2005) Multi-scale patterns and Soil, bush encroachment in an arid environment with a single soil Layer. *Journal of Vegetation Science*, 16(3), pp.311-320.

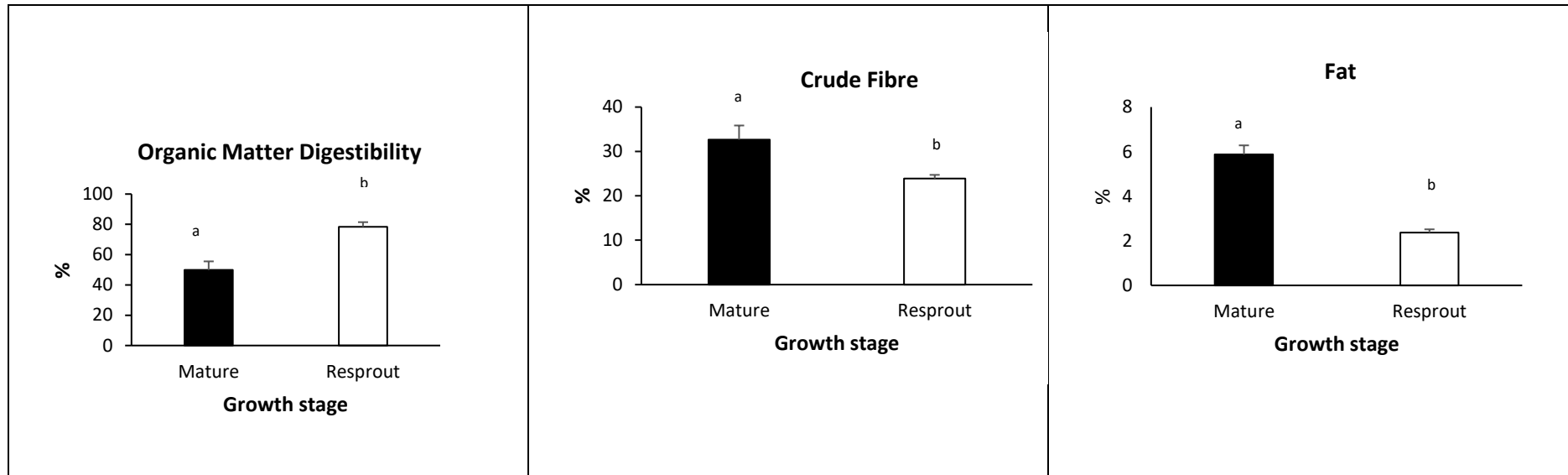
## APPENDICES

### Appendix 1: Study plots in Okahitanda.



**Appendix 2:** Chemical composition of the *Acacia mellifera* subsp. *detinens* in resprouts and mature trees.





**Appendix 2:** Concentration of macro and micro elements in *Acacia mellifera* subsp. *detinens* resprouts and mature trees.

