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The study of the change in vegetation structure in Namibia:

Bush Encroachment

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Bachelor Thesis

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Declaration

I Michael Uerikua, hereby confirm and declare that this bachelor thesis titled “The study of the change in vegetation structure in Namibia: Bush Encroachment” is the original work and results of my own, with the cited references. I agree that the work can be used by the Czech University of Life Science in Prague Library for further research and educational purposes.

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Abstract

The change in the vegetation structure from a grass-dominated ecosystem to a tree-dominated ecosystem in the savanna is of great concern in Namibia as it affects productivity. Bush encroachment and its causes have been noted in the past, but a few knows about it due to farmers and agriculturalist's ignorance on the issue. The main aim on the study was to investigate the change in vegetation structure to a state referred to as bush encroachment in the Highland Savanna rangelands of Namibia. The study was carried out at Neudamm farm in the Khomas region of Namibia, focusing on the degree of infestation and the species of bushes that affects the area, noting the influence of bush infestation on grass composition, as grass is of outmost importance in every livestock farm. In the study area, the transect laying method was employed, whereby a line was laid and bush species that touch the line were studied on their density and the type of species, as well as the grass species distribution in the area. Result of the findings has been determined as per hectare. The results states that there are more than 3000 bushes (woody plants) per hectare, whereby in an area that receives an average rainfall of less than 350 mm, with bush height of 1.5 m, it is expected to have bush counts of 700 bushes per hectare according to the norm. Furthermore, the results show the most infesting species covering more than 80% of the area as *Acacia mellifera.* High bush density areas had the most unpalatable grasses than areas bare from bushes canopy cover. The results of the study and its text can be added to further literature on bush encroachment and it can be used for further findings on the same issue. They can aid in the fight against bush encroachment by Namibian farmers, by understanding the causes and the ways of combating bush encroachment.

Key words: *Acacia mellifera,* Bush encroachment, Grass dominated ecosystem, Highland Savanna, Transect laying method

Abstrakt

Problematika změny vegetační struktury z travních ekosystémů na ekosystémy s převahou dřevin, stojí v popředí zájmu Namibie, neboť tento jev značně ovlivňuje zemědělskou produktivitu. Vzhledem k nízkému povědomí zemědělců o této problematice, není tato příliš prostudována. Hlavním cílem této práce byla studie změny vegetační struktury a míra pronikání invazních dřevin v oblasti vysokohorských pastvin (Highland Savanna rangelands). Studie byla provedena na farmě Neudamm v regionu Khomas, Namibie, a byla zaměřena na stanovení míry rozšíření invazních dřevin a vlivu tohoto jevu na druhové složení trav. Výzkum byl prováděn metodou liniového transektu, prostřednictvím něhož byl vždy zaznamenán druh dřevin, celková hustota dřevin a složení travního porostu. Výsledky byly přepočteny na 1 hektar. Na základě výzkumu bylo zjištěno, že průměrný počet dřevin ve studované oblasti je 3000 ks/ha, přičemž podle normy by pro oblast s ročním strážkovým úhrnem nižším než 350 mm, měla být hustota dřevin vysokých více než 1,5 m 700 ks/ha. Nejčastějším invazním druhem, pokrývajícím více než 80% oblasti, byla *Acacia mellifera*. Oblasti s vysokou hustotou dřevin se vyznačovaly značným výskytem trav špatně stravitelných hospodářskými zvířaty, v porovnání s oblastmi bez zastoupení dřevin. Výsledky této studie mohou přispět k obohacení znalostí o problematice šíření dřevin v oblastech savany. Rovněž mohou napomoci namibijským zemědělcům v boji proti pronikání invazních druhů a pro porozumění příčin tohoto jevu.

Klíčová slova: *Acacia mellifera*, metoda lineárního transektu, šíření invazních dřevin, travní ekosystémy, vysokohorské pastviny

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List of abbreviations

LSU=**L**ive**s**tock **U**nit

GDP=**G**ross **D**omestic **P**roduct

CC= **C**arrying **C**apacity

OC=**O**utside **C**anopy

IC= **I**nside **C**anopy

1. INTRODUCTION

Bush encroachment is a natural phenomenon that results in the transformation of a grass-dominated ecosystem to a tree-dominated ecosystem through a process known as plant succession. It is basically a result of unmanaged grasslands that become colonized by hardy, pioneer tree species. Shade, produced by the canopy of these trees, rapidly begins to stunt and kill the natural grass-dominated groundcover (Walter, 1971).

Bush encroachment is a rapid problem that is experienced in Namibia, all over the country and especially in then Highland Savanna of Namibia. Studies show that bush encroachment has been noted in eastern and southern Africa, South America, and Australia, and is considered to be a major threat to agricultural productivity where it occurs. According to De Klerk (2004), Bush encroachment of approximately 26 million ha of woodland savannas in Namibia resulted in a loss of land productivity of as much as 100% or more. This means that the carrying capacity declined from 1 LSU (Livestock unit) per 10 ha to 1 LSU per 20 or 30 ha. Bush thickening has caused a 47% reduction in cattle numbers on the commercial farmlands over the last 30 years and has resulted in lowered productivity in Namibian farmlands (Schneider, 1994). It has been ascribed to changes in the vertical distribution of soil moisture and nutrients, which may encourage the growth of shrubs. The most probable causes are: increased grazing levels, reduced use of burning to create grassland, changes in rainfall regimes, and the interactions between these factors. Other known causes will be discussed.

Most areas that are affected by bush encroachment are the Highland Savanna (Central part of Namibia) and the eastern part of the country. As it is well known, Namibia's economy is heavily dependent on agriculture, taking about more than a tenth of the country's GDP, it is therefore a necessity for such a research on bush encroachment as it is one of the factors that limit the forward movement of every farmer in the affected areas (by bush encroachment). This is due to the fact that a large portion of land is covered by bushes that are otherwise unutilizable by any of the farm animals (De Klerk, 2004). Farming in the country is the main source of profit for many citizens of the country, which is by cattle farming and small stock at a lower rate. When land is covered by bush, it limits the area's stocking rate and the grazing

capacity caused by a lower amount of pasture, that later leads to smaller profits for farmers than they could earn for the area.

Bush encroachment is the single most important factor hampering sustainable livestock production and improved standards of living in rural areas (De Klerk, 2004).

Bush encroachment is not a permanent phenomenon, and a savannah could be changed to its grass-dominated state by favourable management or environmental conditions (Doughil *et al*., 1999). Thus different methods (chemical, biological & mechanical) to combat bush encroachment and revegetation of the rangeland may be adopted not excluding costs and the environmental protection considerations involved.

By doing such researches and finding out on bush infestation and the causes of the change in vegetation in some of the country's areas will help in future management of the country's biodiversity. It is a way of helping potential farms to maintain their vegetation conditions and others to retain the ideal or the required vegetation that suits the farm's objectives. Such research results will help by adding to more literature based on the bush encroachment in the country and it will make alert of the problem to a lot who take bush problem light. This will be aided by researching on how bush densities and their competition for the factors of plant growth (nutrients, water, sunlight and other allelopathic effects) affects grass growth which is more important for Namibian farmers, taking into considerations that most of them in the Highland Savanna farms with animal production as their targets for high income.

2. LITERATURE REVIEW

2.1. Bush encroachment as a problem in Namibia

Bush encroachment poses a big threat to livestock and game farming, mostly in countries with a lower rainfall such as South Africa, Botswana and Namibia (Barloworld Power, 2010). Due to some problems such as droughts found in these areas, overutilization of the grass layer and the lack of fires, the ideal situation was created for bush areas to become overgrown. Trees or bush have a well developed root system and can absorb ground water deeper and more effectively than grass roots which are mainly concentrated in the upper parts of the soil. As the bush becomes denser year on year, less moisture is available for grass production, which resulted in a lower carrying capacity per live stock unit and grazing ground is reduced (Hudak and Wessman, 1998).

Bourlière (1970) and Lamprey (1983) said savannas are the most important ecosystems for raising livestock in Africa. In the past 50 years, evidence has accumulated suggesting that savannas throughout the world are being altered by a phenomenon known as bush encroachment. Bush encroachment is the suppression of palatable grasses and herbs by encroaching woody species often unpalatable to domestic livestock. Therefore, bush encroachment reduces the carrying capacity for livestock. The reduction in CC (carrying capacity) is of great significance because savannas in southern and central Africa contain a large and rapidly growing proportion of the world's human population, including many pastoralists whose livelihood is threatened by this process (Ward, 2005).

The first attempt at a general explanation for bush encroachment was Walter's (1971) two-layer hypothesis for tree-grass coexistence. Due to root separation of grasses and woody plants Walter (1971) assumed that water is the most limiting factor as it is known that grasses uses the topsoil water whereas trees and shrubs utilize more of the water from the subsoil. Under this assumption, removal of grasses, e.g. by heavy grazing, allows more water to percolate into the sub-soil, where it is available for woody plant growth. But besides this, a lot of other researches in other places show other different causes of bush encroachment.

Nearly 80% of the population of Namibia is engaged in agriculture, and with the sector employing more than half of the country's population, it is therefore of outmost importance to tackle such issues as bush encroachment that poses a threat to farming and agriculture as a whole. The world is now more about industrialization and services, which is viewed as a pool of development, or sectors in which developed nation acquire their wealth, but developing countries finds it more important to start at a sector such as agriculture and farming in general as a ladder towards development. This shows that most African countries are heavily depended on agriculture, and bush encroachment hinders with agricultural produce.

2.1.1. Biodiversity feature

There are three major types of vegetation in Namibia (Giess, 1971): the Namib Desert, savannas, and woodlands.

The Namib Desert covers 15% of the territory of Namibia (Erkkilae & Siiskonen, 1992) and occupies the coastal plain. It consists primarily of scattered, non-woody vegetation, mainly herbaceous and succulent plants. Woody vegetation occurs in the Namib Desert only along the riverbeds. The plant diversity is very high, approximately 200-fold higher than in the Sahara Desert, which has a similar climate (Cowling *et al.*, 1998). However, the Kalahari Desert in the eastern part of Namibia.

Savannas cover 65% of the territory of Namibia (Erkkilae & Siiskonen, 1992) and form a more or less discontinuous crown cover of trees. The savannas of Namibia consist of different types (Schultz, 1997). In the northeastern part of the country, savanna with a well-extended crown cover of trees predominates and consists mainly of scattered tall trees that are usually >15 m high. In the central part of the country, the dominant form is tree-shrub savanna, which is characterized by a scattered distribution of tall trees and low shrubs. In the southern and southeastern parts of the country, the Nama-karoo prevails. This type of savanna comprises deciduous low shrubs, scattered woods, and herbaceous plants. In addition, succulent-karoo occurs in the southeastern-most part of the country, consisting mainly of

succulent plants mixed with low deciduous woods. In northwestern Namibia, the most common savanna type is dominated by mopane.

2.1.2. Encroaching species

The woody plants that are responsible for encroaching large areas in Namibia are listed below. (Scientific name, family name and common name)

- *Acacia mellifera,* (*Fabaceae*) (Black thorn)
- *Acacia fleckii,* (*Fabaceae*) (Blade thorn)
- *Acacia reficiens,* (*Fabaceae*) (False umbrella thorn)
- *Colophospermum mopane,* (*Fabaceae*) (Mopane)
- *Dichrostachys cinerea,* (*Fabaceae*) (Sickle bush)
- *Rhigozum trichotomum,* (*Bignoniaceae*) (Three thorn)
- *Terminalia sericea,* (*Combretaceae)* (Silver Teminalia)
- *Terminalia prunoides,* (*Combretaceae)* (Purple-pod Terminalia)

The *Prosopis glandulosa* and *Catophractes alexandrii* can be added to the list, but they do not cover larger areas at once (De Klerk, 2004).

The same author highlighted that *Acacia mellifera* is clearly the most widely distributed encroacher species, with *Dichrostachys cinerea* in strong second place. And also that:

- *Acacia mellifera* dominates in the Highland Shrubland (central Namibia), Thornbush Shrubland (north central Namibia) and Camelthorn Savanna (eastern Namibia).
- *Dichrostachys cinerea* dominates in the Burkea-Baikiaea Woodlands, the Dolomite Karstveld (north to northeastern Namibia) and the Tamboti Woodlands, while showing a strong presences in the Loam and Turf Karstveld, the Shrubland of the Central Escarpment, the Thornbush Shrubland and the Tree Savanna and Woodlands
- *Terminalia prunoides* is the dominant species in the Loam and Turf Karstveld, while showing strong presence in the Dolomite Karstveld

- *Terminalia sericea* is significant in the Burkea-Baikiaea Woodlands, Camelthorn Savanna, and the Tree Savanna and Woodlands
- *Acacia reficiens* dominates in the Acacia Hilly Shrubland and Inselbergs, and the Shrubland of the Central Escarpment
- *Dichrostachys cinerea* is widely distributed north of the Windhoek-Gobabis road (91% of problem bush plots), and
- *Acacia reficiens* is distributed widely and occurs further west than any of the other encroachers (De Klerk, 2004).

De Klerk's (2004) findings are that the total bush densities in more than 80% of the affected area varied between 2,000 and 4,000 bushes per hectare, with Tsumeb district (north-central Namibia) having the highest densities. The trend, however, is that 77% of the "very high" and 52% of the "high" densities varying sites lie north-east of the otjiwarongo-Gobabis axis, while 58% of the "medium" and 58% of the "low" density sites lie south-west of this same axis. The major encroaching species' locations and the density are shown in figure 1.

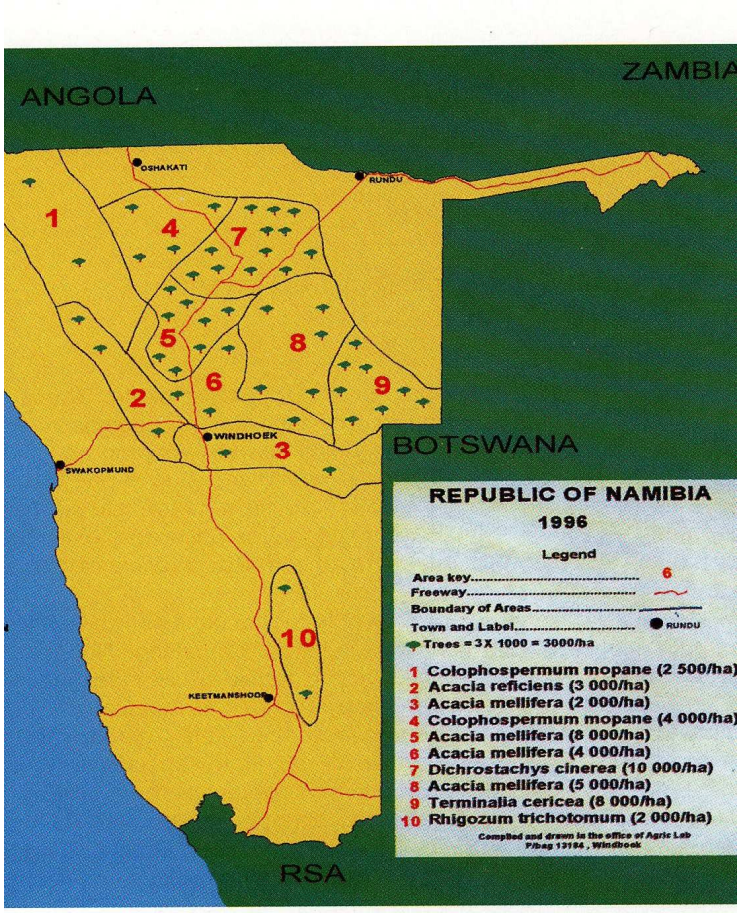


Figure 1: Map showing major species and density of infestation in Namibia (Source: Bester, 1998)

2.2. Causes of bush encroachment

Bush encroachment is caused by many distinguished factors that can be interactive. The main factors that causes bush encroachments are not well understood (Ward, 2005). To simplify the understanding of the causes of bush encroachment there have been two models that are well explained (De Klerk, 2004).

Walter's Two-layer Model, which maintains that, if the grass layer is over utilized, it loses its competitive advantage and can no longer use water and nutrients effectively. This results in a higher water and infiltration rate into the subsoil. Such a scenario will benefit trees and bushes and allow them to dominate (De Klerk, 2004).

The State-and-Transition Model, which recognizes the dynamic nature of savanna ecosystems. Savannas are event-driven where rainfall and its variability plays a more important role in vegetation growth (and composition) than the intensity of grazing. It implies, therefore, that bush encroachment is not a permanent phenomenon and a savanna could be changed to its grass-dominated state by favorable management or environmental conditions (De Klerk, 2004).

A particular cause of bush encroachment in a certain area cannot be identified easily, but suggestions of the causes of bush encroachment have been notified. Teague and Smit (1992) divided the causes of bush encroachment into two determinants.

2.2.1. Primary determinants (climatic features and soil properties)

These are a function of a specific geographical region and they are beyond the control of the manager. Plant composition is influenced by soil properties such as nutrient status, pH, soil salinity and its texture, and most important soil moisture balance (Walker, 1985). Fine textured soil (clay) hold more water and water is more available for the plants of roots in reach, whereas in sandy soils due to high porosity the water drains deeper and makes it difficult for plants of shorter roots.

De Klerk (2004) concluded following Walter's two layer model by saying, if the grass is overutilized it loses its competitive advantage and can no longer utilize water and nutrients effectively. This in turn results in a higher infiltration rate of water and nutrients into the subsoil, and this benefits trees and bushes and allow them to become dominant.

Walter's two layer model suggests that water is the most limiting factor for both grasses and woody plants, and if a vigorous grass layer is present then more water will be used by grasses and the ecosystem will be dominated by grasses. On the other hand Doughill *et al*. (1999) proposed the state and transition model, which implies that bush encroachment is not a permanent phenomenon and that a savanna could be changed to its grass-dominated state by favourable management or environmental conditions.

2.2.2. Secondary determinants

Those that in one way or another can be modified by management

Natural Fire

There are different factors that play the greatest role in the season, frequency and intensity of natural fires in the savanna where fuel load, fuel moisture and the incidence of lightning occurs. Both natural fires and fires caused deliberately have had increasing effects on debushing as well as the change in vegetation composition. Trollope (1992), showed that the frequency of burning in the natural fire regime have been largely influenced by the rate of accumulation of sufficient grass fuel to support a fire. Rainfall supports the productivity of grass under veld conditions and therefore the accumulation of grass fuel. Natural fires occur from at the beginning of the rainy season and they occur for a short period of time when the availability of dry fuel overlaps with the occurrence of thunderstorm, so if there are a few grasses, there will be little fuel for a fire to occur and in this way natural fire is prevented (Zimmermann, 2002). The prevention of fire and their non-occurrence in the recent years in Namibia have contributed to a vast growth of woody plants than grasses, due to the fact that the bushes and trees are not negatively affected in their growth and they tend to outcompete grasses, thus causing bush encroachment.

Herbivores

Herbivores are organisms that are anatomically and physiologically adapted to eat plant-based foods or so related as primary producers. There are large herbivores like Giraffes, Zebras and water Buffalo etc, and smaller herbivores ranging from Squirrels to worms. It was in the form of hunting and consuming large herbivorous animals that the Namibian government implemented a way of conserving their animals, which might see a sustainable and stable number of herbivores in the country (MET, 2008). Herbivores consume leaves of plants and also graze. Owen-Smith (1989) highlighted that high grazing and browsing herbivory reduces the growth and reproduction of individual plants, influencing competitive outcomes and community composition. With this, the rangeland's plant species (woody and grasses) are

maintained in an acceptable ration depending on the area. De Klerk (2004) also highlighted the removal of large herbivores through hunting and transporting them to parks and zoos has contributed to a decrease in the number of herbivorous animals. The same author further explained that such a decrease in herbivores number makes the ratio of herbivores to grazers lower and many animals are grazers, thus causing an increase in growth of woody plants due to the fact that they (woody plants) are underutilized. This causes an infestation by certain woody plants that have competitive potential.

Competition between plant species

It is known that plants scramble for resources. Trees, bushes, shrubs and grasses all find a way of survival from the outside conditions like soil moisture (water), light, nutrients and so on (Wu *et al*., 1985). This creates competition between the plants as resources are scarce in some places especially the highland savanna (water). Grasses competes well for water in the top soil layer, whereas trees and bushes compete well for water in the subsoil. On the other hand grasses can only use soil nutrients that are in their small reach, while bushes have long and wider roots that absorb nutrients from different angles, this in turn makes bushes to have a competitive advantage over grasses and it causes an increase of bushes in an area (Walter, 1971). When it comes to light, it is well understood that a bush infestation that have a large (wide) canopy cover causes a blockage in light penetration to the lower plants hence blocking the light absorption that provides energy to plants. Overall woody vegetation reduces grass cover by increasing the competition for available water and nutrients and reducing sun light that should reach to the grass layer (Walter, 1971).

Overgrazing

Many rangelands historically have supported native grasslands, originally dominated by perennial grasses. These grasses are useful for soil stabilization (they maintain cover of the ground year around and have extensive root systems), they are also quite productive, and are very palatable to cattle (Lubbe, 2002). As the size of livestock herds (or the duration of grazing) increases, the perennial grasses are consumed, trampled, and decline. Their roots suffer from loss of above-ground parts and soil compaction. In addition, when they are heavily

grazed (particularly at flowering and seed set times) they produce fewer seeds, decreasing recruitment of new individuals into the population. This in turns favor an increase in the unused bushes and they encroach the whole area (Cramer *et al*., 2007).

There are many other theories of the increase in bush infestations explained such as: rainfall and draught, temperature and distribution of plant seeds (De Klerk, 2004).

2.3. Environmental and Economic influence of bush encroachment

Bush encroachment affects the agricultural productivity and biodiversity of the country especially in the heavily infested areas. An estimated 26 million ha is currently affected by bush thickening in Namibia, resulting in severe economic implications (Zimmermann & Joubert, 2002). Savannas are extensive, socioeconomically important ecosystems with a mixture of two life forms, trees and grasses (Scholes, 1997; cited by De Klerk, 2004). Bush encroachment is the suppression of palatable grasses and herbs by encroaching woody species often unpalatable to domestic livestock (Ward, 2005). Overall woody vegetation reduces grass cover through increasing the competition for available water and nutrients and reducing sun light that should reach to the grass layer. Von Wietersheim (1998) said that the biodiversity of commercial farms in Namibia has been altered drastically by overgrazing which causes bush thickening. Bush thickening has caused a reduction of 47 % of the commercial farmland's cattle numbers over the last 30 years (Schneider, 1994) and has resulted in lowered productivity on Namibian farmlands (Nghikembua *et al*., 2002).

Bush encroachment is one of the most extensive changes in land cover in Namibia, others being deforestation, soil erosion and other possible land degrading factors. Bush encroachment is an urgent problem for cattle farming as it reduces the productivity of the rangeland.

With the country's heavy dependence on agriculture (contributing 13 -15% to the GDP) and farming in particular beef and livestock as well as karakul for pelts and wool

according to the World Bank (2000), such factors that affects the country's forward movement should be taken into deep consideration.

The economic well-being of more than two thirds of the population of Namibia depends directly or indirectly on agriculture and 65% of the national agricultural output is produced on commercial rangeland (Mendelsohn *et al*., 2009). Therefore, the condition of the ecosystem has an immediate effect on the economy and bush encroachment severely restricts profitability of cattle farming.

2.3.1. Impact on farmer's carrying capacity

Carrying capacity determines the maximum livestock or wildlife population that a habitat or ecosystem can support on a sustainable basis (Stoddard *et al*., 1975). It is important to consider this factor because Namibia is a country that depends on its habitat for grazing. Bush encroachment reduces the carrying capacity for livestock (Ward, 2005). This is caused by the fact that an increase in bush or its infestation causes the grass cover to become poor and it lowers the carrying capacity. The reduction in carrying capacity is of great significance because savannas in southern and central Africa contain a large and rapidly growing proportion of the world's human population, including many pastoralists whose livelihood is threatened by this process (Scholes, 1997; cited by De Klerk, 2004). For example an approximately 26 million ha of woodland savannas in Namibia resulted in a loss of land productivity of as much as 100% or more. This means that the carrying capacity declined from 1 LSU per 10 ha to 1 LSU per 20 or 30 ha (Sheuyange *et al*., 2005). According to Sheuyange (2005), bush encroachment also impacts adversely on biodiversity, water-use efficiency and underground water tables, thereby contributing to the process of desertification and it leaves bare areas, making no use to the farm's livestock.

2.3.3. Productivity

Bush encroachment has serious economic implications in the agricultural sector in Namibia. As it is one of the sectors that contribute heavily to the country's economy, hence the economy is affected. Bush encroachment results in the decline of livestock production due to the loss of grass production (de Klerk, 2004). Individual animal production is also lowered by the loss of grass production (Kruger, 2002). It remains the single most important factor that limits red meat production in commercial farms in Namibia (Els, 1995). At the national level, bush encroachment has resulted in the loss of up to N$ 700 million in lost of meat production each year (de Klerk, 2004). As indicated in the previous topic of carrying capacity bush infestation in Namibia affects 26 million hectares and has lead to a 60 percent decline of commercial livestock over the last 40 years, causing losses to the national economy, according to Combating Bush Encroachment for Namibia's Development (CBEND, 2009).

2.4. Ways of controlling bush encroachment

Three methods of bush control may be adopted. Treatment of infesting bushes would mean reverting the land to nature. The possible ways of controlling bush encroachment are chemical, mechanical or biological methods. The application of individual techniques will always depend on individual circumstances such as bush density, bush species composition, soil profile, rainfall, landscape morphology and the capital available (De Klerk, 2004). The specific method and the costs associated will vary between areas and between farmers. Consequently, each farmer applies the method(s) that suits his/her particular environment and economy best (De Klerk, 2004).

2.4.1. Chemical method

There are about 150 basic chemicals used as herbicides (Ashton & Crafts, 1973; cited by Stoddart *et al*., 1975). New compounds are constantly being formed, although environmental considerations are adding caution to this search. Stoddart *et al*. (1975) said that herbicides can be classified in many ways: (1) by their method of entry, (2) by their physiological action, (3)

by their selectivity, (4) by their mobility in the plant, (5) by their method of application, or (6) by their chemical makeup.

To control bush infestation in Namibia, different types of herbicides have been used and it have been viewed as one of the best options for bush encroachment treatment. Herbicides available for chemical control of invader bush are either root-absorbent or foliar and stem-absorbent (Smit *et al*., 1999 & Lubbe, 2001). Chemical control methods are normally expensive to apply and should be considered only under specific circumstances (De Klerk, 2004). Smit *et al*. (1999) & Trollope *et al*. (1989) recommended the application of certain chemicals under the following circumstances:

- When the woody component is so dense that not enough fuel accumulates to support a fire sufficiently intense to kill the top-growth of the target woody species.
- Where a majority of the trees have grown out beyond the reach of browsing animals
- Where the tree density is such that animal access is severely restricted
- Where the woody component is largely unpalatable
- Where, for a variety of reasons, it is not practical to incorporate browsers in the livestock system, and
- Where herbicides are available which will selectively affect the target woody species more severely that the palatable species.

In the infested areas chemical control of the invasive bush is carried out by using a method of aerial application or applying by hand (MET, 2008). The method of application is influenced by the amount of area needing to be covered, funds available, and availability of a labor force, but both methods are successful as it is a way of applying the chemicals. Aerial applications is less labor intensive, but it is more expensive than hand spraying, however, when treating large amounts of land, aerial application can be the more cost effective option.

Stoddart *et al*. (1975) indicated that varied results have been obtained from application of herbicides to woody plants. Some vigorously sprouting species are affected only temporarily, and this characteristic is exploited to kill back the tops of palatable shrubs that

have grown out of reach of grazing animals. The results are increased production and quality of forage. Non-sprouting species are more readily killed or thinned to desirable densities.

Great care needs to be taken, therefore, to ensure no misperceptions cause a negative impact on the export of beef to the European Union (Dahl & Nepembe, 2001). This is because Namibia is one of the biggest beef export country to Europe and some chemical application mentioned in Table 1., causes health risks to the end product (through the consumption of grasses growing in chemical applied soils).

De Klerk (2004) further assured that according to the Environmental Impact Assessment (EIA) carried by Joubert (2003), the herbicides in themselves do not seem to pose any environmental or health risk. However, due to health risks all chemical products used in Namibia should be registered with the registrar in accordance with the Fertilizers, Farmfeeds, Agricultural Remedies and Stock Remedies Act, 1947 (No. 36 of 1947). A number of herbicides that have been subjected to strict criteria for registration have so far been registered in Namibia (De Klerk, 2004). Some of the Common Herbicidal Products for Bush Control in Southern Africa are shown in Table 1.

Knowing that everything has disadvantages, the use of herbicides as an aftercare treatment is effective in killing unwanted plants, but in some cases (MET, 2008) the treated plants have shown a resistance to decay and decomposition, which can hinder the growth of other plants in that area. Furthermore, herbicides must be properly stored on site, and a separate space must be made for storage if transported in the accommodation trailers.

Table 1: Herbicides used in Southern African against bushes, Table provided by the CBEND report taken from Kellner (2008)

Chemical Trade Name	Active ingredient	Active Ingredient(s)Content (pure)	Type of Formulation	Supplier/ Distributor
Access	Picloram (potassium salt)	240 g/ l	SL	Dow AgroSciences/ Ecoguard Distributors
Buschwacker	Bromacil	800 g/ kg	WP	Enviro Industries
Garlon 4	Triclopyr	480 g/ l	EC	Dow AgroSciences/Efekto
Hyvar X	Bromacil	800 g/ kg	WP	DuPont
Savana 500 SC	Bromacil/ Tebuthiuron	250 g/l / 250 g/l	SC	Sanachem
Tordon Super	Picloram	120/ 240 g/ l	OL	Dow AgroSciences
Ustilan 20 GG	Ethidimuron	200 g/ kg	GG	Bayer
Ustilan 70 WP	Ethidimuron	700 g/ kg	WP	Bayer
Abbreviations: EC = Emulsifiable Concentrate, SC = Suspension Concentrate, SL = Soluble Concentrate, GG = Macro Granule, GR = Granule, OL = Oil Miscible Liquid, WP = Wettable Powder				

2.4.2. Biological method

The use of biological agents for plant control has been successful in some instances, but the list thus far is not impressive (Stoddart *et al*., 1975). Careful and complete ecological study

should precede introduction of any biological agent, to be absolutely sure that the plant nor the animal concerned will neither displace, nor shift its activities to, desirable native species (Stoddart *et al*., 1975). Stoddart *et al*. (1975) highlighted the following as necessary for use of a biological agent: (1) the agent must be specific to one host, or have a narrow range of alternate hosts; and (2) alternate hosts must not be economically valuable or be more important to the stability of the ecosystem. Obviously, these criteria preclude elimination of a species and permit only control. The first is accomplished by destruction of the host plant, the second by weakening it so that other pathogens attack it or making it non-competitive with other plants (Huffaker, 1964; cited by Stoddart *et al*., 1975).

Insects have been the agents most employed against plants. Their effects can be more readily assessed and the outcome predicted than can those of disease (Stoddart *et al*., 1975). Natural enemies that are used for biological attack specific plant organs such as the vegetative parts (leaves, stems or roots) or reproductive parts (flowers, fruits or seeds) (Klein, 2002; cited by De Klerk, 2004)

The natural die-back of bushes and trees had already been observed by the early 1970s (De Klerk, 2004). The same author indicated that observations in Namibia showed that bushes and trees were killed on thousands of hectares. It soon became evident that four organisms (fungi) act in concert to cause mortalities in *Acacia mellifera* (De Klerk, 2004). These are *Cytospora chrysosperma, Phoma cava, Phoma eupyrena and Phoma glomerata.*

Stoddart *et al*. (1975) highlighted that the effectiveness of domestic livestock as agents for manipulating vegetation rests upon four conditions: (1) effective control over livestock, (2) acceptance of the target plant as forage by livestock, (3) presence of other forage species which can replace the target species or site favorable to seeding, and (4) differential susceptibility of plants to grazing at some time of the year.

Livestock are most successfully used against sprouting shrubs in connection with other control methods –fire, herbicides, or mechanical methods (Stoddart *et al.,* 1975). Goats are used in many countries as agents of brush control, although Malecheck and Leinweber (1972) did not consider browse in Texas a first-choice item of forage (Stoddart *et al.,* 1975). The

goat's reputation comes from its ability to accept browse more readily than other livestock in the absence of other vegetation. According to Stoddart *et al*. (1975), Du Toit (1973) gave evidence that goats can effectively hold *Acacia karoo* in check following other control methods under continuous grazing without affecting production from herbaceous vegetation. If ruminants are allowed to browse on the land they may actually stimulate bush, in this case the use of megaherbivores such as elephant and black rhino previously played an especially important role by keeping bush growth in check. These large megaherbivores have been seriously depleted due to the construction of fences and hunting (Zimmermann & Joubert, 2002). Due to this reasons, goats are used as agents in bush control. This is because goats are primarily browsers (especially boar goats) and they are suited to the arid and semi-arid savanna of Namibian rangeland (Rothauge *et al*., 2001; cited by De Klerk, 2004). However, goats cannot be used to control dense stands of woody plants whose canopies extend above the browse line of approximately 1.5 m (Smit *et al*., 1999). Furthermore, De Klerk (2004) indicated that goats as a control measure is not recommended where high bush densities occur, although it is very effective as an aftercare treatment.

The use of wildlife and livestock combinations to control woody plants has been demonstrated in Kenya. Here eland and giraffe were used in an improved cattle-ranching operation to keep bush from reinvading pastures following clearing (Stoddart *et al*., 1975).

De Klerk (2004) concluded that at this stage that, in semi-arid savannas, goats can improve the condition of the rangeland for use by cattle. This means that they can be used in combination on the land. In addition, that the total meat production can be increased considerably by introducing browsers to utilize the bush component.

Controlled fires can also be used as a management tool. On plants that do not coppice from the base of the stem when the top-kill of the stem occurs, fire has an adverse effect on these plants (De Klerk, 2004). It was also stated by him that the susceptibility of trees and shrubs to fire differs and varies as it depends on various factors such as the intensity of the fire, age of the plant, environmental conditions at the time of the fire, the ability of the plant to coppice, the type of bark around the stem, the frequency of the fire, season of burning, fire-

herbivory interaction etc. (De Klerk, 2004). Trollope (1974) stated that bush encroachment can be controlled through the use of intense fires because they allow trees and shrubs to be maintained at an available height and in an acceptable state for browsers.

Strohbach (1999) indicated that veld fires are not regarded as an effective means in reducing the number of woody plants, because the unwanted woody plants do not die from fire, and often regrow strongly, a suitably high fuel load is not always available, and grazing management is often in conflict with the use of fires. The aim of farmers to improve their livestock production by utilizing the good regrowth and quality of grass obtained after burning of the rangeland is an aspect to be reconsidered for the short and long-term (Snyman, 2003).

Bester (1985) indicated that fire only kills between 15-25% of bush and is responsible for dense coppice thereafter. He said, for this reason, fire is best used as a preventive rather than curative measure against bush thickening.

2.4.3. Mechanical method

The mechanical method is basically the removal of bushes from the area, through cutting, or digging to the roots. This method control efforts have led to the adaptation or development of costly machinery, used primarily against individual trees and shrubs, although some can be mass produced (Stoddart *et al*., 1975). The method is advantageous due to the worldwide demand for fuel. There is already a lot of trade in wood and charcoal, both for export and for local consumption, against which new demands would need to compete though there are risks of leaving bare spaces that leaves the soil exposed and leads to further degradation (Zimmermann & Joubert, 2002).

In treating the symptoms of land degradation, there are ways like chopping out even the smaller smaller bushes and/or apply arboricides (chemical) to reduce the regrowth. The degradation may have been caused by a combination of over-grazing of the palatable grasses, over-resting of the rangeland, lack of fierce fire late in an occasional dry season, and lack of browsing pressure especially by mega-herbivores such as elephants and black rhinos. If wood

harvesting is to be sustainable under such conditions, the initial yield would be significantly higher than subsequent yields, which would achieve a higher production of grass and a lower production of bushes (Zimmermann & Joubert, 2002). Non-sprouting species can be effectively cleared by mechanical devices alone, sprouting species require specialized equipment or companion treatments with fire, chemical, or browsing with animals (Stoddart *et al*., 1975). Under mechanical methods, the most common techniques used are stumping/felling and bulldozing.

Stumping or felling involves manual removal of the plants from the area. It is taken to be a very demanding way of controlling bush encroachment in terms of manpower. However, it is a method that can create a lot of employment opportunities (De Klerk, 2004). The technique entails removing bush above or below-ground by using axes, mattocks, handsaws, or chainsaws. The stumps are then treated using chemical weed control method (arboricides mentioned above) immediately. Besides that, a lot should be taken into consideration when using this method because most species shows regrowth after they have been cut at above ground level, it is therefore important to take into consideration the height of cut, it is considered to be one of the method's disadvantage (Dahl & Nepembe, 2001; cited by De Klerk, 2004). Where bushes are removed 10 cm or more below the soil surface, the advantage is that most of the species will not show regrowth, except for *D. cinerea*. But the disadvantage is that the method is slow and it therefore needs a good aftercare in the case of *Dichrostachys cineria* (De Klerk, 2004).

The aim of tree clearing is usually to increase herbaceous production, but the species composition of herbaceous plants is also important as species may vary significantly in their acceptability to grazing herbivores (Smit & Rethman, 1999). The same authors further explained that there have been noted changes in grass species composition in areas where tree clearing have been done throughout the world.

Another mechanical method of bush control is **bulldozing** or removal of bush by means of a bulldozer. Bush clearing using this method is considered to be faster. However, it is one of the methods that disturb the soil so much that it becomes degraded (De Klerk, 2004).

According to Zapke (1986; cited by De Klerk, 2004) bush clearing by means of bulldozers for rangeland reclamation purposes is not recommended for the following reasons:

- The topsoil is disturbed to a very large extent
- The establishment of bush seedlings is favoured and usually results in a bigger problem, and
- The practice is too expensive

The method can be used for crop production purposes whereby the land is then leveled and crops planted, in that way the land is not degraded or the soil is not exposed for natural soil loss through erosion (De Klerk, 2004).

Mechanical method of clearing alone does not result in the deaths of bush effectively, Barnes (1972), found out that 80% of bush recovery in 20 years after debushing mechanically in Zimbabwe. This is due to the fact that the seeds remain in the soil after the bush have been shaken and it starts re-establishing. This is one of the reasons why soon after bush removal, crop production should follow. Moreover, the stirring of the soil and removal of competition favors the establishment of a new stand from seed. And this is not always a disadvantage for where other valuable plants are present; they too escape and produce more forage than before (Stoddart *et al*., 1975).

2.5. Preventing bush encroachment

Considering the ways in which bush encroachment occurs, it will be clear that taking the causes of bush encroachment in mind may prevent the occurrence of infesting species. It will keep woody plant growth at a minimal desired density. Maintaining an already balanced (woody and grass plants) vegetation is possible by using the biological methods of bush eradication or consumption. Employing browsers such as goats to utilize bushes that have densities within their height, which is 1.5 m as stated by Smit *et al*., (1999), it will be a good way of ensuring grass growth while woody plants are being used that way. Every farm management have long-term plans and does not only consider the present state of the farm or

vegetation, considering that overgrazing is a cause of farm destruction especially in allowing bare places that in the long run encourage bush encroachment, it should be kept in mind at all times. Other ways of preventing bush encroachment is the allowance of natural fires, and not intervening by fighting fire at its occurrence (Routhauge, 2006).

3. AIMS OF THE THESIS

The main aim of the study was to investigate the change in vegetation structure from a balanced or grass dominated vegetation to a bush infested rangeland in the Highland Savanna of Namibia.

The specific aims are the following

- To evaluate bush encroachment and infesting species in Neudamm farm in the Khomas region, which will help in coming up with a broader understanding of what bush encroachment is and what species are responsible for the infestation.
- To investigate the distribution, composition and diversity of the bush species, to provide an indication of the causes of bush encroachment in study area, even though it is an already encroached area.
- To assess the influence of bush species on grass composition in the Khomas region of Namibia.

4. METHODS AND MATERIALS

4.1. Target area: Neudamm Farm in Khomas region

The study carried out at Neudamm farm in the Khomas region, in the central part of Namibia. The farm is in the Highland Savanna shown in figure 2 about it is 35 km east of the capital Windhoek. This farm is located between 22°26.21" S and 17°20.9.96" E, in the Khomas region. The term savanna refers to vegetation in the subtropics and tropics which is characterized by a mix of grasses, trees and shrubs. Characteristic for savanna is that changes in the dominance of the three main components (grasses, trees, shrubs) are common from year to year. As mentioned earlier grazing and browsing animals, rainfall and fire are the main environmental factors driving these changes. Plant life of the semi-arid central part of Namibia is named as highland savanna. It is a small vegetation type in Namibia that occupies around 45 000 km² which is 5.5% of the Namibian land area (Coetzee, 1998; cited by Van der Merve, 2011).

The savanna has broken terrains. It is mountainous with lithic leptosols and the overlaying base material of sandstone and metamorphic schists. The soils are shallow and contain a lot of gravel and they are low of organic matter, hence they are considered infertile, as their nutrients are easily leached and are susceptible to erosion (Van der Merve, 2011).

Rainfall in this area ranges from 300-350 mm per annum, whereby the rainy season is between January to April, with the maximum average temperature of 29°C.

Neudamm farm is situated in the Highland savanna and it is a farm that houses an Agricultural college called Neudamm Agricultural College, which is part of the University of Namibia, where there is the Faculty of Agriculture and Natural Resources. Neudamm no. 63 farm as its registration number is a farm with its functions as a farm, whereby stud Afrikaner breeds, Karakul sheep are kept for their meat, pelt and fibre, respectively, Boar goat, Damara sheep and Dorper are also kept in the farm. With all these in place the Agricultural College's students familiarize themselves with agricultural practices and they carry their practical and researches on the farm as part of their curriculum.

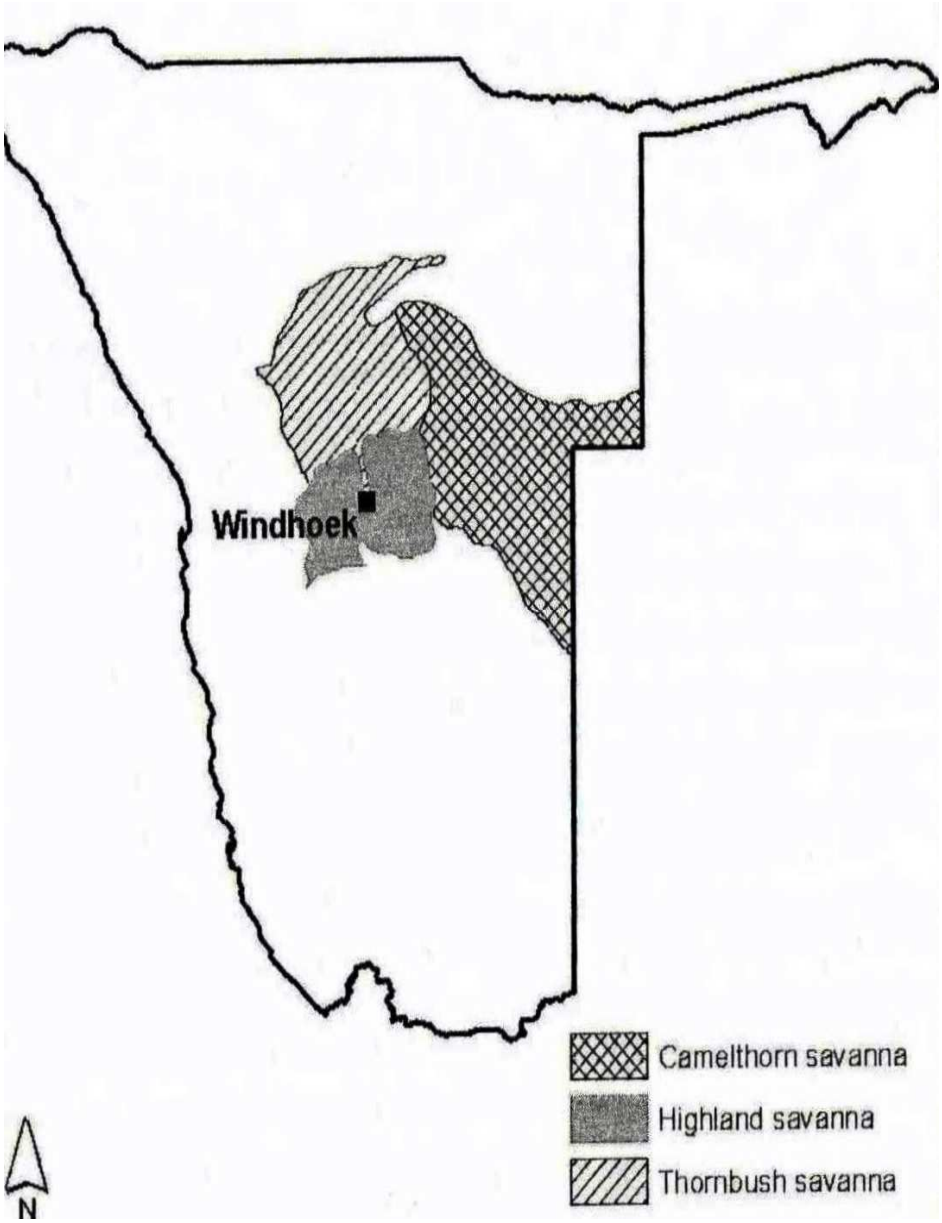


Figure 2: The Highland Savanna, Camelthorn and Thornbush Savannaof Namibia (Source: De Klerk, 2004)

The farm covers an area of 10 187 hectares, and is divided into 9 blocks (A, B, C, D, E, F, G, H, I, J), each block is further divided into camps and all camps together are 197, according to figure 3. On assessing the bush infestation in the farm, a sample of data from 3 camps was taken, where the encroaching species were studied and important figures recorded.

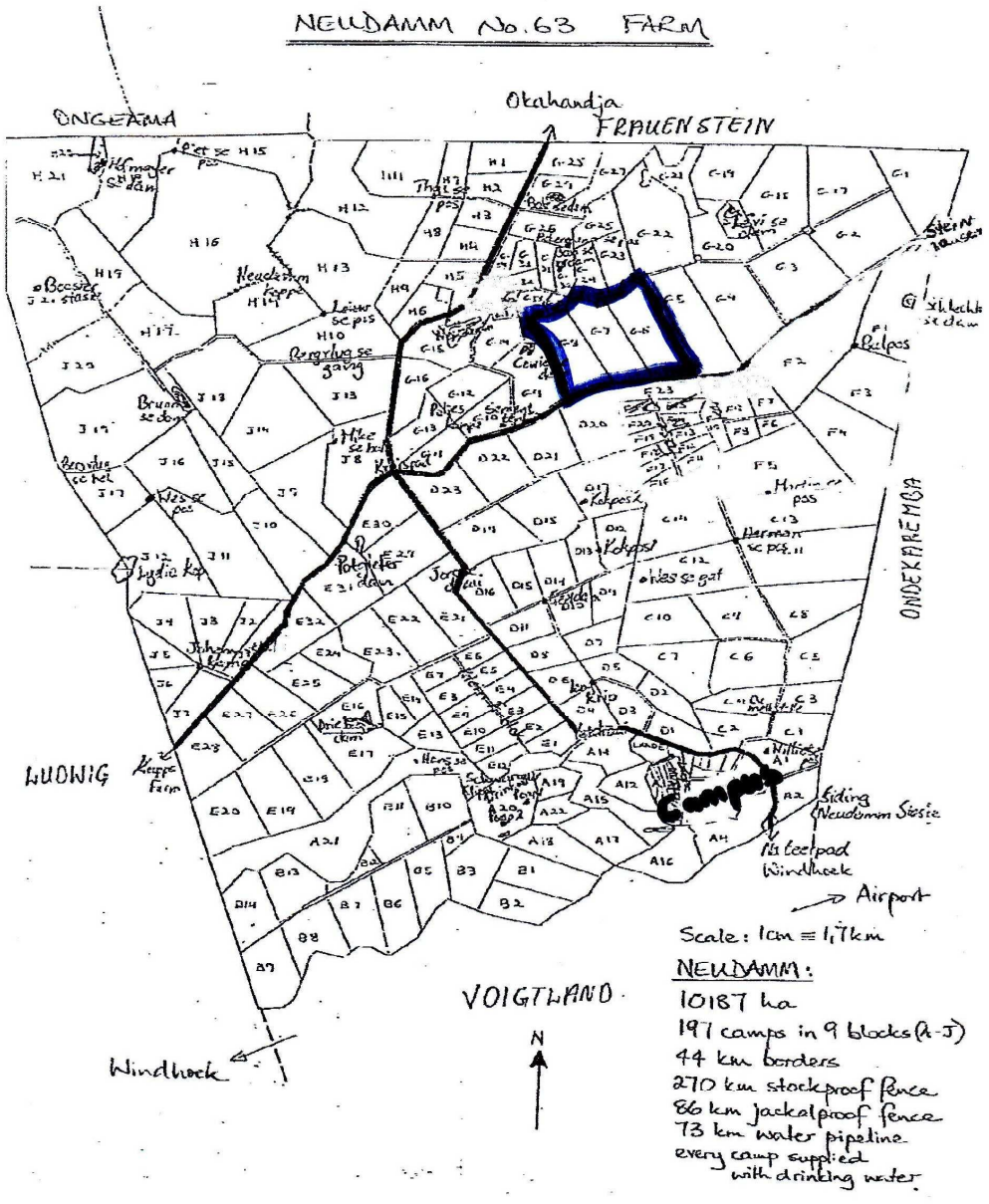


Figure 3: Map of Neudamm farm (provided by Neudamm farm Manager)

The study was done with the presence of researchers (University of Namibia staff member) on bush infestation and persons with differing objectives in the range of bush encroachment. While investigating on the vegetation and its change, researchers and research students studied the ways of controlling bush encroachment using mechanical and chemical methods on the area. With the help of the researchers and as people who have some background on the issue ways of assessing the encroachment and the infesting species were developed. The effectiveness of such methods and ways are found from recommendations from literatures of previous researchers. With the fact that the research site is heavily infested, it made it easier for the study on bush encroachment to be done with the important tools for the job.

Bush encroachment and the effects on grass composition was assessed using the materials that measures the density of bush and the distribution or coverage of stems under a certain canopy cover and the type of bush (species) and the grasses found there, their palatability and ground cover.

4.2. Study of infesting species

Bush encroachment occurs heavily in the Highland savanna and certain plant species (woody plants) cover a huge area of land which came to the attraction of writing this thesis. With basic knowledge of recognizing species of trees and grasses and the help of expertise from the supervising personnel, encroaching species were noted. The study was carried out in Camp G6, G7 and G8 which are on the road to Steinhausen (east of Neudamm farm). These are encroached farms where data was collected indicating the bush canopy cover and its density on the area. The study was done during the August-September time of the year 2011. Infestation or the encroaching species were studied in the whole area and not necessarily the mentioned camps. The study of the infesting species gave a clear picture of bush encroachment by being on the camps and with the basic knowledge of names of plants in the country, it could easily be noted. With a walk on the farm while assessing the infestation, different species of plants like bushes and grasses were seen. The purpose of studying the

infesting species was to compare the distribution of the grasses close to a large canopy cover and far from a large canopy cover as well as on sites where there is no bush at all.

In finding out the influence that bushes or woody plants have on grass species composition, the guide to the Grasses of Southern Africa, by Van Oudtshoorn (1999) was used as a help in determining the species, their names and their characteristics, palatability. This book has only been used during hard times, when one is failing to recognize the specie, which was minimal. The researchers and other parties have the basic knowledge of the plant characteristics and naming, which makes it easier for the work to be done in a minimum of time.

With the basic knowledge of plant production and nutrition of the researchers and considering what is written in the literature helped in the analyzing of the veld. Whereby species were studied and noted on their cover on the area, the composition and the influence of the infesting bush species on the production and growth of grasses. Noticing the difference in grass cover and the type of grass on heavily infested sites of the farm and on the least infested sites as well as on bare (free from bush) areas, it was possible to analyze and come with conclusions on the influence or the competition between grass and taller or woody plants. For testing grass composition in the area, 10 clamps were used in every camp (G6, G7 & G8). Every clamp have a bush cover of a reasonable density, enough to quantify that the quadrats were laid under the canopy cover. 4 quadrats were laid under each clamp, and 4 outside the canopy cover of the same clamp as in figure 4 and 5. The laying of the quadrats outside the canopy cover was just a meter away from the last leave of the woody plant adjacent to the quadrat under the canopy (same direction). The number of species in each quadrat was recorded, summed and averaged as per clamp in and outside the canopy cover.

Figure 4: Recognizing the grass species under a canopy cover (photo by: J. Jeomba)

Figure 5: Recognizing grass species on an area where there is no bush canopy cover (photo by: J. Jeomba)

4.3. Assessment of bush encroachment: transect laying method

The assessment of bush encroachment and the infesting species was done using the line intercept methods, which involves the laying out a transect and measuring the length of a species intersected. Bauer (1943; cited by Lubbe, 2002) developed the line intercept method for dense, shrub-dominated vegetation. He has found it to be as accurate as traditional quadrat methods, but less time-consuming. If a quadrat is reduced to a single dimension, it becomes a line. The line may be thought of as representing one edge of a vertical plane that is perpendicular to the ground; all plant canopies projecting through that plane, over the line, are tallied. The total decimal fraction of the line covered by each species, multiplied by 100, is equal to its percent cover. Just as with quadrats, total cover can be more that 100%. Disadvantages of the method are the loss of density and frequency measures, because there is no area involved (although frequency can be expressed on a cover basis if the line is broken up into segments).

The transect laying method entails the laying of a transect over a 100 m distance and plant canopies projecting over the line and small plants below or that touches the line are identified, tallied and length and canopy cover determined and found as per hectare. The figure of the determined amount of woody plants per hectare is arrived at by calculations, whereby the average number of woody plants recorded in each line transect covered is further multiplied by 200. This figure (200) is used to in order quantify or convert the number of plants per 50 m of each transect or a transect set to a hectare in the camp. The 200 used in multiplying the number of woody plants in a 50 m line transect is arrived at from the fact that as a rule of thumb 1 hectare measures 100 m by 100 m (square), the 50 m covers a half of the total 100 m on one side of the square making the hectare, as it covers only half of this 100 m, it is then multiplied by 2, and for it to cover the other 100 m to complete the full square making a hectare, it is then multiplied by 100, for simplicity the whole figure of woody plants per 50 m line is therefore multiplied by 200.

When using this method a baseline is established, along which the sampling is conducted. It is a good method where there are variable in the vegetation, this is why it was

used for this purpose of assessing bush encroachment. This is because the line of conduct touches areas where there are rivers, wetlands, uplands, bare and dense areas and by this method representative data can be collected. The instruments used include a 50m long measuring tape, a 0.5 x 0.5 m quandrat and the botanical guide for recognizing the species.

On the selected site and a line determined, a transect was laid to determine the species of grasses that grows under a certain bush species infesting that area (see figure 6). The transects where laid over a distance of 20 m in each plot covering 50 m using a measuring tape and the rod in order to determine: (a) the density (to describe how many individual stems or plants occur per unit ground area), (b) tree canopy cover (to estimate relative areas that a plant controls to receive sunlight), (c) grass plants height as well as species identification in the area. During this process, thorny species were identified, and their canopy cover, height and number where recorded which then formed the basis for an estimate of an extent to which bush infestation is pronounced, and the species and analyze the influence of the infesting species on grass production.

Figure 6: Laying the line transect (photo by: J. Jeomba)

When the method is used the composition of plants that causes the change in vegetation are noted as well as their infestation , the density and the ground cover that they occupy by using the measuring tape at the selected sample sites. As noted the sample is a prerequisite for such a study because counting all plants of a particular specie in a farm or in a camp is not possible, or it is either possible but time consuming.

5. RESULTS AND DISCUSSION

5.1. Study of bush encroachment in Khomas region/Neudamm farm

5.1.1. Investigation of bush encroachment extent in Neudamm farm

Neudamm farm is an infested area by observation, although this have to be proven by research on the extent of infestation. Bush encroachment extent in the farm was done using transect laying method and the number of bushes per hector determined. Using the camps G7, G7 and G8, 4 transects were laid to take data as a sample for each camp. Each laid transect (line) was 50 meters long and all woody plants that come across the line was recorded. Each transect was laid after every 20 meters as highlighted in the previous chapter. The records of the number of woody plants noted in each transect have been simplified in table 2 for camp G6, G7 and G8. These camps were used as samples because it is not possible to take records of all woody plants numbers (encroaching) in the farm or else it is time consuming.

Table 2: The Average woody plants per hectare for all the camps:

Transect	Camp G6		Camp G7		Camp G8	
	Density/ 50 m	Density/ ha	Density/ 50 m	Density/ ha	Density/ 50 m	Density Per ha
T1	28	5600	31	6200	10	2000
T2	25	5000	31	6200	13	2600
T3	17	3400	20	4000	8	1600
T4	15	3000	14	2800	9	1800
Total	85	17000	96	19200	40	8000
Average	21.25	**4250**	24	**4800**	10	**2000**

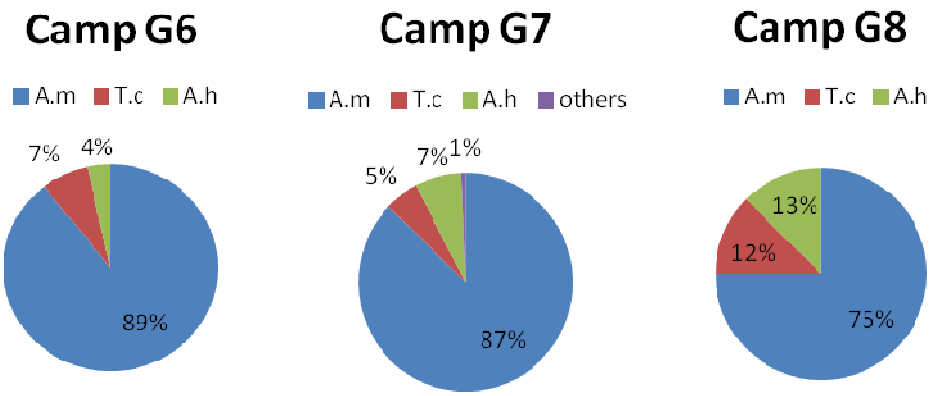
Transects (T1-T4) records the woody plants number per 50 meters line. The main aim of recording the number of plants in a transect is to find out the number of plants that can be estimated as to occur in a hectare, and then in the whole camp as well as the whole farm. The number also helps give an estimate of the number of woody plants that can be found in an area of the same vegetation type, in this case, the Highland Savanna. The camps G6, G7 & G8 has an area of 96 ha, 89 ha and 67 ha, respectively. From table 2, it is easy to calculate the estimated amount of woody plants per camp, where one can multiply the area of each camp with the woody plants per hectare of each camp. The total area of all three camps together add up to 252 hectares. The average number of plants per hectare have also been determined as 3846 woody plants per hectare from the sample transects and calculations. Withought doubt these figures shows that this area is heavily encroached. An encroached area is one that have bush counts or tree counts of >1000 bushes per hectare (De Klerk, 2004). With an average of 3846 bushes per hectare in an area of 252 hectares, it is approvable that Neudamm farm is encroached.

5.1.2. Infesting species in Neudamm farm

The method of determining infestation and infesting species at large was explained in the methodology part of the thesis. Bush encroachment in Neudamm area was studied using the botanical guide (Van Oudtshoorn, 1999) to recognize the plant species, and with the expertise of the research personnel (members of the University of Namibia). The recording of the bush species that encroach the area was done together with the recordings of the data of the line transect explained in the previous section. In each transect laid, the encroaching species were determined and recorded.

In every laid transect it was seen that different species of woody plants were noted. The area is mostly affected by the dominant *Acacia mellifera (Fabaceae)*, other species of *Acacia*, as well as *Tarchonantus camphoratus* (Camphor bush) as shown in the chats on figure 7. The plants in all transects entails the number of plants recorded in the four transects in each camp, they are added together and determined as bushes per 200 m. As is the case in the

previous section, in order to determine the possible amount of each species type per hector or per camp, the number of plants per 200 m can be multiplied by 50 and by the camp area, respectively. The dominant plant species in each of the camps is presented in the pie charts on figure 7.



A.m- *Acacia mellifera,* **T.c**- *Tarchonantus camphorates,* **A.h**- *Acacia hereoensis*

Figure 7: Infesting species in all camps

The highland Savanna is more heterogeneous due to its topographical diversity (Kellner, 1986), it makes it impossible that in this whole vegetation there will only be a few species of woody plants. But *Acacia mellifera* covers more space of the vegetation. The dominance of *Acacia mellifera* is initiated by the sufficient duration of growth that allows plants to set viable seeds and a good seedling establishment (Van der Merwe, 2011). The growth of bush species is initiated by the grazing of animals at a higher rate than the suitable time and rate of grazing, further it is initiated by the prevention of veld fires, or rather the fighting of natural fires that could otherwise hinder with the growth of bushes. It is therefore important to allow fierce fire in times of heavy rainfall of continuous years, because this is what allows bush seedlings establishment and setting viable seeds. In an already encroached area like Neudamm farm and most parts of the highland savanna fire is not more effective, this is due to the fact that there is a little fuel load on the veld. The best possible way of

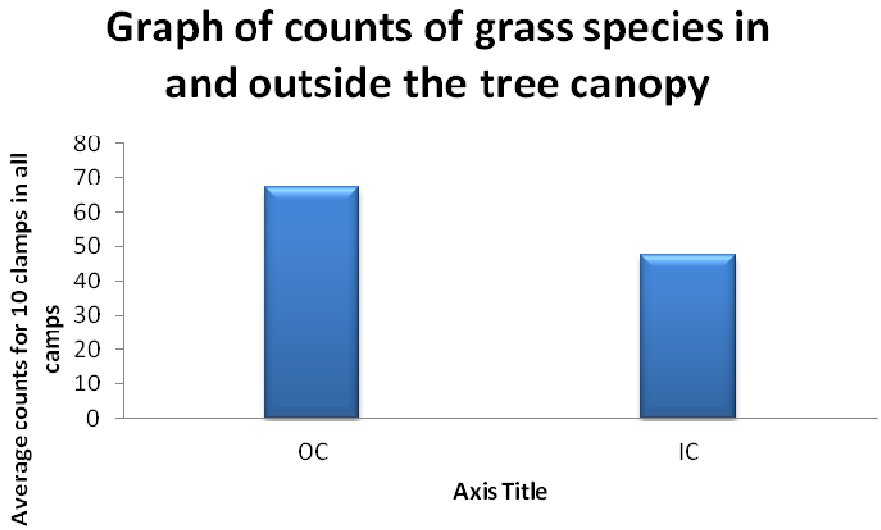
fighting the existing bush encroachment by *Acacia mellifera* at Neudamm farm is by chemical and mechanical means according to Neudamm farm manager. The occurrence of *Acacia mellifera* has exceeded its expected density, even though De Klerk (2004) highlighted that there is no scientific norm of what this plant density should be. The theory of Smith (1999) states that a tree of 1.5 m height in an area that receives less than 350mm of rainfall annually is expected to have a natural density of 700 bushes per hectare. In the case of this research it have been found that 3840 bushes were found per hectare, many of who are *Acacia mellifera* or bushes of a height less than 1.5 m. The findings of the research exceed the expected density norm. Bester (1999), further highlighted that *Acacia mellifera* encroached areas finds a density of 6000 to 16 000 bushes per hectare. Another woody plant species found in the area was *Tarchonantus camphoratus* it is a plant species that grows well in thicket bushveld and shallow soils (Van Wyk, 1997), which a characteristic soil of the Highland Savanna. It was found to occur with other species such as *Acacia hereroensis* and *Acacia hebaclada.* In each transect laid it was found that there exist all these species in combination with the *Acacia mellifera*.

The results of the degree of infestation presented on the charts clearly describes the infestation of bushveld dominated by one species, but on Camp G8 it was noted that there was a slight change in the distribution of species, where there is an increase in the density of *Tarchonantus camphoratus* and *Acacia hereroensis.*

5.1.3. Influence of infesting species on grass production

In camp G6 it was found that in quadrats under the canopy had an average species counts of 4.75 and outside the canopy recorded 6.5 species per quadrat. In camp G7 there was a slight difference, whereby the average species counts under the canopy was 5 species of grass and 7 species of grasses outside the canopy on average. Lastly, Camp G8 recorded an average of 4.5 grass species under the tree canopy and 6.5 species outside the canopy. Summing up all the clamps in each respective camp and averaging the species counts in all camps together it was found that the total average species counts for 10 clamps in three camps under the canopy and

outside the bush canopy was 47.5 and 67 counts, respectively. This is simplified in the graph in figure 8.



OC= outside canopy, IC= Inside canopy

Figure 8: Counts of grass species for all camps

According to the results it is clearly understood that the grass species composition outside the canopies had a higher number of species than under canopies. It can be due to the competition between plant species explained by Wu *et al* (1985) (follow the text on competition between plant species), that water, nutrients and light is extracted by some species of advantage than others who are disadvantaged. One could argue that the lower amount of different species under canopies could mainly be due to insufficient amount of light and water as a result of interception by the tree canopies. Also, disturbance has a role to play in a lower turnout of number of grass species under canopies; this is through trampling and grazing by animals basking under trees for shade. However, previous studies shows that a larger amount of grass species could be found under the tree canopy because of several reasons like more nutrients found under the tree due to nitrogen fixation by *Acacia* species, more organic matter

found under large tree canopies caused by falling leaves from the tree and manure from animal dung as animals stand under the trees for shade (Power *et al*, 2003).

By physical observation grasses under trees are mostly young and greener, this may be due to the fact that animals opt for them first and they are grassed often, so they develop a mechanism of quick regrowth. However, most of the grass species that are not mostly found under the canopy are amongst others, the very sensitive and palatable grass species (*Anthephora pubescens, Brachiaria nigropedata and Schmidtia pappophoroides)*, that escape such disturbances and establish outside canopies, leaving only some opportunistic grasses (*Porgonathria fleckii and Setaria verticilata* and some *Eragrostis* species) and forbs, since they may be favored by or withstand the conditions.

The disturbance or grazing outside canopies is not as constant and concentrated as under canopies. Outside canopies, animals mostly graze in motion because of the larger grazing radius and a greater range forages to select, whereas when under shades or canopies, they stand to graze, avoiding sunlight. Although trees are said to create favorable environments for grasses under their canopies, the case with the *A. mellifera* clumps as shown by results from the study is that such environments do not favor all grass species, but only some. The tree-grass interaction can only favor one that captures and best utilize an optimum combination of moisture, sunlight, and nutrients from the soil. Therefore, tree-grass interaction can be positive or negative to any of the two depending on the species involved. The bush seedling survives better after coppice of grasses by animals and this have been testified by Coffin and Lauenroth (1990). However, researches in some parts indicates that , that competition of bushes with grasses had a significant negative impact on seedling germination of *A. karroo* and some other woody plants (Cramer *et al*., 2007).

The experimental results are not in line with Walter's (1939) two-layer hypothesis, at least in terms of encroachment. Following this equilibrium hypothesis, grasses access water in the upper soil layer while trees use deeper water. When the grasses are removed by grazing, trees have an opportunity to encroach. This does not mean a change in Walter's thoughts, but these results and observations came with conclusions that the fewer grasses and the most

unpalatable found under the tree canopies is a cause of disturbances from trampling animals and always being utilized faster.

6. CONCLUSIONS

Bush encroachment is a real threat to Namibian farmers especially in the Highland Savanna area. It have been found that in normal terms an area which have bush densities of >1000 plants per hectare is referred to as “a bush encroached area”. However, the results did not deviate from that number and it indicates that there are averagely 3840 bushes per hectare in the area of research. Such a huge increase in woody plants over grass species has caused changes in the carrying capacity and lower productivity. Moreover, it was found that the dominant encroaching species are the *Acacia mellifera* covering a large area followed by some *Acacia* species. Other species also found according to the results and observations is the Camphor bush, *Grewia flava*. The results further found the effects of which bushes and their densities have on grass species composition, coming to conclude that more grass species and of higher grazing qualities were found in the areas further from bush canopies. A few grass species composition have been under the canopy of bushes in the selected clamps and those are the most unpalatable grass species, but because they are spotted easily by animals as they rest under trees, especially for shade. The grass species of high quality found on bare areas (bare from bushes) are *Anthephora pubescens, Brachiaria nigropedata and Schmidtia pappophoroides* amongst others, and their heights were as well higher than those under bush canopies. The advantage of increases in woody plants provides resources for building and firewood and increases browse available for browser animals. Considering that the highland savanna’s land is predominantly used for profitable beef production on the farmlands, farmers depend more on natural vegetation as sources of food for animals. The results can encourage other researchers and concerned to develop better ways of preventing bush encroachment. It is better and easier to prevent bush encroachment, looking at the results. It is the only way in which potential farms will continue producing in quantum and achieving their goal of high income. The results can aid by encouraging farmers after looking at the infestation and its consequences to manage their farms using preventative methods to avoid bush encroachment.

7. REFERENCES

- Ashton, F. M., Crafts, A. S. (1973). Mode of action of herbicides, John Wiley and Sons, New York, p. 504
- Barloworld Power, (2010). The-solution-for-bush-encroachment. [online], Available on http://www.bwep.co.za/News/ID/2/BOSCUT-- [Accessible on 24 October 2011]
- Barnes DL (1972). Bush control and veld productivity 1. Modern Farming, Salisbury, p. 10-19
- Bauer H.L., (1943). The Statistical Analysis of Chaparral and Other Plant Communities by Means of Transect Samples: Ecology, 24 (1): 45-60
- Bester F. V. (1998). Major problem bush species and densities in Namibia, in Agricola, p. 2
- Coetzee, M. E., (1998). Preliminary Agro-Ecological Zones. Addendum to Agricola 10, p 28, ISSN: 1015-2334
- Coffin DP, Lauenroth WK (1990). A gap dynamics simulation model of succession in a semi-arid grassland. Ecol Modell. 49: 229–266
- Combating Bush Encroachment for Namibia's Development project (CBEND), (2009). available on http://www.drfn.info/arc/pdf/reports/drfn2774.pdf [Accessible on 22 December 2011]
- Cowling, R.M., P.W. Rundel, P.G. Desmet,. Esler K.J (1998). Extraordinary high regionalscale plant diversity in southern Africa arid lands: sub continental and global comparisons. Diversity and Distribution, 4: 27-36.
- Dahl, J., Nepembe, M. (2001). Socio-economic factors which will influence farmers' participation in a planned monitoring & management project of bush encroachment in Namibia. Ministry of Environment & Tourism, Windhoek, p. 82

- De Klerk, J.N. (2004). Bush Encroachment in Namibia: Report on Phase 1 of the Bush Encroachment Research, Monitoring & Management Project. Ministry of Environment and Tourism, Windhoek, Namibia, p. 12-150

- Doughill, A.J., Thomas, D.G., Heathwaite, A.L. (1999). Environmental change in Kalahari: Intergrated land degredation studies for non-equilibrium dryland environment, Annals of the Association of American Geographers, 89: 19-46, DOI: 10.1111/0004-5608.00156

- Els, J.F. (1995). Flock in Bush Savanna Veld, Production Analysis of Boer Goat, Master thesis, University of Pretoria, Pretoria, South Africa, p. 34

- Erkkilae, A., Siiskonen, H. (1992). Forestry in Namibia 1850-1990, Silva Carelica 20, University of Joensuu, Joensuu, p. 244

- Giess, W. (1971). A preliminary vegetation map of South-West Africa. Dinteria 4, p. 5-114

- Grant, J. A., Koeberl C., Reimold W. U., Schultz P. H. (1997), Gradation of the Roter Kamm impact crater, Namibia, J. Geophys. Res, p. 102, ISBN 16,327-16,338.

- Hudak A. T., Wessman C. A. (1955-1996). Textural analysis of high resolution imagery to quantify bush encroachment in Madikwe Game Reserve, South Africa, 20: 317-330, ISSN 1366-5901

- Hudak, A.T., Wessman C.A. (1998). 'Textural analysis of historical aerial photography to characterize woody plant encroachment in South African Savanna', Remote Sens. Environ, p. 66

- Huffaker, C.B. (1964). Fundamentals of biological weed control, In "Biological Control of Insect Pest and Weeds" (P. DeBach, Ed.), Reinhold, New York, p. 631– 670.

- Klein, H. (2002). “Biological control of alien invasive plants: Principles of Biological control,” Plant Protection research Institute leaflet series: Weeds biocontrol, No 1.3, Pretoria: Agricultural research Council, Plant Protection Research Institute, p 1-4.
- Kruger, B. (2002). Bush encroachment Research, Monitoring and Management Project-(BERMMP): Bio-physical and Socio-economic impact of Bush Encroachment in the Communal areas of Namibia, Desert Research Foundation of Namibia, Windhoek, p. 18
- Lamprey, H.F. (1983). Pastoralism yesterday and today, the overgrazing problem, In: Bouliere, F. (ed.). Tropical Savannas: Ecosystems of the World. Elsevier, Amsterdam The Netherlands. p. 643-666
- Lubbe, L. (2002). Range Management II: notes, p. 5-21
- Malechek, John C., Leinweber, C.L. (1972), Forage selectivity by goats on lightly and heavily grazed ranges. J. Range Manage. Volume 25(2): 105-111
- MET-Ministry of Environment and Tourism (2008). De-bushing and After-care, Final Report. p. 3
- Mendelsohn J., Jarvis. A., Roberts. C., Robertson. T., (2009). Atlas of Namibia: A portrait of the land and its people, 3rd ed, Sunbird Publishers, Cape Town, South Africa, p. 111-113
- Ngikembua, M.T., Muroua D., Jeo R.M., Ekondo F.E., Marker, L.L. (2002). Assessing the ecologal impact of bush encroachment on Namibian farmlands, Unpublished proceedings of the 16th Annual Meeting of the Society for Conservation Biology, Canterbury, p. 14-19
- Owen-Smith, N. (1989). Megaherbivores: The influence of very large body size on ecology, Cambridge: Cambridge University press, p. 188
- Power I.L., Thorrold B.S., Balks M.R. (2003). Soil properties and nitrogen availability in silvopastoral plantings of Acacia melanoxylon in North Island, New Zealand, Agrofor Syst 57, pp. 225–237, DOI: 10.1023/A:1024838311287

- Rothauge. A., (2006). After effects of a hot fire in 2001/2002, Unpublished report, Neudamm Agricultural College, Windhoek, Namibia, p. 7-8
- Sheuyange, A., Oba, G., Weladji, R. B., (2005). Effects of Anthropogenic Fire History on Savanna Vegetation in Northeastern Namibia, Journal of Environmental Management, 75: 189-198, PMID: 15829362
- Schneider, H.P. (1994). Animal health & veterinary medicine in Namibia: Agrivet, p. 1
- Smit, G.N., Rethman, N.F.G. (1999). The influence of tree thinning on the establishment of herbaceous plants in a semi-arid savanna of southern Africa, African Journal of Range & Forage Science. 16(1): 9-18, ISSN: 1022-0119
- Snyman, H.A. (2003). Fire and the dynamics of the semi-arid grassland; influence on plant survival, productivity and water use efficiency, African Journal of Range and Forage Science, p. 20, 29-39
- Stoddart, L.A., Smith, A.D., Box, T.W. (1975). Range Management, 3rd Ed, McGraw-Hill Book Company, New York, USA
- Strohbach, B.J., Sheuyange T.P. (1999). Vegetations Survey of Namibia. Paper Presented at the Annual Research reporting Conference of the Directorate of Agriculture Research and Training, Ministry of Agriculture, Water and Rural Development, Swakopmund, September 1999, p. 94-98
- Teague, W.R., Smit, G.N. (1992). Relations between woody and herbaceous components and the effects of bush-clearing in southern African savannas. Tydskrif van die Wiedingsvereninging van Suider Afrika, 9(2): 60-71, ISSN: 1022-0119
- The World Bank, (2000). World Development Report 2000/2001. Attacking Poverty, New York, N.Y.: Oxford University Press. On http://worldbank.org/poverty/wdrpoverty/report/, referenced in http://www.iiasa.ac.at/Research/POP/pde/briefs/na-econ.html [Accessible on 16 November 2011]

- Trollope, W.S.W. (1974). Role of fire in preventing bush encroachment in the eastern cape: Proceedings of the Grassland Society of Southern Africa, 9: 67-72, ISSN: 1022-0119
- Van der Merve, P. (2011). Agricola compilations, p. 7-21, ISSN: 1015-2334
- Van Oudtshoorn, F. (1999). The guide to the Grasses of Southern Africa, Briza Publications
- Van Wyk, B., Van Wyk, P. 1997. Trees of Southern Africa. Struik Publishers. Cape Town
- Von Wietersheim, F. (1988). Game farming. Africa wildlife, 42 (2), p. 69-75
- Ward, D. (2005). Do We Understand the Causes of Bush Encroachment in Africa Savannas? Africa Journal Range and Forage Science, p. 101-105
- Walter, H., (1971). Ecology of Tropical and Subtropical Vegetation, Oliver and Boyd, Edinburgh, UK, p. 5-134
- Wu, H, Sharp, P.J.H., Walker J., Penridge, L.K. (1985). Ecological field theory: A spartial analysis of resources interference among plants, Ecological modeling, 29: 215-243, ISSN: 03043800
- Zimmermann, I., Joubert, D.F. (2002). A crude quantification of wood that is and can be harvested from bush thickening species in Namibia. Proceedings of the First National Forestry Research Workshop held on 12 and 13 March 2002 in Windhoek, Namibia, Ministry of Environment and Tourism, Forestry Publication 9: 56-66.