EFFECT OF LAND DEGRADATION ON THE ABOVE-GROUND VEGETATION AND SOIL SEED BANK OF A RANGELAND IN KUNENE REGION NAMIBIA

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ABSTRACT

Land degradation is a global threat to ecological, economic, and social sustainability, particularly in semi-arid and arid regions such as Namibia. Degradation is affecting above-ground vegetation and seed bank composition, hindering their recovery. To address this issue, it is crucial to assess land conditions at different levels and develop effective strategies for restoring degraded rangeland. The understanding of how land degradation impacts the seed bank composition could provide insights into the potential for natural regeneration and the need for active restoration efforts. This study assessed and compared the characteristics of the aboveground vegetation and soil seed bank at sites of varying degrees of degradation in the Kunene Region of Namibia. A total of three sites were identified per level of degradation. At each site, two belt transects were set up, and five quadrats were sampled along each transect. Woody plant species were identified and counted in a 20 x 20 m quadrat, while herbaceous plants were assessed in a 1 m^2 quadrant, nested within the larger quadrat. Soil cores samplers measuring 9.7 cm in diameter and 5 cm in depth were obtained using a soil drill at the centre of the 20 x 20 m quadrat. The species diversity, richness, density, and regeneration of the above-ground vegetation showed an ascending pattern along the degradation gradient from high to low. The dominant species in moderate and low degradation sites was *Catophractes alexandri*, while *Pechuel-Loeschea leubnitziae* was the dominant species in high degradation sites. Seed bank species diversity and density increased along the degradation gradient from low to high. Though the high degradation sites recorded the highest density and diversity of seed banks, most of these plants were annual herbaceous species, including alien invasive species, namely *Datura stramonium.* Perennial grasses, with high fodder value, were replaced by annual species in soil seed banks due to degradation. Perennial species dominated low- and moderate-degradation sites. In the seed bank, a few woody species were found at low and moderate degradation sites, while no woody species were found at high degradation sites. The findings emphasise the current and future challenges to the study region and that restoring woody vegetation from soil seed banks has limited potential, hence highlighting and recommending the need for further research.

KEY WORDS: Above-ground vegetation, degradation sites, Kunene region, Land degradation, species composition, soil seed banks.

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LIST OF ABBREVIATIONS

DRFN	Desert Research Foundation of Namibia
FAO	Food and Agriculture Organisation of the United Nation
IECN	Integrated Environmental Consultants Namibia
KRC	Kunene Regional Council
MEFT	Ministry of Environment, Forestry & Tourism
NBRI	National Botanical Research Institute
NGO	Non-Governmental Organisation
PAST	Paleontological Statistics
PCA	Principal Component Analysis
SSB	Soil Seed Bank
UNAM	University of Namibia

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DEDICATION

I dedicated my research project to my late father (Elias Muukonga Nghikwafelwa), who was an inspiration to me and will always be missed.

DECLARATION

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CHAPTER ONE

1. INTRODUCTION

1.1 Background

Land degradation is a negative trend in land conditions caused by direct or indirect human-induced processes, expressed as a loss of biological productivity, ecological integrity, or value to humans (Olsson et al., 2019). Land degradation threatens the dry lands of Sub-Saharan Africa more than any other region in the world. This is because of pressures from human and livestock populations coupled with the effects of recurrent droughts (Abdi et al., 2013). According to the Desert Research Foundation of Namibia (DRFN) (2015), human activities contributing to land degradation include unsustainable agricultural practices, improper soil and water management, deforestation, vegetation removal, excessive use of machinery, overgrazing, inadequate crop rotation, and inefficient irrigation. Additionally, natural occurrences like climate change and landslides can also contribute to land degradation (DRFN, 2015).

As the driest country in Sub-Saharan Africa, Namibia's physical environment presents serious challenges in terms of desertification, overgrazing, deforestation, and drought (Ministry of Environment, Forestry, and Tourism (MEFT), 2014; Klintenberg & Seely, 2015). Large sections of the Namibian land surface are degraded, and landscapes have been simplified due to various land-use patterns, making it one of the conservationists' most challenging issues (Mohammed et al., 2020). As a dry country whose ecosystems are already degraded, climate change is an added stress to already threatened habitats, ecosystems, and species in Namibia (DRFN, 2015). In addition, Namibia's economy relies on climate-sensitive sectors such as agriculture, fisheries, and tourism (Reid et al., 2007), and about 70% of its rural residents are subsistence farmers (DRFN, 2008; Mendelsohn et al., 2002) who depend on rain-fed crops and livestock production for their livelihood, making them vulnerable to climate change and variability.

The Kunene region is one of the worst drought-affected and most degraded regions in Namibia (National Planning Commission (NPC), 2015). It has endured a persistent drought, which, together with other pressures on the rangeland, has resulted in different levels of degradation in the region (Inman et al., 2020). The region is mainly inhabited by pastoral communities that depend heavily on their livestock for subsistence. Therefore, if the region continues to experience droughts, as per climate change predictions for this part of the world, the resource base and, consequently, the livelihoods of the people living in this area will undoubtedly continue to deteriorate (Food and Agriculture Organisation (FAO), 2016).

Avoiding stress and allowing degraded land to recover on its own is the most recommended technique for degradation, second only to the preservation of natural ecosystems, and it has garnered widespread recognition as a means of preventing further biodiversity loss (Mohammed et al., 2020). Hence, in Namibia, the government and non-governmental organisations (NGOs) have begun restoration procedures on the country's degraded lands, mainly by passive rehabilitation techniques such as ex-closures, to reduce land degradation, promote natural plant regeneration, replenish biodiversity, and restore soil fertility (DFRN, 2015). However, restoring degraded areas can be a very slow process, posing a threat to the ecosystem's survival and increasing the vulnerability of the people who depend on the land for ecosystem services (Mitchell, 2004).

A soil seed bank is a significant activator in regenerating degraded areas (Abdella et al., 2007). Hence, it has previously been used as a source of propagules in the recovery of ecosystems where the plant layer has been lost (Mitchell, 2004). However, the success of propagating native species from soil seed banks depends on the level of degradation (Mohammed et al., 2020) and, therefore, the availability of a viable soil seed bank, which in turn may greatly affect the recovery of degraded lands. Therefore, to ensure the successful restoration of degraded land, there is a need to understand the status of the soil seed banks and the influence of land degradation on soil seed banks. It is also crucial to understand the relationship between the above-ground and the seed bank vegetation. There is limited information on the effects of degradation on soil seed banks in Africa. Studies dealing with vegetation in arid and semi-arid pastoral Africa have mainly focused on the above-ground vegetation community rather than on seed banks stored in the soil (Solomon et al., 2006), despite the undisputable importance of the soil seed banks in restoring degraded lands. Thus, this study seeks to assess and compare the characteristics of the aboveground and seed bank vegetation at sites of varying degrees of degradation as part of an effort to identify the best methods for ecological restoration in the region**.**

1.2 Statement of the problem

Namibia is the driest country in Sub-Saharan Africa, with 92% of its land classified as semi-arid, arid, or hyper-arid, and thus land degradation is a serious problem in the country, a situation exacerbated by climate change (DRFN, 2015). It is also worth noting that the climate in Namibia is highly variable, fragile, and unpredictable (Seely et al., 1995). Kunene is one of the regions worst affected by land degradation (NPC, 2015). In addition, due to unsustainable agricultural practices in the region, such as livestock numbers exceeding carrying capacity, land degradation is likely to worsen in the predictable future (FAO, 2016). This problem needs urgent attention as the region is home to some of the country's poorest communities, who are largely dependent on the land for subsistence but lack the adaptive capacity to deal with such changes. Understanding the current status of the above-ground vegetation and soil seed bank is the first step towards predicting the possibility of self-recovery and/or determining the interventions needed to restore Kunene rangelands.

1.3 Objectives

1.3.1 General objective

The general objective of the study was to assess and compare the characteristics of above-ground vegetation and soil seed banks in sites of varying degrees of land degradation in the Kunene Region, Namibia.

1.3.2 Specific objectives

The specific objectives of this study were:

(a) To compare species richness, diversity, density and composition of above-ground vegetation among areas of low, moderate and high degradation levels.

(b) To compare species richness, diversity, density and composition of seed banks among areas of low, moderate and high degradation levels.

(c) To compare species composition between the soil seed banks and above-ground vegetation within the three different levels of degradation (low, moderate and high).

(d) To determine the regeneration capacity of sites with different levels of degradation (low, moderate and high).

1.4 Significance of the study

This study will provide a baseline understanding of the extent of degradation in the study area, particularly regarding above-ground vegetation and soil seed banks. By examining these data, recommendations can be made about how land degradation impacts these aspects and their role in restoration efforts. Furthermore, the findings from this research can shed light on the amount of degradation that is acceptable for the system to recover from the soil seed bank, as well as identify when a threshold is crossed that hinders recovery. Therefore, it is crucial to comprehend both above-ground and seed bank vegetation dynamics to effectively maintain and restore desirable species in degraded systems. Studying these characteristics in different areas of land degradation will help us understand ecosystem resilience and guide restoration initiatives. This knowledge can also provide insights of identifying plant species that are more resilient and have potential for use in restoration projects.

CHAPTER TWO

LITERATURE REVIEW

2.1 Land degradation

Land degradation is one of the additional drivers of biodiversity loss, which would interact with climate change (Praveen et al., 2016). For instance, land degradation causes fertile topsoil to erode with seeds and freshwater resources to be depleted, endangering biodiversity (Ritter, 2012). Change in temperature, rainfall, solar radiation, and wind changes brought on by climate change may exacerbate land degradation (Peterson, 2005). The ongoing loss of the protective plant cover leads to soil erosion and irreversible damage to the land in arid and semi-arid savanna environments where plant species are in high demand for grazing, fuel, and shelter (Archibold, 1995). Habitats in arid and semi-arid areas suffer from many types of degradation, adversely affecting millions of people who depend directly on these ecosystems (Holmes et al., 2008). Various factors (unsustainable agricultural land use, poor soil and water management practices, deforestation, removal of natural vegetation, frequent use of heavy machinery, overgrazing, improper crop rotation, poor irrigation) contribute to this degradation, including climate change (Fuhlendorf et al., 2001). According to Archibold (1995), the southern region of Africa is experiencing significant desertification due to high land demand paired with dry weather.

Land degradation is undeniably a problem in Namibia, owing to deforestation, overgrazing, and soil nutrient depletion (Erkkila & Siiskonen, 1992; Quan et al., 1994). According to Seely and Jacobson (1994), the proximate causes of land degradation in Namibia include both biophysical and land management issues. Non-adaptive management in a high-climate variability is seen as a primary source of land degradation

(Naraa et al., 1993). Rainfall also has a significant influence on soil erosion (Morgan, 1991),especially when the rain water-erodes soils at the end of slopes (downslope),which might delays seed emergence and/or burying young seedlings, and require reseeding of impacted regions again (Ritter, 2012).

2.2 Overview of soil seed banks

The study of the soil seed bank began in 1859, when Charles Darwin witnessed the development of seedlings using soil samples from the bottom of a lake (Mall et al., 2014). Most ecologists (Darwin, 1859; Roberts, 1981; Bannister, 1966; Barclay-Estrup & Gimingham, 1975) began their research by attempting to understand the density of live seeds in the soil. Many scientists have observed the presence and critical significance of seed banks in soil since the beginning of modern biology (Garwood, 1989; Young et al., 1987; Sanford, 2010; Mall et al., 2014). However, soil seed bank research is still in its early stages, despite its importance as a source of variety in plants and long-term occupancy by plants (Mall et al., 2014).

Soil seed banks include all mature, viable seed stocks buried in the soil, littered, or found on the soil's surface (topsoil) (Swaine, 2001). Seeds are an essential component of the ecosystem since they show the current and historical state of standing plants and future deviations (Anju et al., 2022). The presence of buried viable seeds in soil has practical implications for the conservation of various plant species and the control of invasive alien species (Fenner et al., 2005). It is often assumed that the soil seed bank contains the seed resources of native plants and would provide many seedlings for vegetation regeneration (Jalili et al., 2003).

Soil seed banks represent a critical component of terrestrial ecosystems, playing a pivotal role in plant population dynamics, community composition, and ecological succession (Anju et al., 2022). Soil seed banks are essential to ecosystem resilience, serving as a reservoir of regeneration potential in many plant assemblages (González et al., 2009). A healthy soil seed bank, with enough representation of an ecosystem's flora, is critical for the conservation of individual species and plant groups (Fisher et al., 2009). Seed banks can also be used to store genetic material or evolutionary recollections (Thompson, 1978).

Depending on the frequency and intensity of the preceding disturbance, seed banks can act as a "succession primer" for secondary regrowth in abandoned or degraded areas, making them significant determinants of the initial floristic composition after disturbance (Pakeman et al., 2005). The composition of emerging vegetation and its rate of development are significantly influenced by seed bank density and diversity (Thompson et al., 2003). Thus, knowing the seed banks and their relationships to standing vegetation and disturbances is crucial for developing effective strategies for recovering vegetation and comprehending community dynamics (Kassahun et al., 2009).

The dynamics of soil seed banks refer to the changes in seed composition, abundance, and viability over time (Fenner & Thompson, 2005; Scott et al., 2010). Understanding the dynamics of soil seed banks is essential for predicting vegetation changes, assessing restoration potential, and designing effective conservation and land management strategies (Dreber, 2011; Dreber & Elser, 2011). Soil seed banks are not static but are influenced by various factors that affect seed dispersal, germination, and survival (O'Connor, 1991; Leck et al., 1989; Page et al., 2006). Seeds enter the soil seed bank through various means, including seed dispersal by wind, water, animals, or human activities. The composition of the seed bank is influenced by the surrounding vegetation, seed availability, and dispersal mechanisms (Anju et al., 2022). Variation in environmental circumstances affects seed bank dynamics in a variety of ways, including seed production and other life cycle phases (Anju et al., 2022).

Soil conditions significantly influence the growth and size of a seed bank, with the viability of seeds varying depending on factors like seed age, dormancy mechanisms, and environmental conditions (Anju et al., 2022). Some seeds remain viable for a short time, while others persist for years or decades (Bekker et al., 2005; Qian et al., 2016; Savadogo et al., 2017). The persistence of seeds in the soil seed bank is also influenced by factors such as seed traits, soil conditions, and disturbance regimes. Overall, the persistence of seeds is crucial for successful plant growth and development (Levin, 1990). Germination of seeds in the soil seed bank depends on favourable environmental conditions such as moisture, temperature, light, and nutrient availability (Pellissier et al., 2008). Different species have specific germination requirements, and the seed bank can be depleted through germination, predation, decay, or other factors, or replenished through new seed inputs or seed dispersal events. Because of these differences in the characteristics and behaviour of soil seed banks, using one method to study the vegetation dynamics of a specific area, such as the seedling emergence method, may not provide reliable results. Therefore, this study attempts to compare vegetation at two levels: above-ground vegetation vs. seed bank, and to analyse the seed bank using two approaches.

According to Madawala et al. (2016), seeds of herbaceous species dominate the soil seed bank due to their small seed size. Tiny seeds may readily enter deeper soil, facilitating seedling growth in varied conditions. The size also improves their capacity to adapt to changing climates, enhancing their chances of survival (Zhu et al., 2005). Smaller, more compact seeds last longer in the soil. The seeds in forest soils range from 102 to 103 per m^2; in grassland, they range from 103 to 106 per m^2; and in arable soils, they range from 103 to 105 per m^2 (Thompson, 1978).

2.3 The relationship between soil seed bank and above-ground vegetation

Considering the link between the soil seed bank and above-ground vegetation is critical for understanding the effects of restoration and reforestation, as well as the effects of disturbance, succession, invasive species, and management strategies (Hopfensperger, 2007). The link between the soil seed bank and above-ground vegetation provides information on ecosystem dynamics, plant community composition, and the resilience of plant populations (Kassahun et al., 2009). The soil seed bank serves as a reservoir of seeds that can contribute to the establishment and maintenance of above-ground vegetation. Further to the above, the seeds in the soil seed bank represent a historical record of the plant species that have occurred in an area (Dreber, 2011; Tessema et al., 2011). The composition of the seed bank can influence the species composition of the above-ground vegetation (Hopfensperger, 2007). The presence of specific seeds in the soil can, therefore, contribute to the regeneration of particular plant species, leading to their inclusion in the plant community (de Villers et al., 2003; Hopfensperger, 2007).

In the event of a disturbance, such as fire, flood, or human activities, the seeds in the soil seed bank can germinate and help restore the above-ground vegetation (Leck et al., 1989; Scott et al., 2010). This seed bank reservoir allows for the recovery of plant communities and helps maintain biodiversity (Tessema et al., 2011). The availability and composition of the soil seed bank can influence the establishment and growth of above-ground vegetation (Thompson, 1992). If the seed bank lacks certain species or has a low abundance of viable seeds, it may limit the potential diversity and composition of the plant community. In such cases, the above-ground vegetation may be influenced by factors such as seed dispersal from neighboring areas or human intervention (Wilson et al., 1993).

However, the literature contains inconsistent findings. According to a study by Whipple (1978), the seed banks have a connection to the above-ground vegetation. Many plant communities have demonstrated that seed banks differ from above-ground vegetation (Thompson & Grime, 1979).Disturbance and physical stress interact to alter standing vegetation, and as a result, the density of the soil seed bank decreases Grime (1979). Because latent seeds are spread by numerous plant generations, possibly over a lengthy period of time, the species present in the soil seed bank and the above-ground plant groups are generally comparable in often damaged ecosystems (Anju et al., 2022). Ma et al. (2010) established the significance of the soil seed bank in relation to the grazing disturbance gradient and its interaction with the vegetation of alpine meadows on the Tibet plateau, asserting that 39 out of 230 species were shared by both the vegetation and the seed bank.

2.4 The role of soil seed banks in vegetation restoration

Soil seed banks serve as a natural source of seeds that can contribute to the re-establishment of plant communities in degraded or disturbed areas. The presence of persistent soil seed banks must be known in order to estimate the possibility of appropriate regeneration (Teketay, 2005). Soil seed banks are critical in providing information for restoration and maintenance (Harper, 1977), as they play an important role in plant regeneration by replacing individual plants (Taiwo et al., 2018). Soil seed banks also play an important role in vegetation maintenance, succession, ecosystem restoration, and genetic variability conservation (Lemenih & Teketay, 2006). Seed banks contain a reservoir of viable seeds that have accumulated in the soil over time. By harnessing the seeds in the seed bank, restoration practitioners can tap into the local seed pool and promote the establishment of native plant species. The accumulation of long-lived seeds in the soil over time permits the continual re-colonisation of plant species on a site following disruptions (Scott et al., 2010).

Soil seed banks are vital in the vegetation restoration process, and management strategies must account for the variances in seed bank development at each site (González Alday et al., 2009). As early as 1940, Oostings and Humphreys explored the link between soil seed banks and plant succession. Fourie (2008) suggested that the soil seed bank would be sufficient to reestablish a viable cover of indigenous flora following clearance. Including certain missing seeds might help restoration by improving vegetation structure and composition, provided that post-clearing follow-up actions do not prohibit or restrict the establishment of these indigenous species (Fourie, 2008). Seed banks often contain a wide range of species, including both early successional pioneers and late successional species.

By utilising the seeds from the seed bank, restoration efforts can promote a diverse plant community that resembles the original ecosystem.

The seeds present in the soil seed bank are adapted to local environmental conditions; hence, these seeds have experienced and survived the specific climate, soil, and disturbance regimes of the area. Utilising the seeds from the seed bank means that restoration projects can enhance the adaptation and resilience of the plant community to the local environment. However, a study of soil seed banks along a degradation gradient in arid rangelands of the Somali region in eastern Ethiopia revealed insufficient evidence to show that severely degraded rangelands maintain adequate soil seed banks that could be improved through restoration (Kassahun et al., 2009). Interestingly, some other authors (Klimkowska et al., 2009; Thompson et al., 1992) have proposed that establishing new species in severely disturbed areas is more dependent on seed banks. In contrast, restoration in less disturbed and mature meadows did not rely on seed banks, and, according to Ma et al. (2010), the establishment of vegetation in these communities is more likely to rely on seed dispersal from standing vegetation and species with vegetative reproduction.

In areas with low land degradation, the seed bank characteristics may include a diverse range of seeds from various plant species (Inman et al., 2020). The soil might contain a high number of viable seeds from various plant species, indicating a healthy and resilient ecosystem (Teketay, 1998). In areas of moderate land degradation, the seed bank characteristics may show signs of decline (Inman, 2020). The species composition might be less diverse, and the number of viable seeds may decrease. This could be due to factors such as soil erosion, nutrient depletion, or encroachment by invasive species (Anju et al., 2022). In areas of high land degradation, the seed bank characteristics are likely to be significantly affected (Inman, 2020). The soil may contain a limited number of viable seeds, with a reduced diversity of the aboveground and seed bank vegetation species (Dreber, 2011; Tessema et al., 2011). This could be a result of intensive land use practices, habitat loss, or pollution, which can negatively impact seed germination and survival (Bakker, 1989).

The soil seed bank is a key potential seed source for plant ecosystem restoration (Beatrijs & Olivier, 2008). Knowing which species are at risk of local extinction and which could be able to colonise a site if a site is altered, for example, can be inferred from the seed bank's makeup (Zepeda et al., 2014). The diversity of seed banks can provide information on the degree of degradation, their relationship to standing vegetation, as well as reactions to various environmental conditions, making seed bank research a useful tool for conservation and restoration (Zepeda et al., 2014).

There are two generally used procedures for assessing the composition of seed banks: seed extraction and seedling emergence (Roberts, 1981). The extraction approach (via sieving) is thought to provide a more accurate quantitative estimate of total seed bank densities (Brown 1992). However, it is not widely employed since it is time-consuming, useless for locating tiny seeded species, and may overstate the viable seed bank by incorporating non-viable seeds (Baskin & Baskin 1998). In contrast, the seedling emergence method, while it may significantly underestimate the density of the seed bank due to errors associated with seed dormancy and specific environmental requirements for germination (Wright & Clarke 2009), is widely used and provides a good indication of the readily germinable seed bank.

Seed banks are classified into two types: soil and canopy seed banks. A canopy seed bank, also known as an aerial seed bank, is a collection of viable seed stored within a plant's canopy (Lamont et al., 1991). Canopy seed banks form when plants postpone seed release for any reason. It is frequently related with serotiny, which is the tendency of some plants to store seed in cones (e.g., in the genus Pinus) or woody fruits (e.g., in the species Banksia) until seed release is triggered by the passage of wildfire. It is also found in plants that colonise places with changing sands, such as sand dunes. In such instances, the seed is kept in the canopy even if it is buried.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

The fieldwork was carried out around Otjimuhaka village, situated in Epupa Constituency in Kunene Region (Fig.1). Kunene Region is located in north-western Namibia, bordering Angola in the north, Otjozondjupa Region to the east, Erongo Region to the south and the Atlantic Ocean to the west. There are 86 856 people living in Kunene, of whom 17 696 are residents of Epupa Constituency (NPC, 2015). Kunene is home to the ovaHimba people, who are predominantly pastoralists and semi-nomadic (Inman, 2020). One of the main means of livelihoods for many rural households in the Kunene Region is, therefore, livestock production. Kunene contains a mosaic of shrubland-woodland vegetation and the vegetation in this environment is primarily Mopane savanna (colophospermum mopane), mixed woods with many species of Acacia, Cammiphora, and Terminalia. (Mendelsohn et al., 2002). The geology of Kunene is complex with massive Mesoproterozoic igneous complex, mostly formed of anorthosites and gabbroic rocks that stretches from southwest Angola to northwest Namibia. It experiences irregular annual rainfall that ranges from less than 50 to 415 mm from west to east (Integrated Environmental Consultants Namibia (IECN), 2011). Summer daytime highs can frequently reach 35 °C, with an average low temperature of 14 °C. The typical wintertime temperature is between 5 and 26 °C (Kunene Regional Council, 2015).

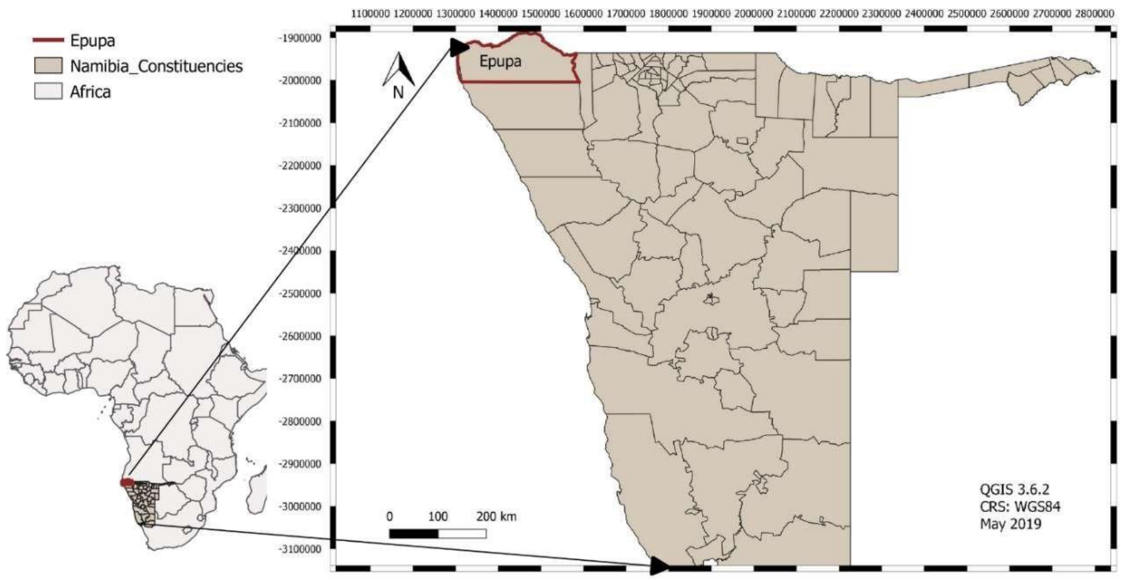

Figure 1: Location of the study area in Namibia's Kunene Region. Adopted from Inman, 2020.

3.2 Data collection

The study was conducted between April and July 2022. Sites representing different levels of degradation (low, moderate, and high) were identified in villages surrounding Otjimuhaka, following classification of degradation as perceived by livestock herders (Inman et al.,2020). For this study, three sites were randomly selected at each level of degradation (thus, nine sites in total), all of which were 3-6 km apart. Data were collected at three levels, as outlined below.

3.2.1 Above-ground vegetation sampling

At each site, two belt transects of 100m x 20m were laid out next to each other, 100m apart. On each transect, five 20m x 20m quadrats (Fig. 2) were demarcated at 10m intervals, and all the woody plants (trees and shrubs) in each quadrat were identified to species level, counted, and their height and diameter at breast height (dbh) measured using ranging poles and a flexible tape, respectively. All herbaceous plants in a 1m x 1m plot, nested within the 20m x 20m quadrat in the upper right corner/northeast direction (Fig. 2), were identified by species level where possible and their percentage cover was visually determined per species. The plant species were identified on site using books as identification guides, and for those species that could not be identified in the field, samples were collected and taken to the National Botanical Research Institute (NBRI), in Windhoek, for identification.

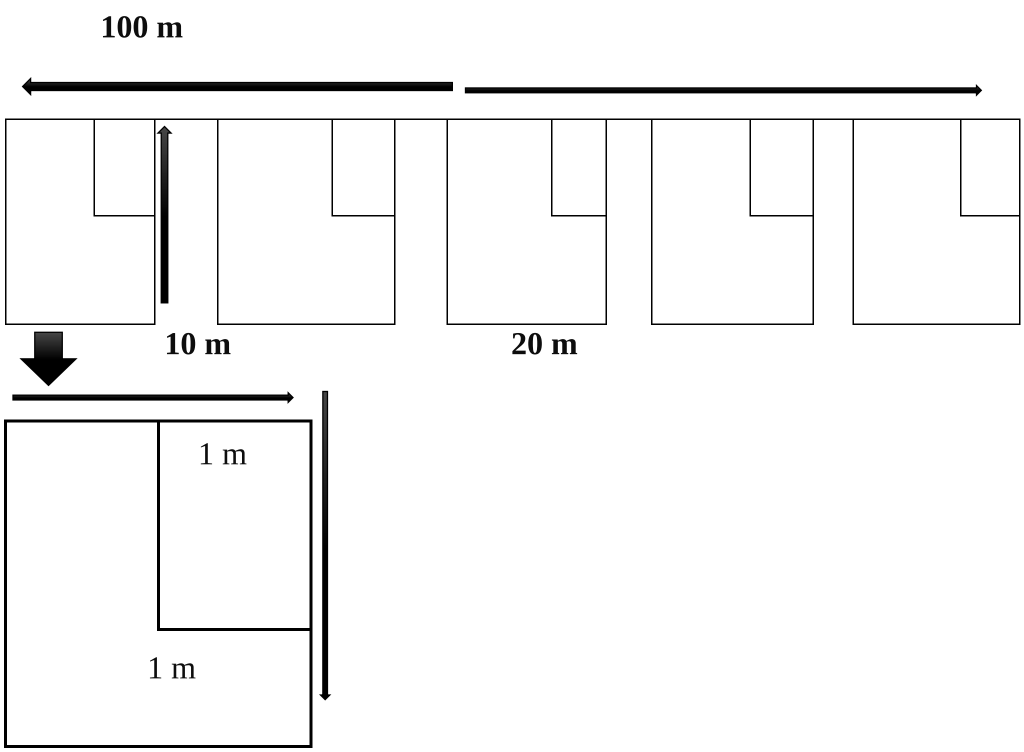

Figure 2: Layout of the sampling units in the field: belt transects of 100 m x 20 m with 10m interval and 20 m by 20 m quadrat for woody species and nested within it, displaying the reference corner (north-east direction), and a 1 m x 1 m plot for herbaceous plant sampling (not drawn to scale).

3.2.2 Soil sampling

To investigate the composition, density, and diversity of the soil seed bank, two soil samples were taken from the centre of each 20 m by 20 m quadrat by hammering a hollow metal ring, 5 cm in depth and 9.7 cm in diameter, into the soil until it was filled to the brim and levelled off (equal volume). A total of 180 soil samples were collected: 3 levels of degradation, 3 sites, and 2 belt transects, 5 plots, and 2 samples. The soil samples were collected into zip-lock plastic bags and taken to the greenhouse of the University of Namibia in Windhoek for further processing.

3.2.3 Seedling establishment and seed identification from soil samples

3.2.3.1 Seedling establishment

The seedling emergence method, though it can dramatically underestimate the density of the seed bank due to errors associated with seed dormancy and specific environmental requirements for germination (Wright & Clarke, 2009), is commonly used and gives a good indication of the readily germinable seed bank (Espeland et al., 2010). Therefore, this was used as the main method to determine the composition, density, and diversity of the seed banks.

One of the two soil samples collected in each quadrat (i.e., 90 of the 180 samples) was placed in a 20 cm × 20 cm polythene bag with a base of store bought sterile sand and allowed to germinate in a greenhouse, in the Department of Environmental Science at the University of Namibia in Windhoek. The bags were arranged randomly in the greenhouse and kept continuously moist by watering daily with a watering can. Germination was recorded daily in each bag by counting each new seedling and identifying it to species level where possible. Germination was recorded for 4 months (March to June), until no new germinations were recorded for a consecutive period of 7 days, to reduce the chances of underestimating the composition of the seed bank. Any seedlings that could not be identified by the end of the experiment were send to the National Botanical Research Institute (NBRI) for identification.

3.2.3.2 Seed identification from soil samples

To ensure that the study does not exclude seeds that might be present in the soil seed bank but missed by the seedling emergence method, as explained above, the other half of the soil samples (n = 90) were sieved with a 12 mesh sieve, allowing for the direct identification of seeds in the soil seed bank. The seeds that were not identifiable with the naked eye were examined under a microscope or magnifying glass (Malone, 1967).

3.3 Data manipulation and analysis

3.3.1. Species richness, density and diversity

For the seed banks, the total number of seedlings and seeds per species identified from both the emergence and sieving methods, respectively, were combined for each degradation level. Aboveground woody plant density was determined as the number of individuals per plot (400 m2). To determine the seed bank size and density, the total number of seeds identified in each soil core (5 cm deep and 9.7 cm diameter) through the sieving and floatation methods and the total number of seedlings identified through the emergence method were combined. The seed bank density was determined by calculating the volume of the cylinder and the total number of seeds. The total number of seeds, dividing it by the volume of the cylinder (total surface area (299.43) * depth (5cm) = volume =1497.15 cubic cm), was calculated (Teketay, 1998).

Species diversity for the aboveground and seed bank was calculated using the Shannon diversity index as follows:

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where *H* = Shannon diversity index, *S* = number of species in each microsite replicate, and *Pi* = relative abundance of species *i*.

To test for statistical differences in the density, species richness, and diversity of both the aboveground and seed banks, a Kruskal-Wallis test in IBM SPSS v. 25 (SPSS Inc, 2017) was used and tested at level of $p < 0.05$ as significant difference . The Dunn's post-hoc test was used to determine which degradation levels (if any) differed significantly in terms of species density, richness, and diversity.

3.3.2. Herbaceous cover

The medians of herbaceous cover were compared between the three degradation levels using a Kruskal-Wallis test. In order to clarify where significant differences ($p < 0.05$) in the data were, a Mann-Whitney U test was utilised.

3.3.3. Species composition

A Principal Component Analysis (PCA) in the Paleontological Statistics (PAST) software v.1.99 (PAST Inc., 2018) was used to provide possible groupings of the different plots based on similarity in species composition using presence and absence data matrices. Species were used on the ordination diagrams as explanatory variables for the groupings.

3.3.4. Regeneration capacity/status

All aboveground woody plants were classified as either seedlings, saplings, or mature plants according to their height and diameter at breast height or diameter at root collar (DBH/DRC) as follows: Established seedlings were considered individuals <3.2 cm in diameter and >30 cm in height, while saplings were considered individuals of dbh 3.2 - 9.6 cm (Sagar & Singh, 2005). Adult plants were considered individuals >9.6 cm in dbh.

The regeneration status of woody plants was calculated following Khumbongmayum et al. (2006) as follows, based on number of individuals:

- If seedling > sapling > mature tree, it has "***good***" regeneration.
- If seedling > sapling < mature tree, the regeneration status is "***fair***".
- If it exists only in the sapling stage but not as seedlings (although saplings may be less than, more than, or equal to mature), the regeneration of that species is "poor."
- if a species is absent both in the sapling and seedling stages but present as mature, the status is "***none***"; and
- If a species has no individuals in mature stage but only sapling and/or seedling stages, the species is "***new***."

3.3.5 Ethical Considerations

Ethics and morality were crucial in research, guiding researchers to ensure informed consent, protect privacy, assess risks, and care for vulnerable groups. Obtaining an ethical clearance certificate from an oversight board was essential to ensure that the study met established ethical standards. Following these guidelines not only safeguarded participant rights but also enhanced the credibility of the findings and contributed to responsible knowledge. Please see the attached Appendix 1 for further details.

CHAPTER FOUR

RESULTS

4.1 Comparing species richness, diversity, density and composition of above-ground vegetation among levels of degradation.

4.1.1. Species richness

There were significant differences in species richness in the above-ground vegetation among the three levels of degradation ($F = 13.37$, df =2, $p < 0.05$). The post hoc test further revealed significantly higher species richness at the low degradation level than at the high degradation level ($p < 0.05$), and at the moderate degradation level than at the high degradation level ($p < 0.05$). There was, however, no significant difference ($p > 0.05$) in plant species richness between the moderate and low degradation levels (Figure 3).

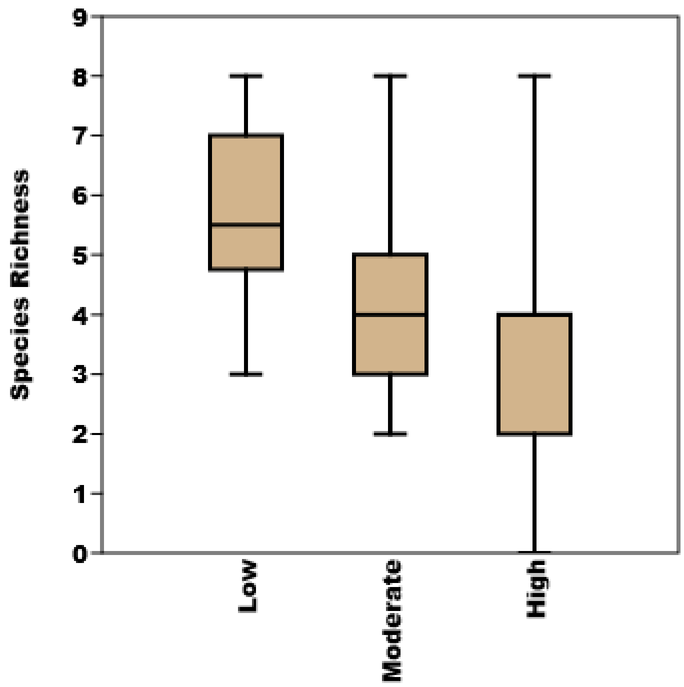

Figure 3: Species richness of the above-ground vegetation among three degradation levels in the Kunene region of the north-west Namibia.

4.1.2. Species diversity

There was a significant difference in woody plant species diversity among the three levels of degradation ($F = 57.02$, df =2, $p < 0.05$) (Fig. 4A). The post hoc test further revealed a significantly higher woody plant species diversity at the low degradation level than at the moderate ($p < 0.05$) and high degradation levels ($p < 0.05$), respectively. There was no significant difference ($p > 0.050$) in woody plant species diversity between the moderate and high degradation levels (Fig. 4A).

Above-ground herbaceous species diversity was also significantly different among the three degradation levels ($F = 5.629$, df = 2, $p < 0.05$) (Fig. 4B). The post hoc test further revealed a significantly higher herbaceous plant species diversity in the high degradation level than the low ($p < 0.05$) and significantly higher herbaceous plant species diversity in the moderate degradation levels than the low ($p < 0.05$). Herbaceous plant species diversity did not differ significantly between the moderate and high degradation levels ($p > 0.05$) (Fig. 4B).

A B

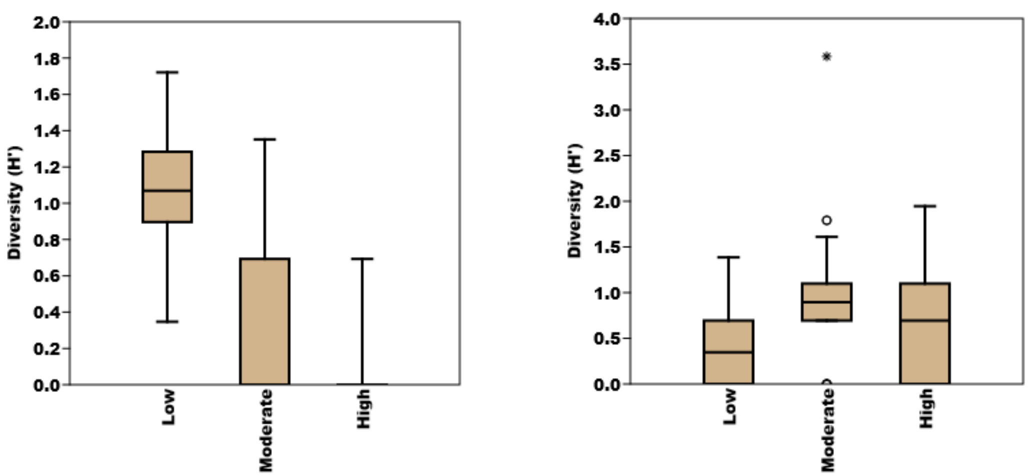

Figure 4: Box plot comparing the woody (A) and herbaceous species (B) diversity (H') among three degradation levels in the Kunene region of the north-west Namibia.

4.1.3 Species density (woody) and cover (herbaceous)

There was a significant difference in the woody plant species density of the above-ground vegetation among the three levels of degradation ($F = 14.94$, df =2, $p < 0.05$). The post hoc test further revealed a significantly higher woody plant species density at the low degradation level than at the high ($p < 0.05$) and moderate degradation levels ($p < 0.05$), respectively. There was no significant difference ($p > 0.05$) in woody plant species density between the moderate and high degradation levels (Fig. 5A).

There was a significant difference in the herbaceous plant species cover of the above-ground vegetation among the three levels of degradation ($F = 7.302$, df =2, $p < 0.05$). The post hoc test further revealed a significantly higher herbaceous plant species cover at the moderate and high degradation level than at the high ($p < 0.05$). No other significant differences were observed in herbaceous species cover (Fig. 5B).

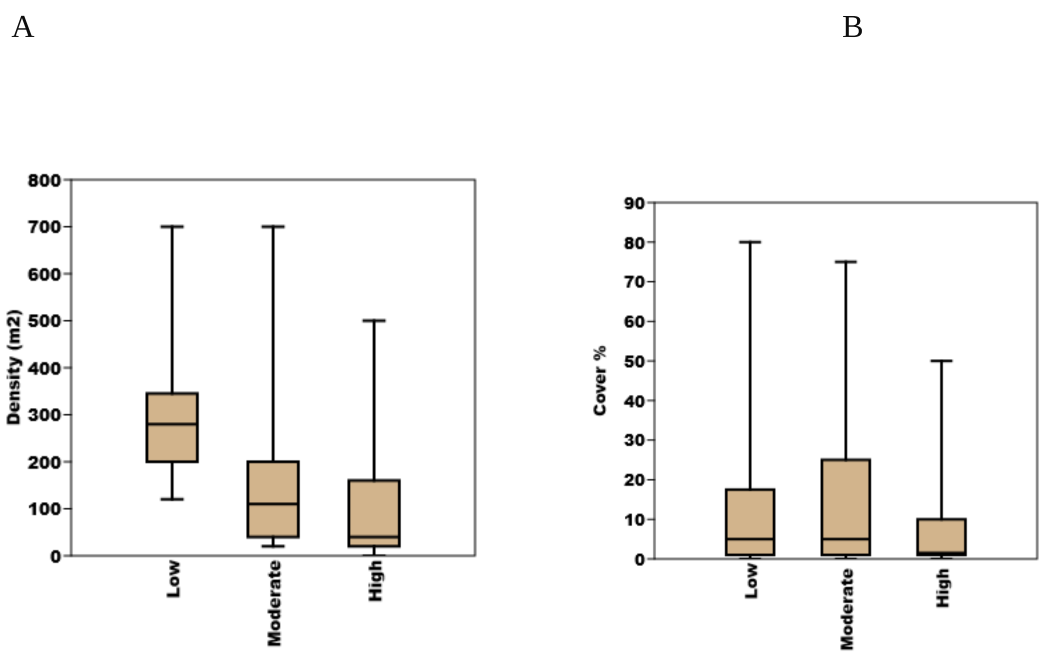

Figure 5: Box plot comparing the woody species density (A) and herbaceous cover (B) among three degradation levels in the Kunene region of the north-west Namibia.

4.1.4. Species composition of the above-ground vegetation

The above-ground vegetation had a total of 61 species, which belonged to 17 families. The Asteraceae was the most dominant family, contributing 41.8% of species, followed by the Bignoniaceae (20%), the Fabaceae (13%), and the Poaceae (9%). The proportions of annuals and perennials were 6.2% and 93.8%, respectively (Table 1), across all the sites. The five woody species across all degradation levels with the highest percentage were *Catophractes alexandri* (27.7%), *Pechuel-Loeschea leubnitziae* (25.7%), *Colophospermum mopane* (20.1%), *Croton gratissimus (6.5%), and Terminalia prunioides* (6.4%). The five dominant species made up 68.4% of the total of 800 plants belonging to 31 species. *Catophractes alexandri* was the most abundant species in the low degradation and moderate degradation sites, while *Pechuel-Loeschea leubnitziae* was the most abundant woody species at the high degradation level.

Among the 30 herbaceous plant species observed, grasses accounted for 65%, while forbs comprised 35%. The majority of these species are from the families Poaceae (45.8%) and Zygophyllaceae (12.6%). Perennial and annual herbs accounted for 69.5% and 30.5% across all levels of degradation, respectively. In the high degradation sites, species that dominated were *Tribulus terrestris* (perennial), *Sesuvium sesuvidides* (perennial), and *Tragus berteronianus* (annual), while in the moderate sites, species that dominated were *Anthephora schinzii* (annual), *Melinis repens* (perennial), and *Eragrostis dinteri* (annual), and lastly, in the low degradation sites, species that dominated were perennial grasses such as *Aristida meridionalis*, *Melinis repens*, and *Stipagrostis uniplumis* (Tables 2 and 3).

The PCA, which explains 35.5% of the total variance (PCA 1 = 21.0% and PCA 2 = 14.5%), produced three main groupings (Fig. 6). The first group (black ring) was species generally composed of sites with high degradation levels (Fig. 6). This group is mainly associated with a relatively unpalatable species, *Pechuel-Loeschea leubnitziae*. The second group (green ring) is species with a moderate degradation level, associated with such as *Melinis repens (*Fig. 6*)*, and the third group (the red ring) are species found at low degradation levels and are associated with species such as *Catophractes alexandri* (Fig. 6).

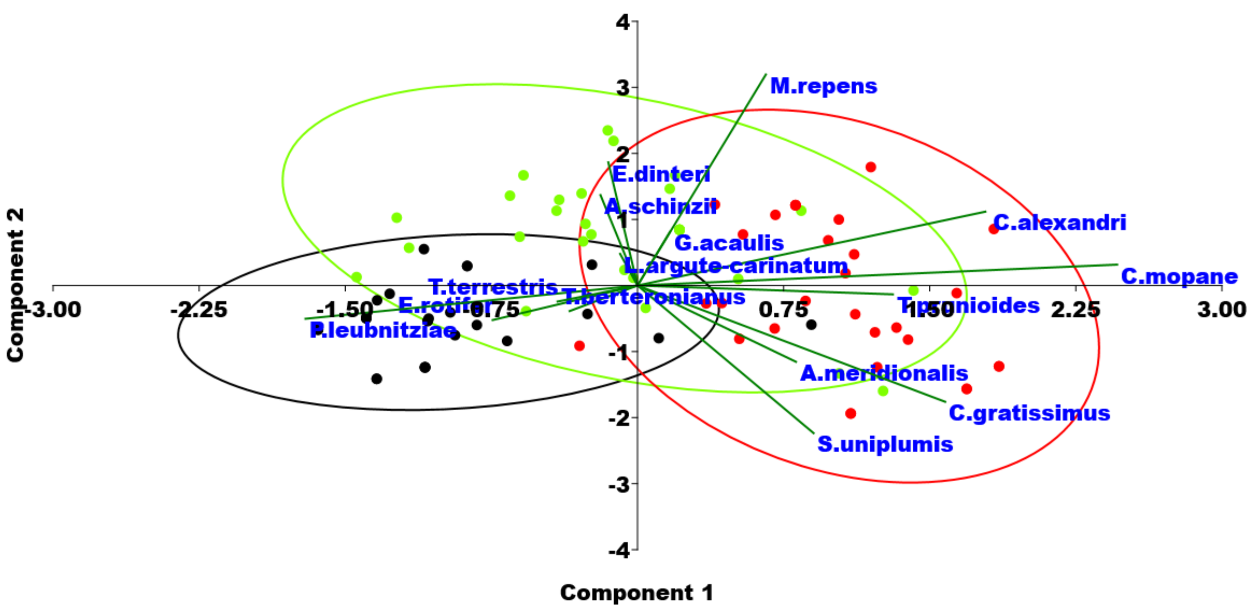

Figure 6: Principal component analysis (PCA) ordination diagram indicating the comparison of the above-ground vegetation between the low, moderate and high degradation levels. The groupings are based on species presence/absence data. The black dots represent the high, the green dots represent moderate and the red dots represent the low degradation level.

4.2. Comparing species richness, diversity, density and composition of seed banks among levels of degradation.

4.2.1 Species richness

There was a significant difference in the species richness of the soil seed bank among the three levels of degradation ($F = 5.936$, df =2, $p < 0.05$). The post hoc test further revealed a significantly higher species richness at the high degradation level than at the low degradation level ($p < 0.05$), but no significant difference in species richness between the moderate and low degradation levels or between the moderate and high degradation levels ($p > 0.05$) (Figure 7)

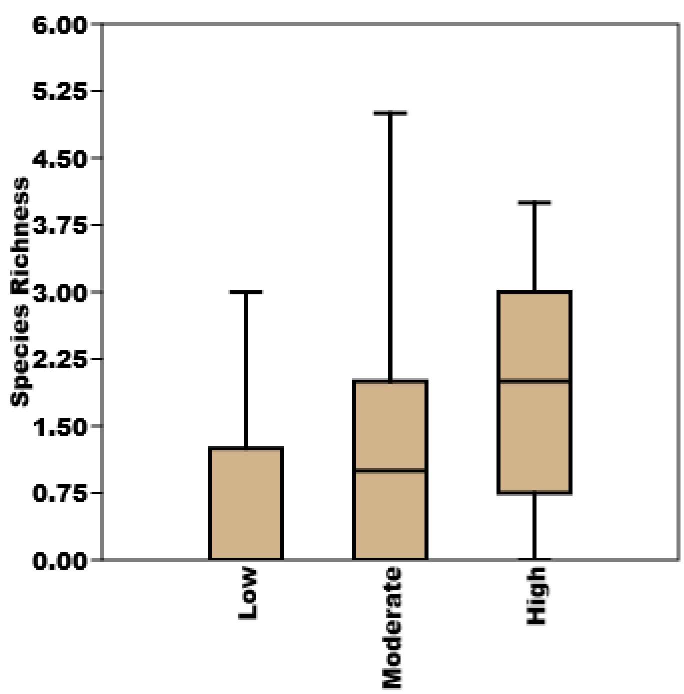

Figure 7: Species richness of the soil seed banks among three different degradation levels.

4.2.2 Species diversity

There was a significant difference in species diversity among the three levels of degradation ($F = 5.348$, df =2, $p < 0.05$). The post hoc test further revealed that the high degradation level had significantly higher species diversity than the low level ($p < 0.05$). No other significant differences were observed (Fig. 8).

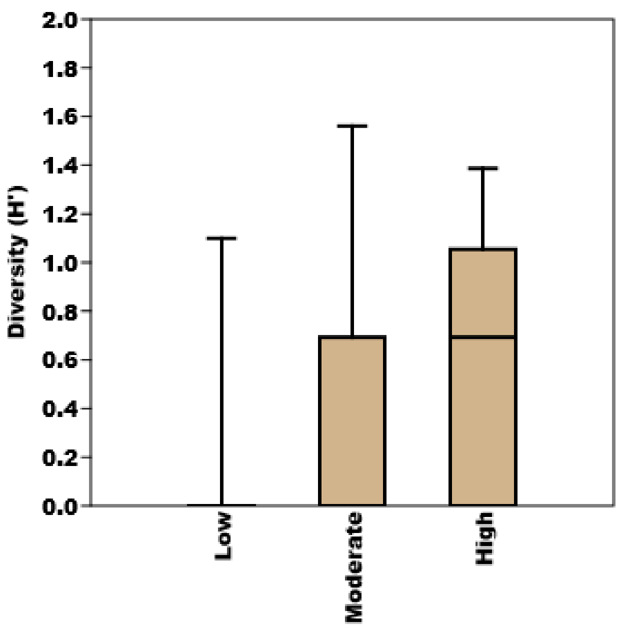

Figure 8: A box plot showing the seed bank species diversity (H) comparisons among three degradation levels of seed bank.

4.2.3 Species density

There was a significant difference in the species density of seed banks among the three levels of degradation ($F = 3.081$, df = 2, $p < 0.05$). The post hoc test revealed a significantly higher species density at the high than the low degradation level ($p < 0.05$), with the other comparisons not yielding significant differences in plant species density (Fig. 9).

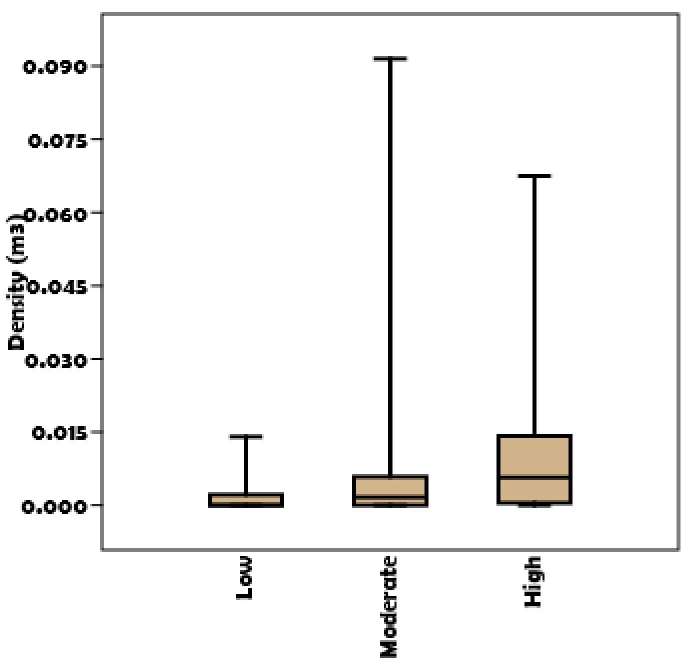

Figure 9: A box plot showing the species density comparisons of soil seed bank among three degradation levels.

4.2.4. Species composition of the soil seed banks

A total of 32 species from 11 families were identified within the soil seed banks across the three levels of degradation (Table 2). The dominant families represented in the seed banks included Poaceae (accounting for 45.8% of the total), Fabaceae (making up 12.7%), and Zygophyllaceae (contributing 12.6%). Among these species, 53.1% were classified as annuals, while the remaining 46.8% were classified as perennials. Sixty-three (63) germinated seeds were counted, with all herbaceous species belonging to 16 species and seven families. Specifically, in sites with high degradation, 38 seedlings were recorded. In sites with moderate degradation, 23 seedlings were recorded, while in sites with low degradation, only two seedlings were recorded. The most common families were Solanaceae (22%), followed by Poaceae (20%). Throughout the soil identification procedure (sieving), 822 seeds were found belonging to 23 distinct species and nine families. The study recorded 21 species in the high degradation sites, 14 in the moderate degradation sites, and 11 in the low degradation sites.

In the high degradation sites, the dominant species were *Stipagrostis uniplumis, Datura stramonium*, and *Euphorbia prostrata*; in the moderate degradation sites, *Anthephora schinzii, Tribulus terrestris*, and *Indigofera auricoma*; and in the low degradation sites, *Melinis repens, Catophractes alexandri*, and *Croton gratissimus* (Table 2). Annuals outnumbered perennials in high degradation sites, but perennials outnumbered annuals in moderate and low degradation sites.

The PCA, which explained 31.3% of the total variance (PCA 1 = 17.7% and PCA 2 = 13.6%), produced three main groupings (Fig. 10). The first group (black ring) was species generally composed of sites with high degradation levels (Fig. 10). This group is mainly associated with *Euphorbia prostrata* and *Tribulus terrestris*. The second group (green ring) is species from moderate degradation levels, associated with species like *Indigofera auricoma* and *Kahontia caespitosa* (Fig. 10). And the third group (red ring) are species found at low degradation levels and are associated with species like *Croton gratissimus* and *Melinis repens* (Fig. 10).

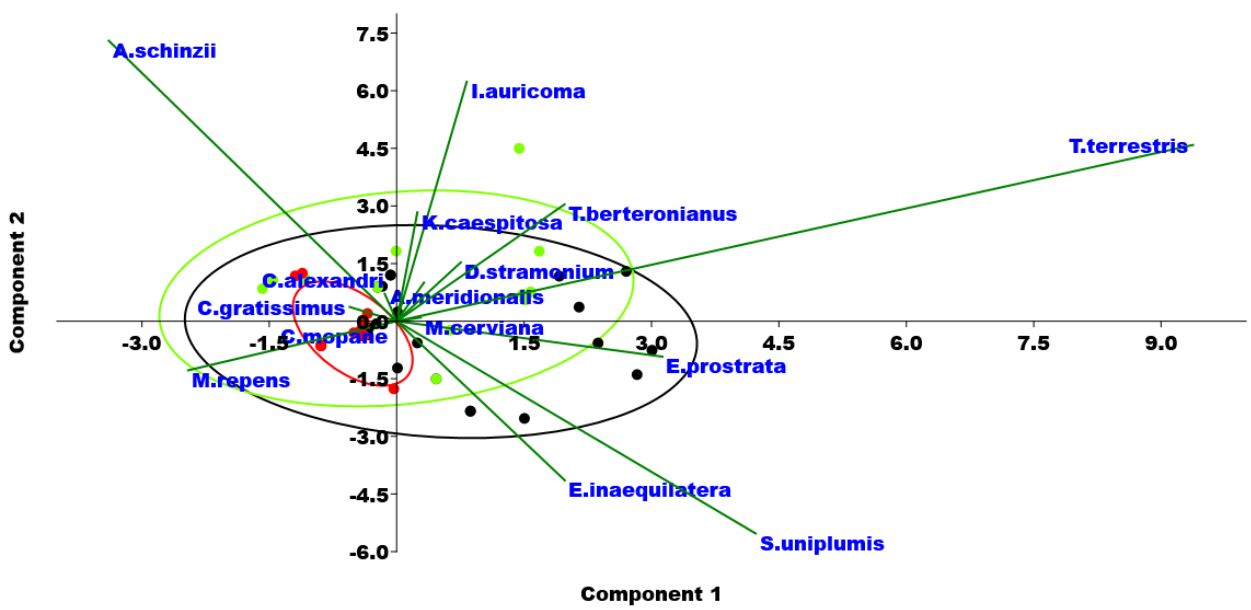

Figure 10: PCA ordination indicating the comparison of the seed bank between the three degradation levels (Low, Moderate and High). The groupings are based on species presence/absence data. The black dots represent the high, the green dots represent moderate and the red dots represent the low degradation.

4.3. Comparing species composition between the soil seed banks and above-ground vegetation within levels of degradation.

4.3.1 High degradation level

The PCA, which explained 35.2% of the total variance (PCA 1 = 20.6% and PCA 2 = 14.6%), produced two rings that are overlapping (Fig. 11). The first group (black ring) was above-ground species from one of the high degradation sites (Fig. 11). This group is mainly associated with a relatively unpalatable species, *Pechuel-Loeschea leubnitziae*. The second group (green ring) are seed bank species of high degradation sites, associated with species such as *Tribulus terrestris* and *Tragus berteronianus* (Fig. 11).

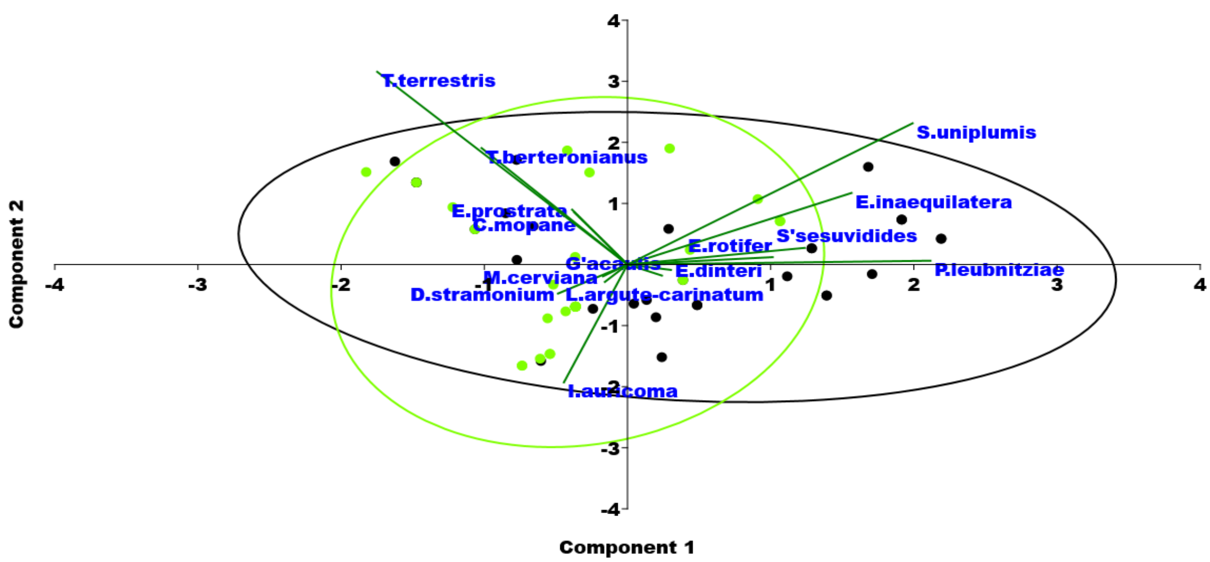

Figure 11: PCA ordination indicating the comparison between the above-ground vegetation and soil seed bank species of the high degradation site. The groupings are based on species presence/absence data. The black dots represent the above-ground vegetation, and the green dots represent the soil seed bank.

4.3.2 Moderate degradation level.

The PCA, which explained 41.1% of the total variance (PCA 1 = 23.1% and PCA 2 = 18.3%), produced two groupings (Fig. 12). The first group (black ring) was above-ground plants generally composed of sites with moderate degradation (Fig. 12). This group is mainly associated with species such as *M. repens and C.mopane*. The second group (green ring) are seed bank species from moderate degradation sites, associated with species such as *Kohautia caespitosa* and *Tribulus terrestris* (Fig. 12).

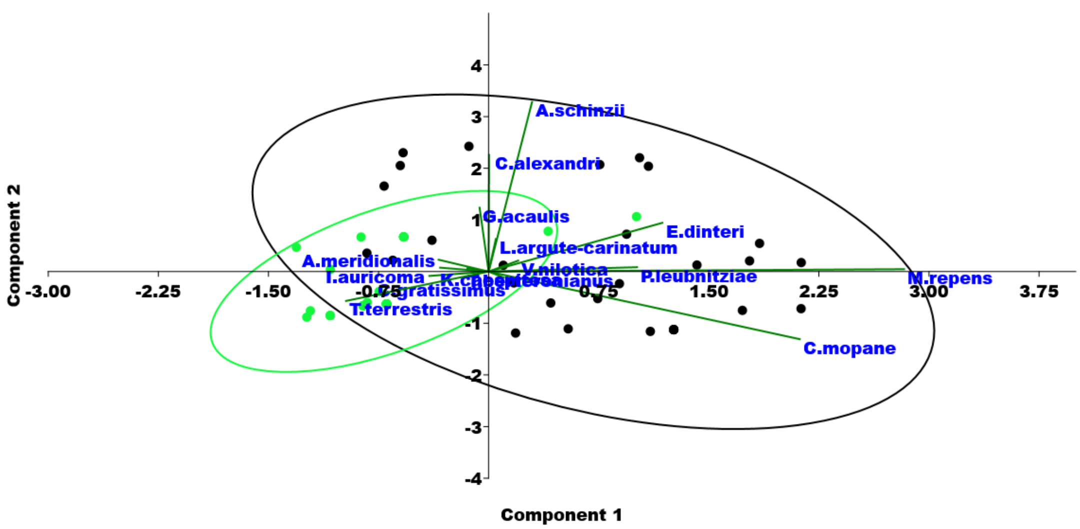

Figure 12: PCA ordination indicating the comparison between the above-ground vegetation and soil seed bank species in moderate degradation level. The groupings are based on species presence/absence data. The black dots represent above-ground vegetation and the green dots represent the soil seed bank.

4.3.3 Low degradation level.

The PCA, which explained 46.3% of the total variance (PCA 1 = 31.2% and PCA 2 = 15.1%), produced two groupings (Fig. 13). The first group (black ring) was species generally composed of sites with low degradation (Fig. 13). This group was mainly associated with species such as *M.repens*, *C.alexandrii*, and *C.mopane*. The second group (green ring) are seed bank species with low degradation levels, associated with species such as *Kohautia caespitosa* (Fig. 13).

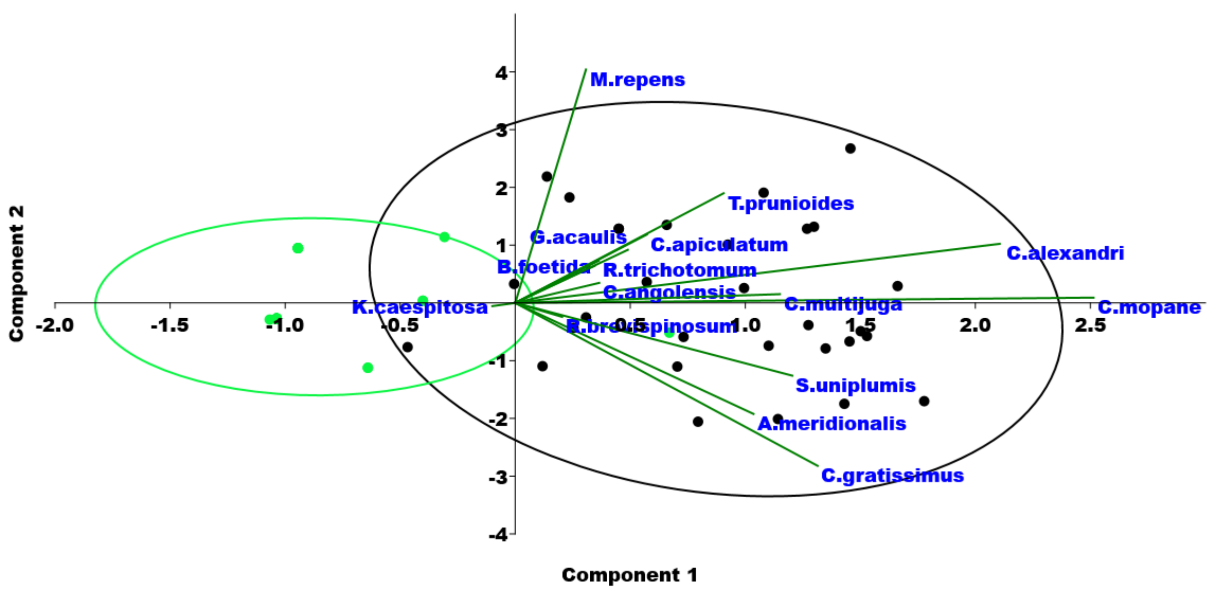

Figure 13: PCA ordination indicating the comparison between the above-ground vegetation and soil seed bank species from low degradation sites. The groupings are based on species presence/absence data. The black dots represent the above-ground vegetation and the green dots represent the seed bank.

4.4 Regeneration capacity of sites

The high degradation level had new regeneration, with more saplings and seedlings. The regeneration status of the moderate and low degradation sites was poor because the density of saplings was greater than that of seedlings and mature trees (Figure 14). The mean was similar across the three levels of degradation (F = 2.516, df =2, p >0.05).

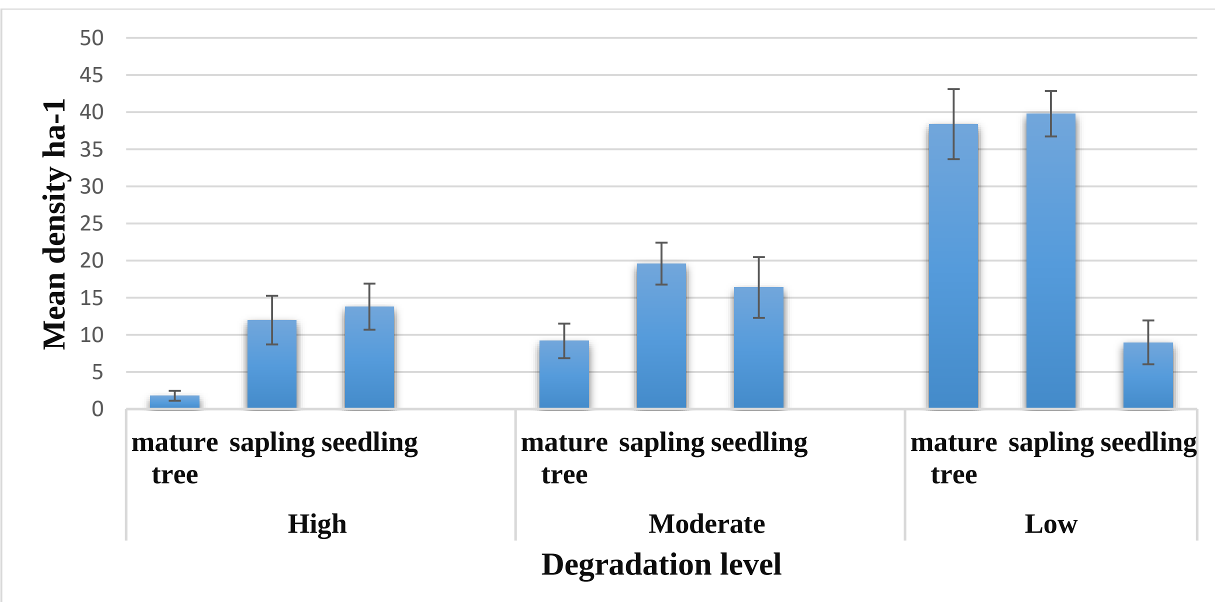

Figure 14: A mean (±SE) of life stages compared in all the three degradation levels, Kunene Region, Namibia.

CHAPTER FIVE

DISCUSSION

5.1 Comparing species richness, diversity, density and composition of above-ground vegetation among levels of degradation.

The results show, that for the above-ground vegetation, the low degradation sites recorded higher woody species richness, diversity and density than the moderate and high degradation sites. Anthropogenic activities such as cattle grazing, wood gathering, and farming are practiced in the region which have been connected to high levels of disturbance and hence high land use intensities (Zeidler et al., 2002; Veach et al., 2003). Other researchers have related species diversity and richness to the idea of disturbance in general (Beeby, 1993; Mackey & Currie, 2001, Walpope et al., 2004). The diversity values are comparable to those found in earlier studies conducted in communal or overgrazed African rangelands (e.g., Inman, 2020; Gobelle & Gure, 2018; Rutherford et al., 2014). Other studies have indicated that increasing the frequency and intensity of disturbances reduces plant variety and other associated vegetation qualities (Funk & Vitousek, 2007; Perrings, 2010).

Land degradation is harmful to plants' richness, diversity, density, and composition of above-ground woody plant species, because it alters aboveground properties (Leggett et al., 2002; Zeidler et al., 2002; Sheil & Burslem, 2003). Some studies (Shackleton et al., 1994) discovered that as degradation intensifies, above-ground woody diversity and species richness significantly decrease. Several studies have also related species richness and diversity to the broader concept of disturbance (Mackey & Currie, 2001; Walpope et al., 2004). It has been frequently asserted that as disturbance rates grow, species diversity and its indicators such as richness and evenness should rise and subsequently collapse (Mackey & Currie, 2001). Leggett et al. (2003) observed poor vegetation richness and variety in Palmfontein, a heavily grazed area in Namibia's Hoanib River watershed. When grazing pressure increases, plant species diversity diminishes and areas become dominated by a few karroid species, resulting in low overall species diversity (Evans et al., 1997).

Because only the greatest competitors survive at high levels of degradation, diversity is predicted to be low at high levels of degradation because only the greatest competitors can withstand high levels of disturbance. Similarly, severe degradation results in the persistence or repeated colonisation of a few species following a disturbance, resulting in low species diversity. The high degradation sites were dominated by *Pechuel-loeschea leubnitziae*, which contributed about 80% of the total of number of individuals in this level of degradation. Similar results were found by Inman et al. (2020) who assessed the vegetation structure and composition of woody species in community-derived categories of land degradation in the same rangeland in Kunene and found that *P.leubnitziae* also dominated the high degradation sites and various encroacher species (*Colophospermum mopane*, *Catophractes alexandri*) were also found in the low and moderate degradation sites. This indicates that the high degradation sites are vulnerable to the invasion of unpalatable and undesirable species such as *Pechuel-loeschea leubnitziae* is an indicator of degradation (Inman et al., 2020) and it is frequently found in disturbed areas such as overgrazed and trampled sites (Tedder et al., 2012). Strohbach (2000) found that the cover of *Pechuel-loeschea leubnitziae* increases as rangeland degradation increases.

The study also found out that the high degradation sites recorded the highest herbaceous species richness, density and diversity. Most of these herbs were annuals. The dominant species in the high degradation sites included undesirable and annual species such as *Tribulus terrestris*. The discrepancies in species composition among levels of degradation of the above-ground vegetation, could be attributed mostly to overgrazing, which results in the growth of unpalatable species (Vetter 2005, Legget et al., 2003; Burke, 2006). Furthermore, the high occurrence of the weeds like *Tribulus terrestris* and *Sesuvium sesuvidides* in the high degradation level indicates that the vegetation has been disturbed and over-exploited. According to Walter et al. (1990), weeds can occupy niches formed by lower plant cover and possibly reduce root mass in perennial species by 60 % species. Furthermore, *T.terrestris* colonise disturbed environments easily due to its rising dominance in high degradation levels (Curtis & Mannheimer, 2005).

5.2 Comparing species richness, diversity, density and composition of seed banks among levels of degradation.

Soil seed banks that, are made up of all viable seeds found in the soil, record some of the history of the vegetation and can play a significant role in its regeneration or restoration following disturbances (Teketay, 2005). Soil seed banks have been used to regulate the composition and structure of existing vegetation as well as to restore and establish native vegetation (Teketay, 2005). In this study, the soil seed bank contained huge populations of buried seeds of forbs and grasses (90% of the total species) and a few woody species of shrubs and trees (10%). The dominance of herbaceous species in the soil seed banks matched findings from other studies (De Leo'n Ibarra et al., 2019; Souza et al., 2016; Ma et al., 2014; Ma et al., 2011; Savadogo et al., 2016; Teklu & Bekele, 2019; Mndela et al., 2020; Omomoh et al., 2020; Zida et al., 2020). Herbaceous species' dominance might be linked to their ease of dispersal by diverse factors, such as wind and water, due to their low weight.

The dominance of herbaceous species in soil seed banks might also mean that herbaceous species had a greater probability of establishing themselves in disturbed areas than woody species. According to Luzuriaga et al. (2005), seed production and intrinsic seed characteristics impact the presence and durability of seeds in soils. Furthermore, the density of these species in the soil seed bank, their capacity to spread in a wide variety of habitats, adapt to severe circumstances, and quickly interact with other populations may be associated factors (Levicket et al., 2015; Girmay et al., 2020). The fruits of woody species, on the other hand, are bigger, appears to have poor long-distance dispersal, and have fleshy qualities (exposing them to rot, extensively predated, and decomposes swiftly before it emerges as a seedling) (Rico-Gray and Garcia, 1992; Tenkir, 2006). Following that, it may have led to the inadequate abundance and germination of woody species that was observed in this study.

In this study, the species richness, diversity, and density of the soil seed banks varied across degradation levels, with high degradation sites having recorded the greatest diversity of species, with 70% of them being annuals (Table 4.3). On the contrary, perennial herbaceous plants dominated the low- and moderate-degradation sites. Degradation, tends to limit the growth rate and reproductive potential of perennial grasses, altering competitive interactions among various species (Smith, 1979; Bilotta et al., 2007). As a result, heavily grazed perennial grasses species lose competitive strength to lightly grazed perennial grasses species, whereas unpalatable and grazing-tolerant annual plants emerge dominant in severely degraded environments. High levels of grazing intensity favour annuals and grazing disagreeable species (less attractive forbs and annual grass) over palatable perennials (Smith, 1979),and as grazing pressure increases, edible perennial grasses species are replaced by annuals, weeds and woody plants (Milton et al., 1994). So, despite the high degradation sites recording the highest diversity of seed banks, most species were invasive and undesirable annual species. Hence, invasive species which are known to flourish in disturbed settings are, such as *Euphorbia prostrata* and *Datura stramonium*, and only dominated the high degradation sites. These plants species are frequently found in disturbed settings, such as beside roads and trampled areas (Mapaura & Timberlake, 2004). According to Christoffoleti et al. (1998), seed banks could include a varied spectrum of invasive alien and early successional species in addition to standing plants. Most invasive alien species are adapted to adverse climatic circumstances such as high temperatures, humidity, and changes in oxygen supply (Mahe et al., 2021). Consequently, thousands of seeds germinate and spread across the soil. According to Perrings (2010), increasing the frequency and severity of disturbance reduces plant diversity and other vegetative traits.

Some researchers have linked species diversity and richness to the concept of disturbance in general (Mackey & Currie, 2001; Walpope et al., 2004). Disturbances are deleterious to plant diversity, ecosystem structure, and regeneration because they affect ambient conditions and ecological processes researchers (Sheil & Burslem, 2003). Additionally, degradation has a significant impact on ecological systems, impacting species composition and diversity. The "intermediate-disturbance" hypothesis (Fox, 1985;

Mackey & Currie, 2001) contends that as the rate of disturbance increases, species diversity and associated measurements such as richness and evenness should rise and then fall, with maximum diversity occurring at intermediate levels of disturbance.

In this study, the high degradation sites contained more herbaceous species, whereas the moderate and low degradation sites had a mix of herbaceous and woody species. The dominance of herbaceous species and species of the Poaceae plant family in the soil seed bank could be due to the fact that most of the species have small seed sizes (Benvenuti, 2007). Hence, the structure and size of most woody seeds might have trouble penetrating the soil surface, leaving them more vulnerable to predation (Gomez, 2004). As a result, seeds seldom create a long-term and sustainable seed bank (Thompson et al., 1997). Furthermore, some of these woody species rely on vegetative reproduction rather than sexual reproduction, so they may contribute little to the soil seed bank (Ma et al., 2010), in contrast, herbaceous plant species relatively release a large number of little seeds that spread quickly and readily into the soil (Douh et al., 2018).

Another important aspect to note is that the soil samples were collected during the wet season, and this might have led to fewer seed banks recorded, especially in the moderate and high degradation sites. The low species diversity and density of seed banks in these sites may indicate that the seeds in the soil seed bank might have germinated by rain before the soil samples were taken. Some woody species may employ seed rain and coppicing from stumps as alternate regeneration methods, which might be another cause for woody species' poor regeneration (Senbeta & Teketay, 2002).

Alternative studies in comparable environments utilising the seedling emergence method with other means of relieve dormancy suggest that perennial plants may contribute to the species richness of the soil seed bank (Fisher et al., 2009). However, because the study focus on easily viable seed for vegetation restoration, the study did not reproduced natural habitat conditions for seed bank and employed no soil pre-treatment to break dormancy of latent woody seeds. These findings are consistent with those of Baskin and Baskin (1998) and Martins and Engel (2007) who showed that seeds of herbaceous weeds and forbs dominate soil seed banks in dry and/or seasonal ecosystems, whereas only a few tree species produce long-lived seeds that can accumulate in the soil. The depletion of woody plants by disturbance provides resources for other life forms to exploit, and the germination of perennial species, despite their low abundance, can boost ecosystem resilience in a disturbed area. The woody species, according to Caturla et al. (2000) and De Andrade and Miranda (2014), are capable of developing following disturbance, allowing them to successfully contribute to the soil seed bank once the seeds are treated to break the domancy.

5.3 Comparing species composition between the soil seed banks and above-ground vegetation among levels of degradation.

A comparison of the soil seed bank and above-ground vegetation revealed a discrepancy, especially for woody species. Some species found in aboveground vegetation were not found in the soil seed bank. The findings of the Principal Component Analysis (PCA) Ordination based on species presence/absence data revealed a strong grouping between the species composition of above-ground vegetation and the soil seed bank, indicating a low resemblance. Many plants species were missing from the soil seed bank and the possibility could be because of the regeneration capacity which is dependent on the existence of standing plants nearby and successful seed distribution mechanisms (Reubens et al., 2007). As a result, the high degradation sites had inadequate standing vegetation, long-term overexploitation, and deterioration, which resulted in a low capacity for desirable species (Wang, 2013). This is similar with the findings of Looney and Gibson (1995), Erfanzadeh et al. (2016), and Tessema et al. (2016).

Degradation's impact on soil seed bank and above-ground vegetation is a topic of debate. Some authors (Unger & Woodell, 1996) believe it may increase seeds, while others (He & Ne'eman, 2012) believe it may reduce seeds. Peco et al., 1998 disagree. (He & Ne'eman, 2012), or have had no effect. These disparities might be attributed to the grazing regime, environmental factors, or the species' regional distribution.

The limited resemblance between the soil seed bank and above-ground vegetation across different degradation levels could be attributed to the impacts of land degradation, which can reduce vegetation species richness and significantly modify the soil seed bank. This could be a major reason why certain species are missing from the soil seed bank or have a lower emergence potential. This result is congruent with the findings of Tessema et al. (2016), who found a low mean similarity in species composition between the soil seed bank and above-ground vegetation. Furthermore, disturbed habitats generally have a weaker relationship between the species present in the seed bank and the vegetation (Tessema et al., 2012; Wellstein et al., 2007). Hence, the comparisons of soil seed bank and above-ground vegetation in the degraded sites of this study revealed minimal association.

5.4 The regeneration capacity of sites with different levels of degradation

The species' regeneration status is deemed non-regenerative if it is lacking, both in sapling and seedling stages, yet still present as a mature plant (Dhaulkhandi et al., 2008; Tiwari et al., 2010). The regeneration status of the aboveground vegetation density was higher at the low degradation sites. The low density of seedlings in the high degradation sites with high grazing intensities indicate that tree seedling recruitment is limited, likely due to livestock effects. This study agrees with Honu and Dang (2002) that these tree seedlings can survive adverse environments or that the species is tolerant.

At the high degradation level, there were only saplings and seedlings and no mature trees, which indicates “new” species, based on data. The regeneration status of the moderate and low degradation sites was poor because sapling density was higher than seedling and mature tree density. The new regeneration status recorded at the high degradation sites reflects the fact that these sites were dominated by a single species, *Pechuel-Loeschea leubnitziae*. This species contributed nearly 80% of the total number of individuals in high degradation sites. It has also been related to veld degradation and the dominance of shade-tolerant, low-quality grass species, notably in Okavango Delta (Tedder et al., 2012). The low regeneration capability of woody species in arid environments may be mostly due to current overexploitation as well as the ecosystem's lengthy dry season (Teketay & Granstrom, 1995). This suggests that seeds in such regions require a lengthy period of dormancy, which contradicts the characteristics of seeds from woody species (Shen et al., 2007). Singh et al. (2016) demonstrated that the health of plant communities was dependent on species' potential regeneration states in space and time.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main objective of this study was to assess and compare the above-ground vegetation and soil seed bank characteristics (species richness, species density, species diversity, and composition) at sites of varying degrees of degradation in the Kunene region. Species richness, diversity, and density of above-ground woody vegetation rose sequentially from high to low degradation. This suggests that land degradation may generate changes in the structure and the vegetation in this rangeland. The high degradation level is dominated by an unpleasant and unpalatable herb, and the regeneration was low, which is a great concern. In the absence of intervention, even low-degradation locations are likely to become substantially degraded in the future.

Findings of this study, show that the soil seed bank was distinguished by the presence of significant numbers of buried seeds of herbaceous plants, particularly annual and perennial grasses. The findings also indicated that only a few woody species seeds were represented in the soil seed bank, and there was a significant difference in the composition of woody species between above-ground vegetation and the soil seed bank. Because of the diverse soil seed banks, the herbaceous flora had a better chance of natural recovery in the event of disturbances, whereas regeneration of woody species would be prevented by the removal of mature individuals and their seedlings on the savannah floor because most lack soil seed reserves. As a result, intervention may be critical to improve the regeneration of underrepresented species by planting seedlings and providing an external source of tree propagules. Nonetheless, research in different local environments should continue in order to improve understanding in order to formulate mitigation strategies. The findings clearly shown that in degraded parts of the Kunene region, there are a lot of buried seeds of unpalatable herbaceous annuals. Consequently, grazing herd control are required for ecosystems to preserve and restore the ecological integrity of soil seed banks. The most common plants colonising disturbed environments were annual and perennial herbaceous species. These species can also aid in promoting soil fertility and enriching the soil seed bank by producing circumstances favourable to the trapping of tree seeds (i.e., microhabitats).

However, given the scarcity of tree seeds in the soil seed bank, natural regeneration will be delayed and possibly restricted in severely disturbed areas, such as those with high degradation levels where there was frequently bare soil and low soil seed bank densities of woody species. The fact that most of the prominent tree species of the savanna-woodland do not store seeds in the soil seed bank emphasises the necessity of vegetative propagation for these species and the importance of retaining mature trees.

6.2 Recommendations

Based on our findings, there is an urgent need for effective interventions to improve rangeland conditions and, as a result, help sustain the livelihoods of many people who live there. More research on the Kunene region's soil seed bank is needed. For example, there is still a paucity of understanding about seed production rates, seed dispersal processes, seed lifetime in soil, and the rates of seed predation. Future studies should focus on these gaps, among other topics, to better understand the dynamics of soil seed banks and support their long-term management. Because there are not enough tree seeds in the soil seed bank, human intervention would be required to speed up natural regeneration in many heavily degraded savanna-woodland habitats. Some of the possible ways and/or interventions which the study recommends include, reducing the frequency and/or intensity of anthropogenic disturbances by establishing firebreaks and fences to limit wildfire spread and to protect young regrowth, secondary mulching bare soils to facilitate soil building, improved conditions for soil seed bank accumulation, and finally regeneration, and strategic local planting of native tree and shrub species. Careful species selection for planting would help to promote herbaceous and ligneous species richness and facilitate local biodiversity conservation.

Grazing pressures should also be managed since this disturbance can have a significant impact on the quantity and quality of soil nutrients, which can influence seedling regeneration. Successful restoration plans require close collaboration among many stakeholders, including local residents, ecologists, non-governmental organisations, and government policy and decision-makers. Such restoration would necessitate human involvement, such as seedling planting and the creation of favourable conditions to increase soil seed bank accumulation, seedling germination, and the development of species. However, further studies are needed and recomended to better understand the impacts of microhabitats and varied land uses on soil seed bank composition and its potential to contribute to savanna-woodland restoration.

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APPENDIXES.

APPENDIX 1: ETHICAL CLEARANCE CERTIFICATE

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ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0036 Date: 04 March 2022

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project: EFFECT OF LAND DEGRADATION ON DENSITY, DIVERSITY AND COMPOSITION OF SEEDLINGS ARISING FROM SOIL SEED BANKS: A CASE OF KUNENE REGION IN NAMIBIA

Student: NGHIKWAFELLWA IYALOO

Student Number: 201402416

Supervisor(s): Dr. WELLENCIA C. NESONGANO; DR. NDEINEKELA E. INMAN

Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee
4. The ethics committee retains the right to:

i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,

ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

Table 1: List of woody plant species identified from above-ground vegetation and the soil seed banks in the (low, moderate and high) degradation levels in Kunene, Namibia.

SPECIES	Family	Degradation level	Above ground vegetation	Soil seed Bank	Degradation level
Adenium boehmianum	Apocynaceae	M	√	×	
Albizia anthelmintica	Fabaceae	L	√	×	
Albizia brevifolia	Fabaceae	L	√	×	
Boscia foetida	Capparaceae	L	√	×	
Catophractes alexandri	Bignoniaceae	H,LM	√	√	L,M
Colophospermum mopane	Bignoniaceae	H,L,M	√	√	L
Combretum apiculatum	Bignoniaceae	L	√	×	
Combretum imberbe	Bignoniaceae	L	√	×	
Commiphora africana	Bignoniaceae	L	√	×	
Commiphora angolensis	Bignoniaceae	L,M	√	×	
Commiphora glandulosa	Bignoniaceae	H	√	×	
Commiphora multijuga	Bignoniaceae	L,M	√	×	
Croton gratissimus	Bignoniaceae	H,L,M	√	√	L
Dialium engleranum	Bignoniaceae	L	√	×	
Dichrostachys cinerea	Bignoniaceae	M	√	×	
Diospyros lycioides	Bignoniaceae	H,L	√	×	
Elephantorrhiza suffruticosa	Bignoniaceae	L	√	×	
Euclea pseudebenus	Bignoniaceae	L	√	×	
Euphorbia guerichiana	Bignoniaceae	L	√	×	
Grewia bicolor	Bignoniaceae		×	√	L
Grewia flava	Bignoniaceae	M	√	×	

Grewia flavescens	Bignoniaceae	H	√	×	
Pechuel-loeschea leubnitziae	Bignoniaceae	H,M	√	×	H
Rhigozum brevispinosum	Bignoniaceae	L	√	×	
Rhigozum trichotomum	Bignoniaceae	L	√	×	
Rhigozum virgatum	Bignoniaceae	M	√	×	
Senegalia mellifera	Bignoniaceae	M	√	×	
Species 7			×	√	L
Terminalia prunioides	Combretaceae	H,L,M	√	√	M,L
Vachellia nilotica	Fabaceae	H,M	√	×	

Grewia bicolor recorded from the soil seed bank but was not identified in the above-ground vegetation. ✓ - present × - absent
H(high degradation level)-L(low degradation level- M(Moderate degradation level)

Table 2: List of species identified from the soil seed banks found in three degradation levels

Species	**Family**	**Growth form**	**Life span**	**Life form**	**Degradation**
1 Not identified		F	A	H	High
2 Not identified		F	A	H	High
3 Not identified		F	A	H	High
4 Not identified		F	A	H	High
5 Not identified		G	P	H	Moderate
6 Not identified		F	A	H	Moderate
7 Not identified		S	P	W	Low
Acrotome inflata	Lamiaceae	F	A	H	High
Anthephora schinzii	Poaceae	G	A	H	Low
Aristida meridionalis	Poaceae	G	P	H	Moderate
Catophractes alexandrii	Bignoniaceae	S	P	W	Low
Colophospermum mopane	Fabaceae	T	P	W	Low
Croton gratissimus	Euphorbiaceae	S	P	W	Low
Datura stramonium	Solanaceae	F	A	H	High
Eragrostis annulata	Poaceae	G	A	H	High
Eragrostis dinteri	Poaceae	G	A	H	High
Eragrostis rotifer	Poaceae	G	P	H	High
Euphorbia inaequilatera	Euphorbiaceae	F	A	H	High
Euphorbia prostrata	Euphorbiaceae	F	A	H	High
Grewia bicolor	Malvaceae	S	P	W	Low
Indigofera auricoma	Fabaceae	F	P	H	Moderate
Indigofera miniata	Fabaceae	F	A	H	High
Kohantia caespitosa	Rubiaceae	F	P	H	Moderate
Melinis repens	Poaceae	G	P	H	Low
Mollugo cerviana	Molluginaceae	F	A	H	Moderate
Schmidtia kalahariensis	Poaceae	G	A	H	High
Sporobolus consimilis	Poaceae	G	P	H	High
Stipagrostis giessi	Poaceae	G	P	H	High
Stipagrostis uniplumis	Poaceae	G	P	H	High
Terminalia prunoide	Combretaceae	T	P	W	Low
Tragus berteronianus	Poaceae	G	A	H	Moderate
Tribulus terrestris	Zygophyllaceae	F	A	H	High

Growth forms-Forb (F), Shrub(S),G(Grass),T(Tree).**Life span**-Perennial(P) and Annual(A).**Life form** – Herb(H) and Woody(W)

Table 3: List of herbaceous plant species identified from above-ground vegetation and the soil seed banks found in three levels of degradation

SPECIES	Growth Form	Lifespan	Degradation level	Above-vegetation	soil seed bank	Degradation level
1 Not identified	F	A		×	√	H
2 Not identified	F	A		×	√	H
3 Not identified	F	A		×	√	H
4 Not identified	F	A		×	√	H
5 Not identified	G	P		×	√	M
6 Not identified	F	A		×	√	M
7 Not identified	S	P		×	√	L
Acrotome inflata	F	A	M	√	√	H
Anthephora schinzii	G	P	H,M	√	×	L,M
Aristida meridionalis	G	P	H,L,M	√	√	H,L,M
Boerhavia coccinea	F	P	H	√	×	
Cleome suffruticoa	S	P	H,M	√	×	
Dactyloctenium aegyptium	G	A	H	√	×	
Datura stramonium	F	A		×	√	H
Eragrostis annulata	G	A	H	√	√	H
Eragrostis dinteri	G	A	H,L,M	√	√	H,M
Eragrostis nindensis	G	A	L,M	√	×	
Eragrostis rotifer	G	P	H	√	√	H
Euphorbia inaequilatera	F	A	H	√	√	H
Euphorbia prostrata	F	A		×	√	H
Geigeria acaulis	F	P	H,L,M	√	×	
Hermbstaedtia odorata	G	P	L	√	×	
Indigofera auricoma	F	P	H,M	√	√	H,M
Indigofera miniata	F	A		×	√	H
Kohantia caespitosa	F	P		×	√	L,M
Limeum argyle-carnation	F	A	H,L,M	√	×	
Melinis repens	G	P	L,M	√	√	L,M
Mollugo cerviana	F	A	H,M	√	√	H,M

Schmidia pappophoroides	G	A	L	√	×	
Schmidtia kalahariensis	G	A	H,L	√	√	H
Sesamum capense	F	A	M	√	×	
Sesuvium sesuvidides	F	P	H	√	×	
Species1	F	A	M	√	×	
Species2	F	A	M	√	×	
Sporobolus consimilis	G	P	H	√	√	
Stipagrostis ciliata	G	P	M	√	×	
Stipagrostis geissii	G	P	L	√	√	H
Stipagrostis hirtigluma	G	P	H	√	×	
Stipagrostis uniplumis	G	P	H,L,M	√	√	H,L,M
Tragus berteronianus	G	A	H	√	√	H,M
Tribulus terrestris	F	A	H,M	√	√	H,M

Datura stramonium recorded from the soil seed bank but was not identified in the above-ground vegetation. ✓ - present
× - absent
H (high degradation level)-L (low degradation level- M (Moderate degradation level) **Growth forms**-Forb (F), Shrub(S),G(Grass),T(Tree).**Life span**-Perennial(P) and Annual(A

APPENDIX 2: CALCULATION OF THE SEED BANK DENSITY

To calculate the density, two components need to be consider total number of seeds and volume. To calculate the surface area of a cylinder, two components were consider: the lateral surface area and the two circular ends (top and bottom). To calculate the lateral surface area (the side of the cylinder): Lateral Surface Area = 2 * π * radius * height the radius is half of the diameter, so the radius (r) is 9.7 cm / 2 = 4.85 cm. The height (h) is 5 cm. Lateral Surface Area = 2 * π * 4.85 cm * 5 cm Lateral Surface Area ≈152.39 square centimeters. To calculate the area of one circular end: Area of a Circle = π * radius^2 Area of one end = π * (4.85 cm) ^2 Area of one end ≈ 73.52 square centimeters. Lastly, to calculate the total surface area by adding the lateral surface area and the two circular ends: Total Surface Area = 2 * (Area of one end) + Lateral Surface Area Total Surface Area = 2 * 73.52 square centimeters + 152.39 square centimeters Total Surface Area ≈ 299.43 square centimeters. To find the volume of the cylinder, you need to multiply this surface area by the depth of the cylinder. Volume of the Cylinder = Total Surface Area * Depth Volume = 299.43 square centimeters * 5 cm Volume = 1497.15 cubic centimeters. Now, if you found 34 seeds in this volume, you can calculate the density of the seeds by dividing the total number of seeds by the volume: Density = Total Number of Seeds / Volume Density = 34 seeds / 1497.15 cubic centimeters Density ≈ 0.0227 seeds per cubic centimeter. So, the density of the seeds in the cylinder is approximately 0.0227 seeds per cubic centimeter

Table: 4 Calculation of the soil seed bank density in the three degradation level (low, high moderate)

Degradation level	Site	Transect	Plot	Total number of seeds	Density
Low	1	1	1	0	0
Low	1	1	2	0	0
Low	1	1	3	0	0
Low	1	1	4	0	0
Low	1	1	5	0	0
Low	2	1	1	0	0
Low	2	1	2	0	0
Low	2	1	3	1	0.00067
Low	2	1	4	7	0.00468

Low	2	1	5	0	0
Low	3	1	1	0	0
Low	3	1	2	0	0
Low	3	1	3	14	0.0093511
Low	3	1	4	2	0.001335871
Low	3	1	5	0	0
Low	1	1	1	4	0.002671743
Low	1	1	2	0	0
Low	1	1	3	0	0
Low	1	1	4	0	0
Low	1	1	5	12	0.008015229
Low	2	1	1	2	0.001335871
Low	2	1	2	13	0.008683165
Low	2	1	3	0	0
Low	2	1	4	3	0.002003807
Low	2	1	5	0	0
Low	3	1	1	1	0.000667936
Low	3	1	2	0	0
Low	3	1	3	21	0.014026651
Low	3	1	4	5	0.003339679
Low	3	1	5	0	0
Moderate	1	1	1	4	0.002671743
Moderate	1	1	2	2	0.001335871
Moderate	1	1	3	2	0.001335871
Moderate	1	1	4	24	0.016030458
Moderate	1	1	5	8	0.005343486
Moderate	2	1	1	1	0.000667936
Moderate	2	1	2	6	0.004007614
Moderate	2	1	3	5	0.003339679
Moderate	2	1	4	11	0.007347293
Moderate	2	1	5	0	0
Moderate	3	1	1	3	0.002003807
Moderate	3	1	2	1	0.000667936
Moderate	3	1	3	0	0
Moderate	3	1	4	3	0.002003807
Moderate	3	1	5	0	0
Moderate	1	1	1	0	0
Moderate	1	1	2	2	0
Moderate	1	1	3	6	0.001335871
Moderate	1	1	4	0	0.004007614
Moderate	1	1	5	0	0
Moderate	2	1	1	12	0
Moderate	2	1	2	6	0.008015229

Moderate	2	1	3	30	0.004007614
Moderate	2	1	4	1	0.020038072
Moderate	2	1	5	0	0.000667936
Moderate	3	1	1	21	0
Moderate	3	1	2	1	0.014026651
Moderate	3	1	3	137	0.000667936
Moderate	3	1	4	51	0.091507197
Moderate	3	1	5	0	0.034064723
High	1	1	1	7	0.00467555
High	1	1	2	4	0.002671743
High	1	1	3	5	0.003339679
High	1	1	4	1	0.000667936
High	1	1	5	0	0
High	2	1	1	0	0
High	2	1	2	0	0
High	2	1	3	101	0.06746151
High	2	1	4	9	0.006011422
High	2	1	5	5	0.003339679
High	3	1	1	8	0.005343486
High	3	1	2	29	0.019370137
High	3	1	3	0	0
High	3	1	4	20	0.013358715
High	3	1	5	3	0.002003807
High	1	1	1	30	0.020038072
High	1	1	2	0	0
High	1	1	3	15	0.010019036
High	1	1	4	0	0
High	1	1	5	0	0
High	2	1	1	19	0.012690779
High	2	1	2	11	0.007347293
High	2	1	3	31	0.020706008
High	2	1	4	4	0.002671743
High	2	1	5	73	0.048759309
High	3	1	1	11	0.007347293
High	3	1	2	24	0.016030458
High	3	1	3	21	0.014026651
High	3	1	4	11	0.007347293
High	3	1	5	22	0.014694586

APPENDIX 3: ABOVE-GROUND VEGETATION MATRIX

Code	*A.schinzii*	*A.meridionalis*	*C.alexandri*	*C.mopane*	*C.gratissimus*	*E.dinteri*	*E.rotifer*	*G.acaulis*	*L.argute-carinatum*	*M.repens*	*P.leubnitziae*	*S.uniplumis*	*T.prunioides*	*T.berteronianus*	*T.terrestris*
HA1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
HA2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HA3	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1
HA4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
HA5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
HA6	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
HA7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
HA8	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
HA9	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0
HA10	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0

HB1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1
HB2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1
HB3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
HB4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
HB5	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
HB6	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0
HB7	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
HB8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HB9	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
HB10	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
HC1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
HC2	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
HC3	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
HC4	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
HC5	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0

HC6	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
HC7	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
HC8	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
HC9	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
HC10	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
MA1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MA2	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0
MA3	1	0	1	0	0	0	0	1	0	1	1	0	0	0	0
MA4	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
MA5	1	0	1	0	0	1	0	0	0	1	0	0	0	0	0
MA6	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
MA7	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0
MA8	1	0	1	0	0	1	0	0	1	1	0	0	0	0	0
MA9	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0

MA10	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
MB1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
MB2	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
MB3	0	0	1	1	0	1	0	0	0	1	1	0	0	0	0
MB4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
MB5	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0
MB6	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MB7	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MB8	0	0	0	1	0	1	0	0	0	1	1	0	0	0	0
MB9	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MB10	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MC1	1	0	0	1	0	1	0	0	0	1	0	1	1	0	0
MC2	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0

MC3	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0
MC4	1	0	0	1	1	0	0	0	0	1	0	1	1	0	0
MC5	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0
MC6	0	0	1	0	1	0	0	0	0	0	0	1	1	0	0
MC7	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0
MC8	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0
MC9	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
MC10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
LA1	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0
LA2	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
LA3	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
LA4	0	0	0	1	0	0	0	1	0	1	0	0	1	0	0
LA5	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
LA6	0	1	0	1	0	0	0	1	0	1	0	0	1	0	0

LA7	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0
LA8	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0
LA9	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0
LA10	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0
LB1	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0
LB2	0	0	1	1	1	0	0	0	0	1	0	1	0	0	0
LB3	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0
LB4	0	0	1	1	0	1	0	0	0	1	0	0	1	0	0
LB5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
LB6	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
LB7	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
LB8	0	1	0	1	1	0	0	0	0	0	0	0	1	0	0
LB9	0	1	1	1	1	0	0	0	0	0	0	1	0	0	0
LB10	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0
LC1	0	0	1	1	0	0	0	0	0	1	0	1	0	0	0

LC2	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0
LC3	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
LC4	0	0	1	1	0	1	0	1	0	0	0	0	1	0	0
LC5	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
LC6	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0
LC7	0	0	1	1	1	0	0	1	0	1	0	0	1	0	0
LC8	0	1	1	1	0	0	0	1	0	0	0	1	0	0	0
LC9	0	1	1	1	1	0	0	0	0	0	0	1	0	0	0
LC10	0	0	1	1	1	0	0	0	0	0	0	1	1	0	0