The impact of cattle grazing on a recently rehabilitated grassland ecosystem in an open cast coal mine in Mpumalanga, South Africa

by

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Declaration

I declare that this research report is my own and unaided work. It is being submitted to meet the requirements for the Degree of Masters of Environmental Science at the University of Venda, Thohoyandou. It has not been submitted before for any degree or examination in any university.

Thovhakale Ndivhuho Duke

Signature…………………… **Date** 26/08/2020…………………………

Dedication

I would like to dedicate this work to:

In memory of my late mother Delina Ndivhaleni Thobakgale,

(1979-2002)

And my late sister Muyahavho Eaglet Thobakgale

(1994-2009)

Lastly, to my late grandfather, France Madidimalo Thobakgale

(1965-2011)

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Abstract

This study was about the impact of cattle grazing on recently rehabilitated site at a former opencast coal mine in Mpumalanga, Witbank coalfield. The area has been rehabilitated by backfilling and levelling of spoil material, subsoil material, placement of approximately 400-mm topsoil layer and grassing. For the purpose of this study, ten (5 x 5 m^2) exclosures were erected and cattle was allowed to graze outside the exclosures. Two benchmark sites were identified and vegetation surveys were done in two wet seasons in 2017 and 2018. Soil samples were collected and analysed for pH, Ca, Na, Mg, K, P, NO_3, NH_4 and textural classes. Most soil parameters were in an acceptable range when compared to the grassland soil fertility index. The effect of grazing in block I based on individual plant species showed some effects in terms of plant diversity, biomass and ground cover. There was a decrease in plant diversity over the study period. For a significant effect of grazing on species composition, more time is needed for sampling, one year is not enough to see changes, and to conclude if the change was positive or negative. However, in terms of species composition, there was an increase in forb species from 12% to 17 % and disappearance of grass species such as *Digitaria eriantha* and *Chloris virgata* in and around exclosures. Rainfall data was considered from the past 30 years, and it was found that during the study period the rainfall in the area was just above the normal range (650-700 mm/year). In other studies, it took more than six year to see the effects of cattle grazing on vegetation in disturbed areas, and also to determine the progress on vegetation development when comparing to other areas.

Key words: *grazing, grassland biome, rehabilitation, mining, exclosure, benchmarking, correspondence analysis.*

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background of the study

The grasslands biome is the second largest biome in South Africa, covering 29% of South Africa and occurring in 8 provinces including Gauteng, Limpopo, Eastern Cape, Mpumalanga, KwaZulu-Natal, Free State, North West and the Northern Cape (Cadman *et al.* 2013). Grasslands in South Africa have high plant species richness and high turnover of biodiversity across the landscape. The grasslands also play a vital role in water filtration and purification. The term grasslands create the impression that the biome consists only of grass species, whereas, only one in six plant species in the biome is a grass. The remainder includes bulbous plants such as arum lilies, red-hot pokers, aloes, watsonias, gladioli and ground orchids. Examples of animal species found in the grassland biome are blue cranes, antelopes (springbok) and mongooses (dwarf mongoose) (Cadman *et al*. 2013; Carbutt *et al*. 2011).

The South African Grassland biome is threatened by mining, urban development, agriculture, overgrazing, forestry, invasive species and climate change. In Mpumalanga mining is a major threat as this province supplies 84% of South Africa`s coal (Matsika 2007).

Coal is the world's most abundant and widely distributed fossil fuel and it remains the primary energy source for several countries worldwide with reserves of more than 100 trillion tons (Zou *et al*. 2016). In South Africa, coal mining makes a significant contribution to economic activity, development of sustainable job opportunities and foreign exchange earnings (Motsie *et al*. 2017). The biggest strength of industrial minerals is that their consumption correlates strongly with GDP growth per capita in various sectors like construction and agriculture (Motsie *et al*. 2017). Mining industry contributed 7.3% to GDP (Mineral Council of South Africa 2017). In South Africa, over 70% of the primary energy/electricity supply is delivered by coal fired power stations. Most of these are located on the Mpumalanga Highveld (Ratshomo and Nembahe 2016)

Coal is mined by two methods, namely underground and opencast mining. Both are destructive processes with serious effects on the environment but opencast is worse than underground mining, because opencast mines remove large volumes of soil and rock overburden to get to the harvestable coal seams (Balasubramanian 2017; Munnik 2010).

A large portion of the coal reserves and operations on the Eastern Highveld is situated in the heart of the South African grassland biome (Zaloumis 2013). On a global scale, the grassland biome is considered to be the most threatened, and the South African grassland biome has been identified as critically endangered (Carbutt *et al*. 2011). Despite covering around 11% of the earth's vegetated land surface grassland systems are still largely underappreciated and under-conserved even with the increasing realisation that these systems are some of the most threatened systems in the world (Zaloumis 2013).

According to the Minerals and Petroleum Development Act (Act no 28 of 2002) opencast mines have to be rehabilitated and the post mining landscape returned to a sustainable and productive land use (South African constitutions of 1998). The land-use after rehabilitation could be agriculture, cattle ranching or industrial development. The land can be used by farmers or community members or government for any of the above mentioned land-use activities.

Grazing can influence the structure and organization of grass communities in different ways. Direct effect of cattle grazing occurs when there is selective removal of grass species (Schmitz and Isselstein 2020). This means that the cattle select their favourite grasses (palatable grass) leaving the rest ungrazed. While the indirect effects on botanical composition and species diversity can occur when selective grazing on dominant species reduces their vigour and presence, thus favouring the spread of less competitive sour or hard grasses and more grazing-tolerant plants (Briske and Noy-Meir 1998). The effects of bulk grazing on rangeland biodiversity include the removal of biomass and destruction of root systems by trampling (Alkemade *et al*. 2013).

There are many grazing systems, which falls under two broad classifications continuous and rotational grazing (with rotational systems ranging in intensity) (Boakye *et al*. 2013; Kirkman 2001). In continuous grazing, grazers are placed in a camp when the forage is first ready to graze at the start of the growing season and they are left in that camp for the entire grazing season of the year. It is a widely used method in some countries (USA and Australia for instances), but has for long been condemned (if not enough rest is allowed) by many grassland management advisors in South Africa (Sanjari, Ghadiri, and Yu 2016). This practice lead to change of plant structure and the disappearance of desirable species and the emergence of bare soil spots as a result of overgrazing, and the dominance of harmful plants (Abdelsalam *et al*. 2017).

In other studies, it was discovered that long term continuous grazing reduces pasture productivity and destroys the protective layer of soil surface by promoting erosion through selective grazing. On the other hand, time controlled rotational grazing (TCR grazing) reduces such negative effects (destroying of the protective layer of soil) and leaves pasture with a higher amount of vegetation securing food for animals and conserving the environment (Sanjari, Ghadiri, and Yu 2016; Teague and Barnes 2017).

Rotational grazing is a system with few to many pastures, often times called paddocks or cells. Livestock is moved from paddock to paddock based on forage growth and utilization. The number of paddocks and frequency of rotation depends on many factors, including type of livestock and production goals of the manager (Chen 2018). It involves the successive grazing of these enclosures in rotation so that not all the veld is grazed simultaneously. There are a number of rotation systems used in grazing, for example non-selective grazing (NSG), controlled selective grazing (CSG), high-utilisation grazing (HUG) and high performance grazing (HPG) (Kirkman 2001;Milton 1999).

In grasslands of the northern region of Israel, cattle grazing management is commonly conducted as continuous grazing at moderate stocking rates with supplementation during periods of low forage quality or forage scarcity, but the long-term effect on the vegetation of this intensive grazing management is not fully known (Briske and Noy-Meir 1998; Stromberg *et al*. 2012). The same practice is used by farmers in Mpumalanga grassland, during dry months (May - August) when there is forage scarcity or low forage quality.

The effects of grazers on plant diversity differ with the environment (Lauenroth 1988). Grazing mammals in more productive grasslands such as the temperate grasslands in Europe and tall grasslands in the western Serengeti increase plant diversity. However, grazers in arid or saline environments often do not change or can even decrease diversity. For example, herbivores in North American tall grass prairie on poor soils decrease plant diversity, whereas those on rich soils increase it (Olff and Ritchie 1998).

The effects of grazers on plant species richness appear to depend on the type and abundance of grazing species in a particular environment. These effects can be either positive or negative (Schultz, Morgan, and Lunt 2011). For example, natural populations of large grazing mammals are reported to increase plant diversity, while insect herbivores often have weak or negative effects (Belsky and Blumenthal 1997).

The body size of grazers might interact with the scale of diversity, because local effects of large herbivores can occur over a much larger spatial scale than local effects of smaller herbivores (Liu et al. 2015; Provenza *et al*. 2007). However, large grazing herbivores such as livestock have more consistent effects on grass since they can use much low-quality forage (such as competitively dominant grassland plants) and typically create frequent, small disturbances across the landscape (Anderson and Briske, 2010).

Overgrazing is one of the primary contributors to grassland degradation around the world, through reduction in vegetation cover, degradation of topsoil, causing soil compaction as a result of trampling, reduction in soil infiltration rates, and enhancement of the susceptibility of soils to erosion (Uyang *et al*. 2017). Uncontrolled grazing may lead to overgrazing. Overgrazing reduces the usefulness, productivity, and biodiversity of the land and is one cause of erosion and desertification. It is also seen as a cause of the spread of invasive species of non-native plants, bush encroachment and weeds (Czeglédi and Radácsi 2005). In connection with overgrazing, the most important factor resulting in range deterioration is poor livestock distribution, which leads to the overutilization of some parts of the range and over-resting of others (Krueger 1984).

1.2 Problem statement

Our study site is in the process of rehabilitating an opencast coal pit, and the rehabilitated block is being used as grazing land for cattle. However, the rehabilitated soil is highly compacted and not its natural state anymore which makes it difficult for grass to establish itself and grow. Though the effects of grazing on grassland ecosystem have been well researched in South Africa, this is not the case in newly rehabilitated land after coal mining. The mines are therefore lacking information to base management decisions on regarding timing of introduction of grazing and optimum grazing pressure. The current research project seeks to contribute to filling this information gap.

1.3 Aim and objectives

1.3.1 Aim

To study the effects of cattle grazing on a recently rehabilitated grassland ecosystem after open-cast coal mining

1.3.2 Objectives

To determine soil properties, plant species composition and biomass of the rehabilitated grassland ecosystem against non-mined managed pasture.

To measure soil properties at the rehabilitated and benchmark area.

To establish the grazing regime used at the rehabilitated site

To assess the effect of cattle grazing on the veld condition at the rehabilitated site

1.4. Limitations of the study

This study is initiated to assess the productivity of the land after coal mining rehabilitation. It is important to know post rehabilitation land capability. As the mine aims to stabilise the soil and return the vegetation and landscape closer to what it was pre-mining, it is important to know how introducing cattle on recently rehabilitated land affect the goal of stabilizing the land and restoring the vegetation cover. However, the study will only focus on grasses and grazing.

The study will only contrast grazing with no grazing, using exclosures. The grazing intensity is determined by the farmer with whom the mine has a lease agreement for the land where the experiment is being conducted.

1.5 Study Area

Our study area mine is an opencast and underground coal mine which is situated 55 km west of Witbank (Emalahleni) in Mpumalanga. The main office buildings are located on the farm Cologne 34-IS (-26.12275; 29.00414). The mine is on the Witbank coalfields. The study area is located on the Leeuwfontein and Schoongezicht farm. Site preparation for mining was initiated in March 1984 and the first coal was mined in August 1986 with the delivery to Kendal Power Station in November 1986. The mining area investigated is Block I which has Block I extension A (-26.12275: 28.97918) and Block I extension B (-26.11640; 28.98489). These blocks have been rehabilitated since mining ceased in 2005.

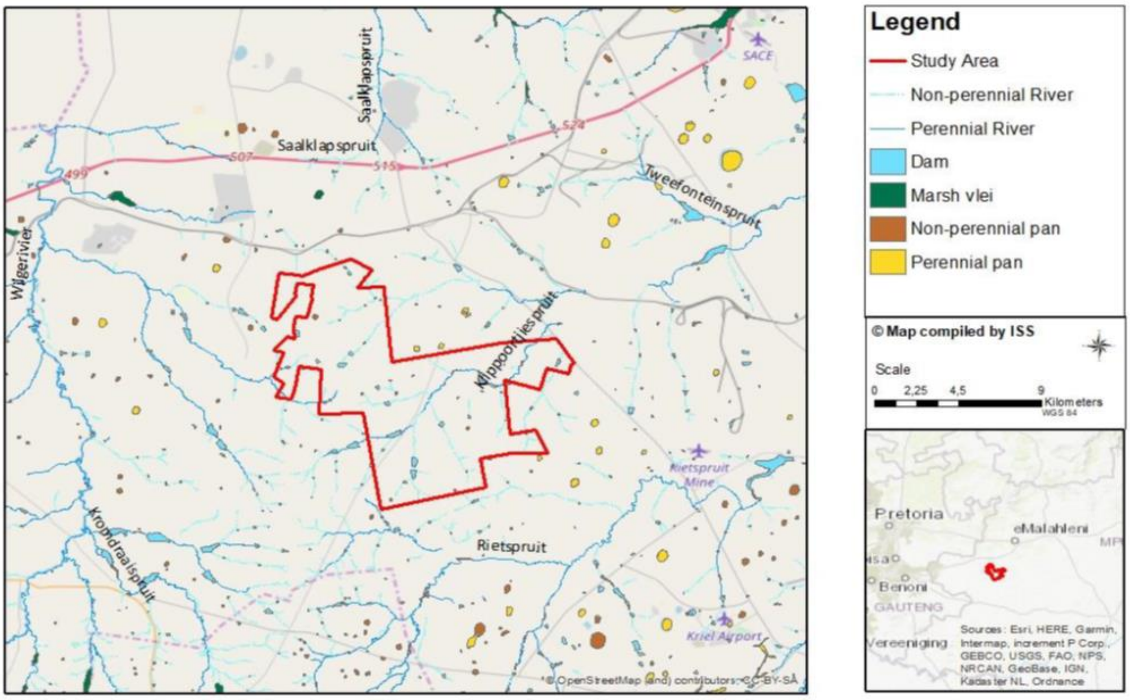


Figure 1: Locality map, mine footprint.

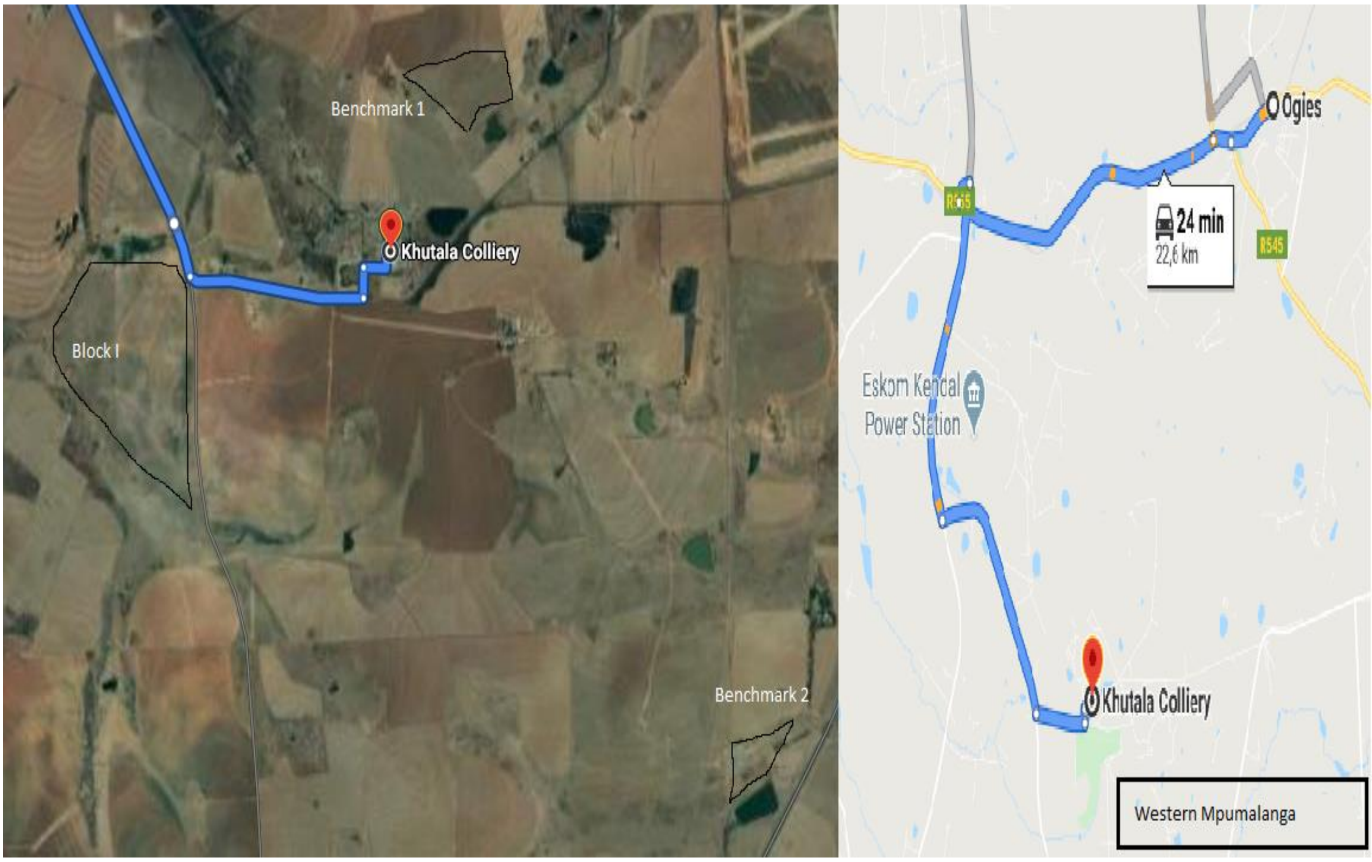


Figure 2: Study area and benchmark site 1 & 2.

1.5.1 Characteristics of the study area

1.5.1.1 Vegetation

The vegetation of the study area falls under the Eastern Highveld Grassland (Gm 12) (Mucina and Rutherford 2006). It has slightly to moderately undulating plains, including some low hills and pan depressions. The natural vegetation is short dense grassland dominated by a highveld grass composition, for example *Aristida*, *Digitaria, Eragrostis, Themeda* and *Tristachya*, with small, scattered rocky outcrops with wiry, sour grasses and some woody species, for example *Acacia caffra, Celtis africana, Diospyros lycoides* subsp *lycioi-des, Parinari capensis, Protea caffra, P. welwitschii* and *Searsia magalismontanum* (Mucina and Rutherford 2006).

1.5.1.2 Climate

The region is characterized by high rainfall in summer with a mean annual rainfall ranging between 660 – 1180 mm per annum (Mucina and Rutherford 2006). Temperatures in the region vary from below 0º C in winter to 39 ºC in summer with an average of 15º C per annum (Mucina et al. 2006; Rutherford, Bredenkamp, and Powrie 2006).

1.5.1.3 Altitude

The region is situated within an altitudinal range of 1260 – 2160 m above sea level with undulating plains and mountains (Mucina and Rutherford 2006).

1.5.1.4 Land use

The dominant land use around the study area is livestock farming, primarily with cattle in the commercial farms and mixed herds of cattle, sheep and goats in the communal farms. The second dominant land use is mining (Boakye *et al*. 2013).

1.5.1.5 Geology

The study area is located in the Witbank Coalfield which is one of the major coalfields in South Africa. The geology of this coalfield is made up of dolerite sills generally about 50 m thick which occur throughout the coalfield and caused large-scale displacements where they intersect the coal seams. There is an important dyke in the area, the well-known Ogies Dyke which is about 15 m thick (Jeffrey 2005; Morton 2016). There are five major seams that are mined in this area. The depth of the seams for underground mining ranges from about 30 metres to about 110 m. The number 1 seam is about 1.5 to 2.0 m thick, while he number 2 seam has an average thickness of 6 m, the number 3 seam is about 0.5m, number 4 seam is 2.5 m to 5.0 m thick and widens to the west where it is in excess of 6.0 m and the last seam, number 5 has an average thickness of 1.5 m to 2.0 m. The latter is found approximately 25 m above the number 4 seam and is on average 30 m below the surface (Chabedi and Zvarivadza 2016).

1.6 Significance of the study

Mining is one of the activities that have a severe negative impact on components of the environment, i.e. surface and groundwater, air and soil. The Minerals Act (No. 50 of 1991) requires that an Environmental Management Programme Report (EMPR) containing rehabilitation plans be submitted and approved by the authorities before any mining activity can start, and that finances be set aside for rehabilitation (Madalane 2012).

The main aim of rehabilitation is to restore the land to a potential similar to what it had before the activity started. Among other rehabilitation goals, the landscape must also be visibly acceptable – excavations must be backfilled and visible structures, such as mine dumps, must be effectively camouflaged. Shrubs and grass can be used to blend the re-shaped areas and to prevent dust and soil erosion problems.

The study by (Lechmere-Oertel 2014), focused on management of the grassland biome through grazing and fire to maintain the grass species and composition. The aim of this study is to expand the knowledge regarding whether grazing by cattle on a recently rehabilitated land affect the plant structure, composition, and vigour and species richness. This will also help farmers and the community in general to know how and when to introduce their cattle on rehabilitated grassland and to help them manage their cattle grazing regime better.

CHAPTER TWO

LITERATURE REVIEW

2.1 Ecology of South African grasslands

Globally grasslands contribute significantly to environmental, economic and cultural values through the provision of several important ecosystem services (Bengtsson et al. 2019; Bojars 2017). The livelihoods of almost one billion people depend on grasslands. Improved management of grasslands is key to food production and sustainable development in many countries. Grassland management has a large potential to mitigate greenhouse gas (GHG) emissions at a low (or even negative) cost, by combining a moderate intensification and the restoration of degraded pastures (Paltsev *et al*. 2012). Some ecosystem services are well documented and their loss can have significant consequences in a local context. These include the production of high quality grazing and erosion control (Fidelis 2014; Zaloumis 2013).

South Africa has an unusual combination of climatic environments, natural resources and ethnic groups, which makes it an interesting and challenging country Grasslands are an important component of the natural vegetation, because alone, the biome comprises 295 233 km^2 in the central regions of the country, and it borders on most of the other biomes such as forest, savannah, thicket and Nama-Karoo in the region (Palmer and Ainslie 2005).

South Africa is subtropical and its temperatures are modified by altitude (Palmer and Ainslie 2005). The grasslands are found in the interior of the country and these areas are mesic to semi-arid and have the rainfall decreasing westwards. The grassland biome is the second largest biome in South Africa mostly situated on the high central plateau commonly known as the Highveld (Ltas 2013). The grassland is comprised of mainly the sour veld occurring under high-rainfall on acid soils, and sweet veld on fertile soils in semi-arid zones (Mucina and Rutherford 2006).

South Africa's mesic grasslands are seasonal with an annual rainfall between 500mm and 700 mm that predominantly falls in the summer months (December to March) (Ellery, Scholes, and Scholes 1995).

Grassland biomes are heavily utilised by humans and face increasing anthropogenic pressure as human populations increase and the need for the resources that grasslands provide increases as well (Myers *et al*. 2000). Agriculture, afforestation, urban expansion and mining are the main drivers of grassland loss (Matsika 2007).

South Africa`s intact natural grasslands play an important role in the major summer-rainfall catchment areas where they stabilise soils, promote rainfall infiltration, and support more stream flow than other vegetation, such as pine plantations grown under the same conditions (Blignaut and Aronson 2008). In South Africa grasslands and other biomes are responsible for providing water to the entire Gauteng province (Carbutt and Tau 2011). Gauteng province has three of the major South African metros (Johannesburg, Tshwane and Ekurhuleni) and is the economic hub of the country with the population of 12.3 million people (23.7% of South Africa`s population lives in Gauteng) (Masoud 2013). Natural grasslands also provide high quality grazing for South Africa`s beef industry (Truter *et al*. 2015).

Matsika (2007), mentioned that South African natural grasslands are facing increased habitat loss and fragmentation and are amongst the most threatened vegetation types in South Africa making them a priority for conservation efforts. Restoration can be used both as a tool in the conservation of grasslands and to improve our understanding of the grassland system (Stromberg *et al*. 2012). However, literature on South African grassland rehabilitation is scarce (Milton 2004) and often only compares post-disturbance grasslands to natural grassland. There are however some studies that have focused on the re-seeding of common grass species and these have reported some success in re-establishing vegetation cover and some grazing value (Mentis 2008; Van Oudtshoorn, Brown, and Kellner 2011).

South African grasslands have shown not to follow natural succession when left to recover after major disturbance. They may establish a grassy layer, but the plant species are different from the natural vegetation (Van Oudtshoorn, Brown, and Kellner 2011). In these circumstances the key grassland elements have failed to re-colonise the degraded environment and there is a need to determine if this is because of physical limitations, due to changes in soil attributes, or biological limitations such as plant composition or plant reproductive constraints (Kardol, Wal, and Boer 2008).

Only 2.8% of the grassland biome is formally protected in nature reserves and national parks, mostly in the Drakensberg mountains (Balfour 2016; Carbutt and Tau 2011),. On the other hand 65% of grassland habitat is irreversibly transformed. Grasslands are heavily exploited for urban and agricultural development, commercial forestry and mining.

Any form of rehabilitation is likely to be very expensive and time consuming, and will require clarity regarding the historic context and the current management scenario (Kimball *et al*. 2015). The bottom line is that it is relatively easy and rapid to cause extensive damage to grassland, and extremely difficult and expensive to undo this damage, especially at a scale of anything larger than a small camp. Once plant diversity, basal cover and then soil have been lost from grassland, they are unlikely to return within a meaningful management time frame (Lechmere-Oertel 2014).

2.2Grazing systems and effects of grazing on South African grasslands

Grazing and fire are the most important factors that can influence the ecology of grasslands. From a planning perspective, any change in land-use that results in a change in the grazing regime will have a significant impact on grassland vegetation (Cadman *et al*. 2013).

Grazing is the removal of above-ground plant matter by animals, either indigenous or domestic (Avenue,and Manor 2013). Appropriate grazing has positive effects which include stimulation of biomass production and removal of dead or dying plant biomass that might limit new growth (Schieltz and Rubenstein 2016). The introduction of habitat variation through localised disturbance results in higher species richness and a greater abundance of small grassland animals. Grazing also helps in breaking up the soil surface due to hoof action which allows better infiltration of rainfall. It furthermore enables the recycling of nutrients through animal dung (Cadman *et al*. 2013).

Inappropriate grazing practices such as overgrazing have negative effects. Overgrazing significantly changes the species composition, especially when combined with inappropriate use of fire (Schieltz and Rubenstein 2016). In the long run, this practice might result in dominance of a few, unpalatable species of grasses such as wire grass (*Aristida junciformis)* or it may lead to increased invasion by weedy species and soil erosion (Short and Du Toit 2004). This comes at the cost of both grassland biodiversity and productivity and is highly undesirable.

The most important factors influencing the impact of grazing on grassland biomes are type of grazer, stocking density in relation to carrying capacity of the grassland ecosystem, and the type of grazing system employed (Rutherford, Bredenkamp, and Powrie 2006). Grazing pressure from indigenous grazers (buffalo and rhino) under natural conditions is generally much lower than that resulting from domestic livestock which is being farmed commercially. Domestic grazers (cattle, goat and sheep) are not as mobile as wild grazers, with domestic animals congregating in certain areas, particularly waterways and pools (Tastad 2013). Defoliation by grazing herbivores alters plant height and canopy cover, and changes species composition to include structurally different types of plants (Allred *et al.* 2012; van der Waal *et al.* 2011). Trampling may change the structure of plant communities by breaking and beating down vegetation. However, defoliation caused by ungulates can promote shoot growth and enhance light levels, and nutrient availability (Anderson and Frank 2003).

According to Anderson and Frank (2003), most grazing ecosystems of prehistory have been converted to pasture and rangelands to accommodate domesticated livestock grazing and other human activities. Freilich *et al*. (2003)Traditional livestock grazing is managed basically for the benefit of livestock production. However, though ranchers manage domestic herds trying to mimic natural grazing patterns, human-managed grazing systems are not like natural regimes in how and where they are implemented due to factors such as limited space, competition for land, human infrastructure development and population growth.

There are two grazing systems in particular that are used in grassland ecosystem. The first one is the natural grazing system. This system has a variety of ungulates grazing a variety of plants and the grazing events are of short duration and occur over large areas. For example, the migration of Wildebeest in east Africa. The density of grazing ungulates is determined by natural population controls and plant communities are tolerant to frequent grazing (Santos 2011).

The second one is the domesticated grazing system. This is where usually a single, introduced ungulate species grazes a few types of plants and grazing events are seasonal and sedentary. The density of grazing ungulates is determined by human controls in terms of stocking rates and the plant communities may or may not be tolerant to frequent grazing (Bailey and Brown 2011).

2.3 Rehabilitation after open cast coal mining

South Africa has relied and is still relying heavily on mining activities to generate wealth that could be translated into economic development, infrastructure and employment opportunities for the country (Tanner, Beukes, and Möhr-Swart 2007). Formal mining in South Africa is more than 100 years old, and mining has substantial impacts on the environment. Before the establishment of the Mineral Act (Act 50 1991) mining companies used methods of mining with no regards for protecting the environment (Tanner, Beukes, and Möhr-Swart 2007b). Today mines have to comply with the South African constitution by conducting their operational and closure activities with diligence and care for others following section 24(a) of the South African constitution.

From the mining industry`s point of view, rehabilitation means restoring the areas impacted by the mining activities back to a sustainably usable condition (Nzimande and Chauke 2012; Tanner, Beukes, and Möhr-Swart 2007). Internationally and in the South African context, the broad rehabilitation objectives include three schools of thought which are (i) restoration of previous land capability and land use; (ii) no net loss of biodiversity; and (iii) what the affected community wants, the affected community gets. In this study we will only focus on restoration of previous land use and land capability. This option is preferred as most mining takes place on land with high potential for agriculture (Tanner, Beukes, and Möhr-Swart 2007).

Before mining commences, environmental impact assessment should be implemented which includes a series of public participation sessions with the communities to discuss the impacts of the activity and plans to manage and remediate for post-mining land use, which in many cases is agriculture or grazing. The re-vegetation of mined areas has to be done in accordance with the environmental management plan approved by the department of environmental affairs for post-closure land uses for the site which may be pasture, agriculture, or re-establishment of the native vegetation (Tanner, Beukes, and Möhr-Swart 2007).

Mining is a temporary activity, with the operating life span of a mine lasting from a few years to several decades. Mining takes place as underground mining or opencast. It is impossible for these methods not to impact the environment in an adverse way (Lloyd 2002).

All mines have to go through the several stages of a mine lifecycle, which ends with mine closure and rehabilitation with the primary objective of returning the land impacted by the mining activity back to a sustainably usable condition (Tanner, Beukes, and Möhr-Swart 2007b). Mine closure occurs once the mineral resource at a working mine is exhausted, or operations are no longer profitable. Mine closure activities typically consist of several steps, such as shut down, decommissioning, remediation/reclamation and post mining monitoring (VanTonder *et al*. 2008).

The reclamation/remediation step focuses on returning the land and watercourses to an acceptable standard of productive use, ensuring that any landforms and structures are stable, and any watercourses are of acceptable water quality. Reclamation typically involves a number of activities such as removing any hazardous materials, reshaping the land, restoring topsoil, and planting native grasses, trees, or other ground cover (Mhlongo and Amponsah-Dacosta 2016).

Once the final land form has been created, soil replacement can begin as part of rehabilitation. However, compaction is the single greatest limitation to the re-establishment of land use capability of rehabilitated soils and remains a focus of significant research effort in South Africa today (Houlbrooke *et al.* 2009). For example, in the Mpumalanga Highveld almost 40,000 hectares of coal strip-mined land that has been rehabilitated suffers from high bulk density of the soil which affects infiltration, rooting depth, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity (Tanner, Beukes, and Möhr-Swart 2007b). Many of the South African soils are highly susceptible to compaction.

Plant species used for rehabilitation should provide, *inter alia*, protection from erosion and meet the biodiversity objective (Amalero *et al.* 2003). Some plant species are more tolerant to high bulk densities than others, such as legumes in common use in

South Africa like soybeans, cowpeas and vetch. Of the grasses, *Cynodon dactylon* and *Paspalum notatum* possess dense rooting systems capable of penetrating compact subsoil (Tanner, Beukes, and Möhr-Swart 2007a; Teague and Barnes 2017). In the re-vegetation part of rehabilitation there are a range of methods that are used, depending on vegetation goals of the land use. Commonly used methods include seeding, hydro-seeding, seedling planting, transplanting, natural re-colonisation and direct topsoil return (Jamison *et al*. 2016).

Failure to properly rehabilitate open cast coal mines can result in negative impacts on the environment and the communities around the mined area (Limpitlaw and Briel 2014). For instance, in Mpumalanga (Witbank), there was an old abandoned Transvaal and Delagoa Bay colliery which caused sink holes associated with combustion of coal. These are the results of poor closure practices (Limpitlaw, Aken, and Lodewijks 2005).

Many of the abandoned mines in South Africa cause water pollution in the form of acid mine drainage (AMD) as a result of failure to rehabilitate (Waygood, Palmer, and Schwab 2006). For instance, the Brugspruit catchment, where some of the earliest mining in the Witbank coal field took place, is particularly affected by acid mine drainage.

Opencast mines should be designed to achieve the objective in the guidelines for rehabilitation because the age of mine abandonment is past and rehabilitation of mined land is now the norm in South Africa (Milaras, Ahmed, and McKay 2014). Serious challenges remain, however, as rehabilitated land is rarely returned to a land capability equivalent to its pre-mining state. This can only be achieved by careful management of soil resources, promotion of biodiversity and management of latent risks post-closure. Even where these actions are undertaken, poor post-closure land use practices can quickly degrade the rehabilitated surface (Limpitlaw, Aken, and Lodewijks 2005).

2.4 Grazing in a rehabilitated grassland

Little is known about the effects of cattle grazing on a recently rehabilitated grassland ecosystem. Although there is no conclusive model of grassland degradation, there is some agreement amongst grassland ecologists that degradation of grasslands is non-linear, meaning it progresses in a series of discrete stages that represent observable shifts in species composition, structure and function (Lechmere-Oertel 2014).

Grassland may appear to be sustaining its condition under a management scenario, but could be degrading without the obvious signs being evident (Richard, Craig, and Trevor 2004). This highlights the need for sensitive observation of the grassland by the manager to be able to know whether the management model is meeting its objectives or not. In particular, reduced plant vigour is probably the earliest sign of degradation (Lechmere-Oertel 2014).

Cattle grazing in large numbers in a small grassland area stimulates biological activity in the soil by breaking open the soil surface with the hooves, pressing down seeds so that they will produce new growth, pressing down other dead plant matter so that it decomposes in the soil, and depositing their animal waste thereby adding beneficial microorganisms and organic matter to the soil (Lat 1989).

Grazing of rehabilitated lands has been investigated in Australia, USA and other countries overseas, and it has been shown to be feasible within certain limits to the grazing pressure. A study by (Grigg, Shelton, and Mullen 2000) have demonstrated similar productivity of pastures established on rehabilitated coal mines compared to other nearby un-mined areas. This is achievable with fertilizer, lime and other supplements used on rehabilitated sites (Cameron 2014).

In the rehabilitation pastures, where the erosion risk is high, it is advisable to exclude cattle from grazing for few years, unlike in an area with good vegetation composition where systems will recover from grazing pressure (Fernandes *et al*. 2006). There will also be an improvement in infiltration of water which will assist in removing salts from rooting zones and further improving soil productivity. Initial grazing acts as an adjustment phase which helps removing more palatable feed, and begin the process of nutrient cycling and promote new growth and spread of pasture species(Schuman and Hart 1999). A suitable grazing pressure actually enhances both the productivity and surface protection abilities of the rehabilitated pastures.

Light stocking rate is desirable for rehabilitated pasture, but high stocking rates may initiate or exacerbate erosion, and resultant deep erosion channels potentially hinder stock management and may lead to cattle injury (Grigg, Shelton, and Mullen 2000). The productivity of the rehabilitated grass pasture will gradually decline with time if the supplementation of fertilizers is not maintained. Key research in the 1980s and early 1990s documented the decline in productivity as grass pastures age, and identified the underlying cause to be reduced available soil nitrogen for pasture growth (Lawrence *et al*. 2014).

2.5 Conclusions

Grasslands have a history of being the least conserved and as such grasslands have suffered a high level of transformation and degradation, while they are possibly ancient and fragile systems (Matsika 2007; Zaloumis and Bond 2011). Rehabilitated grass pastures are relatively sensitive system and grazing intensity should be controlled in order to allow regrowth of grass species over time. The grassland is affected by mining activities that reconstruct these pastures on steep slopes, on spoils and on replaced soils that are less than optimal for plant growth. Thus, overgrazing on these pastures must be avoided, but some grazing pressure is required to maintain the grass productivity (for cattle and making income from selling hay) and enhance stability after rehabilitation of an open cast coal mine.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research site

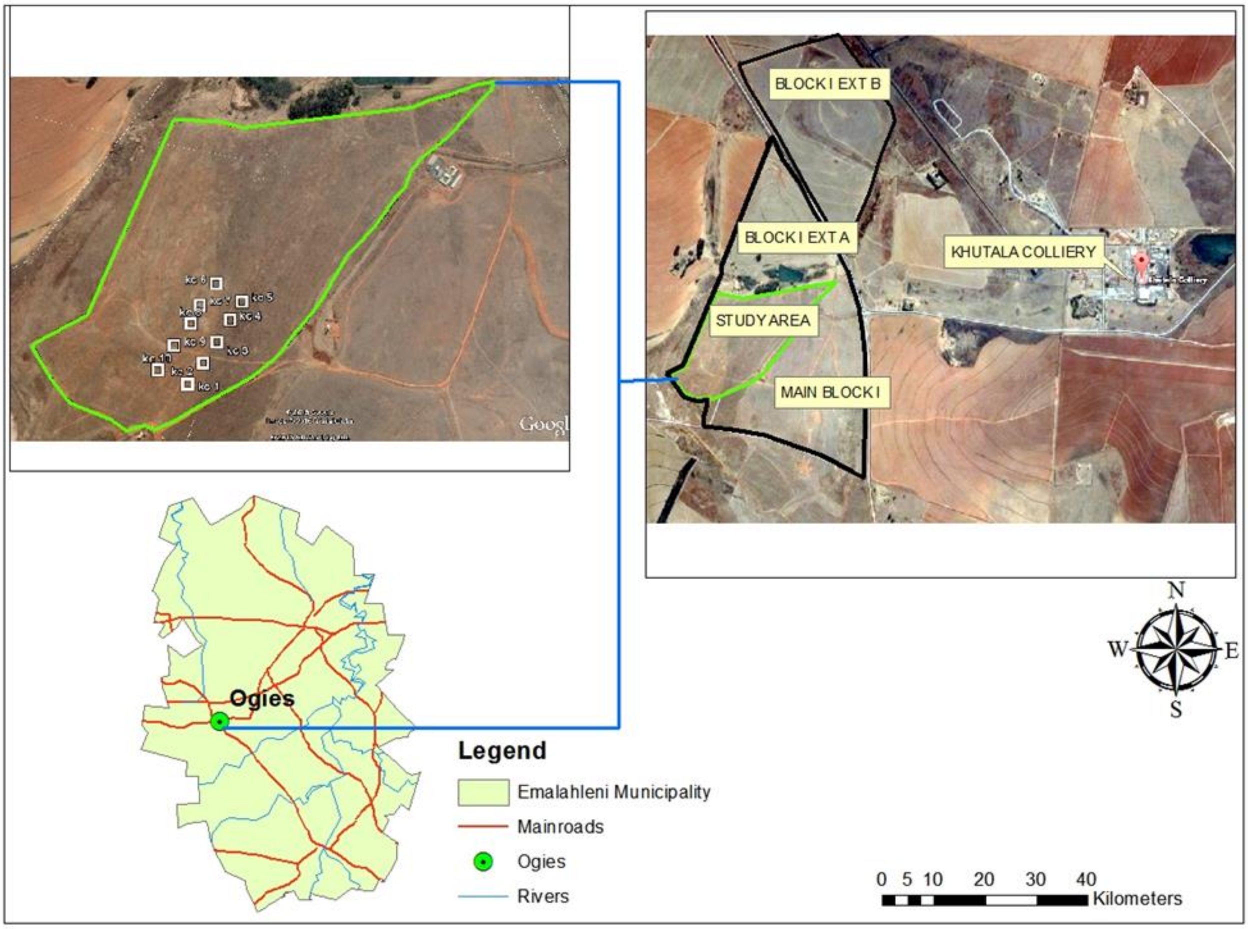


Figure 3: Study area map showing exclosure in Block

The research took place at coal mine in Mpumalanga. It is an open-cast and underground coal mine with two strip mining pits which are block A and KSA, where topsoil and hard rock were stripped off to reach the coal deposits and main block I which was rehabilitated. They were stockpiled/spoil piled and then used at a later stage to fill the old strips for rehabilitation. The soil was then planted with grasses. Eventually, after the area has been stabilised, the land was returned to the community. Our research is located in block I, which was rehabilitated in 2008. Presently, cattle graze in this area.

The area has natural vegetation which is short dense grassland dominated by a highveld grass composition, for example *Aristida*, *Digitaria, Eragrostis, Themeda* and *Tristachya*, with small, scattered rocky outcrops with wiry, sour grasses and some woody species, for example *Acacia caffra, Celtis africana, Diospyros lycoides* subsp *lycioi-des, Parinari capensis, Protea caffra, P. welwitschii* and *Searsia magalismontanum.*

The region is characterized by high rainfall in summer with a mean annual rainfall ranging between 660 – 1180 mm per annum. Temperatures in the region vary from below 0º C in winter to 39 ºC in summer with an average of 15º C per annum.

3.2 Objective 1: Benchmarking

With the help of local experts (environmental officers of the mine and environmental researchers), a comparable but relatively pristine area has been identified for benchmarking. Veld assessment was carried out in both the benchmarking and the experimental site. The 1 m^2 quadrat method was used for vegetation sampling. The cover percentages were estimated for each species. Bare patches were mapped and measured. Above ground biomass was measured with a disc pasture meter.

Two benchmarking areas were identified; Benchmark 1 is an un-mined land with planted pastures. Benchmark 2 is a natural area which is neither mined nor planted with pasture. The common activity in these study areas is grazing, although the numbers of cattle differ between the sites. In all sites, rotational grazing was practiced.

Benchmark 1 and Benchmark 2: two 50 x 20 m^2 areas were selected for the vegetation survey. Stratified random sampling was used to select 10 sampling points in each site. The 1 square metre quadrant method was used for vegetation sampling for collecting the data in both sites.

3.3 Objective 2: Grazing intensity

An estimate was made of the number of animal units in the herd present on site by a farmer and estimating cattle body weight and calculating the grazing unit with time spent grazing dividing the total mass of the herd by 450 kg body weight (the average body weight for matured animal). Information on how the herd is managed was obtained through interviews with the owner of the cattle and the environmental officer at the mine.

3.4 Objective 3: Determining the effects of grazing

Ten 5m x 5m exclosures were placed in the area along two parallel elevational transects in March 2016. The exclosures were spaced evenly 10m apart along transects. Two vegetation surveys were carried out using 1 square meter quadrant method inside and outside each exclosure. The survey was carried out in February 2017 and in March 2018.

Veld assessment was carried out using ecological index method inside and outside the exclosures. 3 samples were taken inside and outside of each exclosures, in total we had 60 samples taken for analysis. Sampling points were selected using stratified random sampling. The 1 square meter quadrat method was used for vegetation sampling. Bare patches were mapped and measured. Biomass was also measured using a disc pasture meter (DPM) inside and outside the exclosures. Three DPM readings were done inside the exclosures and another three outside the exclosures.

3.5 Objective 4: Measuring soil properties

A random sampling method was applied to collect equal size soil cores inside the study area and within the exclosures. Samples were collected using soil auger (51-102 mm), vegetation was cleared first were we took the sample. The samples were sent to an accredited soil laboratory where they were air dried, crushed and sieved to < 125 µm for the chemical and physical analysis. The results allowed us to determine the properties of soil such as pH, soil texture, soil organic matter and soil fertility in the study areas.

3.6 Data analysis

Benchmarking: Block I was compared to the two benchmark areas by using the following variables: (i) species richness and Shannon`s and Simpson`s diversity indices. (ii) ground cover percentage by site. (iii) standing biomass. and, (iv) species composition.

Effect of grazing was tested by comparing different aspects of the vegetation inside and outside the exclosures. Percentage of bare ground was analysed in a repeated measure ANOVA using Statistica. A correspondence analysis model was developed using species composition to see the relationship between the study areas. The effect of grazing was also analysed by comparing all univariate variables measured inside and outside the exclosures (biomass, bare ground, species richness) in two-way repeated measure ANOVA using exclosure (in/out) as one factor and exclosure number as the other for Block I.

The grazing regime of the herd was obtained through a key informant interview with the farmer. The number of grazing unit in the herd was determined by estimating cattle body weight and dividing the total weight of the herd (139 cattle) by 450 kg, and was compared with the carrying capacity of the area.

Results of the soil analyses were compared between the rehabilitated site and two benchmark site 1 and 2 using t-tests. 2 samples were taken from each exclosure in the rehab site, one inside and one outside. 10 samples each were taken from both benchmark sites using random stratified sampling method.

CHAPTER FOUR

RESULTS

4.1 Species composition

During the data collection, the grasses listed in Table 1 were identified in block I and, benchmark site 1 and 2. Block I rehabilitated and planted, benchmark 1 not mined but planted and benchmark 2 which is natural grazing land.

Table 1: Identified grass species

Grass species names	Common names	Grazing values	Ecological status
Agrostis eriantha	Black bent	High	Not known
Andropogon eucomus	Snowflake grass	High	Increaser III grass
Chloris virgata	Feather fingergrass	Average	Increaser III grass
Cortaderia selloana	Pampas grass	Low	Not known
Cynodon dactylon	Couch grass	Average-high	Increaser II grass
Digitaria eriantha	Common Finger grass	High	Decreaser grass
Eragrostis chloromelas	Lehman lovegrass	Average	Increaser II grass
Eragrostis gummiflua	Gum grass	Low	Increaser II grass
Eragrostis plana	Tough lovegrass	Low	Increaser II grass
Eragrastis curvula	Weeping lovegrass	Average	Increaser II grass
Eustachys paspaloides	Brown Rhodes grass	High	Decreaser grass
Hyparrhenia hirta	Thatching grass	Average	Increaser I grass
Imperata cylindrica	Cotton wool grass	Low	Increaser I grass
Panicum schinzii	Swart grass	High	Increaser II grass
Paspalum dilatatum	Dallis grass	High	Exotic grass

Pennisetum clandestinum	Kikuyu grass	High	Exotic grass
Setaria pumila	Pigeon grass	High	Increaser II grass
Sporobolus africanus	Ratstail dropseed	Low	Increaser III grass
Urochloa mocambicensis	Bushveld-signal grass	High	Increaser II grass
Urochloa panicoides	Garden signal grass	High	Increaser II grass

In Table 1, most grasses are of low grazing value. Ecological status of identified grasses are described as decreasers, increasers i, ii, iii and exotic grasses. Increaser ii grasses are most prominent in all three sites with fewer decreasers and increasers I and iii.

Table 2: Grass occurrence per site.

Ecological status	Grass species name	Common name	Grass occurrence		
			Block I	BM 1	BM 2
Decreaser	*Digitaria eriantha*	Common Finger grass	**X**	**0**	**0**
	Eustachys paspaloides	Brown Rhodes grass	**X**	**0**	**0**
Increaser I	*Hyparrhenia hirta*	Thatching grass	**X**	**0**	**0**
	Imperata cylindrica	Cotton wool grass	**0**	**0**	**X**
Increaser II	*Cynodon dactylon*	Couch grass	**X**	**X**	**X**
	Eragrostis chloromelas	Lehman lovegrass	**X**	**X**	**X**
	Eragrostis gummiflua	Gum grass	**0**	**0**	**X**
	Eragrostis plana	Tough lovegrass	**X**	**0**	**X**
	Eragrastis curvula	Weeping lovegrass	**X**	**X**	**X**
	Panicum schinzii	Swart grass	**X**	**0**	**0**
	Setaria pumila	Pigeon grass	**0**	**X**	**0**
	Urochloa mocambicensis	Bushveld-signal grass	**X**	**0**	**X**
	Urochloa panicoides	Garden signal grass	**X**	**X**	**0**
Increaser III	*Sporobolus africanus*	Ratstail dropseed	**X**	**X**	**X**
	Andropogon eucomus	Snowflake grass	**0**	**0**	**X**
	Chloris virgata	Feather fingergrass	**X**	**0**	**0**
Exotic grass	*Pennisetum clandestinum*	Kikuyu grass	**X**	**0**	**0**
	Paspalum dilatatum	Dallis grass	**X**	**0**	**0**
Unknown	*Agrostis eriantha*	Black bent	**0**	**0**	**X**

Cortaderia Selloana	Pompas grass	**0**	**0**	**X**

Table 2 above, shows each grass species identified and where they occur between block I, benchmark 1 and benchmark 2. Block I rehabilitated and planted, Benchmark 1 (BM 1) not mined but planted and Benchmark 2 (BM 2) which is natural grazing land.

Table 3: Forb and shrub species composition

SCIENTIFIC NAMES	COMMON NAMES	LIFE CYCLE
Bidens bipinnata	Spanish needles	Perennial
Conyza bonariensis	Horseweed	Annual
Conyza podocephala	Fleabane	Annual
Crabbea acualis	Prickle head	Perennial
Helichrysum rugulosum	Marotole	Perennial
Plantago lanceolata	Plantain	Annual
Schkuria pinnata	Bitterboss	Annual
Sonchus dregeanus	Hare thistle	Annual or biennial
Sonchus wilmsii	Sow thistle	Annual or biennial
Cyprus escualentus	Red nut sedge	Perennial
Tragopogon dubius	Yellow salsify	Annual
Tagetes minuta	Khakhi bush	Annual
Verbena brasiliensis	Purpletop vervain	Annual
Waliphrida densiflora	Dense flowered rotala	Annual
Tephrosia capensis	Cape Honeysuckle	Annual
Dichondra micrantha	Asian ponysfoot	Perennial
Erica woodi or/alticola	Pink heath	Perennial
Mariscus congestus	Dense flat sedge	Annual
Bidens pilosa	Blackjack	Annual

Lapeirousia sandersonii	Autumn painted petals	Annual

Table 3 is listing the forbs which were identified during vegetation sampling in all sites. The forbs are categorized according to their life cycle. Forbs are important in this study because they have an impact on the veld condition score of the grazing site surveyed. The majority of the forbs are annuals.

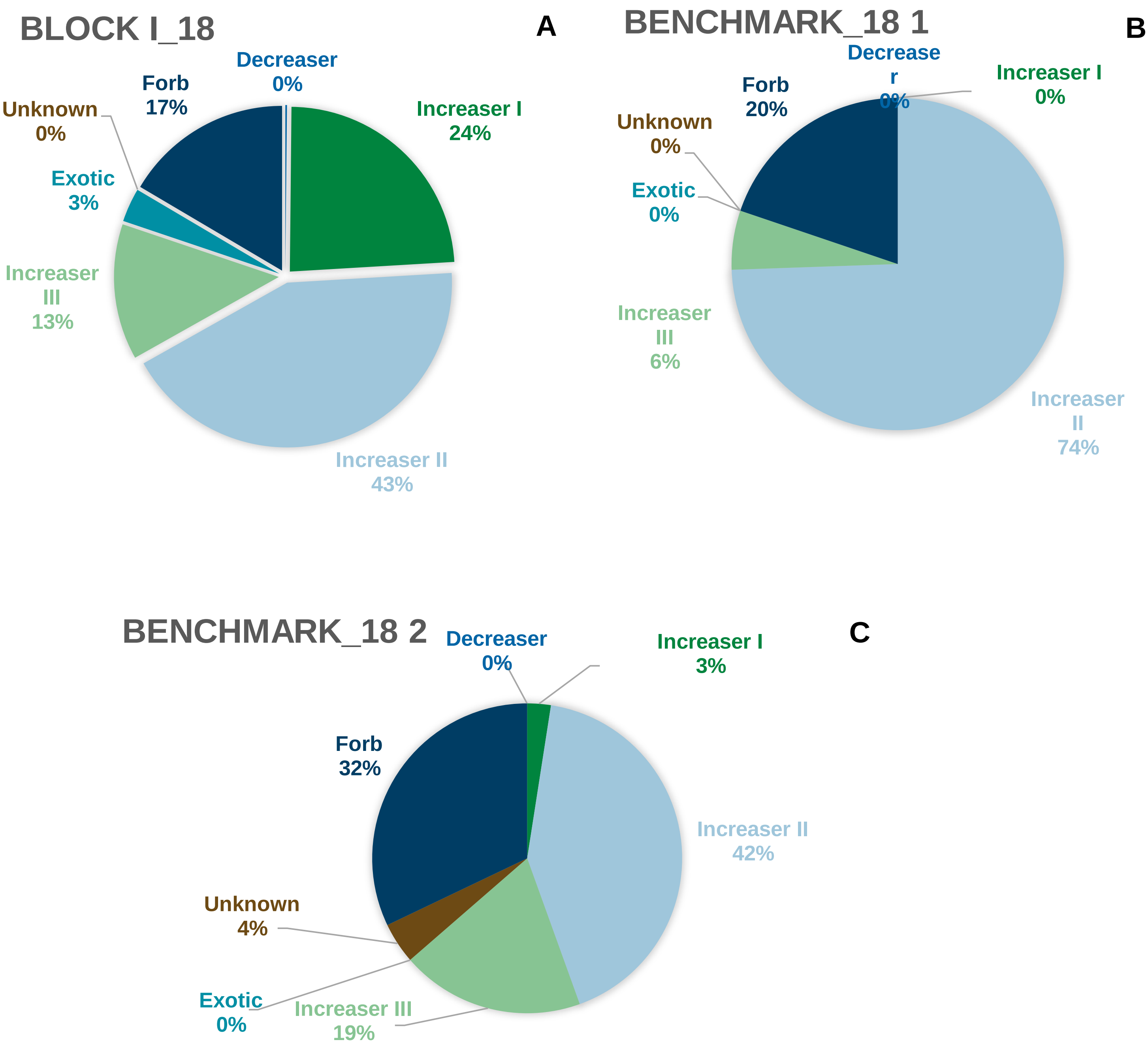


Figure 4: Relative abundances of each ecological category. A: block I in 2018; B: benchmark site 1 2018 and C: benchmark site 2 2018.

Figure 4 shows the relationship and difference in the surveyed areas in terms of the ecological status of each sampled grass species and the proportion of forbs in each area. From these pie charts, it is shown that all areas don't have decreaser grasses and block I has high percentage of increaser I grasses (24%), benchmark 1 has high number of increaser II (74%), while benchmark 2 has high percentages of forbs (32%).

4.2 Species diversity

Species richness and Simpsons and Shannon's biodiversity index for Block I and Benchmark site 1 and 2 are shown in table 3.

Table 4: Species diversity by site

Measure	Block I 2017	Block I 2018	Benchmark 1	Benchmark 2
Species richness	29	19	15	18
Simpson`s index	0.82	0.82	0.75	0.90
Shannon`s index	2.12	2.09	1.84	2.55

Block I had the species richness of 29 individual species in 2017 while in 2018 19 individual species were counted (Table 4). Benchmark site 2 had 18 species which is close to what Block I had in 2018. Benchmark site 1 had the lowest species richness value of all three sampled site with only 15 individual species identified.

Digitaria erientha, Paspalum dilatatum and *Urochloa panicoides* are the grass species which were absent in 2018, In terms of forbs, the following were not found in that year: *Bidens bipinnata, Conyza bonariensis, Crabbea acualis, Plantago lanceolata, Sonchus dregeanus, Sonchus wilmsii* and *Trogopogon dubius*.

Biodiversity index calculations where conducted (table 3), For Simpsons index Benchmark site 2 had the highest and Benchmark 1 had the lowest index, Block I had equal index values in terms of Simpsons. In Shannon's biodiversity index, Benchmark 2 had the highest. Block I in 2017 had index value of 2.12 and 2.09 in 2018. This could be attributed to the reduced number of species recorded.

4.3 Ground cover percentages

Average bare ground data for Block I, Benchmark 1 and 2.

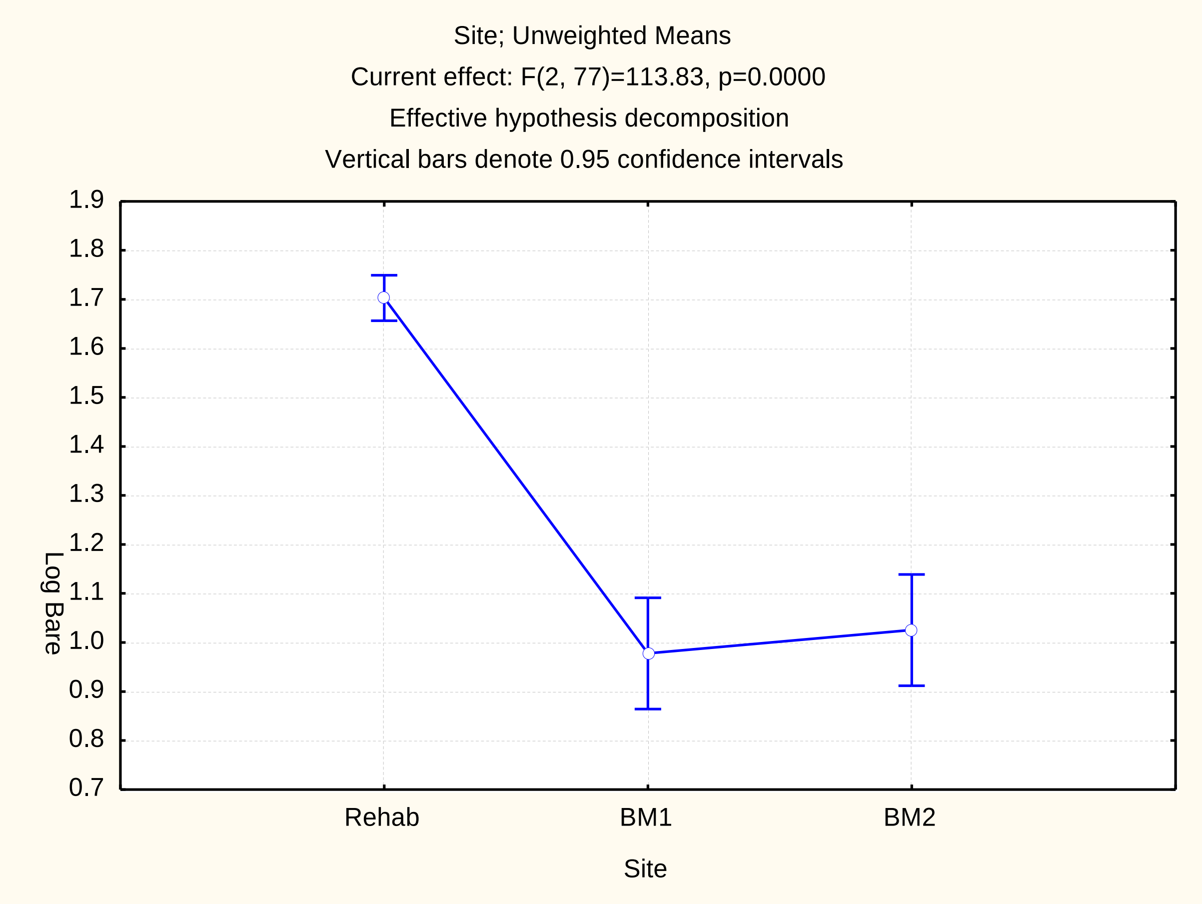


Figure 5: Average bare ground cover by site

Figure 4 shows a comparison of percentage bare ground at the rehabilitated area in 2017 and the two benchmark areas. The percentage bare ground at the rehabilitated area is considerably higher with 1.7% while benchmarks site 1 is below 1.0% and benchmark is 2 above 1.0%.

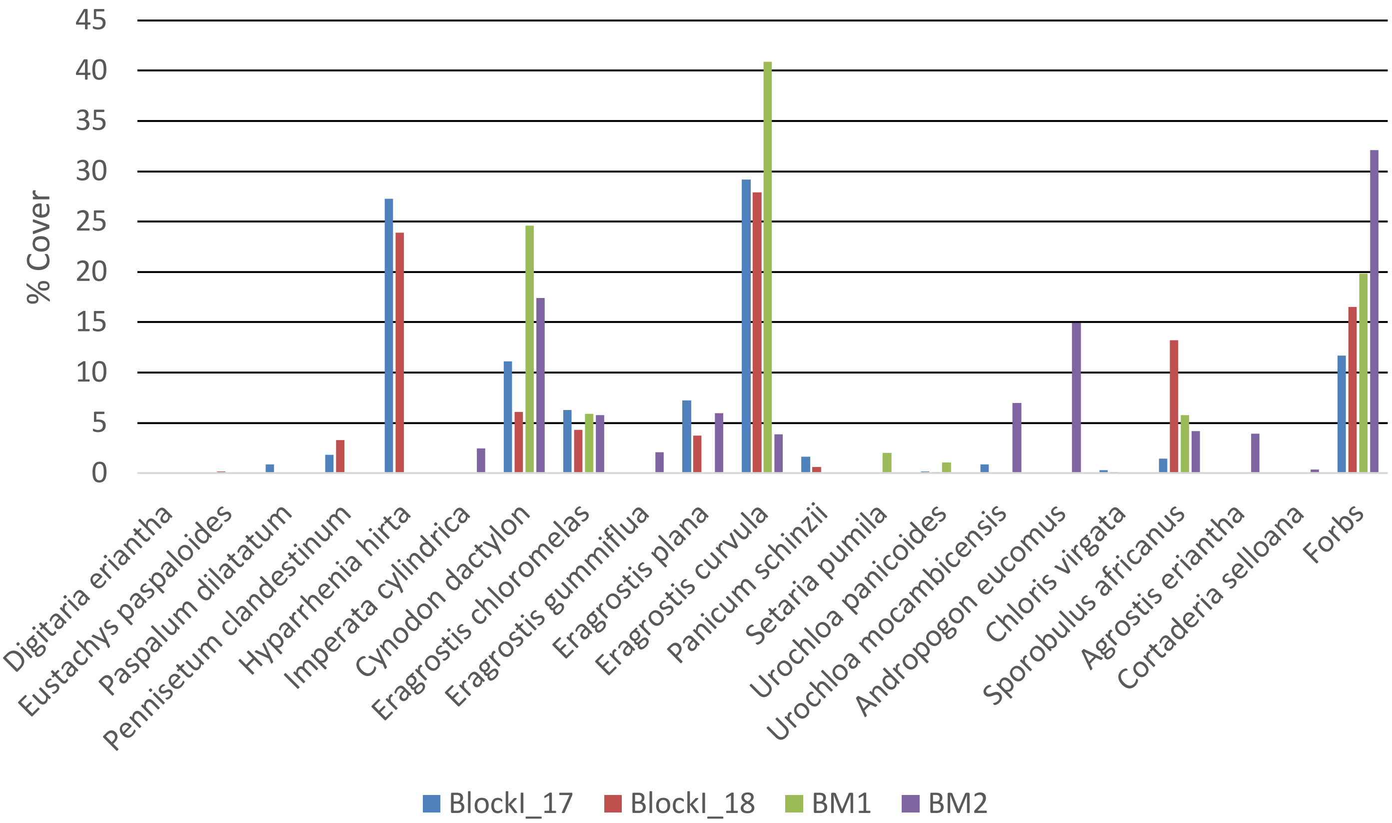


Figure 6: Cover percentage by grass species by site.

According to Figure 5, there are some grass species that are absent from one site and present in another. For example *Agrostis erientha* and *Cortaderia selloana* only occurred in Benchmark site 2 while *Setaria pumili* was sampled in benchmark site 1 only. *Hyparrhenia hirta* was only present in Block I. Block I is dominated by *Hyparrhenia hirta* and *Eragrostis curvula* while benchmark site 1 is dominated by *Eragrostis curvula* and *Cynodon dactylon* and benchmark site 2 is dominated by *Cynodon dactylon* and *Andropogon eucomus*. Benchmark data used is from 2018.

4.4 Biomass

Table 5: Repeated measures ANOVA for biomass in block I.

Effects	Repeated Measures Analysis of Variance (RMAnovaData) Stigma-restricted parameterization Effective hypothesis decomposition				
	SS	Degr. Of Freedom	MS	F	P
Intercept	1.21525	1	1.21525	1602.63	**0.000**
InOut	5.82371	1	5.82371	76.80	**0.000**
Exclosure	5.81566	9	6.46185	8.52	**0.000**
InOut*Exclosure	3.90395	9	4.33772	5.72	**0.000**
Error	**3.03314**	**40**	**7.58285**		
Time	4.32888	1	4.32888	11.58	**0.001**
Time*InOut	2.60447	1	2.60447	69.70	**0.000**
Time*Exclosure	8.49849	9	9.44276	2.52	**0.021**
Time*InOut*Exclosure	1.07260	9	1.19178	3.18	**0.005**
Error	**1.49482**	**40**	**3.73706**		

InOut= Inside and outside; Excl= Exclosure; TIME= sapling period 2017-2018; SS= sum of square, df= degree of freedom, MS= mean square, F= variance and P= probability.

The repeated measure ANOVA performed on the biomass data showed a highly significant effect of all factors and their interactions (Table 5). The local differences in biomass between exclosures were clearly observable in the field, and so was the difference in biomass between inside and out of the exclosures, especially in 2018. The interaction term of time and inside/outside reflects the accumulation of biomass inside the exclosures between 2017 and 2018 (Figure 7).

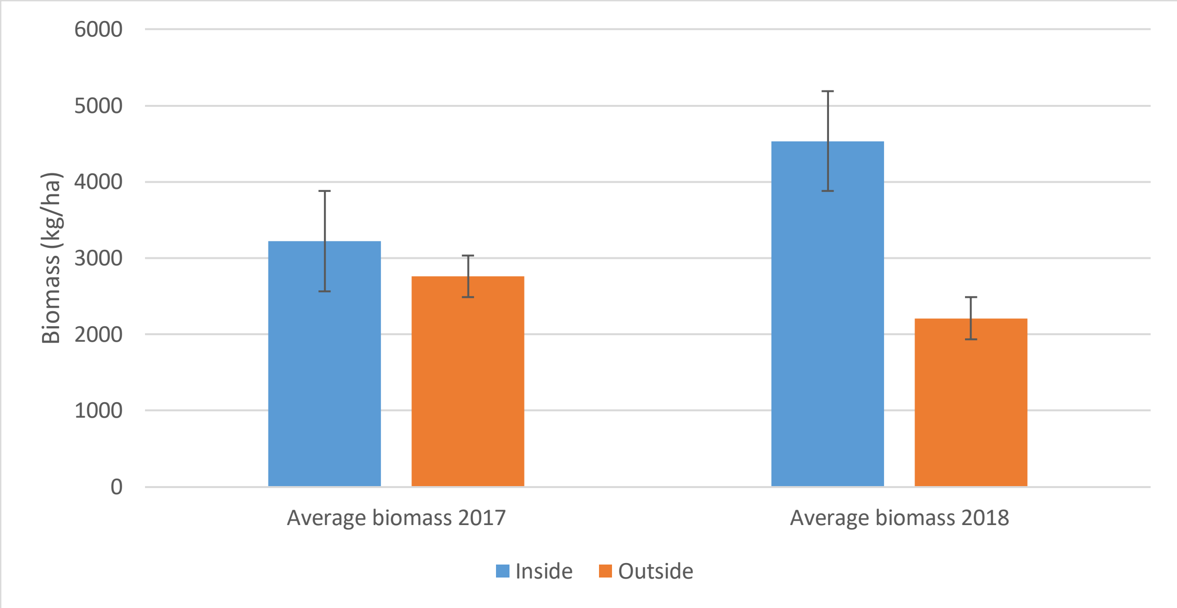


Figure 7: Standing biomass in Block I during 2017 and 2018.

Biomass in block I showed a slight decrease on the outside in 2018 when compared to 2017.There was an increase in biomass on the inside of exclosure from just above 3000 kg/h in 2017 to 4500 kg/h in 2018.

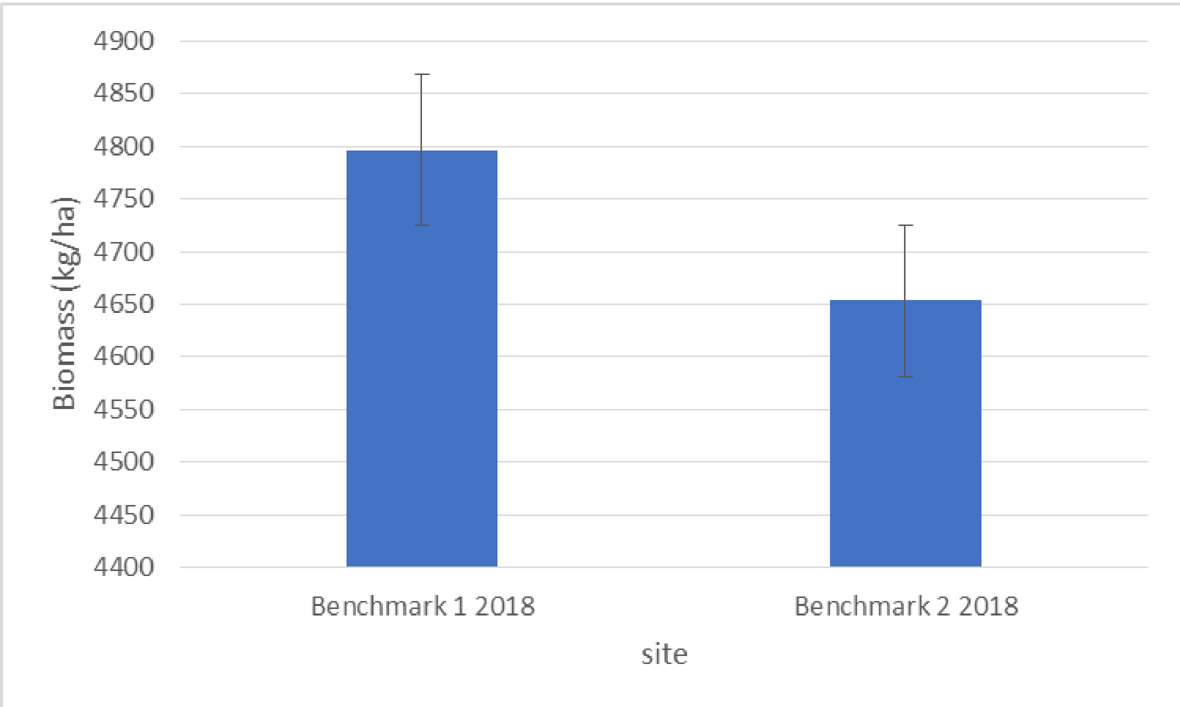
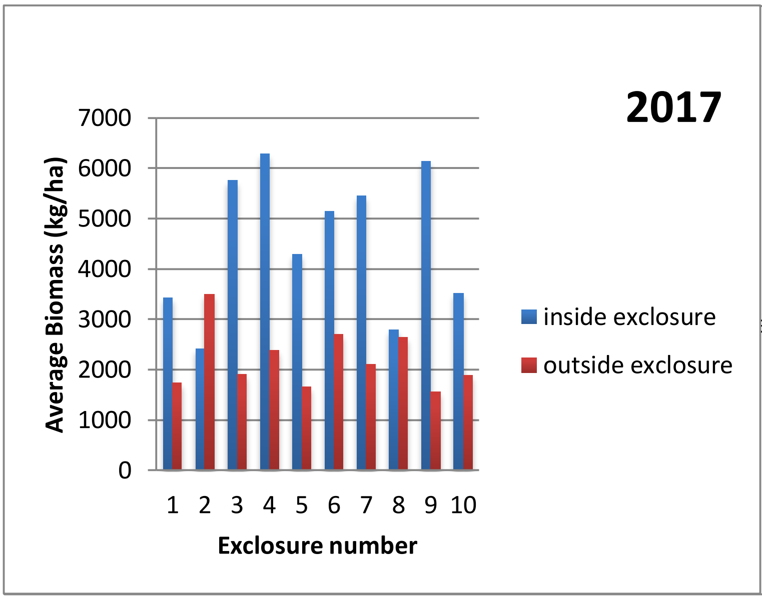


Figure 8: Average biomass for Benchmark site 1 & 2 in 2018

Benchmark 1 had high average biomass compared to benchmark 2. Both areas were grazed with rotational grazing system but different in that benchmark 1 is planted pasture while benchmark 2 is natural area. Exclosure were not erected in both benchmark sites.



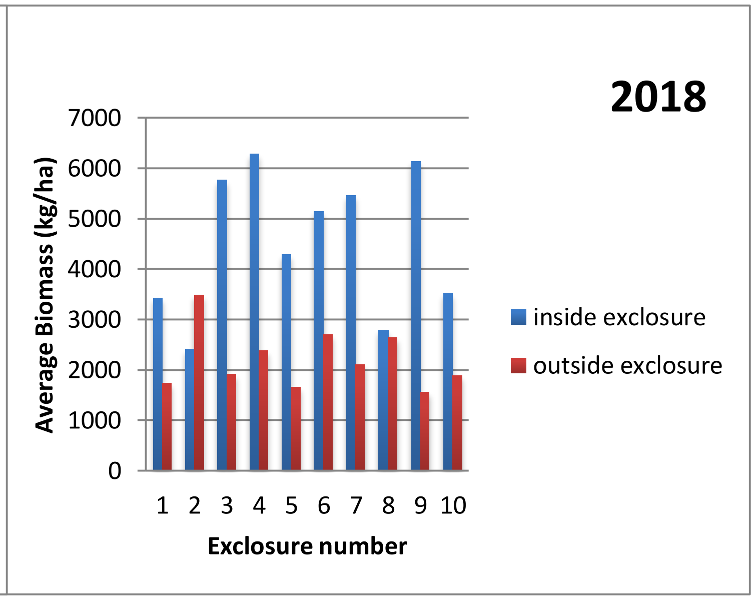


Figure 9: Average biomass inside and outside exclosure in 2017 and 2018

From 2017 to 2018 there was a considerable increase in biomass inside exclosure (Figure 9). However, outside the exclosures biomass decreased between those two years. The decrease in biomass outside the exclosures shows the impact of grazing by cattle. In exclosure 2 in 2018 there was an increase in biomass on the outside of the exclosure and in exclosure 10 the biomass remained the same over the study period, which could be attributed to the type of vegetation around this exclosure.

4.5 Effects of grazing

Grazing effects was analyzed for its effects on ground cover and secondly on species composition.

4.5.1 Effect of grazing on ground cover

Effects of grazing on ground cover were analyzed based on the effects of inside & outside exclosure, time and their interactions on percentage bare ground.

4.5.1.1 Repeated measure analysis of variance

Table 6 is showing the results of a repeated measure ANOVA of the bare ground data for Block I. The significant effects values are bolded.

Table 6: Repeated measure ANOVA log transformed results for bare ground in 2017

	SS	df	MS	F	p
Intercept	346737.0	1	346737.0	918.34	0.0000
InOut	760.7	1	760.7	2.0148	0.1635
Excl	**12224.1**	**9**	**1358.2**	**3.5973**	**0.0023**
InOut*Excl	3240.1	9	360.0	0.9535	0.4915
Error	15102.7	40	377.6		
TIME	**602.7**	**1**	**602.7**	**5.2794**	**0.02689**
TIME*InOut	194.7	1	194.7	1.7055	0.19903
TIME*Excl	**3660.7**	**9**	**406.7**	**3.5627**	**0.00250**
TIME*InOut*Excl	1344.7	9	149.4	1.3087	0.26301

InOut= Inside and outside; Excl= Exclosure; TIME= sapling period 2017-2018; SS= sum of square, df= degree of freedom, MS= mean square, F= variance and P= probability.

The effect of grazing on ground cover is determined by comparison of percentage bare ground inside and outside exclosures, which in Table 6 is indicated as InOut. It is evident from this table that grazing had a significant effect on ground cover, or at least not within a year, as the effects of InOut as well as all its interaction effects are not significant. The only factors which did have significant effects on ground cover are Time, Exclosure and Time x Exclosure.

4.5.1.2 Time effect on bare ground

The effect of time on bare ground over the study period (2017 to 2018) in Block I is shown in Figure 10.

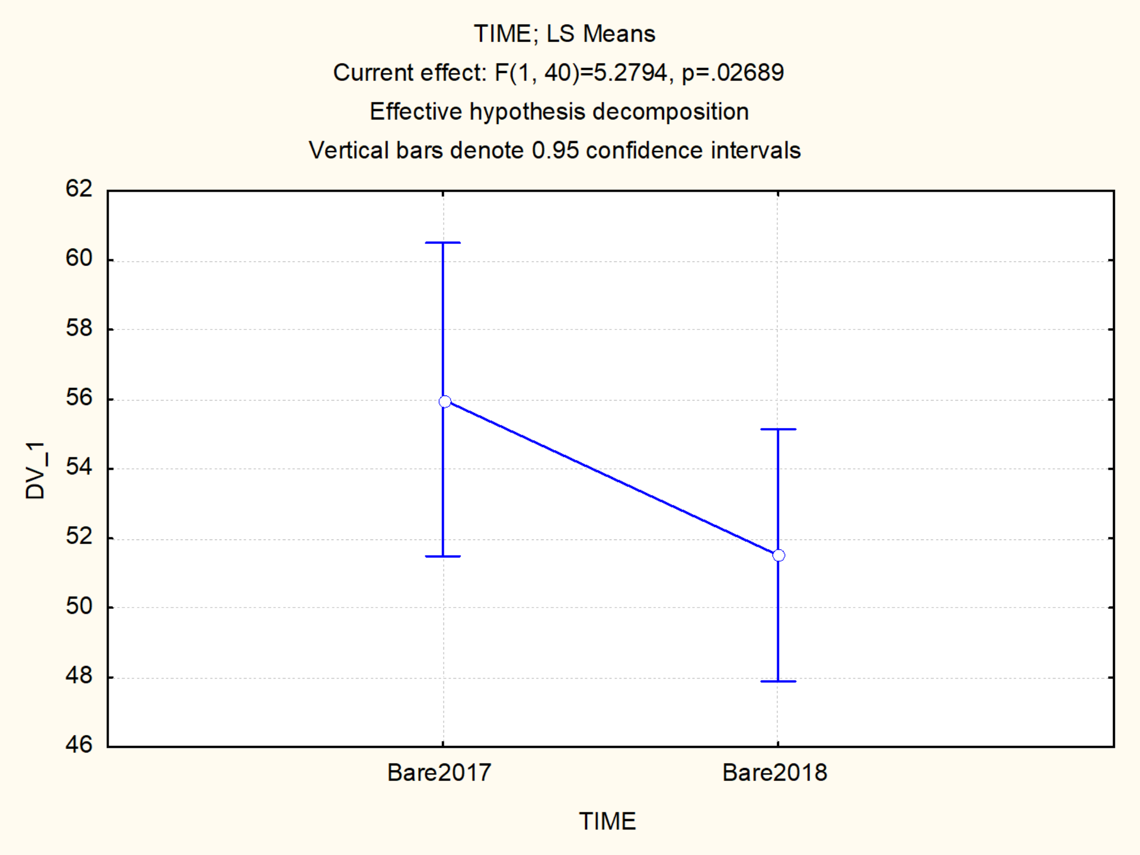


Figure 10: Change of percentage bare ground over time.

The effect of Time here shows the higher percentage bare ground overall during the first survey (Figure. 10, 2017) as compared to the second survey (Figure. 10, 2018). However, the difference is small, close to 3.8 % but significant. The calculations done on the averages of inside and outside samples from Block I data.

4.5.1.3 Effects of exclosure on bare ground

Figure 11 shows the average impact that exclosures had on bare ground in Block I 2017/2018.

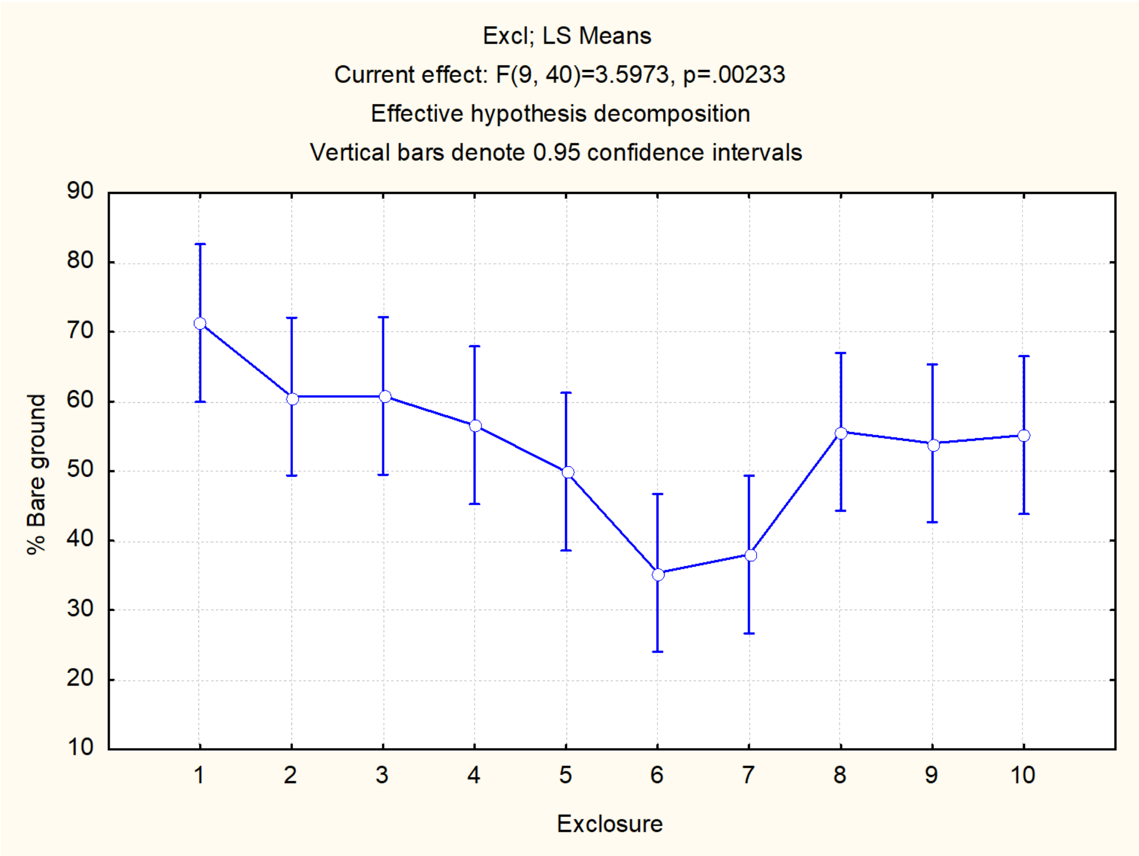


Figure 11: Effect of exclosure on bare ground.

The effect of exclosure is an effect of location. As explained in Chapter 3 the exclosures are arranged along two parallel transects on an elevational gradient. This arrangement was expected to capture most of the spatial heterogeneity in the vegetation. The significant effect of Exclosure (Table 6, Figure. 11) indicates that there is spatial heterogeneity in ground cover. The numbering of the exclosures gives an indication of the elevation as they were numbered 1 to 5 going up the slope (transect 1) and 6 to 10 going back down (transect 2). Exclosure 1, 2 &3 are above 60%; 4, 5, 8, 9 & 10 are between 50%-60%; 5, 6 and 7 are between 30%-40%. Most exclosures have a bare ground percentage between 50 and 60. Calculations done on averages of 3 samples inside and 3 samples outside for each exclosure.

4.5.1.4 The effects of time and exclosure on bare ground

The results of exclosure and time on bare ground in block I is shown in Figure 12. This information is important because it shows us how each exclosure has changed in terms of bare ground with time.

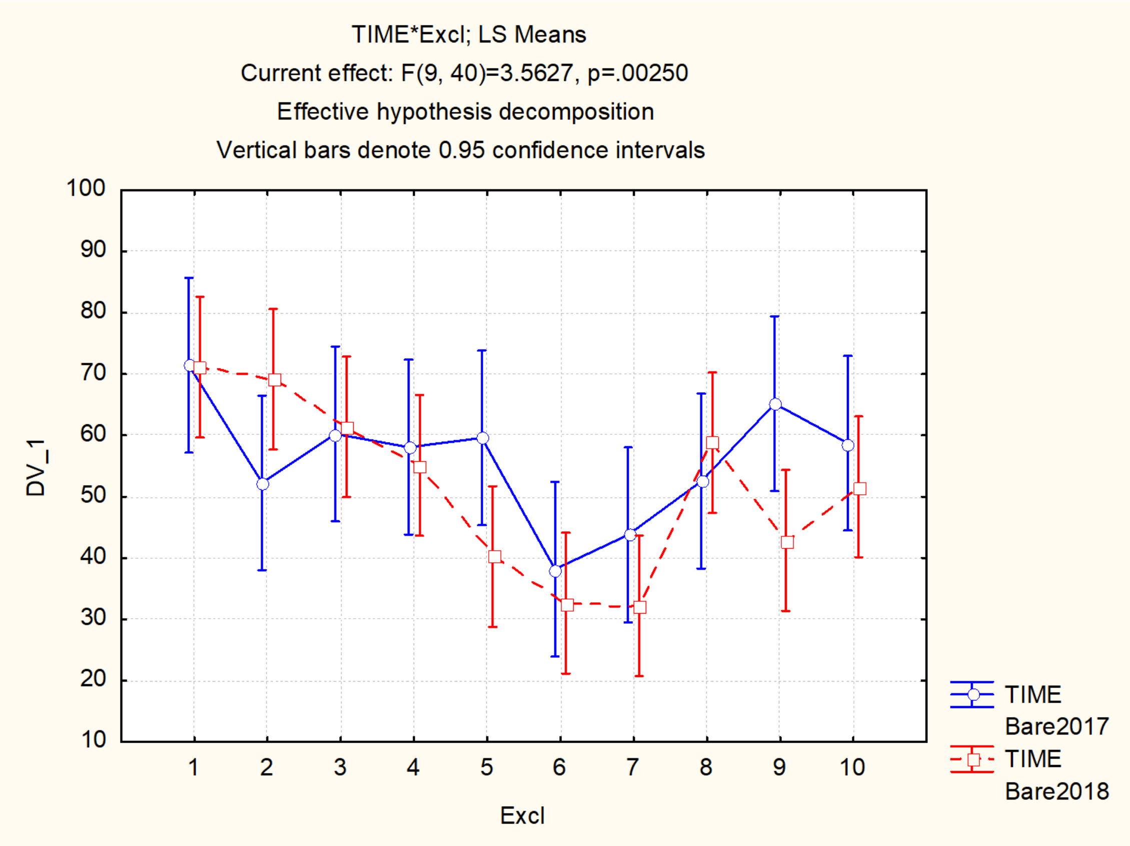


Figure 12: Effect of time and exclosure on bare ground

The interaction effect between Time and Exclosure signifies that the change in percentage of bare ground is not the same for each exclosure (Figure 12). For instance, at exclosure 2 it has increased significantly, while at exclosures 5, 7 and 9 there is a significant decrease. At all other exclosures there is significant difference in ground cover.

4.5.2 Effects of grazing and time on the vegetation in Block I

Vegetation composition is a very important aspect in ecology because it shows the contribution of each plant species to vegetation of a particular area. In block I there was a change in vegetation composition between 2017 and 2018 (Figure13).

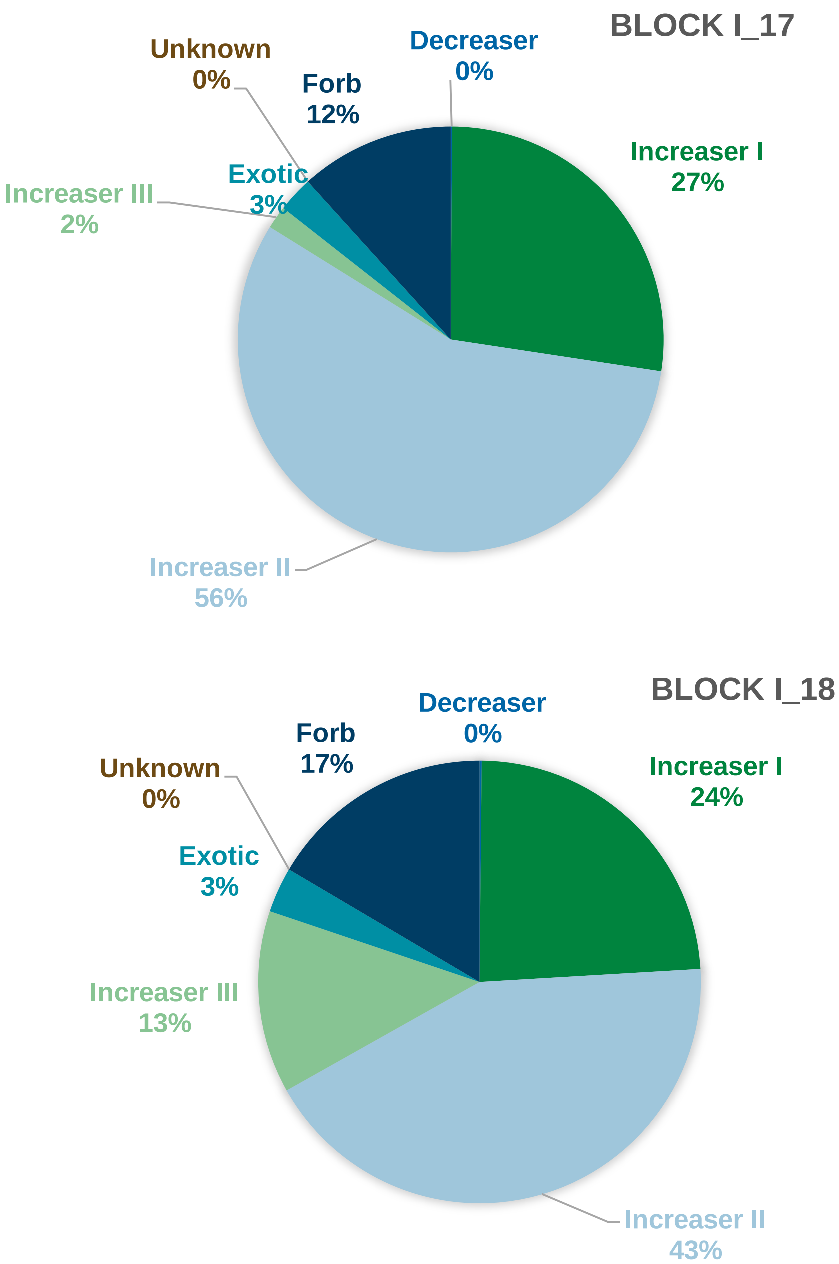


Figure 13: Ecological status of vegetation in block I in 2017 and 2018

The grass species identified in Block I were divided into broad ecological categories based on how they respond to over or underutilization and their grazing value (Table 1). Figure 13 shows the relative abundances of each of these categories during the first and second survey. This figure is the complete absence of Decreaser species in both surveys. Then, when comparing between the two surveys, there is a sizable increase in Increaser III (*Sporobolus africanus*) species and Forbs (*Conyza podocephala*, *Schkuria pinnata, Syperacea escalentus*). These increases happened at the expense of Increaser II species and, to a lesser extent, Increaser I species.

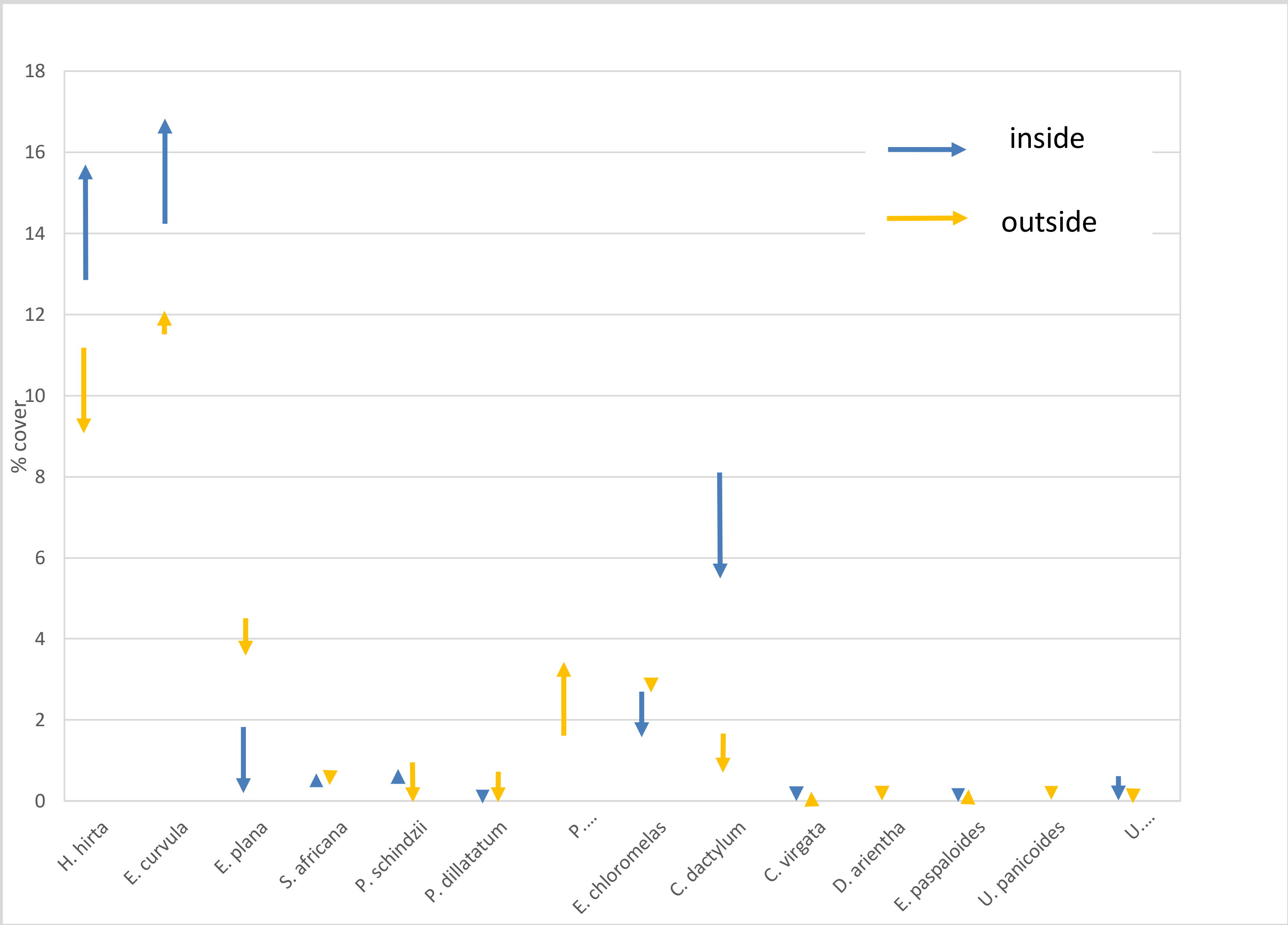


Figure 14: Species basal cover percentage in Block I 2017/18

Hyparrhenia hirta increased inside and decrease outside of exclosure. *Eragrostis curvula* increased inside and outside but much more inside the exclosure. *Eragrostis plana* decreased on the inside (with a considerable decrease) and outside of exclosure. *Eragrostis chloromelas* showed an decrease in cover outside and inside the exclosures. *Cynodon dactylon* decreased in cover inside and outside the exclosures but more inside. *Pennisetum clandestinum* showed a considerable increase on the outside of the exclosure, while other grass species did not show a clear increase or decrease over the sampling time.

Table 7: Repeated Measures Analysis of Variance for abundances of individual plant species showed in Figure 14.

SPECIES	Repeated Measures Analysis of Variance (Repeat (B2:BI61)) Sigma-restricted parameterization Effective hypothesis decomposition						
	InOut	Excl	InOut *Excl	Time	Time* InOut	Time* Excl	Time* InOut *Excl
Hyparrhenia hirta	**0.024729**	**0.000001**	0.184148	0.184148	**0.041850**	**0.047342**	0.198767
Eragrastis curvula	0.150992	0.224312	0.346507	0.364584	0.570450	**0.049893**	0.573920
Eragrostis plana	0.087449	**0.000246**	**0.000379**	0.073215	0.683200	0.256036	0.486867
Panicum schinzii	0.754798	0.325663	0.539147	0.276679	0.178759	0.076623	0.707499
Pennisetum clandestinum	0.079869	0.231170	0.231170	0.059517	0.059517	**0.006087**	**0.006087**
Eragrostis chloromelas	0.482418	**0.004108**	**0.006454**	0.486403	0.542235	0.551840	0.264788
Cynodon dactylon	**0.037364**	**0.033819**	0.221401	**0.037244**	0.301162	0.422522	0.759420
Eustachys paspaloides	0.334978	0.463577	0.512036	0.558396	0.346434	0.352219	0.508074

InOut= Inside and outside; Excl= Exclosure; TIME= sapling period 2017-2018

Table 7 is shows that there is a significant relationship between all grasses and exclosure except on *Pennisetum clandestinum*; *Eustachys paspaloides; Panicum schinzii* and *Eragrostis curvula. Hyparrhenia hirta; Eragrastis curvula* and *Pennisetum clandestinum* showed a significant effect with time and exclosures. Only *Pennisetum clandestinum* showed a significant effect with time, InOut and on exclosures. *Panicum schinzii* and *Eustachys paspaloides* did not have a significant effect of any factors with In and Out exclosure, between exclosure and InOut exclosure and with time. Calculations done on dominant grass species.

4.6 Grazing capacity and grazing systems

The third specific objective of the study was to determine the grazing capacity of the area and the grazing system used in Block I. Its objective is to get information on the impact of cattle in the area in terms of the grazing system used and grazing pressure.

4.6.1 Grazing capacity

With the data about abundances of different grass types, biomass and area it is possible to make an estimate of the grazing capacity, the number of 'animal units' an area can support. For this we used the following formula was used:

$$y = \frac{d \cdot r}{DM \cdot f}$$

Source: http://www.econatics.co.za/?page_id=23358

in which *y* is the grazing capacity in ha/animal unit, *d* is the grazing period in # days per year, *r* is the daily dry mass requirement per animal unit , *DM* is the dry mass in kg/ha and *f* is the utilization factor which depends on the result of a veld assessment (Van Oudtshoorn, 2015). The result based on 2017 to 2018 data for Block I is 1.025 ha/animal unit. The herd of cattle which was grazing the area is 105 animal units, which means that it would require 107.6 ha. The actual size for Block I is 31.8 ha, which means that it is severely overgrazed.

4.6.2 Grazing system

If given a choice, livestock will only eat the highest-quality, most palatable plants in a pasture (Rinehart, 2006). In order to ensure that plant biodiversity is maintained in the pasture, it is necessary to set up a grazing management system to better control livestock grazing.

In Block I the grazing system practiced is rotational grazing. The cattle were placed in the study site for approximately 3 months (12 weeks) from May to July. The farmer explained that the area is dominated by low quality grasses such *Hyparrhenia hirta*, *Eragrostis curvula* and *Cynodon dactylon* which makes him supplement the cattle with additional hay when they are grazing this site. He also mentioned that he uses the camp during the dry season so that the cattle can graze other areas with nutritious high quality grass during the wet seasons. This allows the other areas to regrow without disturbances.

4.7 Model for monitoring vegetation development

Figure 15 shows the correspondence analysis of vegetation sampled from the rehabilitated site and the benchmark sites. The two ellipses encircle the points for benchmark 1 and 2, while the square represents an area which has been enlarged in the inset. The vectors connect points for the same sites in 2017 and 2018. It is evident that in terms of species composition, block I is more similar to benchmark area 1 than benchmark area 2.

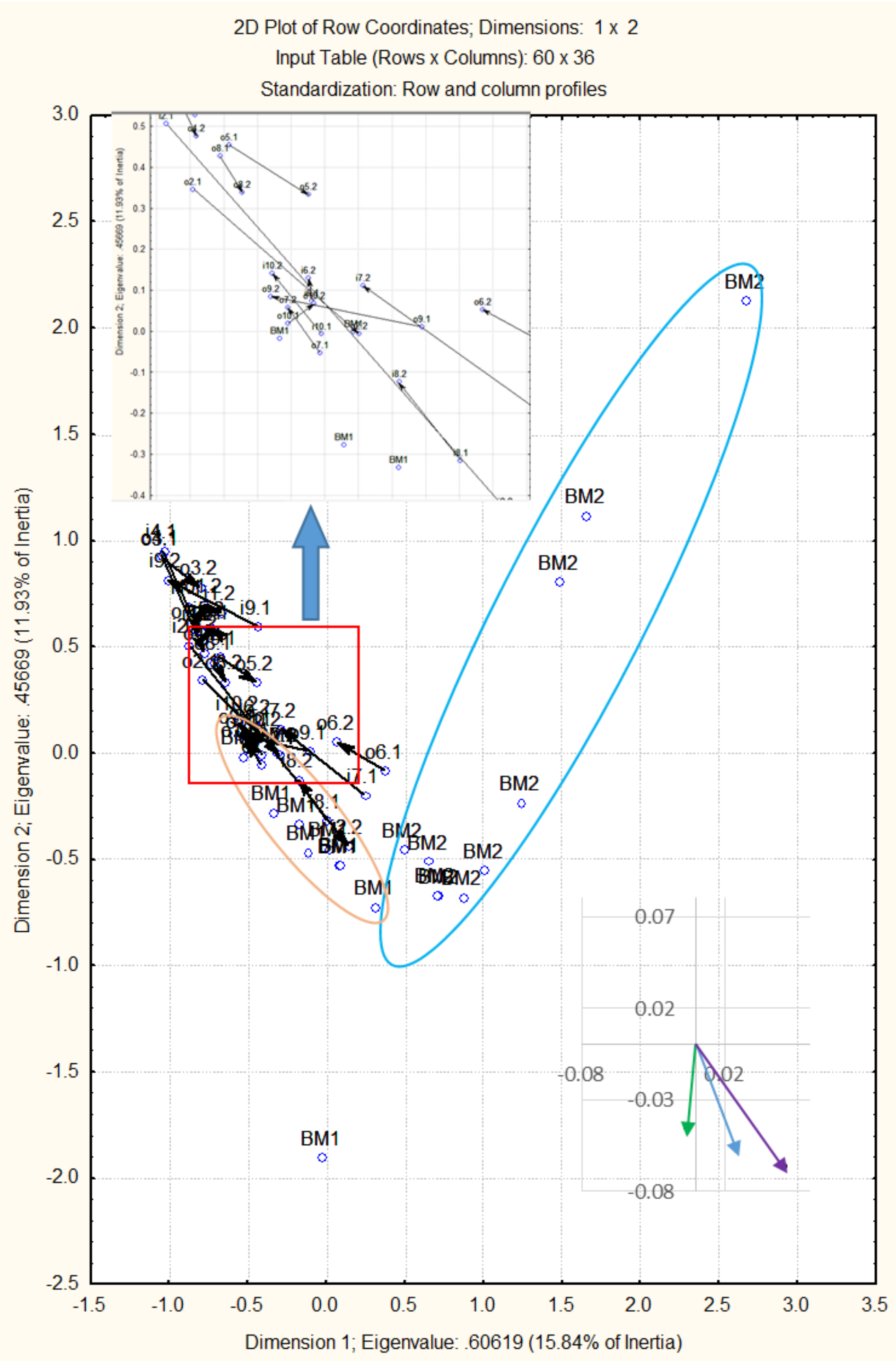


Figure 16: Correspondence analysis

The result from Figure 15 above is shows that species composition. In Block I is more closely similar to Benchmark site 1 than Benchmark site 2. The sites which are similar in species composition are close together and sites that are very different in species composition are far apart. The vectors are basically pointing in all directions. However, the average vector points in the direction of the benchmark area but it is very short and there is too much uncertainty surrounding it for it to be significant. There is a lot of variation in both vector length and directions (Figure16).

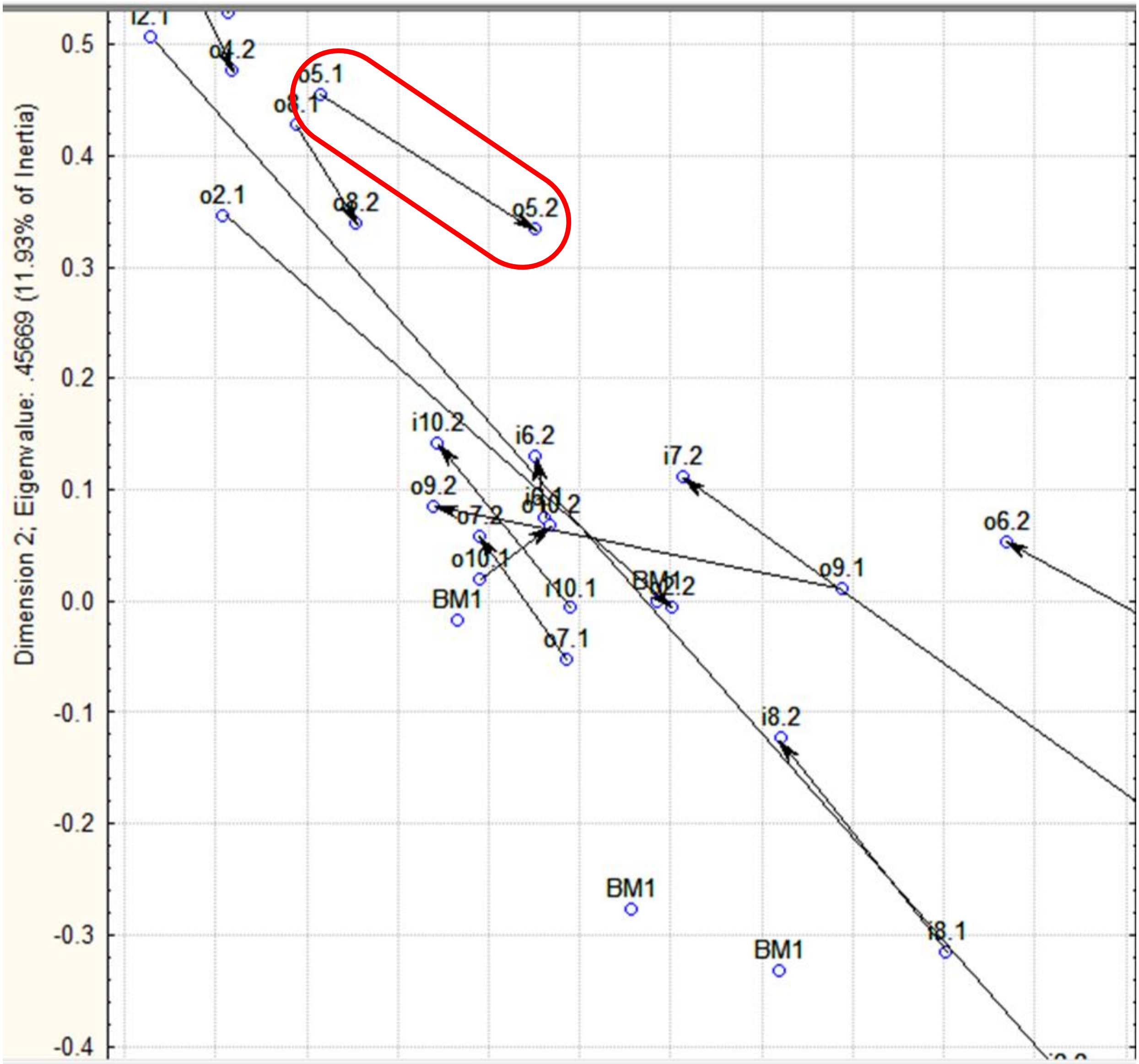


Figure 16: Vectors for correspondence analysis in Figure 13.

A closer look of the square inset from Figure 15 (Top left corner), where the direction and distance between sampling points in terms of species composition are showed. Some vectors are closer together while others are further apart in relation to the vegetation composition between the samples.

4.8 Soil conditions

The results from the soil analysis are shown below.

4.8.1 Average soil results from sampled sites

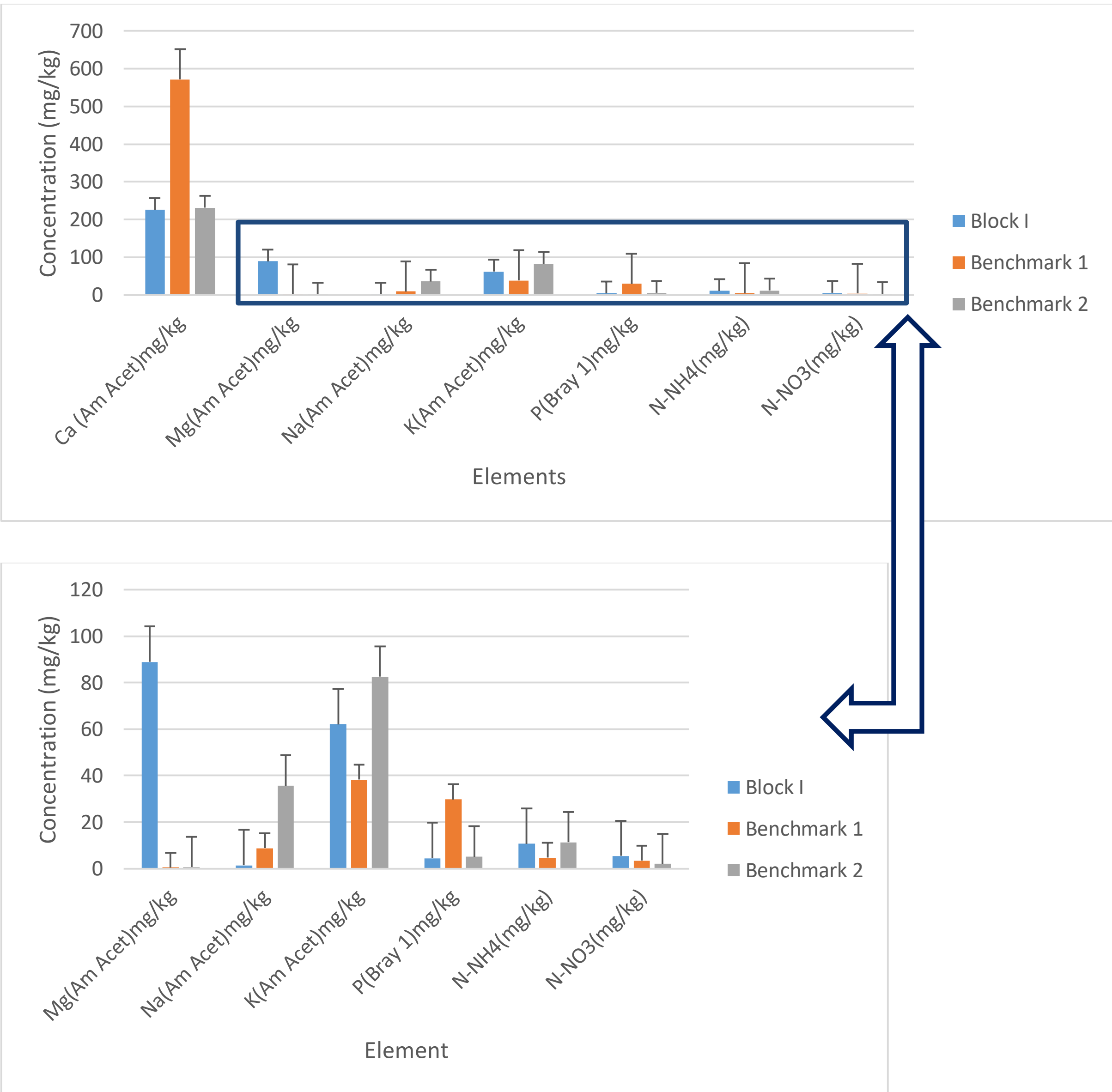


Figure 17: Average soil results from block I, benchmark 1 and 2.

Block I has the highest Mg^{2+} and NO_3^- concentration when compared with both benchmark sites (Figure 17). All three sites have levels of NO_3^-, NH_4^+ and PO_4^{3} lower than 10 mg/kg, except benchmark 1 with 30 mg/kg of P. Benchmark site 1 has the highest concentration of Ca^{2+} and PO_4^-, while in benchmark 2 K^+, Na^+ and NH_4^+ were the highest.

4.8.2 pH

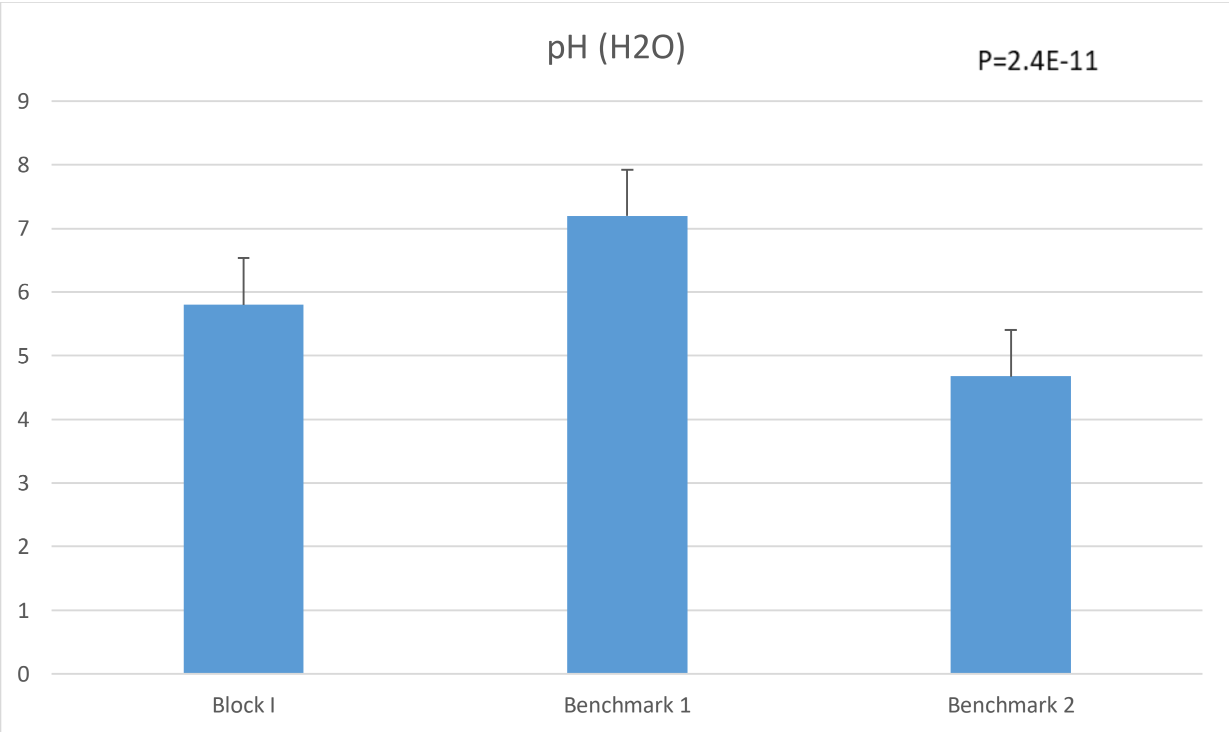


Figure 18: pH in the three sampled sites

Benchmark 1 had neutral pH while Block I and Benchmark 2 were acidic (Figure18). Soil pH is important because it influences several soil factors affecting plant growth, such as soil bacteria; nutrient leaching; nutrient availability, and toxic elements. Plant nutrients are generally most available to plants in the pH range 5.5 to 6.5.

4.8.3 Soil textures

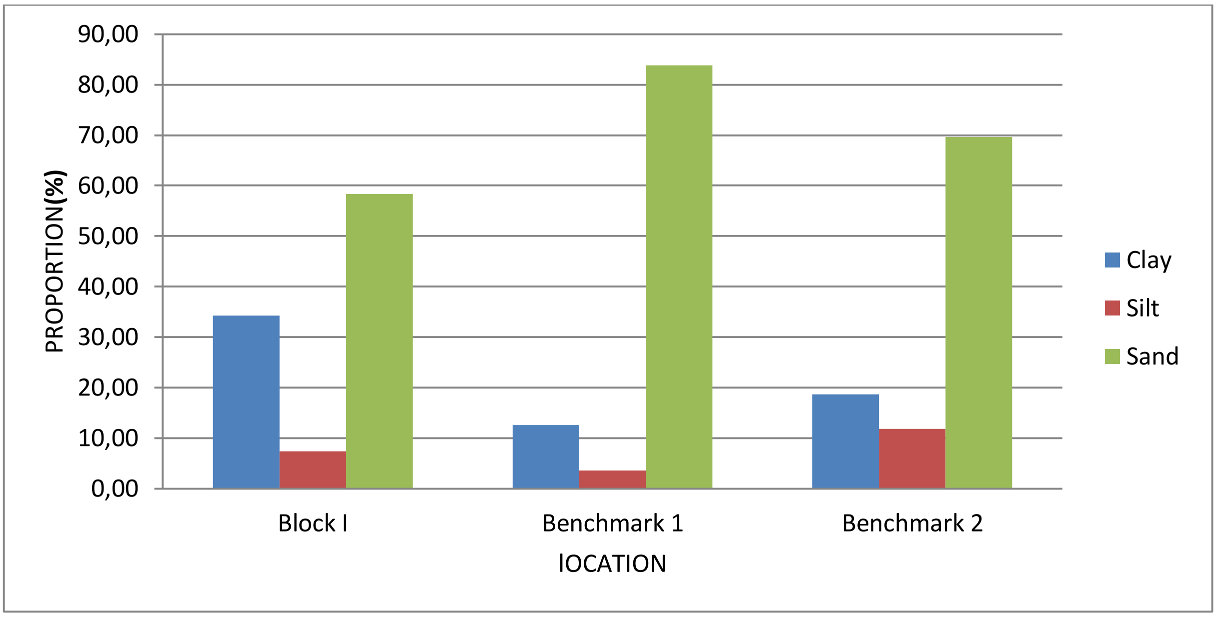


Figure 19: Soil textural classes for 3 sampled sites

Textural class in Figure 19 indicates the proportion of silt, clay and sand in the study sites. All sites had the highest level of sand followed by clay and then silt. Benchmark 1 were the highest proportion of sand. Silt levels were below 10% in all sites.

4.9 Rainfall data

Rainfall data were observed from a rainfall gauge at a farm called Bombardie, located within 12 km radius from block I and both benchmark sites.

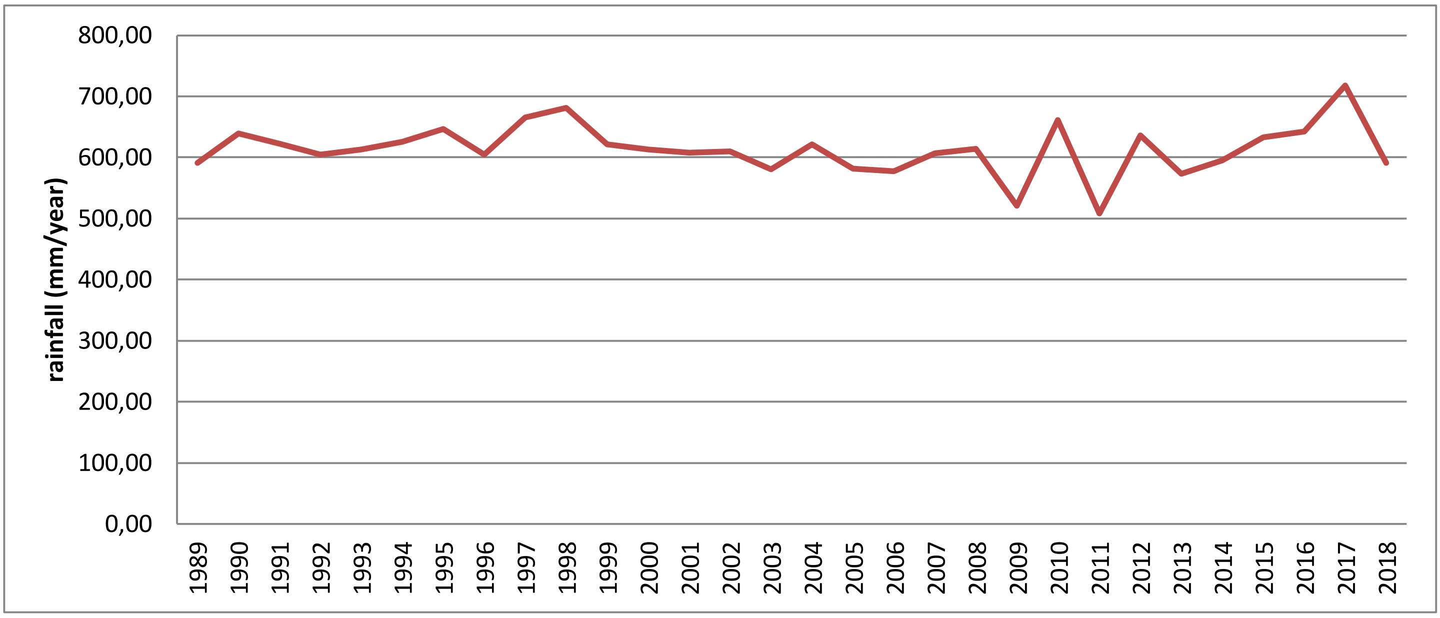


Figure 20: Rainfall data for the study areas.

When comparing rainfall received in the study area from 2016 to 2018 with that of the past 30 years, it is observed that during the study period, rainfall increased from 2015 reaching the all-time high in 2017 with a peak of 700 mm. The increase in rainfall was experienced in 1996 -1998 and also in 2010 and then again in 2015-2018, when rainfall was above 650 mm/year. The average rainfall per year in the area is between 600-650 mm/year.

CHAPTER FIVE

DISCUSSION

5.1 Species composition

After two years of vegetation sampling in Block I, small but significant differences in plant relative cover were detected outside the exclosures. This could be attributed to grazing impact on grass cover. Schuman and Hart, (1999) found no significant differences in relative cover of any plant species at any grazing intensity in a Wyoming mixed grassland. However, the results of the present study also showed the disappearance of some plant species such as *Digitaria eriantha*, *Eustachys paspaloides*, *Pennisetum clandestinum* and *Urochloa panicoides* inside the exclosures. Outside the exclosure there were also grass species which had disappeared at the second plant survey after a year, such as *Panicum schinzii*, *Paspalum dilatatum*, *Digitaria eriantha*, and *Urochloa mocambicensis.* Amiri (2008), found out that there was a significant increase in Gramineae in the enclosure site compared to the surrounding grazed site (outside exclosures) and a considerable decrease in forb species.

Cingolani and Diaz (2005), stated that change in relative cover may be due to the decrease in plant species that are better competitors for soil resource, and an increase in plant species that are less successful competitors but can withstand grazing. This can only apply to the grazed site. There was an increase of vegetation cover on the enclosure over the period of a year, mostly of *Hyparrhenia hirta* and *Eragrostis curvula* (Figure13). Amiri (2008) also reported that after 24 years livestock exclusion in Kuhrang grassland, total canopy cover within an exclosure was higher than on the outside. There was a higher density of grasses and forbs within the exclosure than outside, but shrubs were not significantly different.

There was decrease in species richness with grazing in Block I. The possible explanation to this could be that of Lwiwski (2013), that plant species that disappeared in Block I were rare species that contributed little to overall cover, thus their disappearance had few strong ecological consequences. Block I is dominated by less palatable grasses compared to other sites around such as Benchmark 1. Rutherford and Powrie (2013), also found that heavy grazing in the communal areas appears to have reduced overall species richness and changed species composition to less palatable grasses, especially on nutrient-poor soils.

In terms of species composition, the study area and benchmark sites have quite a low diversity of natural grasses, forbs and shrubs. One could attribute these changes to type of land use activities such as coal mining and grazing.

Cattle grazing in Block I had a direct (through eating) and indirect (trampling) effects on the species composition. The vegetation in the study areas was mainly dominated by Increaser II grasses such as *Eragrostis chloromelas; Hyparrhenia hirta, Eragrostis curvula, Eragrostis gummiflua; Cynodon dactylon* and *Sporobolus africanus* with low grazing value and forbs like *Tagetes menuta*; *Schkuria pinnata and Verbena brasiliensis* which are perennials. Block I had only two decreaser grasses at a very low density which are *Digitaria erientha* and *Eustachys paspaloides.* The absence of many decreaser grasses in these areas shows that they are dominated by less palatable grasses which have low nutritional value to cattle because of overgrazing. All pasture plants are sensitive to grazing. Kemp and Culvenor (1994), stated that, this sensitivity varies with stages in their growth cycles, soil fertility, and seasonal conditions. When it comes to species composition, there is no quick fix which will improve degraded composition of grasses, Different management strategies require time to take effect. The important desirable species will change with environmental changes; hence no one management technique will be ideal for all circumstances (Kemp, Dowling, and Michalk 1996).

5.2 Species diversity

The results showed that there was a decrease in species richness with grazing intensity over time. When comparing the species richness from Block I with that of benchmark sites we found that Block I had the higher species richness. This could be attributed to the field management like grazing system used and environmental factors such as rain with grazing. The fact that block I is mined area while the benchmark sites are not mined, still have normal and not disturbed soils, shows a good vegetation development in terms of diversity. However, it could also be attributed to the fact that larger area was sampled compared to benchmark sites. Hart and Carpenter, (2005) found that rangeland species richness was lowest in lightly grazed pasture, compared to ungrazed and heavy grazed pastures.

Block I had the species richness of 29 species in 2017 while in 2018 only 19 species were counted (Table 3). Milchunas *et al*.(2008), stated that in the field, grasses may respond three different ways to grazing overall: decreased growth, equal growth, or increased growth. When grass growth is decreased by grazing, grazing will cause the plant to have slowed growth or will cause the plant to stop growing all together. The number of species disappeared on the enclosure is lower than the one outside exclosure, this show that grazing did affected species diversity in Block I when looking at the 2017 and 2018 results. However, block I had the higher species diversity when compared to benchmark site 1 and 2 as shown in Figure 3.

High species diversity also indicates that the community is complex, there are many species interactions. Benchmark 1 showed low species diversity because is a planted pasture. Socher *et al*. (2013), stated that, in addition to fertilization and mowing, grazing intensity is a major factor influencing grassland plant diversity.

Block I is dominated by low quality grazing grasses and forbs (Figure 5). This is due to heavy grazing practiced in the area grazing. Heavy grazing altered species composition on all studied sites across the arid and semi-arid rangeland biomes of South Africa, usually with reduced grazing quality and favoring annual plants (Rutherford and Powrie 2013).

5.3 Ground cover

Ground cover is very important for erosion control. A good ground cover protects the soil from wind and water erosion, thereby reducing sedimentation in surface waters, it utilizes nutrients, thereby minimizing nutrient loading to surface water and leaching of nutrients to groundwater (Undersander *et al.* 1991). Groundcover levels will vary across a paddock, between paddocks and over time, because of differences in pasture type, plant growth, grazing pressure, grazing habits of stock, paddock aspect and soil type, fertility and moisture (Dee *et al.* 2017), More erosion will occur in block I since ground cover percentages are low and the area is partly sloping. However, in block I there was a small increase in ground cover from 2017 to 2018. In this case, grazing had little to no influence on ground cover percentages according to our results.

Species with above ground runners or stolon's such as *Pennisetum clandestinum* and *Cynodon dactylon*, offer advantages such as their ability to spread and provide good contact cover but are only found in some portions of the study area. For best ground cover it is best to use high grazing resistance grasses such as kikuyu (*Pennisetum clandestinum*), buffalo grass (*Bouteloua dactyloides*), *Cynodon spp*, bantgrass (*Agrostis stolonifera*), Little bluestem (*Schizachyrium scoparium*) and Sideoats grama (*Bouteloua curtipendula*) Reducing stocking rate so that some plants can escape grazing and allowing resting seasons can help plants to reproduce (Lyons and Hanselka 2001).

5.4 Aboveground biomass

In this study, a disc pasture meter was used to measure the amount of dry matter which existed in block I and how it was affected by grazing between 2017 and 2018 outside and inside the exclosures. The reason for general increase in biomass from 2017 to 2018 (Figure 6 and Figure 7) inside most of the exclosures is that they were not grazed and dominated by hard grasses such as *Hyparrhenia hirta* and *Eragrostis plana.* The area outside the exclosure was dominated by the same grasses, but the biomass showed a slight decrease which could be explained by the fact that these grasses are subjected to mowing and grazing.

Figure 7, shows that biomass increased significantly in the enclosures from just above 3000 kg/h in 2017 to 4500 kg/h in 2018. A study in various grassland types of the Tibetan plateau (which country) showed that grazing exclusion increased plant height, coverage, biomass, and species diversity in all four grasslands. The aboveground biomass in alpine meadow (180.8%), temperate steppe (117.3%), and swamp meadow (105.9%) increased significantly more than alpine steppe (10.1%) (Wang et al. 2019) without grazing over the study period.

Both benchmark sites have average biomass of between 4800kg/ha (Benchmark 1) and 4650kg/ha (Benchmark 2), when compared to Block I which has average biomass of 2800kg/ha. Block I has the lowest biomass when compared to the benchmark sites. This can be partly explained by the ground cover percentage of the area.

Another factor which contributed to the biomass decrease outside the exclosure is livestock traffic/trampling. Every pasture will experience the loss of plant material because the plants could not survive the traffic of livestock. Certain species are more sensitive to trampling and the stage of maturity also influences the effect of heavy traffic (Bilotta, Brazier, and Haygarth 2007). In our case, examples of sensitive grasses are *Paspalum dilatatum, Urochloa mosambicnsis* and *Eustachys paspaloides.*

5.5 Effects of grazing

There was not enough evidence to conclude that these was an effect of grazing in block I between inside and outside exclosures. This is because there was no significant effect on ground cover, but there is a clear effect on some plant species (individual species responses) and biomass. One year is too little to see the effect of grazing on plant diversity, biomass and cover percentage. After six year of grazing. Schuman *et al*. (1999), found no significant differences in relative cover of any plants species at any grazing intensity in the native mixed –grass rangeland in Wyoming. Plant species community changes take longer to appear and depends on soil quality, livestock management and plant species in the area. In terms of ground cover, there was no significance effect of grazing when compared inside and outside exclosures. Grazers can have impact on grasslands through their effects on plant populations and community composition, on energy flow and nutrient cycling in grassland ecosystems, and on landscape-level heterogeneity and movement of materials (Knapp *et al*. 1999). To explain these changes, one could look at changes in species composition from 2017 to 2018 outside exclosures where there was a decrease in increaser I and increaser II species and increase in forbs and increaser III which are not favorable to grazers while inside exclosures there was a small increase in *Eragrostis curvula* and *Hyparrhenia hirta* between 2017and 2018. This is in line with Willms, Smoliak and Dormaar, (2007) findings, which observed that in grasslands regions, grazing causes a decline of some grass species.

This is in contrast with Briske and Noy-Meir (1998), who found that the reproduction of palatable perennial grass plants in plots excluded (exclosures) from grazing was much faster than those which were grazed. Biomass increased considerably inside the exclosures where it not grazed and generally decreased outside the exclosure. Forbs increased between sampling years in Block I, it is however different from what Amiri, (2008), discovered that the change in plant communities due to grazing in northern Mongolia that species diversity and biomass of forb decreased with increasing grazing intensity. The proportion of forbs decreased significantly (by 98.8%)

under grazing excluded site, but there were no obvious differences found in all other grassland types (Wang *et al*. 2019).

5.6 Grazing capacity and grazing system

There is debate about which grazing system is best for improving biodiversity. According to Bozkurt and Kaya, (2011) there is no one system that is best for all situations. In this study it was found that a seasonal rotational grazing system was used, allowing the area rest and regenerate. Selective grazing of sweet and palatable grasses causes them to be overgrazed while unpalatable grasses are under-grazed, which is a possible cause of dominance of Increaser grasses (Little, Hockey, and Jansen 2015).

The grazing system used had small impacts on Block I vegetation composition, standing biomass and plant ground cover percentages. Although one year is perhaps too short to asses' changes that rotational grazing would have. Metera et al. (2010) stressed that moderate grazing increases fertility of very poor soils and promotes species richness at the local scale as well as vegetation cover, which contributes to protecting the soil from erosion. Grazing improves the soil's ability to retain water, which is important for seed germination and seedling establishment in environments where the main limiting factor for these processes is water.

However, based on our results, there was overgrazing in Block I because there were more cattle than the area can sustain without deteriorating the conditions of the area. Low stocking rate of cattle in Block I is crucial since overgrazing can result in complete disappearance of other grazing intolerant grasses and forbs.

5.7 Method for monitoring vegetation development

In the correspondence analysis the Block I points were closer to those of Benchmark site 1 and Benchmark site 2. Indicating that block I and benchmark site1 have more similar species composition. However, in terms of vegetation development in block I, the vectors are not showing a clear direction. The reason for this may be that a year is too short for a clear direction in the vegetation composition of the whole area to be discernible. The average vector points in the direction of the benchmark area 2 but it is very short and there is too much uncertainty surrounding it for it to be significant. There is a lot of variation in both vector length and directions (Stam and Thovhakale, 2018).

Over a longer period the method may enable us to monitor the rehabilitation process in Block I. In South America grassland rehabilitation after coal and mineral extraction showed a gradual increase in cover percentage to approximately pre-mining conditions over 20 to 30 years with grazing (Stam and Thovhakale, 2018). Biomass production followed a pattern of gradual increase following mining on rehabilitated lands, and it even exceeded pre-mining levels in the interridge zones where moisture collects. However, the steeper slopes would not be expected to ever attain full growth potential. Diversity increase slowly on abandoned mine sites, and will reach 50 to 60 percent of the pre-mining level after 50 years (Macdonald *et al*. 2015). Weed dominance shows a very rapid rise following mining, with a rapid decline after 2 years on reclaimed areas following the increase in planted grasses (Iverson 1992).

5.8 Soil conditions

Soil tests are used to measure soil nutrients that are expected to be plant-available. Measurements of total nutrient content are not useful indicators of sufficiency for plant growth, because only a small portion of the nutrients are plant available. Dinkins and Jones (2011) and Espinoza (2010), published soil nutrient classes, toxicity levels and optimal pH and all levels displayed are for soil samples collected in the 0 – 6 inch soil depth.

Current results showed that phosphorus (P), in Block I and Benchmark site 1 have medium levels while benchmark site 2 high levels, potassium (K) levels were low in all sites with less than 150 ppm. Calcium (Ca) is rarely deficient when soil pH is adequate in most cases. The high levels in benchmark site 1 is due to application of calcium carbonate ($CaCo_3$) 8 weeks before we collected samples. Normally magnesium (Mg) should be between 60-300 ppm, and both benchmark sites showed very low levels while block I had optimum levels (Espinoza, Slaton and Mozzaffari 2010). Ammonium-nitrogen (NH_4-N) concentrations of 2–10 ppm are typical and our results in all sites were within this range. Nitrate-nitrogen (NO_3-N) were found to be in medium levels for plant growth in all study sites. Soil nutrients content in Block I showed optimum level for plant development and survival when compared with benchmark site 1 and 2.

5.9 Rainfall data

The size and timing of rain events are strong drivers of ecological processes (Zeppel, Wilks, and Lewis 2014). This means that how much rain is received in a particular area and when it rains have an influence in the development of vegetation. In this study, the effect of rainfall was the same inside and out of exclosures. However, rainfall has an effect on soil water content which could affect the growth of vegetation in the area. In limestone grassland in England, 20 % increases in summer precipitation increased summer growth, whereas increased autumn and winter precipitation had no effect on growth. Zhang *et al*. (2013), found that plant production (mainly above ground net primary production (ANPP) or aboveground biomass (AGB)) was positively correlated with changes in precipitation along spatial gradients. There was a decrease of rain by average of 92,38 mm in Bombardie rainfall data capturing stations from 831.38 in December 2016 to 739mm in December 2017. The data is also showing that on average, 2016 had more rain than 2017 which may have had an influence on grass development in all the sites, more especially inside exclosures.

CHAPTER SIX

CONCLUSION

The primary purpose of establishing vegetation after open pit coal mining is to make use of the area again for grazing or any other land use activity, and to reduce soil erosion. The results showed that a two years of sampling during wet cycle is not enough to show cumulative effects on the whole vegetation but on a level of individual species there was some effects evident of cattle grazing in rehabilitated coal mined area, if given more time, the effect may negatively or positively increase/decrease over time. For instance we found an increase in number of forbs and decrease in some species richness and plant composition. It was also not clear in terms of species composition if whether Block I is moving towards benchmark site 1 or 2 state. To see a considerable change in species diversity, cover percentage and biomass, the exclosure needs to be monitored for several years.

In terms of aboveground biomass, there was a significance increase on the inside of the exclosure and decrease on the outside which was influenced by grazing and once of mowing in the area. The repeated measure correspondence analysis method can be useful in the future research to see changes in vegetation composition for different area when compared. In this study to showed us that in terms of species composition, block I is more similar to benchmark area 1 than benchmark area 2.

The soil parameters analyzed were on a normal range, with just few elements that were very high in block I such as magnesium and ammonium nitrate. An above normal rainfall (700 mm) was recorded in the area in 2017.

CHAPTER SEVEN

SUMMARY OF FINDINGS AND RECOMMENDATIONS

7.1 SUMMARY OF THE STUDY FINDINGS

The summary of the study findings is presented based on the four main objectives of the study which are as follows:

7.1.1 Benchmarking Block I against well protected area.

The study results showed that, in terms of species composition, Block I was dominated by increaser II, increaser I, increaser III grasses and forbs while benchmark site 1 is also dominated by increaser II and forbs, benchmark site 2 is dominated by increaser II, forbs and increaser III and other grasses with unknown ecological status.

In terms of Simpson's diversity index, benchmark 2 was more diverse followed by Block I and lastly benchmark 1. In species richness, Block I had more species richness by with 19 in 2018, followed by benchmark 2 with 18, and lastly benchmark 1 had 15. The bare ground was used to compare the three areas, block I had higher percentage of bare ground while the benchmark sites had significantly lower bare ground percentage. This means that the benchmark sites have more basal cover than Block I. Both benchmark sites have average biomass of between 3600kg/ha and 6000kg/ha.

7.1.2 Effect of cattle grazing on the rehabilitated site

There were changes in terms of species composition and above ground biomass between inside and outside exclosures in block I. Forbs increased considerably over the study period while grasses decreased slightly. Above ground biomass increased significantly in the enclosure while it decreased on the outside, grazing and mowing influenced these changes.

In terms of bare ground percentage, on average there was a decrease of 4% in bare ground percentage over the study period. However, the results from changes per exclosure showed that there was an increase in bare ground in some exclosures and decrease in others.

7.1.3 The grazing regime used at the rehabilitated site

The calculation showed that 105 animal units would require 3.31 ha for three months in order to feed sustainably. This means that Block I was over-utilized with more than 130 cattle on a 31. 8 ha area. There is also an influence of rotational grazing system which its impacts were not quantified or measured.

7.1.4 Soil properties at the rehabilitated and benchmark area

The results from soil analysis showed that Benchmark 1 had the highest concentration of Ca in its soil, the reason being that there had been lime supplement done few months before we took our samples. Block I on the other had the highest concentration of Mg while Benchmark site 2 had the highest level of Na and K. The three sites have different soil chemistry but Benchmark 1 and Block I have similar concentration of most nutrients. In terms of soil texture, they are all sandy clay loam by textural classification. With these results, it is evident that good quality forage for livestock production is possible due the soil quality of the study areas.

7.2 RECOMMENDATIONS

The recommendation given are meant to assist in getting Block I close to state of where it was before mining took place like Benchmark site 2. From the results, we can recommend:

Since the area is dominated by *Hyparrhenia hirta*, (thatch grass), for grazing purposes, it is palatable during early stages of development, it is recommended that it is grazed or cut before it produces seeds and grows stronger in order to keep it under control and to allow other grasses a chance to grow.

It is also recommended to burn the area once in three to five years to stimulate new growth (based on other studies).

Improve on the timing and duration of putting the cattle to graze the areas in order to promote resting seasons for vegetation regeneration.

Applying fertilizers on a yearly basis before wet season can increase the chances of new species to develop and also nourishing the soil.

Using hydroseeding to seed a rehabilitated area can result in best coverage than using tractor/manual seeding, because the seed sprayed is mixed with mulch, organics, lime, binders and NPK that are particularly recommended for the type of soil and help seed germinate and grow fast. However, it is not an economically viable option for larger areas.

7.3 RECOMMENDED AREAS OF FUTURE RESEARCH

Future research can be on the effects of grazing on recently rehabilitated coal mine focusing on the interaction between soil biological, physical and chemical traits with detailed consideration of the climatic conditions of the area.

Second future research area could be a research on how to replace thatching grass (*Hyparrhenia hirta*) with more sweet (palatable) grasses for grazing purposes in disturbed areas.

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