

# **The Impact of Fire and Land Use on the KwaZulu-Natal Sandstone**

**Sourveld**

**By**

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Submitted in fulfilment of the academic requirements for the degree of

MASTER OF SCIENCE

In the Discipline of Ecological Science

School of Life Sciences

College of Agriculture, Engineering and Science

University of KwaZulu-Natal

Pietermaritzburg

South Africa

February 2025

## Abstract

The KwaZulu-Natal Sandstone Sourveld (KZNSS) is one of the most prominent South African grassland types and has undergone large-scale transformation through the years. This endangered, species-rich grassland is endemic to KwaZulu-Natal. Much of the KZNSS remains in patches within the eThekweni Municipality area (EMA), many of which are in communal areas and some in nature reserves. These remnants are under-conserved and under-researched. Fire and land use are focal when conducting research and implementing management and conservation practices in these grasslands. Therefore, this study aimed to determine the effect of long-term burning history on species composition and structure in protected and communal agricultural land in KZNSS grassland remnants within the eThekweni Municipality area. The objectives were to examine fire regime variations over 20 years (2002 – 2022) in reserves and communal agricultural areas found in KZNSS remnants within the EMA using Geographic Information Systems (GIS) and remote sensing. Additionally, to determine: 1) the effect of land use; 2) the effect of fire and 3) the effect of the interaction between fire and land use on grassland plant species composition, richness, evenness, and diversity; veld condition and tree density in the burnt and unburnt patches of the study areas. Remote sensing was used to obtain fire records for the last 20 years, of these remnant patches. Within the selected reserves and communal area study sites, one area with a high fire frequency (burnt five or more times in the last 20 years) and one with a low frequency (two or three times over 20 years) or which had not burnt in these 20 years were sampled. Quadrat sampling was utilised to quantify grassland composition in four communal areas (KwaCele, Qadi, Zwelibomvu, and Toyane) and four reserves (Silverglen, New Germany, Roosfontein, and Krantzkloof). A veld condition assessment (VCA) was conducted in these sites. Additionally, tree density was assessed to account for the woody encroachment in these areas. Over the past 20 years, the communal agricultural areas had a higher fire frequency than protected areas. It was also observed from

the fire records that the season of burning was consistent over the years, both communal agricultural and protected areas burning mostly in the dry season. However, the percentage area burnt in these grassland patches fluctuated, with the proportion of areas burnt being highest in earlier years. Overall, fire, land use, and their interaction influenced the plant species (grasses and forbs) composition. Land use had an effect on plant species richness, evenness, and diversity. Fire, nor the interaction of fire and land use, had a significant effect on these variables. Communal agricultural areas had the highest plant species richness, evenness, and diversity. This could be explained by the fact that over 20 years, communal agricultural areas had a higher fire frequency than nature reserves. This higher frequency of fire encourages diversity as fire removes dominant vegetation, thereby allowing other plant species to grow, which prevents there just being one dominant species that outcompetes the others. For the veld condition assessments, unburnt patches in the protected areas had greater veld condition scores due to overgrazing and stocking rates being low. However, fire and land use, as well as their interaction, did not affect the tree density observed in the study areas. For the KZNSS to remain healthy and functional, land use and fire, as well as their interaction, are essential aspects. Therefore, to maintain biodiversity, effective management necessitates a balanced strategy that considers both ecological needs and human activities.

## Preface

The work contained in this thesis was completed by the candidate while based in the Discipline of Ecological Science, School of Life Sciences of the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Pietermaritzburg Campus, South Africa, under the supervision of Dr Sindiso Nkuna and co-supervised by Dr Michelle Tedder. The research was financially supported by the National Research Foundation. This thesis is the result of the author's original work except where acknowledged or specifically stated to the contrary in the text. It has not been submitted for any degree or examination at any other university or academic institution.

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## **Acknowledgements**

This research would not have been possible without the assistance and support of several important people.

Firstly, I would like to thank my supervisor, Dr Sindiso Nkuna and co-supervisor, Dr Michelle Tedder, for their patience, guidance and encouragement. I am so grateful to have gotten the opportunity to work with these two wonderful ladies.

Secondly, I acknowledge and thank the National Research Foundation (NRF) for funding my research and academics. This would not have been possible without the financial assistance of NRF.

Thirdly, I extend my upmost gratitude to Mr Wiseman Ngcobo for driving me to my study sites and for helping with my data collection.

Fourthly, I would like to thank my mentor, Mr Bheka Memela from eThekweni Municipality for his encouragement and for assisting me through the process of gaining access to conduct my research in eThekweni Municipality nature reserves and communal agricultural areas under the Ingonyama Trust Board.

I would also like to thank Ezemvelo KZN Wildlife, eThekweni Municipality and Ingonyama Trust Board for allowing me to conduct my research in their areas, with special thanks to the reserve managers and locals for going as far as even assisting me with my data collection.

Finally, I thank my biggest support system, my close family and friends. Thank you for the unconditional love and support. I am especially grateful for my mother, Sindis who encourages

me and even stayed up with me during my nights of stressing. I know it is all because of her prayers that I was able to complete my research.

I dedicate this dissertation to my late father and grandmother.

## **Chapter 1: Introduction**

### **1.1. Background**

#### *1.1.1. South African Grasslands*

In South Africa, grasslands are the second largest biome occupying 26.7% of the land, spread out in all the country's provinces (Carbutt et al., 2011). However, this extensive vegetation type is the most threatened ecosystem globally due to agricultural and urban expansion, poor land use management, and land use transformation (O'Connor and Kuylar, 2009). Furthermore, they are poorly conserved, with less than 1% being properly protected in the country (O'Connor et al., 2010).

#### *1.1.2. KwaZulu-Natal Sandstone Sourveld Grasslands*

The KwaZulu-Natal Sandstone Sourveld (KZNSS) is among the most poorly protected grassland types in South Africa despite it being endemic to this country (Naicker, 2015). The KZNSS is not only poorly protected but also endangered due to transformation. It is documented that 73% of the KZNSS has been transformed and most of the remaining grassland is in patches in urban matrices (Buthelezi et al., 2016). Furthermore, these remnant patches of the KZNSS are under-researched (Drury, 2016).

### *1.1.3. Importance of Grasslands*

It is important that the endangered KZNSS, and grasslands in general, are researched and conserved because of the vital role they play in ecological systems. South African grasslands support a wide diversity of plant, animal, and bird species, and this is one of their key roles (Cilliers et al., 2004). Many species that occur in these grasslands are endangered and threatened with some being endemic (Hlanguza, 2015). Grasslands also play important roles in sequestering carbon and in the processes of soil stabilisation and water infiltration (Drury, 2016). The important role of grasslands extends to humans as they ensure a steady supply of water which is critical for human survival (Drury, 2016). In South Africa, many rural communities around grasslands rely largely on these grasslands as a source of their livelihoods as grasslands provide land for grazing livestock and for agriculture (Rouget et al., 2016). They also provide other supportive, regulating, provisioning and cultural services (Rouget et al., 2016).

### *1.1.3. Grassland management*

Grasslands management practices are crucial for conserving these threatened and under-protected and -researched grassland systems which play a vital role in biodiversity, agriculture and in the livelihoods of communities. These practices encourage biodiversity, climatic resilience, and agricultural productivity while preserving the ecological integrity of grasslands. The main grassland management practices used to maintain South African grasslands are fire and grazing (Little et al., 2015). These management tools assist in shaping grasslands and maintaining the productivity and biodiversity of grassland ecosystems (Little et al., 2015). Fire-dependent grasslands such as the KZNSS evolved with fire and are adapted to fire therefore fire is particularly important in these grassland systems (Chamane et al., 2017). Fire has been influential in the evolution of these grasslands in terms of their community structure and

functioning, also in maintaining the grassland communities (Forrestel et al., 2014). Decisions about fire management are informed by continual monitoring of fire frequency, season, and spatial pattern in grasslands, mostly in protected areas (Driscoll et al., 2010). However, in communal agricultural areas there are generally no documented fire management plan and fire records. Hence remote sensing and geographic information systems (GIS) are particularly useful in these areas. Geographic Information Systems are used in monitoring and documenting fires and acquiring historical fire data to inform management decisions (Mashele and Singh, 2022). Land use is also an important factor to consider when making grassland management decisions as it impacts grassland communities. The KZNSS remnants are found in urban matrices; some remnants are in nature reserves, while others are in communal agricultural areas. Therefore, management regimes differ, especially in terms of fire management.

## **1.2. Rationale**

Grasslands, despite being some of the most productive and ecologically important ecosystems, face a number of threats. These threats affect the grassland ecosystems and the species that rely on them and the ecosystem services they provide, such as carbon sequestration, water filtration, and grazing for livestock (Hlanguza, 2015). The biggest threat is human activities. The fast and steady growth of the human population and the onset of climate change in recent years have put a great deal of strain on grasslands (Boon et al., 2016). This rapid rise in human population has brought about the conversion of grasslands for industries and for housing (Boon et al., 2016). Since Africa is the fastest urbanising continent, a large proportion of the grasslands in this continent have experienced major transformation and degradation (Boon et al., 2016).

In South Africa, one specific grassland system that has suffered irreparable habitat loss and fragmentation as a result is the KZNSS (Rouget et al., 2016). Over the years about 73% of the KZNSS has been transformed to accommodate the expansion of agriculture and urbanisation

(Buthelezi et al., 2016). Due to extensive and irreversible transformation, the KZNSS is classified as critically endangered (Naicker, 2015). Today the KZNSS remains in patches in protected and communal agricultural areas in the eThekweni Municipality region (Boon et al., 2016). Overall, less than 30% of the KZNSS remains and under 1% of the remnants are adequately protected (Drury, 2016). Furthermore, not much research has been conducted on these patches, especially the communal agricultural ones. It is important that these critically endangered patches are researched in order to conserve them. Research into their fire regimes and history as well as land use is needed to inform management decisions and strategies to conserve them.

### **1.3. Aim**

The aim of this study was to determine the effect of long-term burning history on species composition and structure in protected and communal agricultural land in KZNSS grassland remnants within the eThekweni Municipality area.

### **1.4. Objectives**

The objectives were to examine fire regime variations over a 20-year period (2002 – 2022) in reserves and communal agricultural areas found in KZNSS remnants within the EMA using Geographic Information Systems (GIS) and remote sensing. Additionally, to determine: 1) the effect of land use; 2) the effect of fire and 3) the effect of the interaction of fire and land use on grassland plant species composition, richness, evenness, and diversity; veld condition and tree density in the burnt and unburnt patches of nature reserves and communal agricultural areas found in KZNSS remnants.

## **1.5. Research Questions**

- 1) How did the fire regime vary over the 20 years (2002 – 2022) between protected and communal agricultural areas found in the KZNSS patches?
- 2) What is the impact of land use on grassland plant species composition, richness, evenness, diversity, veld conditions, and tree density in burnt and unburnt patches of protected and communal agricultural areas in KZNSS?
- 3) What is the effect of fire on grassland plant species composition, richness, evenness and diversity as well as veld conditions and tree density in the burnt and unburnt patches of protected and communal agricultural areas found in the KZNSS?

## **1.6. Format of Thesis**

This thesis contains five chapters, all of which follow the South African Journal of Botany formatting. Chapter 1 is the general introduction which includes the background and rationale of the research and also includes the aim and objectives of the project. Chapter 2 is the literature review. Chapters 3, 4, and 5 are the results chapters. Chapter 6 is the synthesis and recommendations chapter where the main findings of the research are highlighted, and further recommendations are provided.

## **References**

Boon, R., Cockburn, J., Govender, N., Ground, L., Slotow, R., Mclean, C., Douwes, E., Rouget, M., Roberts, D., 2016. Managing a threatened savanna ecosystem (KwaZulu-Natal Sandstone Sourveld) in an urban biodiversity hotspot: Durban, South Africa. *Bothalia-African Biodiversity & Conservation* 46, 1-12.

- Buthelezi, H.Z., Munien, S., Nkambule, S.S., 2016. Opportunities and constraints for community-based conservation: The case of the KwaZulu-Natal Sandstone Sourveld grassland, South Africa. *Bothalia-African Biodiversity & Conservation* 46, 1-8.
- Carbutt, C., Tau, M., Stephens, A., Escott, B., 2011. The conservation status of temperate grasslands in southern Africa. *Grassroots* 11, 17-23.
- Chamane, S., Kirkman, K.P., Morris, C., O'Connor, T., 2017. What are the long-term effects of high-density, short-duration stocking on the soils and vegetation of mesic grassland in South Africa? *African Journal of Range & Forage Science* 34, 111-121.
- Cilliers, S.S., Müller, N., Drewes, E., 2004. Overview on urban nature conservation: situation in the western-grassland biome of South Africa. *Urban Forestry & Urban Greening* 3, 49-62.
- Driscoll, D.A., Lindenmayer, D.B., Bennett, A.F., Bode, M., Bradstock, R.A., Cary, G.J., Clarke, M.F., Dexter, N., Fensham, R., Friend, G., 2010. Fire management for biodiversity conservation: key research questions and our capacity to answer them. *Biological Conservation* 143, 1928-1939.
- Drury, C.C., 2016. A biogeographic study of the KwaZulu-Natal sandstone sourveld patches within the eThekweni Municipal Area. PhD Thesis, University of KwaZulu-Natal, Westville. PhD Thesis, University of KwaZulu-Natal, Westville.
- Forrestel, E.J., Donoghue, M.J., Smith, M.D., 2014. Convergent phylogenetic and functional responses to altered fire regimes in mesic savanna grasslands of North America and South Africa. *New Phytologist* 203, 1000-1011.
- Hlanguza, N., 2015. Mapping the remnant KwaZulu-Natal sandstone sourveld grass patches in the Ethekeeni Municipality using a high resolution multispectral sensor. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg.

- Little, I.T., Hockey, P.A., Jansen, R., 2015. Impacts of fire and grazing management on South Africa's moist highland grasslands: A case study of the Steenkampsberg Plateau, Mpumalanga, South Africa. *Bothalia-African Biodiversity & Conservation* 45, 1-15.
- Mashele, S., Singh, K., 2022. GIS investigation of the fire history of Jonkershoek Nature Reserve. *South African Journal of Geomatics* 11, 189-201.
- Naicker, R., 2015. Assessing the level of habitat fragmentation of the KwaZulu-Natal sandstone sourveld. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg.
- O'Connor, T., Kuyler, P., 2009. Impact of land use on the biodiversity integrity of the moist sub-biome of the grassland biome, South Africa. *Journal of Environmental Management* 90, 384-395.
- O'Connor, T., Kuyler, P., Kirkman, K., Corcoran, B., 2010. Which grazing management practices are most appropriate for maintaining biodiversity in South African grassland? *African Journal of Range & Forage Science* 27, 67-76.
- Rouget, M., Naicker, R., Mutanga, O., 2016. Assessing habitat fragmentation of the KwaZulu-Natal Sandstone Sourveld, a threatened ecosystem. *Bothalia-African Biodiversity & Conservation* 46, 1-10.

## **Chapter 2: Literature Review**

### **2.1. Introduction**

Barnes and Nelson (2003) defined a grassland as “any plant community, including harvested forages, in which the grasses and/or legumes make up the dominant vegetation.” Carlier et al. (2009) described the grassland biome as a diverse biological system with a predominant grass layer mixed with some forbs / herbs. The primary feature of a grassland is the predominance of grasses, which is highlighted in both descriptions. It is believed that the formation of grasslands occurred in the late tertiary period during the global cooling (Carbutt et al., 2011). The Early Miocene continental uplift and this late tertiary global cooling produced ideal conditions for the formation of grasslands (Carbutt et al., 2011). Currently, grasslands are one of the most extensive vegetation types in the world, occupying around 40,5% (52.5 million km<sup>2</sup>) of the earth’s terrestrial surface (Batello et al., 2008). They are extensively distributed, occurring in nearly all the continents of the world, excluding Antarctica (Neary and Leonard, 2020). Their most extensive distribution is in the African continent, sub-Saharan Africa to be specific, with Sudan (1 292 163km<sup>2</sup>) and Angola (1 000 087km<sup>2</sup>), particularly having the largest expanse of grassland in this region (Gibson, 2009).

In South Africa, grasslands are the second most dominant vegetation type following savannas (Carbutt et al., 2011). Grasslands occupy about 349 174km<sup>2</sup> of the country's land area (Graham et al., 2020; Neke and Du Plessis, 2004). This vegetation type is primarily found on the high central plateau or highveld (Carbutt et al., 2011). The distribution and extent of grasslands is largely influenced by the country's climate (Neke and Du Plessis, 2004). Temperate inland and Subtropical grasslands are the main grassland types found in South African (Cadman et al., 2013). Typically, grasslands or the grassland biome receives 400 mm to 2500 mm of rainfall per year and cold, dry winters with frost (Mucina and Rutherford, 2006). Additionally, they occur at an elevation ranging from 300m to 3 482m above sea and on mollisol soils, which have deep horizons rich in humus (Carbutt et al., 2011; Neary and Leonard, 2020). The grassland biome of South Africa is home to numerous endemic plant and animal species and is renowned for its high species diversity (Cilliers et al., 2004). South African grasslands notably harbour endemic forb and dwarf shrub species, along with several endemic fish, animal, and bird species, many of which are endangered (Neke and Du Plessis, 2004). Approximately 136 species classified as endangered are documented in grasslands on the Red Data List (Graham et al., 2020). The status of these species is due to the many threats that grasslands face, face, mainly agricultural expansion and urbanisation (Neke and Du Plessis, 2004). About 60% of the South African grassland biome has been transformed beyond recovery (O'Connor and Kuyler, 2009). Urbanisation and expansion of agriculture are the primary forces driving this change (O'Connor and Kuyler, 2009). In South African grasslands, highly populated urban areas like Johannesburg and Pretoria occupy much of the country's grassland area (Neke and Du Plessis, 2004). The extensiveness of grasslands and the fact that they make good, productive agricultural land make them the most inhabitable biome (Neke and Du Plessis, 2004).

The KwaZulu-Natal Sandstone Sourveld (KZNSS) is a key subtropical grassland system located in the eastern portion of South Africa, distinguished by its distinctive vegetation and

biodiversity (Drury, 2016). This region, which is dominated by nutrient-poor, rocky soils, serves as a habitat for much of the country's endemic plant species and important animal species, making it a key conservation area (Boon et al., 2016). However, like most South African grassland types, this grassland system has undergone significant transformation over the years, induced by urbanisation and agricultural growth (Boon et al., 2016). These, in turn, affect the fire regime and land use in this grassland system. Fire regimes and land use practices have a considerable impact on the grassland's ecological structure and function (Drury et al., 2016). Fire, a natural and essential grassland disturbance, interacts with human activities like urbanisation, farming, and grazing (Blair et al., 2014). This interaction results in complex impacts on grassland biodiversity and vegetation (Blair et al., 2014). In order to monitor and manage these ecological dynamics, modern technology methods—like remote sensing—have grown in importance (Kennedy et al., 2009). Remote sensing offers an effective way to track fire regimes and land use cover over time and their impact over large areas and over time, providing valuable data for making grassland management and conservation decisions (Szpakowski and Jensen, 2019). This review summarises the body of knowledge about the effects of land use and fire on the KZNSS grassland, offering insights into both their interactive and individual effects on this ecosystem. Additionally, it examines the role of remote sensing in understanding and managing this vital grassland ecosystem.

## **2.2. The KwaZulu-Natal Sandstone Sourveld**

The KZNSS is a grassland system that is unique to the KwaZulu-Natal (KZN) Province (Mutanga et al., 2016). This unique grassland type occupies approximately 19.9% of KZN's geographic area, particularly over the eThekweni Municipality region, and covers 9.5% of the country (Drury, 2016). It is known for being species-rich and housing many endemic species ~ 12 endemic taxa (Drury, 2016; Munien et al., 2015). The KZNSS forms part of the Maputaland-

Pondoland Biodiversity Hotspot, Africa's second-richest biodiversity hotspot (Cockburn et al., 2016). This hotspot features a subtropical climate which is ideal for the development and occurrence of grasslands (Munien et al., 2015). This grassland type is characterised by scattered geoxylic suffrutices or underground trees, small shrubs, and proteas on plateau tops and steep slopes (Drury et al., 2016). Rainfall in the KZNSS grassland is mostly summer, with an annual total of 943 mm (Drury et al., 2016).

The environment benefits greatly from this endemic and species-rich grassland system as it offers several vital ecosystem goods and services. One of the grasslands' primary functions is to serve as habitat for significant threatened and endangered species (Hlanguza, 2015). By acting as a carbon sink or sponge and absorbing carbon from the atmosphere, the grassland system contributes to the carbon cycle and is crucial to the sequestration of carbon in the atmosphere (Hlanguza, 2015). Furthermore, grasslands in South Africa have a crucial role in stabilizing the soil and stimulating rainwater infiltration in the main summer rainfall receipt areas (Drury, 2016). They also serve as grazing land for livestock farming and for agriculture for surrounding communities. However, the KZNSS has experienced irreversible habitat loss and fragmentation due to the level of transformation it has undergone (Rouget et al., 2016). About 73% of the KZNSS has been transformed to cater to the expansion of agriculture and urbanisation and it currently exists in patches in the eThekweni region (Buhmann, 2016). This is a major reason why this grassland system has been categorised as critically endangered (Naicker, 2015). Unfortunately, despite the ecological value and conservation status of the KZNSS, it is one of the least conserved and researched grassland systems. According to Drury (2016), compared to other vegetation types within the eThekweni Municipality region, the KZNSS is largely understudied (Drury, 2016). Very little information has been published on the KZNSS remnants (Drury, 2016). Since this threatened grassland system is sensitive to

natural and anthropogenic disturbances, it is important to understand how fire and land use, individually and combined, affect its ecological processes to converse it.

### **2.3. Fire and Its Role in the KwaZulu-Natal Sandstone Sourveld**

Fire is a key ecological process in grassland and has been for the last 420 million years (Simpson et al., 2016). It has always been a part of grasslands even before it was recognised as a management tool that could be controlled by humans (Neary and Leonard, 2020). Many of the plant and animal species found in grassland ecosystems have adapted to fire-prone conditions because fire has evolved with them as a natural disturbance, especially in locations like KwaZulu-Natal and the Eastern Cape (Pooley, 2022). The KZNSS is one particular grassland ecosystem that has evolved with fire (Boon et al., 2016). In the KZNSS grassland, fire is a natural disturbance that significantly influences the ecosystem's structure (Drury et al., 2016). The frequency, intensity, and timing of fire events in the KZNSS all influence plant composition, biodiversity, and the physical structure of this grassland (Drury et al., 2016).

#### *2.3.1. Fire Regimes*

Ecosystems have different fire regimes, resulting in physically and functionally distinct populations (Simpson et al., 2016). The fire regime in South African grasslands describes the frequency, intensity, and seasonality of fires (Bond and Keane, 2017). Grasslands are frequently subjected to natural fires caused by lightning or by humans, i.e. controlled or prescribed burns for land management purposes and accidental fires caused by people (Trollope and Trollope, 2010). Controlled burns are commonly practiced in South African grasslands, particularly in protected and agricultural areas (Househam, 2017). These burns serve as a management tool to suppress alien invasive species, conserve the open grassland structure, and limit the risks of

more significant, uncontrolled fires (Househam, 2017). However, poorly managed burns, especially those that occur too frequently or at the incorrect times of year, can lead to adverse ecological results, such as soil degradation and biodiversity loss (Shlisky et al., 2007). Therefore, fire regimes are very important in grassland ecosystems.

Depending on the climate and land management practices, fire frequency in South African grasslands can vary from one to five years (O'Connor et al., 2010). The intensity of these fires generally being low to moderate depending on environmental factors like air temperature and moisture content, and wind speed (O'Connor et al., 2010). Further, they usually occur in late winter and early spring or dry season when the vegetation is more prone to catching alight (O'Connor et al., 2010). This seasonal pattern is essential as it gives the flora adequate time to recover before the following growing season (Lamont and Downes, 2011). Burns in the dry season also reduce the risk of destructive wildfires (Laris, 2002). According to studies, fire frequency, intensity, and season vary over the KZNSS (Drury et al., 2016). However, this grassland type naturally burns during the dry season with a two to five-year fire frequency (Drury, 2016). However, their fire frequency may vary and ultimately depend on climatic conditions, biomass accumulation, land use type and management practices (Househam, 2017).

### *2.3.2. Ecological Impacts of Fire*

The KZNSS is a fire-dependent grassland system. Hence, fire maintains the structure and functioning of the grassland community (Forrestel et al., 2014). It reduces woody encroachment by preventing the formation of trees and shrubs, therefore conserving this grassland's biodiversity (Forrestel et al., 2014). Fire is also a determining factor of the species composition in this grassland, as it promotes the production of tillers in some grasses e.g., *Themeda triandra* (Everson et al., 1985). Fire also promotes the regeneration of many forb

species found here through their underground storage organs (Chamane et al., 2017). Additionally, fire helps cycle nutrients by breaking down plant matter and enriching the soil, which encourages the germination and growth of fire-adapted grasses (Lamont and He, 2020). Mesic grasslands (grasslands that receive  $\geq 600$  mm mean annual rainfall) like the KZNSS, require good light penetration for persistence; therefore, fire is used to remove dead material to facilitate this (Househam, 2017).

#### **2.4. Land Use in the KwaZulu-Natal Sandstone Sourveld**

Over the years the KZNSS has undergone major land use transformation because of the rapid growth of the human population, urbanisation and agricultural growth (Boon et al., 2016). This transformation has resulted in the KZNSS now existing in small patches around the eThekweni region (Boon et al., 2016). This has intensified the diverse land uses found in these grasslands (i.e. conservation, urban spaces and agriculture). Therefore, this region faces increasing pressures from human activities that alter land use cover and disturbance regimes such as fire, resulting in changes to vegetation, soil health, and biodiversity (Buhrmann, 2016). Additionally, these varying land uses all influence how the area is managed, which can either support or degrade the ecosystem.

##### *2.4.1. Impact of Land Use Practices on the KZNSS*

The main land use practices that greatly impact the KZNSS are grazing, agriculture and urban expansion (Boon et al., 2016). Livestock grazing being the most common activity in the KZNSS due to the grassland's vast grazing area and diverse grasses for livestock such as cattle, sheep and goats to graze on (Buthelezi et al., 2016). Livestock grazing plays a significant role in determining the plant communities and composition of grassland ecosystems like the

KZNSS (Buthelezi et al., 2016). The impacts of livestock grazing on grasslands are widely recognized and can be both positive and negative. The main benefits of grazing are that it maintains and encourages plant diversity by preventing competitive exclusion, thereby allowing a range of plant species to coexist in one area (Buthelezi et al., 2016). Livestock grazing also stimulates plant growth and enhances the production of grass tillers (Buthelezi et al., 2016). Overgrazing is the main challenge that arises from livestock grazing. Overgrazing of livestock can greatly reduce grassland plant species diversity, as the pressure from grazing often promotes the growth of specific species (increaser species) while hindering others (decreaser species) (Fraser et al., 2022). Additionally, livestock overgrazing can cause soil compaction, which in turn negatively impacts how water infiltrates the soil, making the soil more prone to soil erosion (Donovan and Monaghan, 2021). Moreover, grazing can alter grassland fire regimes, and this, coupled with other grassland stressors, can significantly reduce the resilience of the grassland ecosystem (Chambers et al., 2019).

The growth of agriculture, namely crop farming and agroforestry, is another land use practice that significantly impacts the KZNSS. These agricultural activities often encourage the introduction of alien invasive plant species as it reduces the population of indigenous species and causes habitat fragmentation (Fleming et al., 2017). Farmers often suppress fire and, in these regions, where agricultural methods are paired with fire suppression, there can be an increase in the establishment of woody plants, which reduces grassland area and biodiversity (Fleming et al., 2017). Additionally, the use of fertilisers and pesticides can harm soil health which harms the native grassland plants and animals over time (Tripathi et al., 2020).

Urbanisation, while not as widespread as agriculture and grazing still threatens the KZNSS. The growth of urban areas fragments the landscape creating isolated patches of grassland (Williams et al., 2006). When grasslands become isolated patches, important ecological processes are disrupted, such as the movement of animals, and the genetic variation in plant

populations is drastically reduced (Williams et al., 2006). Additionally, when cities grow, they often suppress natural fires events, which alter the structure of grassland plant communities (Williams et al., 2006).

## **2.5. Interactions of Fire and Land Use in the KZNSS**

The significant impacts of fire and land use individually on grasslands have been well documented. However, the combined effect of these two aspects is also notable. The relationship between fire and land use plays a vital role in shaping the KZNSS grassland ecosystem. This interaction of fire with various land use practices—like agriculture, livestock farming, conservation, and urbanisation—has significant implications for the health and sustainability of these ecosystems (Cockburn et al., 2016). Fire's effects are frequently influenced by land use practices, which can lead to both positive and negative outcomes (Bowman et al., 2011).

### *2.5.1. Land Use Altering Fire Regimes in the KZNSS*

Human land use activities can affect the fire regimes in the KZNSS in various ways. Natural fire regimes are frequently suppressed in regions where urbanisation or agriculture have increased (Cochrane et al., 2009). This is because grasslands that are prone to fire like the KZNSS, are frequently replaced by developed area due to urbanisation and agricultural development (Cochrane et al., 2009). The natural cycles of fire may be disturbed by this landscape modification, which could stop fire-dependent species or processes like seed regeneration from recurring (Cochrane et al., 2009). However, sometimes this may also cause flammable material to accumulate, resulting in larger and more powerful fires that may change the species composition (Bowman et al., 2020). In some agricultural areas fires may be

prescribed more regularly to manage vegetation for grazing or to clear land for crops (Bowman et al., 2020). Fire-adapted species that need longer fire return intervals to survive may suffer from unnaturally high fire frequency (Chang, 1996).

### *2.5.2. Alien Invasive Species*

This interaction of fire and land use in the KZNSS can also promote the establishment and spread of alien invasive species (Mkungo et al., 2023). Habitats that have been disturbed by land use practices are more vulnerable to invasion by non-native grass species (Godfree et al., 2017). The spread of these exotic grasses over native species may be favoured by fires in these disturbed regions (Godfree et al., 2017). Land use changes and practices may also lead to fire, which is used to regulate native woody species encroachment, being suppressed (Mkungo et al., 2023). This leads to an increase in the encroachment of woody species in grasslands, as there is no fire to remove the woody species (Mkungo et al., 2023). Without fire, other fire-dependent or sensitive plant species decline, creating more opportunity for these native woody species to establish (Mkungo et al., 2023). Additionally, grasslands that have experienced urban expansion become fragmented. These fragmented grassland remnants created by growing urban areas serve as pathways or corridors for the spread of invasive species (Lynch, 2019). Furthermore, urbanised environments' altered microclimates and decreased biodiversity can more readily support invasive species, and disturbance from transportation, construction, and other activities might enhance the likelihood that these species will infiltrate grasslands (Carlon and Dominoni, 2024).

## **2.6. Remote Sensing**

Remote sensing is the process of obtaining information about a thing or place without coming into direct physical contact with it (Ray, 2016). It employs sensors to identify and quantify radiation (such as heat, light, or electromagnetic waves) that the object or region of interest emits, reflects, or transmits (Ray, 2016). These sensors collect data at various wavelengths (visible light, infrared, microwave, etc.) and are commonly installed on satellites, airplanes, drones, or other platforms (Panda et al., 2016). These sensors can be passive which pick up on natural energy that the target emits or reflects, usually from sunlight, or active which release their own energy, which interacts with the object and then returns to the sensor (Panda et al., 2016).

There are many applications of remote sensing. Deforestation, desertification, water quality, and changes in land use are all monitored by remote sensing (Albalawi and Kumar, 2013). It can be used in agriculture, specifically crop farming, as it can monitor soil conditions, water availability and crop health and can even detect pest infestations (Ray, 2016). It can be utilised in disaster management as it can monitor floods, wildfires, and other natural disasters, which provides real-time information for emergency response (Panda et al., 2016). It can also be used in climate change studies as tracking climate change and comprehending global warming, sea level rise, and other phenomena require long-term satellite data (Panda et al., 2016).

In order to transform raw data from remote sensing into information that can be used by humans, processing and interpretation is required (Hussain et al., 2013). Specialized software and methods such as geographical analysis, change detection, and image categorisation are used to extract the information (Hussain et al., 2013). One of the advantages of remote sensing is that it makes it possible to monitor large or inaccessible areas that would otherwise be too costly or impracticable to research (Ray, 2016). Satellites and various remote sensing platforms have the capability to collect data continuously or at regular intervals, allowing for the

monitoring of changes over time (Ray, 2016). Additionally, because it doesn't require physical interaction with the environment, it can be utilised to examine sensitive or hazardous areas without causing any disturbance (Ray, 2016).

### *2.6.1. The Role of Remote Sensing in Monitoring Fire and Land Use in the KZNSS*

#### *2.6.1.1. Monitoring Land Use*

Remote sensing offers comprehensive maps of various land cover types, such as grasslands, croplands, and forests, and it can monitor changes in land use over time (Macarringue et al., 2022). This helps identify regions where KZNSS grasslands are being transformed into agricultural land or urban development (Macarringue et al., 2022). Vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), which measures the density and health of vegetation, can be measured by satellites like Landsat or Moderate Resolution Imaging Spectroradiometer (MODIS) (Yengoh et al., 2015). These indices aid in evaluating how land use affects the quality of grasslands and how much of the grassland (Yengoh et al., 2015).

#### *2.6.1.2. Monitoring Fire*

By employing thermal infrared sensors to detect fire-related heat signatures, remote sensing enables the real-time identification of current fires (Wooster et al., 2021). For instance, the MODIS satellite offers daily data on fires worldwide (Wooster et al., 2021). Analysing post-fire vegetation recovery is another way that remote sensing can assist in determining the intensity and severity of fires (Gitas et al., 2012). Fire intensity and the landscape's long-term effects can be inferred from changes in vegetation cover, such as drops in NDVI values after a fire (Gitas et al., 2012). Remote sensing enables the reconstruction of fire history in the KZNSS. By examining historical satellite images, researchers can track the frequency and

spread of fires, which aids in understanding how fire patterns have evolved over time and the impact of land use on these fire regimes (Chuvieco et al., 2019).

## **2.7. Conservation and Management Implications**

Knowledge of how fire and land use interact in the KZNSS and the use of remote sensing to track these relationships can help guide conservation and management initiatives. The interaction of land use and fire regimes should be considered for effective management. In order to conserve biodiversity and ecological function, fire management techniques should be based on the KZNSS's natural fire regimes, carefully taking into account fire frequency, intensity, and season. Additionally, while preserving the advantages of fire, promoting sustainable land use techniques like conservation agriculture and rotational grazing can help reduce the detrimental effects of grazing and agriculture on the KZNSS. In regions where land use changes have changed fire regimes, active management is essential to halting the spread of alien invasive species (Keeley, 2006). Restoring natural fire patterns and removing invasive species are two examples of this. Remote sensing can be incorporated into the conservation and management of the KZNSS. By pinpointing locations that require fire suppression or areas at risk of uncontrolled flames, remote sensing data can help guide fire management techniques. Rangeland or grassland managers can do controlled burns at the most suitable periods to replicate natural fire regimes by monitoring the intensity and frequency of fires (Fernandes et al., 2013). The effects of fire and land use on biodiversity can also be tracked via remote sensing. Conservationists can prioritise areas of high conservation importance for restoration or protection by monitoring changes in species composition and vegetation cover (Nagendra et al., 2013).

## 2.8. Key Research Gaps

- Although it is well established that changes in land use, including grazing, urbanisation, and agriculture, affect fire regimes, little is known about how particular land use practices affect fire in the KZNSS. More research is needed to understand how different land-use practices affect fire frequency, severity, and distribution.
- Changes in land use, such as agriculture and urbanisation, are causing the KwaZulu-Natal Sandstone Sourveld to become more fragmented. The behaviour of fire in fragmented habitats as opposed to continuous ecosystems requires further study.
- Research on adapting fire management techniques to fragmented landscapes is necessary in order to reduce the threats to biodiversity. The strategic use of buffer zones, prescribed burns, and fire breaks in conservation initiatives while preserving ecological integrity could be the subject of future research.
- Although fire plays a crucial role in grassland ecosystems, little is known about the fire frequency, intensity, and seasonality in the KZNSS. To fully comprehend the ecological effects of various fire regimes, especially how fire impacts species composition, regeneration, and invasive species, long-term research is required.
- Research on the effects of South Africa's present land use policies—such as those pertaining to urbanisation, agriculture, and conservation—on fire control in the KwaZulu-Natal Sandstone Sourveld is scarce. Developing more effective governance methods requires analysing policy gaps and their effects on land use and fire regimes.
- It is crucial to comprehend local perspectives on fire, particularly in communal agricultural areas where fire may be used for grazing or cultivation. Investigating how these views affect land use decisions and fire management procedures is necessary.

## **2.9. Conclusion**

Fire and land use significantly shape the dynamics of the KZNSS, affecting vegetation composition, biodiversity, and overall ecosystem function. The relationship between these two elements can either enhance or harm the ecosystem, depending on how often fires occur, when they occur, and the types of land use practices in place. Remote sensing is essential for monitoring and understanding these effects, offering valuable insights for fire management, land use planning, and biodiversity conservation. As the KZNSS continues to experience pressures from changes in land use and fire regimes, incorporating remote sensing into management strategies will be vital for maintaining the long-term health of this important ecosystem.

## **References**

- Albalawi, E.K., Kumar, L., 2013. Using remote sensing technology to detect, model and map desertification: A review. *Journal of Food, Agriculture & Environment* 11, 791-797.
- Barnes, R., Nelson, C., 2003. Forages and grasslands in a changing world. Forages, an Introduction to Grassland Agriculture, 6th ed., Iowa State Press, A Blackwell Publishing Company, Ames, Iowa, USA, 3-23.
- Batello, C., Marnette, L., Martinez, A., Suttie, J., 2008. Plant genetic resources of forage crops, pasture and rangelands. Thematic background study. FAO report, 5-7.
- Blair, J., Nippert, J., Briggs, J., 2014. Grassland ecology 14. *Ecology and the Environment* 389, 389-423.
- Bond, W.J., Keane, R., 2017. Fires, ecological effects of. Reference Module in Life Sciences, 1-11.

- Boon, R., Cockburn, J., Govender, N., Ground, L., Slotow, R., Mclean, C., Douwes, E., Rouget, M., Roberts, D., 2016. Managing a threatened savanna ecosystem (KwaZulu-Natal Sandstone Sourveld) in an urban biodiversity hotspot: Durban, South Africa. *Bothalia-African Biodiversity & Conservation* 46, 1-12.
- Bowman, D.M., Balch, J., Artaxo, P., Bond, W.J., Cochrane, M.A., D'antonio, C.M., DeFries, R., Johnston, F.H., Keeley, J.E., Krawchuk, M.A., 2011. The human dimension of fire regimes on Earth. *Journal of Biogeography* 38, 2223-2236.
- Bowman, D.M., Kolden, C.A., Abatzoglou, J.T., Johnston, F.H., van der Werf, G.R., Flannigan, M., 2020. Vegetation fires in the Anthropocene. *Nature Reviews Earth & Environment* 1, 500-515.
- Buhrmann, R.D., 2016. The use of open top chambers to assess the effects of elevated temperatures on subtropical grassland vegetation in situ: a case study on KwaZulu-Natal sandstone sourveld. PhD Thesis, University of KwaZulu-Natal, Durban.
- Buthelezi, H.Z., Munien, S., Nkambule, S.S., 2016. Opportunities and constraints for community-based conservation: The case of the KwaZulu-Natal Sandstone Sourveld grassland, South Africa. *Bothalia-African Biodiversity & Conservation* 46, 1-8.
- Cadman, M., De Villiers, C., Lechmere-Oertel, R., McCulloch, D., 2013. Grassland ecosystem guidelines: landscape interpretation for planners and managers. South African National Biodiversity Institute, Pretoria. 1-139.
- Carbutt, C., Tau, M., Stephens, A., Escott, B., 2011. The conservation status of temperate grasslands in southern Africa. *Grassroots* 11, 17-23.
- Carlier, L., Rotar, I., Vlahova, M., Vidican, R., 2009. Importance and functions of grasslands. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 37, 25-30.

- Carlson, E., Dominoni, D.M., 2024. The role of urbanisation in facilitating the introduction and establishment of non-native animal species: a comprehensive review. *Journal of Urban Ecology* 10, 1-16.
- Chamane, S., Kirkman, K.P., Morris, C., O'Connor, T., 2017. What are the long-term effects of high-density, short-duration stocking on the soils and vegetation of mesic grassland in South Africa? *African Journal of Range & Forage Science* 34, 111-121.
- Chambers, J.C., Brooks, M.L., Germino, M.J., Maestas, J.D., Board, D.I., Jones, M.O., Allred, B.W., 2019. Operationalizing resilience and resistance concepts to address invasive grass-fire cycles. *Frontiers in Ecology and Evolution* 7, 1-25.
- Chang, C.-r., 1996. Ecosystem responses to fire and variations in fire regimes, Sierra Nevada ecosystem project: final report to Congress, 1071-1099.
- Chuvieco, E., Mouillot, F., Van der Werf, G.R., San Miguel, J., Tanase, M., Koutsias, N., García, M., Yebra, M., Padilla, M., Gitas, I., 2019. Historical background and current developments for mapping burned area from satellite Earth observation. *Remote Sensing of Environment* 225, 45-64.
- Cilliers, S.S., Müller, N., Drewes, E., 2004. Overview on urban nature conservation: situation in the western-grassland biome of South Africa. *Urban Forestry & Urban Greening* 3, 49-62.
- Cochrane, M.A., Shlisky, A., Alencar, A.A., Nolasco, M.M., Curran, L.M., 2009. Overview: Global fire regime conditions, threats, and opportunities for fire management in the tropics. *Tropical Fire Ecology: Climate Change, Land Use, and Ecosystem Dynamics*, 65-83.
- Cockburn, J., Rouget, M., Slotow, R., Roberts, D., Boon, R., Douwes, E., O'Donoghue, S., Downs, C.T., Mukherjee, S., Musakwa, W., 2016. How to build science-action

- partnerships for local land-use planning and management: lessons from Durban, South Africa. *Ecology and Society* 21.
- Donovan, M., Monaghan, R., 2021. Impacts of grazing on ground cover, soil physical properties and soil loss via surface erosion: A novel geospatial modelling approach. *Journal of Environmental Management* 287, 112206.
- Drury, C.C., 2016. A biogeographic study of the KwaZulu-Natal sandstone sourveld patches within the eThekweni Municipal Area. PhD Thesis, University of KwaZulu-Natal, Westville.
- Drury, C.C., Ramdhani, S., Sershen, Mbatha, P., Carbutt, C., Boodhraj, R., 2016. A lot gone but still hanging on: Floristics of remnant patches of endangered KwaZulu-Natal Sandstone Sourveld. *Bothalia-African Biodiversity & Conservation* 46, 1-13.
- Everson, C., Everson, T.M., Tainton, N., 1985. The dynamics of *Themeda triandra* tillers in relation to burning in the Natal Drakensberg. *Journal of the Grassland Society of southern Africa* 2, 18-25.
- Fernandes, P.M., Davies, G.M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C.R., Vega, J.A., Molina, D., 2013. Prescribed burning in southern Europe: developing fire management in a dynamic landscape. *Frontiers in Ecology and the Environment* 11, 4-14.
- Fleming, P.J., Ballard, G., Reid, N.C., Tracey, J.P., 2017. Invasive species and their impacts on agri-ecosystems: issues and solutions for restoring ecosystem processes. *The Rangeland Journal* 39, 523-535.
- Forrestel, E.J., Donoghue, M.J., Smith, M.D., 2014. Convergent phylogenetic and functional responses to altered fire regimes in mesic savanna grasslands of North America and South Africa. *New Phytologist* 203, 1000-1011.

- Fraser, M., Vallin, H., Roberts, B., 2022. Animal board invited review: Grassland-based livestock farming and biodiversity. *animal* 16, 1-12.
- Gibson, D.J., 2009. *Grasses and grassland ecology*. Oxford University Press.
- Gitas, I., Mitri, G., Veraverbeke, S., Polychronaki, A., 2012. Advances in remote sensing of post-fire vegetation recovery monitoring—A review. *Remote Sensing of Biomass-Principles and Applications* 1, 143-176.
- Godfree, R., Firn, J., Johnson, S., Knerr, N., Stol, J., Doerr, V., 2017. Why non-native grasses pose a critical emerging threat to biodiversity conservation, habitat connectivity and agricultural production in multifunctional rural landscapes. *Landscape Ecology* 32, 1219-1242.
- Graham, S.C., Barrett, A.S., Brown, L.R., 2020. Impact of *Seriphium plumosum* densification on Mesic Highveld Grassland biodiversity in South Africa. *Royal Society Open Science* 7, 1-10.
- Hlanguza, N., 2015. Mapping the remnant KwaZulu-Natal sandstone sourveld grass patches in the Ethekewini Municipality using a high resolution multispectral sensor. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg.
- Househam, S., 2017. The use of fire in the KwaZulu-Natal mistbelt and highland sourveld. Department of Agriculture and Rural Development. Agricultural Livestock Research Services Grass & Forage Scientific Research Services, Kokstad. 1-4.
- Hussain, M., Chen, D., Cheng, A., Wei, H., Stanley, D., 2013. Change detection from remotely sensed images: From pixel-based to object-based approaches. *ISPRS Journal of Photogrammetry and Remote Sensing* 80, 91-106.
- Keeley, J.E., 2006. Fire management impacts on invasive plants in the western United States. *Conservation Biology* 20, 375-384.

- Kennedy, R.E., Townsend, P.A., Gross, J.E., Cohen, W.B., Bolstad, P., Wang, Y., Adams, P., 2009. Remote sensing change detection tools for natural resource managers: Understanding concepts and tradeoffs in the design of landscape monitoring projects. *Remote Sensing of Environment* 113, 1382-1396.
- Lamont, B., He, T., 2020. The third dimension: How fire-related research can advance ecology and evolutionary biology. *Ideas in Ecology and Evolution* 13, 25-58.
- Lamont, B.B., Downes, K.S., 2011. Fire-stimulated flowering among resprouters and geophytes in Australia and South Africa. *Plant Ecology* 212, 2111-2125.
- Laris, P., 2002. Burning the seasonal mosaic: preventative burning strategies in the wooded savanna of southern Mali. *Human Ecology* 30, 155-186.
- Lynch, A.J., 2019. Creating effective urban greenways and stepping-stones: four critical gaps in habitat connectivity planning research. *Journal of Planning Literature* 34, 131-155.
- Macarringue, L.S., Bolfe, É.L., Pereira, P.R.M., 2022. Developments in land use and land cover classification techniques in remote sensing: A review. *Journal of Geographic Information System* 14, 1-28.
- Mkungo, L., Odindi, J., Mutanga, O., Matongera, T.N., 2023. Modelling landscape vulnerability to the Bracken fern (*Pteridium aquilinum*) invasion in a remnant urban Sandstone Sourveldt grassland ecosystem. *Scientific African* 22, 1-13.
- Mucina, L., Rutherford, M., 2006. The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia* 19,(South African National Biodiversity Institute: Pretoria, South Africa). *Memoirs of the Botanical Survey of South Africa*.
- Munien, S., Nkambule, S.S., Buthelezi, H.Z., 2015. Conceptualisation and use of green spaces in peri-urban communities: Experiences from Inanda, KwaZulu-Natal, South Africa. *African Journal for Physical Health Education, Recreation and Dance* 21, 155-167.

- Mutanga, O., Rouget, M., Hlanguza, N., Odindi, J., 2016. Mapping alien and indigenous vegetation in the KwaZulu-Natal Sandstone Sourveld using remotely sensed data. *Bothalia-African Biodiversity & Conservation* 46, 1-9.
- Nagendra, H., Lucas, R., Honrado, J.P., Jongman, R.H., Tarantino, C., Adamo, M., Mairota, P., 2013. Remote sensing for conservation monitoring: Assessing protected areas, habitat extent, habitat condition, species diversity, and threats. *Ecological Indicators* 33, 45-59.
- Naicker, R., 2015. Assessing the level of habitat fragmentation of the KwaZulu-Natal sandstone sourveld. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg
- Neary, G., Leonard, M., 2020. Effects of fire on grassland soils and water: A review. *Grasses and grassland aspects*, 1-22.
- Neke, K.S., Du Plessis, M.A., 2004. The threat of transformation: quantifying the vulnerability of grasslands in South Africa. *Conservation Biology* 18, 466-477.
- O'Connor, T., Kuyler, P., 2009. Impact of land use on the biodiversity integrity of the moist sub-biome of the grassland biome, South Africa. *Journal of Environmental Management* 90, 384-395.
- O'Connor, T., Kuyler, P., Kirkman, K., Corcoran, B., 2010. Which grazing management practices are most appropriate for maintaining biodiversity in South African grassland? *African Journal of Range & Forage Science* 27, 67-76.
- Panda, S.S., Rao, M.N., Thenkabail, P.S., Misra, D., Fitzgerald, J.P., 2016. Remote Sensing Systems—Platforms and Sensors: Aerial, Satellite, UAV, Optical, Radar, and LiDAR, *Remote Sensing Handbook, Volume I*. CRC Press, 3-86.
- Pooley, S., 2022. A historical perspective on fire research in East and Southern African grasslands and savannas. *African Journal of Range & Forage Science* 39, 1-15.

- Ray, A.S., 2016. Remote sensing in agriculture. *International Journal of Environment, Agriculture and Biotechnology* 1(3), 362-367.
- Rouget, M., Naicker, R., Mutanga, O., 2016. Assessing habitat fragmentation of the KwaZulu-Natal Sandstone Sourveld, a threatened ecosystem. *Bothalia-African Biodiversity & Conservation* 46, 1-10.
- Shlisky, A., Waugh, J., Gonzalez, P., Gonzalez, M., Manta, M., Santoso, H., Alvarado, E., Nuruddin, A.A., Rodríguez-Trejo, D., Swaty, R., 2007. Fire, ecosystems and people: threats and strategies for global biodiversity conservation. Arlington: The Nature Conservancy, 1-17.
- Simpson, K.J., Ripley, B.S., Christin, P.A., Belcher, C.M., Lehmann, C.E., Thomas, G.H., Osborne, C.P., 2016. Determinants of flammability in savanna grass species. *Journal of Ecology* 104, 138-148.
- Szpakowski, D.M., Jensen, J.L., 2019. A review of the applications of remote sensing in fire ecology. *Remote Sensing* 11, 1-31.
- Tripathi, S., Srivastava, P., Devi, R.S., Bhadouria, R., 2020. Influence of synthetic fertilizers and pesticides on soil health and soil microbiology, Agrochemicals detection, treatment and remediation. Elsevier, 25-54.
- Trollope, L., Trollope, L.A., 2010. Fire effects and management in African grasslands and savannas. *Range and Animal Sciences and Resources Management* 2, 121-145.
- Williams, N.S., Morgan, J.W., McCarthy, M.A., McDonnell, M.J., 2006. Local extinction of grassland plants: the landscape matrix is more important than patch attributes. *Ecology* 87, 3000-3006.
- Wooster, M.J., Roberts, G.J., Giglio, L., Roy, D.P., Freeborn, P.H., Boschetti, L., Justice, C., Ichoku, C., Schroeder, W., Davies, D., 2021. Satellite remote sensing of active fires:

History and current status, applications and future requirements. *Remote Sensing of Environment* 267, 1-80.

Yengoh, G.T., Dent, D., Olsson, L., Tengberg, A.E., Tucker III, C.J., 2015. Use of the Normalized Difference Vegetation Index (NDVI) to assess Land degradation at multiple scales: current status, future trends, and practical considerations. Lund University Center for Sustainability Studies (LUCSUS), and The Scientific and Technical Advisory Panel of the Global Environment Facility (STAP/GEF).

### **Chapter 3**

#### **Mapping the fire history of KwaZulu-Natal Sandstone Sourveld patches within nature reserves and communal agricultural areas of the eThekweni Municipal Region**

##### **3.1. Introduction**

Grasslands provide ecological services such as recreation, water purification, biodiversity, erosion management, and carbon storage (Reinermann et al., 2020). However, these vital systems are among the most threatened globally due to climate change and transformation, especially in the case of the KwaZulu-Natal Sandstone Sourveld (KZNSS) (Rouget et al., 2016). Therefore, the monitoring and management of grasslands is important to ensure that they persist, and that their biodiversity is conserved. Effective grassland management practices affect their functioning, composition, and provision of their ecosystem goods and services (Reinermann et al., 2020).

Fire is the most widely utilised grassland management tool (Little et al., 2015). For nearly 420 million years, grasslands have been evolving with fire (Simpson et al., 2016). Over the last few

centuries, fire has become a tool to create ecological disturbance that can be used to regulate, manipulate and promote the growth and development of grasslands (Househam, 2017). The essential elements of regulated or controlled burns are season, frequency, and intensity (Househam, 2017). These elements make up an ecosystem's fire regime, which is primarily determined by the climate, fuel properties, and ignition frequency (Bond and Keane, 2017). Fire frequency is the number of times that a specific area is burnt in a certain period (Prior et al., 2017). It is influenced by rainfall and is reliant on the grass biomass that has accumulated in the system (Prior et al., 2017). Season of fire is the season in which fire is applied in a system (Bond and Keane, 2017). Fire season can cause significant alterations in species composition and ecosystem structure, and fire is usually applied in seasons when there is low or no moisture in the fuel load (Novak et al., 2021). South African grasslands are mostly burnt in spring and winter, as well as in autumn in winter rainfall areas and have a variable natural fire frequency ranging from annual to decadal (Leys et al., 2015). Fire intensity is the release of heat energy during a burn and variations in fire frequency has different effects on the vegetation (Trollope et al., 2002). For example, to remove the moribund layer, a low-intensity fire is recommended, and a high-intensity fire is recommended if the objective is to control bush encroachment (Househam, 2017). Different ecosystems and varying land use types have differing fire regimes and, therefore, have structurally and functionally diverse communities (Simpson et al., 2016). For instance, protected areas may have a different fire regime than communal agricultural areas, even though the grassland type may be the same.

Prescribed burns are meticulously planned and managed to minimise risks. At the same time, ecosystem benefits are maximised (Rego et al., 2021), considering weather conditions, wind patterns, and other factors to ensure that the fire stays within designated boundaries and achieves its intended goals (Wright, 1979). Developing an effective prescribed burn plan or fire management program requires an understanding of fire regimes, which can be achieved by

analysing burn records of a particular grassland system (Househam, 2017). However, this is more feasible in grasslands that are protected and controlled by managers and not in ones that are in communal areas. This aspect, along with the limited effectiveness and high costs of traditional approaches, particularly when examining burn records in large regions like communal areas, highlights the need to look into more effective approaches, including remote sensing. Remote sensing is a component of Geographic Information System (GIS) that involves obtaining information about a location or object without coming into contact with or being near it, usually using a satellite (Patra, 2010). Due to its ability to sample large and remote regions, efficiency, and affordability, remote sensing has been used in agriculture, and fire and grassland management (Reinermann et al., 2020). The use of GIS and remote sensing is uncommon in the KZNSS grassland, but it is suggested for the ongoing monitoring and protection of these endangered systems.

This study aimed to observe the fire history and fire regime of grasslands in protected areas and communal agricultural areas within the eThekweni Municipality area (EMA). The objectives of the study were to determine the fire frequency and season, and the percentage of area burnt each year in the grasslands within the protected and communal agricultural areas, using historical data from MODIS.

## **3.2. Methods and Materials**

### *3.2.1. Study area*

This study was conducted in the EMA, located on the east coast of KwaZulu-Natal (KZN), South Africa. With a population of over 3.6 million, the EMA is the third-largest metropolitan area in South Africa and spans 2297 km<sup>2</sup> of KZN (Zungu et al., 2020). Due to its subtropical climate, this metropolitan area experiences sunny, mild winters and hot, humid summers

(Hlanguza, 2015). The area experiences an annual average minimum temperature of 18°C and a maximum of 25°C (Makhaya, 2021). The majority of the region's rainfall occurs between October and March, with an average annual rainfall of 762 mm (Hlanguza, 2015). The temperate and moist conditions in the area coupled with the fact that the temperature differences between summer and winter are not as extreme, make it ideal for grasses to thrive (Martindale, 2007).

This study observed nature reserves and communal agricultural areas in the eThekweni region. Some of the nature reserves are managed by the eThekweni Municipality (EM) while others by Ezemvelo KZN Wildlife (EKZNW) (Figure 3.1). Ethekweni Municipality managed nature reserves cover about 2 547ha of eThekweni. Nature reserves managed by EKZNW cover about 1 001ha of the region. The communal agricultural areas are all under the Ingonyama Trust board (Figure 3.1). Communal agricultural areas cover about 175 516ha of land in the EMA.

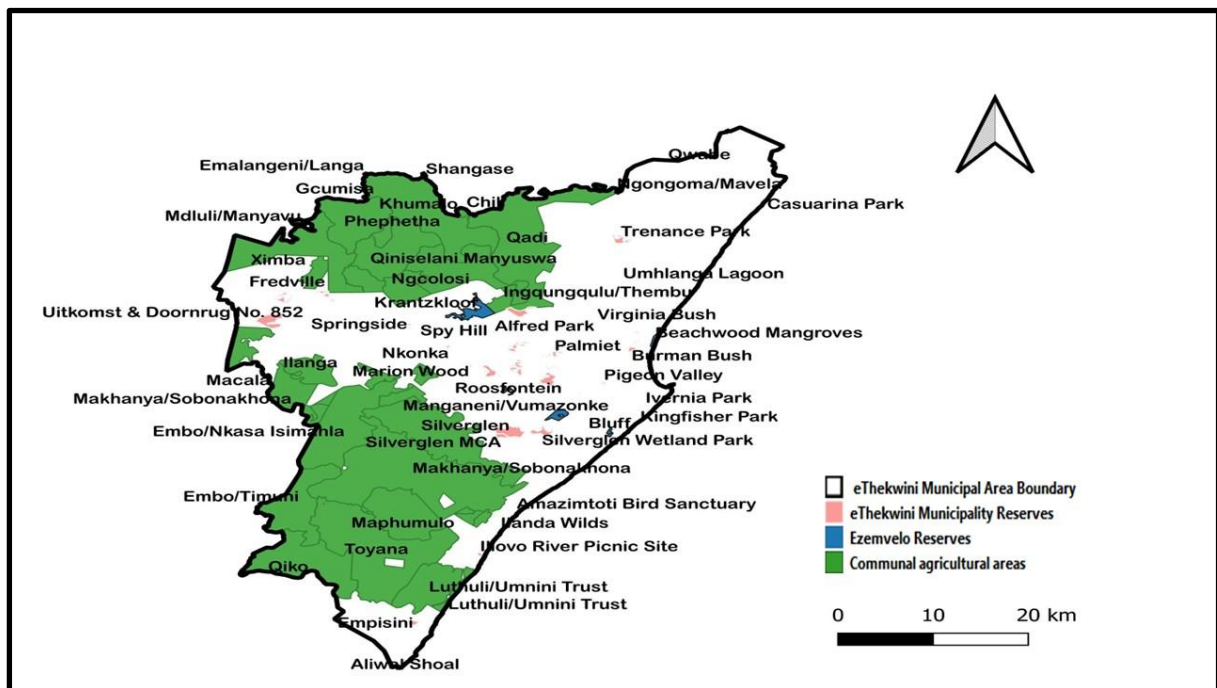


Figure 3.1: Nature reserves, managed by the eThekweni Municipality and Ezemvelo KZN Wildlife, and communal agricultural areas, under the Ingonyama Trust Board, found in the eThekweni Municipality area.

### *3.2.2. Fire data*

Active fire data was obtained from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) website. As a component of NASA's Earth Observing System (EOS), MODIS was launched on the Terra platform in December 1999 (Justice et al., 2002). The satellite-based sensor began collecting data in February 2000 (Justice et al., 2002). The location and coordinates of the fire, as well as its time and date of occurrence, are all provided by the active fire data (Makhaya, 2021). This sensor can detect small fires, about 50m<sup>2</sup> in size, if the intensity is high enough however may miss the fire if it's a low intensity fire in a warm area (Justice et al., 2002). The sensor detects large, high intensity fires more easily than small, low intensity fires. The fire images were specifically used to map fires in the EMA from 2002 to 2022. The year 2002 was chosen as the starting year because the availability of reliable MODIS data from that year and little to no fires were detected in earlier years. The active fire images were processed through QGIS 3.28.0 to generate shapefiles that can be used to create a map layout.

### *3.2.3. QGIS Mapping/Site Selection*

Shapefiles of protected areas/nature reserves and communal agricultural areas in the EMA were obtained from the TM and EKZNW. QGIS 3.28.0 was then utilised to generate a map output with these shapefiles and the active fire data gathered from the MODIS images that were converted into shapefiles (Figure 3.2). Each of the active fire images retrieved from MODIS were overlaid on a KZN shapefile on QGIS. The red part on the imagery, which represented the fire, was then turned into a polygon and saved as a shapefile.

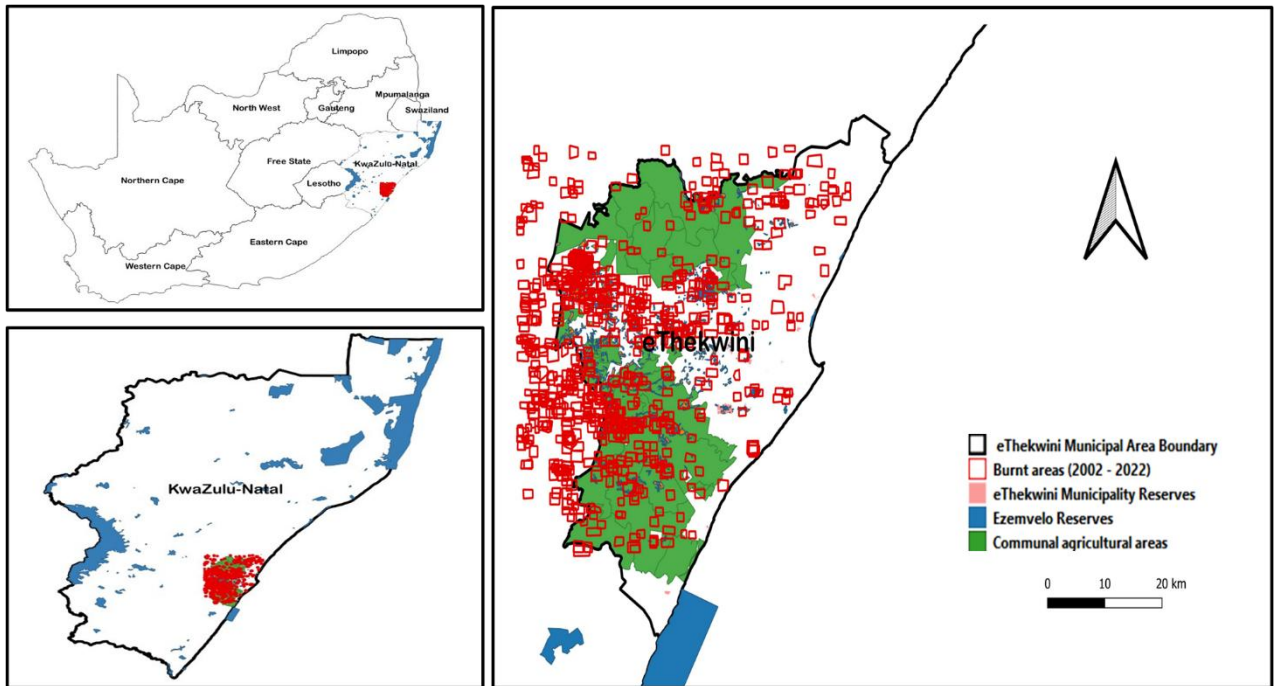


Figure 3.2: Active fires captured between 2002 and 2022 in Nature Reserves and Communal Agricultural areas in eThekweni Municipal Area, KwaZulu-Natal.

### 3.2.4. Fire Data Analysis

The area of the nature reserves that were burnt in a particular year was divided by the total area of all the nature reserves, burnt and unburnt, and then multiplied by 100 to get a percentage area burnt. The same was done for the communal agricultural areas.

$$\% \text{ area burnt} = \frac{\text{total area of nature reserves / communal areas burnt}}{\text{total area of nature reserves / communal areas}} \times 100$$

## 3.3. Results

### 3.3.1. Fire frequency

Over 20 years, communal agricultural areas have had a higher fire frequency than nature reserves (Figure 3.3 and Figure 3.4). Uitkomst, a nature reserve that has not been officially proclaimed, had the most consistent burning regime out of all the nature reserves, with a

maximum period of three years between burns, while Iphithi had the least number of fires, only one in 20 years. Other reserves burned between two and five times over 20 years (Figure 3.3). For the communal areas, Makhanya had the most fires, with portions of it burning annually, except for four years (2014 – 2017), where no burning took place. Most other communal areas burnt only two to three times in 20 years, while five of them burnt five times or more (Figure 3.4).

### *3.3.2 Fire Season*

The burning history of the nature reserves and communal agricultural areas showed that most burning occurred in the months of June, July and August, which are winter months in South Africa (Figure 3.3 and Figure 3.4). Most fires were recorded to have occurred mid to late winter. Few fires were recorded in spring (September - November) for both nature reserves and communal agricultural areas (Figure 3.3 and Figure 3.4). Nature reserves, (EM) and EKZNW managed, were generally burnt in August (Figure 3.3) while communal agricultural areas were mostly burnt in July (Figure 3.4).

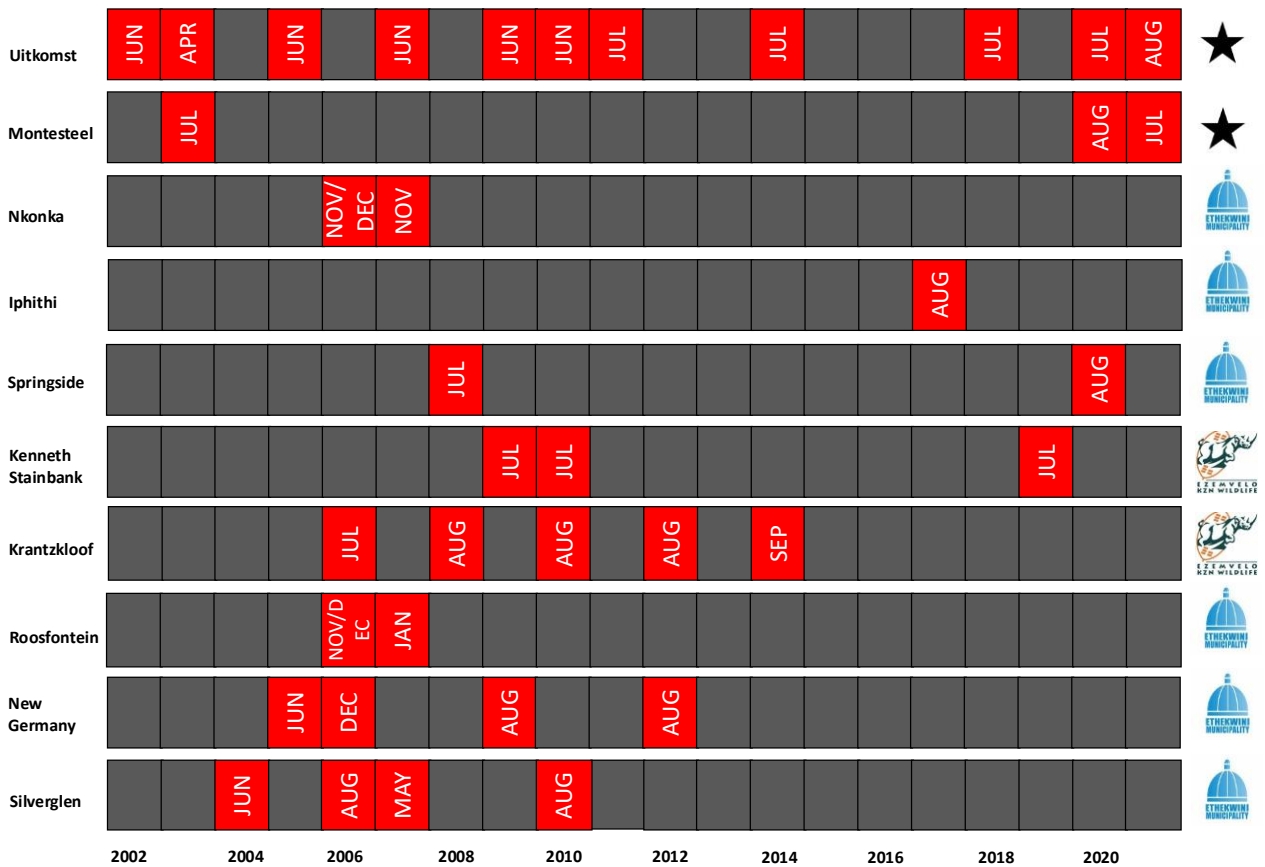


Figure 3.3: Burning history of the nature reserves within the EMA obtained from MODIS imagery. Red blocks represent fire events with the month of burning indicated in text. Star symbol indicates that the nature reserve has not been proclaimed.

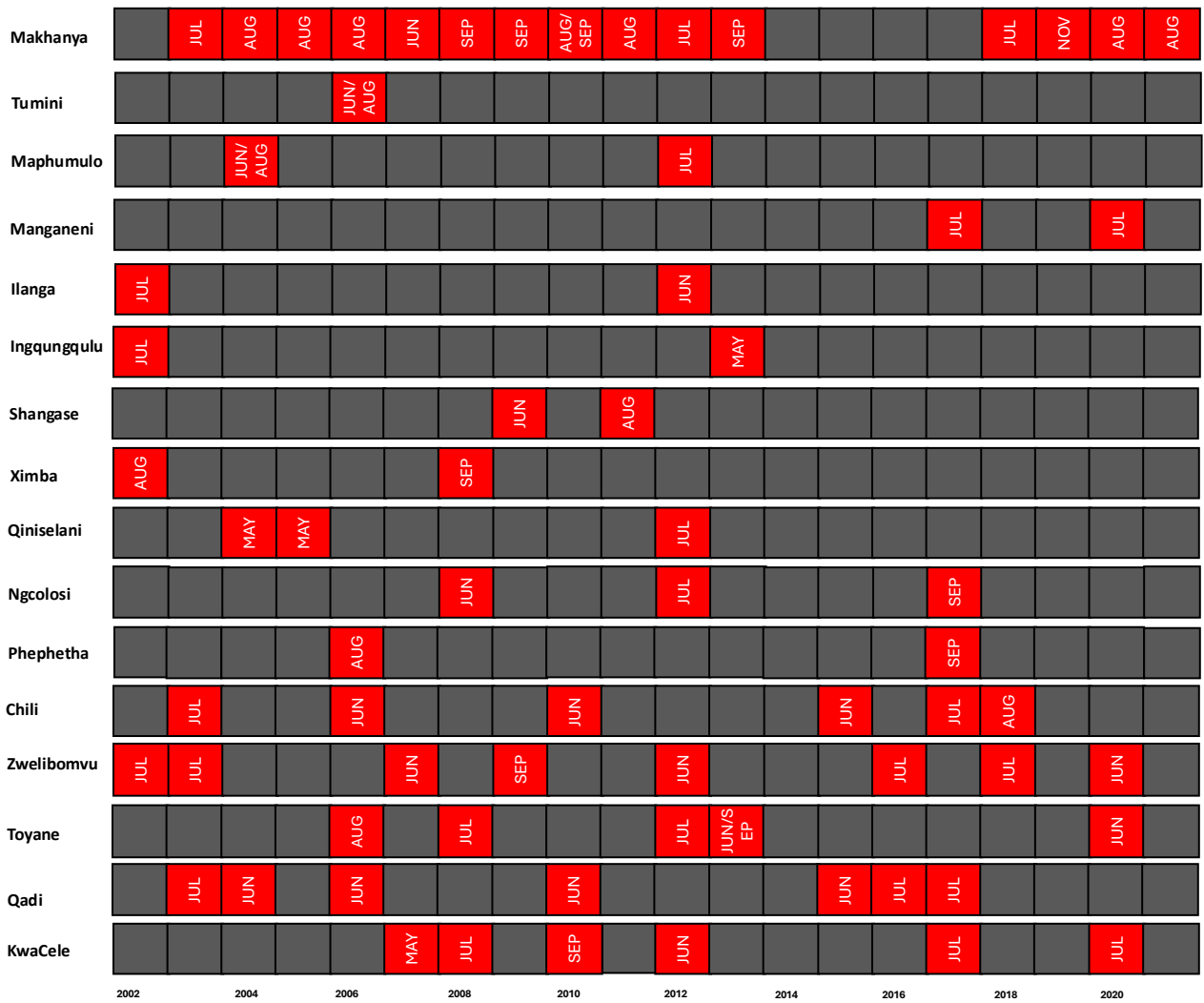


Figure 3.4: Burning history of the communal agricultural areas within the EMA obtained from MODIS imagery. Red blocks represent fire events with the month of burning indicated in text.

### 3.3.3. Percentage area burnt

The percentage area burnt for each of the land uses, nature reserves and communal agricultural areas, in each year were calculated this was based on the total area (ha) of the nature reserves and communal agricultural area that was burnt in each year (Figure 3.5).

The highest percentage area burnt was observed in 2002 for nature reserves (34,81%) (Figure 3.5). The lowest percentage area burnt was in 2015 and 2016 as there were no active fires

captured in these years (Figure 3.6). The highest proportion of the communal areas was burnt in 2007 and 2012 (2,07%), while the lowest was burnt in 2011 (0,28%) (Figure 3.6).

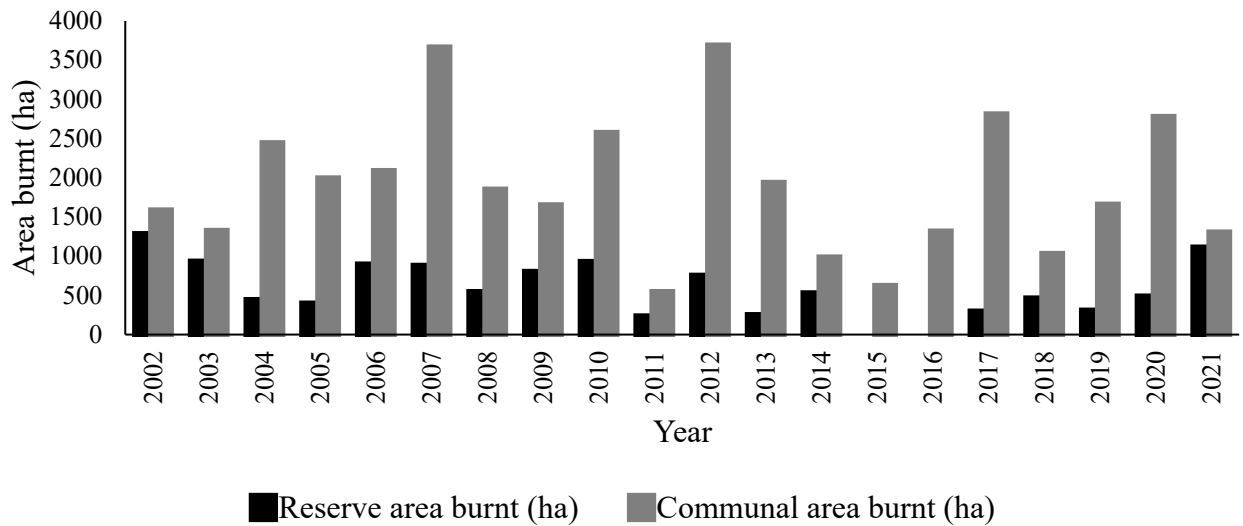


Figure 3.5: The total area burnt (ha) in nature reserves and communal agricultural areas in each year.

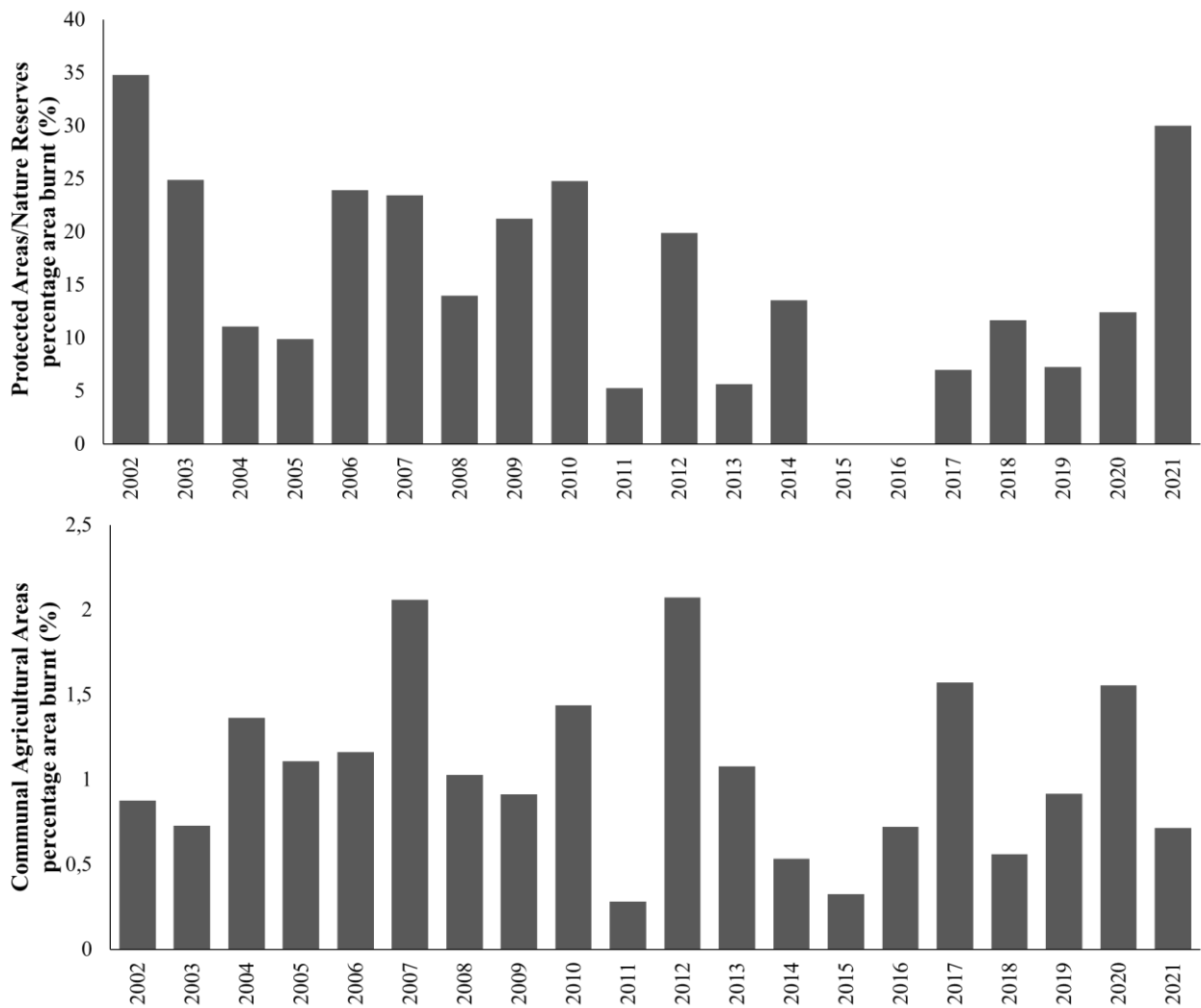


Figure 3.6: Percentage area burnt in nature reserves and communal agricultural areas each year (2002 – 2021).

### 3.4. Discussion

Grassland patches found in communal agricultural areas and those found in protected areas differ in several key aspects. While protected grasslands are often designated for biodiversity conservation and are managed by the government, municipality, or private conservation organizations, communal grasslands are essentially managed by the local people (Sundberg, 2020). This difference in management means that the management practices of these grasslands also vary, for instance in communal grasslands, management practices are primarily based on local community traditions and knowledge, needs, and uses of the community while in

protected areas the basis is on conserving biodiversity (Janišová et al., 2021; Pulido-Chadid et al., 2023). Land use is another fundamental aspect that distinguishes communal and protected grasslands. Communal grasslands are often used as grazing land for livestock while in protected areas livestock grazing is prohibited for conservation purposes (Boval and Dixon, 2012). Protected areas or grasslands limit human activities to minimise their impact (Anderson and Mammides, 2020). These aspects explain why communal and protected grasslands have varying fire regimes even when they are the same grassland type. Communal grasslands have adapted to more frequent fires due to controlled fires, while protected areas usually receive prescribed burns to maintain more stable ecosystems for conserving flora and fauna (Pulido-Chadid et al., 2023; Trollope, 2011). This is in keeping with the findings of this study as communal agricultural areas had a higher fire frequency than the nature reserves. The limited access that nature reserves have can also be used to explain this trend. In contrast, communal agricultural areas, which lack such access control, often have more frequent fires caused by humans (Pereira et al., 2012). Protected areas have restricted access, and more resources are put in place to monitor and manage fire risks (Pereira et al., 2012).

South African mesic grasslands, such as the KZNSS, are burnt between the late winter and early spring months (July to September) (Househam, 2017). This aligns with the finding of this study, most of the grassland patches were burnt in the winter months and some in spring. This timing is ideal as it coincides with the dry season when grasslands are dormant making them more flammable and dry grasses are easier to burn as they have less moisture (Househam, 2017). Applying controlled burns during the dry season is also beneficial as they ensure that all the dry, highly flammable grasses are burnt before the summer season, thereby decreasing the risk of uncontrolled wildfires later in the season (Househam, 2017). Burning during the dry season also benefits livestock and wildlife, as many of them are not as active during this season, reducing stress on animals and enabling them to avoid fires (Bartman, 2023). During burning

seasons, the livestock and wildlife are rotated to other blocks so that they can graze. Furthermore, dry season burns promote new fresh, nutritious growth in the following wet season which also benefits the livestock and other herbivores that feed on the grass (Bartman, 2023). These factors promote a healthier ecosystem for plants and animals and increases the grassland productivity for grazing.

While the season of burning remained consistent along the years, the percentage area burnt in these grassland patches fluctuated over the years. It was evident that the proportion of areas burnt was highest in earlier years for both protected areas and nature reserves. This could be due to the modification of land use practices and the evolution of conservation efforts over time. These factors lead to the adjustment of fire management practices and fire frequency in order to better balance ecological health, especially in nature reserves (Nieman et al., 2021). In the case of the KZNSS which has had major transformation over the years, the frequency of fire and proportion of areas burnt have also been altered due to this. In communal agricultural areas, this fluctuation of the percentage of areas burnt can be brought about by the modification of traditional practices and knowledge. For ages, fire was a common land management tool utilised by indigenous and local communities to control wildlife, enhance grazing areas, encourage new growth, and increase agricultural production (Shaffer, 2010). However, over the years with the increase in urbanisation and changes in land use, a decline in KZNSS patches was observed. There were more built-up areas present in these grassland patches and less natural grasslands therefore there would be less grassland to burn. This is why the proportion of areas burnt was highest in earlier years for both protected areas and nature reserves. Additionally, the modification and increase of fire management regulations and policies has influenced this fluctuation of proportion of areas burnt in the protected areas and communal agricultural areas. Fires could have been more frequent and in more areas in earlier years as there were less fire regulations put in place.

### **3.5. Conclusion**

In order to create efficient fire management plans that conserve ecosystem services and conserve biodiversity throughout the KZNSS, it is essential to comprehend the fire regimes of the remnants found in the protected and communal agricultural areas as well as their ecological effects. Mapping the fire history of these KZNSS patches assists in achieving this object and for understanding fire dynamics and their impact on biodiversity, land use, and ecosystem processes.

### **References**

- Anderson, E., Mammides, C., 2020. The role of protected areas in mitigating human impact in the world's last wilderness areas. *Ambio* 49, 434-441.
- Bartman, S., 2023. Fire: The good servant, the bad master, MyFarm Volume 9.
- Bond, W.J., Keane, R., 2017. Fires, ecological effects of. Reference module in life sciences, 1-11.
- Boval, M., Dixon, R., 2012. The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. *Animal* 6, 748-762.
- Hlanguza, N., 2015. Mapping the remnant KwaZulu-Natal sandstone sourveld grass patches in the Ethekewini Municipality using a high resolution multispectral sensor. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg.
- Househam, S., 2017. The use of fire in the KwaZulu-Natal mistbelt and highland sourveld. Department of Agriculture and Rural Development. Agricultural Livestock Research Services Grass & Forage Scientific Research Services, Kokstad. 1-4.

- Janišová, M., Iuga, A., Ivaşcu, C.M., Magnes, M., 2021. Grassland with tradition: sampling across several scientific disciplines. *Vegetation Classification and Survey* 2, 19-35.
- Justice, C., Giglio, L., Korontzi, S., Owens, J., Morisette, J., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F., Kaufman, Y., 2002. The MODIS fire products. *Remote Sensing of Environment* 83, 244-262.
- Leys, B., Brewer, S.C., McConaghy, S., Mueller, J., McLauchlan, K.K., 2015. Fire history reconstruction in grassland ecosystems: amount of charcoal reflects local area burned. *Environmental Research Letters* 10, 1-14.
- Little, I.T., Hockey, P.A., Jansen, R., 2015. Impacts of fire and grazing management on South Africa's moist highland grasslands: A case study of the Steenkampsberg Plateau, Mpumalanga, South Africa. *Bothalia-African Biodiversity & Conservation* 45, 1-15.
- Makhaya, Z., 2021. The influence of bioclimatic and topographic variables on fire occurrence and frequency within the Ethekwini Municipal Area. MSc Thesis, University of KwaZulu-Natal, Pietermaritzburg.. MSc Thesis, University of KwaZulu-Natal, Pietermaritzburg.
- Martindale, G.J., 2007. Influence of livestock grazing on plant diversity of Highland Sourveld grassland in KwaZulu-Natal. MSc Thesis, University of Witwatersrand, South Africa
- Nieman, W.A., Van Wilgen, B.W., Leslie, A.J., 2021. A review of fire management practices in African savanna-protected areas. *KOEDOE-African Protected Area Conservation and Science* 63, 1-13.
- Novak, E.N., Bertelsen, M., Davis, D., Grobert, D.M., Lyons, K.G., Martina, J.P., McCaw, W.M., O'Toole, M., Veldman, J.W., 2021. Season of prescribed fire determines grassland restoration outcomes after fire exclusion and overgrazing. *Ecosphere* 12, 1-19.

- Patra, P., 2010. Remote sensing and geographical information system (GIS). The Association for Geographical Studies, 1-28.
- Pereira, P., Mierauskas, P., Úbeda, X., Mataix-Solera, J., Cerda, A., 2012. Fire in protected areas-the effect of protection and importance of fire management. *Environmental Research, Engineering and Management* 59, 52-62.
- Prior, L.D., Murphy, B.P., Williamson, G.J., Cochrane, M.A., Jolly, W.M., Bowman, D.M., 2017. Does inherent flammability of grass and litter fuels contribute to continental patterns of landscape fire activity? *Journal of Biogeography* 44, 1225-1238.
- Pulido-Chadid, K., Virtanen, E., Geldmann, J., 2023. How effective are protected areas for reducing threats to biodiversity? A systematic review protocol. *Environmental Evidence* 12, 1-10.
- Rego, F.C., Morgan, P., Fernandes, P., Hoffman, C., Castro Rego, F., Morgan, P., Fernandes, P., Hoffman, C., 2021. Integrated fire management. *Fire science: From chemistry to landscape management*, 509-597.
- Reinermann, S., Asam, S., Kuenzer, C., 2020. Remote sensing of grassland production and management—A review. *Remote sensing* 12, 1-32..
- Rouget, M., Naicker, R., Mutanga, O., 2016. Assessing habitat fragmentation of the KwaZulu-Natal Sandstone Sourveld, a threatened ecosystem. *Bothalia-African Biodiversity & Conservation* 46, 1-10.
- Shaffer, L.J., 2010. Indigenous fire use to manage savanna landscapes in southern Mozambique. *Fire Ecology* 6, 43-59.
- Simpson, K.J., Ripley, B.S., Christin, P.A., Belcher, C.M., Lehmann, C.E., Thomas, G.H., Osborne, C.P., 2016. Determinants of flammability in savanna grass species. *Journal of Ecology* 104, 138-148.

- Sundberg, J.O., 2020. Conserving Biodiversity on South Africa's Privately-Owned Grasslands: Farmer Experiences with Protected Areas. Lincoln Institute of Land Policy.
- Trollope, W., Trollope, L., Hartnett, D., 2002. Fire behaviour a key factor in the fire ecology of African grasslands and savannas. *Forest Fire Research and Wildland Fire Safety*, Millpress, Rotterdam, 1-15.
- Trollope, W.S., 2011. Personal perspectives on commercial versus communal African fire paradigms when using fire to manage rangelands for domestic livestock and wildlife in southern and East African ecosystems. *Fire Ecology* 7, 57-73.
- Wright, H.A., 1979. Fire ecology and prescribed burning in the Great Plains: a research review. Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.
- Zungu, M.M., Maseko, M.S., Kalle, R., Ramesh, T., Downs, C.T., 2020. Effects of landscape context on mammal richness in the urban forest mosaic of EThekweni Municipality, Durban, South Africa. *Global Ecology and Conservation* 21, 1-13.

## Chapter 4

### **The impact of land use and fire on grassland species composition, diversity, structure, and veld condition in KZNSS patches in the eThekweni Municipal area**

#### **4.1. Introduction**

Land use refers to the use and modification of the natural environment by people, mainly done so that people can benefit from the land (Lambin et al., 2003). It entails people changing the primary use of the land or intensifying that primary use (Weyer et al., 2015). This can bring about great development for people however it can cause significant environmental problems (Cockburn et al., 2016). Historically, anthropogenic land use has altered much of the planet's terrestrial surface. Therefore, it has been widely recognised as one of the drivers of the environmental crisis that the world is faced with (Leidinger et al., 2017). The conversion of natural land through forestry, urban expansion, and agriculture has a great effect on the natural landscape and ecosystem function (Gibson et al., 2018) through the modification of both biotic and abiotic factors (Leidinger et al., 2017). It is also a driver of biodiversity loss as it alters species natural habitats and distribution, as well as influences the availability of and provision of ecosystem services (Rouget et al., 2016). The rapid expansion of the human population is the main driver of changes in land use (Marques et al., 2019).

Anthropogenic land use has been more prevalent in grasslands than in any other ecosystem, and therefore, these systems are severely affected by anthropogenic activities (Leidinger et al., 2017). Grasslands are one of the most predominant vegetation types worldwide, covering about 40% of the planet's land surface and providing a wide range of ecosystem goods and services (Tiscornia et al., 2019). Therefore, they have been recognised as suitable for expanding anthropogenic land use (Dixon et al., 2014). A large proportion of productive grasslands around

the world have been converted into crop- and pastureland as well as residential areas (Buckley Biggs, 2022; Dixon et al., 2014). The interaction between the natural environment and anthropogenic farming practices such as grazing and mowing has led to the development of some grasslands in regions previously dominated by other vegetation types (Zarzycki et al., 2022). Land use and agricultural practices changed and intensified due to the socio-economic transformations that occurred in the 20<sup>th</sup> century which then accelerated the decline in grassland area that is ongoing today (Zarzycki et al., 2022).

In South Africa, grassland is the most productive biome for agricultural practices due to the favourable environmental conditions, most importantly the rainfall that this biome receives (Weyer et al., 2015). South African grasslands therefore face major agricultural and development pressures (Carbutt and Kirkman, 2022). Over the years grasslands have been continuously transformed due to these pressures and to cater for rapid urbanisation (Carbutt and Kirkman, 2022). Only about 2% of South African grasslands are formally conserved, this could be the lowest in the world (Carbutt and Kirkman, 2022). The KwaZulu-Natal Sandstone Sourveld (KZNSS) is one of the most transformed South African grassland types. About 73% of this KZN endemic grassland type has been transformed due to agricultural intensification (Buthelezi et al., 2016), which greatly exceeds the proportion protected (Leidinger et al., 2017).

The remaining KZNSS currently occurs in patches, most of which are in the eThekweni Municipal region (Boon et al., 2016). Many of these patches are within urban matrices and nature reserves, while some are in communal agricultural areas (Buthelezi et al., 2016). These KZNSS remnants serve as important habitat for a large proportion of South Africa's biodiversity, especially endemic species, housing 12 endemic taxa (Drury et al., 2016). This ecosystem also serves as land for grazing livestock and a source of medicinal plant species, especially in the communal agricultural areas (Buthelezi et al., 2016). The people who reside in these communal agricultural areas also make use of the grassland patches for their religious

and cultural practices (Drury, 2016). Under 1% of the KZNSS is adequately conserved or in proclaimed nature reserves (Drury, 2016). These nature reserves serve as significant establishments for the conservation of the important KZNSS biodiversity (Mashele and Singh, 2022). The management of these protected and communal agricultural areas in KZNSS remnants is vital for the preservation of this endangered ecosystem.

Fire as a grassland management tool is widely recognised in protected and communal agricultural areas (Trollope, 2011). Fire is important for preserving the cover of indigenous vegetation and maintaining biodiversity in these areas (Mashele and Singh, 2022). However, the use of fire as a management tool tends to be more widely accepted and controlled in nature reserves or protected areas, than in communal agricultural areas. In communal agricultural areas, cultural and political factors largely influence how fire is used and may even hinder the development of fire management regimes in these areas (McGranahan and Kirkman, 2013). In protected areas, fire regimes are often based on rainfall, biomass, and historic fire data, which have more recently been documented and modelled using Geographic information systems (GIS) and remote sensing (Mashele and Singh, 2022). By contrast, very little research has been conducted on communal fire regimes in KZNSS patches (Shaffer, 2010).

This study aimed to determine the effect of land use and fire on plant species composition and structure in KZNSS grassland remnants within the eThekweni Municipality area (EMA). The objectives of the study were to determine the effect of 1) land use (nature reserve vs communal agricultural areas); 2) fire (burnt vs unburnt) using historical data from MODIS; and 3) the interaction of land use and fire on grassland plant species composition, richness, evenness, and diversity; veld condition and tree density in the KZNSS remnants.

## **4.2. Methods and Materials**

### *4.2.1. Study area*

This study was conducted in KZNSS remnant patches in the eThekweni Municipal region, KwaZulu-Natal, South Africa (KZN). The eThekweni region occupies 2297 km<sup>2</sup> of KZN and has a population of about 3.6 million, making it South Africa's third largest metropolitan area (Zungu et al., 2020). eThekweni experiences warm and moist subtropical weather with an annual average minimum temperature of 18°C and a maximum of 25°C (Makhaya, 2021). Winters are dry, and summers are humid, receiving an average precipitation of 975 mm annually (Makhaya, 2021).

Four nature reserves were sampled as protected areas, which were within the KZNSS remnants in the EMA. The nature reserves were Silverglen, New Germany, Roosfontein, and Krantzkloof. Silverglen, New Germany, and Roosfontein are managed by the eThekweni Municipality, while Krantzkloof is under Ezemvelo KZN Wildlife (more information on them in the fire chapter) (Figure 4.1). The communal agricultural areas sampled were Kwacele, Qadi, Toyane, and Zwelibomvu (Nkasa Isimahla) (Figure 4.1). All of these communal agricultural areas are under the Ingonyama Trust board.

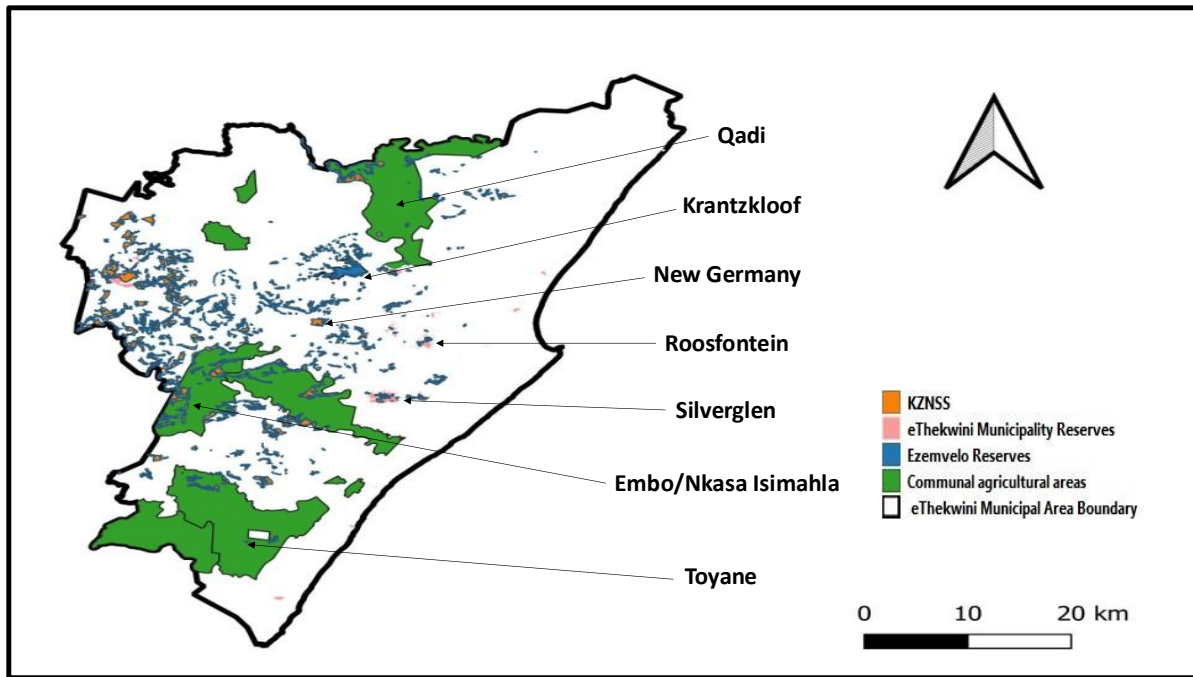


Figure 4.1: Sampled Nature Reserves (Silverglen, New Germany, Roosfontein, and Krantzklouf) and communal agricultural areas (KwaCele, Qadi, Zwelibomvu/Nkasa Isimahla, and Toyane) within the KZNSS in the eThekweni Municipal region.

KwaCele is a small rural area west of Umlazi township, one of the largest townships in South Africa (Mkhize, 2016). KwaCele is approximately 26 km<sup>2</sup> in size and consists of seven smaller villages: Ulwasi, Emahlathini, Umgwempisi, Ntontonto, KwaCele, Amahlabathi and Amandawe (Mkhize, 2016). Sampling was conducted on the Nwabi mountain in the KwaCele village area. The Nwabi mountain is 470 meters above sea level (m asl) and is managed by eThekweni’s Environmental Planning and Climate Protection division. This mountain is usually used for cultural or religious activities by the local people and numerous medicinal plant species grow there. The typical vegetation type that occurs here is bushed grassland or forest (Letty, 2004). KwaCele receives an average annual rainfall of 939 mm and has a mean annual temperature of 20.2°C, with the lowest mean temperature being in July (16.3°C) and the highest in February (23.7°C) (Letty, 2004).

In Qadi, sampling was conducted on the Nanda Mountain, which overlooks the Nanda Dam. The mountain ranges from 428 m to 476 m asl, and the vegetation is typical of the Moist Coast Hinterland Ngongoni Veld (Drury et al., 2016). Qadi receives an annual average rainfall of 969 mm and an average annual temperature of 25°C, with the lowest mean temperature being experienced in June (19°C) and the hottest month being January (29°C) (Letty, 2004). Two hundred hectares of the KZNSS can be found on the Nanda Mountain. Much of the community uses the grassland patches for subsistence and grazing and these activities are important sources of income for these peri-urban communities (Buthelezi et al., 2016). The community also uses the grassland patches for recreational, cultural, and religious functions (Buthelezi et al., 2016), by the Nazareth Baptist Church or Shembe which is particularly widespread in the area of Nanda and was founded by Isaiah Shembe in the early 20th century (Kumalo and Mujinga, 2017).

Toyane is a communal agricultural area near the towns of Magabeni and Illovo. Steep slopes and broken terrain dominate Toyane. Bushed grassland, grassland, and forest are common in this area (Letty, 2004). The mean annual rainfall in Toyane is 940 mm, and the mean annual temperature is 18.6°C, with mean temperatures reaching their lowest in July (14.8°C) and their highest in February (21.8°C) (Letty, 2004). The KZNSS grassland patches in Toyane are mainly used for grazing cattle.

Zwelibomvu (Nkasa Isimahla) is 45 km west of Durban, in the town of Umbumbulu (Kuluse, 2021). Broken terrain dominates this area, and the altitude ranges from 400 m to 500 m asl (Letty, 2004). It receives an average annual rainfall of 956 mm and an annual average temperature of 18.6°C, with the lowest mean temperature average of 14.7°C being in July and the highest of 22.1°C being in February (Letty, 2004). The surrounding communities of the KZNSS patches in Zwelibomvu mainly utilise the grassland patches for cattle grazing (Drury,

2016). Other land use practices that can be observed here include cultural and religious rituals and harvesting natural resources, such as medicinal plants and firewood (Rouget et al., 2016)

#### *4.2.2. Fire data*

Fire data was downloaded as active fire data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) website. MODIS is a satellite-based instrument or sensor operating on board the Terra and Aqua satellites and was launched in December 1999 (Riggs and Hall, 2020). The active fire data provides the coordinates of the area in which the fire is occurring, as well as the time and date of the fire event (Makhaya, 2021). The satellite-based sensor began collecting data in February 2000 (Justice et al., 2002). The sensor detects large, high intensity fires more easily than small, low intensity fires. The fire images were specifically used to map fires in the KZNSS from 2002 to 2022. The active fire images were processed through QGIS 3.28.0 to develop shapefiles.

#### *4.2.3. QGIS Mapping/Site Selection*

Shapefiles of the KZNSS patches, protected areas, and communal agricultural areas were obtained from the eThekweni Municipality. Additional protected areas shapefiles were obtained from Ezemvelo KZN Wildlife for the nature reserves managed by them within the EMA. These shapefiles, along with the fire distribution data collected from MODIS images turned shapefiles were merged to create a map output in QGIS 3.28.0 (Figure 3.2). Suitable sites were selected from this map. The sites had to be part of the KZNSS, within the EMA, had had some burning within the last 20 years (2002 – 2022) (Figure 3.2, 4.3 and 4.4) and have a patch that had not burnt at all or not as frequently.



Figure 4.2: Burning history of the nature reserve study sites within the EMA obtained from MODIS imagery. Red blocks represent fire events with the month of burning indicated in text.



Figure 4.3: Burning history of the communal agricultural area study sites within the EMA obtained from MODIS imagery. Red blocks represent fire events with the month of burning indicated in text.

#### 4.2.4. Study design

In each of the nature reserves and communal agricultural areas, two sites were sampled, one burnt and the other unburnt. These sites were 50m or more apart and were on the same slope.

In these burnt and unburnt patches, quadrat sampling was conducted to quantify the grassland composition. In each site, a 10 m x 10 m plot was laid out and in each corner of that plot, a 1 m x 1 m quadrat was placed. The plant species within the quadrat were identified and recorded. The percentage aerial cover of the species rooted within the quadrat were estimated and recorded.

A veld condition assessment (VCA) was also conducted at each site. A 200 m step point transect was done in each of the burnt and unburnt sites. The species composition and basal cover were estimated at 200 points along the transect. This was done by walking along the transect and at every one meter pitching a spike ahead of us onto the ground. From where the spike landed, the plant species closest to that point was recorded. Basal cover was recorded at the same time by measuring the distance between the spike point and the closest plant and also measuring the average basal diameter of that plant.

Tree density was measured using a modified nearest-individual method (Heydari et al., 2011). Two belt transects of 2m X 50 m were laid out in each of the burnt and unburnt sites. These transects were 50 m apart and ran parallel to each other to get a true representation of the woody species in the area. Tree species rooted within each side of the belt transect were then identified, and their height was measured.

#### *4.2.5. Statistical analysis*

A Canonical Correspondence Analysis (CCA) was utilised using R version 4.2.3 (R Core Team, 2023) to determine which land use type and fire treatment resulted in differing species composition. This was done for the overall plant species combined and for the grasses and forbs separately in order to determine which of these groups caused variation. The R packages used were readxl, vegan, and MASS. To correct for possible statistical errors associated with

rare or very common species and to avoid having zero-inflated data, log+1 transformation was applied to the species occurrence data.

Using Bray Curtis dissimilarity, an analysis of similarities (ANOSIM) was carried out to determine if the plant communities of the burnt and unburnt KZNSS patches found in the nature reserves and communal agricultural areas within the EMA differ statistically. ANOSIM is essentially a statistical test that uses a dissimilarity matrix (such as the Bray-Curtis) obtained from community data to assess if two or more groups differ significantly. A similarity percentages routine (SIMPER) analysis was also performed for pairwise comparisons and to determine the average contributions of each grass and forb species to the overall Bray-Curtis dissimilarity. SIMPER is used to further explain the dissimilarity as it determines which species are primarily responsible for the differences between predetermined groups. These analyses were carried out in PAST (version 4.03) (Hammer, 2001).

The species richness for grasses, forbs, and overall plant species (grasses and forbs) was determined for all the reserves and communal agricultural areas. The Shannon-Wiener Index ( $H'$ ) (Smith and Wilson, 1996),  $H' = \sum p_i \ln(p_i)$ , where  $p_i$  is the proportion of the individuals found in the  $i$ th species, was used to calculate species diversity. Pielou's Evenness Index was used to calculate the species evenness,  $J = H' / \ln(S)$ , where  $H'$  is the Shannon diversity index and  $S$  is the total number of species in the sample population.

Jaccard's similarity index was used to determine the percentage similarity of grass and forb species found between all of the burnt and unburnt patches and between the nature reserves and communal agricultural areas. The formula used for Jaccard being,  $S_j = c / (a + b + c)$ , where  $a$  represents the number of species found only in site A,  $b$  represents those only found in site B and  $c$  represents those shared between the sites.

A two-way analysis of variance (ANOVA) conducted in IBM SPSS version 28 was used to test the effects of burning and land use on species richness, evenness, and diversity respectively. A One-Sample Kolmogorov-Smirnov test was used to assess the assumption of the data being normally distributed and this assumption was satisfied for overall plant species richness ( $p = 0.2$ ), while for grasses ( $p = 0.2$ ) and forbs ( $p = 0.052$ ) it was only satisfied after transformation. To determine if the assumption of equality of variance was met, a Levene's test was run, and the assumption was satisfied ( $p = 1.0$ ,  $F = 0$ ).

The species composition data collected in the burnt and unburnt plots in the reserves and communal agricultural areas for the VCA was grouped according to the grass category in which a particular species belongs, decreaser or increaser. A species is categorised as a decreaser species if it declines when the veld is being overutilised, for instance, when grazing is excessive or when the veld is underutilised (Trollope et al., 1989). An increaser species increases when a decreaser species declines. Increaser species are further divided into three categories: increaser I species, which increase specifically when the veld is being underutilised; increaser II, which increase when the veld is overutilised; and increaser III species, which thrive when grazing in the veld is selective (Trollope et al., 1989). The increaser II species are further subcategorised into increaser IIa (increase with overgrazing and degradation), increaser IIb (increase in response to over- and selective grazing, and reduced fire frequency) and increaser IIc (increase when veld disturbance is moderate). The proportion of decreaser and increaser species were obtained dividing the total abundance of decreaser/increaser species with the overall abundance of species found in the specific sites. The veld condition scores for the nature reserves and communal agricultural areas and burnt and unburnt sites were calculated by dividing the sample site score with the benchmark site score. These proportions of decrease and increaser species, and veld condition scores were compared to those of the benchmark. The benchmark site is a reference area that represents the optimal condition of the veld, the best

possible condition it could be in. The benchmark site selected was the same bioresource group and vegetation type as the study sites.

Tree density was calculated for the reserves and communal agricultural areas. The number of trees in each transect in each of the patches was multiplied by the transect area (50 m x 2 m) to obtain the tree density (trees/ha). A two-way ANOVA was then used to test the effects of burning on tree density in the reserves. A One-Sample Kolmogorov-Smirnov test was used to assess the assumption of the data being normally distributed and it was satisfied ( $p = 0.2$ ) after transformation. A Levene's test was run to determine if the assumption of equality of variance was met, and the assumption was satisfied ( $p = 1.0$ ,  $F = 0$ ) for both the reserves and communal agricultural areas.

### 4.3. Results

#### 4.3.1. Plant species composition, richness, evenness and diversity

A total of 27 grass species and 95 forb species were recorded for all the reserves and communal agricultural areas combined. There were more grass (25), and forb (66) species found in the nature reserves than in the communal agricultural areas (19 grass and 47 forb species). The grass species *Aristida junciformis* and *Digitaria eriantha* and forb species *Helichrysum nudifolium* and *Gerbera ambigua* were the most dominant species overall.

The effect of land use was significant for grass, forb, and overall species richness (Table 4.1). For species diversity and evenness, the effect of land use was also significant but only for grass and overall plant species (Table 4.2 and 4.3). Overall, communal agricultural areas had the greatest richness, evenness, and diversity (Figure 4.5). There was no fire or interaction effect on species richness, evenness, or diversity (Table 4.1; 4.2; and 4.3).

Table 4.1: Two-way ANOVA statistics for species richness of grasses, forbs, and overall plant species in nature reserves and communal areas with burnt and unburnt KZNSS patches. Numbers in bold indicate statistical significance

|                          | d.f | Grasses |              | Forbs |              | Overall |              |
|--------------------------|-----|---------|--------------|-------|--------------|---------|--------------|
|                          |     | F       | P            | F     | P            | F       | P            |
| <b>Land use (L)</b>      | 1   | 4.232   | <b>0.044</b> | 6.734 | <b>0.012</b> | 9.954   | <b>0.003</b> |
| <b>Fire (F)</b>          | 1   | 0.002   | 0.969        | 0.545 | 0.463        | 0.089   | 0.767        |
| <b>Interaction (L*F)</b> | 1   | 0.33    | 0.566        | 0.949 | 0.334        | 0.429   | 0.515        |
| <b>Error</b>             | 60  |         |              |       |              |         |              |
| <b>Total</b>             | 63  |         |              |       |              |         |              |

Table 4.2: Two-way ANOVA statistics for species evenness of grasses, forbs, and overall plant species in nature reserves and communal areas with burnt and unburnt KZNSS patches. Numbers in bold indicate statistical significance

|                          | d.f | Grasses |              | Forbs |       | Overall |                  |
|--------------------------|-----|---------|--------------|-------|-------|---------|------------------|
|                          |     | F       | P            | F     | P     | F       | P                |
| <b>Land use (L)</b>      | 1   | 6.182   | <b>0.016</b> | 0.330 | 0.568 | 14.520  | <b>&lt;0.001</b> |
| <b>Fire (F)</b>          | 1   | 0.187   | 0.667        | 1.988 | 0.164 | 0.994   | 0.323            |
| <b>Interaction (L*F)</b> | 1   | 0.079   | 0.779        | 0.789 | 0.378 | 1.412   | 0.239            |
| <b>Error</b>             | 60  |         |              |       |       |         |                  |
| <b>Total</b>             | 63  |         |              |       |       |         |                  |

Table 4.3: Two-way ANOVA statistics for species diversity of grasses, forbs, and overall plant species in nature reserves and communal areas with burnt and unburnt KZNSS patches. Numbers in bold indicate statistical significance

|                          | d.f | Grasses |              | Forbs |       | Overall |              |
|--------------------------|-----|---------|--------------|-------|-------|---------|--------------|
|                          |     | F       | P            | F     | P     | F       | P            |
| <b>Land use (L)</b>      | 1   | 6.450   | <b>0.014</b> | 2.372 | 0.129 | 8.281   | <b>0.006</b> |
| <b>Fire (F)</b>          | 1   | 0.025   | 0.874        | 0.108 | 0.743 | 0.131   | 0.719        |
| <b>Interaction (L*F)</b> | 1   | 0.465   | 0.498        | 0.057 | 0.812 | 0.070   | 0.792        |
| <b>Error</b>             | 60  |         |              |       |       |         |              |
| <b>Total</b>             | 63  |         |              |       |       |         |              |

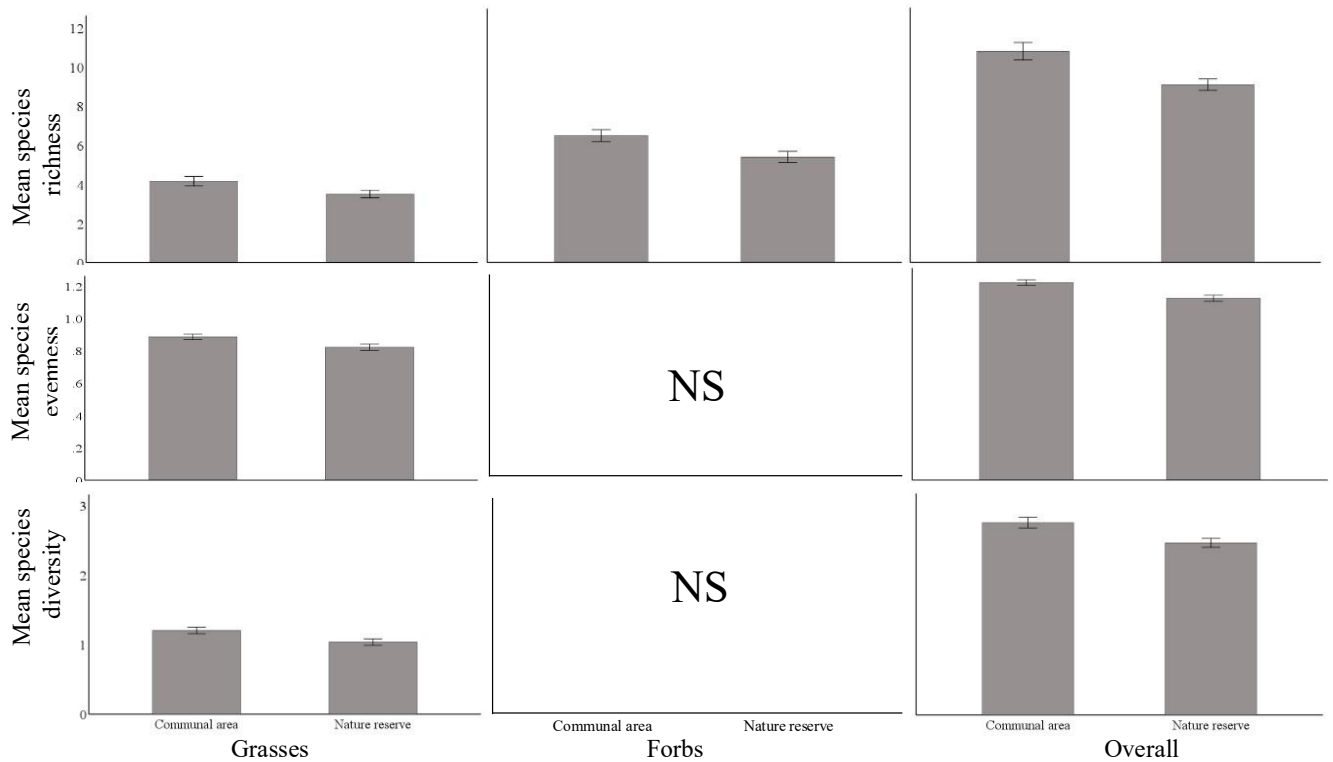


Figure 4.4: Mean species richness, evenness, and species diversity of grasses, forbs, and overall plant species in nature reserves and communal agricultural areas. Error bars represent standard error. NS indicates not significant.

For the CCA performed for overall plant species, the CCA model was significant ( $p = 0.001$ ). The significance of terms (environmental variables) was also assessed, and it was significant for the main effects of land use type and fire, as well as their interaction ( $p = 0.001$ ) (Figure 4.6 and Figure 4.7). For the grass species composition, CCA model was significant ( $p = 0.001$ ). The main effects of land use type and fire and their interaction were also significant ( $p = 0.001$ ,  $p = 0.002$ ,  $p = 0.009$ ) (Figure 4.6 and Figure 4.7). For the forb species composition, the CCA model ( $p = 0.001$ ), the main effects of land use type, fire and their interaction were significant ( $p = 0.001$ ,  $p = 0.001$ ,  $p = 0.002$ ) (Figure 4.6 and Figure 4.7). This indicates that fire, land use and their interaction all had an influence on overall plant-, grass-, and forb species composition.

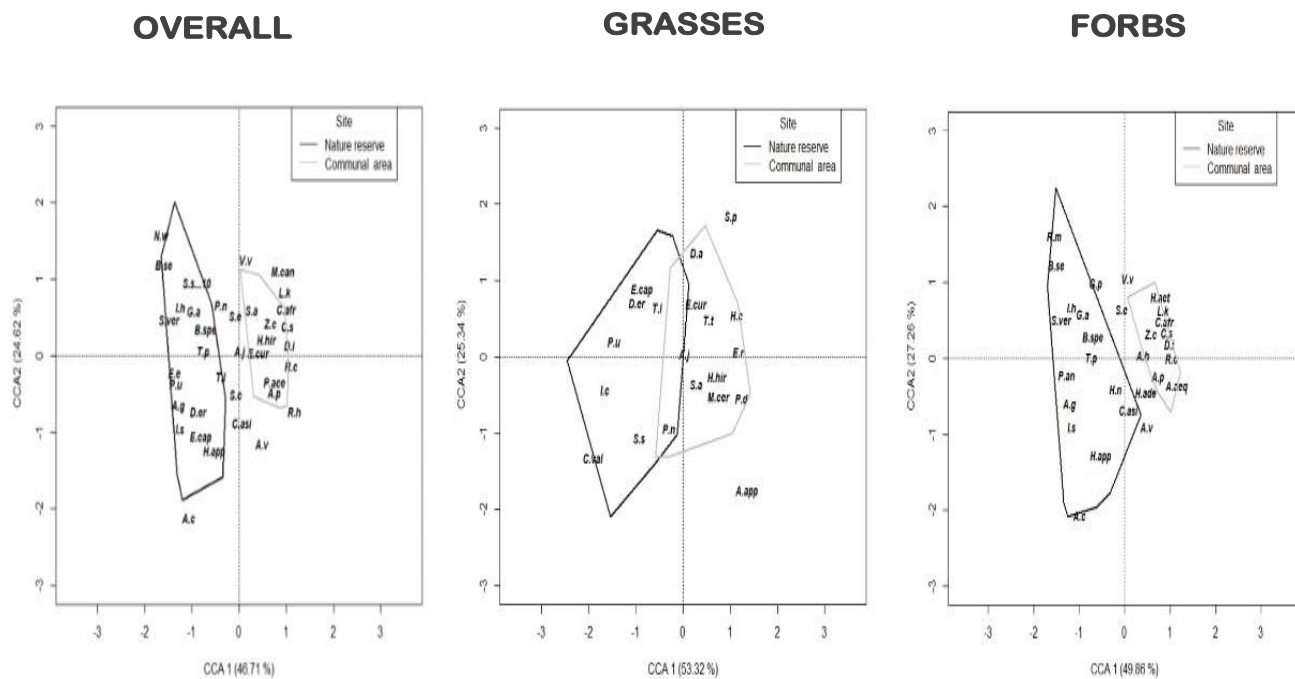


Figure 4.5: Biplots of overall plant species, grass, and forb species composition of a canonical correspondence analysis (CCA) from the KwaZulu-Natal sandstone sourveld (KZNSS) patches in nature reserves and communal agricultural areas in the Ethekwini Municipality area, KwaZulu-Natal. Species: S.p. (*Sporobolus pyramidalis*); D.a. (*Diheteropogon amplexans*); E.cap. (*Eragrostis capensis*); D.er. (*Digitaria eriantha*); T.l. (*Tristachya leucothrix*); E.cur. (*Eragrostis curvula*); T.t. (*Themeda triandra*); H.c. (*Heteropogon contortus*); P.u. (*Paspalum urvillei*); A.j. (*Aristida junciformis*); E.r. (*Eragrostis racemosa*); I.c. (*Imperata cylindrica*); S.a. (*Sporobolus africanus*); H.hir. (*Hyparrhenia hirta*); M.cer. (*Monocymbium ceresiiforme*); P.d. (*Paspalum dilatatum*); S.s. (*Setaria sphacelata*); C.val. (*Cymbopogon validus*); A.app. (*Andropogon appendiculatus*); R.m. (*Rhynchosia minima*); B.se. (*Berkheya setifera*); G.p. (*Gerbera piloselloides*); I.h. (*Indigofera hendecaphylla*); G.a. (*Gerbra ambigua*); S.ver. (*Spermacoce verticillata*); B.spe. (*Berkheya speciosa*); T.p. (*Tephrosia purpurea*); P.an. (*Pentanisia angustifolia*); H.n. (*Helichrysum nudifolium*); A.g. (*Acalypha glandulifolia*); C.asi. (*Centella asiatica*); H.app. (*Helichrysum appendiculatum*); A.c. (*Argyrella canescens*); V.v. (*Vigna vexillata*); S.e. (*Senecio erubescens*); H.aet. (*Hypericum aethiopicum*); L.k. (*Lasiosiphon kraussianus*); C.afr. (*Commelina Africana*); Z.c. (*Zornia capensis*); C.s. (*Cyanotis speciosa*); D.i. (*Desmodium incanum*); A.h. (*Afroaster hispidus*); R.c. (*Ruellia cordata*); A.p. (*Athrixia phylicoides*); H.adc. (*Helichrysum adenocarpum*); A.aeq. (*Aneilema aequinoctiale*); A.v. (*Acalypha villicaulis*); N.w. (*Neonotonia wightii*); E.e. (*Elephantorrhiza elephantina*); I.s. (*Indigofera spicata*); M.can. (*Maianthemum canadense*).



the study sites. Collectively these species contributed 66.38% of cumulative dissimilarity in grass species composition. For forb species, *Helichrysum adenocarpum*, *Phymaspermum acerosum*, *Helichrysum nudifolium*, *Zornia capensis*, and *Centella asiatica* contributed (29.89%) the most to the dissimilarity (Table 4.4).

Table 4.4: SIMPER analysis for species abundance between the burnt and unburnt patches within nature reserves and communal agricultural areas using the Bray-Curtis dissimilarity test showing descending order of average dissimilarity, percentage contribution, cumulative percentage, and mean abundance

| Species                  | Av. dissimilar | Contribution % | Cumulative % | Mean Reserve burnt | Mean Reserve unburnt | Mean Communal burnt | Mean Communal unburnt |
|--------------------------|----------------|----------------|--------------|--------------------|----------------------|---------------------|-----------------------|
| <b>Grasses</b>           |                |                |              |                    |                      |                     |                       |
| <i>A. junciformis</i>    | 17.32          | 26.22          | 26.22        | 9.31               | 9                    | 13.1                | 14.1                  |
| <i>T. triandra</i>       | 7.804          | 11.82          | 38.04        | 1.63               | 0.125                | 4.25                | 3.38                  |
| <i>D. eriantha</i>       | 6.71           | 10.16          | 48.2         | 3.44               | 2.25                 | 1.38                | 0                     |
| <i>H. hirta</i>          | 6.463          | 9.787          | 57.99        | 0.75               | 0.438                | 2.13                | 5.06                  |
| <i>P. natalense</i>      | 5.536          | 8.384          | 66.38        | 0.813              | 2.13                 | 0.0625              | 3.25                  |
| <i>M. ceresiiforme</i>   | 3.05           | 4.619          | 70.99        | 0.875              | 0                    | 0.313               | 2.31                  |
| <i>E. curvula</i>        | 2.823          | 4.275          | 75.27        | 0                  | 0.813                | 1.94                | 0.188                 |
| <i>E. racemosa</i>       | 1.927          | 2.918          | 78.19        | 0                  | 0                    | 0.938               | 1.06                  |
| <i>P. dilatatum</i>      | 1.757          | 2.661          | 80.85        | 0                  | 0                    | 0.688               | 1.56                  |
| <i>S. sphacelata</i>     | 1.705          | 2.582          | 83.43        | 0.125              | 0.875                | 0                   | 0.5                   |
| <i>E. capensis</i>       | 1.582          | 2.396          | 85.82        | 1.25               | 0.313                | 0.188               | 0.0625                |
| <i>I. cylindrica</i>     | 1.442          | 2.183          | 88.01        | 0.375              | 0.813                | 0                   | 0                     |
| <i>P. urvillei</i>       | 1.427          | 2.161          | 90.17        | 0.875              | 0.938                | 0                   | 0                     |
| <i>C. validus</i>        | 1.095          | 1.658          | 91.83        | 0                  | 1.31                 | 0                   | 0                     |
| <i>S. africanus</i>      | 1.074          | 1.626          | 93.45        | 0                  | 0.313                | 0.375               | 0.375                 |
| <i>D. amplectens</i>     | 0.7933         | 1.201          | 94.65        | 0.375              | 0                    | 0.375               | 0.0625                |
| <i>A. appendiculatus</i> | 0.7856         | 1.19           | 95.84        | 0                  | 0                    | 0                   | 0.938                 |
| <i>T. leucothrix</i>     | 0.7438         | 1.126          | 96.97        | 0.188              | 0.25                 | 0.313               | 0                     |
| <i>H. contortus</i>      | 0.5994         | 0.9077         | 97.88        | 0                  | 0                    | 0.375               | 0.125                 |
| <i>M. maximus</i>        | 0.5219         | 0.7904         | 98.67        | 0                  | 0.375                | 0                   | 0                     |
| <i>E. plana</i>          | 0.3919         | 0.5936         | 99.26        | 0                  | 0                    | 0.375               | 0                     |
| <i>C. excavatus</i>      | 0.2059         | 0.3119         | 99.57        | 0                  | 0.125                | 0                   | 0                     |
| <i>H. falx</i>           | 0.1437         | 0.2176         | 99.79        | 0                  | 0.125                | 0                   | 0                     |
| <i>S. pyramidalis</i>    | 0.06873        | 0.1041         | 99.9         | 0                  | 0                    | 0.0625              | 0                     |
| <i>M. repens</i>         | 0.06873        | 0.1041         | 100          | 0                  | 0                    | 0.0625              | 0                     |
| <b>Forbs</b>             |                |                |              |                    |                      |                     |                       |

|                          |        |        |       |        |        |        |        |
|--------------------------|--------|--------|-------|--------|--------|--------|--------|
| <i>H. adenocarpum</i>    | 6.846  | 7.331  | 7.331 | 2.13   | 0      | 4.25   | 2.25   |
| <i>P. acerosum</i>       | 5.525  | 5.917  | 13.25 | 0.625  | 0      | 2.75   | 2.63   |
| <i>H. nudifolium</i>     | 5.442  | 5.828  | 19.07 | 1.5    | 1.19   | 2.5    | 1      |
| <i>Z. capensis</i>       | 5.208  | 5.577  | 24.65 | 0.313  | 0.25   | 1.06   | 4.31   |
| <i>C. asiatica</i>       | 4.888  | 5.235  | 29.89 | 1.63   | 0.375  | 3.69   | 0.0625 |
| <i>T. purpurea</i>       | 3.982  | 4.264  | 34.15 | 1.63   | 1.44   | 0      | 1.38   |
| <i>T. natalensis</i>     | 3.63   | 3.887  | 38.04 | 0      | 0.25   | 2.38   | 1.69   |
| <i>E. elephantina</i>    | 3.317  | 3.552  | 41.59 | 1.5    | 1.69   | 0      | 0      |
| <i>L. flaccida</i>       | 3.134  | 3.356  | 44.95 | 3.13   | 0      | 0      | 0      |
| <i>C. alba</i>           | 2.976  | 3.187  | 48.13 | 0      | 0      | 2.31   | 1.25   |
| <i>I. hendecaphylla</i>  | 2.708  | 2.9    | 51.03 | 0.75   | 1.56   | 0.0625 | 0.125  |
| <i>B. speciosa</i>       | 2.613  | 2.798  | 53.83 | 0.813  | 0.938  | 0      | 1.13   |
| <i>H. aureonitens</i>    | 2.445  | 2.619  | 56.45 | 0      | 0      | 0.0625 | 2.56   |
| <i>I. spicata</i>        | 2.344  | 2.51   | 58.96 | 1.75   | 0.625  | 0      | 0      |
| <i>A. hispidus</i>       | 2.303  | 2.466  | 61.43 | 0.375  | 0      | 0.125  | 1.88   |
| <i>G. piloselloides</i>  | 2.245  | 2.404  | 63.83 | 0.125  | 1.56   | 0.0625 | 0.563  |
| <i>R. cordata</i>        | 1.943  | 2.081  | 65.91 | 0      | 0      | 1.5    | 0.688  |
| <i>D. setigera</i>       | 1.894  | 2.028  | 67.94 | 0      | 0      | 0.938  | 1.44   |
| <i>D. incanum</i>        | 1.696  | 1.816  | 69.75 | 0      | 0      | 0.625  | 0.938  |
| <i>G. ambigua</i>        | 1.663  | 1.781  | 71.53 | 0.25   | 1.19   | 0.0625 | 0.188  |
| <i>V. vexillata</i>      | 1.292  | 1.383  | 72.92 | 0      | 0.375  | 0      | 1      |
| <i>H. auriceps</i>       | 1.219  | 1.305  | 74.22 | 0      | 0      | 0.5    | 0.625  |
| <i>H. ruderales</i>      | 1.15   | 1.231  | 75.45 | 0.563  | 0.5    | 0      | 0      |
| <i>B. setifera</i>       | 1.121  | 1.2    | 76.65 | 0.0625 | 1      | 0      | 0      |
| <i>A. ophrydis</i>       | 1.078  | 1.154  | 77.81 | 0      | 0.0625 | 0.875  | 0.25   |
| <i>A. phyllicodes</i>    | 1.005  | 1.076  | 78.88 | 0.0625 | 0.0625 | 0.75   | 0.0625 |
| <i>C. africana</i>       | 0.9539 | 1.022  | 79.91 | 0      | 0      | 0.188  | 0.688  |
| <i>L. kraussianus</i>    | 0.885  | 0.9477 | 80.85 | 0      | 0      | 0.125  | 0.813  |
| <i>M. hirtus</i>         | 0.8407 | 0.9002 | 81.75 | 0      | 0      | 1.06   | 0      |
| <i>H. appendiculatum</i> | 0.8198 | 0.8779 | 82.63 | 0.625  | 0      | 0      | 0.25   |
| <i>A. vaginalis</i>      | 0.814  | 0.8717 | 83.5  | 0.125  | 0      | 0.688  | 0      |
| <i>C. farinosus</i>      | 0.7715 | 0.8261 | 84.33 | 0      | 0.75   | 0      | 0      |

|                          |        |        |       |        |       |       |        |
|--------------------------|--------|--------|-------|--------|-------|-------|--------|
| <i>N. wightii</i>        | 0.7624 | 0.8164 | 85.15 | 0      | 0.75  | 0     | 0      |
| <i>S. verticillata</i>   | 0.7618 | 0.8158 | 85.96 | 0.188  | 0.5   | 0     | 0      |
| <i>C. vaginata</i>       | 0.7186 | 0.7695 | 86.73 | 0      | 0     | 0.813 | 0      |
| <i>R. hirsuta</i>        | 0.6823 | 0.7306 | 87.46 | 0      | 0     | 0.563 | 0      |
| <i>H. aethiopicus</i>    | 0.6821 | 0.7304 | 88.19 | 0      | 0     | 0     | 0.813  |
| <i>H. aethiopicum</i>    | 0.6597 | 0.7065 | 88.9  | 0      | 0     | 0.313 | 0.438  |
| <i>A. glandifolia</i>    | 0.6408 | 0.6862 | 89.58 | 0.313  | 0.25  | 0     | 0      |
| <i>C. mimosoides</i>     | 0.6215 | 0.6655 | 90.25 | 0      | 0.5   | 0     | 0      |
| <i>S. erubescens</i>     | 0.5342 | 0.572  | 90.82 | 0      | 0.188 | 0.25  | 0.0625 |
| <i>A. aequinoctiale</i>  | 0.5126 | 0.5489 | 91.37 | 0      | 0     | 0.625 | 0      |
| <i>P. angustifolia</i>   | 0.4835 | 0.5177 | 91.89 | 0.188  | 0.188 | 0     | 0      |
| <i>R. minima</i>         | 0.4646 | 0.4975 | 92.39 | 0      | 0.438 | 0     | 0      |
| <i>E. primulifolius</i>  | 0.4385 | 0.4696 | 92.86 | 0.438  | 0     | 0     | 0      |
| <i>D. dregeanum</i>      | 0.4346 | 0.4653 | 93.32 | 0.375  | 0     | 0     | 0      |
| <i>T. minuta</i>         | 0.4329 | 0.4636 | 93.79 | 0.375  | 0     | 0     | 0      |
| <i>C. speciosa</i>       | 0.4062 | 0.435  | 94.22 | 0      | 0     | 0.188 | 0.25   |
| <i>D. elata</i>          | 0.3642 | 0.39   | 94.61 | 0.375  | 0     | 0     | 0      |
| <i>H. spiralepis</i>     | 0.3307 | 0.3541 | 94.96 | 0.375  | 0     | 0     | 0      |
| <i>H. petiolare</i>      | 0.2939 | 0.3147 | 95.28 | 0      | 0.188 | 0     | 0      |
| <i>C. natalense</i>      | 0.2918 | 0.3125 | 95.59 | 0      | 0     | 0.313 | 0      |
| <i>S. densiflora</i>     | 0.2847 | 0.3048 | 95.9  | 0      | 0.25  | 0     | 0      |
| <i>E. canadensis</i>     | 0.2796 | 0.2994 | 96.2  | 0      | 0     | 0     | 0.375  |
| <i>H. aureum</i>         | 0.2717 | 0.2909 | 96.49 | 0      | 0.25  | 0     | 0      |
| <i>H. auriceps</i>       | 0.2389 | 0.2558 | 96.74 | 0      | 0     | 0.188 | 0      |
| <i>S. coronatus</i>      | 0.2378 | 0.2546 | 97    | 0.125  | 0     | 0     | 0.125  |
| <i>T. elongata</i>       | 0.237  | 0.2538 | 97.25 | 0.0625 | 0.125 | 0     | 0      |
| <i>H. hemerocallidea</i> | 0.2144 | 0.2296 | 97.48 | 0      | 0     | 0.25  | 0      |
| <i>L. platycarpa</i>     | 0.2088 | 0.2236 | 97.7  | 0      | 0     | 0     | 0.25   |
| <i>E. cordatum</i>       | 0.2077 | 0.2224 | 97.93 | 0      | 0     | 0.188 | 0      |
| <i>D. grandiflora</i>    | 0.1963 | 0.2102 | 98.14 | 0      | 0.188 | 0     | 0      |
| <i>C. elata</i>          | 0.1535 | 0.1644 | 98.3  | 0      | 0.125 | 0     | 0      |
| <i>S. speciosus</i>      | 0.1535 | 0.1644 | 98.47 | 0      | 0.125 | 0     | 0      |

|                           |         |         |       |        |        |        |        |
|---------------------------|---------|---------|-------|--------|--------|--------|--------|
| <i>S. longicauda</i>      | 0.1496  | 0.1602  | 98.63 | 0      | 0.125  | 0      | 0      |
| <i>M. zeyheri</i>         | 0.1489  | 0.1594  | 98.79 | 0      | 0      | 0      | 0.188  |
| <i>S. venosus</i>         | 0.1414  | 0.1514  | 98.94 | 0.125  | 0      | 0      | 0      |
| <i>A. sessiflora</i>      | 0.1299  | 0.1391  | 99.08 | 0      | 0.125  | 0      | 0      |
| <i>F. muricata</i>        | 0.1265  | 0.1355  | 99.21 | 0.125  | 0      | 0      | 0      |
| <i>D. reptans</i>         | 0.1259  | 0.1348  | 99.35 | 0      | 0      | 0.125  | 0      |
| <i>P. prunelloides</i>    | 0.09949 | 0.1065  | 99.45 | 0.0625 | 0      | 0      | 0      |
| <i>T. atripilicifolia</i> | 0.09514 | 0.1019  | 99.55 | 0      | 0      | 0      | 0.0625 |
| <i>A. canescens</i>       | 0.07243 | 0.07756 | 99.63 | 0.0625 | 0      | 0      | 0      |
| <i>E. alsinoides</i>      | 0.06637 | 0.07107 | 99.7  | 0      | 0.0625 | 0      | 0      |
| <i>H. hirsuta</i>         | 0.06637 | 0.07107 | 99.77 | 0      | 0.0625 | 0      | 0      |
| <i>P. amatymbica</i>      | 0.06043 | 0.06472 | 99.84 | 0      | 0      | 0      | 0.0625 |
| <i>R. brasiliensis</i>    | 0.05597 | 0.05994 | 99.9  | 0      | 0      | 0.0625 | 0      |
| <i>A. australe</i>        | 0.04806 | 0.05146 | 99.95 | 0      | 0      | 0.0625 | 0      |
| <i>M. canadense</i>       | 0.0466  | 0.04991 | 100   | 0      | 0      | 0      | 0.0625 |

The Jaccard's similarity index between reserves and communal agricultural areas was 48% for grasses and 18% for forbs, with 12 grass and 15 forb species in common (Figure 4.8). The Jaccard's similarity index between the burnt and unburnt patches was 68% for grasses and 43% for forbs, with 17 grass and 36 forb species in common (Figure 4.8). More grass species than forb species were shared between the nature reserves and communal agricultural areas, as well as between the burnt and unburnt patches. This indicates that the grasses were the main driver of similarity.

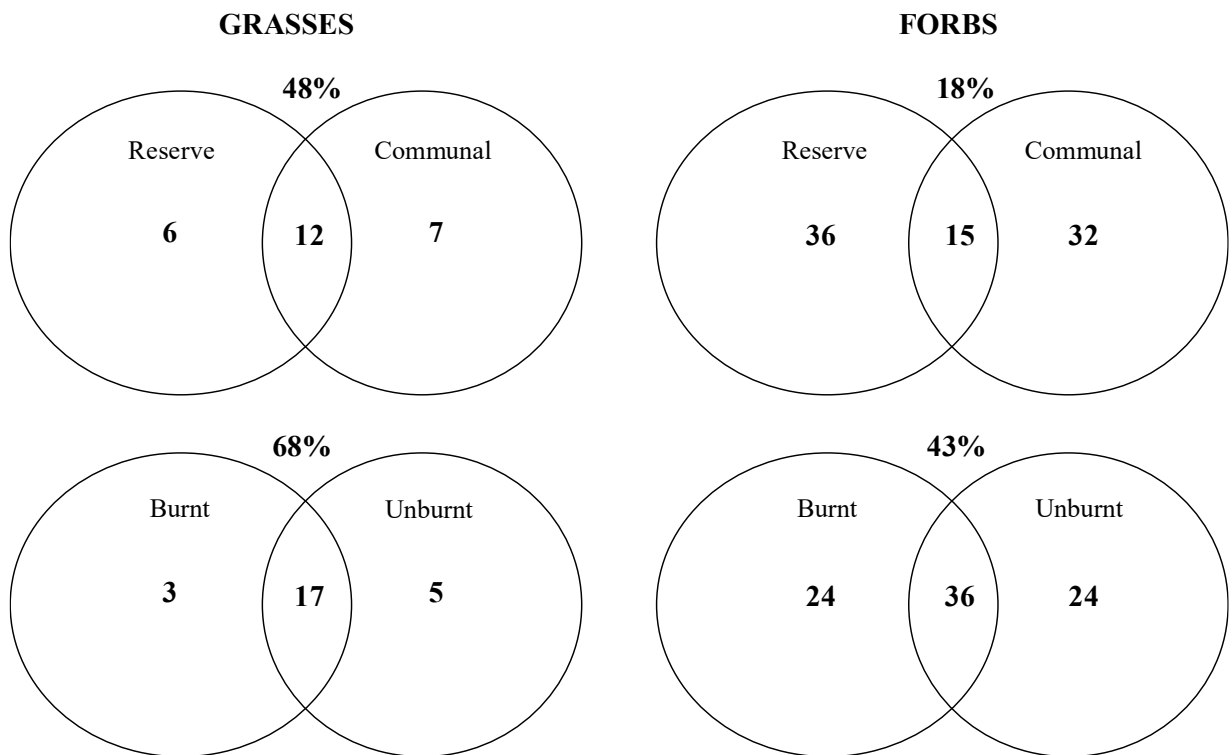


Figure 4.7: Jaccard index showing the number of grass and forb species that are shared between and unique to the nature reserves and communal agricultural areas as well as the burnt and unburnt KZNSS patches.

#### 4.3.2. Veld condition assessment

Nature reserves had a greater veld condition score (41.29%) than communal agricultural areas. This difference was driven by the proportion of decreaser species. The proportion of decreaser species in communal agricultural areas (17.19%) was lower than that of the benchmark (28%), while for nature reserves it was greater (32.63%). Nature reserves had less basal cover (11.28%) than the benchmark (14%) while for communal agricultural areas (18.23%) it was greater (Table 4.5).

Overall, the unburnt patches had the greatest VCA score (37.95%), although the proportions of decreaser species in both the burnt (22.69%) and unburnt (27.13%) patches were less than that of the benchmark (28%). The burnt patches had marginally more basal cover (14.42%) than the unburnt patches (13.98%) (Table 4.5).

Table 4.5: Veld condition analysis table for nature reserves and communal areas, and burnt and unburnt KZNSS patches

|   | <b>Benchmark</b> | <b>Land Use</b> |                 | <b>Fire Treatment</b> |                |
|---|------------------|-----------------|-----------------|-----------------------|----------------|
|   |                  | <i>Reserve</i>  | <i>Communal</i> | <i>Burnt</i>          | <i>Unburnt</i> |
| <b>% Decreaser</b>                        | 28               | 32.63           | 17.19           | 22.69                 | 27.13          |
| <b>% Increaser I</b>                      | 45               | 3.13            | 0.63            | 1.5                   | 2.25           |
| <b>% Increaser IIa</b>                    | 7                | 1.56            | 0.38            | 0.94                  | 1              |
| <b>% Increaser IIb</b>                    | 12               | 5.75            | 17.69           | 13.81                 | 9.63           |
| <b>% Increaser IIc</b>                    | 5                | 22.88           | 19.5            | 23.19                 | 19.19          |
| <b>% Increaser III</b>                    | 3                | 25.4            | 44.2            | 34.5                  | 35.1           |
| <b>Site score</b>                         | 658              | 271.69          | 193.69          | 218.31                | 249.69         |
| <b>Veld condition score (%)</b>           | 100              | 41.29           | 29.44           | 33.18                 | 37.95          |
| <b>Basal cover (%)</b>                    | 14               | 11.28           | 18.23           | 14.42                 | 13.98          |
| <b>Potential grazing capacity (AU/ha)</b> |                  | 2.7             | 2.7             | 2.7                   | 2.7            |
| <b>Current grazing capacity (AU/ha)</b>   |                  | 1.3             | 1.06            | 1.35                  | 1.38           |

### 4.3.3. Tree Density

Tree density in the KZNSS patches was not significantly affected by land use or fire and there was also no significant interaction effect (Table 4.6). This was based on the tree density (trees/ha) calculated for burnt and unburnt patches in each of the nature reserves and communal agricultural areas (Figure 4.9).

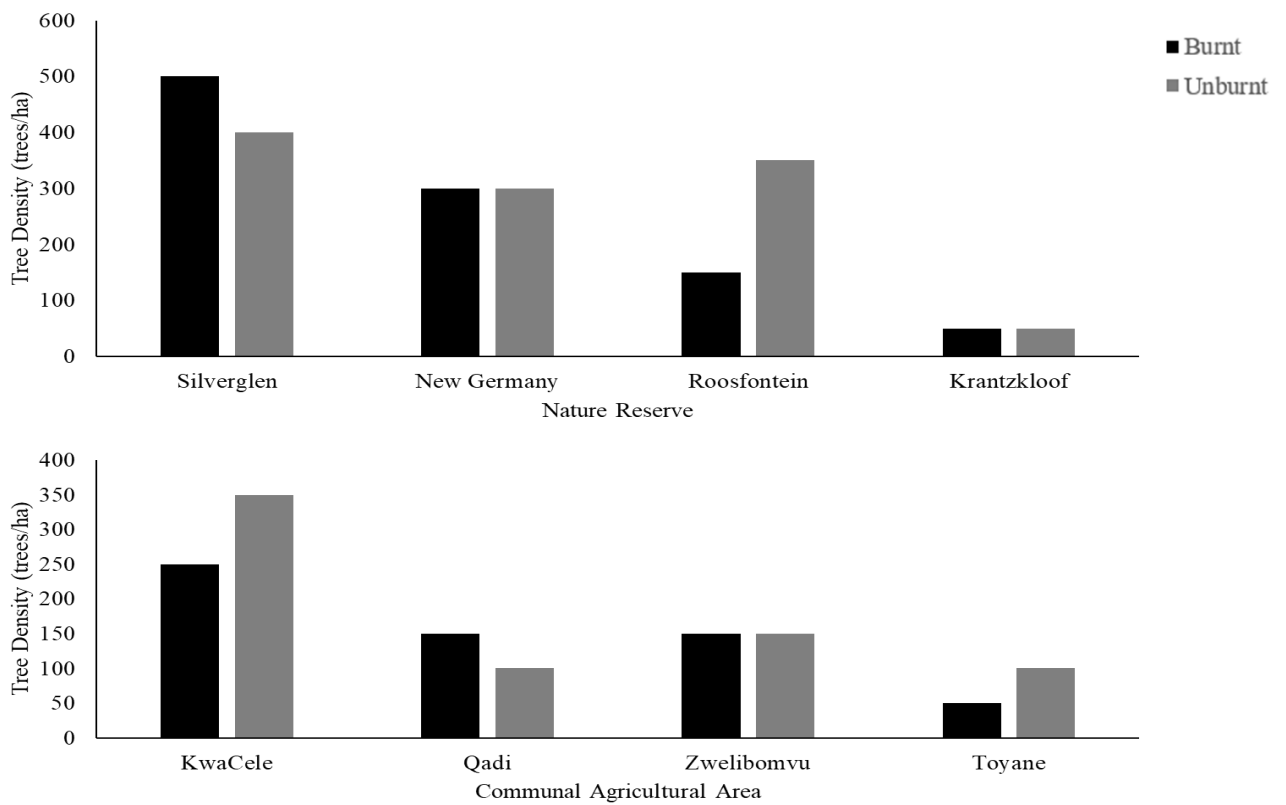


Figure 4.9: Tree density (trees/ha) of the burnt and unburnt patches of the different nature reserves and communal agricultural areas.

Table 4.6: Two-way ANOVA statistics for tree density eThekweni nature reserves and communal areas with burnt and unburnt KZNSS patches

|                          | <b>d.f.</b> | <b>F</b> | <b>P</b> |
|--------------------------|-------------|----------|----------|
| <b>Land use (C)</b>      | 1           | 2.649    | 0.117    |
| <b>Fire (F)</b>          | 1           | 0.600    | 0.446    |
| <b>Interaction (L*F)</b> | 1           | 0.045    | 0.834    |
| <b>Error</b>             | 28          |          |          |
| <b>Total</b>             | 31          |          |          |

#### 4.4. Discussion

Forbs have a higher species richness and typically outnumber the grass species present in South African mesic grasslands, such as the KZNSS (Morris and Scott-Shaw, 2019). This is in line with findings from this study where forb species richness was three times more than the grass species for the nature reserves and communal agricultural areas combined. The Asteraceae family, especially *Helichrysum* species, dominated the burnt and unburnt KZNSS patches within the nature reserves and communal agricultural areas. Of all the plant families, this forb family is thought to be the most diverse and resistant to disturbance (Funk et al., 2005; Muller et al., 2021). For the grasses, *Aristida junciformis* dominated the study sites. This could have been due to the occurrence of selective grazing both in the nature reserves and communal agricultural areas, making it easier for *Aristida junciformis* to invade as the palatable species decrease (Tainton, 1972).

Through the similarity index, it was observed that there was grass and forb species turnover between burnt and unburnt patches as well as the nature reserves and communal agricultural areas. The number of shared species was relatively higher for the grasses compared to the forbs irrespective of land use and fire (Figure 4.7). *Aristida junciformis*, *Themeda triandra*, and *Digitaria eriantha* were shared across the different study sites irrespective of land use and fire. This indicates that they thrive a wide range of landscapes

and fire regimes and may be more resilient to disturbances than other species. For forb species, *Helichrysum adenocarpum*, *Phymaspermum acerosum*, and *Helichrysum nudifolium* contributed the most to the dissimilarity observed and were not shared across the study sites and were most abundant in the burnt communal agricultural areas (Table 4.1). It was evident that fire and land use were important drivers of this turnover. In grasslands, fire shapes plant species turnover in a variety of ways, including succession patterns, community composition, and interactions between native and invading species (Alba et al., 2015; He et al., 2019). On the other hand, because land use may directly affect plant communities, change environmental conditions, introduce new species, and modify habitat layout, it can have a significant impact on the turnover of plant species (Gerstner et al., 2014).

Through landscape modification, fragmentation, and land use intensification, land use directly alters ecosystems (Gerstner et al., 2014). However, land use also indirectly influences habitat features related to species diversity, like area, edges, and age, not only on managed land but also on surrounding residual natural land (Gerstner et al., 2014). Land use proved to be a more important driver for plant species richness, evenness, and diversity than fire. These findings result from climate, geography, and the soil's physical and chemical characteristics, which all impact the distribution patterns of plant communities locally and regionally (Munyai et al., 2023). Slope, aspect, and elevation are primary topographic factors that influence plant species composition, diversity, and distribution, and can be more impactful than other factors such as fire (Munyai et al., 2023). However, species turnover, especially forb species turnover, seems to be apparent based on the CCA and Jaccard's index findings. Diversity indices often do not effectively pick up species turnover (Magurran and Henderson, 2010). The presence of distinct forb

species in both the burnt and unburnt areas suggests that the fire-independent species in the unburnt areas replaced the fire-dependent species. Moreover, grass species may react less strongly to a lack of fire since they require some form of defoliation to persist (Trlica, 1992), unlike fire-dependent forbs which require fire explicitly. This also suggests that some defoliation occurred even in the absence of fire, allowing the grasses to persist.

There is a common perception—especially in South Africa—that, in contrast to conservation areas or commercial rangeland farming, communal land, which is characterised by intensive and frequent grazing, causes plant degradation and decreases diversity (Rutherford and Powrie, 2011). It is also generally expected that plant species richness within the South African grassland biome will be highest in conservation areas, lowest on communal rangeland, and intermediate on commercial rangeland due to grazing pressure (Rutherford and Powrie, 2011). The opposite was determined in this study as it was the communal agricultural areas that had the greatest plant species richness, evenness, and diversity. These findings were similar to those obtained by Shackleton (2000), who found that even though the majority of protected areas saw biodiversity preservation as their main objective, they had significantly lower plant species richness than the heavily utilised communal agricultural areas nearby in the Bushbuckridge lowveld which is found in the southernmost region of South Africa’s Northern Province, bordering onto the Mpumalanga Province. Grassland sections that have been consistently grazed since the 18th century contain the richest diversity of grassland flora as the persistence of heavy grazing and mowing increases the number of plant species found on forest edges and grasslands (Zarzycki et al., 2022). Furthermore, it was evident from the fire history data that communal areas had more frequent fires than nature reserves. Given that the KZNSS is a fire-dependent system, more fires increase the diversity of fire-

dependent species, particularly the forbs. Similarly, this was observed at Ukulinga Research Farm in Pietermaritzburg, where the annually burnt plots had higher species richness than less frequent burns (Kirkman et al., 2014).

The veld condition assessments conducted for the land use types and fire treatments indicated that there was a loss of palatable species in the communal agricultural areas as well as the burnt and unburnt patches as the proportion of decreaser species found in these areas was lower than that of the benchmark. This can be attributed to the difference in grazing pressure between communal agricultural areas and nature reserves. The grazing pressure is typically more intense in communal areas as more intensive livestock grazing occurs here compared to nature reserves where there is only light grazing by wild herbivores, therefore nature reserves had a higher proportion of decreaseers (Madhusudan, 2004). This also explains the slightly higher veld condition score of the nature reserves. The occurrence of overgrazing was evident in all the sample sites further substantiating the loss of palatable species and the abundance of forbs witnessed. The grazing also appears to be selective in the sampling sites due to the abundance of increaser III species. Selective grazing removes decreaser species, even at very modest stocking rates, and leaves behind a patchy mosaic of unpalatable species such as *Aristida junciformis* (Little et al., 2015), which was abundant in all the sample sites. The poor veld condition scores obtained reflected the species composition and veld management of the sites. Although there is low grazing pressure on nature reserves, they burn less frequently while communal areas burn more frequently but have high grazing pressure, affecting the veld condition.

Since grasslands are dynamic, it is reasonable to anticipate that the veld state will change over time (Mamayo, 2018). Trends in grasslands over a few years might be expected, but

short-term variations brought on by above-average rainfall or a drought in the previous year for instance may also be evident (Hobbs et al., 2007). As a result, variations in species composition, abundance, and cover are to be expected due to the effects of fire, grazing, and climate (Hobbs et al., 2007). An evaluation of the grass communities' state or veld condition thus provides a useful approach to compare them and allows one to measure and track changes over time and space within a certain community or kind of vegetation (Tainton, 1972). While veld condition is the main emphasis, changes in the amount of game or the frequency of fires may be represented in veld condition models that are unique to the soils or a portion of a certain management unit (Hobbs et al., 2007). In addition to soil, climate, and topography, veld management practices are important determinants of the veld condition score (Trollope et al., 1989).

Fire, particularly fire frequency, affects the physiognomic structure of trees in grasslands (Trollope and Trollope, 2010). However, it does not have much of an effect on tree density (Smit et al., 2010). This is aligned with the findings of this study as it was observed that fire did not affect tree density in the KZNSS. It is also important to note that the KZNSS is a fire-dependent system (Boon et al., 2016) and the frequency of fire in this system may have been too low to influence the tree density. Additionally, land use had no effect on tree density. Land use type, soil, climate, land management practices, and natural disturbances like fire all play a significant role in determining the type or degree of effect that land use can have on grassland tree density (Zarzycki and Bedla, 2017). However, these factors did not have much of an impact on the nature reserves and communal agricultural areas to cause any significant change in the tree density.

#### **4.5. Conclusion**

The influence of land use and fire, as well as their interaction, on the endemic KZNSS is evident. Fire had an effect on plant species composition and turnover as it was observed that there were distinct forb species in the burnt and unburnt areas. Plant species richness, evenness, and diversity were more strongly influenced by land use than fire. The interaction of land use and fire also play a significant role, especially in the veld condition of the sites. Sustaining the KZNSS and grasslands requires careful management of both land use and fire, as their interaction plays a crucial role in maintaining ecological balance. Therefore, effective management necessitates a balanced strategy that considers ecological needs and human activities to maintain biodiversity and ecosystem services. Additionally, effective grazing management practices in communal areas are crucial as the relationship between grazing and fire is complex, grazing may both impact and be affected by fire regimes.

#### **References**

- Alba, C., Skálová, H., McGregor, K.F., D'Antonio, C., Pyšek, P., 2015. Native and exotic plant species respond differently to wildfire and prescribed fire as revealed by meta-analysis. *Journal of Vegetation Science* 26, 102-113.
- Boon, R., Cockburn, J., Govender, N., Ground, L., Slotow, R., Mclean, C., Douwes, E., Rouget, M., Roberts, D., 2016. Managing a threatened savanna ecosystem (KwaZulu-Natal Sandstone Sourveld) in an urban biodiversity hotspot: Durban, South Africa. *Bothalia-African Biodiversity & Conservation* 46, 1-12.

- Buckley Biggs, N., 2022. Drivers and constraints of land use transitions on Western grasslands: insights from a California mountain ranching community. *Landscape Ecology*, 1-21.
- Buthelezi, H.Z., Munien, S., Nkambule, S.S., 2016. Opportunities and constraints for community-based conservation: The case of the KwaZulu-Natal Sandstone Sourveld grassland, South Africa. *Bothalia-African Biodiversity & Conservation* 46, 1-8.
- Carbutt, C., Kirkman, K., 2022. Ecological grassland restoration—A South African perspective. *Land* 11, 1-25.
- Cockburn, J., Rouget, M., Slotow, R., Roberts, D., Boon, R., Douwes, E., O'Donoghue, S., Downs, C.T., Mukherjee, S., Musakwa, W., 2016. How to build science-action partnerships for local land-use planning and management: lessons from Durban, South Africa. *Ecology and Society* 21, 1-21.
- Dixon, A., Faber-Langendoen, D., Josse, C., Morrison, J., Loucks, C., 2014. Distribution mapping of world grassland types. *Journal of biogeography* 41, 2003-2019.
- Drury, C.C., 2016. A biogeographic study of the KwaZulu-Natal sandstone sourveld patches within the eThekweni Municipal Area. PhD Thesis, University of KwaZulu-Natal, Westville.
- Drury, C.C., Ramdhani, S., Sershen, Mbatha, P., Carbutt, C., Boodhraj, R., 2016. A lot gone but still hanging on: Floristics of remnant patches of endangered KwaZulu-Natal Sandstone Sourveld. *Bothalia-African Biodiversity & Conservation* 46, 1-13.
- Funk, V.A., Bayer, R.J., Keeley, S., Chan, R., Watson, L., Gemeinholzer, B., Schilling, E., Panero, J.L., Baldwin, B.G., Garcia-Jacas, N., 2005. Everywhere but

- Antarctica: using a supertree to understand the diversity and distribution of the Compositae. *Biol. Skr.* 55: 343-373.
- Gerstner, K., Dormann, C.F., Stein, A., Manceur, A.M., Seppelt, R., 2014. EDITOR'S CHOICE: REVIEW: Effects of land use on plant diversity—A global meta-analysis. *Journal of Applied Ecology* 51, 1690-1700.
- Gibson, L., Münch, Z., Palmer, A., Mantel, S., 2018. Future land cover change scenarios in South African grasslands—implications of altered biophysical drivers on land management. *Heliyon* 4, 1-35.
- Hammer, O., 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontol electron* 4, 9.
- He, T., Lamont, B.B., Pausas, J.G., 2019. Fire as a key driver of Earth's biodiversity. *Biological Reviews* 94, 1983-2010.
- Heydari, R., Zobeyri, M., Namiranian, M., Sobhani, H., Safari, A., 2011. Study of accuracy of nearest individual sampling method in Zagross forests. *Iranian Journal of Forest* 2(4), 323-330
- Hobbs, R.J., Yates, S., Mooney, H.A., 2007. Long-term data reveal complex dynamics in grassland in relation to climate and disturbance. *Ecological Monographs* 77, 545-568.
- Justice, C., Giglio, L., Korontzi, S., Owens, J., Morisette, J., Roy, D., Descloitres, J., Alleaume, S., Petitcolin, F., Kaufman, Y., 2002. The MODIS fire products. *Remote Sensing of Environment* 83, 244-262.
- Kirkman, K.P., Collins, S.L., Smith, M.D., Knapp, A.K., Burkepile, D.E., Burns, C.E., Fynn, R.W., Hagenah, N., Koerner, S.E., Matchett, K.J., 2014. Responses to fire

- differ between South African and North American grassland communities. *Journal of Vegetation Science* 25, 793-804.
- Kuluse, P.G., 2021. Household sustainability through wage labour and land-use in Zwelibomvu. University of KwaZulu-Natal, Pietermaritzburg.
- Kumalo, S., Mujinga, M., 2017. 'Now we know that the enemy is from within': Shembeites and the Struggle for Control of Isaiah Shembe's Legacy and the Church. *Journal for the Study of Religion* 30, 122 – 153.
- Lambin, E.F., Geist, H.J., Lepers, E., 2003. Dynamics of land-use and land-cover change in tropical regions. *Annual review of environment and resources* 28, 205-241.
- Leidinger, J.L., Gossner, M.M., Weisser, W.W., Koch, C., Rosadio Cayllahua, Z.L., Podgaiski, L.R., Duarte, M.M., Araújo, A.S., Overbeck, G.E., Hermann, J.M., 2017. Historical and recent land use affects ecosystem functions in subtropical grasslands in Brazil. *Ecosphere* 8, 1-20.
- Letty, B., 2004. eThekweni Agricultural Status Quo. Institute of Natural Resources.
- Little, I.T., Hockey, P.A., Jansen, R., 2015. Impacts of fire and grazing management on South Africa's moist highland grasslands: A case study of the Steenkampsberg Plateau, Mpumalanga, South Africa. *Bothalia-African Biodiversity & Conservation* 45, 1-15.
- Madhusudan, M., 2004. Recovery of wild large herbivores following livestock decline in a tropical Indian wildlife reserve. *Journal of Applied Ecology* 41, 858-869.
- Magurran, A.E., Henderson, P.A., 2010. Temporal turnover and the maintenance of diversity in ecological assemblages. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365, 3611-3620.

- Makhaya, Z., 2021. The influence of bioclimatic and topographic variables on fire occurrence and frequency within the Ethekewini Municipal Area. MSc Thesis, University of KwaZulu-Natal, Pietermaritzburg..
- Mamayo, N., 2018. Optimal spatial and temporal utilisation of grassland resources for extensive livestock production. University of KwaZulu-Natal, Pietermaritzburg.
- Marques, A., Martins, I.S., Kastner, T., Plutzer, C., Theurl, M.C., Eisenmenger, N., Huijbregts, M.A., Wood, R., Stadler, K., Bruckner, M., 2019. Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nature Ecology & Evolution* 3, 628-637.
- Mashele, S., Singh, K., 2022. GIS investigation of the fire history of Jonkershoek Nature Reserve. *South African Journal of Geomatics* 11, 189-201.
- McGranahan, D.A., Kirkman, K.P., 2013. Multifunctional rangeland in Southern Africa: Managing for production, conservation, and resilience with fire and grazing. *Land* 2, 176-193.
- Mkhize, B.I., 2016. Improving conflict resolution in cooperatives: a study in the Vumengazi authority, Umlazi. MSc Thesis, Durban University of Technology, Durban.
- Morris, C.D., Scott-Shaw, R., 2019. Potential grazing indicator forbs for two mesic grasslands in South Africa. *Ecological Indicators* 107, 1-11.
- Muller, M., Siebert, S., Ntloko, B., Siebert, F., 2021. A floristic assessment of grassland diversity loss in South Africa. *Bothalia-African Biodiversity & Conservation* 51, 1-9.

- Munyai, N., Ramoelo, A., Adelabu, S., Bezuidenhout, H., Sadiq, H., 2023. Influence of Environmental Factors on Species Richness and Diversity in a Semi-Arid Environment, South Africa. *Grasses* 2, 218-229.
- Riggs, G., Hall, D., 2020. Continuity of MODIS and VIIRS snow cover extent data products for development of an earth science data record. *Remote sensing* 12, 1-20.
- Rouget, M., Naicker, R., Mutanga, O., 2016. Assessing habitat fragmentation of the KwaZulu-Natal Sandstone Sourveld, a threatened ecosystem. *Bothalia-African Biodiversity & Conservation* 46, 1-10.
- Rutherford, M., Powrie, L., 2011. Can heavy grazing on communal land elevate plant species richness levels in the Grassland Biome of South Africa? *Plant Ecology* 212, 1407-1418.
- Shackleton, C.M., 2000. Comparison of plant diversity in protected and communal lands in the Bushbuckridge lowveld savanna, South Africa. *Biological conservation* 94, 273-285.
- Shaffer, L.J., 2010. Indigenous fire use to manage savanna landscapes in southern Mozambique. *Fire Ecology* 6, 43-59.
- Smit, I.P., Asner, G.P., Govender, N., Kennedy-Bowdoin, T., Knapp, D.E., Jacobson, J., 2010. Effects of fire on woody vegetation structure in African savanna. *Ecological Applications* 20, 1865-1875.
- Smith, B., Wilson, J.B., 1996. A consumer's guide to evenness indices. *Oikos*, 70-82.
- Tainton, N., 1972. The relative contribution of overstocking and selective grazing to the degeneration of tall grassveld in Natal. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa* 7, 39-43.

- Team, R.C., 2023. R: A language and environment for statistical computing R Foundation for Statistical Computing.
- Tiscornia, G., Jaurena, M., Baethgen, W., 2019. Drivers, process, and consequences of native grassland degradation: Insights from a literature review and a survey in Río de la Plata grasslands. *Agronomy* 9, 239.
- Trlica, M.J., 1992. Grass growth and response to grazing. Colorado State University Cooperative Extension.
- Trollope, L., Trollope, L.A., 2010. Fire effects and management in African grasslands and savannas. *Range and animal sciences and resources management* 2, 121-145.
- Trollope, W., Potgieter, A., Zambatis, N., 1989. Assessing veld condition in the Kruger National Park using key grass species. *Koedoe* 32, 67-93.
- Trollope, W.S., 2011. Personal perspectives on commercial versus communal African fire paradigms when using fire to manage rangelands for domestic livestock and wildlife in southern and East African ecosystems. *Fire Ecology* 7, 57-73.
- Weyer, V.D., Granger, J.E., Hill, T.R., O'Connor, T.G., 2015. Land transformation and its implication for biodiversity integrity and hydrological functioning from 1944 to 1999, Karkloof catchment, South Africa. *Bothalia-African Biodiversity & Conservation* 45, 1-13.
- Zarzycki, J., Bedla, D., 2017. The influence of past land-use and environmental factors on grassland species diversity. *Applied Ecology & Environmental Research* 15.
- Zarzycki, J., Korzeniak, J., Perzanowska, J., 2022. Impact of land use changes on the diversity and conservation status of the vegetation of mountain grasslands (Polish Carpathians). *Land* 11, 252.

Zungu, M.M., Maseko, M.S., Kalle, R., Ramesh, T., Downs, C.T., 2020. Effects of landscape context on mammal richness in the urban forest mosaic of EThekweni Municipality, Durban, South Africa. *Global Ecology and Conservation* 21, 1-13.

## Chapter 5

### **The impact of fire on grassland community properties and veld condition in KZNSS protected patches**

#### **5.1. Introduction**

The species-rich KwaZulu-Natal Sandstone Sourveld (KZNSS) is a fire-dependent grassland system, endemic to KwaZulu-Natal (Beaumont, 2021). Fire-dependent ecosystems are those where fire is an essential ecosystem driver and influences habitat vitality, community structure, and functioning (Forrestel et al., 2014). The species composition of these ecosystems is influenced by fire since many plant species that are found there rely on fire for germination and reproduction (Ghebrehiwot et al., 2009). Another reason they are referred to as fire-dependent grasslands is that the sward diversity is dominated by forb species and fire essentially causes this dominance as it promotes forb regeneration from their underground storage organs (Uys, 2000). The KZNSS thrives under frequent burning, but not too frequent as it could have negative impacts on the ecosystem (Rouget et al., 2016). Prescribed burns are recommended every two to five years in this grassland system depending on the biomass accumulated, veld condition and the grazing and resting regime (Househam, 2017). The recommended season of burn for the KZNSS is late winter to early spring, when there is low fuel moisture, and when the susceptibility of soil erosion can be reduced (Uys et al., 2004).

Currently, the KZNSS grassland occurs in remnant patches within the eThekweni Municipality area, and only 9 806ha of the 66 611ha remains (Boon et al., 2016). Only 223,1ha (2,3%) of the 9 806ha of KZNSS remaining is within proclaimed nature reserves

(Boon et al., 2016) but under 1% is adequately conserved (Drury, 2016). Some patches of the KZNSS are within nature reserves but may still not be adequately conserved because of the management of the reserves and their access control. The management of these protected areas is vital as they serve as important establishments for the conservation of biodiversity (Mashele and Singh, 2022). Prescribed burning has been a management tool in nature reserves for many years. Protected areas have undergone many modifications in fire management practices due to a developing understanding of the role and importance of fire in ecosystems and in response to the challenges brought about by the environmental crisis of global climate change (Nieman et al., 2021). Fire is necessary for preserving the cover of indigenous vegetation and for the maintenance of biodiversity in reserves (Mashele and Singh, 2022). Fire frequency, season, and the spatial pattern of fire are continually monitored in reserves to inform fire management decisions (Driscoll et al., 2010). Geographic information systems (GIS) are used to aid in monitoring and documenting fires and in acquiring historical fire data (Mashele and Singh, 2022). Geographic information system is particularly beneficial for reserves that do not document burning history and management practices, which is common in small reserves (Humphrey et al., 2021). Reserve managers decide on whether, how, where, and when fire should be applied in the protected areas (Nieman et al., 2021). Weather conditions and the goal of burning are focal when making these decisions on fire management practices (Nieman et al., 2021). Furthermore, visitor impacts and the level of accessibility or boundary porousness of the reserves influence the decision-making process, as although the primary purpose of reserves is conservation, they also serve as recreational spaces (Fleming et al., 2017). These factors also impact fire activity as increased porosity increases the likelihood of accidental fires in reserves (Galizia and Rodrigues, 2019).

This study aimed to determine the effect of long-term burning history on species composition and structure in protected areas in the KZNSS grassland remnants within the eThekweni Municipality area. The objectives of the study were to determine: 1) grass and forb species composition, richness, evenness, and diversity; 2) veld condition and 3) tree density in the burnt and unburnt KZNSS remnants.

## **5.2. Methods and Materials**

### *5.2.1. Study area*

This study was conducted in the remnant patches of the KZNSS at eThekweni Municipal Area (EMA) in the province of KwaZulu-Natal. The EMA is 2297 km<sup>2</sup> in size and has a population of about 3.6 million (Zungu et al., 2020). It is also the country's third biggest metropolitan area (Zungu et al., 2020). The EMA experiences a humid and warm subtropical climate with a mean annual minimum temperature of 13.9°C in winter and a maximum reaching 24°C in summer months (Makhaya, 2021). It is characterised by dry winters and humid temperate summers receiving an average precipitation of 975 mm annually (Makhaya, 2021). Mist is also common in the EMA, unlike frost, which is infrequent (Zungu et al., 2020).

Four protected areas or nature reserves were sampled within the KZNSS remnants in the EMA (Figure 5.1). The nature reserves were Silverglen, New Germany, Roosfontein, and Krantzkloof. Silverglen, New Germany and Roosfontein are managed by the eThekweni Municipality, while Krantzkloof is under Ezemvelo KZN Wildlife

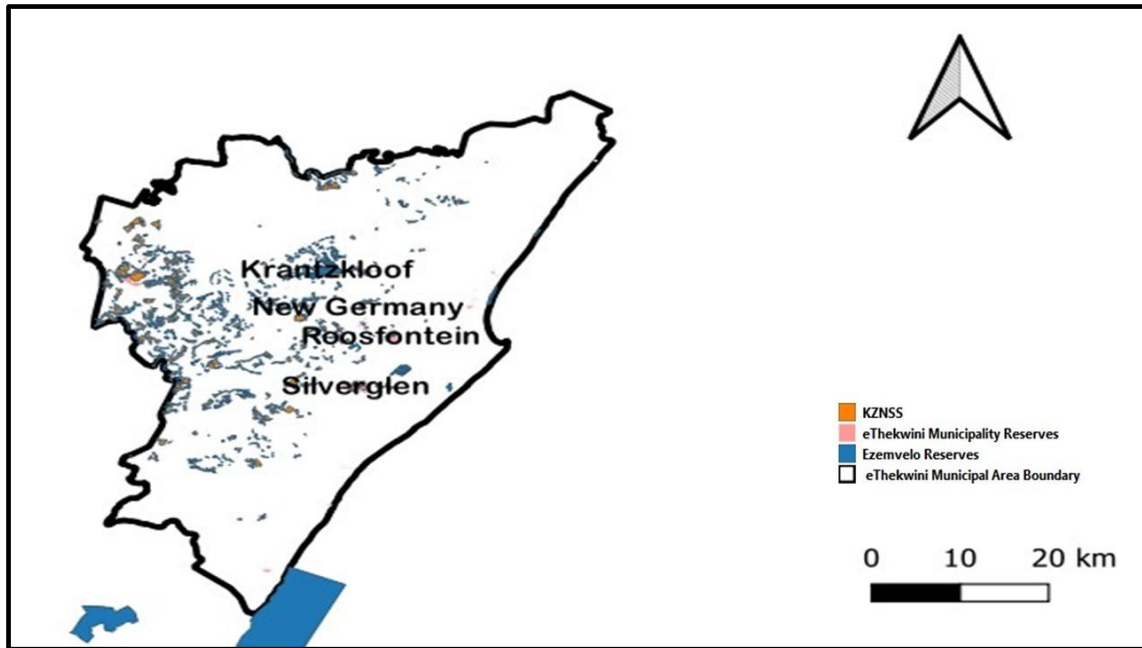


Figure 5.1: Sampled Nature Reserves (Silverglen, New Germany, Roosfontein, and Krantzklouf) within the KZNSS in the eThekweni Municipal region.

Silverglen Nature Reserve is located in Chatsworth. It is 460 hectares in size and is on the northern margin of the Umlazi River (Nsele, 2019). Of all the municipality's reserves, it supports the greatest bird and tree species richness, approximately 150 bird and 120 tree species (Marimuthoo, 2009). More than 280 grassland plant species also occur in Silverglen, with 35 grass species (Marimuthoo, 2009). It also contains approximately 70 hectares of the KZNSS. There is no fire management regime in place for this reserve, fires are usually accidental or wildfires.

New Germany Nature Reserve is on the outskirts of Pinetown, in the suburb of New Germany. It is approximately 110 hectares (Duggan and Hocking, 1990) and is a habitat for over 120 local bird species (SA-Venues, 2023). The vegetation is dominated by coastal grassland and the KZNSS with interspersed forest patches (Duggan and Hocking,

1990). Approximately 60 hectares of the KZNSS can be found within New Germany Reserve. This reserve is usually burnt biennially in August.

Roosfontein Nature Reserve is located in Westville, near Westville Prison, and was proclaimed in 2015 (SA-Venues, 2023). It contains 150 hectares of grassland (Adam, 2016), with 36 hectares of that being KZNSS. It supports many bird species, particularly those common to grassland ecosystems (Open Green Map, 2013). In addition, it also contains a range of herbivorous mammals, commonly small antelope species. This reserve houses two protected species, the plant species *Tephrosia inandensis* and *Bradypodion pumilum*, commonly known as the Dwarf Chameleon (SA-Venues, 2023). Burning usually occurs annually in September for this reserve.

Krantzkloof Nature Reserve is found in Kloof, north-west of Durban, and is 532ha in size. The Molweni River is the main river in this reserve and this, along with the Nkutu River, cut into the Kloof Plateau (Krantzkloof Nature Reserve, 2023). It contains 147 hectares of the KZNSS. This reserve is rich in biodiversity, supporting 253 bird, 50 mammal, 273 tree, and 1500 herbaceous plant species (McLean et al., 2016). This reserve contains the rare plant species, *Brachystelma natalense*, *Dahlgrenodendron natalense* (Natal Sandstone-quince), and *Streptocarpus molweniensis* which is endemic to South Africa (McLean et al., 2016). Controlled burns are conducted before 15 September in this reserve. The reserve is divided into 33 burning blocks and burning in these blocks is rotated. However, some blocks have not been burnt or burnt infrequently.

### *5.2.2. Fire data*

Fire data was downloaded from NASA's Moderate-resolution imaging spectroradiometer (MODIS) website. MODIS is a satellite-based instrument or sensor that is operating on board the Terra and Aqua satellites (Riggs and Hall, 2020). These two satellites orbit the Earth and observe the surface daily or every two days (Riggs and Hall, 2020). They acquire earth data in 36 spectral bands that range from 0.4µm to 14.4 µm wavelengths (Makhaya, 2021). The algorithm used by MODIS for detection identifies pixels that showcase active fires in areas that the satellite passes (Makhaya, 2021). This active fire data provides the coordinates of the area in which the fire is occurring as well as the time and date of the fire event (Makhaya, 2021). The active fire images were used to map fires in the KZNSS from 2002 to 2022. QGIS 3.28.0 was used to create shapefiles from these active fire images.

### *5.2.3. QGIS Mapping/Site Selection*

Shapefiles of KZNSS patches and protected areas were obtained from the eThekweni Municipality and Ezemvelo KZN Wildlife. These shapefiles along with the fire data obtained from MODIS were merged to create a map in QGIS 3.28.0 (Figure 5.2). Sample sites were selected from this map using the following criteria. The sites had to be part of the KZNSS, within the EMA, had experienced some burning within the last 20 years (2002 – 2022) (Figure 4.3), and have a patch that had not burnt at all or had only burnt once or twice in the 20 years.

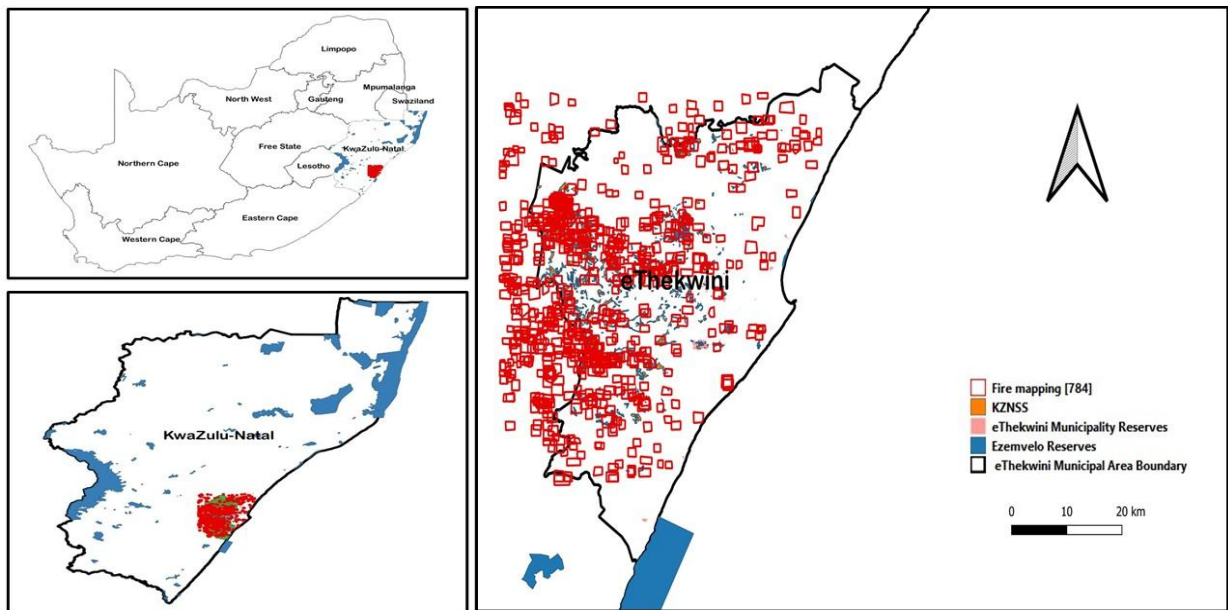


Figure 5.2: Fires in nature reserves within KZNSS remnants in the eThekweni Municipal Area.

#### 5.2.4. Study design

In each of the four nature reserves, two sites were sampled. One site was the burnt patch of the KZNSS in the study area and the other was the unburnt patch. In these burnt and unburnt patches, quadrat sampling was conducted to collect data to quantify the grassland composition. In the burnt and unburnt sites, a 10 m x 10 m plot was laid out and in each corner of that plot, a 1 m x 1 m quadrat was placed. The plant species (grass and forbs) within the quadrat were identified and recorded. The species abundances and percentage aerial cover of the species rooted within the quadrat were estimated and recorded.

A veld condition assessment (VCA) was also conducted. A 200 m step point VCA was done in each of the burnt and unburnt sites. The species composition and basal cover were estimated at 200 points along the transect. This was done by walking along the transect and at every step (equivalent to every meter) pitching a spike ahead onto the ground. From

where the spike landed, the plant species closest to that point was recorded. Basal cover was recorded at the same time by measuring the distance between the spike point and the closest plant and measuring the average diameter of the basal area of that plant.

Tree density was measured using a modified nearest individual method (Heydari et al., 2011). Two belt transects of 50 m were laid out in each of the burnt and unburnt sites. These transects were 50 m apart and ran parallel to each other to get a true representation of the woody species in the area. Tree species that were within 1 m of the transect line were then identified, and their height was measured.

#### *5.2.5. Statistical analysis*

A Principal Components Analysis (PCA) was utilised in CANOCO 4.5 to determine if there was plant compositional variation between the different reserves. This was done for overall plant species (forbs and grasses) and for grasses and forbs individually to determine which of these groups caused the variation.

The species richness for grasses, forbs, and overall plant species (grasses and forbs) was counted for each of the burnt and unburnt plots in the four reserves. Pielou's Evenness Index was used to calculate the species evenness,  $J = H' / \ln(S)$ , where  $H'$  is the Shannon diversity index and  $S$  is the total number of species in the sample population. This evenness index is based on the Shannon-Wiener Index ( $H'$ ) (Smith and Wilson, 1996),  $H' = -\sum p_i \ln(p_i)$ , where  $p_i$  is the proportion of the individuals found in the  $i$ th species, which was used to calculate species diversity.

Jaccard's similarity index was used to determine the percentage similarity of grass and forb species found between the burnt and unburnt patches in each of the four reserves.

The formula used for the Jaccard's similarity index being,  $S_j = c / (a + b + c)$ , where a represents the number of species found only in site A, b represents those only found in site B and c represents those shared between the sites.

A two-way Analysis of Variance (ANOVA) in IBM SPSS version 28 was used to test the effects of burning on species richness, evenness, and diversity respectively in the reserves. A One-Sample Kolmogorov-Smirnov test was used to assess the assumption of the data being normally distributed, which was satisfied ( $p = 0.2$ ). A Levene's test was run to determine if the assumption of equality of variance was met, and the assumption was satisfied ( $p = 1.0$ ,  $F = 0$ ). However, a Generalized linear model (GLM) was used for forb species evenness because this data did not satisfy the assumptions of the two-way ANOVA even when it was transformed.

The species composition data collected in the burnt and unburnt plots in the reserves for the VCA was grouped according to the grass ecological category in which a particular species belongs, decreaser or increaser. A species is categorised as a decreaser species if it declines when the veld is being overutilised, for instance when grazing is excessive, or when the veld is underutilised (Trollope et al., 1989). Increaser species are those that increase when decreaser species decline. Increaser species are further divided into three categories: increaser I species which increase specifically when the veld is being underutilised, increaser II which increase when there is overutilisation of the veld, and increaser III species which thrive when grazing in the veld is selective (Trollope et al., 1989). The VCA calculations are then done after grouping the species and completing the VCA table. Basal cover estimations are also used in the calculations.

Tree density was calculated for each of the burnt and unburnt patches in the reserves (Duluth, 2023). The number of trees found along the transects in each of the patches was multiplied by the transect area (50 m x 1 m) to determine the tree density (trees/ha). A two-way ANOVA was then used to test the effects of burning on tree density in the reserves. A One-Sample Kolmogorov-Smirnov test was used to assess the assumption of the data being normally distributed and it was satisfied ( $p = 0.2$ ). A Levene's test was run to determine if the assumption of equality of variances was met, and the assumption was satisfied ( $p = 1.0$ ,  $F = 0$ ).

### 5.3. Results

#### 5.3.1. Plant species composition

There was a total of 25 grass species and 66 forb species recorded in all the reserves combined. Krantzkloof Nature Reserve had the highest grass species richness with 15 species and New Germany had the highest forb species richness, 27. The grass species *Aristida junciformis* and *Digitaria eriantha* and forb species *Helichrysum nudifolium* and *Gerbera ambigua* were among the most dominant species in the burnt and unburnt patches, respectively, across all the reserves.

For the PCA performed for overall plant species, Krantzkloof had the largest envelope indicating that it was more varied than the other nature reserves. Krantzkloof again had the largest envelope for forbs and grasses, but New Germany also had a large envelope for grasses (Figure 5.4).

Overall, Jaccard's similarity index was 56% for grasses and 33% for forbs when the reserves were combined, with 10 grass and 17 forb species shared between the burnt and

unburnt patches (Figure 5.5 and Table 5.1). The Jaccard's similarity index for Roosfontein Nature Reserve, which was not fenced and the most porous throughout, was 56% for grasses and 23% for forbs, with five grass and three forb species shared between the burnt and unburnt patches. For Silverglen Nature Reserve it was 25% for grasses and 28% for forbs, with two grass and five forb species shared among the burnt and unburnt patches. New Germany burnt patches shared four for grass and seven for forb species with the unburnt patches, with a similarity index of 40% for grasses and 37% for forbs. Krantzkloof, which was the least porous reserve, had a similarity index of 40% grasses and 11% forbs, with four grasses and two forbs occurring in both the burnt and unburnt patches (Figure 5.6 and Table 5.1)

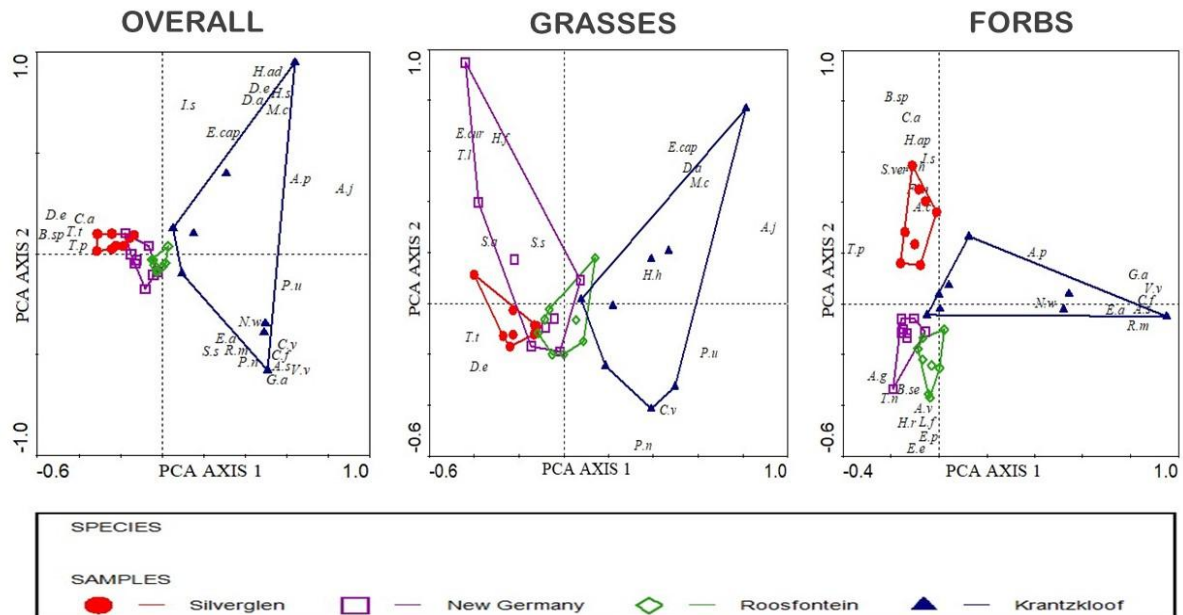


Figure 5.3: PCA biplots of overall plant species, grass, and forb species composition in Silverglen, New Germany, Roosfontein and Krantzkloof Nature Reserves in the eThekweni Municipal Area, KwaZulu-Natal.

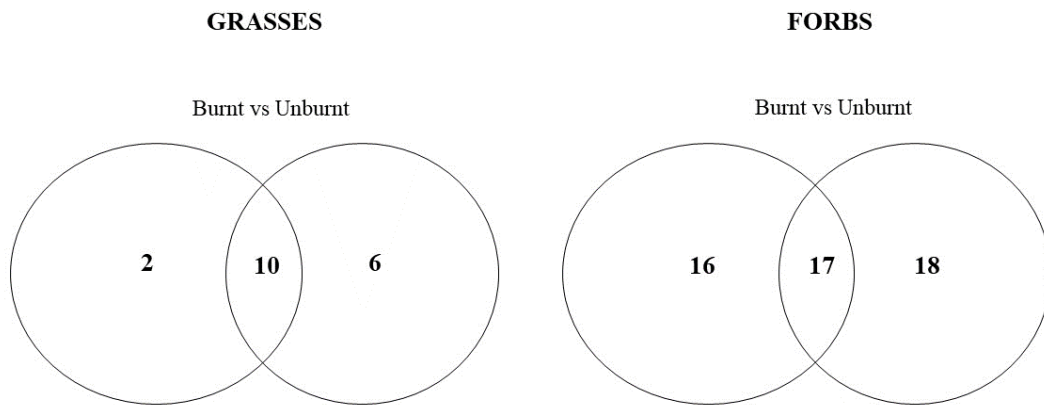


Figure 5.4: Jaccard index showing the number of grass and forb species that are shared and unique to burnt and unburnt KZNSS patches in all four nature reserves located in the eThekweni Municipal Area.

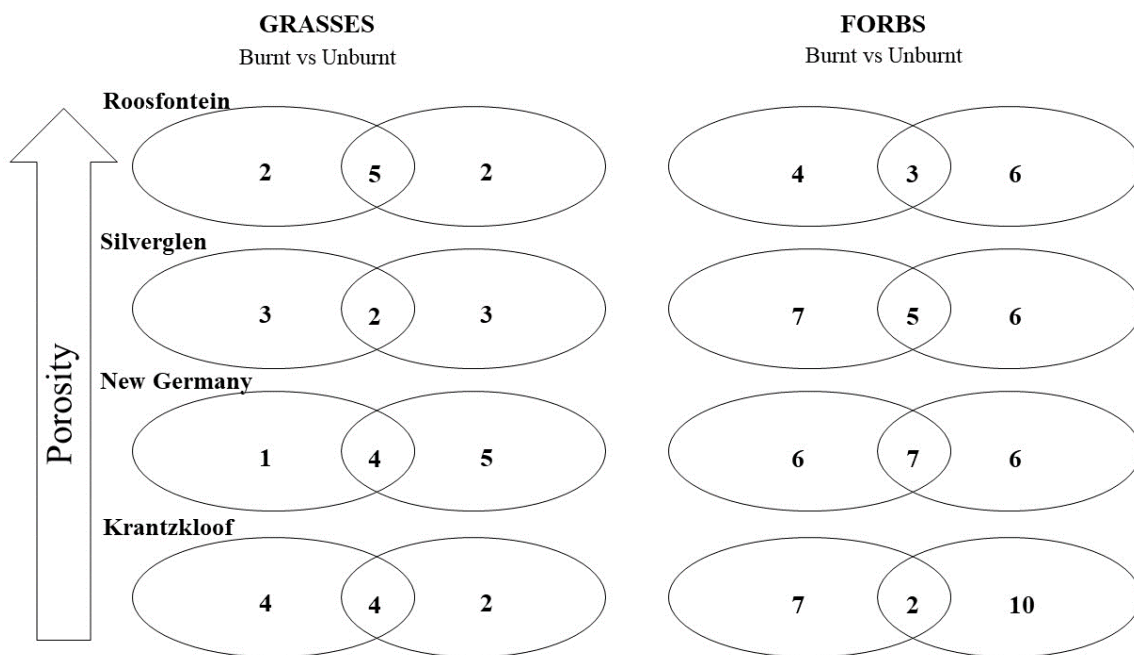


Figure 5.5: Jaccard index showing the number of grass and forb species that are shared and unique to burnt and unburnt KZNSS patches in Roosfontein, Silverglen, New Germany and Krantzklouf Nature Reserves located in the eThekweni Municipal Area. Nature reserves are arranged from most to least porous.

Table 5.1: Jaccard's similarity index of grass and forbs species in burnt and unburnt KZNSS patches in nature reserves located in the eThekweni Municipal Area

| Reserves (Burnt and Unburnt) | Grasses | Forbs |
|------------------------------|---------|-------|
|                              | %       | %     |
| Roosfontein                  | 56      | 23    |
| Silverglen                   | 25      | 28    |
| New Germany                  | 40      | 37    |
| Krantzkloof                  | 40      | 11    |
| Overall                      | 56      | 33    |

### 5.3.2. Richness, evenness and diversity

Species richness (Table 5.2), evenness (Table 5.3), and diversity (Table 5.4) were significantly different between the four nature reserves except for overall plant species richness. Grass species richness was greatest in Krantzkloof Nature Reserve while forb species richness was greatest in Silverglen (Figure 5.7). For grass species evenness, Roosfontein had the greatest while Silverglen had a high evenness for forb species and overall plant species only (Figure 5.7). New Germany Nature Reserve had the greatest species diversity for grasses and overall plant species. Forb species diversity on the other hand was greater in Silverglen (Figure 5.7). The effect of fire history was not significant (Tables 5.2, 5.3, 5.4). However, there was only an interaction (nature reserve and fire history) effect for grass species richness (Table 5.5). In New Germany and Roosfontein, the grass species richness was high in the unburnt patches while in Krantzkloof and Silverglen it was high in the burnt patches (Table 5.5).

Table 5.2: Two-way ANOVA statistics for species richness of grasses, forbs, and overall plant species. Numbers in bold indicate statistical significance

|                          | d.f. | Grasses |                  | Forbs |              | Overall |       |
|--------------------------|------|---------|------------------|-------|--------------|---------|-------|
|                          |      | F       | P                | F     | P            | F       | P     |
| <b>Reserve (R)</b>       | 3    | 11.353  | <b>&lt;0.001</b> | 4.401 | <b>0.013</b> | 1.610   | 0.213 |
| <b>Fire (F)</b>          | 1    | 0.529   | 0.474            | 2.312 | 0.141        | 0.780   | 0.386 |
| <b>Interaction (R*F)</b> | 3    | 4.294   | <b>0.015</b>     | 1.599 | 0.216        | 0.650   | 0.590 |
| <b>Error</b>             | 24   |         |                  |       |              |         |       |
| <b>Total</b>             | 31   |         |                  |       |              |         |       |

Table 5.3: Two-way ANOVA statistics for species evenness of grasses and overall plant species and GLM results for forb species evenness. Numbers in bold indicate statistical significance

|                          | d.f. | Grasses |              | Forbs    |                  | Overall |              |
|--------------------------|------|---------|--------------|----------|------------------|---------|--------------|
|                          |      | F       | P            | $\chi^2$ | P                | F       | P            |
| <b>Reserve (R)</b>       | 3    | 6.550   | <b>0.002</b> | 17.304   | <b>&lt;0.001</b> | 4.534   | <b>0.012</b> |
| <b>Fire (F)</b>          | 1    | 0.015   | 0.904        | 3.592    | 0.058            | 3.010   | 0.096        |
| <b>Interaction (R*F)</b> | 3    | 0.418   | 0.742        | 1.454    | 0.693            | 0.747   | 0.535        |
| <b>Error</b>             | 24   |         |              |          |                  |         |              |
| <b>Total</b>             | 31   |         |              |          |                  |         |              |

Table 5.4: Two-way ANOVA statistics for species diversity of grasses, forbs, and overall plant species. Numbers in bold indicate statistical significance

|                          | d.f. | Grasses |              | Forbs  |                  | Overall |              |
|--------------------------|------|---------|--------------|--------|------------------|---------|--------------|
|                          |      | F       | P            | F      | P                | F       | P            |
| <b>Reserve (R)</b>       | 3    | 5.383   | <b>0.006</b> | 10.563 | <b>&lt;0.001</b> | 3.074   | <b>0.047</b> |
| <b>Fire (F)</b>          | 1    | 0.546   | 0.467        | 0.007  | 0.934            | 0.268   | 0.609        |
| <b>Interaction (R*F)</b> | 3    | 2.001   | 0.141        | 1.334  | 0.287            | 0.484   | 0.696        |
| <b>Error</b>             | 24   |         |              |        |                  |         |              |
| <b>Total</b>             | 31   |         |              |        |                  |         |              |

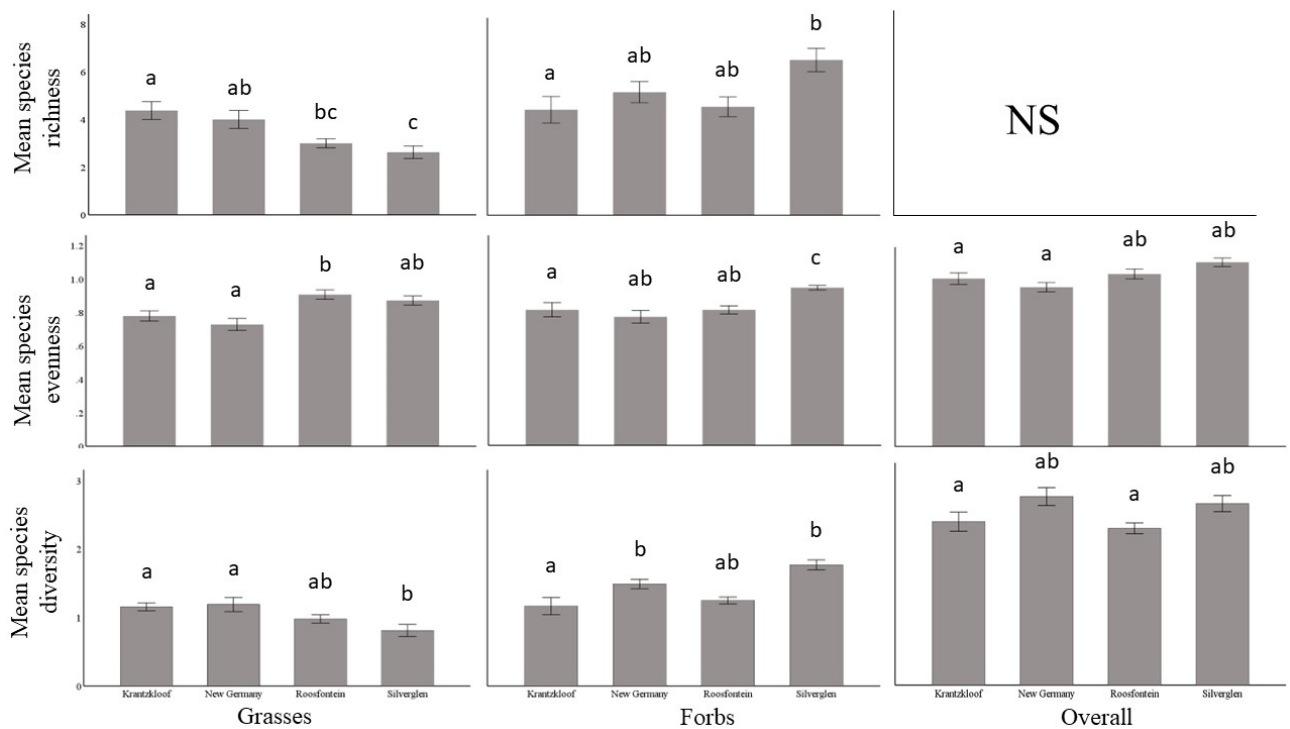


Figure 5.6: Mean ( $\pm$  SE) species richness, evenness, and species diversity of grasses, forbs, and

overall plant species in Krantzkloof, New Germany, Roosfontein, and Silverglen Nature Reserves. Bars with letters in common are not different.

Table 5.5: Mean ( $\pm$  SE) species richness, evenness, and species diversity of grasses, forbs, and overall plant species in burnt and unburnt KZNSS patches in Krantzkloof, New Germany, Roosfontein and Silverglen Nature Reserve. Numbers in bold indicate statistical significance

| Index            |                | Krantzkloof                      |                                  | New Germany                      |                                  | Roosfontein                          |                                  | Silverglen                           |                                     |
|------------------|----------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|--------------------------------------|----------------------------------|--------------------------------------|-------------------------------------|
|                  |                | <i>Burnt</i>                     | <i>Unburnt</i>                   | <i>Burnt</i>                     | <i>Unburnt</i>                   | <i>Burnt</i>                         | <i>Unburnt</i>                   | <i>Burnt</i>                         | <i>Unburnt</i>                      |
| <b>Richness</b>  | <i>Grasses</i> | <b>5 <math>\pm</math> 1.155a</b> | <b>3.75</b> $\pm$ <b>0.500bd</b> | <b>3.25</b> $\pm$ <b>0.500be</b> | <b>4.75</b> $\pm$ <b>0.957ad</b> | <b>2.75 <math>\pm</math> 0.500ce</b> | <b>3.25</b> $\pm$ <b>0.500cd</b> | <b>2.75 <math>\pm</math> 0.957ce</b> | <b>2.50 <math>\pm</math> 0.577c</b> |
|                  | <i>Forbs</i>   | 4 $\pm$ 1.414                    | 5 $\pm$ 1.826                    | 5.75 $\pm$ 1.708                 | 4.75 $\pm$ 0.500                 | 5.5 $\pm$ 1.00                       | 3.75 $\pm$ 0.500                 | 7.25 $\pm$ 1.258                     | 6 $\pm$ 1.414                       |
|                  | <i>Overall</i> | 9 $\pm$ 2.160                    | 9 $\pm$ 1.826                    | 9 $\pm$ 2.160                    | 9.5 $\pm$ 1.00                   | 8.25 $\pm$ 1.258                     | 7.25 $\pm$ 0.500                 | 10 $\pm$ 1.414                       | 8.5 $\pm$ 1.732                     |
| <b>Evenness</b>  | <i>Grasses</i> | 0.78 $\pm$ 0.053                 | 0.779 $\pm$ 0.121                | 0.739 $\pm$ 0.106                | 0.718 $\pm$ 0.112                | 0.875 $\pm$ 0.091                    | 0.939 $\pm$ 0.059                | 0.88 $\pm$ 0.050                     | 0.859 $\pm$ 0.103                   |
|                  | <i>Forbs</i>   | 0.78 $\pm$ 0.133                 | 0.85 $\pm$ 0.115                 | 0.771 $\pm$ 0.130                | 0.773 $\pm$ 0.108                | 0.768 $\pm$ 0.028                    | 0.863 $\pm$ 0.065                | 0.92 $\pm$ 0.037                     | 0.976 $\pm$ 0.011                   |
|                  | <i>Overall</i> | 1.04 $\pm$ 0.076                 | 1.092 $\pm$ 0.130                | 0.997 $\pm$ 0.095                | 1.021 $\pm$ 0.086                | 1.029 $\pm$ 0.074                    | 1.156 $\pm$ 0.053                | 1.164 $\pm$ 0.101                    | 1.170 $\pm$ 0.042                   |
| <b>Diversity</b> | <i>Grasses</i> | 1.23 $\pm$ 0.131                 | 1.080 $\pm$ 0.168                | 1.065 $\pm$ 0.197                | 1.316 $\pm$ 0.338                | 0.866 $\pm$ 0.164                    | 1.094 $\pm$ 0.067                | 0.863 $\pm$ 0.324                    | 0.761 $\pm$ 0.172                   |
|                  | <i>Forbs</i>   | 1.019 $\pm$ 0.34                 | 1.314 $\pm$ 0.334                | 1.528 $\pm$ 0.265                | 1.453 $\pm$ 0.113                | 1.303 $\pm$ 0.173                    | 1.196 $\pm$ 0.090                | 1.812 $\pm$ 0.160                    | 1.726 $\pm$ 0.263                   |
|                  | <i>Overall</i> | 2.25 $\pm$ 0.353                 | 2.394 $\pm$ 0.458                | 2.593 $\pm$ 0.437                | 2.769 $\pm$ 0.300                | 2.168 $\pm$ 0.280                    | 2.290 $\pm$ 0.147                | 2.674 $\pm$ 0.353                    | 2.487 $\pm$ 0.312                   |

### 5.3.3. Veld condition assessment

All nature reserves had low veld condition scores, with the exception of Silverglen which had a score of 92.78% for unburnt patches and 75% for burnt patches. The veld condition scores were higher for the unburnt patches in three of the four reserves, namely Silverglen, New Germany, and Roosfontein. The proportion of decreaser species in the burnt and unburnt patches in the reserves were lower than that of the benchmark (28%), except for Silverglen which had 56.5% decreaser species in the burnt patches and 79.5% in the unburnt patches. Both the burnt and unburnt patches had lower basal cover than that of the benchmark (14%) (Table 5.6).

Table 5.6: Veld condition analysis table for burnt and unburnt KZNSS patches in Silverglen, New Germany, Roosfontein, and Krantzkloof Nature Reserves

|   | <b>Benchmark</b> | <b>Silverglen</b> |                | <b>New Germany</b> |                | <b>Roosfontein</b> |                | <b>Krantzkloof</b> |                |
|---|------------------|-------------------|----------------|--------------------|----------------|--------------------|----------------|--------------------|----------------|
|   |                  | <i>Burnt</i>      | <i>Unburnt</i> | <i>Burnt</i>       | <i>Unburnt</i> | <i>Burnt</i>       | <i>Unburnt</i> | <i>Burnt</i>       | <i>Unburnt</i> |
| <b>% Decreaser</b>                        | 28               | 56.5              | 79.5           | 11.5               | 9.5            | 15                 | 15             | 18.5               | 7              |
| <b>% Increaser I</b>                      | 45               | 3                 | 0              | 0.5                | 1.5            | 3                  | 7              | 5                  | 5              |
| <b>% Increaser IIa</b>                    | 7                | 0                 | 0              | 1.5                | 7.5            | 3                  | 0              | 0.5                | 0              |
| <b>% Increaser IIb</b>                    | 12               | 2                 | 0              | 7                  | 17.5           | 1                  | 1              | 4.5                | 13             |
| <b>% Increaser IIc</b>                    | 5                | 34                | 17.5           | 25.5               | 33.5           | 21.5               | 11             | 22.5               | 17.5           |
| <b>% Increaser III</b>                    | 3                | 2.5               | 2.5            | 26.5               | 29.5           | 31.5               | 19             | 48                 | 44             |
| <b>Site score</b>                         | 658              | 493.5             | 610.5          | 188.5              | 224            | 137                | 183.5          | 176                | 160.5          |
| <b>Veld condition score (%)</b>           | 100              | 75                | 92.78          | 28.65              | 34.04          | 20.82              | 27.89          | 26.75              | 24.39          |
| <b>Basal cover (%)</b>                    | 14               | 11.87             | 10.34          | 11.17              | 13.84          | 12.23              | 12.28          | 11.10              | 8.47           |
| <b>Potential grazing capacity (AU/ha)</b> |                  | 2.7               | 2.7            | 2.7                | 2.7            | 2.7                | 2.7            | 2.7                | 2.7            |
| <b>Current grazing capacity (AU/ha)</b>   |                  | 1.56              | 1.55           | 1.20               | 1.34           | 1.21               | 1.26           | 1.18               | 0.86           |

### 5.3.4. Tree Density

The trend observed for tree density in the KZNSS patches differed significantly between nature reserves, but there was no significant effect of fire history or interaction (Table 5.7). The overall

average tree density was 128 trees/ha for all the nature reserves. Silverglen Nature Reserve had the greatest tree density while Krantzkloof had the least (Figure 5.8).

Table 5.7: Two-way ANOVA statistics for tree density in burnt and unburnt KZNSS remnants in eThekweni nature reserves. Numbers in bold indicate statistical significance

|                          | d.f. | F     | P            |
|--------------------------|------|-------|--------------|
| <b>Reserve (R)</b>       | 3    | 5.458 | <b>0.025</b> |
| <b>Fire (F)</b>          | 1    | 0.125 | 0.733        |
| <b>Interaction (R*F)</b> | 3    | 0.792 | 0.532        |
| <b>Error</b>             | 8    |       |              |
| <b>Total</b>             | 15   |       |              |

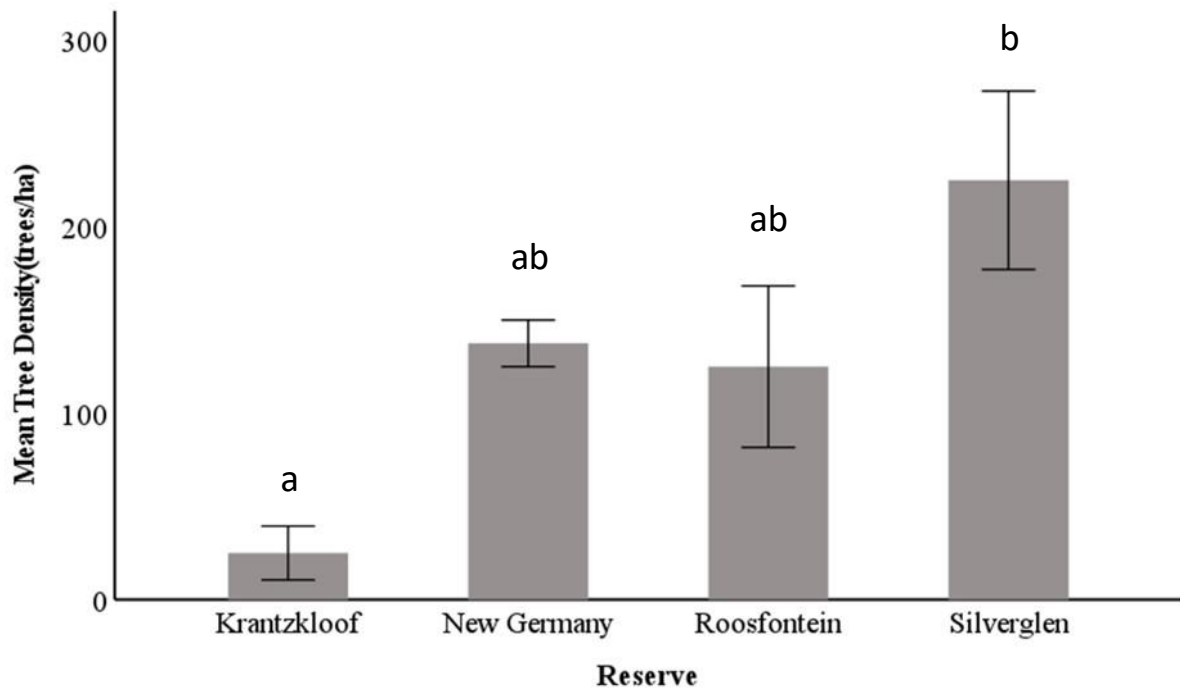


Figure 5.7: Mean tree density (trees/ha) ( $\pm$  SE) in KZNSS patches in Krantzkloof, New Germany, Roosfontein, and Silverglen Nature Reserves. Bars with letters in common are not different.

#### 5.4. Discussion

While grasses characterise a grassland and determine its distinct structural characteristics, many non-grass plant species of different life forms, including geophytes, herbaceous dicots,

and non-graminoid monocots (collectively called forbs), have coexisted and coevolved with grass species in tropical and subtropical grasslands around the world (Morris and Scott-Shaw, 2019). In South African mesic grasslands, like the KZNSS, there is a diverse population of forbs and they usually outnumber the grass species found in these grassland systems. Naturally, this was the case for all of the study sites that were sampled. Large underground storage organs and quick flowering after fires enable many of the forb species found in the KZNSS to avoid competing with grasses (Boon et al., 2016). *Helichrysum nudifolium* and *Gerbera ambigua*, both from the Asteraceae family, dominated both burnt and unburnt study areas. The dominance of Asteraceae in the KZNSS has been documented before (Muller et al., 2021). This can be attributed to the regenerative traits of Asteraceae, which enable this family to be more resistant to disturbance than other forb families (Muller et al., 2021).

A trend of dominance of *Aristida junciformis* was also observed in both the burnt and unburnt sites. The dominance of *A. junciformis* has been documented in a large proportion of mesic grasslands, particularly in KwaZulu-Natal's south-eastern coastal hinterland and mistbelt (Wiseman et al., 2002). This grass species typically dominates after palatable species, such as *Themeda triandra*, decrease as a result of selective grazing (Tainton, 1972). *Aristida junciformis* contributed significant cover, especially in the unburnt study sites. This species can effectively invade grasslands that have been left unburnt for an extended period, mainly due to its thin, pointed leaves which enable it to pierce through the dense layer of moribund biomass (SA Forestry, 2024). *Aristida junciformis* is highly unpalatable and only produces minimal forage following a burn so its invasion indicates grassland degradation (Tainton, 1972).

The similarity index showed grass and forb species turnover between burnt and unburnt patches in the nature reserves, with the number of shared species being lower. In grasslands edaphic variation and disturbances such as fire are known to have an apparent impact on plant species occurrence (Collins and Calabrese, 2012). Fire is a significant driver of variation and species

occurrence in plant communities due to its impact on the availability of resources and competitive interactions of plant species (Alba et al., 2015). The average fire-return interval, as well as the seasonality and intensity of fire, are the primary components of a fire regime that significantly influence environmental heterogeneity (Gordijn and O'Connor, 2021). This explains the low similarity indices that were observed between the burnt and unburnt sites. However, this species turnover can be attributed to the spatial or temporal distance between samples, in this case, the burnt and unburnt sites, as highlighted by McGlenn and Palmer (2011). Additionally, it was evident that the unique forb species found in the burnt and unburnt patches for all the reserves was relatively high. This implies that the fire-dependent species present in the burnt patches were replaced by the fire-independent species in the unburnt patches.

The relationship between fire and plant species richness, evenness, and especially diversity is well documented and researched (Burkle et al., 2015; Silva et al., 2013; Uys et al., 2004). Fire affects plant species differently and this impacts the plant species richness, evenness, and diversity in an area. For instance, it promotes the production of tillers for certain grasses, such as *Themeda triandra* (Strong et al., 2013). This is evident in the findings of this study, as *T. triandra* was more common in the burnt patches of the nature reserves. Fire also promotes the resprouting of some forb species and in the absence of fire, forbs generally decrease in numbers in grasslands (Chamane et al., 2017). The Asteraceae family were the most common resprouters found in the study areas and were more dominant in the burnt patches. Cyperaceae (sedges) family, which are resprouters, were also more dominant in the burnt patches. Overall, the findings suggested that fire had no effect on the evenness, richness, and diversity of plant species in the burnt and unburnt KZNSS patches in the sampled nature reserves. This is similar to a study done by Munyai et al. (2023) where there was no significant effect of fire on these variables in burnt and unburnt sites in mountainous grassland at Mountain Zebra National Park, Eastern Cape, South Africa. However, as observed in our study, there was species turnover that

was identified by the Jaccard similarity index for both the grasses and forbs. Unique species were observed in the burnt and unburnt patches, and this was particularly pronounced for the forbs, but the diversity indices do not pick up these species turnover.

Climatic factors and the local conditions of the sites (Yeboah et al., 2016) may have also influenced these findings as it was apparent that plant species evenness, richness, and diversity were significantly different between the four reserves. Elevation can be another factor that influences plant species richness, evenness, and diversity. Dorji et al. (2014) highlighted that the primary underlying factors influencing spatial variation in these plant community properties are changes in temperature and the availability of water along elevation gradients. Lastly, the porosity (level of fencing/ how secure the area is) of the nature reserves plays a role in the richness, evenness, and diversity observed in these sites. It was observed that grass richness, evenness, and diversity were usually higher in the less porous reserves while forb richness, evenness, and diversity were highest in one of the most porous reserves, Silverglen Nature Reserve. Silverglen had people and vehicles constantly passing through. Therefore, it experienced more disturbance than the other reserves, strongly influencing the observed trend. This disturbed the soil, encouraging forb, weed establishment, and growth (Fulbright, 2004).

The veld condition assessment indicated that the proportion of decreaser species in both the burnt and unburnt patches in most of the nature reserves was lower than that of the benchmark implying that some palatable species in these sites have been depleted. However, this was not the case for Silverglen as the proportion of decreaser species was higher than the benchmark for both the burnt and unburnt patches. Occurrences of overgrazing are also evident as the proportion of increaser IIc species in all of our sample sites is much higher than that of the benchmark site. This further explains the loss of palatable species and the high abundance of forb species observed. Additionally, the high abundance of increaser III species in the sample sites, excluding Silverglen, suggests that some level of selective grazing is occurring in the

sites. This selective grazing observed in the burnt and unburnt sample sites had an impact on the composition of the species found in these patches and further promoted the encroachment of unpalatable species (Tainton, 1972). The significant abundance of *A. junciformis* in the patches demonstrates this. The low veld condition scores calculated for the burnt and unburnt patches of the nature reserves suggest that the patches are not in good condition, which deviates from the predicted outcome of the burnt patches being in a relatively good condition as compared to the unburnt patches. Silverglen however, had high veld condition scores for both the burnt and unburnt patches and this was due to the high proportion of decreaser species in the reserve.

Variations in soil and local climatic conditions could be factors that influenced the veld condition. Precipitation is a primary documented climatic factor that has an impact on veld condition (Peel et al., 1991). The veld condition significantly decreases when there are low levels of precipitation as this results in decreased biomass production and increased susceptibility to overgrazing (Mamayo, 2018). However, the precipitation was fairly similar between the nature reserves. Additionally, the results obtained could be influenced by the VCA method used. The method used for a VCA needs to be improved consistently so that it is effective and not outdated (Mentis, 1983). The benchmark used could also affect the results as the benchmark site may have been sampled during a different season (Morokong, 2016).

Fire regulates species dominance and tree density in ecosystems that are both fire-dependent and fire-adapted (Hood et al., 2018). However, in these burnt and unburnt patches of the fire-dependent KZNSS fire did not have a significant effect on tree density. When it comes to the relationship between fire and tree density. Giddey et al. (2022) highlighted that it may be fire intensity that impacts tree density, not fire frequency. Additionally, it was observed that the nature reserves, like the specific location and local conditions of each reserve, affected tree density. Tree density is influenced by a wide range of factors, such as the amount of light, air

temperature, soil moisture, and nutrients (Brown and Fredericksen, 2008). These factors are frequently associated with topographic characteristics such as aspect, slope position, inclination, and elevation (Brown and Fredericksen, 2008). It can be inferred that the specific local and topographic characteristics of the nature reserves had more of an impact on tree density than fire.

## **5.5. Conclusion**

Spatial differences and specific local conditions between the nature reserves had a greater influence on the species composition, richness, evenness, and diversity in the study sites. This was also the case for tree density. The effect of fire was insignificant, deviating from the study's hypotheses and predictions. This could be an indication that the fire management practices in the nature reserves need to be revised and updated. It was evident from the fire records and fire mapping that the intervals between burning were not consistent, some reserves would go years without any fire being applied. This influenced the dominance of unpalatable species such as *A. junciformis* and poor veld condition that were observed in the nature reserves. It was also observed that the grassland plant communities remained similar between the different fire regimes which could also lead to the inference that the KZNSS grassland is adapted to a flexible fire regime, which is an accurate representation of how fire is in the natural environment. In nature fire is flexible and does not follow a fixed fire regime or frequency.

## **References**

Adam, Y., 2016. The role of remote sensing in invasive alien plant species detection and the assessment of removal programs in two selected reserves in the eThekweni

- Municipality, KwaZulu-Natal Province. PhD Thesis, University of KwaZulu-Natal, Durban.
- Alba, C., Skálová, H., McGregor, K.F., D'Antonio, C., Pyšek, P., 2015. Native and exotic plant species respond differently to wildfire and prescribed fire as revealed by meta-analysis. *Journal of Vegetation Science* 26, 102-113.
- Beaumont, S.N., 2021. Development and application of novel ornithological survey methods for the detection of cryptic avian indicator species that predict grassland health. MSc Thesis, University of KwaZulu-Natal, Pietermaritzburg.
- Boon, R., Cockburn, J., Govender, N., Ground, L., Slotow, R., Mclean, C., Douwes, E., Rouget, M., Roberts, D., 2016. Managing a threatened savanna ecosystem (KwaZulu-Natal Sandstone Sourveld) in an urban biodiversity hotspot: Durban, South Africa. *Bothalia-African Biodiversity & Conservation* 46, 1-12.
- Brown, R.C., Fredericksen, T.S., 2008. Topographic factors affecting the tree species composition of forests in the upper Piedmont of Virginia. *Virginia Journal of Science* 59(1), 1-9.
- Burkle, L.A., Myers, J.A., Belote, R.T., 2015. Wildfire disturbance and productivity as drivers of plant species diversity across spatial scales. *Ecosphere* 6, 1-14.
- Chamane, S., Kirkman, K.P., Morris, C., O'Connor, T., 2017. What are the long-term effects of high-density, short-duration stocking on the soils and vegetation of mesic grassland in South Africa? *African Journal of Range & Forage Science* 34, 111-121.
- Collins, S.L., Calabrese, L.B., 2012. Effects of fire, grazing and topographic variation on vegetation structure in tallgrass prairie. *Journal of Vegetation Science* 23, 563-575.
- Dorji, T., Moe, S.R., Klein, J.A., Totland, Ø., 2014. Plant species richness, evenness, and composition along environmental gradients in an alpine meadow grazing ecosystem in central Tibet, China. *Arctic, Antarctic, and Alpine Research* 46, 308-326.

- Driscoll, D.A., Lindenmayer, D.B., Bennett, A.F., Bode, M., Bradstock, R.A., Cary, G.J., Clarke, M.F., Dexter, N., Fensham, R., Friend, G., 2010. Fire management for biodiversity conservation: key research questions and our capacity to answer them. *Biological conservation* 143, 1928-1939.
- Drury, C.C., 2016. A biogeographic study of the KwaZulu-Natal sandstone sourveld patches within the eThekweni Municipal Area. PhD Thesis, University of KwaZulu-Natal, Westville.
- Duggan, A., Hocking, A., 1990. Reader's Digest illustrated guide to the game parks and nature reserves of southern Africa. Reader's Digest Association.
- Duluth, U.o.M., 2023. Online at: <https://wormwatch.d.umn.edu/research/research-methods/sampling-trees>. (accessed October 2023).
- Fleming, P.J., Ballard, G., Reid, N.C., Tracey, J.P., 2017. Invasive species and their impacts on agri-ecosystems: issues and solutions for restoring ecosystem processes. *The Rangeland Journal* 39, 523-535.
- Forrestel, E.J., Donoghue, M.J., Smith, M.D., 2014. Convergent phylogenetic and functional responses to altered fire regimes in mesic savanna grasslands of North America and South Africa. *New Phytologist* 203, 1000-1011.
- Fulbright, T.E., 2004. Disturbance effects on species richness of herbaceous plants in a semi-arid habitat. *Journal of Arid Environments* 58, 119-133.
- Galizia, L.F.d.C., Rodrigues, M., 2019. Modeling the influence of eucalypt plantation on wildfire occurrence in the Brazilian savanna biome. *Forests* 10, 1-19.
- Ghebrehiwot, H.M., Kulkarni, M.G., Kirkman, K.P., Van Staden, J., 2009. Smoke solutions and temperature influence the germination and seedling growth of South African mesic grassland species. *Rangeland Ecology & Management* 62, 572-578.

- Giddey, B.L., Baard, J.A., Kraaij, T., 2022. Fire severity and tree size affect post-fire survival of Afrotropical forest trees. *Fire Ecology* 18(5), 1-13.
- Gordijn, P.J., O'Connor, T.G., 2021. Multidecadal effects of fire in a grassland biodiversity hotspot: Does pyrodiversity enhance plant diversity? *Ecological Applications* 31(6), 1-19.
- Heydari, R., Zobeyri, M., Namiranian, M., Sobhani, H., Safari, A., 2011. Study of accuracy of nearest individual sampling method in Zagross forests. *Iranian Journal of Forest* 2(4), 323-330.
- Hood, S.M., Varner, J.M., Van Mantgem, P., Cansler, C.A., 2018. Fire and tree death: understanding and improving modeling of fire-induced tree mortality. *Environmental Research Letters* 13, 1-17.
- Househam, S., 2017. The use of fire in the KwaZulu-Natal mistbelt and highland sourveld. Department of Agriculture and Rural Development. Agricultural Livestock Research Services Grass & Forage Scientific Research Services, Kokstad. 1-4.
- Humphrey, G.J., Gillson, L., Ziervogel, G., 2021. How changing fire management policies affect fire seasonality and livelihoods. *Ambio* 50, 475-491.
- Magazine, S.F.O., 2024. Paperjetstudios. Online at: <https://saforestryonline.co.za/articles/%EF%BB%BF%EF%BB%BFmanaging-fire-in-natural-grasslands/> (accessed February 2024).
- Makhaya, Z., 2021. The influence of bioclimatic and topographic variables on fire occurrence and frequency within the Ethekwini Municipal Area. MSc Thesis, University of KwaZulu-Natal, Pietermaritzburg..
- Mamayo, N., 2018. Optimal spatial and temporal utilisation of grassland resources for extensive livestock production. University of KwaZulu-Natal, Pietermaritzburg.

- Map, O.G., 2013. Durban eThekweni Municipality South Africa. Online at: <https://www.opengreenmap.org/greenmap/durban-ethekweni-municipality-south-africa/roosfontein-nature-reserve-25073>. (accessed September 2023).
- Marimuthoo, D., 2009. Silverglen Nature Reserve. *Veld & Flora* 95, 156-157.
- Mashele, S., Singh, K., 2022. GIS investigation of the fire history of Jonkershoek Nature Reserve. *South African Journal of Geomatics* 11, 189-201.
- McGlenn, D.J., Palmer, M., 2011. Quantifying the influence of environmental texture on the rate of species turnover: evidence from two habitats. *Plant Ecology* 212, 495-506.
- McLean, C., Ground, L., Boon, R., Roberts, D., Govender, N., McInnes, A., Botes, W., Allan, D., Ivins, J., 2016. Durban's systematic conservation assessment. Environmental Planning and Climate Protection Department: Durban, South Africa.
- Mentis, M., 1983. Towards objective veld condition assessment. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa* 18, 77-80.
- Morokong, T., 2016. Sustainable options in communal beef cattle grazing systems in the Matatiele Local Municipality of the Eastern Cape, South Africa. PhD Thesis, Stellenbosch University, Stellenbosch.
- Morris, C.D., Scott-Shaw, R., 2019. Potential grazing indicator forbs for two mesic grasslands in South Africa. *Ecological Indicators* 107, 1-11.
- Muller, M., Siebert, S., Ntloko, B., Siebert, F., 2021. A floristic assessment of grassland diversity loss in South Africa. *Bothalia-African Biodiversity & Conservation* 51, 1-9.
- Munyai, N., Ramoelo, A., Adelabu, S., Bezuidenhout, H., 2023. The influence of fire presence and absence on grass species composition and species richness at Mountain Zebra National Park. *KOEDOE-African Protected Area Conservation and Science* 65, 1-7.

- Nieman, W.A., Van Wilgen, B.W., Leslie, A.J., 2021. A review of fire management practices in African savanna-protected areas. *KOEDOE-African Protected Area Conservation and Science* 63, 1-13.
- Nsele, N.W., 2019. Synergistic effects of plant extracts and penicillins on staphylococcus and enterococcus faecalis. PhD Thesis, Durban University of Technology.
- Peel, M., Grossman, D., Van Rooyen, N., 1991. Determinants of herbaceous plant species composition on a number of ranches in the north-western Transvaal. *Journal of the Grassland Society of southern Africa* 8, 99-102.
- Reserve, K.N., 2023. Ezemvelo KZN Wildlife. Online at: <https://kknr.org.za/flora-and-fauna/> (accessed September 2023).
- Riggs, G., Hall, D., 2020. Continuity of MODIS and VIIRS snow cover extent data products for development of an earth science data record. *Remote sensing* 12, 1-20.
- Rouget, M., Buthelezi, N.L., Sibanda, M., Mutanga, O., 2016. A spatial and temporal assessment of fire regimes on different vegetation types using MODIS burnt area products. *Bothalia-African Biodiversity & Conservation* 46, 1-9.
- SA-Venues, 2023. Online at: <https://www.sa-venues.com/attractionskzn/new-germany-nature-reserve.php>. (accessed September 2023).
- Silva, L.C., Hoffmann, W.A., Rossatto, D.R., Haridasan, M., Franco, A.C., Horwath, W.R., 2013. Can savannas become forests? A coupled analysis of nutrient stocks and fire thresholds in central Brazil. *Plant and Soil* 373, 829-842.
- Smith, B., Wilson, J.B., 1996. A consumer's guide to evenness indices. *Oikos*, 70-82.
- Strong, D.J., Ganguli, A.C., Vermeire, L.T., 2013. Fire effects on basal area, tiller production, and mortality of the C 4 bunchgrass, purple threeawn. *Fire Ecology* 9, 89-99.

- Tainton, N., 1972. The relative contribution of overstocking and selective grazing to the degeneration of tall grassveld in Natal. Proceedings of the Annual Congresses of the Grassland Society of Southern Africa 7, 39-43.
- Trollope, W., Potgieter, A., Zambatis, N., 1989. Assessing veld condition in the Kruger National Park using key grass species. Koedoe 32, 67-93.
- Uys, R.G., 2000. The effects of different burning regimes on grassland phytodiversity. MSc Thesis, University of Cape Town, Cape Town.
- Uys, R.G., Bond, W.J., Everson, T.M., 2004. The effect of different fire regimes on plant diversity in southern African grasslands. Biological conservation 118, 489-499.
- Wiseman, R., Morris, C., Granger, J., 2002. Effects of pre-planting treatments on the initial establishment success of indigenous grass seedlings planted into a degraded *Aristida junciformis*-dominated grassland. South African journal of botany 68, 362-369.
- Yeboah, D., Chen, H.Y., Kingston, S., 2016. Tree species richness decreases while species evenness increases with disturbance frequency in a natural boreal forest landscape. Ecology and evolution 6, 842-850.
- Zungu, M.M., Maseko, M.S., Kalle, R., Ramesh, T., Downs, C.T., 2020. Effects of landscape context on mammal richness in the urban forest mosaic of EThekweni Municipality, Durban, South Africa. Global Ecology and Conservation 21, 1-13.

## Chapter 6

### Synthesis and Recommendations

#### 6.1. Synthesis

Both fire and land use have a major influence on South African grasslands playing a significant role in determining the composition, structure, and biodiversity of these ecosystems (O'Connor and Kuyler, 2009). South African grasslands offer vital functions like carbon sequestration, cattle grazing, and habitat for a variety of wildlife species (Bengtsson et al., 2019). However, anthropogenic actions such as changes in land use and fire management have affected these ecosystems in positive and negative ways. Changes in land use and fire are major drivers of changes in the natural environment, which need to be accurately quantified to understand their effects.

This study investigated burnt and unburnt KwaZulu-Natal Sandstone Sourveld (KZNSS) grassland patches in protected and communal agricultural areas in the eThekweni Municipal region to quantify and understand the impacts of land use and fire. The KZNSS was the focus of the investigation because of it is unique to the province of KwaZulu-Natal and it is one of the most species rich ecosystems in the province. It is critically endangered and drastically under-researched and -conserved, which was another motivation for this study.

Chapter 3 focused broadly on documenting the 20-year fire history of the KZNSS within eThekweni. The percentage of the protected and communal agricultural grassland patches that burned annually, the frequency of fires, and the season of burning were recorded. The fire history showed that burning occurred predominantly in the winter months for both protected and communal agricultural areas, which is typical for South African mesic grasslands as the sward is dry and flammable (Househam, 2017). The fire history showed that over the last 20 years, the fire frequency differed by land use, with communal agricultural areas having a higher

fire frequency than protected areas overall. Communal agricultural areas are not access-controlled and are essentially for the use of the whole community, while nature reserves are fenced and less accessible so as to conserve the wildlife and plant communities present. Communal agricultural areas would therefore experience more instances of uncontrolled or unplanned burns and did not have a formal burning plan, unlike protected areas that have more formalized fire management practices in place (Pereira et al., 2012). Despite these differences in fire frequency, the percentage area burnt in protected areas and communal agricultural areas exhibited a similar trend. A decrease in the total area burnt was observed for both protected areas and communal agricultural areas in more recent years. This can be directly linked to the increase in urbanisation which saw more built-up areas being constructed in areas that were grassland patches. With this increase in urbanisation, came an increase in the demand for space for industries and residential areas (Zhang, 2016). This increase in urbanisation can also be linked back to fire frequency as this can alter the fire regime of grasslands. Urbanisation changes the overall behaviour of fire in these ecosystems, as well as the frequency and intensity of fires (Price and Bradstock, 2014). Restrictions on prescribed burns, or controlled fires, on adjacent grasslands are common in urban areas which alters the fire frequency.

In chapter 4, the effect of fire and land use on plant species composition and vegetation structure in KZNSS grassland remnants was examined. This chapter focused on specific nature reserves and communal agricultural areas within KZNSS patches in the eThekweni region. The findings showed that land use was a more important driver for plant species richness, evenness, and diversity than fire or their interaction. Land use directly impacts the landscape through habitat destruction, fragmentation, and changes in ecological processes. Therefore, it tends to be a more dominant and long-lasting driver of plant species richness, evenness, and diversity than fire (Hermosilla-Palma et al., 2021). Although fire is crucial in shaping grassland plant communities, changes in land use frequently result in more extensive and lasting disturbances.

This study also determined that the communal agricultural areas had the greatest plant species richness, evenness, and diversity. This could have been as a result of various reasons, but this study focussed on the fire frequency. It was evident from the fire history data, which was thoroughly investigated in chapter 3, that communal areas had more frequent fires than nature reserves. However, although there were no significant effects of fire in the analysis, we believe that (due to the findings in chapter 3) fire and land use are so closely interlinked that it is difficult to separate these effects. Since the KZNSS is a fire-dependent system, the richness and diversity of fire-dependent species, particularly forbs which were more abundant than grasses, increases with the rise in fire frequency.

The veld conditions of the protected and communal agricultural areas were also investigated. The poor veld condition scores obtained from the VCA reflected the species composition and veld management of the burnt and unburnt protected and communal agricultural areas. However, protected areas had a slightly greater veld condition score than communal agricultural areas. This can be attributed to their differing grazing pressures as although protected areas have low grazing pressure, they burn less frequently (chapter 3) while communal areas burn more frequently (chapter 3) but have higher grazing pressure. Additionally, protected areas will also have a greater proportion of decreaser species because of the lower grazing pressure resulting in a higher veld condition score.

Chapter 5 focuses on fire. It investigates the effect of long-term burning history on species composition and vegetation structure in the KZNSS grassland patches in the protected areas only. The component of land use is removed in order to focus on the impacts of fire alone. The findings from this chapter further justify the results from the previous chapter as it was determined that fire did not have an overriding effect on plant species richness, evenness, and diversity. However, there was an interaction (nature reserve and fire history) effect for grass species richness, confirming that land use is a significant driver of plant species richness in

these grassland patches. The veld condition scores were similar to the scores obtained in the previous chapter. They differed between the nature reserves with all of the reserves having a poor score except for New Germany, which had the highest score for both burnt and unburnt patches. These findings are linked to the grazing pressure and fire management observed in reserves as discussed in chapter 4. Additionally, tree density was investigated, and it was found that fire also did not have much of an effect. This may be a result of the infrequent fires that were observed in nature reserves (Chapter 3). The nature reserves were burnt between two and five times over 20-year period that was investigated. It was observed that reserve had a main effect on tree density. Therefore, factors such as the local conditions of the nature reserves could have also had more of a significant impact on tree density than fire. Factors such as air temperature, soil moisture and nutrients have been documented to have an impact on tree density (Brown and Fredericksen, 2008).

## **6.2. Recommendations**

There are a number of recommendations that can be made from this study, particularly for fire management. The findings from this study highlighted that land use had a significant impact on grassland composition, structure and veld condition; therefore, it is important that land use and its impacts (i.e., overgrazing, urbanisation) be considered when creating effective grassland management practices to conserve biodiversity in grassland ecosystems. An interaction effect of fire and land use was also observed on grassland richness. For South African grasslands, particularly the fire-dependent KZNSS which exists in urban matrices, to remain sustainable, the balance between fire and land use is fundamental. By managing these two aspects well, grassland ecosystems can remain resilient while preventing overgrazing, land degradation, and biodiversity loss. Measures to mitigate the impact of increasing urbanisation in these urban matrices is also crucial as it was one of the key factors that affected fire frequency. Urbanisation

can reduce fire frequency and spread, through development of firebreaks. It can also increase the risk of fire in interface zones and interfere with the natural fire cycles that are vital to the health of grassland ecosystems. Integrated grassland management techniques that strike a balance between ecological health and fire safety are required to lessen the effects of urbanisation on fire regimes. Lastly, poor veld condition was observed in most of the sites. This can be improved by implementing effective management practices that include regular burning particularly on protected areas, restoring degraded land and controlling grazing pressure on communal agricultural areas.

### **6.3. Future possibilities**

Further studies should include grazing as a variable, as grazing pressure significantly affects plant species communities and veld condition in grassland ecosystems. The grazing management practices of the protected areas and communal agricultural areas should be quantified in order to understand role of grazing pressure and how the varying grazing pressures impact the sites differently. By investigating grazing pressure, we can understand its relationship with the fire, specifically fire frequency. Other factors that can be investigated are rainfall variations between the study sites, soil type and other spatial differences and specific local conditions of the protected areas and communal agricultural areas.

### **6.4. Final comments and summary conclusion**

The effects of fire and land use are closely connected and hard to separate. Therefore, it is more feasible that their interaction had a major effect on the KZNSS. This suggests that even though fire plays a significant role in grasslands, especially mesic or fire-dependent grasslands, and have been for decades, it is the interaction between fire and land use that is key in determining

grassland structure, functioning and diversity. The relationship between fire and land use is a complex one as land use affects fire directly and indirectly. Land use practices can increase the risk of fire and also hinder effective fire management practices. Therefore, it is important to understand the interaction between fire and land use especially in the threatened KZNSS. Understanding this relationship is particularly important for veld condition as it was evident that interaction of land use and fire are key in determining the veld condition of the sites.

## References

- Bengtsson, J., Bullock, J., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'farrell, P., Smith, H., Lindborg, R., 2019. Grasslands—more important for ecosystem services than you might think. *Ecosphere* 10, 1-20.
- Brown, R.C., Fredericksen, T.S., 2008. Topographic factors affecting the tree species composition of forests in the upper Piedmont of Virginia. *Virginia Journal of Science* 59(1), 1-9.
- Hermosilla-Palma, K., Pliscoff, P., Folchi, M., 2021. Sixty years of land-use and land-cover change dynamics in a global biodiversity hotspot under threat from global change. *Journal of Land Use Science* 16, 467-478.
- Househam, S., 2017. The use of fire in the KwaZulu-Natal mistbelt and highland sourveld. Department of Agriculture and Rural Development. Agricultural Livestock Research Services Grass & Forage Scientific Research Services, Kokstad. 1-4.
- O'Connor, T., Kuyler, P., 2009. Impact of land use on the biodiversity integrity of the moist sub-biome of the grassland biome, South Africa. *Journal of Environmental Management* 90, 384-395.

- Pereira, P., Mierauskas, P., Úbeda, X., Mataix-Solera, J., Cerda, A., 2012. Fire in protected areas-the effect of protection and importance of fire management. *Environmental Research, Engineering and Management* 59, 52-62.
- Price, O., Bradstock, R., 2014. Countervailing effects of urbanisation and vegetation extent on fire frequency on the Wildland Urban Interface: Disentangling fuel and ignition effects. *Landscape and urban planning* 130, 81-88.
- Zhang, X.Q., 2016. The trends, promises and challenges of urbanisation in the world. *Habitat international* 54, 241-252.

## Appendices

Appendix 1: List of plant species (grass and forbs) found in the Nature Reserves and Communal agricultural areas

| Nature Reserves                    | Communal Agricultural Areas       |
|------------------------------------|-----------------------------------|
|                                    | <b>Grass species</b>              |
| <i>Aristida junciformis</i>        | <i>Andropogon appendiculatus</i>  |
| <i>Cymbopogon excavatus</i>        | <i>Aristida junciformis</i>       |
| <i>Cymbopogon validus</i>          | <i>Digitaria eriantha</i>         |
| <i>Digitaria eriantha</i>          | <i>Diheteropogon amplexans</i>    |
| <i>Diheteropogon amplexans</i>     | <i>Eragrostis capensis</i>        |
| <i>Eragrostis capensis</i>         | <i>Eragrostis curvula</i>         |
| <i>Eragrostis curvula</i>          | <i>Eragrostis plana</i>           |
| <i>Harpochloa falx</i>             | <i>Eragrostis racemosa</i>        |
| <i>Hyparrhenia hirta</i>           | <i>Heteropogon contortus</i>      |
| <i>Imperata cylindrica</i>         | <i>Hyparrhenia hirta</i>          |
| <i>Megathyrsus maximus</i>         | <i>Melinis repens</i>             |
| <i>Monocymbium ceresiiforme</i>    | <i>Monocymbium ceresiiforme</i>   |
| <i>Panicum natalense</i>           | <i>Panicum natalense</i>          |
| <i>Paspalum urvillei</i>           | <i>Paspalum dilatatum</i>         |
| <i>Setaria sphacelata</i>          | <i>Setaria sphacelata</i>         |
| <i>Sporobolus africanus</i>        | <i>Sporobolus africanus</i>       |
| <i>Themeda triandra</i>            | <i>Sporobolus pyramidalis</i>     |
| <i>Tristachya leucothrix</i>       | <i>Themeda triandra</i>           |
|                                    | <i>Tristachya leucothrix</i>      |
|                                    | <b>Forb species</b>               |
| <i>Acalypha glandulifolia</i>      | <i>Acalypha villicaulis</i>       |
| <i>Afroaster hispidus</i>          | <i>Acanthospermum australe</i>    |
| <i>Ajuga ophrydis</i>              | <i>Aeollanthus parvifolius</i>    |
| <i>Alectra sessiliflora</i>        | <i>Afroaster hispidus</i>         |
| <i>Alysicarpus vaginalis</i>       | <i>Ajuga ophrydis</i>             |
| <i>Argyrella canescens</i>         | <i>Aneilema aequinoctiale</i>     |
| <i>Athrixia phyllicoides</i>       | <i>Berkheya speciosa</i>          |
| <i>Berkheya setifera</i>           | <i>Centella asiatica</i>          |
| <i>Berkheya speciosa</i>           | <i>Commelina africana</i>         |
| <i>Centella asiatica</i>           | <i>Conostomium natalense</i>      |
| <i>Chamaecrista mimosoides</i>     | <i>Crassula alba</i>              |
| <i>Convolvulus farinosus</i>       | <i>Crassula vaginata</i>          |
| <i>Cyphia elata</i>                | <i>Cyanotis speciosa</i>          |
| <i>Desmodium dregeanum</i>         | <i>Desmodium incanum</i>          |
| <i>Dietes grandiflora</i>          | <i>Diclis reptans</i>             |
| <i>Drimia elata</i>                | <i>Dyschoriste setigera</i>       |
| <i>Elephantorrhiza elephantina</i> | <i>Erigeron canadensis</i>        |
| <i>Erigeron primulifolius</i>      | <i>Eriosema cordatum</i>          |
| <i>Evolvulus alsinoides</i>        | <i>Gerbera ambigua</i>            |
| <i>Felicia muricata</i>            | <i>Gerbera piloselloides</i>      |
| <i>Gerbera ambigua</i>             | <i>Helichrysum adenocarpum</i>    |
| <i>Gerbera piloselloides</i>       | <i>Helichrysum appendiculatum</i> |

*Helichrysum adenocarpum*  
*Helichrysum appendiculatum*  
*Helichrysum aureonitens*  
*Helichrysum nudifolium*  
*Helichrysum petiolare*  
*Helichrysum ruderale*  
*Helichrysum spiralepis*  
*Hilliardiella hirsuta*  
*Indigofera hendecaphylla*  
*Indigofera spicata*  
*Lobelia flaccida*  
*Neonotonia wightii*  
*Pentanisia angustifolia*  
*Pentanisia prunelloides*  
*Phymaspermum acerosum*  
*Rhynchosia minima*  
*Satyrium longicauda*  
*Selago densiflora*  
*Senecio coronatus*  
*Senecio erubescens*  
*Senecio speciosus*  
*Senecio venosus*  
*Spermacoce verticillate*  
*Tagetes minuta*  
*Tephrosia elongata*  
*Tephrosia purpurea*  
*Thunbergia natalensis*  
*Vigna vexillata*  
*Zornia capensis*

*Helichrysum aureum*  
*Helichrysum auriceps*  
*Helichrysum nudifolium*  
*Hibiscus aethiopicus*  
*Hilliardiella aristata*  
*Hypericum aethiopicum*  
*Hypoxis hemerocallidea*  
*Indigofera hiliaris*  
*Lasiosiphon kraussianus*  
*Leobordea platycarpa*  
*Macledium zeyheri*  
*Maianthemum canadense*  
*Mitracarpus hirtus*  
*Phymaspermum acerosum*  
*Polygala amatymbica*  
*Richardia brasiliensis*  
*Rothea hirsuta*  
*Ruellia cordata*  
*Senecio coronatus*  
*Senecio erubescens*  
*Tephrosia purpurea*  
*Tetraselago natalensis*  
*Thunbergia atriplicifolia*  
*Vigna vexillata*  
*Zornia capensis*

Appendix 2: List of plant species (grass and forbs) found in the burnt and unburnt patches

| Burnt                           | Unburnt                          |
|---------------------------------|----------------------------------|
| <b>Grass species</b>            |                                  |
| <i>Aristida junciformis</i>     | <i>Andropogon appendiculatus</i> |
| <i>Digitaria eriantha</i>       | <i>Aristida junciformis</i>      |
| <i>Diheteropogon amplectens</i> | <i>Cymbopogon excavatus</i>      |
| <i>Eragrostis capensis</i>      | <i>Cymbopogon validus</i>        |
| <i>Eragrostis curvula</i>       | <i>Digitaria eriantha</i>        |
| <i>Eragrostis plana</i>         | <i>Diheteropogon amplectens</i>  |
| <i>Eragrostis racemosa</i>      | <i>Eragrostis capensis</i>       |
| <i>Heteropogon contortus</i>    | <i>Eragrostis curvula</i>        |
| <i>Hyparrhenia hirta</i>        | <i>Eragrostis racemosa</i>       |
| <i>Imperata cylindrica</i>      | <i>Harporchloa falx</i>          |
| <i>Melinis repens</i>           | <i>Heteropogon contortus</i>     |
| <i>Monocymbium ceresiiforme</i> | <i>Hyparrhenia hirta</i>         |
| <i>Panicum natalense</i>        | <i>Imperata cylindrica</i>       |
| <i>Paspalum dilatatum</i>       | <i>Megathyrsus maximus</i>       |
| <i>Paspalum urvillei</i>        | <i>Monocymbium ceresiiforme</i>  |
| <i>Setaria sphacelata</i>       | <i>Panicum natalense</i>         |

*Sporobolus africanus*  
*Sporobolus pyramidalis*  
*Themeda triandra*  
*Tristachya leucothrix*

*Paspalum dilatatum*  
*Paspalum urvillei*  
*Setaria sphacelata*  
*Sporobolus africanus*  
*Themeda triandra*  
*Tristachya leucothrix*

#### Forb species

*Acalypha glandulifolia*  
*Acalypha villicaulis*  
*Acanthospermum australe*  
*Aeollanthus parvifolius*  
*Afroaster hispidus*  
*Ajuga ophrydis*  
*Alysicarpus vaginalis*  
*Aneilema aequinoctiale*  
*Argyrella canescens*  
*Athrixia phyllicoides*  
*Berkheya setifera*  
*Berkheya speciosa*  
*Centella asiatica*  
*Commelina africana*  
*Conostomium natalense*  
*Crassula alba*  
*Crassula vaginata*  
*Cyanotis speciosa*  
*Desmodium dregeanum*  
*Desmodium incanum*  
*Diclis reptans*  
*Drimia elata*  
*Dyschoriste setigera*  
*Elephantorrhiza elephantina*  
*Erigeron primulifolius*  
*Eriosema cordatum*  
*Felicia muricata*  
*Gerbera ambigua*  
*Gerbera piloselloides*  
*Gerbera ambigua*  
*Helichrysum adenocarpum*  
*Helichrysum appendiculatum*  
*Helichrysum aureum*  
*Helichrysum auriceps*  
*Helichrysum nudifolium*  
*Helichrysum ruderale*  
*Helichrysum spiralepis*  
*Hibiscus aethiopicus*  
*Hilliardiella aristata*  
*Hypoxis hemerocallidea*  
*Indigofera hendecaphylla*  
*Indigofera hiliaris*

*Acalypha glandulifolia*  
*Aeollanthus parvifolius*  
*Afroaster hispidus*  
*Ajuga ophrydis*  
*Alectra sessiliflora*  
*Athrixia phyllicoides*  
*Berkheya setifera*  
*Berkheya speciosa*  
*Centella asiatica*  
*Chamaecrista mimosoides*  
*Commelina africana*  
*Convolvulus farinosus*  
*Crassula alba*  
*Cyanotis speciosa*  
*Cyphia elata*  
*Desmodium incanum*  
*Dietes grandiflora*  
*Dyschoriste setigera*  
*Elephantorrhiza elephantina*  
*Erigeron canadensis*  
*Evolvulus alsinoides*  
*Gerbera ambigua*  
*Gerbera piloselloides*  
*Helichrysum adenocarpum*  
*Helichrysum appendiculatum*  
*Helichrysum aureonitens*  
*Helichrysum aureum*  
*Helichrysum auriceps*  
*Helichrysum nudifolium*  
*Helichrysum petiolare*  
*Helichrysum ruderale*  
*Hibiscus aethiopicus*  
*Hilliardiella hirsuta*  
*Hypericum aethiopicum*  
*Indigofera hendecaphylla*  
*Indigofera hendecaphylla*  
*Indigofera hiliaris*  
*Indigofera spicata*  
*Indigofera spicata*  
*Lasiosiphon kraussianus*  
*Leobordea platycarpa*  
*Macleodium zeyheri*

|                                |                                  |
|--------------------------------|----------------------------------|
| <i>Indigofera spicata</i>      | <i>Maianthemum canadense</i>     |
| <i>Lasiosiphon kraussianus</i> | <i>Neonotonia wightii</i>        |
| <i>Lobelia flaccida</i>        | <i>Pentanisia angustifolia</i>   |
| <i>Mitracarpus hirtus</i>      | <i>Phymaspermum acerosum</i>     |
| <i>Pentanisia angustifolia</i> | <i>Polygala amatymbica</i>       |
| <i>Pentanisia prunelloides</i> | <i>Rhynchosia minima</i>         |
| <i>Phymaspermum acerosum</i>   | <i>Ruellia cordata</i>           |
| <i>Richardia brasiliensis</i>  | <i>Satyrium longicauda</i>       |
| <i>Rothea hirsuta</i>          | <i>Selago densiflora</i>         |
| <i>Ruellia cordata</i>         | <i>Senecio coronatus</i>         |
| <i>Senecio coronatus</i>       | <i>Senecio erubescens</i>        |
| <i>Senecio erubescens</i>      | <i>Senecio speciosus</i>         |
| <i>Senecio venosus</i>         | <i>Spermacoce verticillata</i>   |
| <i>Spermacoce verticillata</i> | <i>Tephrosia elongata</i>        |
| <i>Tagetes minuta</i>          | <i>Tephrosia purpurea</i>        |
| <i>Tephrosia elongata</i>      | <i>Tetraselago natalensis</i>    |
| <i>Tephrosia purpurea</i>      | <i>Thunbergia atriplicifolia</i> |
| <i>Tetraselago natalensis</i>  | <i>Thunbergia natalensis</i>     |
| <i>Zornia capensis</i>         | <i>Vigna vexillata</i>           |
|                                | <i>Zornia capensis</i>           |

Appendix 3: List of plant species (grass and forbs) found in the burnt and unburnt patches at Silverglen Nature Reserve

| Burnt                             | Unburnt                         |
|-----------------------------------|---------------------------------|
|                                   | <b>Grass species</b>            |
| <i>Aristida junciformis</i>       | <i>Aristida junciformis</i>     |
| <i>Digitaria eriantha</i>         | <i>Cymbopogon excavatus</i>     |
| <i>Hyparrhenia hirta</i>          | <i>Digitaria eriantha</i>       |
| <i>Themeda triandra</i>           | <i>Paspalum urvillei</i>        |
| <i>Tristachya leucothrix</i>      | <i>Sporobolus africanus</i>     |
| <b>Forb Species</b>               |                                 |
| <i>Afroaster hispidus</i>         | <i>Berkheya speciosa</i>        |
| <i>Argyrella canescens</i>        | <i>Centella asiatica</i>        |
| <i>Berkheya speciosa</i>          | <i>Chamaecrista mimosoides</i>  |
| <i>Centella asiatica</i>          | <i>Cyphia elata</i>             |
| <i>Felicia muricata</i>           | <i>Indigofera hendecaphylla</i> |
| <i>Gerbera ambigua</i>            | <i>Indigofera spicata</i>       |
| <i>Helichrysum appendiculatum</i> | <i>Satyrium longicauda</i>      |
| <i>Helichrysum nudifolium</i>     | <i>Senecio erubescens</i>       |
| <i>Indigofera spicata</i>         | <i>Senecio speciosus</i>        |
| <i>Senecio coronatus</i>          | <i>Spermacoce verticillata</i>  |
| <i>Spermacoce verticillata</i>    | <i>Tephrosia purpurea</i>       |
| <i>Tephrosia purpurea</i>         |                                 |

Appendix 4: List of plant species (grass and forbs) found in the burnt and unburnt patches at New Germany Nature Reserve

| <b>Burnt</b>                    | <b>Unburnt</b>                  |
|---------------------------------|---------------------------------|
| <b>Grass species</b>            |                                 |
| <i>Aristida junciformis</i>     | <i>Aristida junciformis</i>     |
| <i>Digitaria eriantha</i>       | <i>Digitaria eriantha</i>       |
| <i>Panicum natalense</i>        | <i>Eragrostis capensis</i>      |
| <i>Setaria sphacelata</i>       | <i>Eragrostis curvula</i>       |
| <i>Themeda triandra</i>         | <i>Harpochloa falx</i>          |
|                                 | <i>Setaria sphacelata</i>       |
|                                 | <i>Sporobolus africanus</i>     |
|                                 | <i>Themeda triandra</i>         |
|                                 | <i>Tristachya leucothrix</i>    |
| <b>Forb Species</b>             |                                 |
| <i>Acalypha glandulifolia</i>   | <i>Acalypha glandulifolia</i>   |
| <i>Berkheya setifera</i>        | <i>Berkheya setifera</i>        |
| <i>Desmodium dregeanum</i>      | <i>Chamaecrista mimosoides</i>  |
| <i>Gerbera piloselloides</i>    | <i>Dietes grandiflora</i>       |
| <i>Helichrysum nudifolium</i>   | <i>Gerbera piloselloides</i>    |
| <i>Helichrysum ruderales</i>    | <i>Helichrysum aureonitens</i>  |
| <i>Indigofera hendecaphylla</i> | <i>Hilliardiella hirsuta</i>    |
| <i>Pentanisia angustifolia</i>  | <i>Indigofera hendecaphylla</i> |
| <i>Phymaspermum acerosum</i>    | <i>Indigofera spicata</i>       |
| <i>Senecio venosus</i>          | <i>Pentanisia angustifolia</i>  |
| <i>Tagetes minuta</i>           | <i>Tephrosia purpurea</i>       |
| <i>Tephrosia purpurea</i>       | <i>Thunbergia natalensis</i>    |
| <i>Zornia capensis</i>          | <i>Zornia capensis</i>          |

Appendix 5: List of plant species (grass and forbs) found in the burnt and unburnt patches at Roosfontein Nature Reserve

| <b>Burnt</b>                       | <b>Unburnt</b>                     |
|------------------------------------|------------------------------------|
| <b>Grass species</b>               |                                    |
| <i>Aristida junciformis</i>        | <i>Aristida junciformis</i>        |
| <i>Digitaria eriantha</i>          | <i>Hyparrhenia hirta</i>           |
| <i>Eragrostis capensis</i>         | <i>Imperata cylindrica</i>         |
| <i>Hyparrhenia hirta</i>           | <i>Megathyrsus maximus</i>         |
| <i>Imperata cylindrica</i>         | <i>Panicum natalense</i>           |
| <b>Forb Species</b>                |                                    |
| <i>Alysicarpus vaginalis</i>       | <i>Ajuga ophrydis</i>              |
| <i>Elephantorrhiza elephantina</i> | <i>Chamaecrista mimosoides</i>     |
| <i>Erigeron primulifolius</i>      | <i>Elephantorrhiza elephantina</i> |
| <i>Gerbera piloselloides</i>       | <i>Helichrysum nudifolium</i>      |
| <i>Helichrysum nudifolium</i>      | <i>Helichrysum ruderales</i>       |
| <i>Helichrysum ruderales</i>       | <i>Indigofera hendecaphylla</i>    |
| <i>Lobelia flaccida</i>            | <i>Selago densiflora</i>           |
|                                    | <i>Senecio erubescens</i>          |

|  |                           |
|--|---------------------------|
|  | <i>Tephrosia elongata</i> |
|--|---------------------------|

Appendix 6: List of plant species (grass and forbs) found in the burnt and unburnt patches at Krantzklouf Nature Reserve

| Burnt                           | Unburnt                       |
|---------------------------------|-------------------------------|
| <b>Grass species</b>            |                               |
| <i>Aristida junciformis</i>     | <i>Aristida junciformis</i>   |
| <i>Digitaria eriantha</i>       | <i>Cymbopogon validus</i>     |
| <i>Diheteropogon amplexans</i>  | <i>Digitaria eriantha</i>     |
| <i>Eragrostis capensis</i>      | <i>Panicum natalense</i>      |
| <i>Hyparrhenia hirta</i>        | <i>Paspalum urvillei</i>      |
| <i>Monocymbium cerasiiforme</i> | <i>Setaria sphacelata</i>     |
| <i>Panicum natalense</i>        |                               |
| <i>Paspalum urvillei</i>        |                               |
| <b>Forb Species</b>             |                               |
| <i>Athrixia phyllicoides</i>    | <i>Alectra sessiliflora</i>   |
| <i>Drimia elata</i>             | <i>Athrixia phyllicoides</i>  |
| <i>Helichrysum adenocarpum</i>  | <i>Berkheya setifera</i>      |
| <i>Helichrysum nudifolium</i>   | <i>Berkheya speciosa</i>      |
| <i>Helichrysum Spiralepis</i>   | <i>Convolvulus farinosus</i>  |
| <i>Indigofera spicata</i>       | <i>Evolvulus alsinoides</i>   |
| <i>Pentania prunelloides</i>    | <i>Gerbera ambigua</i>        |
| <i>Tephrosia elongata</i>       | <i>Helichrysum nudifolium</i> |
| <i>Zornia capensis</i>          | <i>Helichrysum petiolare</i>  |
|                                 | <i>Neonotonia wightii</i>     |
|                                 | <i>Rhynchosia minima</i>      |
|                                 | <i>Vigna vexillata</i>        |

Appendix 7: List of plant species (grass and forbs) found in the burnt and unburnt patches at KwaCele

| Burnt                           | Unburnt                           |
|---------------------------------|-----------------------------------|
| <b>Grass species</b>            |                                   |
| <i>Aristida junciformis</i>     | <i>Aristida junciformis</i>       |
| <i>Eragrostis curvula</i>       | <i>Diheteropogon amplexans</i>    |
| <i>Eragrostis racemosa</i>      | <i>Hyparrhenia hirta</i>          |
| <i>Heteropogon contortus</i>    | <i>Panicum natalense</i>          |
| <i>Hyparrhenia hirta</i>        | <i>Setaria sphacelata</i>         |
| <i>Monocymbium cerasiiforme</i> | <i>Sporobolus africanus</i>       |
| <b>Forb Species</b>             |                                   |
| <i>Acalypha villicaulis</i>     | <i>Berkheya speciosa</i>          |
| <i>Crassula alba</i>            | <i>Commelina africana</i>         |
| <i>Cyanotis speciosa</i>        | <i>Cyanotis speciosa</i>          |
| <i>Dielis reptans</i>           | <i>Erigeron canadensis</i>        |
| <i>Eriosema cordatum</i>        | <i>Helichrysum appendiculatum</i> |
| <i>Gerbera ambigua</i>          | <i>Helichrysum auriceps</i>       |
| <i>Helichrysum auriceps</i>     | <i>Hypericum aethiopicum</i>      |

|                                |                               |
|--------------------------------|-------------------------------|
| <i>Hilliardiella aristata</i>  | <i>Macledium zeyheri</i>      |
| <i>Lasiosiphon kraussianus</i> | <i>Maianthemum canadense</i>  |
| <i>Phymaspermum acerosum</i>   | <i>Tephrosia purpurea</i>     |
| <i>Rothea hirsuta</i>          | <i>Tetraselago natalensis</i> |
| <i>Ruellia cordata</i>         | <i>Vigna vexillata</i>        |
| <i>Senecio erubescens</i>      |                               |

Appendix 8: List of plant species (grass and forbs) found in the burnt and unburnt patches at Qadi

| <b>Burnt</b>                   | <b>Unburnt</b>                   |
|--------------------------------|----------------------------------|
| <b>Grass species</b>           |                                  |
| <i>Aristida junciformis</i>    | <i>Andropogon appendiculatus</i> |
| <i>Digitaria eriantha</i>      | <i>Aristida junciformis</i>      |
| <i>Eragrostis curvula</i>      | <i>Eragrostis capensis</i>       |
| <i>Hyparrhenia hirta</i>       | <i>Eragrostis curvula</i>        |
| <i>Themeda triandra</i>        | <i>Eragrostis racemosa</i>       |
|                                | <i>Monocymbium ceresiiforme</i>  |
|                                | <i>Panicum natalense</i>         |
| <b>Forb Species</b>            |                                  |
| <i>Aeollanthus parvifolius</i> | <i>Aeollanthus parvifolius</i>   |
| <i>Commelina africana</i>      | <i>Desmodium incanum</i>         |
| <i>Desmodium incanum</i>       | <i>Gerbera ambigua</i>           |
| <i>Eriosema cordatum</i>       | <i>Gerbera piloselloides</i>     |
| <i>Helichrysum aureum</i>      | <i>Helichrysum aureum</i>        |
| <i>Helichrysum nudifolium</i>  | <i>Helichrysum nudifolium</i>    |
| <i>Lasiosiphon kraussianus</i> | <i>Lasiosiphon kraussianus</i>   |
| <i>Phymaspermum acerosum</i>   | <i>Senecio coronatus</i>         |
| <i>Tetraselago natalensis</i>  | <i>Tetraselago natalensis</i>    |
| <i>Zornia capensis</i>         | <i>Zornia capensis</i>           |

Appendix 9: List of plant species (grass and forbs) found in the burnt and unburnt patches at Zwelibomvu/Nkasa Isimahla

| <b>Burnt</b>                    | <b>Unburnt</b>               |
|---------------------------------|------------------------------|
| <b>Grass species</b>            |                              |
| <i>Aristida junciformis</i>     | <i>Aristida junciformis</i>  |
| <i>Diheteropogon amplexans</i>  | <i>Eragrostis curvula</i>    |
| <i>Eragrostis capensis</i>      | <i>Eragrostis racemosa</i>   |
| <i>Eragrostis plana</i>         | <i>Heteropogon contortus</i> |
| <i>Hyparrhenia hirta</i>        | <i>Hyparrhenia hirta</i>     |
| <i>Monocymbium ceresiiforme</i> | <i>Paspalum dilatatum</i>    |
| <i>Paspalum dilatatum</i>       | <i>Sporobolus africanus</i>  |
| <i>Sporobolus africanus</i>     | <i>Themeda triandra</i>      |
| <i>Themeda triandra</i>         |                              |
| <b>Forb Species</b>             |                              |
| <i>Centella asiatica</i>        | <i>Centella asiatica</i>     |
| <i>Crassula alba</i>            | <i>Crassula alba</i>         |
| <i>Dyschoriste setigera</i>     | <i>Dyschoriste setigera</i>  |

|   |   |
|---|---|
| <i>Gerbera piloselloides</i><br><i>Helichrysum adenocarpum</i><br><i>Helichrysum nudifolium</i><br><i>Richardia brasiliensis</i><br><i>Ruellia cordata</i><br><i>Tetraselago natalensis</i><br><i>Zornia capensis</i> | <i>Gerbera piloselloides</i><br><i>Helichrysum adenocarpum</i><br><i>Helichrysum nudifolium</i><br><i>Lasiosiphon kraussianus</i><br><i>Leobordea platycarpa</i><br><i>Polygala amatymbica</i><br><i>Ruellia cordata</i><br><i>Tetraselago natalensis</i><br><i>Zornia capensis</i> |
|---|---|

Appendix 10: List of plant species (grass and forbs) found in the burnt and unburnt patches at Toyane

| <b>Burnt</b>  | <b>Unburnt</b>   |
|---|--|
|   | <b>Grass species</b>   |
| <i>Aristida junciformis</i><br><i>Eragrostis racemose</i><br><i>Eragrostis capensis</i><br><i>Eragrostis curvula</i><br><i>Hyparrhenia hirta</i><br><i>Melinis repens</i><br><i>Panicum natalense</i><br><i>Sporobolus africanus</i><br><i>Sporobolus pyramidalis</i><br><i>Tristachya leucothrix</i>   | <i>Aristida junciformis</i><br><i>Hyparrhenia hirta</i><br><i>Monocymbium ceresiiforme</i><br><i>Panicum natalense</i>   |
|   | <b>Forb Species</b>  |
| <i>Acanthospermum australe</i><br><i>Afroaster hispidus</i><br><i>Ajuga ophrydis</i><br><i>Aneilema aequinoctiale</i><br><i>Centella asiatica</i><br><i>Conostomium natalense</i><br><i>Crassula vaginata</i><br><i>Dyschoriste setigera</i><br><i>Helichrysum aureum</i><br><i>Hibiscus aethiopicus</i><br><i>Hypoxis hemerocallidea</i><br><i>Indigofera hilaris</i><br><i>Mitracarpus hirtus</i><br><i>Phymaspermum acerosum</i><br><i>Zornia capensis</i> | <i>Afroaster hispidus</i><br><i>Ajuga ophrydis</i><br><i>Dyschoriste setigera</i><br><i>Helichrysum auriceps</i><br><i>Helichrysum nudifolium</i><br><i>Hibiscus aethiopicus</i><br><i>Indigofera hilaris</i><br><i>Phymaspermum acerosum</i><br><i>Senecio erubescens</i><br><i>Thunbergia atriplicifolia</i><br><i>Vigna vexillata</i> |

Appendix 11: Evaluation sheet for calculating the veld condition score of the KZNSS patches within Nature Reserves

| <u>Species</u>                   | <u>Grazing Value</u> | <u>Benchmark %</u> | <u>Benchmark score</u> | <u>Sample site %</u> | <u>Sample site score</u> |
|----------------------------------|----------------------|--------------------|------------------------|----------------------|--------------------------|
| <b><u>Decreaser</u></b>          |                      |                    |                        |                      |                          |
| <i>Brachiaria serrata</i>        | 3                    | 1                  | 3                      |                      |                          |
| <i>Diheteropogon amplexans</i>   | 8                    | 2                  | 16                     | 0,13                 | 1                        |
| <i>Themeda triandra</i>          | 10                   | 25                 | 250                    | 6,5                  | 65                       |
| <i>Digitaria eriantha</i>        | 7                    |                    |                        | 19,19                | 134,31                   |
| <i>Andropogon appendiculatus</i> | 5                    |                    |                        |                      |                          |
| <i>Panicum natalense</i>         | 2                    |                    |                        | 6,06                 | 12,13                    |
| <i>Melinis nerviglumis</i>       | 2                    |                    |                        | 0,31                 | 0,63                     |
| <i>Monocymbium ceresiiforme</i>  | 6                    |                    |                        | 0,44                 | 2,63                     |
| <b>Total</b>                     |                      | <b>28</b>          | <b>269</b>             | <b>32,63</b>         | <b>215,69</b>            |
| <b><u>Increaser I</u></b>        |                      |                    |                        |                      |                          |
| <i>Alloteropsis semialata</i>    | 3                    | 1                  | 3                      |                      |                          |
| <i>Digitaria tricholaenoides</i> | 6                    | 12                 | 72                     |                      |                          |
| <i>Setaria nigrirostris</i>      | 5                    | 6                  | 30                     |                      |                          |
| <i>Trachypogon spicatus</i>      | 3                    | 1                  | 3                      |                      |                          |
| <i>Tristachya leucothrix</i>     | 9                    | 25                 | 225                    | 0,19                 | 1,69                     |
| <i>Paspalum urvillei</i>         | 7                    |                    |                        | 1,63                 | 11,38                    |
| <i>Hyparrhenia filipendula</i>   | 5                    |                    |                        | 1,25                 | 6,25                     |
| <i>Cymbopogon excavatus</i>      | 1                    |                    |                        | 0,06                 | 0,06                     |
| <b>Total</b>                     |                      | <b>45</b>          | <b>333</b>             | <b>3,13</b>          | <b>19,38</b>             |
| <b><u>Increaser IIa</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis capensis</i>       | 2                    | 4                  | 8                      | 1,38                 | 2,75                     |
| <i>Harpochloa falx</i>           | 3                    | 1                  | 3                      | 0,13                 | 0,38                     |
| <i>Heteropogon contortus</i>     | 6                    | 2                  | 12                     | 0,06                 | 0,38                     |
| <b>Total</b>                     |                      | <b>7</b>           | <b>23</b>              | <b>1,56</b>          | <b>3,5</b>               |
| <b><u>Increaser IIb</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis chloromelas</i>    | 2                    | 2                  | 4                      |                      |                          |
| <i>Eragrostis curvula</i>        | 5                    | 1                  | 5                      | 2,13                 | 10,63                    |
| <i>Eragrostis gummiflua</i>      | 2                    | 1                  | 2                      |                      |                          |
| <i>Eragrostis plana</i>          | 2                    | 1                  | 2                      | 0,06                 | 0,13                     |
| <i>Eragrostis racemosa</i>       | 2                    | 4                  | 8                      | 0,19                 | 0,38                     |
| <i>Hyparrhenia hirta</i>         | 6                    | 1                  | 6                      | 0,25                 | 1,5                      |
| <i>Sporobolus africanus</i>      | 3                    | 2                  | 6                      | 0,13                 | 0,38                     |
| <i>Setaria sphacelata</i>        | 6                    |                    |                        | 2,94                 | 17,63                    |
| <i>Sporobolus pyramidalis</i>    | 2                    |                    |                        | 0,06                 | 0,13                     |
| <b>Total</b>                     |                      | <b>12</b>          | <b>33</b>              | <b>5,75</b>          | <b>30,75</b>             |
| <b><u>Increaser IIc</u></b>      |                      |                    |                        |                      |                          |
| <i>Aristida congesta</i>         | 0                    | 1                  | 0                      |                      |                          |
| Forbs                            | 0                    | 2                  |                        | 19,13                | 0                        |
| Sedges                           | 0                    | 2                  |                        | 3,75                 | 0                        |
| <i>Melinis repens</i>            | 1                    |                    |                        |                      |                          |

|                             |   |            |             |              |               |
|-----------------------------|---|------------|-------------|--------------|---------------|
| <b>Total</b>                |   | <b>5</b>   | <b>0</b>    | <b>22,88</b> | <b>0</b>      |
| <b>Increaser III</b>        |   |            |             |              |               |
| <i>Aristida junciformis</i> | 0 |            |             | 25,4         | 0             |
| <i>Elionurus muticus</i>    | 0 | 3          | 0           |              |               |
| <b>Total</b>                |   | <b>3</b>   | <b>0</b>    | <b>25,4</b>  | <b>0</b>      |
| <b>Others</b>               |   |            |             |              |               |
| <i>Cymbopogon validus</i>   | 1 |            |             | 2,38         | 2,38          |
| <i>Imperata cylindrica</i>  |   |            |             | 5,94         |               |
| <i>Oplismenus hirtellus</i> |   |            |             | 0,31         |               |
| <b>Total</b>                |   |            |             | <b>8,63</b>  | <b>2,38</b>   |
| <b>Grand Totals</b>         |   | <b>100</b> | <b>658</b>  | <b>100</b>   | <b>271,69</b> |
| <b>Score</b>                |   |            | <b>100%</b> |              | <b>41,29%</b> |
| <b>Basal Cover</b>          |   |            | <b>14</b>   |              | <b>11,28</b>  |

### CALCULATIONS:

$$\text{Distance}(D) = 2,51\text{cm}$$

$$\text{Diameter}(d) = 1,24\text{cm}$$

$$\text{VCS} = (\text{total sample score} / \text{total benchmark score}) * 100\% = (271,69 / 658) * 100\% = 41,29\%$$

$$\text{BCB} = 14\%$$

$$\text{BCS} = 19,8 + 0,39(D) - 11,87(\log_e D) + 0,64(d) + 2,93(\log_e d) = 19,8 + 0,39(2,51) - 11,87(\log_e 2,51) + 0,64(1,24) + 2,93(\log_e 1,24) = 11,28\%$$

$$\text{BCF} = -0,75 + 2(\text{BCS}/\text{BCB}) - (\text{BCS}/\text{BCB})^2 = -0,75 + 2(11,28 / 14) - (11,28 / 14)^2 = 0,21$$

$$\text{CF} = 0,25((\text{VCS} + \text{number of units of Increaser I species in excess of the benchmark})/100) = 0,25((41,29 + 3) / 100) = 0,11$$

$$\text{SEF} = 0,08$$

$$\text{TF} = 0,08$$

$$\text{NR} = \text{CF} + \text{BCF} + \text{TF} + \text{SEF} = 0,11 + 0,21 + 0,08 + 0,08 = 0,48$$

$$\text{Potential Grazing Capacity} = 2,7\text{AU ha}^{-1}$$

$$\text{Current Grazing Capacity} = \text{PGC} * \text{NR} = 2,7\text{AU ha}^{-1} * 0,48 = 1,30\text{AU ha}^{-1}$$

Appendix 12: Evaluation sheet for calculating the veld condition score of the KZNSS patches within Communal Areas

| <u>Species</u>                   | <u>Grazing Value</u> | <u>Benchmark %</u> | <u>Benchmark score</u> | <u>Sample site %</u> | <u>Sample site score</u> |
|----------------------------------|----------------------|--------------------|------------------------|----------------------|--------------------------|
| <b><u>Decreaser</u></b>          |                      |                    |                        |                      |                          |
| <i>Brachiaria serrata</i>        | 3                    | 1                  | 3                      |                      |                          |
| <i>Diheteropogon amplexans</i>   | 8                    | 2                  | 16                     | 0,63                 | 5                        |
| <i>Themeda triandra</i>          | 10                   | 25                 | 250                    | 8,5                  | 85                       |
| <i>Digitaria eriantha</i>        | 7                    |                    |                        | 0,69                 | 4,81                     |
| <i>Andropogon appendiculatus</i> | 5                    |                    |                        | 0,31                 | 1,56                     |
| <i>Panicum natalense</i>         | 2                    |                    |                        | 3,81                 | 7,63                     |
| <i>Melinis nerviglumis</i>       | 2                    |                    |                        |                      |                          |
| <i>Monocymbium cerasiiforme</i>  | 6                    |                    |                        | 3,25                 | 19,5                     |
| <b>Total</b>                     |                      | <b>28</b>          | <b>269</b>             | <b>17,19</b>         | <b>123,5</b>             |
| <b><u>Increaser I</u></b>        |                      |                    |                        |                      |                          |
| <i>Alloteropsis semialata</i>    | 3                    | 1                  | 3                      |                      |                          |
| <i>Digitaria tricholaenoides</i> | 6                    | 12                 | 72                     |                      |                          |
| <i>Setaria nigrirostris</i>      | 5                    | 6                  | 30                     |                      |                          |
| <i>Trachypogon spicatus</i>      | 3                    | 1                  | 3                      |                      |                          |
| <i>Tristachya leucothrix</i>     | 9                    | 25                 | 225                    | 0,63                 | 5,63                     |
| <i>Paspalum urvillei</i>         | 7                    |                    |                        |                      |                          |
| <i>Hyparrhenia filipendula</i>   | 5                    |                    |                        |                      |                          |
| <i>Cymbopogon excavates</i>      | 1                    |                    |                        |                      |                          |
| <b>Total</b>                     |                      | <b>45</b>          | <b>333</b>             | <b>0,63</b>          | <b>5,63</b>              |
| <b><u>Increaser IIa</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis capensis</i>       | 2                    | 4                  | 8                      | 0,06                 | 0,13                     |
| <i>Harpochloa falx</i>           | 3                    | 1                  | 3                      |                      |                          |
| <i>Heteropogon contortus</i>     | 6                    | 2                  | 12                     | 0,31                 | 1,88                     |
| <b>Total</b>                     |                      | <b>7</b>           | <b>23</b>              | <b>0,38</b>          | <b>2</b>                 |
| <b><u>Increaser IIb</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis chloromelas</i>    | 2                    | 2                  | 4                      |                      |                          |
| <i>Eragrostis curvula</i>        | 5                    | 1                  | 5                      | 5,38                 | 26,88                    |
| <i>Eragrostis gummiflua</i>      | 2                    | 1                  | 2                      |                      |                          |
| <i>Eragrostis plana</i>          | 2                    | 1                  | 2                      | 0,69                 | 1,38                     |
| <i>Eragrostis racemose</i>       | 2                    | 4                  | 8                      | 8,81                 | 17,63                    |
| <i>Hyparrhenia hirta</i>         | 6                    | 1                  | 6                      | 2,56                 | 15,38                    |
| <i>Sporobolus africanus</i>      | 3                    | 2                  | 6                      | 0,06                 | 0,19                     |
| Setaria sphacelate               | 6                    |                    |                        | 0,13                 | 0,75                     |
| <i>Sporobolus pyramidalis</i>    | 2                    |                    |                        | 0,06                 | 0,13                     |
| <b>Total</b>                     |                      | <b>12</b>          | <b>33</b>              | <b>17,69</b>         | <b>62,31</b>             |
| <b><u>Increaser IIc</u></b>      |                      |                    |                        |                      |                          |
| <i>Aristida congesta</i>         | 0                    | 1                  | 0                      |                      |                          |
| Forbs                            | 0                    | 2                  |                        | 13,25                |                          |
| Sedges                           | 0                    | 2                  |                        | 5,75                 |                          |
| <i>Melinis repens</i>            | 1                    |                    |                        | 0,13                 | 0,13                     |
| <b>Total</b>                     |                      | <b>5</b>           | <b>0</b>               | <b>19,50</b>         | <b>0,13</b>              |

| <b>Increaser III</b>        |   |            |             |             |               |
|-----------------------------|---|------------|-------------|-------------|---------------|
| <i>Aristida junciformis</i> | 0 |            |             | 44,2        | 0             |
| <i>Elionurus muticus</i>    | 0 | 3          | 0           |             |               |
| <b>Total</b>                |   | <b>3</b>   | <b>0</b>    | <b>44,2</b> | <b>0</b>      |
| <b>Others</b>               |   |            |             |             |               |
| <i>Cymbopogon Validus</i>   | 1 |            |             | 0,13        | 0,13          |
| <i>Imperata cylindrica</i>  |   |            |             | 0,31        |               |
| <i>Oplismenus hirtellus</i> |   |            |             |             |               |
| <b>Total</b>                |   |            |             | <b>0,44</b> | <b>0,13</b>   |
| <b>Grand Totals</b>         |   | <b>100</b> | <b>658</b>  | <b>100</b>  | <b>193,69</b> |
| <b>Score</b>                |   |            | <b>100%</b> |             | <b>29,43%</b> |
| <b>Basal cover</b>          |   |            | <b>14</b>   |             | <b>18,23</b>  |

### CALCULATIONS:

$$\text{Distance}(D) = 1,35\text{cm}$$

$$\text{Diameter}(d) = 1,27\text{cm}$$

$$\text{VCS} = (\text{total sample score} / \text{total benchmark score}) * 100\% = (193,69 / 658) * 100\% = 29,43\%$$

$$\text{BCB} = 14\%$$

$$\text{BCS} = 19,8 + 0,39(D) - 11,87(\log_e D) + 0,64(d) + 2,93(\log_e d) = 19,8 + 0,39(1,35) - 11,87(\log_e 1,35) + 0,64(1,27) + 2,93(\log_e 1,27) = 18,23\%$$

$$\text{BCF} = -0,75 + 2(\text{BCS}/\text{BCB}) - (\text{BCS}/\text{BCB})^2 = -0,75 + 2(18,23 / 14) - (18,23 / 14)^2 = 0,16$$

$$\text{CF} = 0,25((\text{VCS} + \text{number of units of Increaser I species in excess of the benchmark})/100) = 0,25((29,43 + 0) / 100) = 0,07$$

$$\text{SEF} = 0,08$$

$$\text{TF} = 0,08$$

$$\text{NR} = \text{CF} + \text{BCF} + \text{TF} + \text{SEF} = 0,07 + 0,16 + 0,08 + 0,08 = 0,39$$

$$\text{Potential Grazing Capacity} = 2,7\text{AU ha}^{-1}$$

$$\text{Current Grazing Capacity} = \text{PGC} * \text{NR} = 2,7\text{AU ha}^{-1} * 0,39 = 1,06\text{AU ha}^{-1}$$

Appendix 13: Evaluation sheet for calculating the veld condition score of the burnt KZNSS patches

| <u>Species</u>                   | <u>Grazing Value</u> | <u>Benchmark %</u> | <u>Benchmark score</u> | <u>Sample site %</u> | <u>Sample site score</u> |
|----------------------------------|----------------------|--------------------|------------------------|----------------------|--------------------------|
| <b><u>Decreaser</u></b>          |                      |                    |                        |                      |                          |
| <i>Brachiaria serrata</i>        | 3                    | 1                  | 3                      |                      |                          |
| <i>Diheteropogon amplexans</i>   | 8                    | 2                  | 16                     | 0,38                 | 3                        |
| <i>Themeda triandra</i>          | 10                   | 25                 | 250                    | 7,69                 | 76,88                    |
| <i>Digitaria eriantha</i>        | 7                    |                    |                        | 8,75                 | 61,25                    |
| <i>Andropogon appendiculatus</i> | 5                    |                    |                        | 0,06                 | 0,31                     |
| <i>Panicum natalense</i>         | 2                    |                    |                        | 4,5                  | 9                        |
| <i>Melinis nerviglumis</i>       | 2                    |                    |                        | 0,19                 | 0,38                     |
| <i>Monocymbium cerasiiforme</i>  | 6                    |                    |                        | 1,13                 | 6,75                     |
| <b>Total</b>                     |                      | <b>28</b>          | <b>269</b>             | <b>22,69</b>         | <b>157,56</b>            |
| <b><u>Increaser I</u></b>        |                      |                    |                        |                      |                          |
| <i>Alloteropsis semialata</i>    | 3                    | 1                  | 3                      |                      |                          |
| <i>Digitaria tricholaenoides</i> | 6                    | 12                 | 72                     |                      |                          |
| <i>Setaria nigrirostris</i>      | 5                    | 6                  | 30                     |                      |                          |
| <i>Trachypogon spicatus</i>      | 3                    | 1                  | 3                      |                      |                          |
| <i>Tristachya leucothrix</i>     | 9                    | 25                 | 225                    | 0,06                 | 0,56                     |
| <i>Paspalum urvillei</i>         | 7                    |                    |                        | 1                    | 7                        |
| <i>Hyparrhenia filipendula</i>   | 5                    |                    |                        | 0,38                 | 1,88                     |
| <i>Cymbopogon excavatus</i>      | 1                    |                    |                        | 0,06                 | 0,06                     |
| <b>Total</b>                     |                      | <b>45</b>          | <b>333</b>             | <b>1,5</b>           | <b>9,5</b>               |
| <b><u>Increaser IIa</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis capensis</i>       | 2                    | 4                  | 8                      | 0,69                 | 1,38                     |
| <i>Harporchloa falx</i>          | 3                    | 1                  | 3                      |                      |                          |
| <i>Heteropogon contortus</i>     | 6                    | 2                  | 12                     | 0,25                 | 1,5                      |
| <b>Total</b>                     |                      | <b>7</b>           | <b>23</b>              | <b>0,94</b>          | <b>2,88</b>              |
| <b><u>Increaser IIb</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis chloromelas</i>    | 2                    | 2                  | 4                      |                      |                          |
| <i>Eragrostis curvula</i>        | 5                    | 1                  | 5                      | 4,69                 | 23,44                    |
| <i>Eragrostis gummiflua</i>      | 2                    | 1                  | 2                      |                      |                          |
| <i>Eragrostis plana</i>          | 2                    | 1                  | 2                      | 0,63                 | 1,25                     |
| <i>Eragrostis racemosa</i>       | 2                    | 4                  | 8                      | 6,81                 | 13,63                    |
| <i>Hyparrhenia hirta</i>         | 6                    | 1                  | 6                      | 0,63                 | 3,75                     |
| <i>Sporobolus africanus</i>      | 3                    | 2                  | 6                      | 0,19                 | 0,56                     |
| <i>Setaria sphacelata</i>        | 6                    |                    |                        | 0,81                 | 4,88                     |
| <i>Sporobolus pyramidalis</i>    | 2                    |                    |                        | 0,06                 | 0,13                     |
| <b>Total</b>                     |                      | <b>12</b>          | <b>33</b>              | <b>13,81</b>         | <b>47,63</b>             |
| <b><u>Increaser IIc</u></b>      |                      |                    |                        |                      |                          |
| <i>Aristida congesta</i>         | 0                    | 1                  | 0                      |                      |                          |
| Forbs                            | 0                    | 2                  |                        | 17,63                | 0                        |
| Sedges                           | 0                    | 2                  |                        | 5,44                 | 0                        |
| <i>Melinis repens</i>            | 1                    |                    |                        | 0,13                 | 0,13                     |
| <b>Total</b>                     |                      | <b>5</b>           | <b>0</b>               | <b>23,19</b>         | <b>0,13</b>              |

| <b>Increaser III</b>        |   |            |             |               |
|-----------------------------|---|------------|-------------|---------------|
| <i>Aristida junciformis</i> | 0 |            | 34,5        | 0             |
| <i>Elionurus muticus</i>    | 0 | 3          | 0           |               |
| <b>Total</b>                |   | <b>3</b>   | <b>0</b>    | <b>34,5</b>   |
| <b>Others</b>               |   |            |             |               |
| <i>Cymbopogon validus</i>   | 1 |            | 0,63        | 0,63          |
| <i>Imperata cylindrica</i>  |   |            | 2,5         |               |
| <i>Oplismenus hirtellus</i> |   |            | 0,25        |               |
| <b>Total</b>                |   |            | <b>3,38</b> | <b>0,63</b>   |
| <b>Grand Totals</b>         |   | <b>100</b> | <b>658</b>  | <b>100</b>    |
| <b>Score</b>                |   |            | <b>100%</b> | <b>33,18%</b> |
| <b>Basal cover</b>          |   |            | <b>14</b>   | <b>14,42</b>  |

### CALCULATIONS:

$$\text{Distance(D)} = 1,87\text{cm}$$

$$\text{Diameter(d)} = 1,22\text{cm}$$

$$\text{VCS} = (\text{total sample score} / \text{total benchmark score}) * 100\% = (218,31 / 658) * 100\% = 33,18\%$$

$$\text{BCB} = 14\%$$

$$\text{BCS} = 19,8 + 0,39(\text{D}) - 11,87(\log_e \text{D}) + 0,64(\text{d}) + 2,93(\log_e \text{d}) = 19,8 + 0,39(1,87) - 11,87(\log_e 1,87) + 0,64(1,22) + 2,93(\log_e 1,22) = 14,42\%$$

$$\text{BCF} = -0,75 + 2(\text{BCS}/\text{BCB}) - (\text{BCS}/\text{BCB})^2 = -0,75 + 2(14,42 / 14) - (14,42 / 14)^2 = 0,25$$

$$\text{CF} = 0,25((\text{VCS} + \text{number of units of Increaser I species in excess of the benchmark})/100) = 0,25((33,18 + 3) / 100) = 0,09$$

$$\text{SEF} = 0,08$$

$$\text{TF} = 0,08$$

$$\text{NR} = \text{CF} + \text{BCF} + \text{TF} + \text{SEF} = 0,09 + 0,25 + 0,08 + 0,08 = 0,5$$

$$\text{Potential Grazing Capacity} = 2,7\text{AU ha}^{-1}$$

$$\text{Current Grazing Capacity} = \text{PGC} * \text{NR} = 2,7\text{AU ha}^{-1} * 0,5 = 1,35\text{AU ha}^{-1}$$

Appendix 14: Evaluation sheet for calculating the veld condition score of the unburnt KZNSS patches

| <u>Species</u>                   | <u>Grazing Value</u> | <u>Benchmark %</u> | <u>Benchmark score</u> | <u>Sample site %</u> | <u>Sample site score</u> |
|----------------------------------|----------------------|--------------------|------------------------|----------------------|--------------------------|
| <b><u>Decreaser</u></b>          |                      |                    |                        |                      |                          |
| <i>Brachiaria serrata</i>        | 3                    | 1                  | 3                      |                      |                          |
| <i>Diheteropogon amplexans</i>   | 8                    | 2                  | 16                     | 0,38                 | 3                        |
| <i>Themeda triandra</i>          | 10                   | 25                 | 250                    | 7,31                 | 73,13                    |
| <i>Digitaria eriantha</i>        | 7                    |                    |                        | 11,13                | 77,88                    |
| <i>Andropogon appendiculatus</i> | 5                    |                    |                        | 0,25                 | 1,25                     |
| <i>Panicum natalense</i>         | 2                    |                    |                        | 5,38                 | 10,75                    |
| <i>Melinis nerviglumis</i>       | 2                    |                    |                        | 0,13                 | 0,25                     |
| <i>Monocymbium cerasiiforme</i>  | 6                    |                    |                        | 2,56                 | 15,38                    |
| <b>Total</b>                     |                      | <b>28</b>          | <b>269</b>             | <b>27,13</b>         | <b>181,63</b>            |
| <b><u>Increaser I</u></b>        |                      |                    |                        |                      |                          |
| <i>Alloteropsis semialata</i>    | 3                    | 1                  | 3                      |                      |                          |
| <i>Digitaria tricholaenoides</i> | 6                    | 12                 | 72                     |                      |                          |
| <i>Setaria nigrirostris</i>      | 5                    | 6                  | 30                     |                      |                          |
| <i>Trachypogon spicatus</i>      | 3                    | 1                  | 3                      |                      |                          |
| <i>Tristachya leucothrix</i>     | 9                    | 25                 | 225                    | 0,75                 | 6,75                     |
| <i>Paspalum urvillei</i>         | 7                    |                    |                        | 0,63                 | 4,38                     |
| <i>Hyparrhenia filipendula</i>   | 5                    |                    |                        | 0,88                 | 4,38                     |
| <i>Cymbopogon excavatus</i>      | 1                    |                    |                        |                      | 0                        |
| <b>Total</b>                     |                      | <b>45</b>          | <b>333</b>             | <b>2,25</b>          | <b>15,50</b>             |
| <b><u>Increaser IIa</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis capensis</i>       | 2                    | 4                  | 8                      | 0,75                 | 1,5                      |
| <i>Harporchloa falx</i>          | 3                    | 1                  | 3                      | 0,13                 | 0,38                     |
| <i>Heteropogon contortus</i>     | 6                    | 2                  | 12                     | 0,13                 | 0,75                     |
| <b>Total</b>                     |                      | <b>7</b>           | <b>23</b>              | <b>1,00</b>          | <b>2,63</b>              |
| <b><u>Increaser IIb</u></b>      |                      |                    |                        |                      |                          |
| <i>Eragrostis chloromelas</i>    | 2                    | 2                  | 4                      |                      |                          |
| <i>Eragrostis curvula</i>        | 5                    | 1                  | 5                      | 2,81                 | 14,06                    |
| <i>Eragrostis gummiflua</i>      | 2                    | 1                  | 2                      |                      |                          |
| <i>Eragrostis plana</i>          | 2                    | 1                  | 2                      | 0,13                 | 0,25                     |
| <i>Eragrostis racemosa</i>       | 2                    | 4                  | 8                      | 2,19                 | 4,38                     |
| <i>Hyparrhenia hirta</i>         | 6                    | 1                  | 6                      | 2,19                 | 13,13                    |
| <i>Sporobolus africanus</i>      | 3                    | 2                  | 6                      |                      |                          |
| <i>Setaria sphacelata</i>        | 6                    |                    |                        | 2,25                 | 13,5                     |
| <i>Sporobolus pyramidalis</i>    | 2                    |                    |                        | 0,06                 | 0,13                     |
| <b>Total</b>                     |                      | <b>12</b>          | <b>33</b>              | <b>9,63</b>          | <b>45,44</b>             |
| <b><u>Increaser IIc</u></b>      |                      |                    |                        |                      |                          |
| <i>Aristida congesta</i>         | 0                    | 1                  | 0                      |                      |                          |
| Forbs                            | 0                    | 2                  |                        | 14,75                | 0                        |
| Sedges                           | 0                    | 2                  |                        | 4,06                 | 0                        |
| <i>Paspalum dilatatum</i>        | 7                    |                    |                        | 0,38                 | 2,63                     |
| <b>Total</b>                     |                      | <b>5</b>           | <b>0</b>               | <b>33,5</b>          | <b>0</b>                 |

| <b>Increaser III</b>        |   |            |             |             |               |
|-----------------------------|---|------------|-------------|-------------|---------------|
| <i>Aristida junciformis</i> | 0 |            |             | <b>35,1</b> | <b>0</b>      |
| <i>Elionurus muticus</i>    | 0 | 3          | 0           |             |               |
| <b>Total</b>                |   | <b>3</b>   | <b>0</b>    | <b>35,1</b> | <b>0</b>      |
| <b>Others</b>               |   |            |             |             |               |
| <i>Cymbopogon validus</i>   | 1 |            |             | 1,88        | 1,88          |
| <i>Imperata cylindrica</i>  |   |            |             | 3,75        |               |
| <i>Oplismenus hirtellus</i> |   |            |             | 0,06        |               |
| <b>Total</b>                |   |            |             | <b>5,69</b> | <b>1,88</b>   |
| <b>Grand Totals</b>         |   | <b>100</b> | <b>658</b>  | <b>100</b>  | <b>249,69</b> |
| <b>Score</b>                |   |            | <b>100%</b> |             | <b>37,95%</b> |
| <b>Basal cover</b>          |   |            | <b>14</b>   |             | <b>13,98</b>  |

### CALCULATIONS:

$$\text{Distance}(D) = 1,99\text{cm}$$

$$\text{Diameter}(d) = 1,29\text{cm}$$

$$\text{VCS} = (\text{total sample score} / \text{total benchmark score}) * 100\% = (249,69 / 658) * 100\% = 37,95\%$$

$$\text{BCB} = 14\%$$

$$\text{BCS} = 19,8 + 0,39(D) - 11,87(\log_e D) + 0,64(d) + 2,93(\log_e d) = 19,8 + 0,39(1,99) - 11,87(\log_e 1,99) + 0,64(1,29) + 2,93(\log_e 1,29) = 13,98\%$$

$$\text{BCF} = -0,75 + 2(\text{BCS}/\text{BCB}) - (\text{BCS}/\text{BCB})^2 = -0,75 + 2(13,98 / 14) - (13,98 / 14)^2 = 0,25$$

$$\text{CF} = 0,25((\text{VCS} + \text{number of units of Increaser I species in excess of the benchmark})/100) = 0,25((37,95 + 2) / 100) = 0,1$$

$$\text{SEF} = 0,08$$

$$\text{TF} = 0,08$$

$$\text{NR} = \text{CF} + \text{BCF} + \text{TF} + \text{SEF} = 0,1 + 0,25 + 0,08 + 0,08 = 0,51$$

$$\text{Potential Grazing Capacity} = 2,7\text{AU ha}^{-1}$$

$$\text{Current Grazing Capacity} = \text{PGC} * \text{NR} = 2,7\text{AU ha}^{-1} * 0,51 = 1,38\text{AU ha}^{-1}$$