The effect of fire on savanna vegetation dynamics in the semi-arid Molopo Bushveld region of the North-West Province, South Africa

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ABSTRACT

Land degradation in semi-arid areas is a worldwide phenomenon. Both land users and researchers have become increasingly aware of the environmental changes that occur over time due to land degradation. Among such changes, bush encroachment results from land degradation, especially in savanna rangeland areas. Fire is known as a major driver of the dynamics of woody and herbaceous vegetation dynamics in the savanna biome. A workshop held in Potchefstroom, North-West Province, South Africa, in 2015 for the IDESSA project (IDESSA: An integrative decision-support system for sustainable rangeland management in southern African savannas) within the BMBF (German Federal Ministry of Education and Research) SPACES framework (SPACES: Science Partnerships for the Assessment of Complex Earth System Processes) indicated that more in-depth scientific information was needed on the potential role of fires in the dynamics and shaping of the savanna vegetation of the Molopo Bushveld region in the North-West Province, which is a semi-arid area. Several studies have indicated the potential use of fire to maintain the balance between woody and grass species and to prevent bush encroachment. However, information is limited with regards to this specific area.

The study area comprised three locations, namely the Molopo Nature Reserve (Molopo), Khamab Reserve (Khamab) and a commercial cattle farm (Farm) in the Molopo Bushveld region. Each area was divided into reference and burnt sites. The reference sites included unburnt sites within the Molopo and Khamab area and burnt sites within the Farm area as there were no non-burnt sites within the Farm area. The first objective of this study was therefore to assess the effects of fire on the vegetation composition and structure in the Molopo Bushveld region. This objective was achieved by conducting vegetation surveys that included the use of belt transects for the woody component and a step-point method for the herbaceous component. The second objective was to evaluate the use of fire as a management tool to make long-term predictions and management decisions in semi-arid savanna areas. This objective was achieved by using semi-structured interviews with land users and questionnaires which included relevant questions regarding management, vegetation, rainfall, causes of fires and damage suffered due to the fire; as well as by analysing and comparing the gathered quantitative and qualitative data. Considering the various studies done on the influence of fire on savanna vegetation, the hypothesis for this study was that fire events influence the structure and composition

of the vegetation in semi-arid savanna regions and can be used as a management tool, especially in terms of land degradation caused by bush encroachment.

The results indicated vegetation differences within reference and burnt sites. However, the results were inconsistent, except for *Grewia flava*, which had higher densities in burnt sites than in reference sites. The inconsistency within the data regarding species composition for all three areas (Molopo, Khamab and Farm) may be due to different management practices and the type of animal being kept (i.e. game or livestock), as some areas were grazed and others browsed. With regards to the overall woody density, the burnt sites had lower woody densities compared to that of the reference sites with some sites showing significant differences. The sites with the lowest overall woody densities were chemically controlled reference and burnt sites.

Differences in canopy volume were also observed between the reference and burnt sites, but no consistent differences were observed between species and sites. This may be due to the differences in when fires occurred, meaning that some species could either have recovered or were browsed over a longer period by the time that the surveys were done. Regarding herbaceous species composition, a clear distinction occurred between the sampling areas (Molopo Nature Reserve, Khamab Reserve and commercial cattle farm) according to canonical correlation analyses. This was presumably mainly due to the different management strategies within each site rather than the influence of fire however differences in soil types and rainfall across the sites should not be excluded from having influenced the vegetation. Due to these differences, the results for the study sites were discussed separately. The commercial cattle farm had the highest woody species richness, which may be due to the dispersal of seeds by cattle, whereas the two nature reserves had lower woody species richness, which may be due to the presence of both browsers and grazers rather than just grazers.

The results indicated that most land users had no management strategy prior to or after the fires. Some land users did, however, reduce their stock after the occurrence of a fire or started rotating/resting their camps. The land users' observations of vegetation were varied, which may be due to how they perceived their land and whether the land is overgrazed/browsed. However, most land users agreed that *G. flava* increased after a fire, corresponding to the vegetation surveys conducted. Most land users also stated that the amount of rainfall was not higher prior to the fire occurring, but most land users did not keep records and the land-users' memories are not necessarily accurate after a time

has passed since the fire event. Most land users were opposed to the use of fire as a management strategy for woody vegetation, as they did not want to lose valuable grazing and, with rainfall being unpredictable in the area, they excluded fire management completely.

The first part of the hypothesis, namely that fire events influence the structure and composition of vegetation in semi-arid savanna regions, was accepted based on this study's results as there were differences in the vegetation within the reference and burnt sites, however not significant differences. The second part of the hypothesis, namely that fire can be used as a management tool, especially in terms of land degradation caused by bush encroachment, was accepted to some extent, as it was dependent on the specific area. More information with regards to fire frequency, the exclusion of fire by land-users, management practices in the area and the effects of frequent fires should be gathered with regards to the semi-arid Molopo Bushveld region.

Keywords: Fire; bush encroachment; geographic information systems (GIS); grass-to-woody ratio; indigenous knowledge.

OPSOMMING

Gronddegradasie in semi-ariede areas is ’n wêreldwye verskynsel. Beide grondgebruikers en navorsers is al meer bewus van die omgewingsveranderings wat, as gevolg van gronddegradasie, oor tyd voorkom. Ingesluit in hierdie veranderinge is bosverdigting wat die gevolg van gronddegradasie, veral in savanna weiveldgebiede, is. Brand is daarvoor bekend dat dit 'n belangrike drywer van die dinamika van houtagtige en kruidagtige plante in die savannabioom is. ’n Werkswinkel wat in Potchefstroom, Noordwes Provinsie, Suid-Afrika, in 2015 vir die IDESSA projek (IDESSA: An integrative decision-support system for sustainable rangeland management in southern African savannas) tesame met die BMBF (Duitse Federale Ministerie van Onderwys en Navorsing) SPACES raamwerk (SPACES: Science Partnerships for the Assessment of Complex Earth System Processes) gehou is, het aangedui dat meer in-diepte wetenskaplike inligting oor die potensiële rol van brand in die dinamika en vorming van die savanna weivelde van die Molopo Bosveldstreek in die Noordwes Provinsie, wat 'n semi-ariede area is, benodig word. Verskeie studies het op die potensiële gebruik van brand gewys om die balans tussen houtagtige en grasse te handhaaf en om bosverdigting te voorkom, maar inligting met betrekking tot hierdie spesifieke area is beperk.

Die studie-area het uit drie gebiede, naamlik die Molopo Natuurreservaat (Molopo), Khamab Reservaat (Khamab) en ’n kommersiële beesplaas (Farm) in die Molopo Bosveldstreek bestaan. Elke area het uit verwysing- en gebrande persele bestaan. Die verwysings persele sluit nie-gebrande persele in die Molopo en Khamab area en gebrande persele in die Farm area insluit omrede daar geen nie-gebrande persele in die Farm area was nie. Die eerste doelwit van hierdie studie was om die effek van brand op die plantsamestelling en -struktuur in die Molopo Bosveldstreek te evalueer. Hierdie doelwit is bereik deur plantopnames uit te voer deur van lyntransekte vir die houtagtige komponent en 'n stappuntmetode vir die kruidagtige komponent gebruik te maak. Die tweede doelwit was om die gebruik van brand as 'n bestuurspraktyk te evalueer om langtermynvoorspellings en bestuursbesluite in semi-ariede savanna-gebiede te maak. Hierdie doelwit is bereik deur van semi-gestruktureerde onderhoude met grondgebruikers gebruik te maak asook vraelyste wat toepaslike vrae aangaande bestuur, plantegroei, reënval, oorsaak van brande en skade as gevolg van die brand ingesluit het; asook deur die versamelde kwantitatiewe en kwalitatiewe data te analiseer en te vergelyk. Met inagneming van die verskeie studies wat oor die invloed van brand op

savannaplantegroei gedoen is, was die hipotese vir hierdie studie dat brand die struktuur en samestelling van die plantegroei in semi-ariede savanna streke beïnvloed en as 'n bestuurspraktyk, veral ten opsigte van gronddegradasie wat deur bosverdigting veroorsaak word, gebruik kan word.

Die resultate het aangedui dat daar verskille in plantegroei in die verwysing- en gebrande persele is. Die resultate was egter nie konsekwent nie, behalwe vir *Grewia flava*, wat hoër digthede in gebrande persele gehad het as in die verwysingspersele. Die inkonsekwentheid in die data rakende spesiesamestelling vir al drie gebiede (Molopo, Khamab en Farm) kan as gevolg van verskillende bestuurspraktyke en die tipe diere wat aangehou word (dit wil sê wild of vee) wees, aangesien sommige areas se gras bewei is en in ander areas is die houtagtige plante se blare gevreet. Met betrekking tot die algehele houtagtige digtheid het die gebrande persele laer houtagtige digthede vergeleke met dié van die verwysingspersele gehad met sommige persele wat betekenisvolle verskille aangedui het. Die persele met die laagste algehele houtagtige digthede was chemies beheerde verwysing- en gebrande persele.

Verskille in volume van die blaardak is ook tussen die verwysing- en gebrande persele se houtagtige plante waargeneem, maar geen konsekwente verskille is tussen spesies en persele waargeneem nie. Dit kan wees as gevolg van die verskillende tye wat die brande plaasgevind het, wat beteken dat sommige spesies óf herstel het óf oor 'n langer tydperk gevreet was teen die tyd dat die opnames gedoen is. Met betrekking tot kruidagtige spesiesamestelling, was daar 'n duidelike onderskeid tussen die opname-areas (Molopo Natuurreservaat, Khamab Reservaat en kommersiële beesplaas) volgens die Kanoniese korrelasie-analises ("Canonical Correspondance Analysis"). Dit was waarskynlik as gevolg van die verskillende bestuurstrategieë binne elke area eerder as die invloed van brand maar verskille in grondsoorte en reënval oor die areas moet nie uitgesluit word as aspekte wat die plantegroei kon beïnvloed nie. As gevolg van hierdie verskille, was die resultate van die studie areas apart bespreek Die kommersiële beesplaas het die hoogste houtagtige spesie rykheid gehad, vermoedelik as gevolg van die verspreiding van sade deur beeste, terwyl die twee natuurreservate laer houtagtige spesie rykheid gehad het, wat moontlik die gevolg van die teenwoordigheid van beide blaarvreters en grasvreters eerder as slegs grasvreters is.

Die resultate het aangedui dat die meeste grondgebruikers voor of na die brande geen bestuurstrategieë gehad het nie. Sommige grondgebruikers het egter hul vee na die brand verminder of hul kampe begin roteer/rus. Die grondgebruikers se waarnemings oor die plantegroei het verskil - dit kan wees as gevolg van hoe hulle die grond waarneem en ook of die grond oorbewei is. Die meeste grondgebruikers het egter saamgestem dat *G. flava* na 'n brand toegeneem het, wat met die plantegroei-opnames wat uitgevoer is, ooreenstem. Die meeste grondgebruikers het ook aangetoondat die hoeveelheid reënval nie hoër was voordat die brande plaasgevind het nie, maar die meeste grondgebruikers het nie rekords gehou nie en die grondgebruikers se geheue is nie noodwendig akkuraat na die tydsverloop sedert die brand plaasgevind het nie. Die meeste grondgebruikers was teen die gebruik van brand as 'n bestuurstrategie vir houtagtige plantegroei gekant, aangesien hulle nie waardevolle weiding wou verloor nie en omdat die reënval onvoorspelbaar in die gebied is, hulle het dus brandbestuur geheel en al uitgesluit.

Die eerste deel van die hipotese, naamlik dat brand die struktuur en samestelling van plantegroei in semi-ariede savannastreke beïnvloed, is op grond van die resultate van hierdie studie aanvaar aangesien daar verskille in die plantegroei in die verwysings- en gebrande persele was, alhoewel meeste van die verskille nie statisties betekenisvol was nie. Die tweede deel van die hipotese, naamlik dat brand as 'n bestuursinstrument, veral in terme van gronddegradasie as gevolg van bosverdigting, gebruik kan word, is tot 'n mate aanvaar, aangesien dit van die spesifieke gebied afhanklik was. Meer inligting ten opsigte van frekwensie van brande, die uitsluiting van brand deur grondgebruikers, bestuurspraktyke in die gebied en die effek van gereelde brande moet met betrekking tot die semi-ariede Molopo Bosveldstreek versamel word.

Sleutelterme: Brand; bosverdigting; geografiese inligtingstelsels (GIS); gras-tot-houtagtige verhouding; inheemse kennis.

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CHAPTER 1: INTRODUCTION

1.1 General introduction

Land degradation in semi-arid areas is a worldwide phenomenon and both land users and researchers have become increasingly aware of the environmental changes that occur over time as a result (Dregne, 2002; Gisladottir & Stocking, 2005). Among such changes, land degradation leads to bush encroachment, especially in savanna rangeland areas (Hoffman & Ashwell, 2001). Bush encroachment involves an imbalance in the woody-to-grass ratio due to increased woody density, usually resulting from mismanagement, and is observed in savannas worldwide (Smit, 2004), including the semi-arid Kalahari region in southern Africa (Dougill & Thomas, 2004; Harmse *et al*., 2013; Kgosikoma *et al*., 2012). Bush encroachment commonly leads to a loss of forage production, biodiversity and ecosystem stability (Blaum *et al*., 2007; Smit, 2004; Kgosikoma *et al*., 2012). Furthermore, decreased perennial grass cover and biomass production lead to decreased carrying capacity in the specific area and have negative economic implications for grazing-based farming enterprises (Trollope, 1980; Dougill *et al*., 1999; Tainton, 1999; Ward, 2005; Blaum *et al*., 2007).

In savanna areas where bush encroachment occurs, the ratio of tree to grass biomass is disturbed, often reducing the number of climax, palatable and perennial grasses, which negatively influences the carrying capacity of farmland and the profitability of the farming enterprise (O'Connor *et al*., 2014; Wiegand *et al.*, 2006). The encroachment of woody species in the Molopo Bushveld region was first recorded in the 1960s, with more than 856 700 ha of rangeland already having been impacted by bush encroachment (Donaldson, 1967). Smit (2004) stated that Moore *et al.* (1985) found a reduction in the growth of the grass layer with an increased number of woody species in the Shrub Bushveld and Thornveld of the Molopo Bushveld region. Smit (2004) also stated that Moore and Odendaal (1987) found that if woody species have a density of up to 200 individuals/ha, the grass layer was not impacted. However, a decrease in grass layer production occurred linearly with a further increase in woody species; Richter (1991) and Richter *et al.* (2001) reported similar results in the Molopo Bushveld region. Moreover, woody density increases (bush encroachment) and the composition and structure of woody vegetation change due to a lack of frequent fires (Smit, 2004; Wiegand *et al*., 2006; Higgins *et al*., 2007; Gordijn & Ward, 2014).

Fire is known as a major driver of woody and herbaceous vegetation dynamics in the savanna biome (Trollope *et al*., 2014). Several studies have indicated the potential use of fires to maintain the balance between woody and grass species (Bond *et al.*, 2003; Govender *et al.*, 2006; Smit *et al.*, 2010; Joubert *et al.*, 2012; Gordijn & Ward, 2014). However, despite reports (Donaldson, 1966; O'Connor *et al*., 2014) and local oral histories mentioning the suppression of fire in the Molopo Bushveld region as a major cause of the severe bush encroachment problem in the area, little research has been done in this respect. Most research on the effects of fire on savanna ecosystems has been carried out in mesic areas, where the use of controlled fire (by management) and wildfires played a crucial role in determining the type and structure of the woody species (Sankaran *et al*., 2004; Joubert *et al*., 2012).

Little is therefore known about the impacts of fires in semi-arid savannas (with mean annual rainfall of <650 mm), where the main determinant of vegetation composition and structure is rainfall. A study by Trollope *et al.* (2014) on both moist and arid areas of the Kruger National Park in South Africa indicated that, on the one hand, moist savanna areas showed improved rangeland condition in terms of their increaser and decreaser grass ratios after regular burning and under grazing by wildlife, but, on the other and, that there was a decrease in rangeland condition after regular burning and under grazing by wildlife in arid sites, which emphasises the importance of more research on fire in semi-arid areas.

Scholes (1997) and Govender *et al*. (2006) indicated that if fires do not occur in African savannas, such areas may develop into closed woodland areas, depending on the precipitation. Van Langevelde (2003) states that an intense fire directly affects the woody vegetation cover and structure of such ecosystems due to an increase in tree mortality and a reduction in tree size. Fires often destroy herbaceous vegetation while larger trees remain largely unaffected, depending on the type and severity of the fire (Van Langevelde, 2003; Bond & Keeley, 2005; Govander *et al.*, 2006). Fire is thus used as a management tool in many African savannas for acceptable grass–tree coexistence and control of bush encroachment (Trollope, 1982; Govender *et al*., 2006; O'Connor *et al*., 2014).

At a workshop held in Potchefstroom, North-West Province, on 26 June 2015 for the IDESSA[1] project within the BMBF[2]–SPACES framework[3] it was identified that more in-depth scientific information was needed on the potential role of fire in the dynamics and shaping of the savanna vegetation in the Molopo Bushveld region, which is a semi-arid savanna area.

The IDESSA project aims to understand how savanna dynamics change due to management practices and *vice versa*. IDESSA further aims to improve understanding of the complex interplay between management and environmental changes and to implement an integrative monitoring and decision-support system for the sustainable management of different savanna areas in southern Africa (http://www.idessa.org/). IDESSA falls within the SPACES research programme and has three subprojects, namely Subprojects 1 (monitoring), 2 (management and restoration) and 3 (database and analysis system). The research for this study formed part of Subproject 2, which entails the creation of a tool that can be used to assess the effects of fire in the restoration and management of savanna areas. This subproject includes the development of a savanna simulation model, which will assist with predictions of the response of vegetation to disturbances and their interactions (for example rainfall patterns, fire and grazing management) in mesic to arid savanna types.

This study contributes to the development of the DSS[4] for the IDESSA project and will assist farmers in making scientifically sound decisions over the long-term. The model is currently being developed by Mr Bastian Hess, a PhD student of Prof Kerstin Wiegand from the University of Göttingen. The draft title of the PhD study is ‘Modelling, management and restoration of grassland savannas in southern Africa’. This model is based on the model developed by Mr Sebastian Hanss (‘Across farms and scales: modelling vegetation change in a semiarid rangeland’) at the Friedrich Schiller University in Jena, Germany, also under the supervision of Prof Wiegand.

Models are used to make predictions about vegetation dynamics by focusing on mechanisms and processes that can cause changes in vegetation communities. These computer simulations use a set of rules that predict the outcomes of certain interactions

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[1] IDESSA: An integrative decision-support system for sustainable rangeland management in southern African savannas

[2] BMBF: German Federal Ministry of Education and Research

[3] SPACES: Science Partnerships for the Assessment of Complex Earth System processes

[4] DSS: Decision Support System

of individual plants in a community, referred to as community dynamics (Wiegand & Milton, 1996; Wiegand *et al*., 1995; Jeltsch *et al*., 1999).

Two types of models have generally been accepted for explaining the co-existence of trees and grasses in savannas, namely competition-based and demographic-bottleneck models (Sankaran *et al.*, 2004; Meyer *et al.*, 2009; Murphy *et al.*, 2010). Competition-based models are based on certain mechanisms that limit resources, such as water, whereas demographic-bottleneck models are based on mechanisms or disturbances, such as grazing, fire and variable rainfall. Fire regimes can be included in both types of model. For example, in competition-based models, fire is accepted as a modifier of savanna vegetation structure and in demographic-bottleneck models fire can be accepted as both a maintainer and a modifier of the savanna vegetation structure (Van Langevelde *et al*., 2003; Sankaran *et al*., 2004; Riginos, 2009).

Lastly, since bush encroachment is perceived as an indicator of rangeland degradation (Kgosikoma *et al.*, 2012), effective management plans to combat it are important for sustainable rangeland management (Richter *et al.*, 2001). Dreber *et al.* (2014) emphasise the importance of including land users' perceptions when combating land degradation. Therefore, apart from the focus on vegetation structure, this study also included local land users' perceptions on how fire is used as a tool in savanna rangeland management. The indigenous knowledge of land users, managers and extension officers was used to investigate the effects of fire frequency on the vegetation dynamics in the Molopo Bushveld region, North-West Province, South Africa.

1.2 Main objectives

The two main objectives for this study were as follows:

1. To assess the effects of fire on the vegetation composition and structure in the Molopo Bushveld region. (Objective 1 was achieved by conducting vegetation surveys quantitatively that included the use of belt transects for the woody component and a step-point method for the herbaceous component).

2. To evaluate how fire can be used as a management tool to make long-term predictions and management decisions in semi-arid savanna areas. (Objective 2 was achieved qualitatively by (1) semi-structured interviews with land users and questionnaires and (2) analysing and comparing the data obtained via various methods).

1.3 Hypothesis

Considering the various studies done on the influence of fire on savanna vegetation, the hypothesis for this study was that fire influences the structure and composition of the vegetation in semi-arid savanna regions and can be used as a management tool, especially in terms of land degradation caused by bush encroachment.

1.4 Dissertation structure and content

This dissertation consists of six chapters. Chapter 1 gives a short introduction to the study and states the objectives. Chapter 2 contains the literature review, which highlights several important topics necessary for understanding the outcomes of this study, for example the savanna biome in Southern Africa, the phenomena of woody shrub and tree encroachment, the role of fires in shaping savanna ecosystems, the influence of fire on grazing-based enterprises, the use of geographic information systems, mapping and aerial photography in scientific studies and the use of local and indigenous knowledge for research purposes. Chapter 3 provides background information on the study area and Chapter 4 describes the methods used to gather and analyse the data to achieve the objectives. Chapter 5 describes and discusses the quantitative and qualitative results and Chapter 6 contains the conclusion and recommendations. The dissertation ends with a reference list, followed by the appendices.

CHAPTER 2: LITERATURE REVIEW

2.1 Savanna biome in South Africa

The South African savanna is located from approximately 34°S in the Eastern Cape Province and spreads northwards along the eastern parts of the country. At 26°S, the savanna biome stretches westward towards Namibia (Figure 2.1) (Cowling *et al.*, 1997). The savanna biome is one of the largest terrestrial biomes on earth and consists of a mixture of grassland and woodland cover (Beerling & Osborne, 2006). Approximately 32.8% (399 600 km^2) of the total land surface in South Africa comprises this biome (Rutherford *et al.*, 2006).

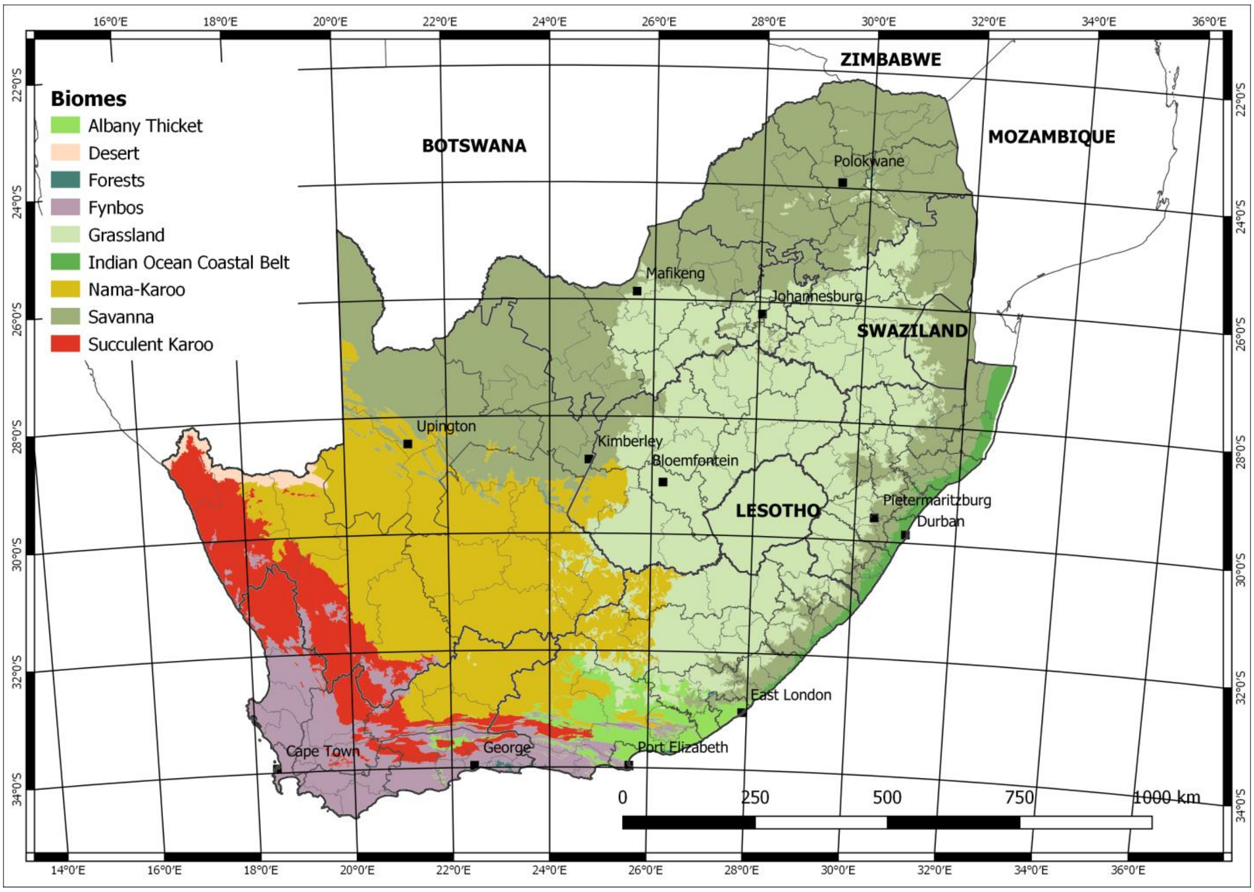

Figure 2.1: Map indicating the biomes of South Africa, Lesotho and Swaziland (Mucina & Rutherford, 2006).

Savannas consist of a lower grass layer and an upper woody layer (which usually covers less than 75% of the area). The ratio of grasses to woody plants is determined by factors such as herbivory, drought, fire, availability of soil nutrients and soil moisture (Low & Rebelo, 1998; Van Langevelde *et al.*, 2003; Beerling & Osborne, 2006; Rutherford *et al.*, 2006; Wiegand *et al.*, 2006). The woody-to-grass ratio is a defining characteristic of savannas and is sensitive to disturbances. An imbalance in this ratio can occur due to the factors mentioned above. Imbalances may cause an increase in the density of the woody vegetation, which is referred to as bush encroachment. The theory of how bush encroachment occurs is that the grass layer absorbs moisture from the upper part of soil, whereas the woody layer absorbs moisture from the deeper soil due to the extended and deep root system of woody species (Van Langevelde *et al.*, 2003; Ward, 2005; Wiegand *et al.*, 2005; O'Connor *et al.*, 2014). When the grass layer is removed, the competition for soil moisture between the grass and woody layers is also removed, favouring the root system of the woody species, which can lead to an increase in the woody density, or bush encroachment (Van Langevelde *et al.*, 2003; Ward, 2005; Wiegand *et al.*, 2005; O'Connor *et al.*, 2014).

The savanna biome in southern African is affected by the macroclimatic conditions of the Indian and Atlantic Oceans. Characteristics of the macroclimatic conditions of southern African savannas include a specific season of precipitation, namely wet summer months and dry winter months, and subtropical climates with little to no frost (Rutherford *et al*., 2006; Van Oudtshoorn, 2015). Savanna ecosystems are mainly found at altitudes lower than 1 500 m, but in the Highveld region of South Africa they are found at up to 1 800 m, meaning that the temperatures of the lower-lying savannas are usually higher than the adjacent savanna biomes at higher altitudes. The temperature in the savanna biome differs considerably. In the Kalahari area, temperatures usually exceed 32 °C and do not usually drop below 26 °C (mean daily maximum temperature). In the winter months (June and July), this temperature usually remains above 20 °C. The savanna biome also has a distinct dry season, where the amount of rainfall is usually less than 5 mm in June, July and August with a mean annual precipitation of 650 mm (Du Toit & Cumming, 1999; Rutherford *et al*., 2006).

In southern Africa, the savanna biome is mainly underlain by the Kaapvaal Craton (Rutherford *et al*., 2006). The Kaapvaal Craton is a stable mass of ancient continental crust that is mostly unaffected by crustal processes except on the outer edges. It was formed approximately 3.5 billion years ago as a result of accretion, contains igneous intrusions and sedimentary basins and is covered by younger rocks (McCarthy & Rubidge, 2005; Rutherford *et al*., 2006). Soils vary within the different savanna areas and include red sandy soils, clayey soils, rocky areas with shallow soils and plinthic soils. Vegetation and soils interact more closely in drier areas, such as the savannas in South Africa, than they do in more humid biomes. The availability of water is highly dependent on soil characteristics in areas where water is a limiting factor, thus influencing the ratio between woody and grass species. In the Kalahari region, deeper soils dominate, thus allowing the survival of trees and shrubs in this low rainfall savanna area (Rutherford *et al*., 2006).

Furthermore, herbivory has a relatively large impact on the establishment and recruitment of woody species in savannas, for example, overgrazing may lead to an increase in woody species, as space and resources previously used by grass species become available for woody seedlings. Total withdrawal of grazers may also lead to an increase in woody species, as perennial grass species may die off due to a competition for moisture and light, which causes an increase in annual grass and woody. However, browsing animals may decrease the size and number of woody species (Thomas & Twyman, 2004). An example of the influence of herbivores on vegetation was observed with the 19th century rinderpest pandemic in East Africa, which led to a large decline in game and livestock numbers as well as the human population due to starvation, ultimately resulting in an increase in woody species due to reduced grazing, browsing and anthropogenic fires, which are necessary to maintain the grass–tree ratio (Van Langevelde *et al.*, 2003).

The interactions between grazing livestock and the savanna ecosystem are complex. Just enough grazing pressure leads to an increase in the biomass of perennial grass species (Thomas & Twyman, 2004). However, excessive grazing leads to a decrease in palatable perennial grasses, for example, *Centropodia glauca* (Gha grass), and an increase in less palatable annual grasses, such as *Schmidtia kalihariensis* (Kalahari sour grass) (Thomas & Twyman, 2004). This leads to reduced ground cover and can cause shrub and bush species to become dominant (bush encroachment) because of the deeper percolation of water to their rooting depths and higher nutrient availability (Thomas & Twyman, 2004). Overgrazing also leads to a decrease in biomass and fuel, thus decreasing the chances for intense fires and negatively affecting the recruitment of woody species. Tree seeds can germinate relatively easily if the upper grass layer is removed and can form thickets that are rarely browsed by livestock (Skarpe, 1991; Scholes & Archer, 1997; Van Langevelde *et al.*, 2003; Kraaij & Ward, 2005; Botha, 2008; Kgosikoma *et al*., 2012).

According to O'Connor and Pickett (1992), over-utilisation of palatable perennial grasses may lead to the complete extinction of these species in a specific area, especially if the species produce small numbers of seeds, only reproduce with seeds or if seed viability decreases relatively fast; this may then lead to the eradication of the species from the seed bank if grazing is not managed. If livestock and/or game farming is the main agricultural practice in an area, the ratio of woody to grass species should be understood and well managed (Kgosikoma *et al.*, 2012; Dreber *et al.*, 2014).

2.2 Bush encroachment

Several definitions exist for bush encroachment (Dougill *et al.*, 1999; Richter *et al.*, 2001; Smit, 2004; Ward, 2005; Kraaij & Ward, 2006; Dreber *et al.*, 2014; O'Connor *et al.*, 2014), but for the purpose of this study it can be defined as an increase in the density of indigenous woody species in a specific area. Bush encroachment is a wide-spread problem associated with the degradation of rangelands, especially in arid and semi-arid areas in southern Africa, due to a loss of grass cover and productivity (Smit, 2004; Sandhage-Hoffman *et al*., 2015). Land degradation is defined by Bai *et al.* (2008) as 'long-term loss of ecosystem function and productivity caused by disturbances from which land cannot recover unaided'. Furthermore, since degradation occurs slowly over a long period of time, it often goes unnoticed or is ignored by the land user until extensive damage has occurred (Hoffman & Ashwell, 2001).

An example that is frequently used to describe certain thresholds with regards to land degradation and bush encroachment is the ball-and-cup model (Figure 2.2). This model explains that certain thresholds exist between stable vegetation conditions. If a threshold is overcome (for example bush encroachment occurs) and the vegetation is consequently in a new stable state (for example bush encroached state), it is difficult for the vegetation to return to the previous state. However, rehabilitation can be performed to achieve a rehabilitated state (for example bush encroachment is managed) (Briske *et al.*, 2003; Briske *et al.*, 2006).

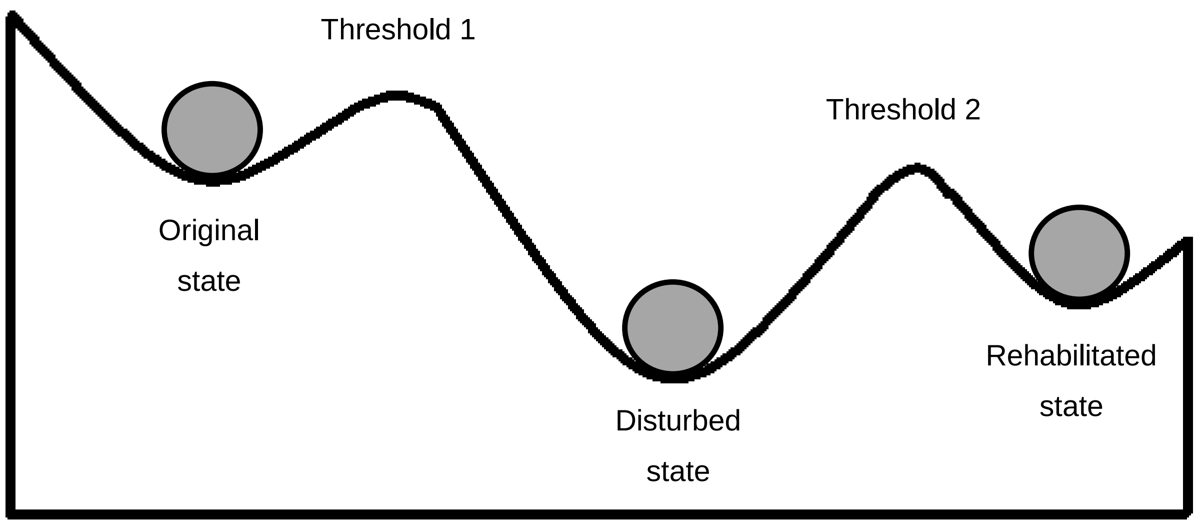

Figure 2.2: Illustration of the ball-and-cup model indicating thresholds between stable vegetation conditions (adapted from Briske *et al.*, 2003).

To ensure sustainable livestock production, rangelands should be well managed. However, the use of some rangelands in savanna areas has become unsustainable since bush encroachment has rendered the properties unprofitable (Snyman, 1998; Smit, 2004; Harmse, 2013; Harmse *et al*., 2016). The causes for bush encroachment are poorly understood, but most researchers state that overgrazing, fire suppression, variable and low precipitation and certain soil properties (for example nutrient and moisture content) affect the ratio of woody to grass species (Donaldson, 1966; Ward, 2005; Kgosikoma *et al.*, 2012). Wigley *et al.* (2010) considered three land use management types (communal, commercial and conservation areas) over three time periods (1937, 1960 and 2004) and found that global factors (for example atmospheric nitrogen and CO_2 levels) impact bush encroachment regardless of management practices implemented.

Ward (2005, 2010) and Kgope *et al.* (2010) stated that higher CO_2 levels can lead to increased woody vegetation over time in savannas and lower CO_2 concentrations can limit the growth of woody plants. Kgope *et al.* (2010) also indicated that woody plants can recover more easily after a fire or intensive grazing/browsing in areas that are rich in CO_2. This is mainly because CO_2 increases the effectiveness of water use, as transpiration is reduced, thereby conserving soil moisture and aiding woody plant growth (Conradi, 2018).

Other causes of bush encroachment include a lack of browsers that control woody plants, species-specific grazing, where only palatable species are grazed, allowing woody species to establish in certain areas, a lack of trampling, changes in rainfall, the removal of large trees, which leads to the emergence of tree seedlings that compete for space and a loss of soil fertility due to soil erosion (Donaldson, 1996; Smit, 2004; Kraaij & Ward, 2006; Wiegand *et al*., 2006; Van Oudtshoorn, 2015). The financial implications of the removal of woody plants which can occasionally exceed the monetary amount that an area of land is worth can also lead to the further degradation of valuable grazing resources (Donaldson, 1996; Smit, 2004; Kraaij & Ward, 2006; Wiegand *et al*., 2006; Van Oudtshoorn, 2015).

With increased woody cover, the herbaceous layer is suppressed due to competition for moisture, especially in the upper soil layer. Walter (1939) as cited by Ward *et al*. (2013) proposed a two-layer model where the herbaceous layer is more water efficient than woody species with regards to subsurface water, whereas woody species have access to shallow and deeper water sources, reducing the grazing capacity and biodiversity of an area. It should however be noted that this model has some shortcomings, for example a site in Namibia, where the soil is too shallow to allow the separation of roots, indicated tree-grass coexistence. The two-layer model also does not include the recruitment phase of tree seedlings (Meyer *et al.*, 2009).

Livestock production is generally negatively affected by bush encroachment, as the encroaching woody species are usually unpalatable to grazers (which mainly feed on the herbaceous component). Farmers then seek methods to decrease the woody component to increase the herbaceous component for increased livestock production (Ward, 2005; Wiegand *et al.*, 2005; Kgosikoma *et al.*, 2012). Bush encroachment is a severe problem in semi-arid to arid rangelands in southern Africa where the growth of the herbaceous component is largely influenced by the amount of rainfall, the availability of nutrients and the amount of grazing, which in turn may affect the success of using fire to manage the woody component (Ward, 2005; Wiegand *et al.*, 2005; Bond, 2008; Harmse, 2013; Sandhage-Hoffman *et al*., 2015).

Herbivores may have a substantial effect on bush encroachment. Overgrazing often increases the ease with which woody species can encroach into an area, since grazers remove the herbaceous layer, which creates more space for woody species to germinate. Browsers (which mainly feed on the woody component) on the other hand, may reduce bush encroachment by reducing the density of woody species. However, if the animals only feed on palatable woody species, unpalatable species may take their place (Gordijn *et al.*, 2012; O'Connor *et al*., 2014). Most woody species in southern Africa are unpalatable or have certain adaptations to discourage browsing (for example spines and/or toxins), which contribute to the success of their encroachment (Gordijn *et al.*, 2012).

2.3 Role of fire in shaping savanna ecosystems

2.3.1 Impacts of fire on savanna ecosystems

Ecosystems where fire affects the distribution and structure of vegetation are found in several areas throughout the world, with only extreme ecosystems (very humid or very dry ecosystems) excluded (Bond, 2001). Fire is an important factor in savanna ecosystems, as savannas can be considered 'flammable ecosystems', defined as ecosystems where fire considerably influences the species composition, available biomass and ratio of different growth forms (Bond & Keely, 2005). Consequently, fire ecology is defined as the response of abiotic and biotic elements in an ecosystem to a fire regime, for example, for an intense fire to occur, there has to be enough biomass, which is determined by the amount of rainfall and grazing, and the type of fire is determined by wind direction (refer to Section 2.3.2 for a description of different types of fire) (Trollope & Trollope, 2010).

The suppression of fire can lead to changes in species composition and structure in savanna ecosystems, for example, a savanna can develop into a woodland system if fires are withheld (Bond *et al.*, 2002; Bond & Keely, 2005; Govender *et al.*, 2006). Moreover, anthropogenic fires have been used over the past 40 000 years to expose and attract game animals, reduce snake populations, clear land for farming and stimulate grass growth for grazing (Van Oudtshoorn, 2015). This may have been exacerbated in grassland and savanna areas with medium and high annual rainfall. Fire is seldom used as a management practice in areas with low rainfall and when wildfires occur in these areas their impact on vegetation is typically severe due to the erratic rainfall. These areas usually have many annual species and few perennial species, which struggle to survive fire disturbances (Van Oudtshoorn, 2015).

Fire is such an important factor in savanna ecosystems that plants have developed characteristic traits in fire-prone areas. Bond and Keely (2005), for example, state that the fire traits (for example thick bark and coarse roots for easier regrowth) in savanna plants differ from those of plants from Mediterranean shrublands (refer to section 2.3.2 for more information on adaptive traits). The grass layer as well as trees smaller than 2 m are typically affected by fires, therefore the co-existence of trees and grass in savanna ecosystems can be attributed to demographic bottlenecks, where trees occur in different life cycles (i.e. seedlings, saplings, young trees and mature trees). Frequent fires largely lead to these bottlenecks, as they benefit the grass layer over the long term by limiting seedling and sapling survival (Bond & Keely, 2005).

Where little to no grazing occurs, fire is the preferred disturbance for maintaining the grass layer and controlling woody species in high rainfall areas where short forbs and tufted grass species are better adapted to survive frequent fires (Van Oudtshoorn, 2015). In areas where the mean annual rainfall is low (<650 mm), plants are less adapted to survive fires, as fires usually occur less frequently in these areas (Van Oudtshoorn, 2015;

Hesselbarth *et al*., 2018). Woody species are not often completely killed by fires, as they regrow/coppice after a fire. Nonetheless, they can be controlled by frequent fires. Frost and trampling reduce the size of woody species, make the plants more susceptible to fire damage and play an important role in maintaining open savanna and grassland areas (Van Oudtshoorn, 2015).

The intensity, frequency and type of fire, as well as the season in which it occurs, largely characterizes the fire regime. Fire intensity is not easily measured, as it may change due to several factors, such as the season of burning, time of day, slope, temperature, available fuel and wind speed. Determining fire regimes may be difficult if no records are available, but remote sensing has been used to provide records of fire scars, which, together with other records indicating the extent of fires, may determine the fire regime (Govender *et al*., 2006; van Oudtshoorn, 2015). A study conducted by Govander *et al.* (2006) in the Kruger National Park indicated that biomass accumulates according to the amount of rainfall and, without fire, this leads to an equilibrium of fuel loads where the accumulation and decomposition of vegetation are equal. However, a fire removes the biomass before equilibrium can be reached, allowing new vegetation to accumulate (Govander *et al*., 2006).

2.3.2 Adaptive traits and functional types of plants in response to fire

According to Keeley *et al.* (2011), adaptive traits are traits that give organisms an advantage in a specific environment, whereas, according to Pausas (1999), functional types can be described as groups of species with shared adaptive traits for a particular function. Fire adaptations can be described as adaptive traits that arise in response to fire as a result of natural selection (Keeley *et al.*, 2011). Plants in ecosystems where fire is common may obtain certain traits for survival and successful reproduction (Pausas & Keeley, 2014). An example is given by Hoffman *et al.* (2012), where certain woody species may acquire thicker bark during fire suppression periods over a relatively short time when compared to non-fire resistant woody species. The time over which traits develop differs among species, possibly due to variations in growth rate and the ratio of bark to stem radius (Hoffman *et al.*, 2012).

It should, however, be understood that plants develop adaptive traits not specifically due to fires but rather a fire regime that includes fire intensity, fire frequency and the pattern of fuel consumption. Plants with these traits may be threatened if the fire regime is altered (Keeley *et al.*, 2011). Fire has the potential to cause micro- and macro-evolutionary changes within plant species (Pausas & Schwilk, 2012). Macro-evolutionary traits develop over long periods of time (i.e. millions of years) and can be traced through the evolutionary history of plants. For example, seeds may sprout more easily after a fire due to the removal of other plants in the area, thus reducing competition for resources. These species may develop a trait that makes them more flammable, to increase the chances for the development of a hot fire for seeds to sprout. If this trait is heritable, the more flammable plants will be selected and drive trait separation in certain plant communities. Other macro-evolutionary traits may include re-sprouting (for example underground rhizomes) and serotiny (the release of seeds in response to an environmental factor) where the origin can be traced back several million years ago (Pausas & Schwilk, 2012).

According to Keeley *et al.* (2011), species from the Fabaceae family are known for the denseness of their seed coats, which often require an external agent, such as heat from a fire event, for sprouting. Therefore, for fire to be used as a management tool for specific plant species, the traits that they have developed in response to disturbances and those that give them an advantage in the ecosystem should be well understood.

2.3.3 Impacts of fire on grazing-based enterprises

Govender *et al.* (2006) stated that fuel build-up, which sustains the fire, is necessary for a fire to occur. In high-rainfall areas, fuel build-up occurs more rapidly (Govender *et al.*, 2006). Areas with a high number of unpalatable species often have more available fuel, as the grazing pressure in these areas is less, allowing grass to accumulate and decompose at a higher rate than more intensively grazed areas (Bond, 2001; Van Langevelde *et al.*, 2003; Govender *et al.*, 2006).

Fires have a similar function to that of herbivores, as it also consumes biomass, which ultimately alters ecosystems. However, unlike herbivores, fires do not select primarily palatable species but also consume unpalatable species. Fire can thus be seen as a ‘consumer control for ecosystems’, as it influences the type of vegetation, amount of biomass available and growth forms, thereby affecting ecosystems evolutionarily, ecologically and biogeographically (Bond & Keeley, 2005).

Fire can have both positive and negative effects on the natural environment:

- Run-off increases due to increased erosion, as the aboveground vegetation cover is removed by fire (Moffet *et al.*, 2007);

- Soil temperatures increase because of the dark ash layer and loss of vegetation cover after fire, which encourages plant growth (Raison, 1979; Sharrow & Wright, 1976);
- Soil moisture decreases due to the removal of litter, which has a negative effect on plant growth, especially in semi-arid and arid areas where soil moisture is limited (Xu *et al.*, 2013; Van Oudtshoorn, 2015);
- Short-term palatability and digestibility increase after fire (Gillon, 1983);
- Seeds of fire-dependent species germinate due to the smoke and/or heat caused by the fire event (Bond & Keely, 2005); and
- Frequent and intense fires can lead to a reduction in microbial activity and organic content in the topsoil and nitrogen levels may decrease after an intense fire (Neary *et al.*, 1999).

2.3.4 Fire as a management tool

When fire is used to manage bush encroachment, it is important to take several factors into account, such as the season of burning (grass suffers less damage when burnt in their dormant period), wind direction and speed, amount of fuel available and legislation. Woody vegetation should be burnt during the active growing period when new growth emerges and reserve nutrients are used. If a fire occurs during the dormant season, i.e. winter, the woody vegetation can recover more easily and coppice (Trollope & Trollope, 2010; Van Oudtshoorn, 2015).

Different types of fire have different effects on vegetation. The two main fire types are crown and surface fires (Trollope *et al.*, 2002; Trollope & Trollope, 2010). Crown fires cause woody species to burn from the top downward. This type of fire is rare in southern Africa and mainly occurs in large forest and woodland areas. Surface fires burn grasses and other plants at ground level and are more common in southern Africa. The wind direction and topography influence the fire and the damage it causes. Surface fires can be divided into head and back fires (Trollope *et al.*, 2002; Trollope & Trollope, 2010). Head fires burn with the wind direction and more heat is released at a higher level from the ground. Back fires burn against the wind direction, with higher energy released at ground level, as these types of fire move more slowly than head fires do (Trollope *et al.*, 2002; Trollope & Trollope, 2010). Observations conducted in the Eastern Cape Province and Kruger National Park showed that ‘crown and surface head fires cause the highest top kill of stems and branches as compared with back fires' (Trollope & Trollope, 2010). Therefore, if fire is to be used as a management tool for removing woody and/or moribund vegetation, a head fire is recommended, as new grass growth tends to be damaged less (Trollope *et al.*, 2002; Trollope & Trollope, 2010).

Legislation that needs to be considered during burning includes the National Veld and Forest Fire Act No. 101 of 1998, regulated by the Department of Agriculture, Forestry and Fisheries, which aims to combat and prevent mountain and forest fires and establish fire protection associations. This legislation assists land users with preventative measures and better communication between relevant parties. This act indicates that land users have the following requirements and responsibilities:

- Fire-fighting equipment, trained people and personal protective equipment should be available;
- Fire breaks should be made on property boundaries;
- Fires should be fought not only on the property of the specific land user but also on neighbouring properties;
- Fires should be prevented from starting on the land owner's property;
- If the land owner is absent, another responsible person should be identified to take charge should a fire occur; and
- Land owners and users on neighbouring land should be notified if prescribed burning will occur and permission should be obtained from the executive officer (as stipulated by the Conservation of Agriculture Act No. 43 of 1983).

According to the Department of Water Affairs and Forestry (2005), the legislation that land users should considered along with the Veld and Forest Fire Act is summarised in Table 2.1.

Table 2.1: Important legislation with regards to land users and fire.

South African legislation	Section/ regulation	Description and relevance
The Constitution	17	People have the freedom to associate with whom they want to and, therefore, joining fire protection associations should be completely voluntary.
	24	‘Everyone has the right—(a) to an environment that is not harmful to their health or well-being; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that—(i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development.’ Fires should therefore be managed to protect human health and the environment over the long term.
	33	‘(1) Everyone has the right to administrative action that is lawful, reasonable and procedurally fair. (2) Everyone whose rights have been adversely affected by administrative action has the right to be given written reasons. (3) National legislation must be enacted to give effect to these rights, and must—(a) provide for the review of administrative action by a court or, where appropriate, an independent and impartial tribunal; (b) impose a duty on the state to give effect to the rights in subsections (1) and (2); and (c) promote an efficient administration.’ Therefore, the enforcement of the Veld and Forest Fire Act should respect human rights and administrative action should be reasonable.

South African legislation	**Section/ regulation**	**Description and relevance**
Forest Act No. 122 of 1984	Sections relating to prevention of veldfires	This act allows the Director-General to declare a period during which no fires may be created in open areas and therefore no ground cover may be burnt, firebreaks created by using fire or block burns be done.
Fire Brigade Services Act No. 99 of 1987	All sections	This act encourages local communities and land users to establish and uphold a fire brigade service that assists with the prevention and management of fires.
Disaster Management Act No. 57 of 2002	All sections	'To provide for an integrated and co-ordinated disaster management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters and post-disaster recovery; the establishment of national, provincial and municipal disaster management centres; disaster management volunteers; and matters incidental thereto.' This act assists with the planning and management of disasters, including veldfires.
Conservation of Agricultural Resources Act No. 43 of 1983	Regulation 12	'(1) Except on authority of a written permission by the executive officer, no land user shall (a) burn any veld on his farm unit; and (b) utilise as grazing any veld on his farm unit that has burned. (2) The provisions of regulation 2(2) and (3) shall apply mutatis mutandis with regard to an application for a permission referred to in subregulation (1): Provided that—(a) such application shall be submitted at least 30 days prior to the intended date of burning or grazing, as the case may be; and (b) a permission referred to in subregulation (1)(a)—(i) shall not be issued unless the executive officer is satisfied that the burning of veld is an accepted veld management practice in the area within which the farm unit concerned is situated, or that exceptional circumstances prevail

South African legislation	Section/ regulation	Description and relevance
		on the farm unit concerned; (ii) shall be issued only if the veld concerned is to be burned during periods of which particulars are available at the extension office concerned; and (iii) shall be issued to the provisions of the Forest Act, 1968 (Act 72 of 1968).’ This act serves to protect natural resources and states that permission should be obtained to manage vegetation through prescribed burning.
Mountain Catchment Areas Act No. 63 of 1970	Sections relating to prevention and control of veldfires	‘(1) The Secretary may, after consultation with the advisory committee established in respect of any mountain catchment area, declare a fire protection plan to be applicable with reference to land situated in such mountain catchment area. (2) Any fire protection plan shall define the land with reference to which it applies and shall state the scope and object thereof and shall contain provisions relating to—(a) the regulation or prohibition of veld burning; (b) the prevention, control and extinguishing of veld and forest fires; (c) the functions, powers and duties of the fire protection committee established in respect of the mountain catchment area within which the land in question is situated, in relation to the execution of the fire protection plan; and (d) the date of commencement of such plan: Provided that a fire protection plan shall not contain provisions which are inconsistent with the provisions of the Forest Act, 1968 (Act 72 of 1968). (3) The Secretary—(a) shall, at least one month prior to the date specified under subsection (2), cause particulars of the fire protection plan to be published by notice in the *Gazette*; (b) may, if he deems fit, at any time cause to be served on every owner or occupier of land with reference to which such fire protection plan is being or is to be applied and whose name and address are known to him, a copy of the fire protection plan. (4) Every owner and occupier of land with reference to which a fire

South African legislation	Section/ regulation	Description and relevance
		protection plan has been applied under this section, and their successors in title, shall be bound by the provisions of such fire protection plan. The Secretary may from time to time after consultation with the advisory committee concerned, and the fire protection committee concerned (if there is one), by notice in the *Gazette* amend the provisions of any fire protection plan: Provided that the Minister shall cause particulars of any such amendment to be published by notice in the *Gazette* at least one month prior to the date upon which such amendments are to come into operation.' Therefore, any area declared as a mountain catchment area may need a fire protection committee as established by the Minister and a fire protection plan as established by the Director-General to manage and control fires.
Atmospheric Pollution Prevention Act No. 45 of 1965	Sections 17–20	There are declared smoke-free zones that should be taken into account when prescribed burning is being considered. People can approach local authorities if smoke is causing a nuisance and the local authority can serve an abatement notice to the responsible persons; if the persons fail to comply with the notice, it will lead to an offence.
National Environmental Management Act No. 107 of 1998	Sections 2 and 30	This act serves to protect the environment and contains 8 constituents and 20 principles that serve to guide decision-making processes in environmental management. The principles specifically applicable to veldfire management include the following: '(i) That the disturbance of ecosystems and loss of biological diversity are avoided, or, where they cannot be altogether avoided, are minimised and remedied: (ii) that pollution and degradation of the environment are avoided, or, where they cannot be altogether avoided, are minimised and

South African legislation	Section/ regulation	Description and relevance
		remedied; (iii) that the disturbance of landscapes and sites that constitute the nation's cultural heritage is avoided, or where it cannot be altogether avoided, is minimised and remedied' as well as '(viii) that negative impacts on the environment and on people's environmental rights be anticipated and prevented, and where they cannot be altogether prevented. are minimised and remedied.' The National Environmental Management Act also includes a section that states that a person is 'liable for taking measures to contain or minimise the effects of the incident, undertaking clean-up procedures and remedying the effects of the incident', which includes veldfires that led to the public being in severe danger. Public authorities (including municipalities) are also held liable for minimising and rehabilitating any harm or damage caused as well designate a specific person that should take charge in the case of an emergency if no other public agency takes responsibility.
Occupational Health and Safety Act No. 85 of 1993	All sections	This act sets out the minimum requirements for employers, which includes safety equipment and clothing for their employees. This should be taken into account if the land user considers prescribed burning as a management tool.
Legislation as set out by local authorities	N/A	Local authorities can create their own bylaws in terms of fire and veld management. Every land user should therefore contact his/her municipality to be certain that no illegal activity takes place when fire is used as a management practice.

2.4 Use of geographic information systems, mapping and aerial photography in fire management studies

There are many ways in which to study the impacts of fire on savanna ecosystems, including vegetation surveys in the field and remote sensing techniques. This section describes the latter. Printed and sketched maps were important tools to examine areas in the past but have certain limitations, for example, certain aspects cannot be removed if one specific aspect is to be studied. The development of geographic information system (GIS) technology has created new fields for scientific study (Ormsby *et al.*, 2010). GIS is a computer-based system for capturing, storing, managing and analysing geographic or spatial data. Several layers of data can be placed over one another and several aspects can be viewed both individually and in relation to each other, for example, topography, vegetation, mineral resources and settlements can be viewed together or individually (Ormsby *et al.*, 2010).

GIS has been used to indicate changes in vegetation over time, for example, Palmer and Van Rooyen (1997) indicated that grazed areas around livestock watering points changed between 1989 and 1994 as near-infrared activity increased as indicated by Landsat Thematic Mapper data. This indicated an increase in bare soil around the watering points. Rembold *et al.* (2000) used aerial photographs to study changes in land cover coupled with socio-economics. This indicated certain trends with regards to crop cultivation and settlements and an increase in cultivated lands was observed near market settlements and major roads. However, the study indicated that there were limitations in accuracy such as the determination of land cover types. Coulter *et al.* (2000) investigated the accuracy of digitising satellite and aerial images into GIS vegetation layers to assist with vegetation interpretation studies and found that digitised maps were 75% accurate with regards to the study area.

A global broad-scale palaeo-vegetation map was created on GIS to assist archaeologists in using their own data together with vegetation data to obtain valuable information with regards to their own discipline, including information on the Late Quaternary community and climate (Ray & Adams, 2001). Cohen and Lara(2003) have studied radar and satellite images over 25 years, which indicated several changes over time in geomorphological and vegetation structure and distribution in North Brazil. In another study, He *et al.* (2007) reconstructed coarse vegetation data into finer data, which increases the accuracy with regards to delineation of vegetation units, by following the hierarchical Bayesian approach (a statistical approach with various levels) and found the following: The Bayesian approach '(1) is effective in predicting historical vegetation distribution, (2) is robust at multiple classification levels (species, genus, and functional groups), (3) can be used to derive vegetation patterns at fine resolutions (for example, in this study, 120 m) when the corresponding environmental data exist, and (4) is applicable to relatively moderate map sizes (for example, 792 x 763 pixels) due to the limitation of computational capacity'.

The use of remote sensing to obtain fire/burn scar data has improved due to technological advances (Lentile *et al.*, 2006; Davies *et al.*, 2009; Meng & Zhao, 2017). A number of global fire software products have been developed to aid scientists in researching and monitoring fire dynamics. Use of remote sensing to identify active fires and burn scars started during the late 1980s with the launch of the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (NOAA-AVHRR) satellites and the development of indices, for example, the normalised difference vegetation index to compare vegetation dynamics in a time series.

Some of the earliest examples include Barbosa *et al.* (1999), who used NOAA-AVHRR Global Coverage time series data for burn scar mapping on a continental scale in Africa. These authors achieved an accuracy of 71% for estimating burn scars at a 5 km spatial resolution. During 1999 and 2002, NASA launched a series of satellites as part of the MODerate Resolution Imaging Spectroradiometer (MODIS) programme named Terra and Aqua. The sensors on these satellites were designed to observe hotspots that indicate active fires as well as the locations and timeframes in which the fires occurred (Justice *et al.*, 2002; Giglio *et al.*, 2006). Active fires and burn scars have been monitored globally through MODIS and other similar satellite systems (for example SPOT-Vegetation) since 2000.

The Terra and Aqua satilites' onboard MODIS instruments provide a wide swath width of 2 330 km, consisting of 36 bands, allowing for global monitoring every 1–2 days (Barnes *et al.*, 1998). MODIS is a continuation of the original NOAA-AVHRR, providing substantial improvements in spatial, spectral and radiometric characteristics (Townsend & Justice, 2002). MODIS provides 12 global terrestrial biophysical data sets, including data on active fires (MOD14A/MYD14) and burn scars (MCD45A1), developed by a broad spectrum of scientists. The current global burn scar data used for this study (MCD45A1) are based on studies by Roy *et al*. (2002), Roy *et al.* (2005) and Roy *et al.* (2008).

Fire monitoring and burn scar mapping using remote sensing have developed into a separate discipline, with considerable focus on mapping and detecting fires at different scales. In South Africa, considerable research has been undertaken in collaboration with the MODIS scientific community towards the validation of the MODIS active fire and burn scar data. Archibald *et al.* (2008) investigated the relationships between MODIS-derived burn scar data and the impact of human and climate predictors on their distribution. Archibald and Roy (2009) evaluated a time series of MODIS MOD45B burn scar data from 2000 to 2008 to identify individual fires using a flood–fill method. Currently, two MODIS burn scar data sets are available, namely the original version 5 (MCD45A1) and version 6 (MCD64A1). Tsela *et al.* (2014) evaluated the two data sets and a combined version. Their results indicated that MCD45A1 had better detection probabilities for smaller fires, whereas MCD64A1 was more reliable in detecting larger fires. Frost and Annegarn (2007) developed an operational fire monitoring system (https://southernafrica .afis.co.za/#) which indicates recorded fires with MODIS and VIIRS. Development in the fields of fire detection and automated burn scar detection is ongoing. Besides MODIS active fire detection and burn scar data sets, data are also available via the European Space Agency’s Copernicus programme (https://www.esa.int/Our_Activities/Observing_ the_Earth/Copernicus).

2.5 Use of local and indigenous knowledge for research purposes

GIS and mapping tools are crucial to understanding the role of fire in savanna ecosystems but can be supplemented by local and indigenous knowledge. This section explores the relevance of such knowledge in scientific enquiry. Several environmental studies have been conducted with the assistance of local managers and have used indigenous knowledge in combination with quantitative data (Reed & Dougill, 2002; Stringer & Reed, 2006; Reed *et al.*, 2007; Kong *et al.*, 2014). In this study, local knowledge played an important role to obtain a better understanding of the changes in vegetation caused by fire events when certain management strategies have been applied and therefore to conclude whether fire can be used as a management tool to make long-term predictions and management decisions in semi-arid savanna areas.

Reed and Dougill (2002) used a participatory framework to obtain indigenous knowledge to assist with the assessment of rangeland degradation in the southern Kalahari region. They found that local knowledge was indicative of current rangeland conditions and that there were early indications of rangeland degradation. Stringer and Reed (2006) followed a participatory approach to gain indigenous knowledge from land-users in Swaziland and Botswana, which, combined with scientific knowledge, could assist in managing land degradation. The results showed that the indigenous and scientific knowledge overlapped, indicating that, by using these two types of knowledge together, challenges to effectively manage and monitor land degradation can be overcome. Reed *et al.* (2007) further used 'a four-stage social learning approach based on stakeholder participation' to obtain indigenous knowledge from farmers in the Kalahari region. This, in turn, indicated that certain land management strategies proposed in the literature cannot be used by farmers in the Kalahari region and that the gained knowledge should be used together with scientific knowledge to manage and adapt to land degradation.

Kong *et al*. (2014a) conducted a study on the interplay of knowledge, attitude and practice of livestock farmers' land management against desertification in the South African Kalahari region. These authors established that management actions depended on several factors (i.e. the size of the farms, available infrastructure and finances and land tenure) and not only on the level of local knowledge or positive attitudes of the farmers. Kong *et al*. (2014c) investigated the effectiveness of combining local ecological knowledge of livestock farmers in Mier, Northern Cape Province, and remotely sensed data to assess rangeland conditions in the Kalahari Duneveld. These authors established that the participating farmers could potentially contribute towards the monitoring of vegetation change of the Duneveld. Kong *et al*. (2014b) further examined whether photo elicitation and photo-voice methods (the use of documenting observations through photographs and explaining the meanings of the photographs through interviews) could collect and enhance data to enhance participatory evaluation of land management in Mier.

CHAPTER 3: STUDY AREA

3.1 Location

The study area is located in the Molopo Bushveld region in the northern part of the North-West Province of South Africa and borders on the Northern Cape, Free State, Gauteng and Limpopo Provinces as well as Botswana. The area is approximately 100 km north of Vryburg and 100 km west of Mafikeng, with the Molopo River in the north. This river forms the border between South Africa and Botswana and gives the local municipality and the general area their names (Harmse, 2013).

The North-West Province is divided into four district municipalities, namely the Dr Kenneth Kuanda, Bojonala Platinum, Ngaka Modiri Molema and Dr Ruth Segomotsi Mompati Districts. The study area is located in the Dr Ruth Segomotsi Mompati District Municipality, formally known as the Bophirima District Municipality (Local Government, 2017). This district municipality consists of five local municipalities, namely the Lekwa–Teemane, Naledi, Mamusa, Kagisano–Molopo and Greater Taung Local Municipalities. The study area is located in the Kagisano–Molopo Local Municipality, which is the largest municipality (23 827 km^2) in the district. This municipality was formed in 2011, when the Molopo and Kagisano Municipalities merged (Local Government, 2017). The area houses both farms and conservation areas (Molopo Nature Reserve and Khamab Reserve). Sampling was conducted west and north of Vorstershoop in the Molopo Nature Reserve and Khamab Reserve, respectively, and west of Ganyesa on a commercial cattle farm (Figure 3.1).

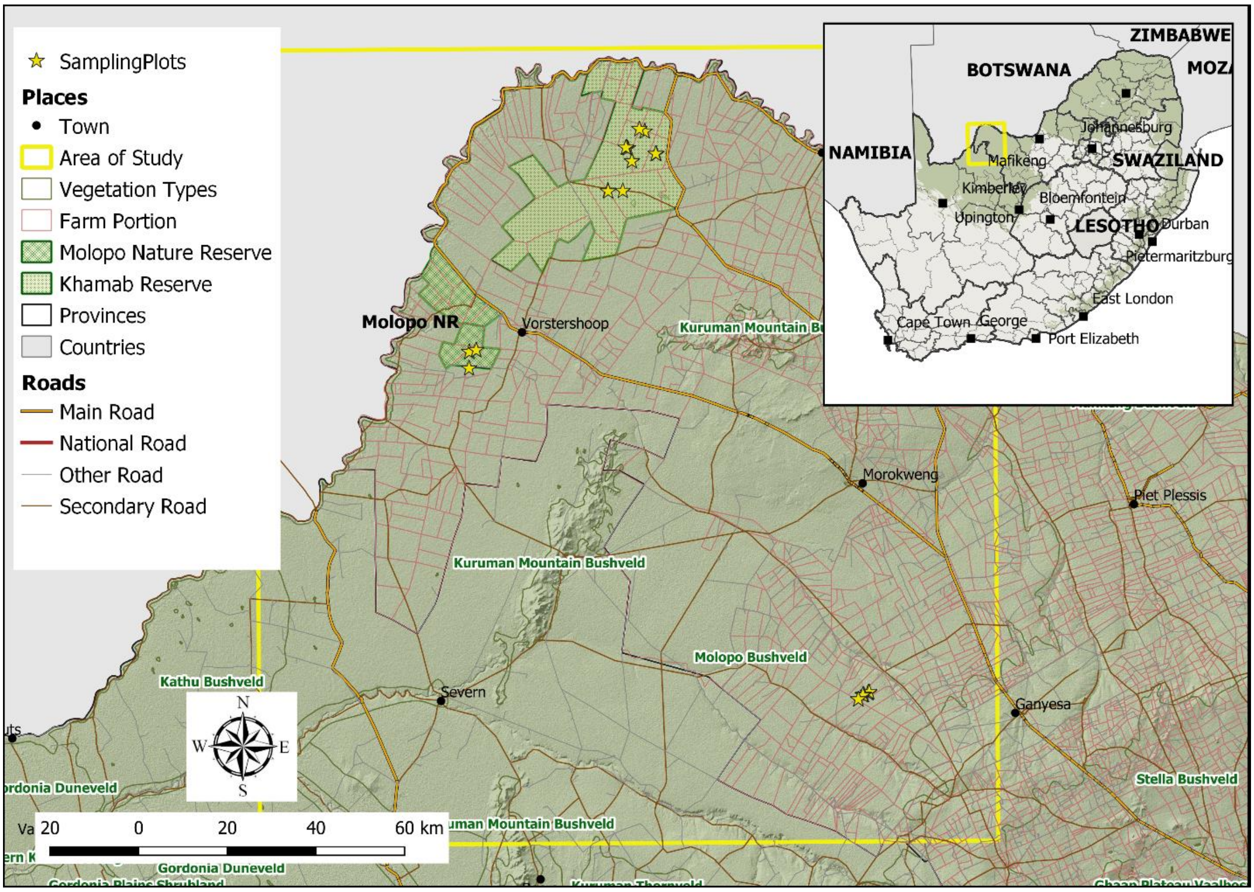

Figure 3.1: Map indicating the study area in the Molopo Bushveld region, North-West Province, in the yellow frame, with sampling sites in the Khamab Reserve, Molopo Nature Reserve and a commercial cattle farm.

3.2 Vegetation

The study area falls within the savanna area of the Eastern Kalahari Bushveld Region and the Molopo Bushveld vegetation unit, also known as the Kalahari Thornveld and Shrub Bushveld (Ackocks, 1953) and the Kalahari Plains Thorn Bushveld (Low and Rebelo, 1996), respectively. The vegetation varies from open woodland, with tree species such as *Boscia albitrunca* (shepherd's tree) and *Vachellia erioloba* (camel thorn) to a more closed shrubland, with common species such as *Lycium hirsutum* (river honey-thorn) and *Grewia flava* (brandy bush). The grass layer consists of species such as *Eragrostis lehmanniana* (Lehmann lovegrass) and *Aristida congesta* (Tassel three-awn). *Vachellia erioloba* has been extensively removed for firewood and *Senegalia mellifera* (black thorn) has encroached into large areas where overgrazing has occurred, which is one of the primary reasons for habitat degradation in the study area (Donaldson, 1966; Moore & Odendaal, 1987; Richter *et al.*, 2001; Smit, 2004, Harmse, 2013). The study area has low potential for crop production and the main uses for vegetation include grazing for livestock and wildlife and firewood collection (Mucina & Rutherford, 2006).

A study conducted by Tews *et al.* (2004) on seed dispersal in the Kalahari rangelands indicated that increased seed dispersal of *G. flava* is linked with increased bush encroachment. *Grewia flava* is a species that easily encroaches in overgrazed areas in the Molopo Bushveld region, as its seeds are easily distributed through the faeces of birds and livestock (Tews *et al.*, 2004; Tews *et al.*, 2006). Moreover, several valuable rangelands have been lost in the Molopo Bushveld region due to the encroachment of *S. mellifera* (Donaldson, 1996). This species is an unpalatable multi-stemmed woody shrub or tree that survives easily in semi-arid areas on many different soil types. It has extremely negative effects on livestock and wildlife grazing-based enterprises, as it is regarded as the dominant species contributing to bush encroachment (Botha, 2008; Smit, 2008). In overgrazed semi-arid areas, *S. mellifera* can form large thickets, leading to a decrease in grass species and causing further degradation (Van Wyk & Van Wyk, 1997; Botha, 2008; Smit, 2008).

The methods used to control woody species (including *S. mellifera*) in the Molopo Bushveld region mainly include mechanical, manual and chemical methods. Mechanical and manual methods involve the removal of tree/shrub individuals by means of machinery, which is often combined with manual control with axes and/or saws. A burn programme can be used in conjunction with other control methods. Such a programme depends on the structure and age of the species to be controlled, the type of fire and season. Chemical methods include basal, foliage and ‘notch-and-cut’ surface applications of arboricide (herbicide for woody species). The application method depends on the type of arboricide used. Donaldson (1966) and Botha (2008) stated that hormone-type arboricides were the most effective chemicals for controlling *S. mellifera* in the Molopo Bushveld region.

3.3 Climate

Rainfall data were obtained from the South African Weather Service (2016) for Van Zylsrus, Severn and Bray (Figure 3.2). The average annual rainfall is 227 mm for the study area, with the highest rainfall being measured in 2001: 305 mm for Van Zylsrus, 453 mm for Severn and 620 mm for Bray. Temperature data were obtained only for Van

Zylsrus (Figure 3.3). Temperatures remained relatively constant, with average maximum and minimum temperatures of 32 °C and 12 °C, respectively (Figure 3.3). According to Mucina and Rutherford (2006), the average number of days in the year with frost is 27 days. The area receives summer and autumn rainfall (October–April), with little to no rainfall during the winter months (June–August).

As stated previously, fuel build-up is necessary for a fire to occur in a natural area, which is determined by the previous season's rainfall (Govender *et al.*, 2006). Temperature is also a determinant of fire intensity (Van Oudtshoorn, 2015): The higher the temperature is, the higher the intensity of the fire will be (Trollope & Trollope, 2002). Rainfall and temperature regimes may differ and change due to global climatic change (Pausas & Keeley, 2014). This should therefore be taken into account by land-users in the Molopo Bushveld region to be able to use fire as a management strategy against bush encroachment.

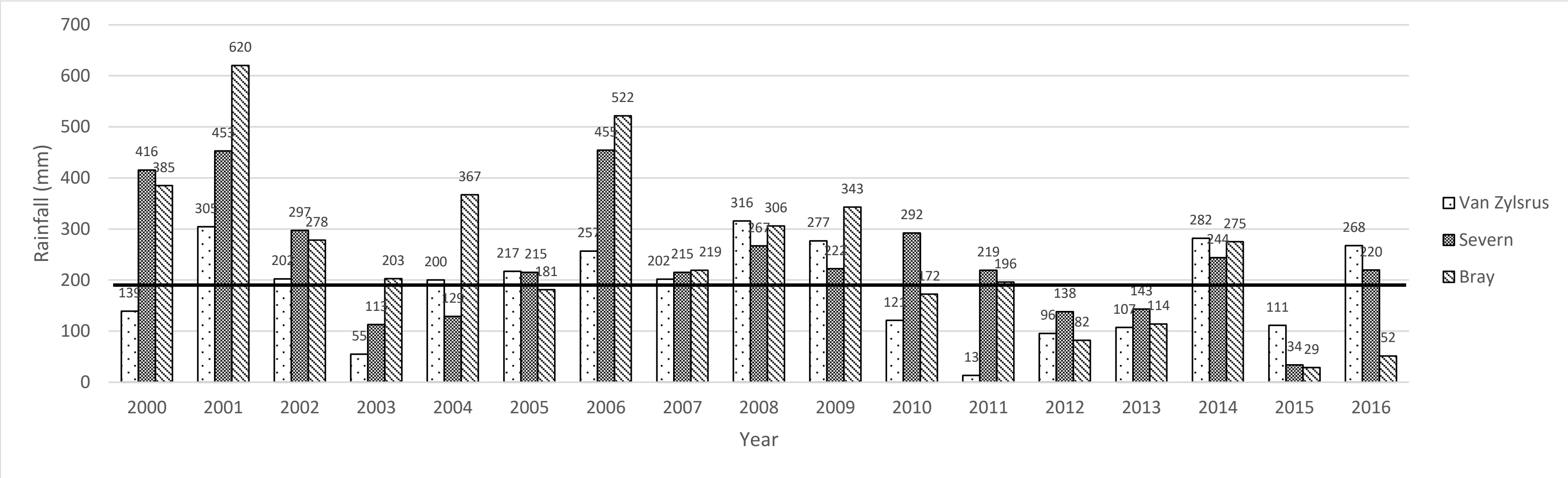

Figure 3.2: Bar plot indicating the annual rainfall, with the horizontal line indicating the mean value for the Van Zylsrus, Severn and Bray weather stations from 2000 to 2016 (South African Weather Service, 2016).

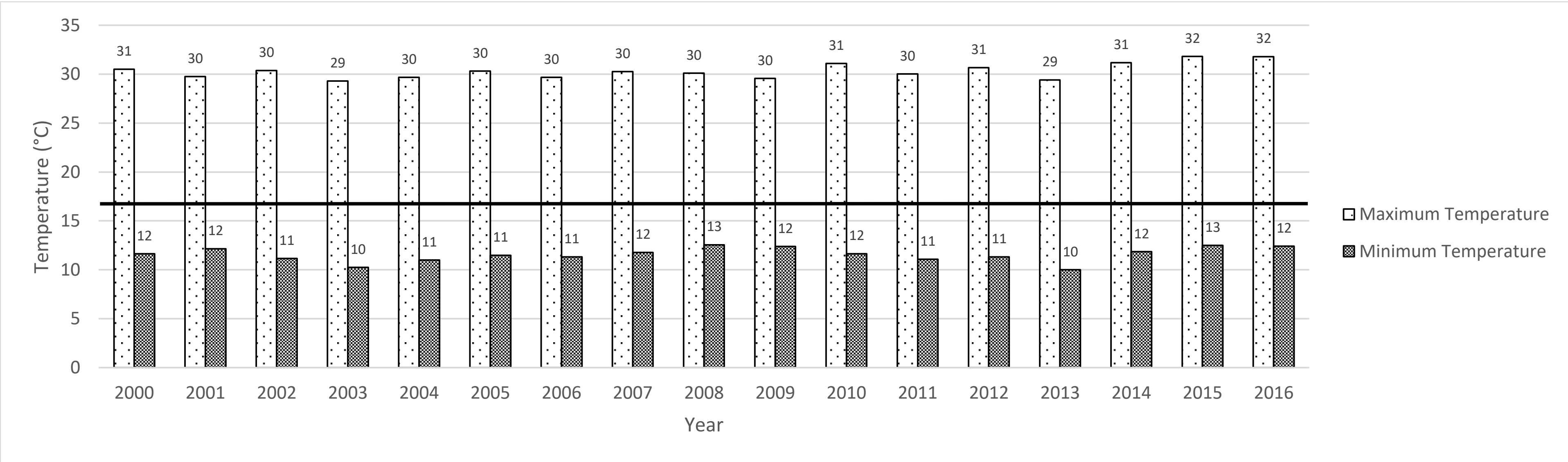

Figure 3.3: Bar plot indicating the average annual minimum and maximum temperatures, with the horizontal line indicating the mean value, for the Van Zylsrus weather station from 2000 to 2016 (South African Weather Service, 2016).

3.4 Geology and soils

As mentioned in Section 2.1, the savanna biome generally overlies the Kaapvaal Craton. The study area in particular predominantly consists of Kalahari sands with underlying calcretes and ironstones in the Molopo Basin. Cyanobacterial crusts are abundant throughout the study area except around watering points, where excessive trampling occurs (Dougill & Thomas, 2004; Thomas & Dougill, 2006). Areas with soil crusts contain more nitrogen than those without crusts and it is suspected that such crusts aid the establishment of *S. mellifera* (Dougill & Thomas, 2004; Thomas & Dougill, 2006). Fire can affect the soil, for example, Snyman (2002) indicated that burning leads to a reduction in soil water content. Moreover, the soil temperature at 50mm depth indicated significant differences between the burnt areas and non-burnt areas (Snyman, 2002). Burning in the growing season reduces the soil organic carbon, nitrogen and extractable phosphate but leads to an increase in pH and the amount of exchangeable magnesium, calcium, potassium and sodium (Snyman, 2002).

3.5 Land use in the Molopo Bushveld region

The Molopo Bushveld region is located within the savanna biome. This biome provides numerous vital ecosystem services for humans, livestock and wildlife. These include provisional services, such as wood for various activities (for example building and fuel), fodder for grazing, regulating services (for example the water cycle), supporting services (for example maintaining biodiversity) and cultural services (for example tourism and aesthetic factors) (De Groot *et al.*, 2002; Fischlin *et al.*, 2007; Harmse, 2013).

Farming is the main land use type in the Molopo Bushveld region with grazing-based enterprises comprising the main agricultural activities in this area, whereas the western and northern Molopo areas contain commercial irrigated lands (Department of Water Affairs and Forestry, 2004). According to Harmse (2013), small-scale mining and industrial activities are also found in the area. The livestock enterprises in the commercially and communally managed areas mainly consist of sheep, cattle and goat farming as well as wildlife, which is generally used for ecotourism and hunting. The communal farmers are largely dependent on their livestock for meat and other products, such as milk (Harmse, 2013). The land use in the Molopo Bushveld region is highly determined by the amount of rainfall. Since rainfall is low and is therefore a limiting factor in this area, crop production is limited (Twyman *et al.*, 2000; Harmse, 2013).

CHAPTER 4: MATERIALS AND METHODS

The methods described in this chapter were used to address the two objectives mentioned in Section 1.2. These methods include (1) quantitative vegetation surveys in the reference sites (unburnt and burnt areas) and burnt sites (where more recent fires occurred as compared to reference sites) as derived from maps where fires previously occurred and (2) the collection of qualitative data from land users by conducting semi-structured interviews and using questionnaires to obtain local knowledge.

4.1 Quantitative methodology

Mapping was done to assist with the selection of areas best suited to achieve the objectives of this study. Vegetation data were collected with the methods described below after selecting the areas by using the maps.

4.1.1 Mapping method

The MODIS programme was used to indicate active fire occurrences within the area, this information was then used to select the sites for the collection of vegetation data. The MODIS programme provides, as secondary products, two global data sets for fire monitoring: an active fire product (Thermal Anomalies and Fires – MCD14) and a burn scar data set (MCD45) (https://modis.gsfc.nasa.gov/).

The Thermal Anomalies and Fires data set uses both MODIS Terra and Aqua data to provide a diurnal indication of active fire occurrences. The Thermal Anomalies and Fire detection algorithm is an improved version of the original algorithm developed for MODIS by Kaufman *et al.* (1998). Active fires are detected using the brightness temperatures derived from MODIS 4 μm (T4 – Channels 21 and 22) and 11 μm (T11 – Channel 31) spectral reflectances (Gigilo *et al.*, 2003). The identification of active fire pixels is an iterative process of actively identifying fire pixels and checking false signals. Further details regarding the algorithm for detecting active fire pixels are described by Gigilo *et al.* (2003).

Archived active fire data are distributed monthly as a plain ASCII file. The point data represent detected fires at 1 km resolution at the time of the overpass under relative cloud-free conditions (Figure 4.1).

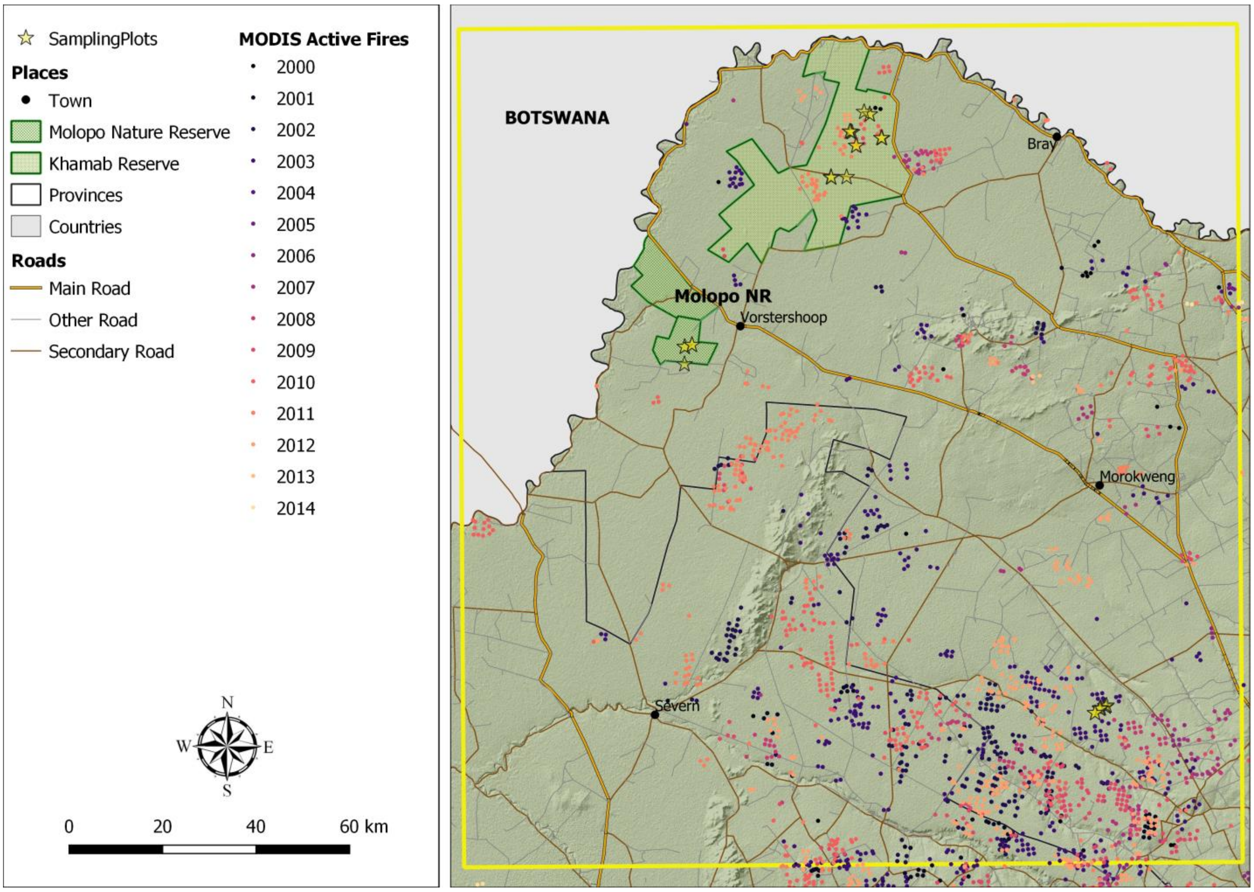

Figure 4.1: Active fire localities indicated by the MODIS Thermal Anomalies and Fire location data for the study area, the Molopo Bushveld region, 2000 to 2015. The data set was produced by the University of Maryland, USA, and provided by NASA Fire Information for Resource Management System operated by NASA/Goddard Space Flight Center/Earth Science Data and Information System (https://earthdata.nasa.gov/active-fire-data#tab-content-6).

Burn area data are estimated per pixel value globally using MODIS Aqua and Terra data. The burn area data are distributed monthly either as 500 m resolution tiles or converted to shape files for download. Roy *et al.* (1999) defined a burned area as spectral changes in vegetation reflectance brought about by the deposition of charcoal and ash and the removal of vegetation and alterations to the vegetation structure as a result of fire.

A detailed description of the methods and algorithms developed to identify burn area pixels from MODIS data are provided by Roy *et al.* (2005). The burn area mapping approach uses a bidirectional reflectance model-based change detection algorithm to identify burn area pixels. The current collection of five burn scar products developed by Roy *et al.* (2005) was evaluated globally by Roy *et al*. (2008) and specifically for southern Africa by Roy and Boschetti (2009).

Both the active fire and burn scar data were provided by the Department of Agriculture Forestry and Fisheries, Directorate: Forestry Regulation & Oversight. The data are standard products processed by the Meraka Institute at CSIR through the Advance Fire

Information System (AFIS: https://www.afis.co.za/#home). Both the MODIS/Aqua+Terra Thermal Anomalies/Fire locations 1km FIRMS V006 NRT and MODIS/Terra+Aqua Direct Broadcast Burned Area Monthly L3 Global 500m SIN Grid V006 are available for download as standard global datasets from https://earthdata.nasa.gov/.

4.1.2 Vegetation survey methods

Vegetation surveys were conducted from 7 to 28 March 2016. Three main sampling areas were chosen according to the fire frequency as indicated by the maps, these areas included the Molopo Nature Reserve, Khamab Reserve and the commercial cattle farm. The sites selected within each area was selected to be representative of each area and therefor to be able to compare the reference sites with the burnt sites. Thus the sites within each area had similar composition, allowing for effective comparisons. The sites selected in the Molopo Nature Reserve (Molopo) included a reference site where no fire had occurred ten years prior as well as a site where a fire occurred in 2002. During the field surveys in Khamab Reserve it was determined that certain areas were chemically controlled for bush encroachment, which opted for the selection of two separate areas within the reserve (Khamab1 and Khamab2) to allow for easier comparisons between the relevant sites. Khamab1 includes a bush encroached reference site where no fire had occurred ten years prior and no chemical control was used as well as two separate burnt sites (burnt in 2010 and burnt in 2011) where no previous chemical control was used. Khamab2 includes a reference site where no fire occurred and chemical control was used in the past as well as a burnt site (burnt in 2012) where chemical control was used in the past. According to the MODIS maps, the entire commercial cattle farm (Farm) burnt in 2002, therefore no unburnt reference site was available to sample, hence the reference site was chosen as an area that burnt in 2002, with two other burnt sites (burnt in 2002 and 2008 and burnt in 2002 and 2011) selected on the farm.

Ten plots were therefore selected, two in the Molopo area, three in the Khamab1 area, two in the Khamab2 area and three in the Farm area. At each of the selected plots, three transects were carried out to obtain averages at each plot, thus 30 transects were carried out in total. A transect is described by Kent (2012) as ‘a line along which samples of vegetation are taken and are usually set up deliberately across areas where there are rapid changes in vegetation and marked spatial environmental gradients’. Transects were chosen to be representative of an area and the aim was to include forbs, shrubs and trees of different species and sizes. Each belt transect was 100 m in length and 4 m in width, therefore 400 m^2. Each plot was selected by comparing MODIS burn data maps. These maps indicated the specific years in which fires were detected in the MODIS data. Thus, areas were selected within the burn scars indicated on maps and areas outside the burn scars as reference sites (Figure 4.2–Figure 4.4).

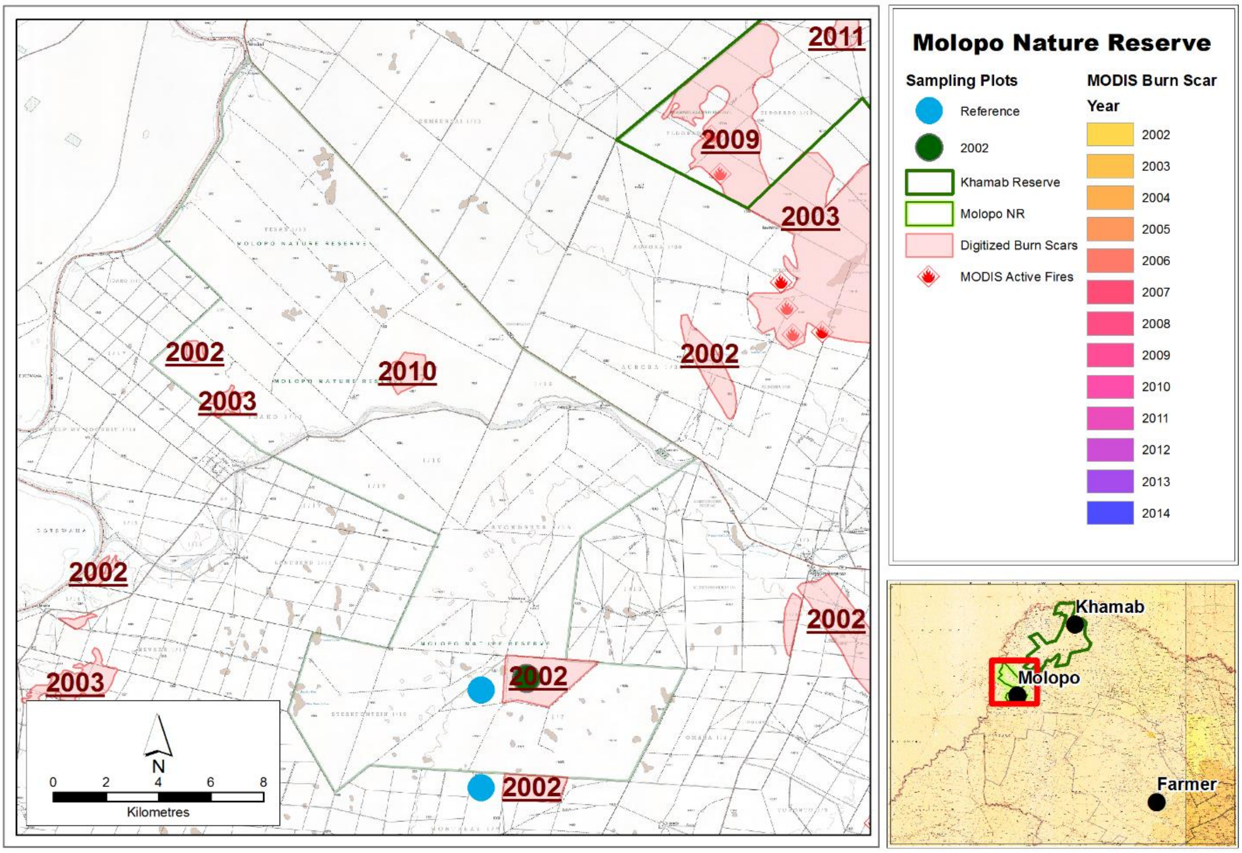

Figure 4.2: Map indicating the sampling plots in the Molopo Nature Reserve for the vegetation surveys carried out in 2016.

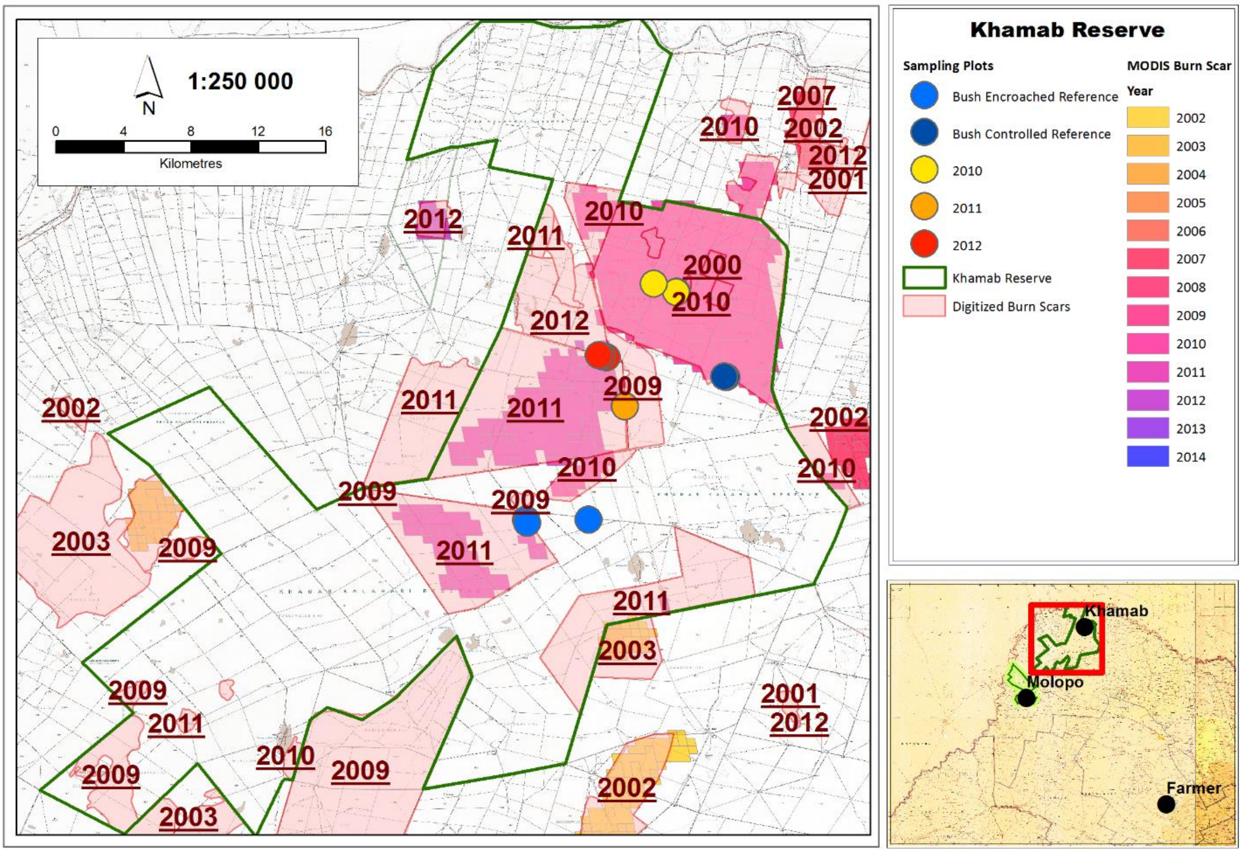

Figure 4.3: Map indicating the sampling pots in the Khamab Reserve for the vegetation surveys carried out in 2016.

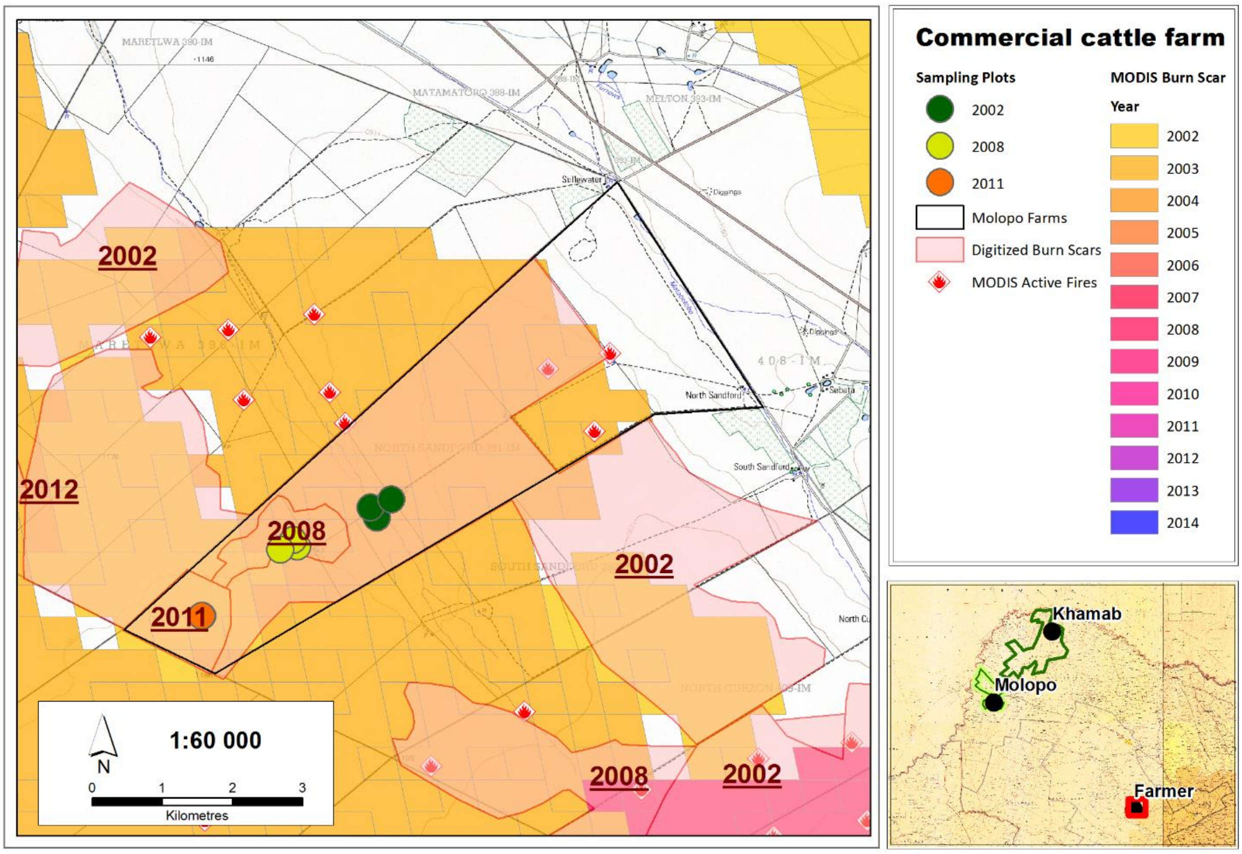

Figure 4.4: Map indicating the sampling plots in the commercial cattle farm for the vegetation surveys carried out in 2016.

A number of variables, including the number of individuals per species, height, width and canopy dimensions (length, width and height) were surveyed at each plot and were included in the vegetation field data sheet (Appendix 1). For the woody component, all woody species that fell within the 400 m^2 transect were noted (the number of woody species was recalculated to the number per hectare for each plot to establish the woody species density) together with the measure variables mentioned above, whereas the step-point method was used to survey the herbaceous component (Evans & Love, 1957). According to Evans & Love (1957), the step-point method is a 'rapid, accurate, and objective method of determining the botanical composition and total cover of herbaceous vegetation'. This method involves putting a pin down on the ground at regular intervals (in the case of this study, the pin was lowered after each metre) and the species is noted as either a 'hit', when the pin makes contact with the centre of the herbaceous species, or a 'miss', where the closest herbaceous plant to the pin is noted.

4.2 Qualitative methodology

To integrate scientific and local indigenous knowledge and promote understanding between the scientists and the local people, it is important to allow mutual learning and discussion between the parties involved (Raymond *et al.*, 2010). A small pilot study was first conducted in the area to determine whether the data will be reliable and understandable and to include or exclude certain questions. The results were then used to formulate the main questionnaire used for this study. The participants for the main questionnaire included three environmental specialists/ecologists and 11 farmers of various ages and both sexes (i.e. a total of 14 land users). These participants were chosen as they represented a specific area that they reside or work in. The participants therefore had a good knowledge of the vegetation and other environmental variables of a certain area. Semi-structured interviews were conducted with the land users (which included participants from the Molopo Nature Reserve, Khamab Reserve, the commercial cattle farm as well as neighbouring areas) by using a questionnaire (Appendix 2) containing relevant questions for this study. This method of gaining local knowledge is described by Doody and Noonan (2013) as follows: semi-structured interviews contain predetermined questions that can be open-ended to allow for discussions and clearing up of uncertainties should they arise during the interviewing process. This method is therefore conducted like a conversation rather than the participants simply filling out a questionnaire.

The interviews took place during the vegetation surveys between 7 and 28 March 2016 as well as during a field visit between 27 February and 3 March 2017. These interviews were conducted where the land users felt comfortable, for example in their home, in the field or in a barn during an information day held by the Department of Rural, Environment and Agricultural Development in the North-West Province. The interviews were conducted in Afrikaans and/or English according to the preferred language of the participant with the answers being written down. Additional notes were made where applicable to obtain a better understanding as to why the participants chose certain answers. Participation in the study was entirely voluntary and it was determined that the study would pose no risk to the participants, therefore ethical approval was obtained during title registration of this thesis.

The following aspects were explained to the participants:

- The purpose of this research was to understand the effects of fire on savanna vegetation dynamics in the semi-arid Molopo Bushveld region and that participation in this survey would last approximately one hour.
- There would be no foreseeable risks or discomforts if the land user agreed to participate in the research.
- The results of the research may be published, but the participant's name or identity would not be revealed.
- The results may be used for secondary studies connected to this research, but the participant's name or identity would not be revealed.
- The North-West University would maintain confidentiality of all records and materials.
- The participant would not be compensated for his/her participation.
- Any questions the land user had concerning this research or his/her participation in it before or after his/her consent would be answered by the researchers.
- The participant could withdraw his/her consent and discontinued participation at any time without penalty or loss of benefit to himself/herself.
- In signing the consent form, the participant would not be waiving any legal claims, rights or remedies.

After agreeing to participate in the study and signing the informed consent form (Appendix 2), the questionnaire was completed through a conversational interview to make the participant more at ease. Questions included multi-choice questions, which were pre-determined through short discussions with land users, and open-ended discussion questions to assist the participants in explaining their view points. Certain questions about the management, vegetation, rainfall events, occurrence of fire and the effects thereof were asked (Appendix 2).

The number of land users who completed the questionnaire can be seen as a limitation of the qualitative part of the study. However, only a small population of land users farm in the area (approximately 10–15 farmers; J. Olivier, pers. comm., 7 August 2017). Another limitation of the study was that the land users used their own common names for plants, which differed between areas. This limitation was overcome by providing all land users with a booklet that contained photographs (from various sources) with the relevant plant's scientific and common names (Appendix 3). This assisted land users in identifying plants and answering the relevant questions with regards to vegetation.

4.3 Data analysis

This study included both quantitative data (mapping and vegetation surveys) and qualitative data obtained in 2016 and 2017 in the Molopo Bushveld region.

4.3.1 Quantitative data analysis: vegetation surveys

After determining the species density, composition and growth forms, graphs were created to illustrate the differences between the reference and burnt sites. The woody species were categorised into groups (i.e. forbs, shrubs and trees) to determine their height class. For the purpose of this study, the three groups were defined as follows: (1) Forbs are small flowering plants (smaller than shrubs and trees) with thin woody stems and small leaves (in this study, *Asparagus suaveolens* was categorised as a forb), (2) shrubs are woody, dense growing plants, usually with more than one stem above ground and smaller than trees and (3) trees are characterized in this study as woody perennial plants that grow to have a single thick stem above ground and several horizontal branches. Within each group, the height classes were as follows:

- Forbs:
    - <0.5 m;
    - 0.5–1 m and

    - >1 m.
- Shrubs:
    - <1 m;
    - 1–2 m and
    - >2 m.
- Trees:
    - <2 m;
    - 2–4 m and
    - >4 m.

Statistica version 13.3 (2018) was used in the analysis of all data (STATSOFT, Inc., 2018). Descriptive statistics were reported and parametric and non-parametric tests were conducted on the vegetation data illustrated in Chapter 5. The T- and non-parametric Mann–Whitney tests as well as analysis of variance and non-parametric Kruskall–Wallis test were done to determine whether there were significant statistical differences between various groupings stated earlier.[5] Differences of $p < 0.05$ were considered to be significant. Multivariate ordination techniques were used and included detrended correspondence analysis (DCA) to indicate the correlation between the dominant species and the sampling sites and canonical correspondence analysis (CCA) to indicate the correlation between the woody height classes in the sampling sites on a burn gradient, using CANOCO version 5 (Ter Braak, 1991), which indicated the species distribution at all the plots and the positive associations with regards to species and sampling sites and their association with fires within the area.[6] It should be noted the eigenvalue for only the x-axis is indicated on the analysis plots and no arrows are included on the plots as there was only one variable, namely fire. A burn gradient is included on the CCA which correlates to when the fire(s) occurred and to when the vegetation sampling was carried out; for example, if a site burnt in 2002, the burn gradient will be from 0 to 16 years.

Canopy volumes were calculated with the following formula:

$$\textit{Canopy Length (cm)} \times \textit{Canopy Width (cm)} \times \textit{Canopy Height (cm)} = \textit{Canopy Volume } (cm^3)$$

[5] With the assistance of Dr Suria Ellis at the Statistical Consultation Services of the North-West University.
[6] With the assistance of Mr Jaco Bezuidenhout at the Department of Microbiology (data analysis) at the North-West University.

The results of the canopy volumes were then included in tables for comparison between reference sites and burnt sites in cm^2.

4.3.2 Qualitative data analysis: questionnaires

Data from the questionnaires were entered into a Microsoft Excel spreadsheet and were analysed through T-tests. Qualitative data were coded as numbers so that they could be treated in a quantitative way. Descriptive statistics and Spearman rank order correlations as well as T-tests were used to examine various associations between experimental and control groups in the data.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Quantitative results

The results indicated differences within reference sites (including the burnt reference sites) and the burnt sites; however, the results were not consistent, except for *G. flava,* which had higher densities within the burnt sites than within the reference sites.

With regard to the overall woody density, the burnt sites indicated lower woody densities when compared to the reference sites (including the burnt reference sites). The site that indicated the lowest overall woody densities was the Khamab2 site, which was chemically controlled in both the reference site and the burnt site. Within this site, the forb *R. brevispinosum*, the shrub *G. flava* and the tree *V. erioloba* were the three dominant species in the low to medium height classes, which might be due to the chemical control, as well as the influence of the fire event.

Differences in canopy volume were also observed between the reference sites (including the burnt reference sites) and the burnt sites. However, no consistent significant differences were observed between specific species and sites, which might be due to the differences in the timelines as to when fires had occurred, meaning that some species could either have recovered or were browsed over a longer time before surveys had been carried out.

With regard to grass species composition, a clear distinction could be made between the three different areas (i.e. Molopo Nature Reserve, Khamab Reserve and Farm).

Detrended correspondence analyses (DCAs) and canonical correspondence analyses (CCAs) are illustrated in Figures 5.10, 5.20–5.22, 5.26, 5.30–5.32 and 5.36 to indicate associations between the various sites and the vegetation found during the surveys. The woody abundance is given in individuals per hectare on the bar plots with the average canopy volumes in cm^3 per species. The herbaceous abundance is illustrated on bar plots as an average abundance of individuals per $100m^2$.

5.1.1 Woody species abundance and composition

The detrended correspondence analysis (DCA) plot indicated that the reference site in the Farm area (FRefB02) was mostly associated with species such as *Laggera decurrens* (*L. decu*), *Lycium cinerium* (*L. cine*), *L. bosciifolium* (*L. bosc*), *Tarchonanthus* *camphoratus* (*T. camp*) and *Ziziphus mucronata* (*Z. mucr*) (Figure 5.1: Group 1). The reference sites at Khamab1 (K1RefBEW), Khamab2 (K2RefBEW) and the Molopo (MRefW), as well as the burnt sites at Khamab1 (K1B10W: burnt in 2010 and K1B11W: burnt in 2011), Khamab2 (K2B12W: burnt in 2012), the Farm (FB0211: burnt in 2002 and 2011) and the Molopo (MB02W: burnt in 2002), were mostly associated with species such as *Boscia albitrunca* (*B. albi*), *Grewia flava* (*G. flav*), *Flueggea virosa* (*F. viro*), *Vachellia erioloba* (*V. erio*), *V. luederitzii* (*V. lued*), *Senegalia mellifera* (*S. mell*) and *Rhigozum brevispinosum* (*R. brevi*) (Figure 5.1: Group 2). The burnt site on the Farm (burnt in 2002 and 2008) was mostly associated with *G. flavescens* (*G. flas*), *Monechma divaricatum* (*M. diva*), *Dichrostachys cinerea* (*D. cine*) and *Searsia tenuinervis* (*S. tenu*) (Figure 5.1: Group 3). Species that were found to be outliers included *Ehretia rigida* (*E. rigi*), *Gymnosporia buxifolia* (*G. buxi*), *V. haematoxylon* (*V. haem*), *Terminalia sericea* (*T. seri*), *Asparagus suaveolens* (*A. suav*) and *V. hebeclada* (*V. hebe*).

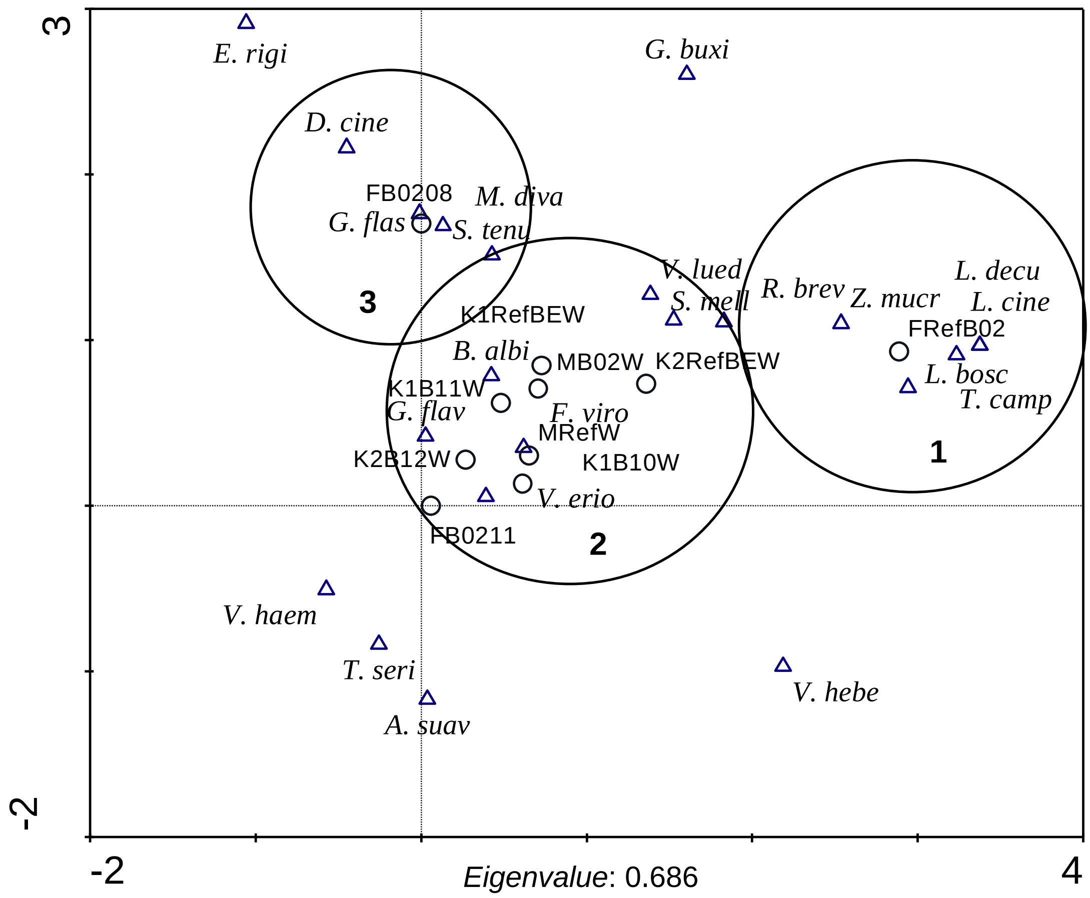

Figure 5.1: Detrended correspondence analysis (DCA) ordination plot indicating the association between woody species (Δ) in the sampling sites (o): *A. suav – Asparagus suaveolens, B. albi – Boscia albitrunca, D. cine – Dichrostachys cinerea, E. rigi – Ehretia rigida, F. viro – Flueggea virosa, G. buxi – Gymnosporia buxifolia, G. flas – Grewia flavescens, G. flav – Grewia flava, L. bosc – Lycium bosciifolium, L. cine – Lycium cinerium, L. decu – Laggera decurrens, M. diva – Monechma divaricatum, R. brev – Rhigozum brevispinosum, S. mell – Senegalia mellifera, S. tenu – Searsia tenuinervis, T. camp – Tarchonanthus camphoratus, T. seri – Terminalia sericea, V. erio – Vachellia erioloba, V. lued – Vachellia luederitzii, V. hebe – Vachelia hebeclada, V. haem*

– *Vachellia haematoxylon, Z. mucr – Ziziphus mucronata* MRefW – Molopo Reference, MB02W – Molopo burnt in 2002, K1RefBEW – Khamab1 Reference, K1B10W – Khamab1 burnt in 2010, K1B11W – Khamab1 burnt in 2011, K2RefBEW – Khamab2 Reference, K2B12W – Khamab2 burnt in 2012, FRefB02 – Farm Reference, FB0208 – Farm burnt in 2002 and 2008, FB0211 – Farm burnt in 2002 and 2011, 1 – Group 1, 2 – Group 2, 3 – Group 3.

5.1.1.1 Woody species abundance on the Molopo Nature Reserve

The study area in the Molopo Nature Reserve was burnt between 2000 and 2016 according to personal communication.[7] Only the 2002 fires are indicated on the map (Figure 4.2). Species that had higher abundance in the reference site than in the burnt site include *Asparagus suaveolens* (233 individuals/ha), *S. mellifera* (108 individuals/ha) and *Vachellia luederitzii* (50 individuals/ha) (Figure 5.2). Species only found in the reference site include *L. bosciifolium* (42 individuals/ha), *Dichrostachys cinerea* (17 individuals/ha) and *Monechma divaricatum* (8 individuals/ha) (Figure 5.2). Species that were found to have higher abundance within the burnt site include *G. flava* (300 individuals/ha), *Searsia tenuinervis* (150 individuals/ha) and *V. erioloba* (83 individuals/ha) (Figure 5.2).

[7] Pieter Nel, Head of Conservation for the North-West Parks and Tourism Board, Contact number 018 397 1500.

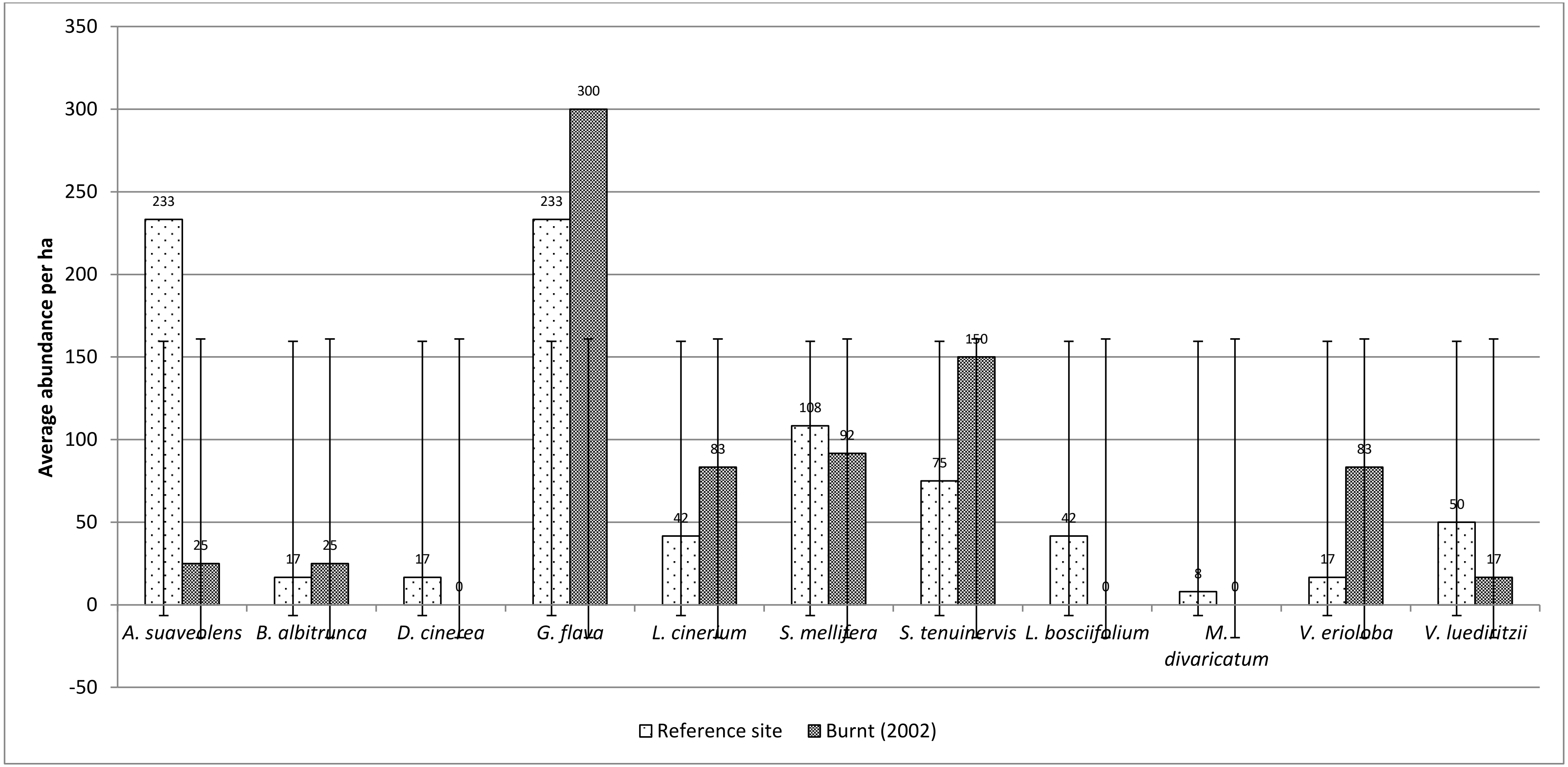

Figure 5.2: Bar plot indicating the average woody species abundance (individuals/ha) between the plots surveyed in the reference and burnt sites (2002) in the Molopo Nature Reserve (Molopo area). The numbers above the bars indicate the average abundance with standard deviations of each species within the sites (see Appendix 4 for species abbreviations).

5.1.1.2 Woody species abundance on the Khamab Nature Reserve

Certain sites in the Khamab Nature Reserve had been chemically controlled in the past to reduce bush encroachment. Therefore, two reference sites were chosen which corresponded to sites where woody species were not controlled (Khamab1) and sites where woody species were controlled (Khamab2). The burnt sites were also selected accordingly to be able to compare the burnt sites and the reference sites in the Khamab study area.

5.1.1.2.1 Khamab1

Within this area, a reference site that was encroached (no bush control) and two burnt sites were identified where a fire occurred in 2010 and in 2011 (Figure 5.3).

Species that had higher abundances in the reference site (not controlled and not burned) compared to the burnt sites include *S. tenuinervis* (508 individuals/ha), *V. luederitzii* (192 individuals/ha), *Rhigozum brevispinosum* (83 individuals/ha), *V. hebeclada* (33 individuals/ha) and *Ziziphus mucronata* (17 individuals/ha) (Figure 5.3). *Asparagus suaveolens* was found to have a higher abundance within the site that was burnt in 2010 (275 individuals/ha) but not within the site that was burnt in 2011 (158 individuals/ha), which might be due to trampling by animals, less rainfall in 2010 than 2011 or due to slower recovery rates of these plants after the fire (Figure 5.3).

Grewia flava was found to have a higher abundance within the site that was burnt in 2011 (358 individuals/ha) compared to the site that was burnt in 2010 (208 individuals/ha), which might be due to the plants coppicing after a fire and then browsed by ungulates (Figure 5.3). *Senegalia mellifera* also had a higher abundance within the site that burnt in 2011 (333 individuals/ha) compared to the site that burnt in 2010 (183 individuals/ha). This might be due to the availability of more soil moisture, as the competition for soil moisture started between the grass and woody layers as soon as the grass layer was removed by a fire, favouring the root system of the woody species. It therefore seems as if the density of this species has increased after the 2011 fire, which could also have led to bush encroachment by this and some other species, such as *Vachellia hebeclada.* The latter species was only found within the reference site and not in the burnt sites. *Terminalia sericea*, *V. haematoxylon* and *L. bosciifolium* were only found within the burnt sites and not the reference site (Figure 5.3).

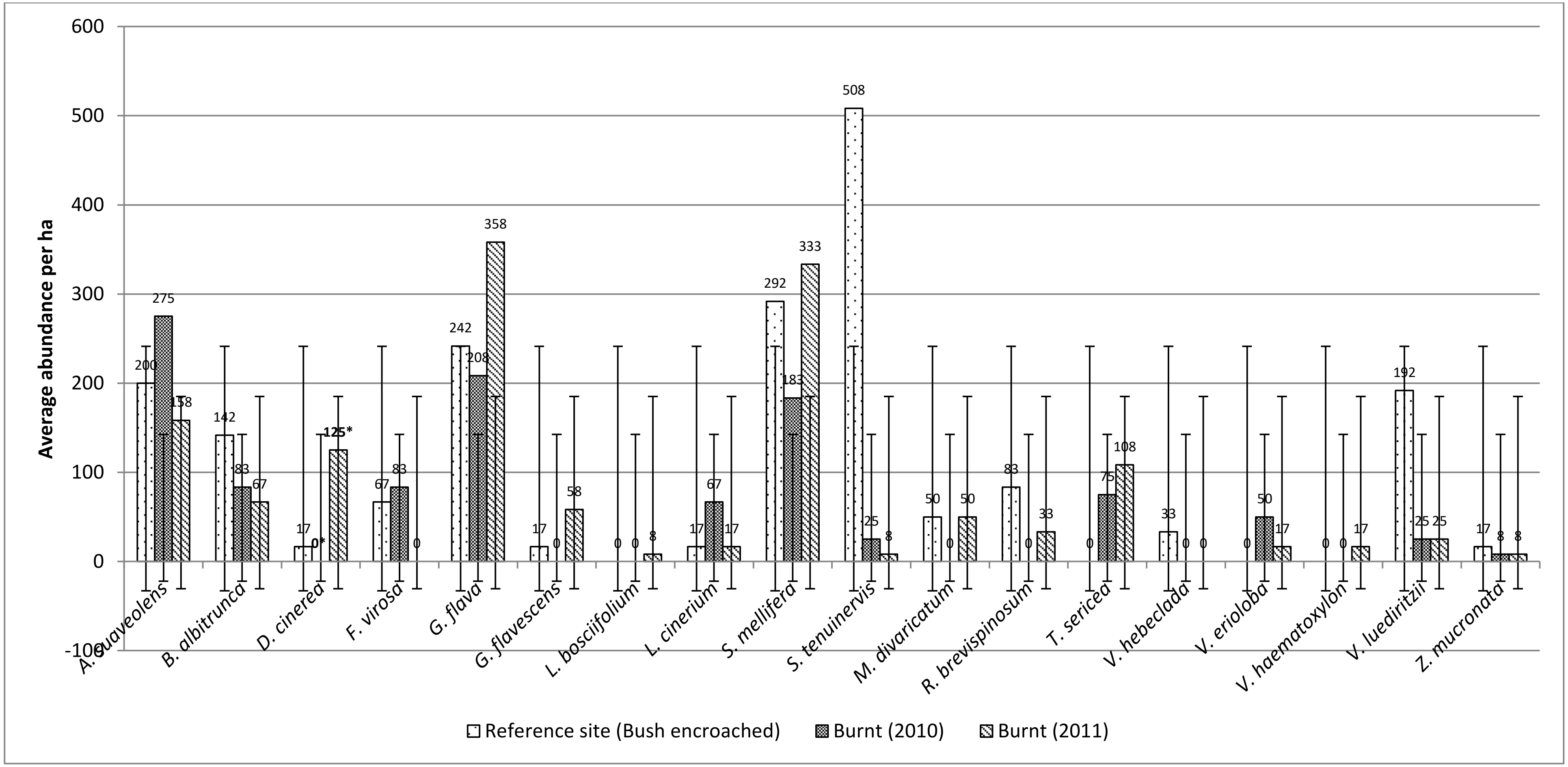

Figure 5.3: Bar plot indicating the average woody species abundance (individuals/ha) between the plots surveyed in the reference site (bush encroached) and burnt sites (burnt in 2010 and 2011) in the Khamab Reserve (Khamab1 area). The numbers above the bars indicate the average abundance with standard deviations of each species within the sites (see Appendix 4 for species abbreviations).[8]

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[8] Figures indicated with an asterisk (*) indicate meaningful differences between the average abundance in species found in the reference site (bush encroached) and burnt sites (burnt in 2010 and 2011) in the Khamab Reserve (Khamab1 area) according to the Kruskal-Wallis test (Chapter 4.3).

5.1.1.2.2 Khamab2

Within the area where woody species were controlled, a reference site was chosen, as well as a site that burnt in 2012 (Figure 5.4). Species found only in the reference site include *R. brevispinosum* (650 individuals/ha), *A. suaveolens* (67 individuals/ha), *Flueggea virosa* (33 individuals/ha), *V. hebeclada* (42 individuals/ha), *B. albitrunca* (17 individuals/ha) and *L. cinerium* (17 individuals/ha) (Figure 5.4). Two species were found only within the burnt site, namely *V. erioloba* (183 individuals/ha) and *V. haematoxylon* (50 individuals/ha). Species that were found to have higher abundances within the burnt site include *G. flava* (217 individuals/ha) and *S. mellifera* (58 individuals/ha) (Figure 5.4).

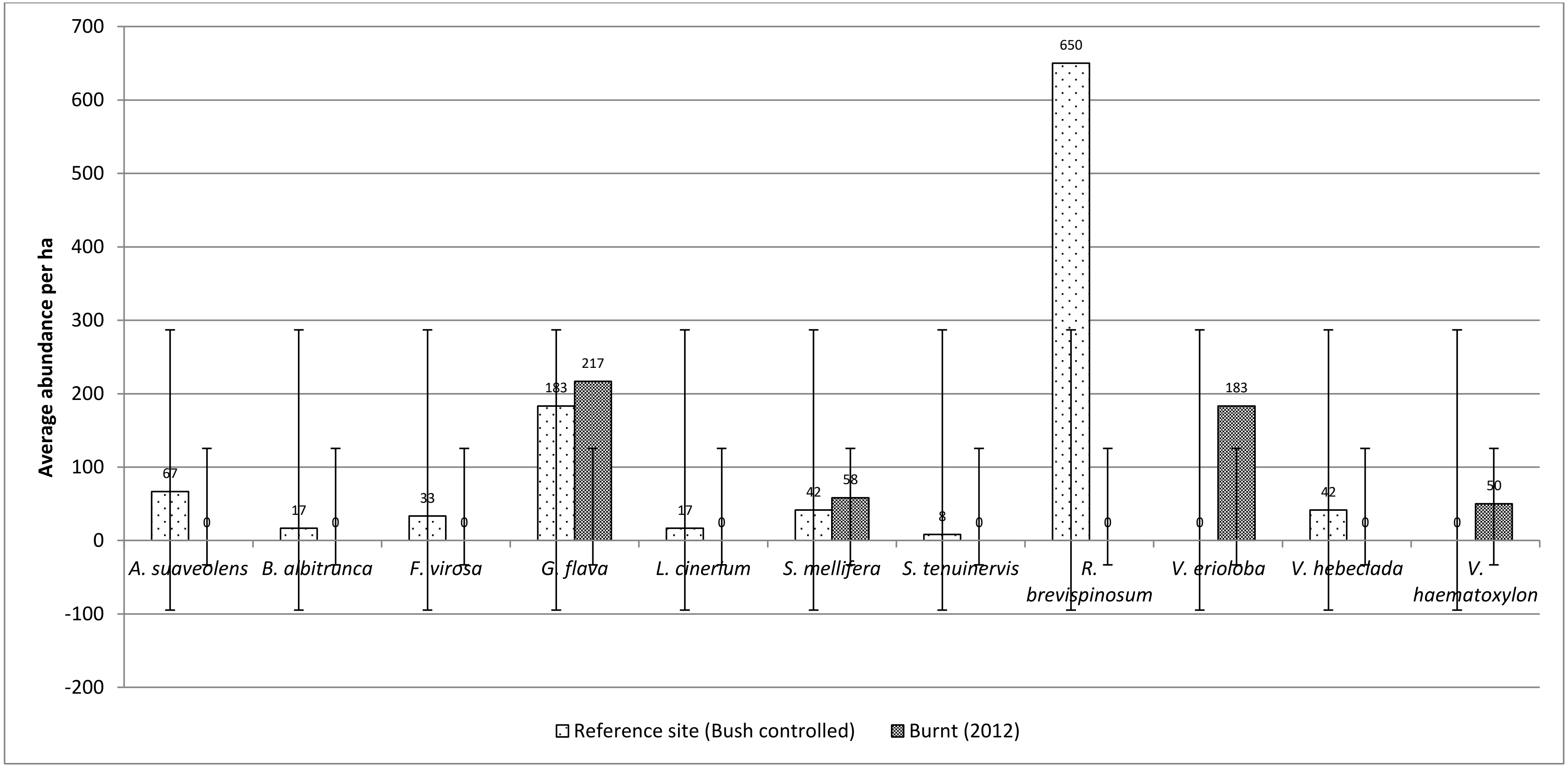


Figure 5.4: Bar plot indicating the average woody species abundance (individuals/ha) between the plots surveyed in the reference site (bush controlled) and burnt site (burnt in 2012) in the Khamab Reserve (Khamab2 area). The numbers above the bars indicate the average abundance with standard deviations of each species within the sites (see Appendix 4 for species abbreviations).

5.1.1.3 Woody species abundance on the Farm

The entire commercial cattle farm (Farm) was burnt in 2002. Certain sites also burnt again afterwards in 2008 and 2011. Therefore, the reference site was chosen as a site that was burnt only in 2002, and two other sites were chosen that were also burnt afterwards, i.e. a site that burnt in 2002 and 2008 as well as a site that burnt in 2002 and 2011 (Figure 5.5). Species found only in the reference site include *L. cinerium* (2108 individuals/ha), *L. decurrens* (142 individuals/ha), *L. bosciifolium* (108 individuals/ha), *R. brevispinosum* (108 individuals/ha), *T. camphoratus* (75 individuals/ha), *V. luederitzii* (50 individuals/ha) and *Z. mucronata* (25 individuals/ha) (Figure 5.5). The high abundance of *L. cinerium* may be attributed to its unpalatability due to the thorns found on this species; there are also no large browsers present in this area and, therefore, this species is not controlled through browsing.

A. suaveolens had a higher abundance within the sites that were burnt in 2002 and 2011 (475 individuals/ha) compared to the site that was burnt in 2002 and 2008 (25 individuals/ha). The abundance of *G. flava* was 483 individuals/ha within the area that was burnt in 2002 and 2011 and 283 individuals/ha within the site that was burnt in 2002 and 2008 respectively. This indicates that these species (*A. suaveolens* and *G. flava*) may be better adapted to a frequent fire regime (Figure 5.5). A higher abundance of *S. mellifera* was found within the reference site (233 individuals/ha) when compared to the two burnt sites, which may indicate that under frequent fires, this woody species can possibly be controlled, depending on the fuel load present. Species that were found only within the burnt sites (2002/2008 and 2002/2008) include *E. rigida*, *S. tenuinervis* and *T. sericea* (Figure 5.5).

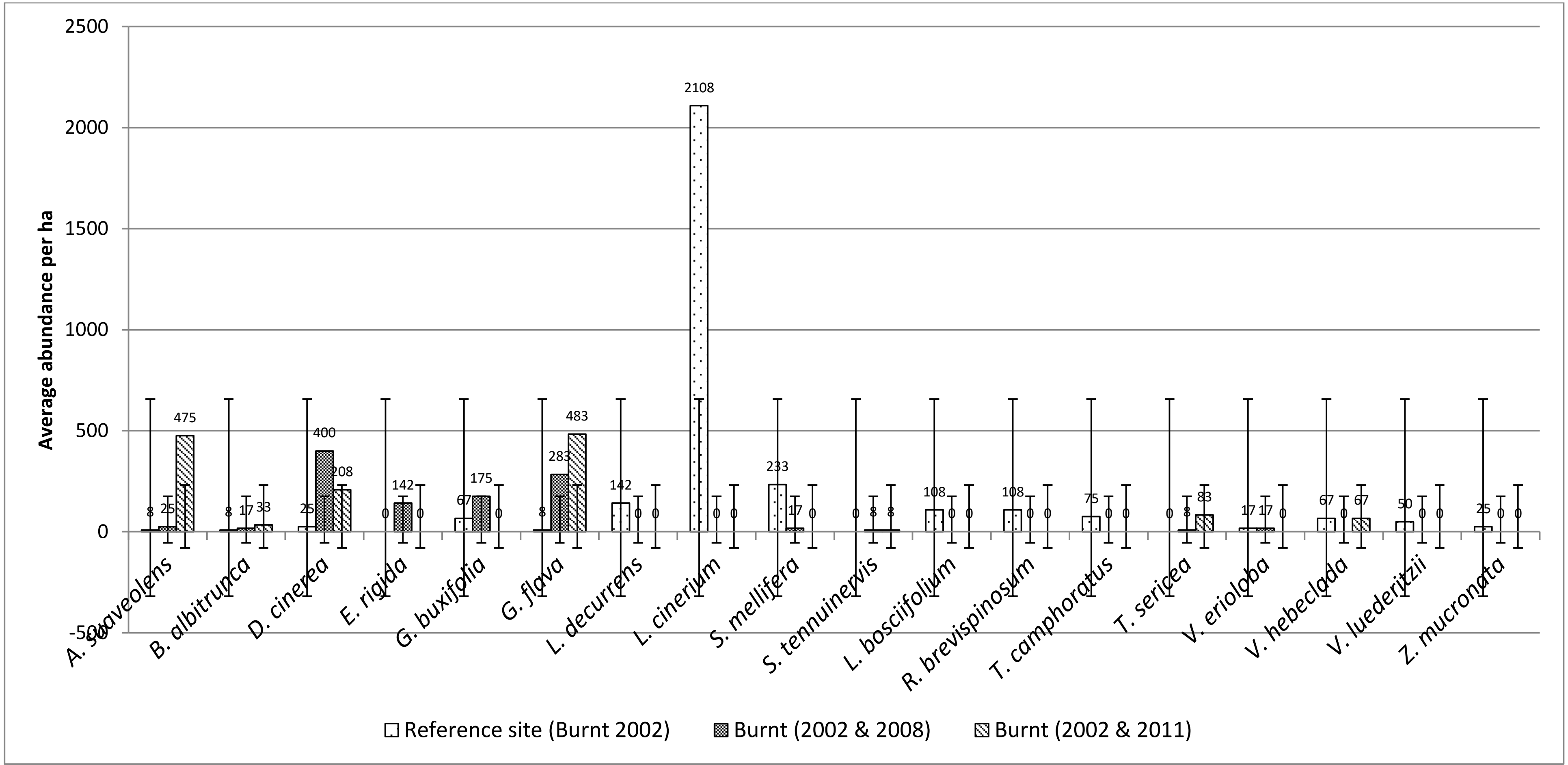


Figure 5.5: Bar plot indicating the average woody species abundance (individuals/ha) in the reference site (burnt in 2002) and other burnt sites (burnt in 2010 and 2011; burnt in 2002 and 2011) on the commercial cattle farm (Farm area). The numbers above the bars indicate the average abundance with standard deviations of each species within the sites (see Appendix 4 for species abbreviations).

5.1.2 Overall woody density

With regard to the overall density of the woody species, the results indicate that fire played a role in reducing the density of woody species, as fewer individuals were found within the burnt sites compared to the reference sites. Figure 5.6 indicates that the overall woody density for reference sites (Molopo reference site, Khamab1 reference site, Kamab2 reference site and Farm reference site) of the Molopo, Khamab and Farm areas was higher than within the burnt sites (Molopo [burnt in 2002], Khamab1 [burnt in 2010], Khamab1 [burnt in 2011], Khamab2 [burnt in 2012], Farm [burnt in 2002 and 2008] and Farm [burnt in 2002 and 2011]) (refer to Chapter 4 for information pertaining to the chosen areas and sites). This corresponds with what was stated earlier, namely that fire is an important factor in shaping the savanna ecosystems and that the suppression of fire could lead to a change in species composition and structure. Savannas could develop into dense woodland systems if fires are withheld (see Chapter 2.3.1). The site that indicated the lowest overall woody densities was the Khamab2 site, which was chemically controlled in both the reference site and the burnt site. This indicates that a combination of both chemical control and fire can be used as an effective management strategy against bush encroachment.

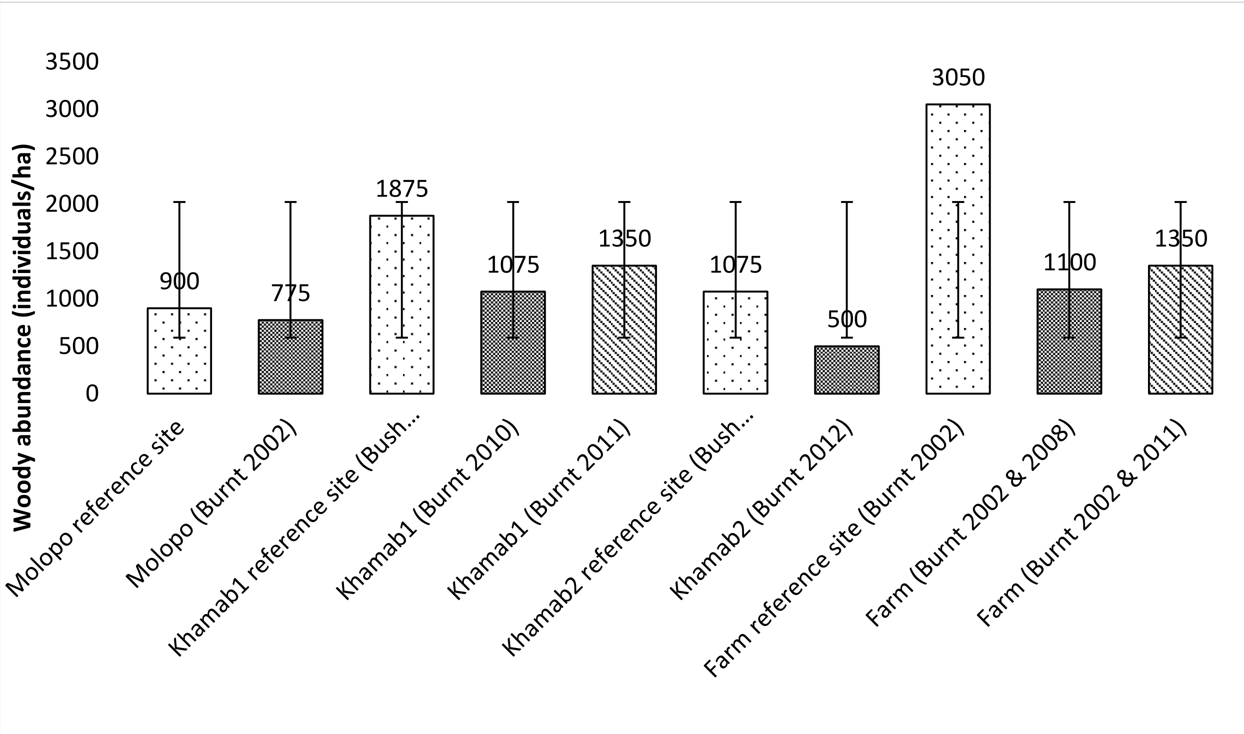


Figure 5.6: Bar plot indicating the overall woody abundance (individuals/ha) with standard deviations of the reference sites and the burnt sites of the Molopo, Khamab and Farm areas (see Appendix 4 for species abbreviations).

5.1.3 Woody species height classes, abundance and burn gradient

The canonical correspondence analysis (CCA) indicated that the burn gradient correlates to when the fire(s) occurred and when the vegetation sampling was carried out; for example, if a site burnt in 2002, the burn gradient will be from 0 to 16 years. Bar plots indicate the specific abundance of species within each height class at the sampling sites. For detailed data, see Appendix 5 attached.

5.1.3.1 Woody species height classes, abundance and burn gradient of the Molopo Nature Reserve

As there was not a high variety of species found within the Molopo Nature Reserve, the forbs, shrubs and trees were analysed together on one CCA plot (Figure 5.7) and will also be discussed simultaneously with the bar plots (Figures 5.17–5.19).

According to the CCA plot (Figure 5.7), most **forbs** were associated with the reference site (MFR) and included species such as *L. bosciifolium* in both the low height class (<0.5 m height class: *L.bo_L*) and the high height class (>1 m height class: *L.bo_H*), *M. divaricatum* within the low height class (0.5–1 m height class: *M.di_L*) and *A. suaveolens* within the low height class (<0.5 m height class: *A.su_L*) (Figure 5.7 & Figure 5.8). *Lycium cinerium* within the medium height class (0.5–1 m height class: *L.ci_M*) and higher height class (>1 m height class: *L.ci_H*) and *A. suaveolens* within the medium height class (0.5–1 m height class: *A.su_M*) were found between the six to ten years burn gradient (Figure 5.7). It would seem that with an increase in burning events (burnt 16 years ago), only *L. cinerium* was present within the low height class (<0.5 m height class: *L.ci_L*) (MF2) (Figure 5.7 & Figure 5.8).

With regard to the **shrubs**, species such as *S. tenuinervis* and *D. cinerea* occurred within the medium height class (1–2 m height class: *S.te_M* & *D.ci_M*) in the reference site (MSR) (Figure 5.7 & Figure 5.9). As both these species were mainly associated with the reference site (MSR), it seems as if these species disappear with an increase in burning events. *S. mellifera,* however, had a higher abundance in both the low height class (<1 m height class: *S.me_L*) and high height class (>2 m height class: *S.me_H*), and *G. flava* in all three height classes (<1 m height class: *G.fla_L*, 1–2 m height class: *G.fla_M* and >2 m height class: *G.fla_H*) with burning events that occurred six to ten years ago (Figure

5.7). The medium-sized shrubs of *S. mellifera* (1–2 m height class: *S.me_M*) had a high abundance in the site burnt 16 year ago (MS2) (Figure 5.7 & Figure 5.9).

With regard to the **trees**, *V. luederitzii* had a high abundance within the low height class (<2 m height class: *V.lu_L*) and high height class (>4 m height class: *V.lu_H*), and *V. erioloba* within the medium height class (2–4 m height class: *V.er_M*) in the reference site (MTR), and not in the burnt site (MT2) (Figure 5.7 & Figure 5.10). *V. luederitzii* in the medium height class (2–4 m height class: *V.lu_M*), *V. erioloba* in the low height class (<2 m height class: *V.er_L*), as well as in the high height class (>4 m height class: *V.er_H*), and *B. albitrunca* within the low height class (<2 m height class: *B.al_L*) were found to have a high abundance if an area would have burnt six to ten years ago (Figure 5.7).

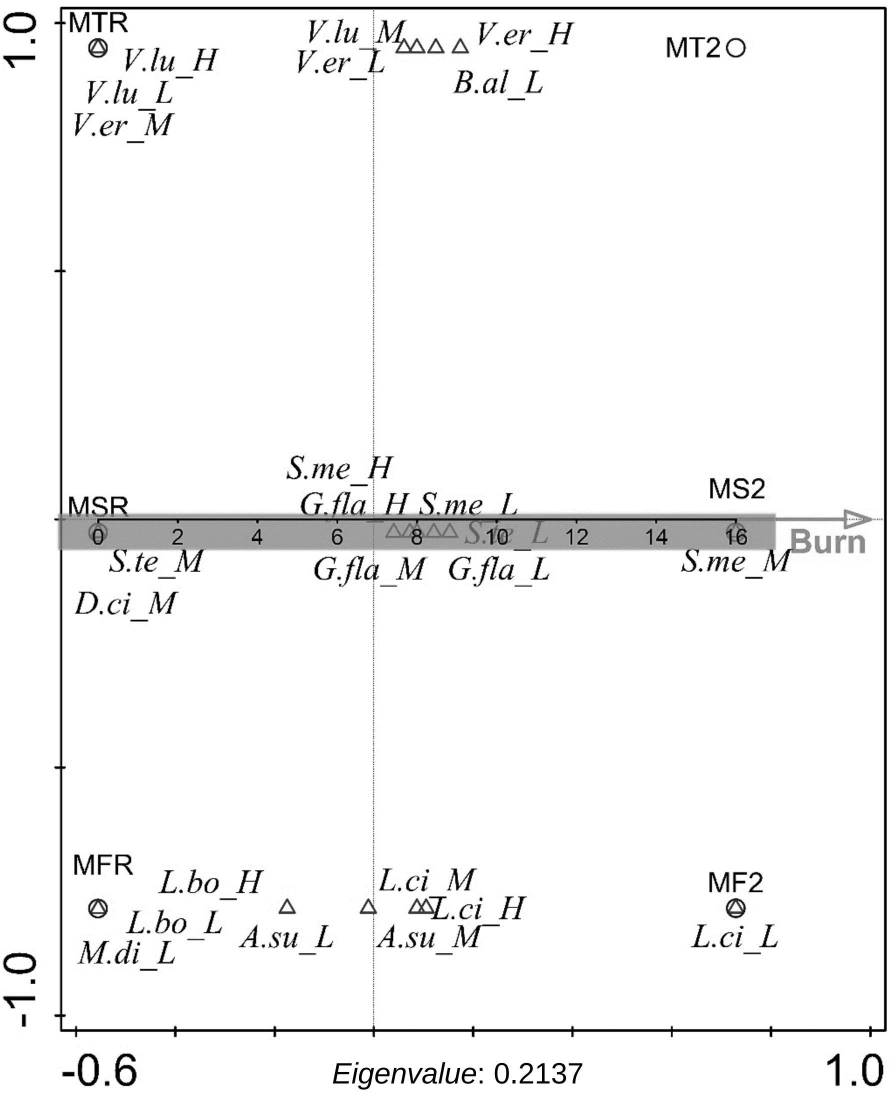


Figure 5.7: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of the **forbs, shrubs** and **trees** (Δ) and sampling sites (o) on a burn

gradient at the Molopo Nature Reserve: *A. su – Asparagus suaveolens*, *L. ci -– Lycium cinerium*, *L. bo – Lycium bosciifolium*, *M. di – Monechma divaricatum*, *G. fla – Grewia flava*, *S. me – Senegalia mellifera*, *S. te – Searsia tenuinervis*, *D. ci – Dichrostachys cinerea*, *B. al – Boscia albitrunca*, *V. er – Vachellia erioloba*, *V. lu – Vachellia luederitzii*, _L – low height class, _M – medium height class, _H – high height class, MFR – Molopo Forbs Reference, MF2 – Molopo Forbs burnt 2002, MSR – Molopo Shrubs Reference, MS2 – Molopo Shrubs burnt 2002, MTR – Molopo Trees Reference, MT2 – Molopo Trees burnt 2002.

- Effects of fire in the Molopo Nature Reserve area according to the burn gradient

It appears that **forbs** decreased with an increase in burning events, with only *L. cinerium* in the low height class at a high abundance being associated with the burnt site (MF2). *L. bosciifolium* completely disappeared with an increase in burning events (Figure 5.7). *A. suaveolens* also decreased with an increase in burning events. Regarding the **shrubs**, species such as *S. tenuinervis* and *D. cinerea* had high abundances within the medium height class in the reference site and it seems as if these species disappear with an increase in burning events (Figure 5.7). *G. flava* was mostly associated with fire events that occurred between six and ten years, with only *S. mellifera* in the medium height class being associated with burning events that occurred 16 years ago (Figure 5.7). It appears that no species in the higher classes were associated within the burnt site and, therefore, with an increase in burning events, a decrease in **tree** density is observed, which correlates with the data obtained during field work.

The abundance of the **forbs** noted in the Molopo Nature Reserve was higher within the reference site than in the burnt site (Figure 5.8). *A. suaveolens* was the dominant species, especially in the <0.5 m height class (183 individuals/ha in the reference site compared to 8 individuals/ha in the burnt site of 2002) and the 0.5–1 m height class (50 individuals/ha in the reference site compared to 17 individuals/ha in the burnt site of 2002) (Figure 5.8). The abundance of *Lycium cinerium* was higher in the burnt site than in the reference site, especially in the <0.5 m height class (33 individuals/ha and 0 individuals/ha respectively), as well as the 0.5–1 m height class (41 individuals/ha compared to 33 individuals/ha) (Figure 5.8). *Lycium bosciifolium* and *M. divaricatum* were only found within the reference site (Figure 5.8).

Regarding the abundance of the **shrubs** within the Molopo Nature Reserve, *G. flava* had the highest abundance in the burnt site compared to the reference site (Figure 5.9). A total of 183 individuals/ha were found in the burnt site within the 0.5–1 m height class compared to 108 individuals/ha in the reference site (Figure 5.9). The abundance of

Searsia tenuinervis was higher in the burnt site, especially in the <0.5 m height class (150 individuals/ha and 58 individuals/ha respectively) (Figure 5.9). *Dichrostachys cinerea* was only found in the reference site, with 17 individuals/ha in the 1–2 m height class (Figure 5.9).

Regarding the abundance of **trees**, *B. albitrunca* was dominant within the <2 m height class within the burnt site compared to the reference site (25 individuals/ha and 17 individuals/ha respectively) (Figure 5.10). *V. erioloba* was dominant in the reference site in the <2 m height class (58 individuals/ha and 42 individuals/ha respectively) and 2–4 m height class (8 individuals/ha and 0 individuals/ha respectively) compared to the burnt site (Figure 5.10). However, for the >4 m height class, the abundance of *V. erioloba* was higher in the burnt site compared to the reference site (17 individuals/ha and 8 individuals/ha respectively) (Figure 5.10). *V. luederitzii* was overall found in higher numbers in the reference site (8 individuals/ha and 0 individuals/ha respectively in the <2 m height class, 17 individuals/ha and 17 individuals/ha respectively in the 2–4 m height class and 25 individuals/ha and 0 individuals/ha respectively in the >4 m height class) (Figure 5.10).

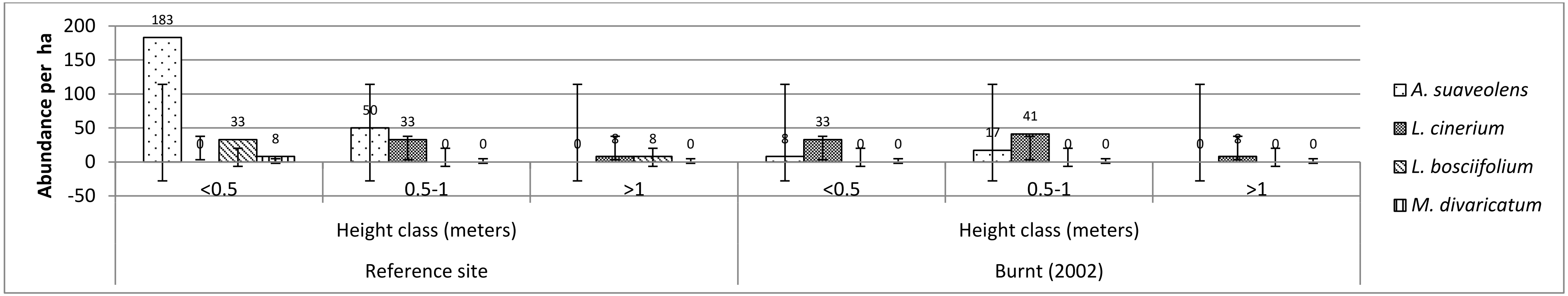


Figure 5.8: Bar plot indicating the height classes and species abundance (individuals/ha) with standard deviations of the **forbs** at the reference and burnt sites in the Molopo area (see Appendix 4 for species abbreviations).

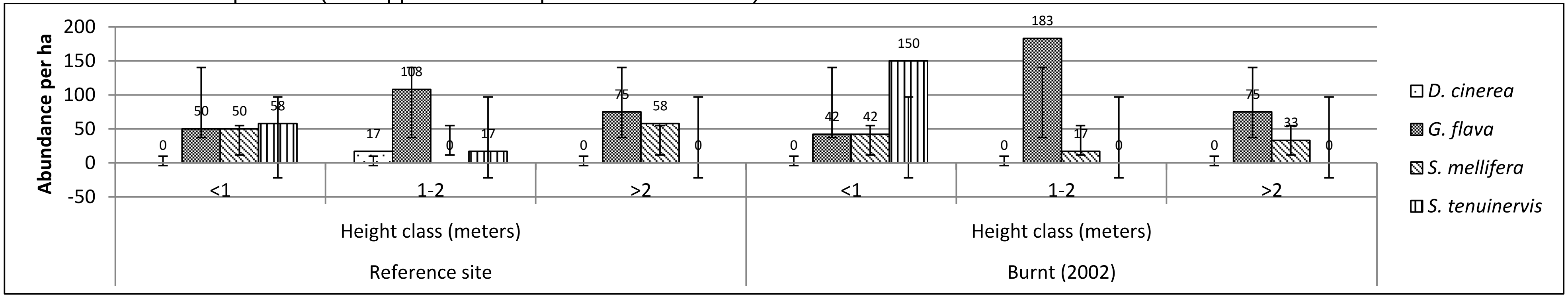


Figure 5.9: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the Molopo **shrubs** for the reference and burnt sites in the Molopo area (see Appendix 4 for species abbreviations).

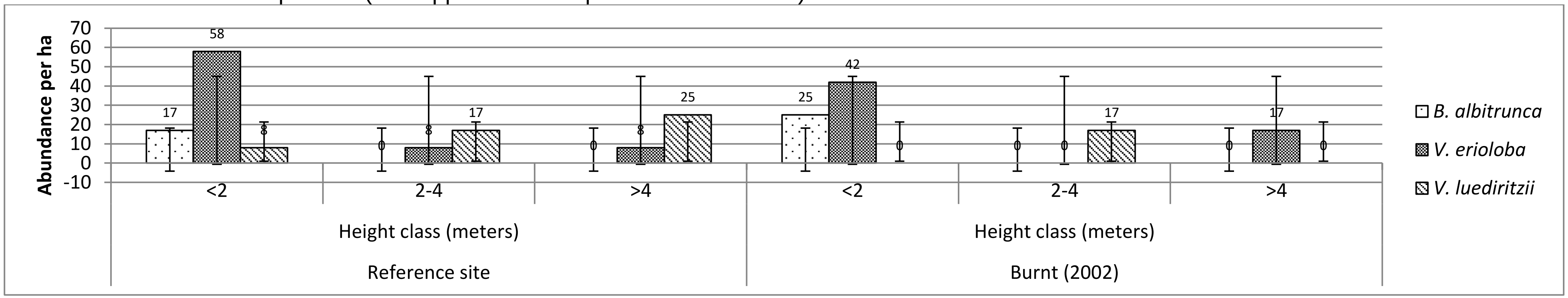


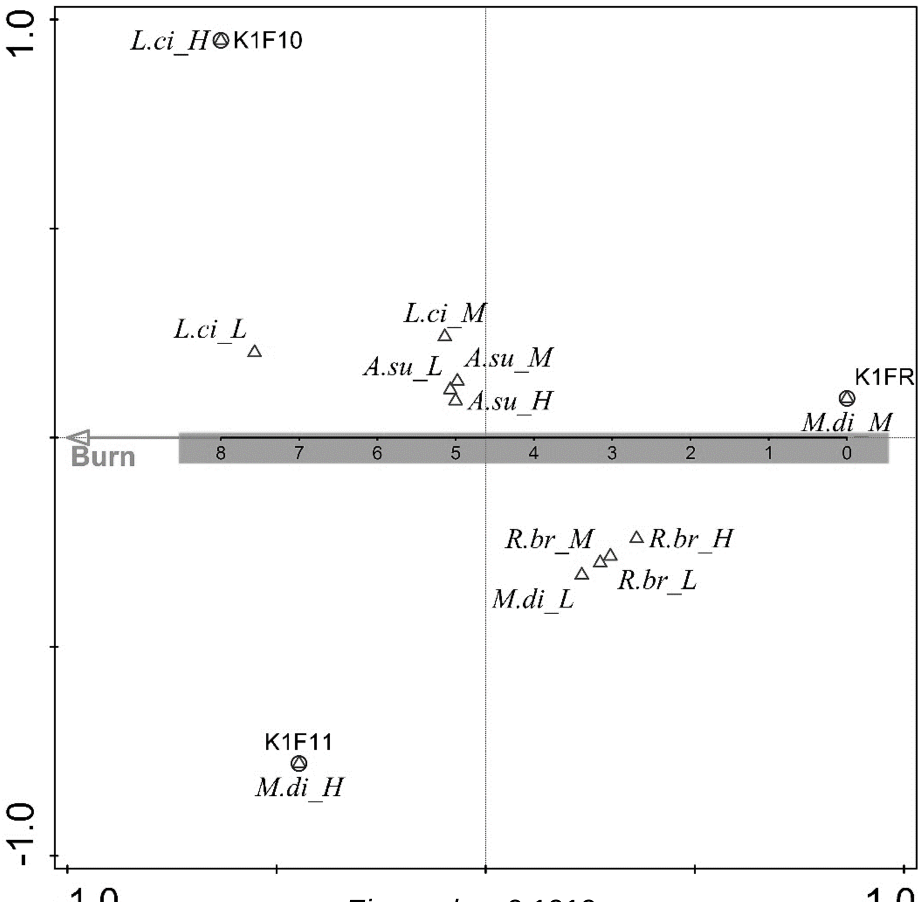
Figure 5.10: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the Molopo **trees** for the reference and burnt sites in the Molopo area (see Appendix 4 for species abbreviations).

5.1.3.2 Woody species height classes, abundance and burn gradient of the Khamab Nature Reserve

5.1.3.2.1 Khamab1

The variety in abundance of forbs, shrubs and trees was high in the Khamab1 area, compared to the other areas, i.e. Molopo Nature Reserve, Khamab2 and Farm. Separate CCA ordinations and bar plots for the forbs, shrubs and trees are discussed (Figures 5.20–5.22).

With regard to the **forbs**, *M. divaricatum,* which were within the medium height class (0.5–1 m height class: *M.di_M*), was only associated with the reference site where no burning occurred (K1FR) (Figure 5.11 & Figure 5.14). *Lycium cinerium* within the medium height class (0.5–1 m height class: *L.ci_M*) and A*. suaveolens* within all three height classes (<0.5 m height class: *A.su_L*, 0.5–1 m height class: *A.su_M* and >1 m height class: *A.su_H*) were found on the burn gradient at a fire event of five years ago (Figure 5.11 & Figure 5.14). *Rhigozum brevispinosum* within all three height classes (<0.5 m height class: *R.br_L*, 0.5–1 m height class: *R.br_M* and >1 m height class) together with *M. divaricatum* within the low height class (<0.5 m height class: *M.di_L*) were found on the burn gradient at fire events of between two and four years ago (Figure 5.11 & Figure 5.14). *Lycium cinerium* within the low height class (<0.5 m height class: *L.ci_L*) was found on the burn gradient at a fire event of between seven and eight years ago (Figure 5.11 & Figure 5.14). *Lycium cinerium* within the high height class (>1 m height class: *L.ci_H*) was only associated with the 2010 burnt site (K1F10), and *M. divaricatum* within the high height class (>1 m height class: *M.di_H*) was only associated with the 2011 burnt site (K1F11) (Figure 5.11 & Figure 5.14).



Eigenvalue: 0.1919

Figure 5.11: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of the **forbs** (Δ) and sampling sites (o) on a burn gradient at the Khamab1 area: *A. su – Asparagus suaveolens*, *L. ci – Lycium cinerium*, *R. br – Rhigozum brevispinosum*, *M. di – Monechma divaricatum*, _L – low height class, _M – medium height class, _H – high height class, K1FR – Khamab1 Forbs Reference, K1F10 – Khamab1 Forbs burnt 2010, K1F11 – Khamab1 Forbs burnt 2011.

Regarding the **shrubs**, *V. hebeclada* within the low height class (<1 m height class: *V.he_L*) was only associated with the reference site (K1SR) and not within the burnt sites (K1S10 & K1S11) (Figure 5.12 & Figure 5.15). *Grewia flavescens* within both the low and medium height class (<1 m height class: *G.fla_L* and 1–2 m height class: *G.fla_M*) and *S. mellifera* within both the low and high height class (<1 m height class: *S.me_L* and >2 m height class: *S.me_H*) were found on the burn gradient at a fire event of five years ago (Figure 5.12 & Figure 5.15). *Flueggea virosa*, *S. tenuinervis* and *G. flava* within the low height class (<1 m height class: *F.vi_L*, *S.te_L* & *G.fla_L*) and *D. cinerea* within the medium height class (1–2 m height class: *D.ci_M*) were found on the burn gradient at a fire event of between three and four years ago (Figure 5.12 & Figure 5.15).

Searsia tenuinervis within the medium height class (1–2 m height class: *S.te_M*) was found on the burn gradient at a fire event that occurred approximately two years ago (Figure 5.12 & Figure 5.15). *Senegalia mellifera* within the medium height class (1–2 m height class: *S.me_M*) and *G. flavescens* within the high height class (>2 m height class: *G.flv_H*) were found on the burn gradient at a fire event that occurred between seven and eight years ago (Figure 5.12 & Figure 5.15). *Flueggea virosa* within the medium height class (1–2 m height class: *F.vi_M*) was only associated with the 2010 burnt site, whereas *G. flava* within the medium height class (1–2 m height class: *G.fla_M*) and *D. cinerea* within the low height class (<1 m height class: *D.ci_L*) were only associated with the 2011 burnt site (Figure 5.12 & Figure 5.15).

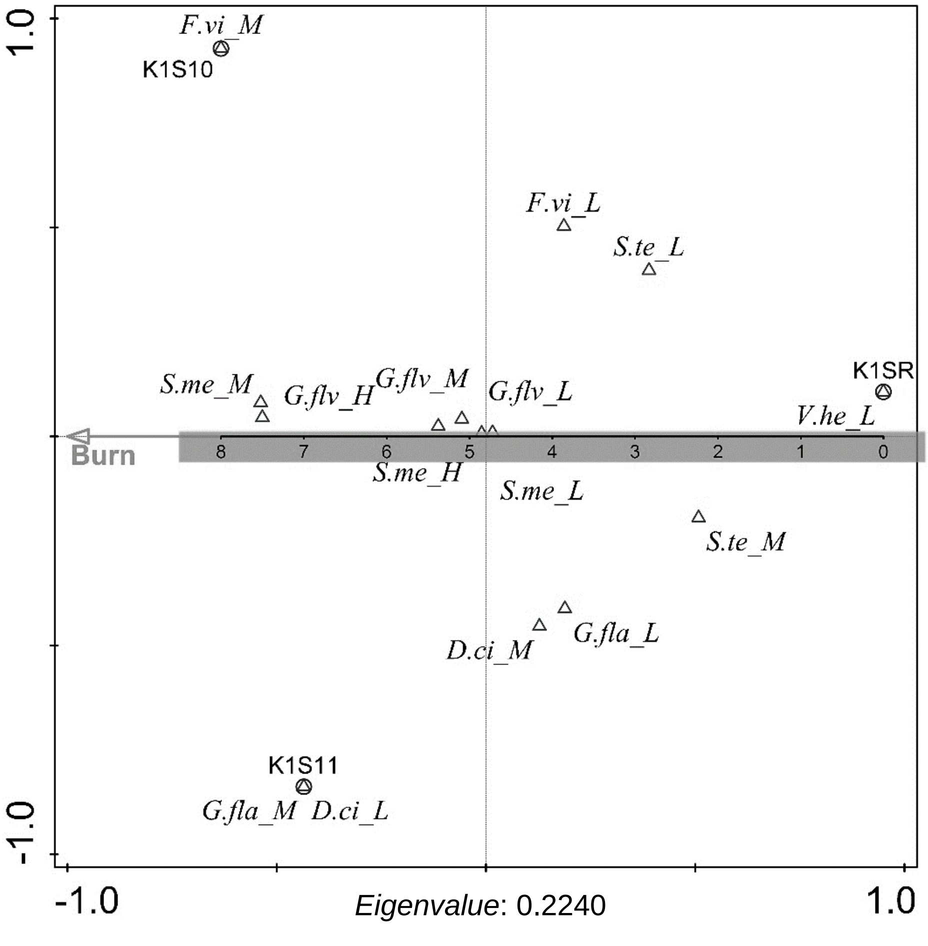


Figure 5.12: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of the **shrubs** (∆) and sampling sites (o) on a burn gradient at the Khamab1 area: *F. viro – Flueggea virosa*, *G. flv – Grewia flavescens*, *G. fla – Grewia flava*, *S. me – Senegalia mellifera*, *S. te – Searsia tenuinervis*, *V. he – Vachellia hebeclada*, *D. ci – Dichrostachys cinerea*, _L – low height class, _M – medium height class, _H – high height class, K1FR – Khamab1 Forbs Reference, K1F10 – Khamab1 Forbs burnt 2010, K1F11 – Khamab1 Forbs burnt 2011.

Regarding the **trees**, *V. luederitzii* within the high height class (>4 m height class: *V.lu_H*) was found on the burn gradient at a fire event that occurred approximately a year ago (Figure 5.13). *Boscia albitrunca* within the low height class (<2 m height class: *B.al_L*), *Z. mucronata* within the high height class (>4 m height class: *Z.mu_H*) and *V. luederitzii* within the low and medium height class (<2 m height class: *V.lu_L*, 2-4 m height class: *V.lu_M*) were found on the burn gradient at a fire event of between two and four years ago (Figure 5.13). *B. albitrunca* within the medium and high height class (2–4 m height class: *B.al_M* and >4 m height class: *B.al_H*) and *T. sericea* within the low and medium height class (<2 m height class: *T.se_L* and 2–4 m height class: *T.se_M*) were found on the burn gradient at a fire event that occurred between five and eight years ago (Figure 5.13). *Terminalia sericea* within the high height class (>4 m height class: *T.se_H*), *V. erioloba* within the low height class (<2 m height class: *V.er_L*) and *Z. mucronata* within the medium height class (2–4 m height class: *Z.mu_M*) were only associated the 2010 burnt site (K1T10) (Figure 5.13 & Figure 5.16). *Vachellia erioloba* within the high height class (>4 m height class: *V.er_H*) and *V. haematoxylon* within the low height class (<2 m height class: *V.ha_L*) were only associated with the 2011 burnt site (Figure 5.13 & Figure 5.16).

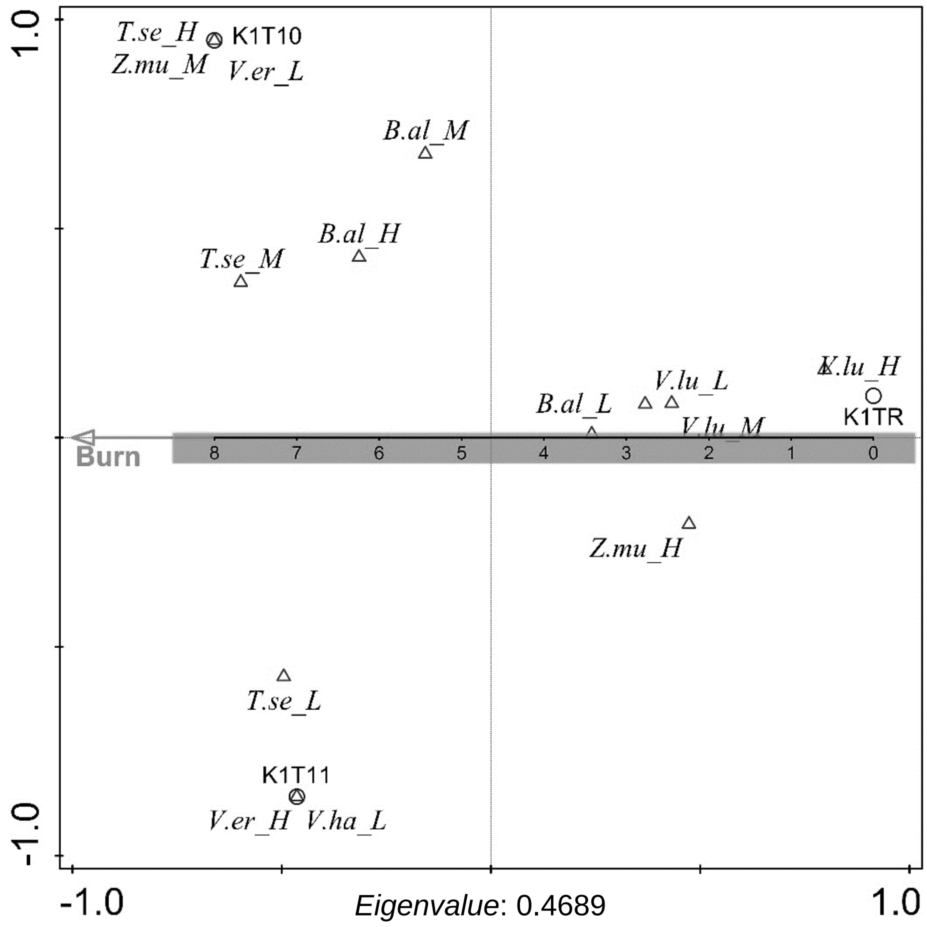


Figure 5.13: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of the **trees** (Δ) and sampling sites (o) on a burn gradient at the Khamab1 area: *B. al* – *Boscia albitrunca*, *V. er* – *Vachellia erioloba*, *V. ha* – *Vachellia* haematoxylon, *V. lu* – *Vachellia luederitzii*, *Z. mu* – *Ziziphuz mucronata*, *T. se* – *T. sericea*, _L – low height class, _M – medium height class, _H – high height class, K1FR – Khamab1 Forbs Reference, K1F10 – Khamab1 Forbs burnt 2010, K1F11 – Khamab1 Forbs burnt 2011.

- Effects of fire at the Khamab1 area according to the burn gradient

With an increase in burning events, the abundance of **forbs** decreases, with *M. divaricatum* in the medium height class only being associated with the reference site (Figure 5.11). Most **shrubs** were associated with the reference site as well as the burnt sites, with only *V. hebeclada* disappearing completely with an increase in burning events (Figure 5.12). With regard to the **trees**, it seems as if *V. luederitzii* disappears with an increase in burning events (Figure 5.13).

Several **forbs** were found at the Khamab1 area (Figure 5.14) with a high abundance (individuals/ha) of *A. suaveolens* within the <0.5 m height class in the 2010 burnt site (183 individuals/ha), the reference site (125 individuals/ha) and the 2011 burnt site (117 individuals/ha). *Lycium cinerium* was found at all of these sites; however, no individuals were found in the <0.5 m height class at the reference site compared to 17 individuals/ha in the 2010 burnt site and 8 individuals/ha in the 2011 burnt site (Figure 5.14). A higher abundance of *L. cinerium* was found at the 2010 burnt site within the 0.5–1 m height class, namely 42 individuals/ha compared to 17 individuals/ha in the reference site and 8 individuals/ha in the 2011 burnt site respectively (Figure 5.14). *Lycium cinerium* was found neither in the reference site nor in the 2011 burnt site within the >1 m height class. Only 8 individuals/ha were found in the 2010 burnt site. *Lycium bosciifolium* was only found within the 2011 burnt site within the <0.5 m height class (8 individuals/ha) (Figure 5.14).

Monechma divaricatum had a high abundance in the reference site within the <0.5 m height class compared to the 2010 burnt site with 0 individuals/ha and the 2011 burnt site with 33 individuals/ha (Figure 5.14). *Rhigozum brevispinosum* was found within all three height classes in the reference site (<0.5 m height class: 17 individuals/ha, 0.5–1 m height class: 33 individuals/ha and >1 m height class: 33 individuals/ha) and to a lesser extent in the 2011 burnt site (<0.5 m height class: 8 individuals/ha, 0.5–1 m height class: 17 individuals/ha and >1 m height class: 8 individuals/ha) (Figure 5.14).

With regard to the **shrubs**, *D. cinerea* within the <1 m height class was only found in the 2011 burnt site (58 individuals/ha) and within the 1–2 m height class, the highest abundance was in the 2011 burnt site (67 individuals/ha), with only 17 individuals/ha in the reference site and none found in the 2010 burnt site (Figure 5.15). *Dichrostachys cinerea* was not found in the >2 m height class at any of the three sites. *Flueggea virosa* was found within the <1 m height class in the reference site (67 individuals/ha), as well as in the 2010 burnt site (50 individuals/ha), and only within the 1–2 m height class in the 2010 burnt site (33 individuals/ha) (Figure 5.15).

Grewia flava had a high abundance within the reference site in the <1 m height class (108 individuals/ha) and in the 1–2 m height class (133 individuals/ha). In the 2010 burnt site within the <1 m height class, 50 individuals/ha were found; within the 1–2 m height class, 150 individuals/ha were found; and within the >2 m height class, 8 individuals/ha were found. A high abundance was also found in the 2011 burnt site within the <1 m height class (125 individuals/ha), the 1–2 m height class (225 individuals/ha) and the >2 m height class (8 individuals/ha) (Figure 5.15). *Grewia flavescens* was not found in the 2010 burnt site but was found in the reference site (<1 m height class: 17 individuals/ha) and in the 2011 burnt site (<1 m height class: 33 individuals/ha and 1–2 m height class: 25 individuals/ha) (Figure 5.15).

Senegalia mellifera was found in all the sites, with the highest abundance in the reference site within the <1 m height class (267 individuals/ha), in the 2010 burnt site (75 individuals/ha) and in the 2011 burnt site (208 individuals/ha) (Figure 5.15). Within the 1–2 m height class, 58 individuals/ha of *S. mellifera* were found within the 2010 burnt site and 42 individuals/ha in the 2011 burnt site, with no individuals found in the reference site (Figure 5.15). Several individuals were found in the 2011 burnt site within the >2 m class (83 individuals/ha), with only 50 individuals/ha in the 2010 burnt site and 25 individuals/ha in the reference site (Figure 5.15).

Searsia tenuinervis was found in the reference site within the <1 m class (383 individuals/ha) and in the 2010 burnt site (25 individuals/ha) (Figure 5.15). Within the 1–2 m height class, 108 individuals/ha were found in the reference site and 8 individuals/ha in the 2011 burnt site (Figure 5.15). *Vachellia hebeclada* was only found within the reference site within the <1 m height class (33 individuals/ha). *Ziziphus mucronata* was found in the reference site within the >2 m height class (17 individuals/ha), as well as in the 2011 burnt site within the >2 m height class (8 individuals/ha) (Figure 5.15).

With regard to the **trees**, *B. albitrunca* was found in all the sites, with a high abundance in the reference site within the <2 m height class (117 individuals/ha) compared to 42 individuals/ha in the 2010 burnt site and 58 individuals/ha in the 2011 burnt site within the same height class (Figure 5.16). Within the 2–4 m height class, 17 individuals/ha were found in the 2010 burnt site compared to 8 individuals/ha in the reference site, with no individuals in the 2011 burnt site within the same height class (Figure 5.16). Within the >4 m height class, 25 individuals/ha were found in the 2010 burnt site compared to 8 individuals/ha in the reference site and 8 individuals/ha in the 2011 burnt site (Figure 5.16).

Terminalia sericea was not found in the reference site, but a high abundance was found in the 2011 burnt site within the <2 m height class (175 individuals/ha) compared to 33 individuals/ha in the 2010 burnt site (Figure 5.16). Within the 2–4 m height class, 17 individuals/ha of this species was found in the 2010 burnt site compared to 8 individuals/ha in the same height class in the 2011 burnt site (Figure 5.16). *Terminalia sericea* was only found in the 2010 burnt site within the >4 m height class (25 individuals/ha). *Vachellia erioloba* was only found in the 2010 burnt site within the <2 m height class (50 individuals/ha) and in the 2011 burnt site within the >4 m height class (17 individuals/ha) (Figure 5.16).

Vachellia haematoxylon was only found in the 2011 burnt site within the <2 m height class (17 individuals/ha) (Figure 5.16). *Vachellia luederitzii* was found in all of the sites, with the highest abundance in the reference site within the >4 m height class (100 individuals/ha) compared to 8 individuals/ha in the 2010 burnt site and no individuals in the 2011 burnt site within the same height class (Figure 5.16). Within the <2 m height class in the reference site, 58 individuals/ha of this species was found compared to 17 individuals/ha in the 2010 burnt site and the 2011 burnt site respectively. Within the 2–4 m height class in the reference site, 33 individuals/ha of *V. luederitzii* were found compared to 8 individuals/ha in the 2010 burnt site and the 2011 burnt site respectively (Figure 5.16).

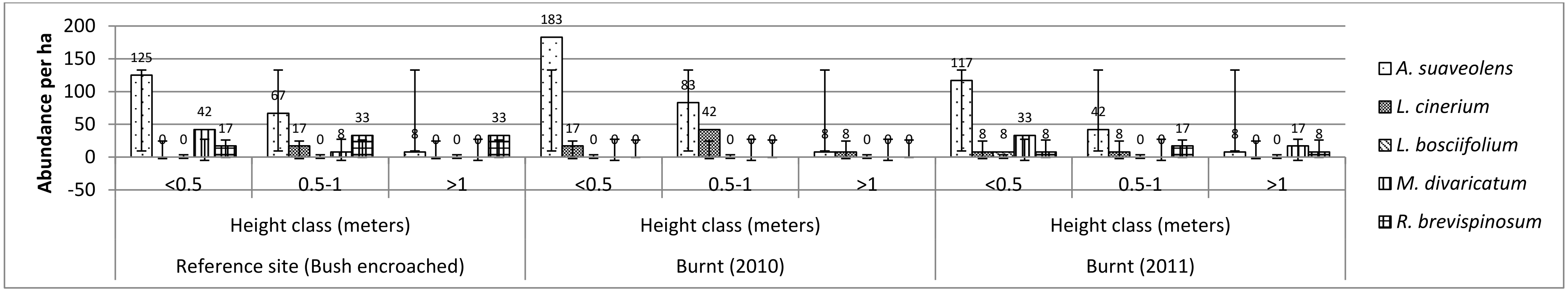


Figure 5.14: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **forbs** for the reference site and burnt sites in the Khamab1 area (see Appendix 4 for species abbreviations).

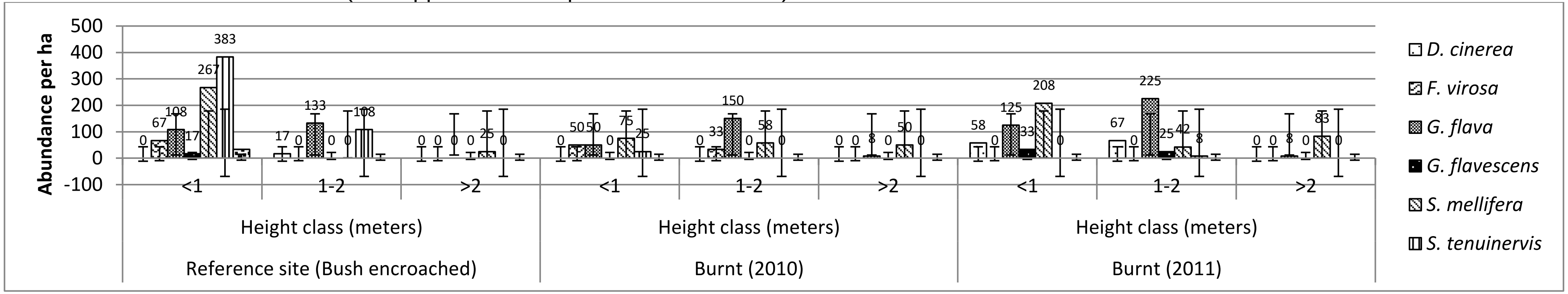


Figure 5.15: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **shrubs** for the reference site and burnt sites in the Khamab1 area (see Appendix 4 for species abbreviations).

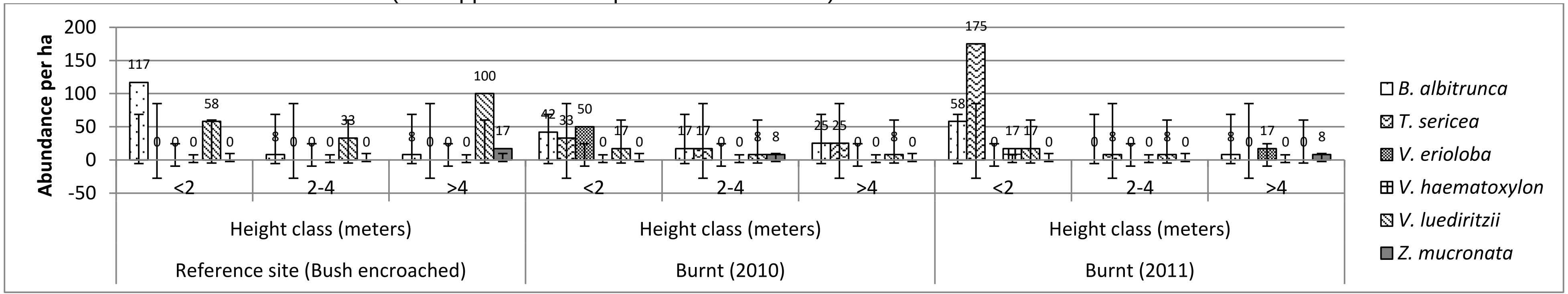


Figure 5.16: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **trees** for the reference site and burnt sites in the Khamab1 area (see Appendix 4 for species abbreviations).

5.1.3.2.2 Khamab2

As a high variety of species has not been found within the Khamab2 sites, the forbs, shrubs and trees were analysed together on one CCA plot. Khamab2 (bush controlled) was indicated to have meaningful differences with regard to the overall abundance between the height classes, the reference site and burnt site.

According to the canonical correspondence analysis (CCA) plot (Figure 5.17 & Figure 5.18), no **forbs** were found within the burnt site during the sampling period. The following species within the different height classes were only associated with the reference site (K2FR): *L. cinerium* within the medium height class (0.5–1 m height class: *L.ci_M*) and high height class (>1 m height class: *L.ci_H*), *A. suaveolens* and *R. brevispinosum* within the low height class (<0.5 m height class: *A.su_L* & *R.br_L*) and the medium height class (0.5–1 m height class: *A.su_M* & *R.br_M*) (Figure 5.17 & Figure 5.18).

With regard to the **shrubs**, the following species at the different height classes were only associated with the reference site (K2SR): *F. virosa* within the low height class (>1 m height class: *F.vi_L*) and within the medium height class (1–2 m height class: *F.vi_M*), *S. tenuinervis* within the low height class (>1 m height class: *S.te_L*), *V. hebeclada* within the low height class (>1 m height class: *V.he_L*) and the medium height class (1–2 m height class: *V.he_M*) and *S. mellifera* within the medium height class (1–2 m height class: *S.me_M*) (Figure 5.17 & Figure 5.19). *Grewia flavescens* in both the medium height class (1–2 m height class: *G.flv_M*) and the high height class (>2 m height class: *G.flv_H*) and *S. mellifera* within the low height class (>1 m height class: *S.me_L*) were found on the burn gradient where a fire event occurred between two and four years ago (Figure 5.17). *Grewia flavescens* within the low height class (>1 m height class: *G.flv_L*) was only associated with the site that was burnt about six years ago (K2S12) (Figure 5.17 & Figure 5.19).

Regarding the **trees**, *V. haematoxylon* within the low height class (<2 m height class: *V.ha_L*) and *V. erioloba* within all three height classes (<2 m height class: *V.er_L*, 2–4 m height class: *V.er_M* and >4 m height class: *V.er_H*) were only associated with the burnt site (K2T12) (Figure 5.17 & Figure 5.20).

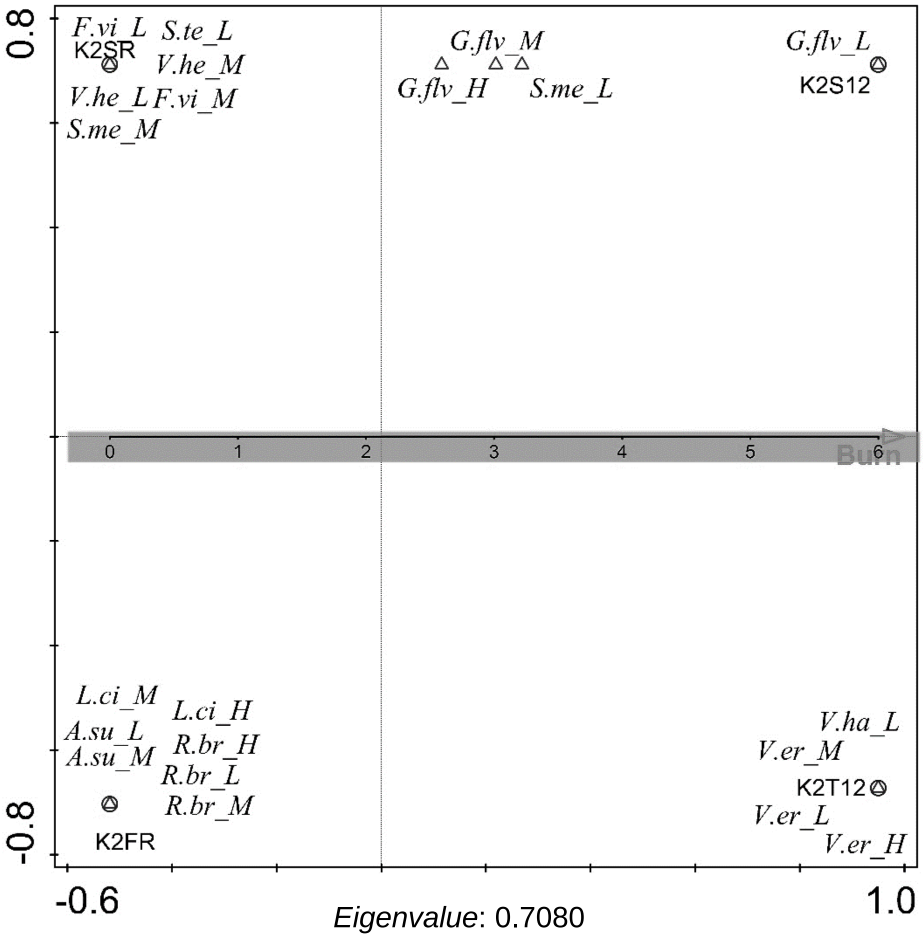


Figure 5.17: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of **the forbs, shrubs and trees** (Δ) and sampling sites (o) on a burn gradient at the Khamab2 area: *A. su – Asparagus suaveolens*, *L. ci – Lycium cinerium*, *R. br – Rhigozum brevispinosum*, *F. viro – Flueggea virosa*, G*. flv – Grewia flavescens*, S*. me – Senegalia mellifera*, *S. te – Searsia tenuinervis*, *V. he – Vachellia hebeclada*, *V. er – Vachellia erioloba*, *V. ha – Vachellia haematoxylon*, _L – low height class, _M – medium height class, _H – high height class, K2FR – Khamab2 Forbs Reference, K2SR – Khamab2 Shrubs Reference, K2S12 – Khamab2 Shrubs burnt 2012, K2T12 – Khamab2 Trees burnt 2012.

- Effects of fire at the Khamab2 area according to the burn gradient

According to the canonical correspondence analysis (CCA) plot, no **forbs** were found within the burnt site during the sampling period (Figure 5.17). Therefore, it would seem that forbs either completely disappeared at this site with an increase in burning events or no forbs were present when the sampling was carried out. The plot also indicates a decrease in shrubs with an increase in burning events. It also seems as if trees increase with an increase in burning events, which may be due to fire removing some competition that can be caused by seedlings of lower-growing plants.

Most **shrubs** were associated with the reference site, with only *G. flavescens* within the low height class being associated with the 2012 burn site (Figure 5.17). Some shrubs (i.e. *G. flavescens* in the medium and high height classes and *S. mellifera* in the low height class) were found on the burn gradient with a fire event that occurred between two and four years (Figure 5.17).

Few **tree** species (*V. erioloba* in all three height classes and *V. haematoxylon* in the low height class) were found at the Khamab2 site, all of which were associated with the 2012 burnt site (Figure 5.17).

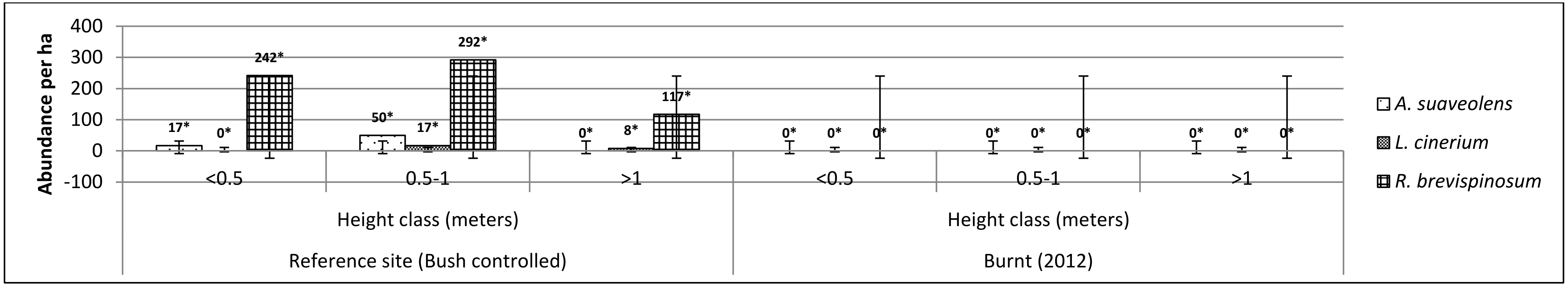


Figure 5.18: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **forbs** for the reference site and burnt site in the Khamab2 area (see Appendix 4 for species abbreviations).[9]

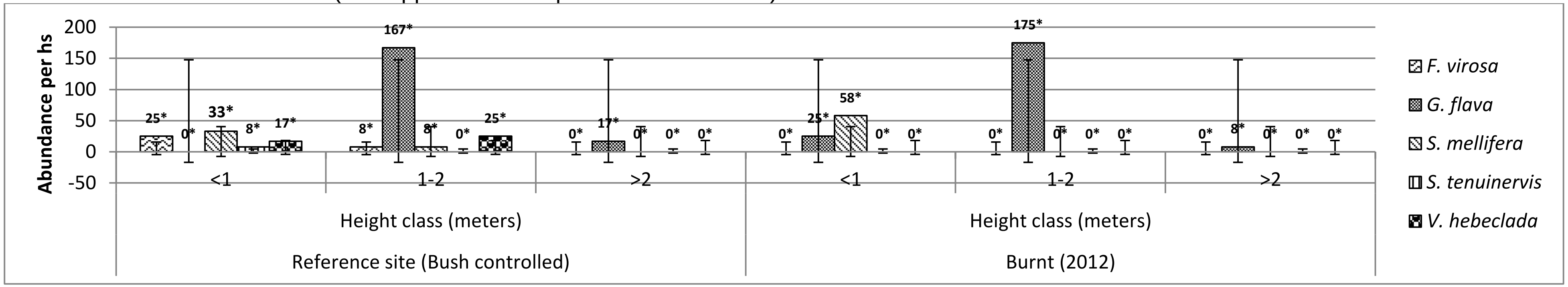


Figure 5.19: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **shrubs** for the reference site and burnt site in the Khamab2 area (see Appendix 4 for species abbreviations).

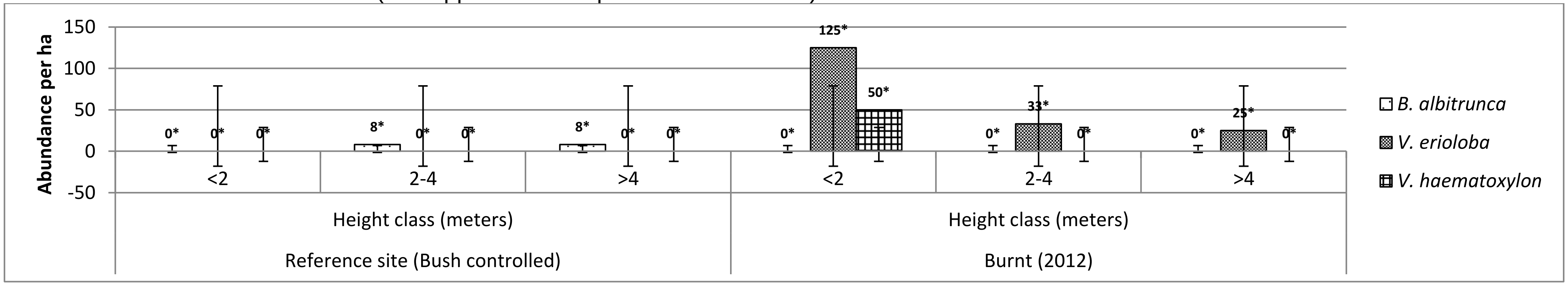


Figure 5.20: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **trees** for the reference site and burnt site in the Khamab2 area (see Appendix 4 for species abbreviations).

[9] Figures indicated with an asterisk (*) indicates meaningful differences between the species height classes and abundance according to T-tests (Chapter 4.3).

5.1.3.3 Woody species height classes, abundance and burn gradient of the Farm

A relatively high variety of species were found within the Farm area when compared to the other study areas. Forbs, shrubs and trees were analysed separately on three CCA plots and will be discussed separately, whereas the bar plots will be discussed simultaneously.

With regard to the **forbs**, the following species at the different height classes were found in the reference site (FFR): *L. bosciifolium* within the low height class (<0.5 m height class: *L.bo_L*), *L. cinerium* within the low height class (<0.5 m height class: *L.ci_L*) and medium height class (1–2 m height class: *L.ci_M*), *R. brevispinosum* within the low height class (<0.5 m height class: *R.br_L*) and the medium height class (1–2 m height class: *R.br_M*) and *L. decurrens* within all three height classes (<0.5 m height class: *L.de_L*, 0.5–1 m height class: *L.de_M* and >1 m height class: *L.de_H*) (Figure 5.21 & Figure 5.24). *Asparagus suaveolens* within the low height class (<0.5 m height class: *A.su_L*) and medium height class (0.5–1 m height class: *A.su_M*) was found on the burn gradient at a fire event that occurred between six and eight years ago (Figure 5.21).

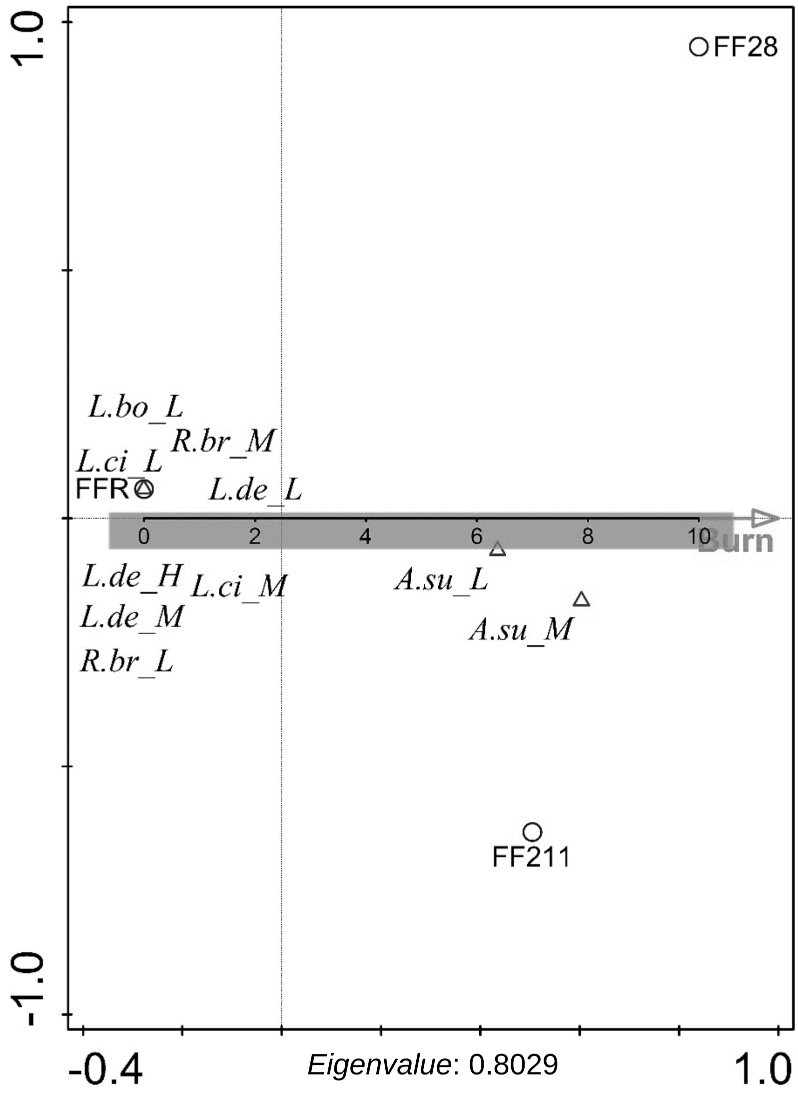


Figure 5.21: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of the **forbs** (Δ) and sampling sites (o) on a burn gradient Farm area: *A. su* – *Asparagus suaveolens*, *L. ci* – *Lycium cinerium*, *L. bo* – *Lycium* bosciifolium, *L. bo* – *Laggera decurrens*, *R. br* – *Rhigozum brevispinosum*, _L – low height class, _M – medium height class, _H – high height class, FFR – Farm Forbs Reference, FF28 – Farm Forbs burnt 2002 & 2008, FF211 – Farm Forbs burnt 2002 & 2011.

The following **shrubs** were only associated with the reference site (FSR): *T. camphoratus* within the low height class (<1 m height class: *T.ca_L*) and the medium height class (1–2 m height class: *T.ca_M*), as well as *S. mellifera* within the low height class (<1 m height class: *S.me_L*) and the high height class (>2 m height class: *S.me_H*) (Figure 5.22 & Figure 5.25). It seems as if *T. camphoratus* disappeared completely with an increase in burn scale (Figure 5.22). *Senegalia mellifera,* which occurred within the medium height class (1–2 m height class: *S.me_M*), and *G. buxifolia* within the low height class (<1 m height class: *G.bu_L*) were found on the burn gradient at a fire event that occurred between four and six years ago. *V. hebeclada* within the low height class (<1 m class: *V.he_L*) was found on the burn gradient at a fire event that occurred between two and four years ago (Figure 5.22). *Grewia flavescens* within all three height classes (<1 m height class: *G.flv_L*, 1–2 m height class: *G.flv_M* and >2 m height class: *G.flv_H*), *D. cinerea* within the low height class (<1 m height class: *D.ci_L*) and the medium height class (1–2 m height class: *D.ci_M*) and *S. tenuinervis* within the low height class (<1 m height class: *S.te_L*) were all found on the burn gradient at a fire event that occurred between six and ten years ago (Figure 5.22 & Figure 5.25). *Gymnosporia buxifolia* within the medium height class (1–2 m height class: *G.bu_M*) and *E. rigida* within the low height class (<1 m height class: *E.ri_L*) were only associated with the 2002 and 2008 burnt site (FS28), whereas *V. hebeclada* within the medium height class (1–2 m height class: *V.he_M*) was only associated with the 2002 and 2011 burnt site (FS211) (Figure 5.22 & Figure 5.25).

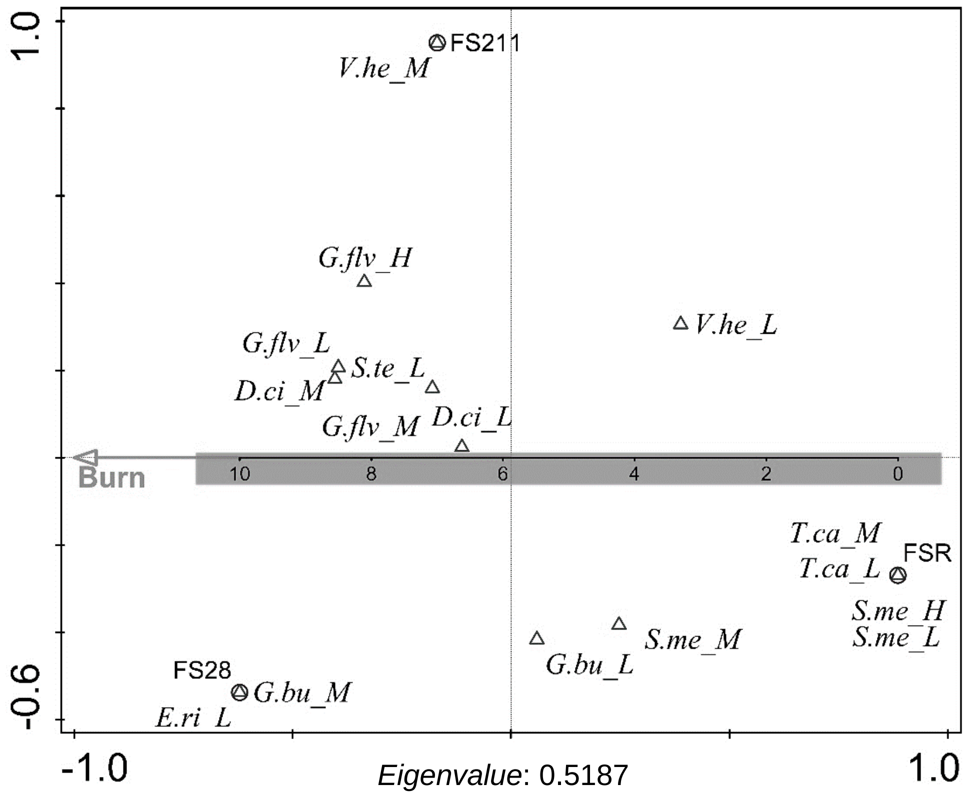


Figure 5.22: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of the **shrubs** (Δ) and sampling sites (o) on a burn gradient at the Farm area: *G. flv – Grewia flavescens*, *S. me – Senegalia mellifera*, *S. te – Searsia tenuinervis*, *V. he – Vachellia hebeclada*, *D. ci – Dichrostachys cinerea*, *E. ri – Ehretia rigida*, *G. bu – Gymnosporia buxifolia*, *T. ca – Terminalia camphoratus*, _L – low height class, _M – medium height class, _H

– high height class, FSR – Farm Shrub Reference, FS28 – Farm Shrubs burnt 2002 & 2008, FS211 – Farm Shrubs burnt 2002 & 2011.

With regard to the **trees**, the following species within the different height classes were associated with the reference site (FTR): *V. luederitzii* within the low height class (<2 m height class: *V.lu_L*) and the high height class (>4 m height class: *V.lu_H*), *Z. mucronata* within the low height class (<2 m height class: *Z.mu_L*) and the medium height class (2–4 m height class: *Z.mu_M*), as well as *V. erioloba* within the high height class (>4 m height class: *V.er_H*) (Figure 5.23 & Figure 5.26). *Boscia albitrunca*, *V. erioloba* and *T. sericea* within the low height class (<2 m height class: *B.al_L*, *V.er_L* and *T.se_L*) were found on the burn gradient at a fire event that occurred between six and eight years ago (Figure 5.23). *Terminalia sericea* within the medium height class (2–4 m height class: *T.se_M*) and *B. albitrunca* within the medium height class (2–4 m height class: *B.al_M*) and the high height class (>4 m height class: *B.al_H*) were only associated with the 2002 and 2011 burnt site (FT211) (Figure 5.23 & Figure 5.26). No tree species were only associated with the 2002 and 2008 burnt site (FT28) (Figure 5.23 & Figure 5.26).

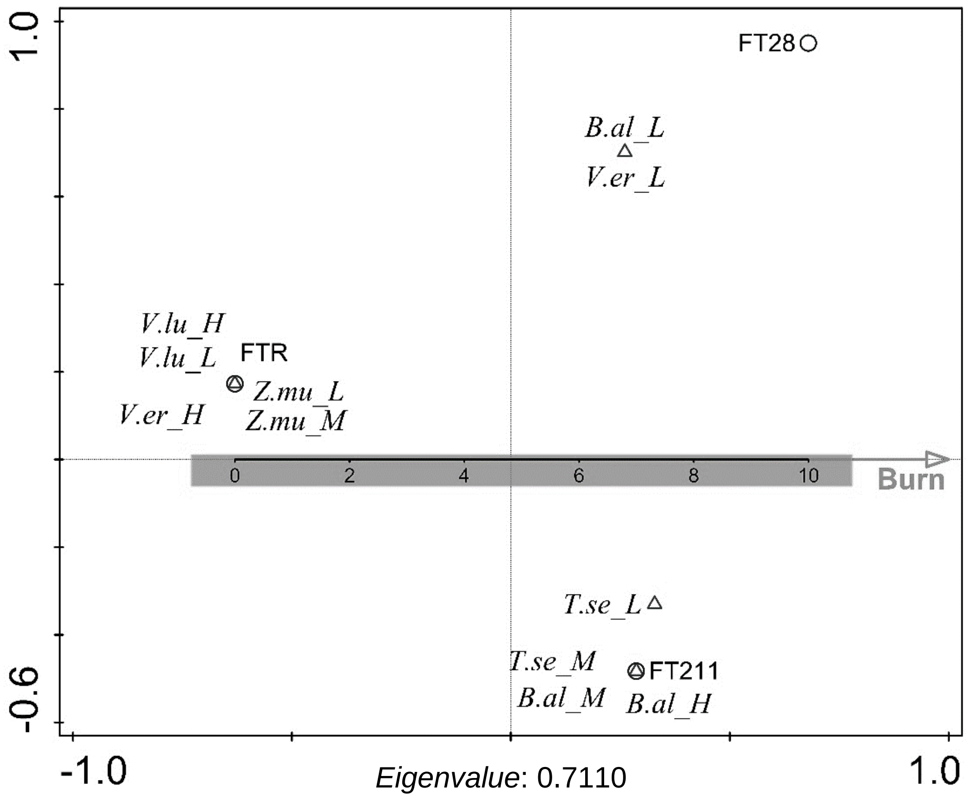


Figure 5.23: Canonical correspondence analysis (CCA) plot indicating the association between species height classes of the **trees** (Δ) and sampling sites (o) on a burn gradient at the Farm: area *B. al* – *Boscia albitrunca*, *V. er* – *Vachellia erioloba*, *V. lu* – *Vachellia luederitzii*, *Z. mu* – *Ziziphuz mucronata*, *T. se* – *T. sericea*, _L – low height class, _M – medium height class, _H –

high height class, FTR – Farm Trees Reference, FT28 – Farm Trees burnt 2002 & 2008, FT211 – Farm Trees burnt 2002 & 2011.

- Effects of fire at the Farm area according to the burn gradient

It would seem that **forbs** do not establish easily in sites that are frequently burnt, as they disappeared within this sampling area with an increase in burn scale during the sampling period (Figure 5.22). Most **shrubs** were dominant around the eight-year-old fire event; however, it seems as if *T. camphoratus* disappeared completely with an increase in fire events (Figure 5.22). Trees were mostly found in the reference site and between the six-year-old and eight-year-old fire events (Figure 5.23).

Regarding the **forbs** at the Farm area, *A. suaveolens* was found in all the sites, with the highest abundance in the 2002 and 2011 burnt site within the <0.5 m height class (283 individuals/ha) compared to 8 individuals/ha in the reference site and 17 individuals/ha in the 2002 and 2008 burnt site of the same height class (Figure 5.24). Within the 0.5–1 m height class, *A. suaveolens* was found only in the 2002 and 2008 burnt site (8 individuals/ha) and in the 2002 and 2011 burnt site (192 individuals/ha), with no individuals found within the >1 m height class (Figure 5.24).

Laggera decurrens was only found in the reference site within the <0.5 m height class (75 individuals/ha), the 0.5–1 m height class (50 individuals/ha) and the >1 m height class (17 individuals/ha) (Figure 5.24). Several *L. cinerium* individuals were found in the reference site within the <0.5 m height class (2 100 individuals/ha), with 8 individuals/ha within the 0.5–1 m height class (Figure 5.24). *Lycium bosciifolium* was only found in the reference site within the <0.5 m height class (117 individuals/ha). *Rhigozum brevispinosum* was found within the <0.5 m height class (17 individuals/ha) and the 0.5–1 m height class (17 individuals/ha) in the reference site (Figure 5.24).

Several **shrub** species were found at the Farm site, with *D. cinerea* in the reference site (17 individuals/ha), the 2002 and 2008 burnt site (183 individuals/ha) and the 2002 and 2011 burnt site (58 individuals/ha), especially within the <1 m height class. *E. rigida* was only found in the 2002 and 2008 burnt site within the <1 m height class (142 individuals/ha) (Figure 5.25). Several *G. flava* individuals were found in all the sites, with 42 individuals/ha within the <1 m height class in both the 2002 and 2008 burnt site and the 2002 and 2011 burnt site (Figure 5.25). Within the 1–2 m height class, 8 individuals/ha of this species were found in the reference site, with 233 individuals/ha in the 2002 and 2008 burnt site and 400 individuals/ha in the 2002 and 2011 burnt site within the same height class (Figure 5.25). Within the >2 m height class, 8 individuals/ha of *G. flava* were found within the 2002 and 2008 burnt site and 42 individuals/ha were found the 2002 and 2011 burnt site (Figure 5.25).

Senegalia mellifera was only found in the reference site and in the 2002 and 2008 burnt site, with 83 individuals/ha in the <1 m height class, 50 individuals/ha in the 1–2 m height class and 100 individuals/ha in the >2 m height class (Figure 5.25). In the 2002 and 2008 burnt site, 17 individuals/ha of this species were found in the 1–2 m height class (Figure 5.25). *Searsia tenuinervis* within the <1 m height class was only found in the burnt sites (8 individuals/ha respectively). *Gymnosporia buxifolia* was found in the reference site within the <1 m height class (67 individuals/ha), as well as in the 2002 and 2008 burnt site within the <1 m height class (167 individuals/ha) and the 1–2 m height class (8 individuals/ha) (Figure 5.25). *Tarchonanthus camphoratus* was only found in the reference site, with 50 individuals/ha found within the <1 m height class and 25 individuals/ha within the 1–2 m height class (Figure 5.25). *Vachellia hebeclada* was found in the reference site within the <1 m height class (67 individuals/ha), as well as in the 2002 and 2011 burnt site within the <1 m height class (42 individuals/ha) and the 1–2 m height class (25 individuals/ha) (Figure 5.25).

Regarding the **trees**, *B. albitrunca* was found in all of the sites, with 8 individuals/ha in the reference site and 17 individuals/ha in the 2002 and 2008 burnt site within the <2 m height class and 17 individuals/ha in both the 2–4 m height class and the >4 m height class in the 2002 and 2011 burnt site (Figure 5.26). *Terminalia sericea* was only found within the burnt sites, with 8 individuals/ha in the 2002 and 2008 burnt site and 67 individuals/ha in the 2002 and 2011 burnt site within the <2 m height class. Within the 2–4 m height class, 17 individuals/ha were found in the 2002 and 2011 burnt site (Figure 5.26).

Vachellia erioloba was found in the reference site within the <2 m height class (8 individuals/ha) and the > 4 m height class (8 individuals/ha), as well as in the 2002 and 2008 burnt site within the <2 m height class (17 individuals/ha) (Figure 5.26). Both *V. luederitzii* and *Z. mucronata* were only found within the reference site, with 42 individuals/ha of *V. luederitzii* and 17 individuals/ha of *Z. mucronata* within the <2 m height class, 8 individuals/ha of *Z. mucronata* within the 2–4 m height class and 8 individuals/ha of *V. luederitzii* within the <4 m height class (Figure 5.26).

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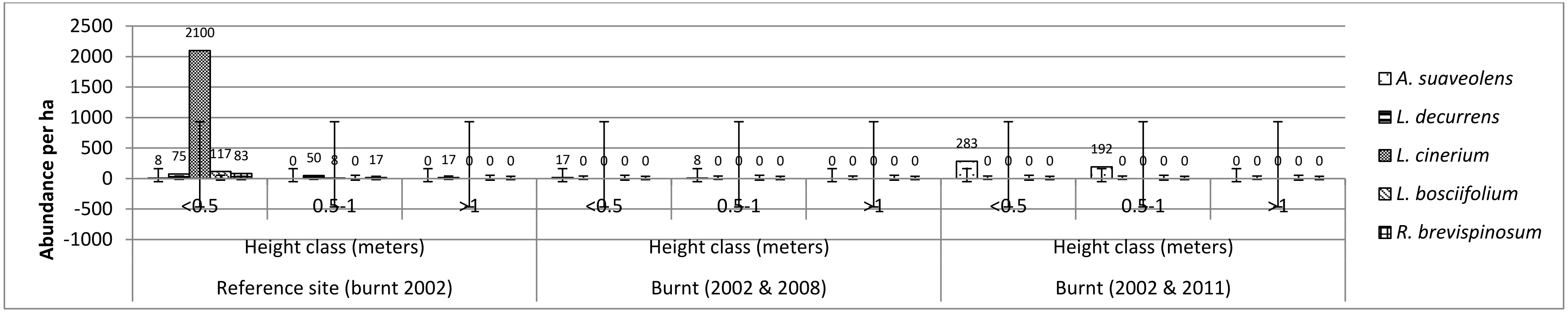

Figure 5.24: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **forbs** for the reference site and burnt sites in the Farm area (see Appendix 4 for species abbreviations).

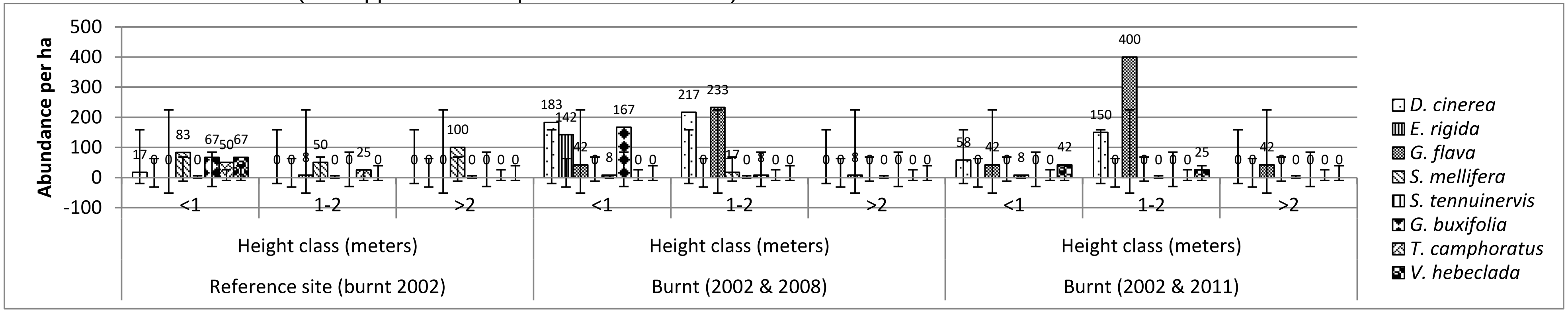

Figure 5.25: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **shrubs** for the reference site and burnt sites in the Farm area (see Appendix 4 for species abbreviations).

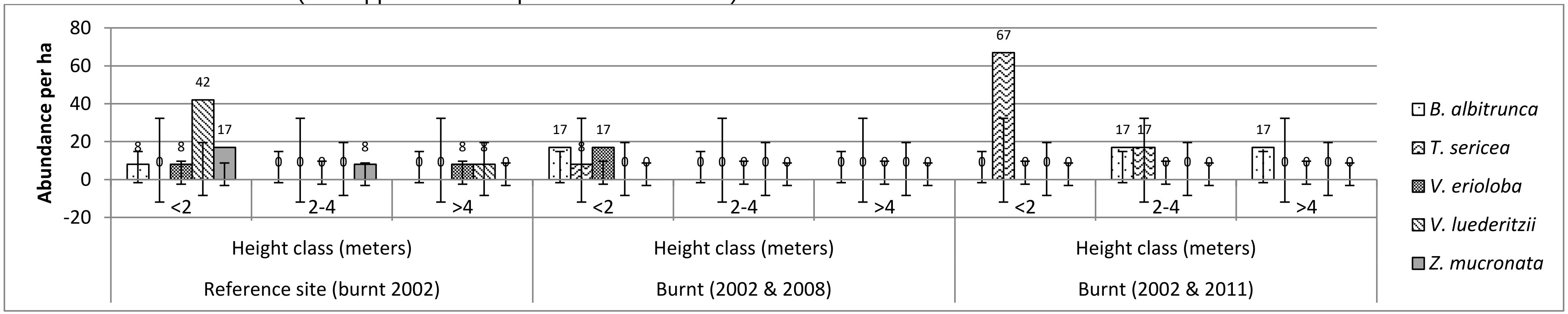

Figure 5.26: Bar plot indicating height classes and species abundance (individuals/ha) with standard deviations of the **trees** for the reference site and burnt sites in the Farm area (see Appendix 4 for species abbreviations).

5.1.4 Woody species average volumes

Volumes were measured in cm^3 of each woody species found at each site within the reference and burnt sites. The calculation of volumes is discussed in Chapter 4.3.1. Volume calculations were carried out to determine whether fire affected the canopies and structure of the vegetation. The average volumes are given in tables below.

5.1.4.1 Average volumes for woody species of the Molopo Nature Reserve

The volume of *A. suaveolens* was slightly higher, whereas the volumes of *B. albitrunca*, *D. cinerea*, *G. flava*, *L. cinerium*, *S. tenuinervis*, *L. bosciifolium*, *M. divaricatum* and *V. luederitzii* were slightly lower in the burnt site (Table 5.1). Larger differences were observed with regard to the volumes of *S. mellifera* and *V. erioloba,* both being higher in the burnt site (Table 5.1). This indicates that each species reacted differently within the Molopo Nature Reserve. It seems as if both *S. mellifera* and *V. erioloba* coppiced after the fire event. Another reason for larger canopy volumes is the possibility of browsing in certain areas, which leads to a reduction in canopy volumes and could also have affected the vegetation at the time of sampling.

Table 5.1: Molopo Nature Reserve woody average volume (cm^3) of all species found.

Molopo Woody Average Volume (cm^3)		
Species	Reference	Burnt (2002)
M. divaricatum	0.01	0.00
A. suaveolens	0.04	0.19
B. albitrunca	0.15	0.10
L. bosciifolium	0.16	0.00
S. tenuinervis	0.38	0.23
L. cinerium	0.70	0.62
D. cinerea	2.66	0.00
G. flava	3.73	3.43
S. mellifera	14.87	32.94
V. luederitzii	33.71	28.40
V. erioloba	39.93	57.91

5.1.4.2 Average volumes for woody species of the Khamab Reserve

5.1.4.2.1 Khamab1

Species that were not affected by burning and had low average values for volume include the following: *A. suaveolens*, *D. cinerea*, *F. virosa*, *G. flavescens*, *L. bosciifolium*, *L. cinerium*, *S. tenuinervis*, *M. divaricatum*, *R. brevispinosum*, *V. hebeclada* and *V. haematoxylon* in the Khamab Reserve (Table 5.2). Larger differences in volume were observed with the following species: *B. albitrunca*, *G. flava*, *S. mellifera* and *T. sericea*, having high average volumes in the 2010 burnt site when compared to the reference site and the 2011 burnt site (Table 5.2). As for species such as *B. albitrunca, Z. mucronata* and *V. erioloba,* it seems as if these species were not affected by the burning, as these species still had high volumes in both the burnt sites after the fire events (Table 5.2). *Vachellia luederitzii,* on the other hand, was negatively affected by frequent burning, as the volume decreased from the reference site to both the burnt sites (burnt in 2010 and 2011) (Table 5.2).

Table 5.2: Khamab1 woody average volume (cm^3) of all species found.

Khamab1 Woody Average Volume (cm^3)			
Species	Reference (bush encroached)	Burnt (2010)	Burnt (2011)
L. bosciifolium	0.00	0.00	0.05
T. sericea	0.00	21.74	1.57
V. erioloba	0.00	1.33	83.33
V. haematoxylon	0.00	0.00	0.06
F. virosa	0.04	0.19	0.00
A. suaveolens	0.07	0.07	0.07
M. divaricatum	0.10	0.00	0.37
D. cinerea	0.24	0.00	0.49
L. cinerium	0.32	0.22	0.24
S. tenuinervis	0.36	0.16	0.44
G. flavescens	0.40	0.00	0.43
R. brevispinosum	0.90	0.00	0.34
G. flava	0.99	2.90	1.24
V. hebeclada	1.06	0.00	0.00
S. mellifera	1.60	6.52	5.87
Z. mucronata	2.69	0.17	7.65
B. albitrunca	7.73	25.96	5.11
V. luederitzii	45.55	31.59	2.43

5.1.4.2.2 Khamab2

In the Khamab2 site, only small differences in average volume were observed, especially for species such as *A. suaveolens*, *F. virosa*, *G. flava*, *L. cinerium*, *S. mellifera*, *S. tenuinervis*, *R. brevispinosum*, *V. hebeclada* and *V. haematoxylon* (Table 5.3). *Boscia albitrunca* had a high average volume in the reference site when compared to other species at the same site, whereas *V. erioloba* had a high average volume within the burnt site and seemed unaffected as for Khamab1 (Table 5.3).

Table 5.3: Khamab2 woody average volume (cm^3) of all species found.

Khamab2 Woody Average Volume (cm^3)		
Species	Reference (bush controlled)	Burnt (2012)
V. erioloba	0.00	19.78
V. haematoxylon	0.00	1.08
A. suaveolens	0.09	0.00
R. brevispinosum	0.23	0.00
F. virosa	0.29	0.00
L. cinerium	0.38	0.29
S. mellifera	0.52	0.00
S. tenuinervis	0.57	0.00
V. hebeclada	1.20	0.00
G. flava	2.81	1.91
B. albitrunca	55.28	0.00

5.1.4.3 Average volumes for woody species of the Farm

Only small differences in volume were observed for the following species at the Farm sites: *A. suaveolens*, *D. cinerea*, *E. rigida*, *G. buxifolia*, *L. decurrens*, *L. cinerium*, *S. tenuinervis*, *L. bosciifolium*, *R. brevispinosum*, *T. camphoratus* and *V. hebeclada*. Larger differences in average volume were observed for the following species: *G. flava*, *S. mellifera*, *V. erioloba*, *V. luederitzii* and *Z. mucronata,* all of which had higher volumes in the reference site (Table 5.4). *Terminalia sericea* had a slightly larger average volume within the 2002 and 2011 burnt site, with *B. albitrunca* having the largest average volume within the 2002 and 2011 burnt site when compared to the other species (Table 5.4). It seems as if these species coppiced after the fire event. It may also be that the cattle do not browse these species within the burnt sites as new grass growth is more palatable.

Table 5.4: Farm woody average volume (cm^3) of all species found.

Farm Woody Average Volume (cm^3)			
Species	Reference (burnt in 2002)	Burnt (2002 and 2008)	Burnt (2002 and 2011)
E. rigida	0.00	0.04	0.00
S. tenuinervis	0.00	0.10	0.03
T. sericea	0.00	0.44	4.07
G. buxifolia	0.01	0.02	0.00
L. cinerium	0.01	0.00	0.00
A. suaveolens	0.03	0.06	0.09
D. cinerea	0.04	0.84	1.32
L. bosciifolium	0.04	0.00	0.00
R. brevispinosum	0.04	0.00	0.00
L. decurrens	0.06	0.00	0.00
B. albitrunca	0.12	0.00	132.65
T. camphoratus	0.69	0.00	0.00
V. hebeclada	1.39	0.00	0.51
Z. mucronata	3.09	0.00	0.00
G. flava	6.48	2.16	2.27
S. mellifera	10.81	3.17	0.00
V. luederitzii	15.00	0.00	0.00
V. erioloba	23.82	0.57	0.00

5.1.5 Composition and abundance of the herbaceous species in the Molopo Nature Reserve

A detrended correspondence analysis (DCA) was carried out to indicate the dominant herbaceous species that occurred in each sampling site in the whole Molopo Bushveld region (Figure 5.27). The DCA indicated three distinct groupings (Groups 1–3), which correlate to the specific study sites, i.e. the Molopo Nature Reserve (Group 1), the Khamab Reserve (Group 2) and the Farm (Group 3) (Figure 5.36). These differences may be due to the different management practices and type of animals found at each site.

The species *Cenchrus ciliaris* was mostly associated with the Molopo Nature Reserve area (MRefG and MB02G) (Figure 5.27 – Group 1), whereas species such as *Urochloa mosambicensis*, *Schmidtia pappophoroides* and *Stipagrostis uniplumis* were associated with the Khamab Reserve area (K1RefBEG, K1B10G, K1B11G, K2RefBEG and K2B12G) (Figure 5.27 – Group 2). Species such as *Eragrostis lehmanniana*, *Aristida meridionalis*, *Centropodia glauca*, *Pogonarthria squarrosa*, *Urochloa panicoides*, *Aristida* *stipitata*, *Eragrostis plana* and *Panicum maximum* were found in the Farm area (FRefB02G, FB0208G and FB0211G) (Figure 5.27 – Group 3).

Fewer grasses were found within the sites sampled in the Molopo Nature Reserve area compared to the other two areas sampled (Khamab and Farm) (Figure 5.36). The following grass species were dominant in each area: *C. ciliaris* within the Molopo Nature Reserve area, *S. uniplumis* within the Khamab1 area, *S. pappophoroides* within the Khamab2 area and *P. maximum* within the commercial farm area (Figure 5.36).

Three other species that were also noted within the study sites but had low abundances were *Melinis repens*, *Enneagon desvauxii* and *E. pallens*.

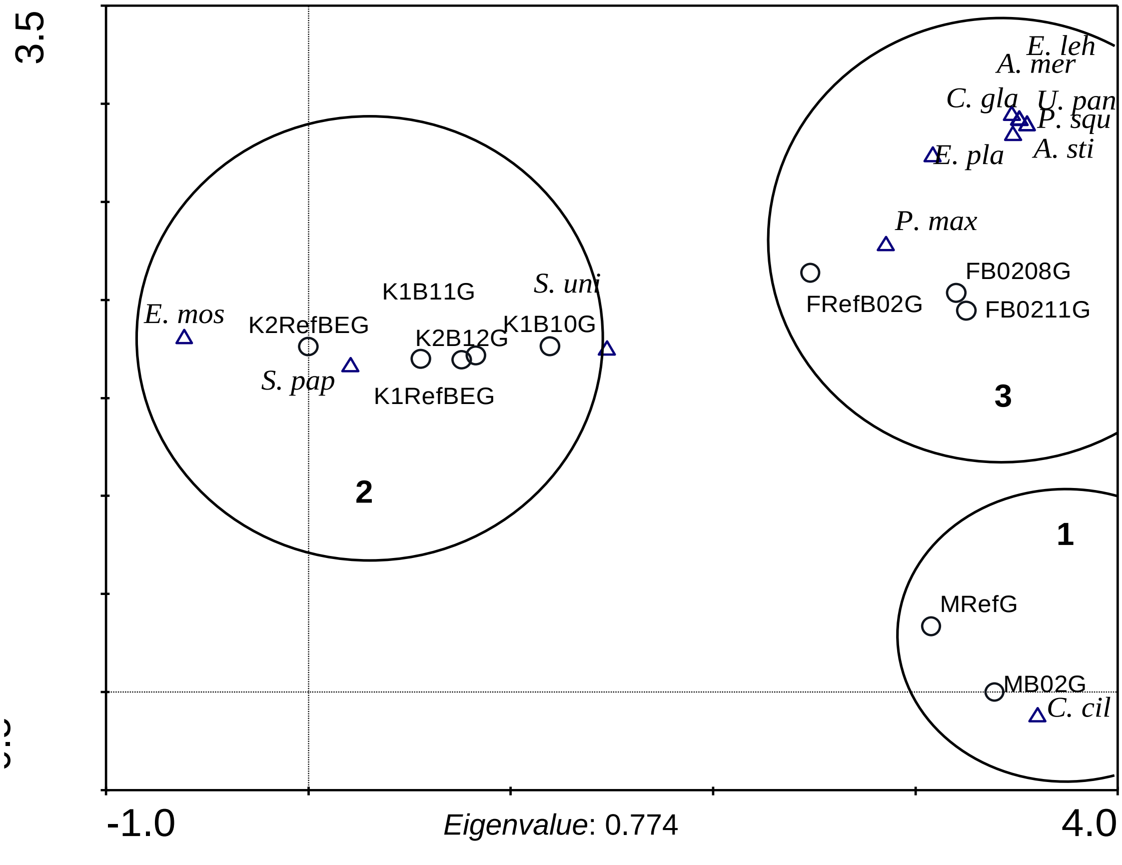

Figure 5.27: Detrended correspondence analysis (DCA) ordination plot indicating the correlation between herbaceous species (Δ) and sampling sites (o): *C. cil – Cenchrus ciliaris*, *E. leh – Eragrostis lehmanniana*, *E. mos – Urochloa mosambicensis*, *S. pap – Schmidtia pappophoroides*, *S. uni – Stipagrostis uniplumis*, *E. pla – Eragrostis plana*, *P. max – Panicum maximum*, *C. gla – Centropodia glauca*, *A. sti – Aristida stipitata*, *P. squ – Pogonarthria squarrosa*, *A. mer – Aristida meridionalis*, *U. pan – Urochloa panicoides*, MRefG – Molopo Reference, MB02G – Molopo burnt 2002, K1RefBEG – Khamab1 Reference, K1B10G – Khamab1 burnt 2010, K1B11G – Khamab1 burnt 2011, K2RefBEG – Khamab2 Reference, K2B12G – Khamab2 burnt 2012, FRefB02G – Farm Reference, FB0208G – Farm burnt 2002 & 2008, FB0211G – Farm burnt 2002 & 2011, 1 – Group 1, 2 – Group 2, 3 – Group 3.

5.1.5.1 Species composition and abundance of the herbaceous species of the Molopo Nature Reserve

The dominant grass species in this area was *Cenchrus ciliaris* at 93 individuals/100m^2 in the burnt area and 64 individuals/100m^2 in the reference site. *Schmidtia pappophoroides* was only found in the reference site (5 individuals/100m^2), and *S. uniplumis* with higher abundances in the reference site (21 individuals/100m^2) than within the burnt site (2 individuals/100m^2) (Figure 5.28). It seemed that this area was overgrazed at the time of sampling, which may be the reason for the low herbaceous species diversity.

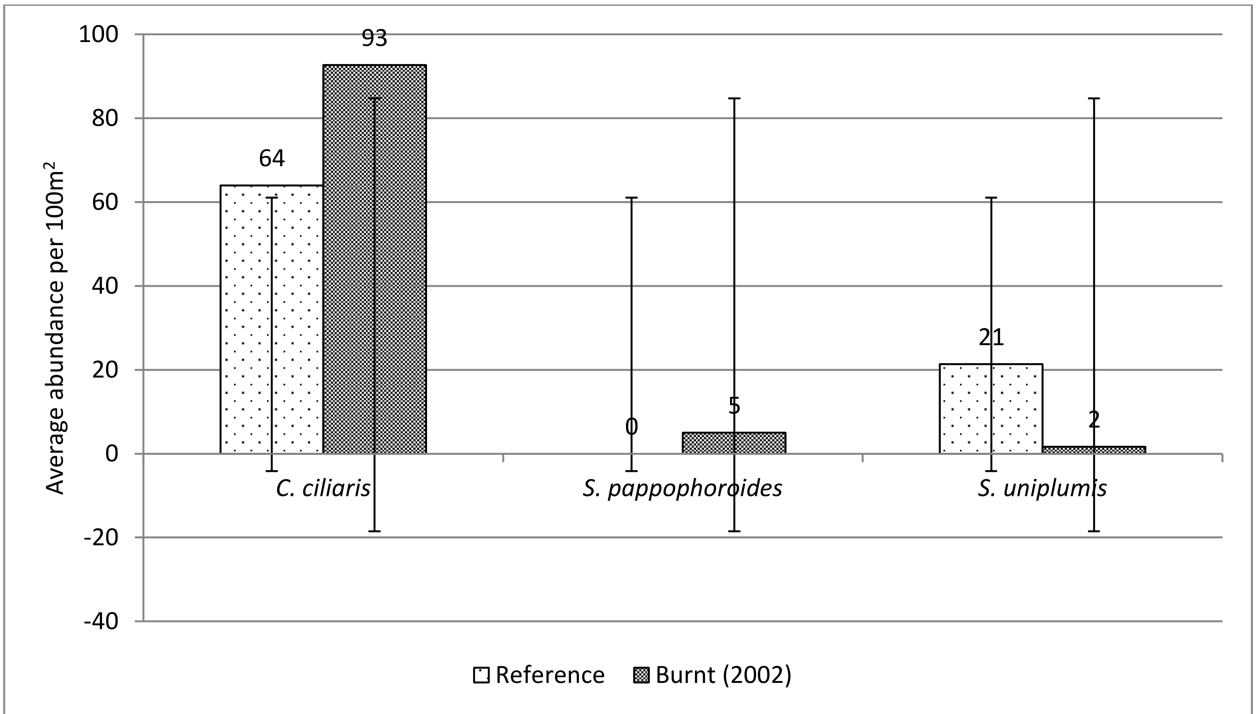

Figure 5.28: Bar plot indicating the average grass species abundance/100m^2 with standard deviations of the Molopo Nature Reserve area in the reference site and burnt site (burnt in 2002) (see Appendix 4 for species abbreviations).

5.1.5.2 Species composition and abundance of the herbaceous species of the Khamab Nature Reserve

5.1.5.2.1 Khamab1

The grass species, *S. uniplumis,* was the dominant species within this area at 33 individuals/100m^2 within the reference site, 70 individuals/100m^2 within the 2010 burnt site and 44 individuals/100m^2 within the 2011 burnt site (Figure 5.29). The other grass species, *S. pappophoroides,* was also found to have high abundances when compared to the other species with 57 individuals/100m^2 found within the reference site, 24 individuals/100m^2 within the 2010 burnt site and 53 individuals/100m^2 within the 2011 burnt site (Figure 5.29). *Urochloa mosambicensis* was not found within the 2011 burnt site but occurred in the reference site (9 individuals/100m^2) and the 2010 burnt site (2 individuals/100m^2) (Figure 5.29). *Eragrostis plana* was not found within the reference site, but at low abundances in the 2010 burnt site (4 individuals/100m^2) and the 2011 burnt site (2 individuals/100m^2) (Figure 5.29).

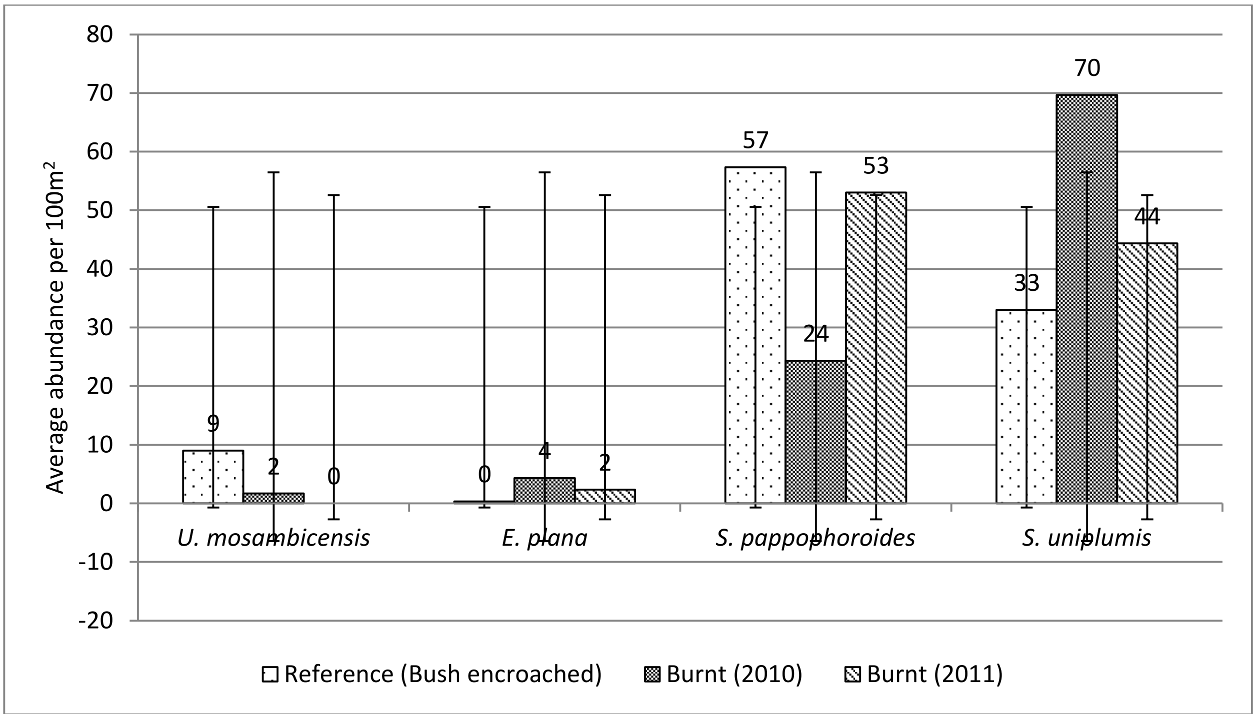

Figure 5.29: Bar plot indicating the average grass species abundance/100m^2 with standard deviations of the Khamab1 area in the reference site and burnt site (burnt in 2010; burnt in 2011) (see Appendix 4 for species abbreviations).

5.1.5.2.2 Khamab2

The grass *S. pappophoroides* was the dominant species within this area with 27 individuals/100m^2 in the reference site and 56 individuals/100m^2 within the 2012 burnt site (Figure 5.30). *Stipagrostis uniplumis* was also found within the reference site (17 individuals/100m^2) and in the burnt site (43 individuals/100m^2) (Figure 5.30). *Eragrostis plana* was only found in the reference site (1 individual/100m^2), with *U. mosambicensis* the only grass found within the reference site (55 individuals/100m^2) (Figure 5.30). As this area was chemically controlled for woody species, it seemed as if the grazing was relatively favorable within the sites sampled. *U. mosambicensis* was only found within the reference site, which may be due to trampling by animals or fire eradicating the species from the burnt sites.

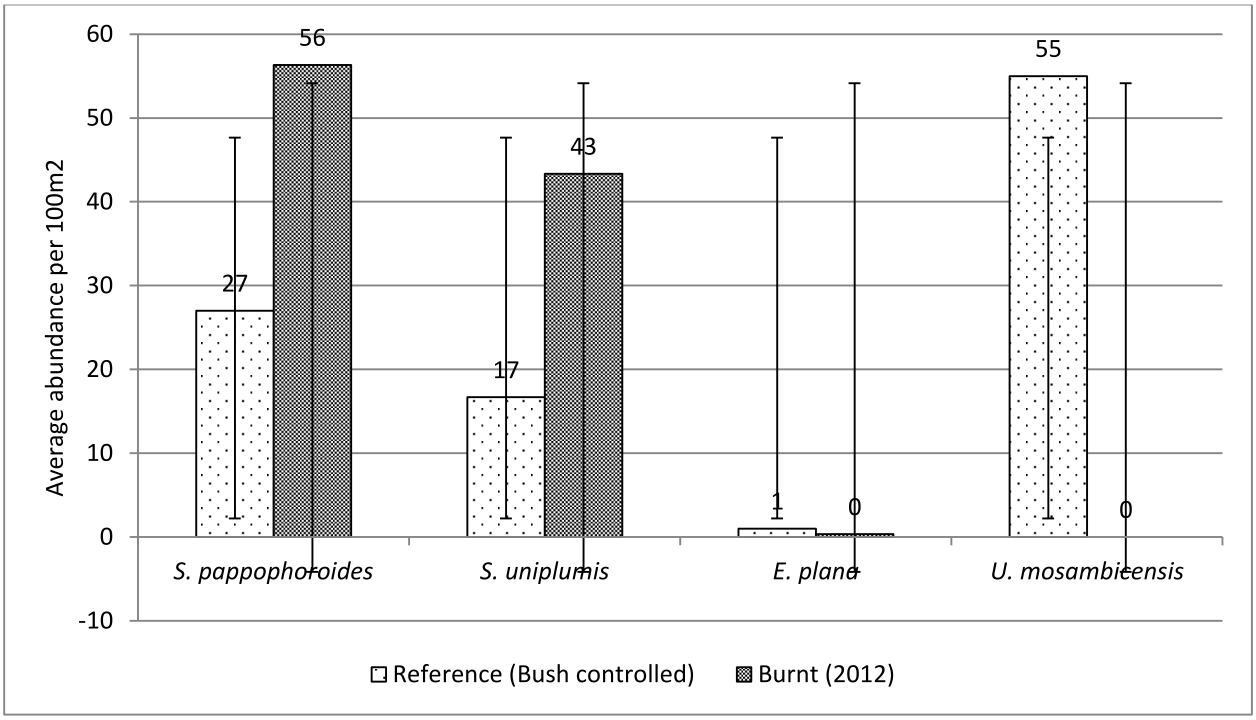

Figure 5.30: Bar plot indicating the average grass species abundance/100m^2 with standard deviations of the Khamab2 area in the reference site and burnt site (burnt in 2012) (see Appendix 4 for species abbreviations).

5.1.5.3 Herbaceous species composition and abundance of the Farm

Several different grass species were found within the Farm sampling site, which may be due to this site being used as a well-managed commercial cattle farm (Figure 5.31). *Panicum maximum* was the dominant grass within this site, with 70 individuals/100m^2 within the reference site, 12 individuals/100m^2 within the 2002 and 2008 burnt site and 5 individuals/100m^2 within the 2002 and 2011 burnt site (Figure 5.31). According to Van Oudtshoorn (2015), this species grows in all types of soils and has a good grazing value with good seed production, therefore explaining the high abundance within this area (Oudtshoorn, 2015).

Stipagrostis uniplumis was found in all three sites, with 28 individuals/100m^2 in the reference site, 9 individuals/100m^2 in the 2002 and 2008 burnt site and 11 individuals/100m^2 in the 2002 and 2011 burnt site (Figure 5.31). The climax grass, *C. glauca,* was also found within all three sites with 2 individuals/100m^2 in the reference site, 3 individuals/100m^2 in the 2002 and 2008 burnt site and 21 individuals/100m^2 in the 2002 and 2011 burnt site (Figure 5.31). This grass is an indicator of good rangeland conditions and also has good grazing value; as this species is found within all three sites, it may indicate that the management of the Farm area is overall good (Oudtshoorn, 2015).

Aristida stipitata was only found within the burnt sites, with 30 individuals/100m^2 found in the 2002 and 2008 burnt site and 27 individuals/100m^2 found in the 2002 and 2011 burnt site (Figure 5.31). This species can be seen as an indicator of overgrazing within an area; thus, frequent fires may lead to an increase of this species and this may be the reason for this species being found only in the burnt sites (Van Oudtshoorn, 2015). *Eragrostis pallens* was also found in only the burnt sites, with 15 individuals/100m^2 found in the 2002 and 2008 and 6 individuals/100m^2 found in the 2002 and 2011 burnt site (Figure 5.31). This species is an increaser III species, and this may be the reason why it is only found within the burnt sites (frequent fires may lead to an increase of this species) (Oudtshoorn, 2015).

Pogonarthria squarrosa, which is usually found in disturbed sandy soils, was only found within the 2002 and 2008 burnt site (8 individuals/100m^2) (Figure 5.31). *Cenchrus ciliaris* was found in both burnt sites, with 22 individuals/100m^2 found in the 2002 and 2008 burnt site and 26 individuals/100m^2 found in the 2002 and 2011 burnt site (Figure 5.31). *Aristida meridionalis* was also found in both burnt sites (1 individual/100m^2). *Urochloa panicoides* (3 individuals/100m^2) and *E. lehmanniana* (1 individual/100m^2) were only found within the 2002 and 2011 burnt site (Figure 5.31). It seems as if frequent fires within this area led to a reduction in good grazing; however, good management has led to a higher diversity of species within this area.

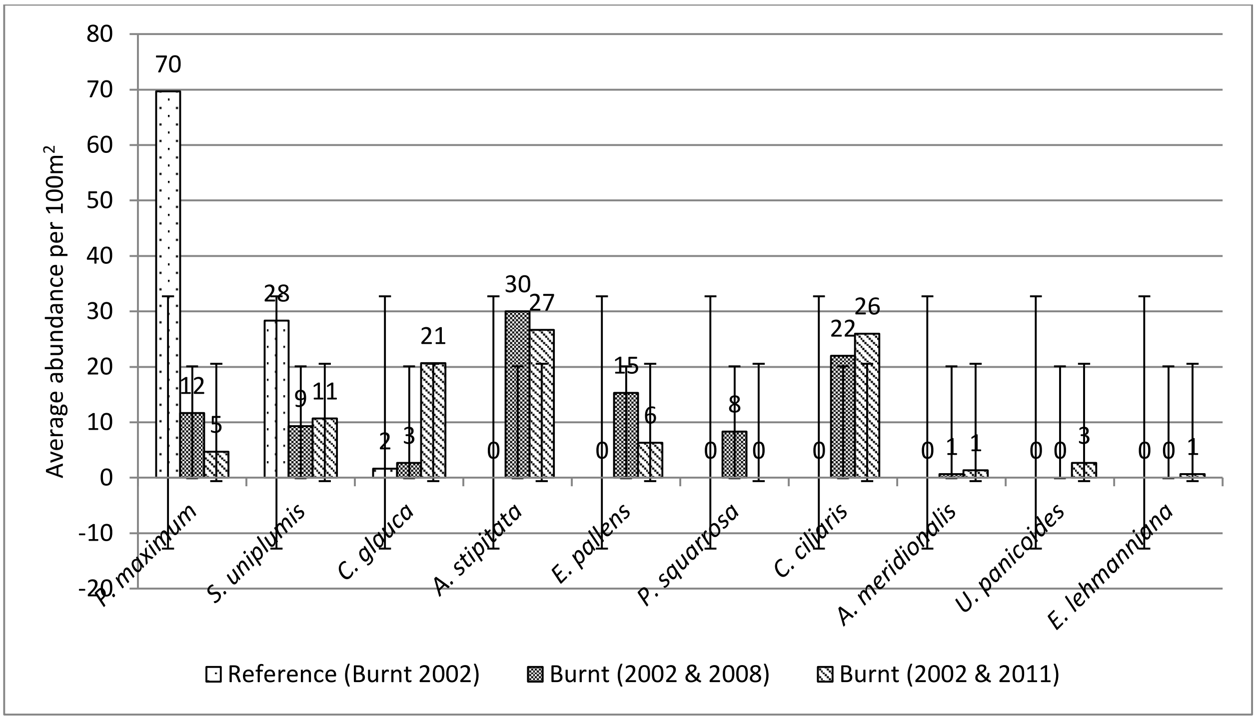

Figure 5.31: Bar plot indicating the average grass species abundance/100m^2 with standard deviations of the Farm area in the reference site and burnt sites (burnt in 2002 and 2008; burnt in 2002 and 2011) (see Appendix 4 for species abbreviations).

5.2 Qualitative results

The results for the qualitative surveys (social component) include answers from 11 land users within the Molopo area, as well as three environmental specialists/ecologists of various ages, including men and women (see Chapter 4.2 for the Methodology and Appendix 2 for the Questionnaire). The results are described according to the types of questions asked and the percentages of applicants who chose a certain answer; therefore only the percentages are given in this chapter (refer to Appendix 6 for qualitative analysis results).

5.2.1 Management of the land

Approximately 64% of the land users stated that they had cattle, 50% had game and 53% had goats and sheep. A total of 14% of the respondents had other animals, which included horses, donkeys, etc.

Before a fire had occurred, the highest percentage of land users (71%) had no management practice such as a rotational system with the resting of paddocks/camps and strategies to control the woody species. The land users who did have management practices in place included the following: 36% rested/rotated their camps, 29% used chemicals to control their woody species, 21% reduced their livestock/game when necessary and 7% changed their herd composition (land users answered ‘yes’ to more than one management strategy; therefore, percentages were determined accordingly per management strategy). However, no land users changed the type of their livestock and/or game, none of them increased their livestock and none used mechanical control for their woody species.

The results obtained with regard to the management **after a fire** had occurred were relatively similar, with the highest percentage of land users (71%) having no management practices such as rotating/resting camps, woody species control, etc. The land users who did have management practices in place included the following: 36% rested/rotated their camps, 7% used mechanical methods to control woody species, 14% used chemicals to control their woody species, 36% reduced their livestock when necessary and 7% changed their herd composition (land users answered ‘yes’ to more than one management strategy; therefore, percentages were determined accordingly per management strategy). However, no land users changed the type of their livestock and/or game and none increased their livestock. Therefore, the chosen management practices were resting/rotating camps and reducing the amount of livestock after a fire had occurred.

5.2.2 The perception of vegetation changes

With regard to changes in woody species composition **after a fire had occurred**, approximately 36% of land users stated that *A. suaveolens* had increased, 57% stated that *B. albitrunca* had decreased, 29% stated that *D. cinerea* had increased and 50% stated that they were uncertain with regard to whether the grass *E. rigida* had increased or decreased. Most of the land users (53%) stated that *F. virosa* had decreased, 50% were of the opinion that *G. buxifolia* had decreased, 43% stated that *G. flava* had increased, 28% stated that *G. flavescens* had decreased and 36% were of the opinion that this species had never occurred on their land. Several land users (43%) stated that *L. bosciifolium* was not found on their land. A total of 37% land users stated that this species had decreased, while 36% stated that *L. cinerium* was not found on the land they managed and 21% stated that it had decreased. Approximately 43% of the land users also stated that *L. decurrens* was not found on the land they managed and 43% stated that it had decreased.

Approximately 36% of the land users either stated that *M. divaricatum* was not found on the land they managed or that the abundance of this species had remained the same. *S. mellifera* had either decreased or remained the same (36% respectively) according to the land users. Most land users (43%) stated that they were uncertain as to whether *S. tenuinervis* had increased or decreased. A total of 36% of land users stated that *R. brevispinosum* was not found on the land they managed. Approximately 36% of the land users either stated that *T. camphoratus* was not found on the land they managed or that the abundance of this species had remained the same. A total of 43% of the land users stated that the abundance of *T. sericea* had remained the same, whereas the same number of land users stated that *V. erioloba* had increased in abundance. With regard to *V. erioloba*, most of the land users (43%) stated that they had observed an increase in abundance for this species. Most of the land users (36%) had perceived a decrease in *V. haematoxylon,* whereas *V. hebeclada* had remained the same. An increase in *V. luederitzii* (50%) and an increase in *Z. mucronata* (36%) had been observed by most of the land users.

When asked whether the overall amount of woody species increased, decreased or remained the same after a fire, most of the farmers (64%) stated that overall the amount of woody species decreased. Approximately 43% of the land users also stated that between 20% and 40% of the surviving woody plants showed damage due to fire such as burnt stems. Most land users (57%) also stated that there was a reduction in canopy sizes after a fire.

With regard to changes in herbaceous species composition after a fire had occurred, most of the land users (43%) stated that *A. meridionalis* had decreased, 50% stated that *A. stipitata* had decreased and 29% stated that *C. ciliaris* was either not found on the land they used or that it had increased. *C. glauca* was either not found on the land or had increased according to most of the land users (36%). *E. desvauxii* was either not found on the land or had decreased according to most of the land users (36%). *E. lehmanniana* had either decreased or remained the same according to most of the land users (29%). Approximately 36% of the land users stated that *E. pallens* had remained the same.

Most of the land users (43%) stated that *E. plana* was not found on the land they used. *M. repens* had remained the same according to most of the land users (57%). Most of the land users stated that *P. maximum* was not found on the land they used, with 36% of the land users stating that they were uncertain whether *P. squarrosa* had increased, decreased or remained the same. *S. pappophoroides* (43%) and *S. uniplumis* (36%) had remained the same according to most of the land users. Most of the land users (43%) stated that *U. mosambicensis* and *U. panicoides* were not found on the land they used.

When asked to what extent the change in species composition had affected the grazing capacity, most of the land users stated that it had either increased (43%) or decreased (43%), with 14% stating that they were uncertain.

5.2.3 Rainfall amount and records

With regard to the amount of rainfall before the fires had occurred, most of the land users (43%) stated that it had remained the same; however, when asked whether they had rainfall records, most of the land users (64%) stated that they did not keep rainfall records.

5.2.4 Main causes of fire

Approximately 57% of land users stated that it had been due to lightning, 71% stated that it had not been due to prescribed burning and 86% stated that it had not been due to malicious arson. Approximately 93% stated that it had not been accidental, with 86% stating that the cause was not known to them. None of the farmers stated that it had had any other cause. With regard to the origin of the fire, the land users (50%) either stated that it had happened within the farm borders or outside the farm borders; approximately 64% stated that the fire had started on a neighbouring farm and 93% stated that there had been no other origin.

5.2.5 Main damages suffered due to fires

Most the land users (79%) stated that no damage had been suffered with regard to livestock; however, 71% stated that their grazing had been damaged. Most of the farmers stated that their farm infrastructure had not suffered any damage and also that no other damage had been recorded (79%).

With regard to whether fire damage could be observed on the vegetation after a fire, most of the land users (86%) stated that fire damage could be observed on individual plants, with most of the land users (21%) stating that the damage observed was between 40% and 50% (in other words, approximately half of the individual plant had been destroyed in the fire).

When asked whether fire could be used as a management strategy for bush encroachment, most of the land users (64%) stated that it could not be used as a management strategy. This was primarily due to the uncertainty of when rainfall would occur and the land users not wanting to lose valuable grazing for their livestock.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The first objective of this study was to assess the effects of fire on the vegetation composition and structure in the Molopo Bushveld region. For this objective, vegetation surveys were conducted by means of belt transects and a step-point method. The results indicated significant differences within reference sites and the burnt sites; however, the results were not consistent, except for *G. flava,* which had higher densities within the burnt sites than within the reference sites. The inconsistency in the data with regard to species composition for all three sites might be due to different management practices within each site, as well as the types of animals being managed (i.e. game and/or livestock) as in some areas more grazing occurred, while in other more browsing or a mixture of grazing and browsing occurred. However, the possibility of different soils and rainfall patterns within the area should not be excluded as factors influencing the vegetation in the different sites.

With regard to the overall woody density, the burnt sites indicated lower woody densities when compared to the reference sites, these differences were however not significant. The site that indicated the lowest overall woody densities was the Khamab2 site, which was chemically controlled in both the reference site and the burnt site. Within this site, the forb *R. brevispinosum*, the shrub *G. flava* and the tree *V. erioloba* were the three dominant species and were found in the low to medium height classes, which might be due to the chemical control, as well as the influence of the fire event. This indicates that a combination of both chemical control and fire can be used as an effective management strategy against bush encroachment.

Differences in canopy volume were also observed between the reference sites and the burnt sites, these differences were however not significant. However, no consistent differences were observed between specific species and sites, which might be due to the differences in the timelines as to when fires had occurred, meaning that some species could either have recovered or were browsed over a longer time before surveys had been carried out.

With regard to grass species composition, a clear distinction could be made between the three different areas (i.e. Molopo Nature Reserve, Khamab Reserve and Farm). It is assumed that this is mainly due to the different management strategies within each area rather than the influence of the fire event. The commercial cattle farm (Farm) had the highest abundances of different grass species, which might be due to the dispersal of seeds by the cattle, whereas the two nature reserves had lower differences in the abundance of grasses, which might be due to having browsers and grazers instead of only grazers. The differences between grass species composition were however not significant.

The second objective was to evaluate how fire could be used as a management tool to make long-term predictions and management decisions in semi-arid savanna areas. For this objective, semi-structured interviews were conducted with land users and questionnaires were completed to document the indigenous knowledge of the land users within the area. The results indicated that most of the land users had no management strategy prior or after the fires. Some land users had, however, reduced their livestock or game after the occurrence of a fire or, where possible, started rotating or resting their camps. With regard to their observations of vegetation, the results were varied, which might be due to how the land users perceived the land that they used and also whether the areas were overgrazed or browsed.

However, most of the land users agreed that *G. flava* increased after a fire, which corresponds to the vegetation surveys conducted. Most of the land users also stated that the amount of rainfall before the fire events had been relatively the same; however, no records had been kept by most of them and there was the possibility of uncertainty about accuracy as the years passed after fire events. Most of the land users were completely against the use of fire as a management strategy for woody vegetation as they did not want to lose their valuable grazing within an area where the rainfall was low and unpredictable.

In conclusion, the first part of the hypothesis, namely that fire events do influence the structure and composition of the vegetation in semi-arid savanna regions, is accepted, based on the results obtained during this study. The second part of the hypothesis, namely that fire can be used as a management tool, especially regarding land degradation caused by bush encroachment, is accepted to some extent, as the results indicated that fire could not be used as the main instrument to manage bush encroachment within this area but should be used together with other methods, such as chemical control, as observed in the Khamab2 area.

6.2 Recommendations for future studies

Due to the area being semi-arid and the exclusion of fire from the area, frequent fires were not detected in the MODIS data. This posed a problem as there was not a variety of possible sampling sites within the area. Fires were also concentrated to the east and south of the study area, while fire occurrence was low and sporadic within the western side of the study area. The application of a similar sampling design throughout the study area proved difficult. Conservation management for the Molopo Nature Reserve indicated numerous burned areas that were not picked up by the MODIS burn scar products and were not clearly visible on the Landsat imagery. It is recommended that burn plots be done over an extended period (at least five years) within a controlled experimental design to determine how the vegetation changes over time with frequent fires. This should provide information on whether fire can be used as a management strategy within the area.

The number of land users with whom the semi-structured interviews had been held was also problematic as the area was extremely vast, with a low population density. Only a few land users were available to assist with the study. Such a study should be expanded to include more land users within the area to obtain a larger data set.

It is further recommended that some trials be established at, for example, the Khamab2 site to show the effects of fire, management and other bush control technologies (for example chemical vs manual vs mechanical) on changes in woody density and structure and herbaceous species.

The cost-effectiveness of the different management procedures should also be determined in a follow-up study, as well as the socio-economic impacts regarding fire events on the land and the land user.

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APPENDICES

APPENDIX 1: FIELD DATA SHEET

Date		Plot nr.		Coordinates		Photo nr.		Woody density (400 m)		Year/s burnt	

Woody Species	Height	Canopy dimensions (L L1: Longest spread; C C1: Cross-spread; V V1: Vertical canopy height)			Nr. of stems (GR: on ground level; 10cm: 10cm above ground level)		Main stem diameter		Coppicing (1 : 0-20%; 2: >20-40%; 3: >40-60%; 4: >60-80%; 5: >80-100%)	Damage Herbivore (1=10%; 2=20% etc.)	Damage fire (1=10%; 2=20% etc.)	Grass species	
		L L1	C C1	V V1	GR	10cm	T	S					
1)													
2)													
3)													
4)													
5)													
6)													
7)													
8)													
9)													
10)													
11)													
12)													
13)													
14)													
15)													
16)													
17)													

APPENDIX 2: LAND USER QUESTIONNAIRE

INFORMED CONSENT

The effect of fire on savanna vegetation dynamics in the semiarid Molopo Bushveld region of the North-West Province, South Africa.

- I have been informed that the purpose of this research is to understand the **effect of fire on savanna vegetation dynamics in the semiarid Molopo Bushveld region** and that my participation in this survey will take approximately one hour.
- I understand that there are no foreseeable risks or discomforts if I agree to participate in the research.
- I understand that the results of the research may be published but that my name or identity will not be revealed.
- I also understand that the results of the study may be used for secondary studies connected to this project, but that my name or identity will not be revealed.
- The North-West University will maintain confidentiality of all records and materials.
- I have been informed that I will not be compensated for my participation.
- I have been informed that any questions I have concerning this research or my participation in it before or after my consent, will be answered by the investigators of this research.
- I understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself.
- In signing this consent form, I am not waiving any legal claims, rights, or remedies.

I, the undersigned, ___________________________________ (full names), have read and understand the above information and by signing this form indicate that I will participate in the research voluntarily.

____________________	____________________
Participant’s signature	Date
____________________	____________________
Researcher’s signature	Date

Kort onderhoud skedule vir grondgebruiker/Short interview schedule for land user

Nommer van vraelys/Number of questionnaire:________________________________

Naam van plaas of reservaat/Name of farm or reserve:__________________________

Sampling site nommer/Sampling site number:_________________________________

Koordinate van sampling site/Coordinates of sampling site:______________________

Jaar(e) gebrand/Year/s of burning: ____

Vee tipe/Livestock type:____

Lading/Possible stocking rate:____

Management questions/Bestuur vrae:

1) Livestock type/Vee tipe?

1 No livestock/Geen vee	2 Cattle/Beeste Type/s/Soort/e:	3 Game/Wild Type/s/Soort/e:
4 Goats/Bokke Type/s/Soort/e:	5 Sheep/Skape Type/s/Soort/e:	6 Other/Ander Type/s/Soort/e:

Why do you choose to farm with this/these livestock/Hoekom verkies jy om met hierdie tipe vee te boer?

____

2) Management **before** the fire occurred/Bestuur wat toegepas is **voor** die brand?

1 None/Geen	2 Rested/Rotated camps/Kampe gerus/Roteer	3 Controlled woody species (Mechanical)/Beheer houtagtige spesies (Meganies) Specify/Spesifiseer:	4 Controlled woody species (Chemical)/Beheer houtagtige spesies (Chemies) Specify/Spesifiseer:
5 Reduced livestock/Vee verminder	6 Increased livestock/Vee vermeerder	7 Change of livestock/game type/Vee/wild soort verander Specify/Spesifiseer:	8 Change in herd composition/Trop samestelling verander Specify/Spesifiseer:

Why did you choose this type of management/Hoekom het jy hierdie tipe bestuur toegepas?

____

3) Management **after** the fire occurred/Bestuur wat toegepas **na** die brand?

1 None/Geen	2 Rested/Rotated camps/Kampe gerus/Roteer	3 Controlled woody species (Mechanical)/Beheer houtagtige spesies (Meganies) Specify/Spesifiseer:	4 Controlled woody species (Chemical)/Trop samestelling verander Specify/Spesifiseer
5 Reduced livestock/ Vee verminder	6 Increased livestock/Vee vermeerder	7 Change of livestock/game type/Vee/wild soort verander Specify/Spesifiseer:	8 Change in herd composition Trop samestelling verander Specify/Spesifiseer

Why did you change to this/these management types/Hoekom het jy na hierdie tipe bestuur verander?

____

Vegetation questions/Plantegroei vrae:

4) Changes in woody species composition **after** the fire/Verandering in houtagtige spesie samesteling **na** die brand?

1. A. suaveolens (Wild Asparagus / Katdoring)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
2. B. albitrunca (Sheperd's tree / Matoppi tree / Witgat)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
3. D. cinerea (Sicklebush / Sekelbos)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
4. E. rigida (Puzzlebush / Deurmekaarbos)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie

5. F. virosa (White-berry-bush / Witbessiebos)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
6. G. buxifolia (Spikethorn / Pendoring)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
7. G. flava (Velvet raisin / Rosyntjiebos)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
8. G. flavescens (Sandpaper raisin / Skurweblaarrosyntjie)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
9. L. bosciifolium (Limpopo honey-thorn / Wolfdoring)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
10. L. cinerium (Karee Honeythorn / Slangbessie)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
11. L. decurrens (Blue-green bitterbush / Pietbos)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
12. M. divaricatum (Wild Lucerne / Wildelusern)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
13. S. mellifera (Blackthorn / Swarthaak)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
14. S. tennuinervis (Kalahari crowberry / Kalaharitaaibos)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie

15. R. brevispinosum	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
16. T. camphoratus (Camphorbush / Kanferbos)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
17. T. sericea (Silver clusterleaf / Vaalboom)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
18. V. erioloba (Camel thorn / Kameeldoring)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
19. V. haematoxylon (Grey camel thorn / Vaalkameel)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
20. V. hebeclada (Candlepod thorn / Trassiedoring)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
21. V. luederitzii (Kalahari thorn / Kalaharidoring)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
22. Z. mucronata (Buffalo-thorn / Blinkblaar-wag-‘n-bietjie)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie

5) Is the amount of woody species now less or more **after** the fire/Is die aantal houtagtiges nou minder of meer **na** die brand/?

1 Less/Minder	2 More/Meer	3 Same/Dieselfde

6) Changes in structure of woody species **after** fire/Verandering in die struktuur van houtagtiges **na** brand?

Regrowth/Hergroei:

1	2	3	4	5
0-20%	>20-40%	>40-60%	>60-80%	>80-100%

Canopy size/Kroon grootte:

1	2	3
Smaller/Kleiner	Bigger/Groter	Same/Dieselfde

7) Changes in grass species composition **after** the fire/Verandering in grasspesie samestelling **na** die brand?

1. A. meridionalis (Giant three-awn / Langbeensteekgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
2. A. stipitata (Long-awned Aristida / Langnaaldsteekgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
3. C. ciliaris (Blue buffalo grass / Bloubuffelsgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
4. C. glauca (Gha grass / Ghagras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
5. E. desvauxii (Eight day grass / Agtdaegras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
6. E. lehmanniana (Lehmann's love grass / Knietjiesgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
7. E. palens	1	2	3	4

(Broom love grass / Besemgras)	Less / Minder	More / Meer	Same / Dieselfde	Unknown / Weet nie
8. E. plana (Tough love grass / Taaipol-eragrostis)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
9. M. repens (Natal red-top / Natal-roopluim)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
10. P. maximum (White buffalo grass / Witbuffelsgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
11. P. squarrosa (Sickle grass / Sekelgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
12. S. pappophoroides (Sand quick / Sandkweek)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
13. S. uniplumis (Silky Bushman grass / Blinkaar-boesmangras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
14. U. mosambicensis (Bushveld signal grass / Bosveldbeesgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie
15. U. panicoides (Garden Urochloa / Tuinbeesgras)	1 Less / Minder	2 More / Meer	3 Same / Dieselfde	4 Unknown / Weet nie

8) To what extent did the change in species composition affect the grazing capacity/In hoe mate het die verandering in spesiesamestelling die weidingskapasiteit beinvloed?

1 Less/Minder	2 More/Meer

Specify (Species)/Spesifiseer (Spesies):

Rainfall questions/Reënval vrae:

9) Was there more or less rainfall before the fire(s)/Was daar meer of minder reënval voor die brand(e)?

1 Less/Minder	2 More/Meer
3 Same/Dieselfde	4 Year/s/Jaar/e:

Any rainfall records available/Enige reënvaldata beskikbaar? Which months/years/Watter maande/jare?

Cause of fire questions/Oorsaak van vuur vrae:

10) How did the fire start/Wat was die oorsaak van die brand?

1 Lightning / Weerlig	2 Prescribed burning / Voorgeskrewe brand	3 Malicious arson / Kwaadwillige brandstigting	4 Accidental / Per ongeluk	5 Unknown / Weet nie	6 Other / Ander Specify / Spesifiseer:

11) Where did the fire start (origin)/Waar het die brand ontstaan?

1 Within farm border / Binne plaas grense	2 On neighbouring farm / Op buurplaas	3 Other / Ander Specify / Spesifiseer:

Damage questions/Skade vrae:

12) Damage as a result of the fire/Skade wat gelei is as gevolg van die brand?

1 Livestock / Vee	2 Grazing/Weiding
3 Farm infrastructure (fences, buildings etc.)/Plaas infrastruktuur (heinings, geboue ens.)	4 Other/Ander Specify/Spesifiseer:

13) Can fire damage be observed on the vegetation after the fire/Kan brand skade waargeneem word op die plantegroei?

1 No/Nee	2 Yes/Ja

14) Percentage of fire damage (on each plant)/Persentasie brandskade wat waargeneem was (op elke plant)?

1 0-10%	2 10-20%	3 20-30%	4 30-40%	5 40-50%
6 50-60%	7 60-70%	8 70-80%	9 80-90%	10 90-100%

15) Do you think fire can be used as management strategy for bush encroachment/Dink u dat vuur gebruik kan word as ‘n bestuurs meganisme teen bosverdigting?

1 No/Nee	2 Yes/Ja
Please explain to me why you think so/Verduidelik asb hoekom u so dink:	

16) Ander NB inligting/Other NB info?

____

____

APPENDIX 3: LAND USER BOOKLET

SPECIES IDENTIFICATION BOOKLET

FOR 2017 QUESTIONNAIRE

A. ESTERHUIZEN

22959254

(Webpages visited: 9/8/2016 for photo references)

Woody species

1. ***Asparagus suaveolens***

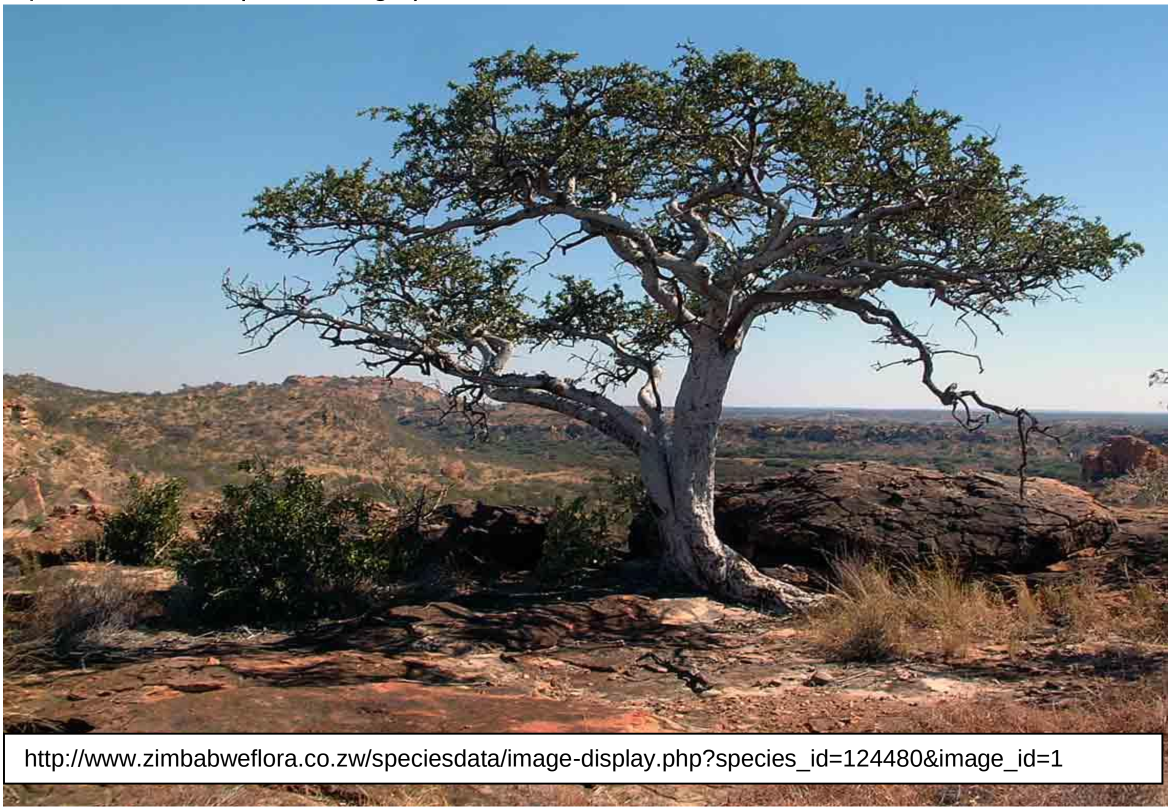
(Wild Asparagus/Katdoring)

https://www.ispotnature.org/species-dictionaries/sanbi/Asparagus%20suaveolens

http://www.ispotnature.org/node/534547

2. ***Boscia albitrunca***

(Sheperd's tree/Matopi tree/Witgat)



http://www.zimbabweflora.co.zw/speciesdata/image-display.php?species_id=124480&image_id=1

3. ***Dichrostachys cinerea***
(Sickle bush/Sekelbos)

http://www.ispotnature.org/node/655365

http://www.feedipedia.org/node/298

http://www.feedipedia.org/node/298

4. ***Ehretia rigida***
(Puzzle bush/Deurmekaarbos)

http://tsammalex.clld.org/parameters/ehretiari

http://www.plantbook.co.za/ehretia-rigida/

5. ***Flueggea virosa***
(White-berry-bush/Witbessiebos)

https://www.ispotnature.org/species-dictionaries/sanbi/Flueggea%20virosa%20subsp.%20virosa

6. Gymnosporia buxifolia
(Spikethorn/Pendoring)


http://pza.sanbi.org/gymnosporia-buxifolia


http://clarensnews.co.za/gymnosporia-buxifolia-pioneer-spikethorn/

7. Grewia flava
(Velvet raisin/Rosyntjiebos)


http://www.southernafricanplants.net/plantdata_sub.php?Mspec_ID=2802


http://www.tswalu.com/media/blog-article/the-velvet-raisin-bush

8. G. flavescens
(Sandpaper raisin/Skurweblaarrosyntjie)


https://commons.wikimedia.org/wiki/File:Grewia_flavescens_(G_pilosa)-_Khatkhati_in_Hyderabad,_AP_W_IMG_9133.jpg

9. Lycium bosciifolium
(Limpopo honey-thorn/ Wolfdoring)


https://www.ispotnature.org/species-dictionaries/sanbi/Lycium%20bosciifolium

10. L. cinerium
(Karee honey thorn/Slangbessie)

http://www.ispotnature.org/node/693349?nav=related

11. Laggera decurrens
(Blue-green bitter bush/Pietbos)

http://www.ispotnature.org/sites/default/files/images/42817/14a2a90017424bb11745ac4bc74f298a.jpg

12. Monechma divaricatum
(Wild Lucerne/Wildelusern)

http://www.ispotnature.org/sites/default/files/images/40742/296c22c3359

http://www.ispotnature.org/sites/default/files/images/40742/ffee2447b152494b43d9816faaea83c8_37.jpg

13. Senegalia mellifera
(Blackthorn/Swarthaak)

https://en.wikipedia.org/wiki/Senegalia_mellifera#/media/File:Acacia_mellifera,_Phalandingwe,_a.jpg

http://www.ispotnature.org/sites/default/files/images/40742/efb5660fde86bb8ad

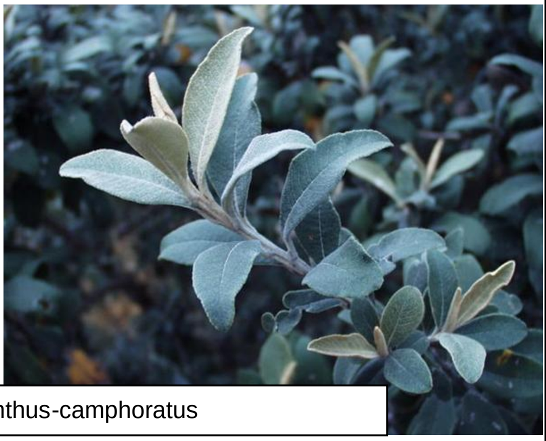
14. Searsia tennuinervis
(Kalahari crowberry/ Kalaharitaaibos)

https://www.ispotnature.org/node/517150?nav=related

http://tropical.theferns.info/image.php?id=Rhus+tenuinervis

15. *Rhigozum brevispinosum*

16. Tarchonanthus camphoratus
(Camphor bush/Kanferbos)



http://witbos.co.za/plant.aspx?plant=tarchonanthus-camphoratus

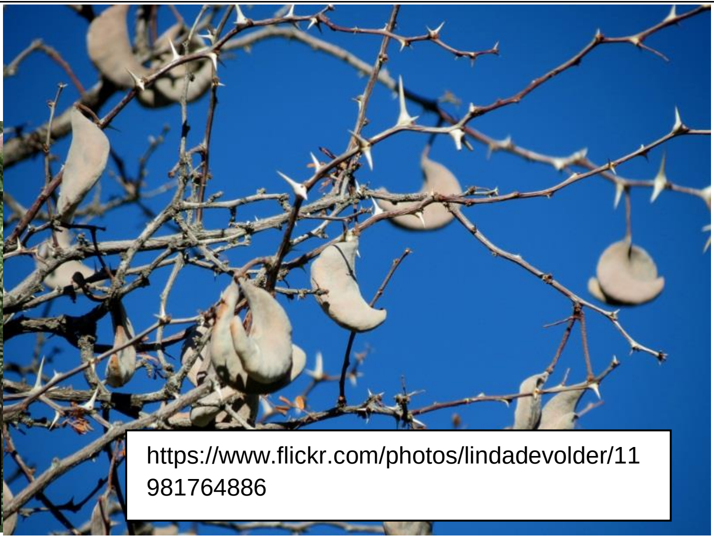
17. Terminalia sericea
(Silver cluster leaf/Vaalboom)

http://www.westafricanplants.senckenberg.de/root/index.php?page_id=78&id=2982#image=11179

https://en.wikipedia.org/wiki/Terminalia_sericea#/media/File:Terminalia_sericea,_a,_Seringveld.jpg

18. Vachellia erioloba
(Camel thorn/Kameeldoring)

http://www.asknature.org/strategy/7c9c613db95f81315b99e4da9e8d15d5



https://www.flickr.com/photos/lindadevolder/11981764886

19. V. haematoxylon
(Grey camel thorn/Vaalkameel)

https://dendrome.ucdavis.edu/treegenes/species/oracjpg/Acacia_haematoxylon_general.jpg

http://sagr.co.za/forum/viewtopic.php?t=306&f=248

20. V. hebeclada
(Candlepod thorn/Trassiedoring)

http://www.plantzafrica.com/plantab/acaciaheb.htm

21. V. luederitzii
(Kalahari thorn/Kalaharidoring)

http://www.zimbabweflora.co.zw/speciesdata/image-display.php?species_id=126010&image_id=4

22. Ziziphus mucronata
(Buffalo-thorn/Blinkblaar-wag-‘n-bietjie)

http://suntrees.co.za/2016/01/29/ziziphus-mucronata-buffalo-thorn-blinkblaar-wag-n-bietjie/#iLightbox[gallery2198]/2

Grass species

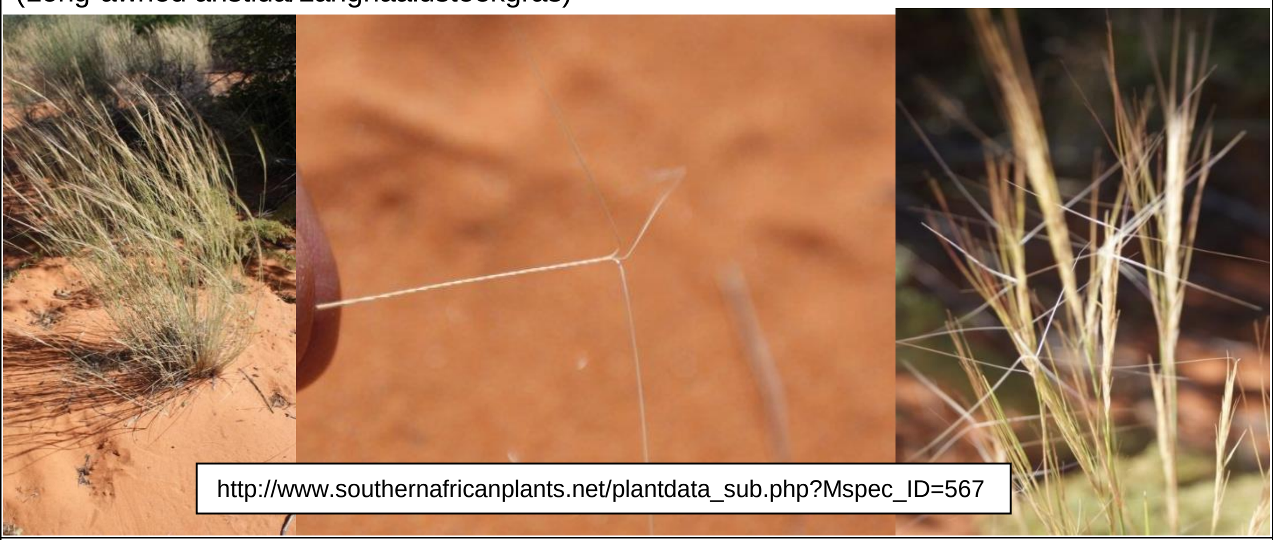
1. ***Aristida meridionalis***

(Giant three-awn/Langbeensteekgras)

http://www.southernafricanplants.net/plantdata_sub.php?Mspec_ID=555&PHPSESSID=sih94kmf4lg6acp1bfheaknta4

2. ***A. stipitata***

(Long-awned aristida/Langnaaldsteekgras)



http://www.southernafricanplants.net/plantdata_sub.php?Mspec_ID=567

3. ***Cenchrus ciliaris***

(Blue buffalo grass/Bloubuffelsgras)

http://www.kyffhauser.co.za/Plants1/Cenchrus_ciliaris/Image1.htm

http://www.kyffhauser.co.za/Plants1/Cenchrus_ciliaris/Image2.htm

4. *Centropodia glauca*
(Gha grass/Ghagras)

http://www.southernafricanplants.net/plantdata_sub.php?Mspec_ID=987&PHPSESSID=o5h3p76jnfep21

http://www.fao.org/ag/agp/agpc/doc/gallery/safricapics/centglau/centglau.htm

5. *Enneapogon desvauxii*
(Eight day grass/Agtdaegras)

http://www.southernafricanplants.net/plantdata_sub.php?Mspec_ID=2182

http://www.ispotnature.org/sites/default/files/images/41098/229c8f85c6d206c4bc32e82a1460f4b5.jpg

6. *Eragrostis lehmanniana*
(Lehmann's love grass/Knietjiesgras)

http://www.graniteseed.com/products/seeds/eragrostis-lehmanniana

http://stevensonintermountainseed.com/devsiseed/?product=eragrostis-lehmanniana

http://wnmu.edu/academic/nspages/gilaflora/eragrostis_lehmanniana.html

7. E. palens
(Broom love grass/Besemgras)



Van Oudtshoorn, F., 2015. *Veld Management Principles and Practices.* Pretoria: Briza Publications.

8. E. plana
(Tough love grass/Taaipol-eragrostis)

http://www.biodiversityexplorer.org/plants/poaceae/eragrostis_plana.htm

http://www.zimbabweflora.co.zw/speciesdata/image-display.php?species_id=105100&image_id=2

9. Melinis repens
(Natal red-top/Natal-roopluim)

http://www.fireflyforest.com/flowers/1543/melinis-repens-rose-natal-grass/

http://redlist.sanbi.org/species.php?species=1164-10

10. Panicum maximum
(White buffalo grass/Witbuffelsgras)

http://www.botany.hawaii.edu/basch/uhnpscesu/htms/haleplnt/fish_pops/poaceae/grass06.htm

http://www.eattheweeds.com/panicum-maximum-and-then-some-2/

11. Pogonarthria squarrosa
(Sickle grass/Sekelgras)

http://www.plantzafrica.com/plantnop/pogonsqua.htm

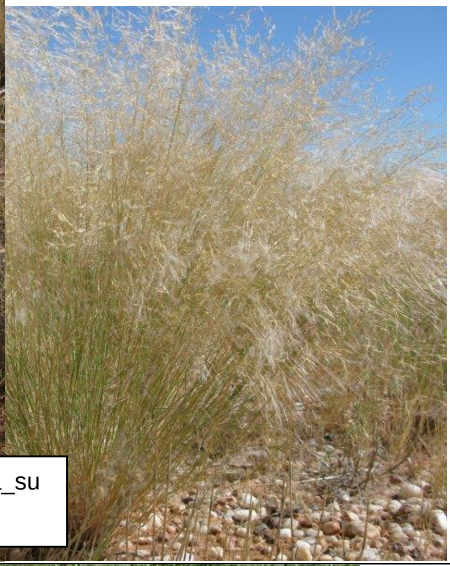
https://www.ispotnature.org/species-dictionaries/sanbi/Pogonarthria

12. Schmidtia pappophoroides
(Sand quick/Sandkweek)

http://www.zimbabweflora.co.zw/speciesdata/image-display.php?species_id=104450&image_id=1

http://plants.jstor.org/compilation/schmidtia.pappophoroides

13. Stipagrostis uniplumis
(Silky Bushman grass/Blinkaar-boesmangras)



http://www.southernafricanplants.net/plantdata_sub.php?Mspec_ID=6030

14. Urochloa mosambicensis
(Bushveld signal grass/Bosveldbeesgras)

http://www.mozambiqueflora.com/speciesdata/image-display.php?species_id=106990&image_id=4

http://www.tropicalforages.info/key/Forages/Media/Html/Urochloa_mosambicensis.htm&image_id=4

15. U. panicoides
(Garden urochloa/Tuinbeesgras)

http://www.weedscience.org/Details/case.aspx?ResistID=5362

http://www.uniprot.org/taxonomy/37563

APPENDIX 4: SPECIES ABBREVIATIONS

Woody Species		Herbaceous Species	
A. suaveolens	*Asparagus suaveolens*	*A. meridionalis*	*Aristida meridionalis*
B. albitrunca	*Boscia albitrunca*	*A. stipitata*	*Aristida stipitata*
D. cinerea	*Dichrostachys cinerea*	*C. ciliaris*	*Cenchrus ciliaris*
E. rigida	*Ehretia rigida*	*C. glauca*	*Centropodia glauca*
F. virosa	*Flueggea virosa*	*E. lehmanniana*	*Eragrostis lehmanniana*
G. buxifolia	*Gymnosporia buxifolia*	*E. pallens*	*Eragrostis pallens*
G. flava	*Grewia flava*	*E. plana*	*Eragrostis plana*
G. flavescens	*Grewia flavescens*	*P. maximum*	*Panicum maximum*
L. bosciifolium	*Lycium bosciifolium*	*P. squarrosa*	*Pogonarthria squarrosa*
L. cinerium	*Lycium cinerium*	*S. pappophoroides*	*Schmidtia pappophoroides*
L. decurrens	*Laggera decurrens*	*S. uniplumis*	*Stipagrostis uniplumis*
M. divaricatum	*Monechma divaricatum*	*U. mosambicensis*	*Urochloa mosambicensis*
R. brevispinosum	*Rhigozum brevispinosum*	*U. panicoides*	*Urochloa panicoides*
S. mellifera	*Senegalia mellifera*		
S. tenuinervis	*Searsia tenuinervis*		
T. camphoratus	*Tarchonanthus camphoratus*		
T. sericea	*Terminalia sericea*		
V. erioloba	*Vachellia erioloba*		
V. haematoxylon	*Vachellia haematoxylon*		
V. hebeclada	*Vachellia hebeclada*		
V. luederitzii	*Vachellia luederitzii*		
Z. mucronata	*Ziziphus mucronata*		

APPENDIX 5: WOODY HEIGHT CLASSES DATA

			Reference site			Burnt (2002)		
			Height class (meters)			Height class (meters)		
			<0.5	0.5-1	>1	<0.5	0.5-1	>1
Molopo	Forbs	A. suaveolens	183	50	0	8	17	0
		L. cinerium	0	33	8	33	41	8
		L. bosciifolium	33	0	8	0	0	0
		M. divaricatum	8	0	0	0	0	0
	Shrubs		Reference site			Burnt (2002)		
			Height class (meters)			Height class (meters)		
			<1	1-2	>2	<1	1-2	>2
		D. cinerea	0	17	0	0	0	0
		G. flava	50	108	75	42	183	75
		S. mellifera	50	0	58	42	17	33
		S. tenuinervis	58	17	0	150	0	0
	Trees		Reference site			Burnt (2002)		
			Height class (meters)			Height class (meters)		
			<2	2-4	>4	<2	2-4	>4
		B. albitrunca	17	0	0	25	0	0
		V. erioloba	58	8	8	42	0	17
		V. luediritzii	8	17	25	0	17	0

			Reference site (Bush encroached)			Burnt (2010)			Burnt (2011)		
			Height class (meters)			Height class (meters)			Height class (meters)		
			<0.5	0.5-1	>1	<0.5	0.5-1	>1	<0.5	0.5-1	>1
Khamab1	Forbs	A. suaveolens	125	67	8	183	83	8	117	42	8
		L. cinerium	0	17	0	17	42	8	8	8	0
		L. bosciifolium	0	0	0	0	0	0	8	0	0
		M. divaricatum	42	8	0	0	0	0	33	0	17
		R. brevispinosum	17	33	33	0	0	0	8	17	8
	Shrubs		Reference site (Bush encroached)			Burnt (2010)			Burnt (2011)		
			Height class (meters)			Height class (meters)			Height class (meters)		
			<1	1-2	>2	<1	1-2	>2	<1	1-2	>2
		D. cinerea	0	17	0	0	0	0	58	67	0
		F. virosa	67	0	0	50	33	0	0	0	0
		G. flava	108	133	0	50	150	8	125	225	8
		G. flavescens	17	0	0	0	0	0	33	25	0
		S. mellifera	267	0	25	75	58	50	208	42	83
		S. tenuinervis	383	108	0	25	0	0	0	8	0
		V. hebeclada	33	0	0	0	0	0	0	0	0
		Z. mucronata	0	0	17	0	8	0	0	0	8
	Trees		Reference site (Bush encroached)			Burnt (2010)			Burnt (2011)		
			Height class (meters)			Height class (meters)			Height class (meters)		
			<2	2-4	>4	<2	2-4	>4	<2	2-4	>4
		B. albitrunca	117	8	8	42	17	25	58	0	8
		T. sericea	0	0	0	33	17	25	175	8	0
		V. erioloba	0	0	0	50	0	0	0	0	17
		V. haematoxylon	0	0	0	0	0	0	17	0	0
		V. luediritzii	58	33	100	17	8	8	17	8	0

			Reference site (Bush controlled)			Burnt (2012)		
Khamab2	Forbs		Height class (meters)			Height class (meters)		
			<0.5	0.5-1	>1	<0.5	0.5-1	>1
		A. suaveolens	17	50	0	0	0	0
		L. cinerium	0	17	8	0	0	0
		R. brevispinosum	242	292	117	0	0	0
	Shrubs		Reference site (Bush controlled)			Burnt (2012)		
			Height class (meters)			Height class (meters)		
			<1	1-2	>2	<1	1-2	>2
		F. virosa	25	8	0	0	0	0
		G. flava	0	167	17	25	175	8
		S. mellifera	33	8	0	58	0	0
		S. tenuinervis	8	0	0	0	0	0
		V. hebeclada	17	25	0	0	0	0
	Trees		Reference site (Bush controlled)			Burnt (2012)		
			Height class (meters)			Height class (meters)		
			<2	2-4	>4	<2	2-4	>4
		B. albitrunca	0	8	8	0	0	0
		V. erioloba	0	0	0	125	33	25
		V. haematoxylon	0	0	0	50	0	0

			Reference site (burnt 2002)			Burnt (2002 & 2008)			Burnt (2002 & 2011)		
			Height class (meters)			Height class (meters)			Height class (meters)		
			<0.5	0.5-1	>1	<0.5	0.5-1	>1	<0.5	0.5-1	>1
	Forbs	A. suaveolens	8	0	0	17	8	0	283	192	0
		L. decurrens	75	50	17	0	0	0	0	0	0
		L. cinerium	2100	8	0	0	0	0	0	0	0
		L. bosciifolium	117	0	0	0	0	0	0	0	0
		R. brevispinosum	83	17	0	0	0	0	0	0	0
			Reference site (burnt 2002)			Burnt (2002 & 2008)			Burnt (2002 & 2011)		
			Height class (meters)			Height class (meters)			Height class (meters)		
			<1	1-2	>2	<1	1-2	>2	<1	1-2	>2
		D. cinerea	17	0	0	183	217	0	58	150	0
		E. rigida	0	0	0	142	0	0	0	0	0
Farm	Shrubs	G. flava	0	8	0	42	233	8	42	400	42
		S. mellifera	83	50	100	0	17	0	0	0	0
		S. tennuinervis	0	0	0	8	0	0	8	0	0
		G. buxifolia	67	0	0	167	8	0	0	0	0
		T. camphoratus	50	25	0	0	0	0	0	0	0
		V. hebeclada	67	0	0	0	0	0	42	25	0
			Reference site (burnt 2002)			Burnt (2002 & 2008)			Burnt (2002 & 2011)		
			Height class (meters)			Height class (meters)			Height class (meters)		
			<2	2-4	>4	<2	2-4	>4	<2	2-4	>4
		B. albitrunca	8	0	0	17	0	0	0	17	17
	Trees	T. sericea	0	0	0	8	0	0	67	17	0
		V. erioloba	8	0	8	17	0	0	0	0	0
		V. luederitzii	42	0	8	0	0	0	0	0	0
		Z. mucronata	17	8	0	0	0	0	0	0	0

APPENDIX 6: QUALITATIVE DATA ANALYSIS

Correlations

			Aantal_soorte1	Manage_before_fire1	Manage_after_fire1
Spearman's rho	Aantal_soorte1	Correlation Coefficient	1.000	0.372	0.442
		Sig. (2-tailed)		0.191	0.114
		N	14	14	14
	Manage_before_fire1	Correlation Coefficient	0.372	1.000	0.302
		Sig. (2-tailed)	0.191		0.294
		N	14	14	14
	Manage_after_fire1	Correlation Coefficient	0.442	0.302	1.000
		Sig. (2-tailed)	0.114	0.294	
		N	14	14	14

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	7.972[a]	9	0.537
Likelihood Ratio	10.437	9	0.316
Linear-by-Linear Association	0.566	1	0.452
N of Valid Cases	14		

a. 16 cells (100.0%) have expected count less than 5. The minimum expected count is .14.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	0.755	0.537
	Cramer's V	0.436	0.537
N of Valid Cases		14	