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**EVALUATING LONG TERM EFFECTS OF FIRE FREQUENCY ON
SOIL SEED BANK COMPOSITION AND SPECIES DIVERSITY IN
A SEMI-ARID, SOUTH AFRICAN SAVANNA**

By:

Thembisile Veronicah Mabuza

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Faculty of Science and Agriculture

University of Fort Hare

Private Bag X1314

Alice 5700

Supervisor: Ms K. Mopipi

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DECLARATION

I Thembisile Veronicah Mabuza declare that the work contained in this thesis (EVALUATING LONG TERM EFFECTS OF FIRE FREQUENCY ON SOIL SEED BANK COMPOSITION AND SPECIES DIVERSITY IN A SEMI-ARID, SOUTH AFRICAN SAVANNA) is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used for or quoted have been indicated and acknowledged by complete reference.

Candidate's Signature: _____

Date: _____

Supervisor's Signature: _____

Date: _____

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My heartfelt gratitude goes out to my family: My mother, sister, nephew and my daughter and many others. Your prayers, sacrifices, love, and support have been the driving force behind me. I am eternally grateful to all of you.

DEDICATION

This thesis is dedicated to my mother Leah Mabuza, my sister Semangele Mabuza, my nephew Keamogetswe Mabuza and my daughter Khanyisile Mabuza

ABSTRACT

Fire is generally used as a management tool for different vegetation types such as savannas and grasslands in southern Africa. In the False Thornveld of the Eastern Cape, fire is commonly used to control bush encroachment and to increase grass production, as grasses are important source of forage for domestic livestock. At the University of Fort Hare farm in the Eastern Cape, a trial was set up in 1980 to investigate the effect of burning frequency on vegetation. There are six treatments replicated twice in a completely randomized design on a 100 m x 50 m plots. The treatments comprise no burn, annual, biennial, triennial, quadrennial and sexennial burns. From this trial a study was conducted to investigate long term effect of burning frequency on species and soil seed bank diversity.

Two 100 m line transects located 25 m apart were laid within each plot, and the herbaceous and woody species were identified and recorded along the line transects. Relative abundances (%) for each species were calculated for each treatment. Soil samples were collected at an interval of 13.3 m along the line transects. The samples were placed in paper bags and kept for use in a germination experiment. The seedling emergence germination method was used in the glasshouse to determine emerging seedlings, pots were filled with Hygromix growth medium and the soils from the fire trials $12 \times 6 = 72$ were spread on top. Soil from the control plots were also pre-treated with heat, smoke and the combination of heat and smoke. The experiment started in January 2010 and was terminated in April 2010. The Shannon-Weaver Diversity Index was used to determine species diversity for standing vegetation and germinated seedlings. Data were tested for normality and species abundances were transformed. Analysis of Variance (ANOVA) was applied to test treatment effects on geminated seedlings, species abundance and diversity at $\alpha = 0.05$ significance level. Significant differences between treatment means were determined by *post*

hoc tests using Fischer's Least Significant Difference test at $\alpha = 0.05$. The Pearson Moment Correlation test was used to test the relationship between vegetation and soil seed banks.

Treatments had significant effects on herbaceous, woody species abundance and diversity ($P < 0.05$), but there was no significant treatment effect on soil seed bank diversity and on pre-germination treatments ($P > 0.05$). The annual, biennial and triennial burns were dominated by *Themeda triandra* while the quadrennial, sexennial and the control treatments were dominated by *Sporobolus fimbriatus* and *Melica decumbens*. *A. karroo* dominated the woody component across all treatments, but it did not change in abundance. *S. fimbriatus* was the most abundant in the soil seed bank across all the treatments and also in all pre-germination treatments. Species diversity was high in standing vegetation in the quadrennial, sexennial and the control treatments. There was no significant correlation between the standing vegetation and soil seed bank diversities ($P > 0.05$). Based on these findings it is apparent that fire can change vegetation in an area to be dominated by fire tolerant or fire intolerant species. Fire frequency, heat and smoke affects soil seed banks to a lesser extent in the False Thornveld. For the management of the False Thornveld of the Eastern Cape, less frequent burning is recommended as it increases aboveground species diversity.

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ABBREVIATIONS

FAO	Food and Agriculture Organization of the United Nations
UNESCO	United Nations Education, Scientific and Cultural Organization
ARDRI	Agricultural Rural Development Research Institute

CHAPTER 1 INTRODUCTION

1.1 Background of study

In southern Africa, fire is regarded as a natural feature of rangelands, given the frequency of lightning storms that occur in both wet and dry periods (Trollope 1999; Higgins et al. 2000; Snyman 2004). Farmers commonly use fire for control encroaching bush, removal of overgrown herbage and the promotion of new growth. Fire can also generate problems associated with its usage. Challenges associated with the use of fire in the rangelands are considered under the four components of fire regimes, which are: frequency, intensity, season and type of fire. Each fire regime and combination of fire regimes impacts vegetation and soil seed banks differently. Problems associated with the use of fire as a management tool in South Africa have been reviewed (Booyesen and Tainton 1984). Due to these problems the need for further continuity of research based on what is known is critical for providing further understanding and effective range and conservation management practises.

Fire frequency, defined as the number of fires per season, has been considered as a pertinent regime in the control of bush density (Trollope 1999). Fire frequency affects species diversity (Trollope 1999) and soil seed banks (Auld and Denham 2006). The Intermediate Disturbance Hypothesis (IDH) suggests that the highest community diversity occurs at intermediate disturbance regimes, and with low richness under low and high disturbance frequencies (Connell 1978; Huston 1979; Hobbs and Huenneke 1992). In a study conducted in Okavango Delta, Botswana Heinl et al. (2005), sites with low fire frequency and long inter-fire intervals were found to be more heterogeneous than frequently burnt sites, hence high fire frequency decreases species diversity (Collins et al. 1995) and limits population growth rate (Garnier and Dajoz 2001).

In the semi-arid savanna of South Africa, fire tolerant species such as *Themeda trianda* were more abundant in annually burned areas and were much rarer in infrequently burned areas, while *Cymbopogon plurinodis* was more abundant in less frequently burned areas (Trollope 1999). These findings necessitate the need for further investigation into fire effects on vegetation.

Given that fire frequency has the ability to change species composition and diversity, the question arises on how it affects the diversity of soil seed banks. In the majority of habitats worldwide, plant populations are presented not only by growing individuals above ground, but also represented by a number of dormant propagules forming seed reserved in the soil (Kellerman 2004; Snyman 2006a). Such storage of seed banks is an effective maintenance of genetic material that permits species to exploit habitats that are temporally variable and subjected to a range of disturbance regimes. Furthermore, soil seed banks assist in the recovery ability of any degraded area. In frequently burned areas, a lack of time between fires prevents replenishment of seed banks (Auld and Denham 2006).

Germination of soil seed banks in fire prone areas can be stimulated by fire cues, smoke and heat. Heat and smoke are able to break seed dormancy in a number of vegetation communities such the chaparral California (Keeley 1991; Keeley and Fotheringham 1998), fynbos in South Africa (Brown 1993), and *Banksia* woodland in Australia (Dixon et al. 1995). Some seeds in fire prone areas are protected with hard coats which promote their survival (Arianoutsou and Margaritis 1981; Menassie and Michelsen 2002). Further investigation into fire effects on soil seed banks and seed germination will enhance knowledge of fire-prone community dynamics.

1.2 Problem Statement

Fire is commonly used to control bush density in rangelands of the False Thornveld of the Eastern Cape Province, which has experienced an increase in bush encroachment. The objective of burning is to reduce bush competition and increase grass production, as grasses are an important source of forage for domestic livestock (Trollope 1983, 1999). However, its effects on species diversity and soil seed banks are not well documented hence the need for further investigation.

1.3 Justification

Studies detailing the impact of fire regimes for specific vegetation types are required to fully understand the ecological implications of a particular burning regime (Uys et al. 2004; Heinl et al. 2005). This study will assist in making recommendations on the use of fire as a management tool in the control of bush encroachment and the associated effects of fire on species diversity and soil seed banks in the False Thornveld of the Eastern Cape Province.

1.4 Objective of the study

The main objective of the study was to investigate long term effect of burning frequency on vegetation and soil seed banks.

Specific objectives were:

- I. To determine the effect of burning frequency on species abundance of standing vegetation and that of viable soil seed banks.
- II. To determine the effect of burning frequency on species diversity and viable soil seed bank diversity.

- III. To determine correlation between species diversity of standing vegetation with that of viable seed banks across the burning treatments.
- IV. To determine the effects of smoke and heat pre-treatments on seed germination.

1.5 The key questions and hypotheses

The key questions to be addressed and hypotheses to be tested were as follows:

Key questions

1. How does burning frequency affect species abundance in the False Thornveld of the Eastern Cape?
2. How does burning frequency affect species diversity in the False Thornveld of the Eastern Cape?
3. Is there any difference in species diversity of above ground vegetation and that of soil seed banks vegetation across fire treatments?
4. Does smoke, heat or both enhance seed germination?

Hypotheses

1. Frequent burning increases the abundance of fire tolerant species and reduces that of fire intolerant species.
2. Frequent burning reduces species diversity
3. There is no difference between species diversity and the diversity of soil seed banks across the fire treatments.
4. Smoke or heat enhances seed germination.

CHAPTER 2 LITERATURE REVIEW

2.1 Fire in southern African Savannas

Savannas are commonly defined as communities with a continuous herbaceous layer usually dominated by grasses, and a discontinuous layer of trees or shrubs (Peterson and Reich 2001), and it constitutes one of the major biomes of South Africa (Trollope 1983). It is divided into two broad types: moist and semi-arid savanna (Trollope 1983). Semi-arid savannas receive less than 650 mm of rain per annum while moist savannas receive more than 650 mm – 1000 mm of rainfall per annum (Trollope 1983). During the wet season, accumulation of plant material increases and the material becomes dry in the absence of rain, which becomes a fuel source for fire to initiate, given the frequency of lightning storms (Trollope 1983, 1999; Higgins et al. 2000; Snyman 2004). Therefore, Africa is regarded as the ‘fire continent’, because fire is a natural factor of the environment that is thought to have occurred from time immemorial (Trollope 1999).

Naturally, the two savannas experience initiation of fire by lightning. In semi-arid savanna the frequency of fire has been far lower than in the moist savannas because rainfall is both less and highly erratic. The grass sward in semi-arid savanna remains acceptable to grazing animals even when matured (Trollope 1983). The frequency of fire in the semi-arid areas varies according to the prevailing conditions. Fires in southern African savannas typically occur late in the dry season (August to November), prior to the first seasonal rains (Hudak et al. 2004). Anthropogenic fires in Africa (Sheuyange et al. 2005) and south-west Australian forest (Burrows 2008) are also an ancient form of environmental disturbance, which probably have shaped the savanna vegetation more than any other human induced disturbance. The importance of fire as a driving variable in most of the vegetation system is well established in southern Africa (Booyesen and Tainton 1984; Snyman 2004).

2.1.1 The use of fire as a management tool in savannas.

In savanna rangelands, fire is used widely to control bush encroachment. Woody plant encroachment is an increase in woody plant density typically resulting in impenetrable thickets, suppressing palatable grasses and herbs (Wiegand et al. 2006). South African savannas have been subjected to thorn bush encroachment. According to Archer (1995), little is known about the dynamics and the causes of bush encroachment. Therefore, it has been widely accepted that the use of savanna for domestic livestock has facilitated shrub invasion through associated overgrazing (Archer 1995; Wiegand et al. 2006) and other factors associated with mismanagement of rangelands, but other studies do not support this theory (Scholes and Archer 1997; Higgins et al. 2000). Hence, frequent burning has been recommended to reduce bush to the size of browsable height for goats and also to increase the abundance of the herbaceous component. However, frequent burning does not eradicate the density of bush, as most shrubs coppice from the base (Scholes and Archer 1997; Trollope 1999; Higgins et al. 2000).

Nutritional compositions of grasses between semi-arid and moist savanna varies. Semi-arid savanna remains palatable throughout the year, due to low rainfall and nutrient losses from the soil are very low when compared to moist savanna. Fire is commonly used in the latter area (Trollope 1983). Moist savannas lose their palatability at an early stage, due to high rainfall and leaching of the soil nutrients. Consequently, burning is highly recommended as it removes the unpalatable grass material left in the previous season and promotes a flush of green grass which contains high protein and reduces moribund material.

2.1.2 Fire regimes

Changes in vegetations associated with the use of fire are usually described under fire regimes (Trollope 1983; Bond and van Wilgen 1996). Fire regimes comprise four components, namely: season, frequency, intensity and type of fire.

➤ Fire season

In most savannas, season of burn is a relatively predictable component of the fire regime since most fires occur during the dry season (Frost and Robertson 1985; Bond and van Wilgen 1996; Hudak et al. 2004). It is this within-year predictability which enables many species to avoid fire by being dormant during the main fire season (Frost and Robertson 1985).

➤ Fire frequency

Fire frequency determines the length of time that a plant has to recover before the next fire occurs. The slower the rate of recovery, the more likely it is that the structure and composition of the vegetation will be altered, particularly where fire occurs frequently (Frost and Robertson 1985; Morrison et al. 1995; Bond and van Wilgen 1996).

➤ Fire intensity

Fire intensity is a function of fuel type, fuel load, moisture content, and atmospheric conditions at the time of fire, and therefore is linked to both the seasonality and frequency of burning. The longer the interval between fires, the greater the fuel load and therefore the more intense the fire (Frost and Robertson 1985; Bond and van Wilgen 1996).

➤ Types of fire

There are three different types of fire namely: ground, surface and crown fire.

- i. Ground fire: this type of fire burns below the surface of the ground in deep layers of organic material;
- ii. Surface fire: is a fire that burns in the herbaceous surface vegetation;
- iii. Crown fire: is a fire that burns in the canopies of the trees and shrubs (Trollope 1983). In the savanna areas both crown and surface fires occur but the most common is the surface fire burning with or against the wind as head or back fires (Trollope 1983).

Each of the fire regimes plays its role when fire occurs, but the dominance of fire as a land management tool has resulted in many debates over the ecological consequences imposed by fire regime (Setterfield 2002).

Trollope (1983) stated that when considering the effect of frequency of burning on vegetation a clear distinction must be made between the effect of burning at a particular frequency, the number of times that the treatment has been applied and the type of management that is used during the interval between the fires. In the absence of grazing, annual burning resulted in a high rooted frequency of grasses but a low rooted frequency of forbs in the False Thornveld (Trollope 1983). In contrast quadrennial burning caused a significant decrease in the grasses and a significant increase in forbs (Trollope 1983). Factors such as overgrazing, drought and frost complicate the interpretation of results ascribed to the response of the vegetation to a particular burning treatment (Trollope 1983).

2.2 Effects of burning frequency on herbaceous vegetation

When fire is described as a natural factor, it becomes part of the ecology of savannas; therefore species occurring in these environments are likely to be highly adaptable to the fire occurrence and the post-fire environments. Each biome of South Africa constitutes a plant population that is adapted to burning frequency according to the local probability of ignition by lightning in the areas they inhabit (Manry and Knight 1986). The response of plant communities to burning

reflects their ancestral exposure to fire in the course of their evolutionary history under pre-existing natural fire regimes (Manry and Knight 1986). The importance of fire in savanna as an ecological factor determines the typical plant species composition and vegetation structure through a permanent reoccurring disturbance (Heinl et al. 2004).

Fire frequency has the ability of modifying both the species composition and the vegetation structure that occurs within the given area. Fire can alter vegetation in frequently burned areas (Heinl et al. 2004). The impact of fire on vegetation can be examined in terms of the response of individual plants, population, species and communities (Allen 2008). Direct fire effects on vegetation that has been subjected to annual fire for several decades appears to be negligible, primarily because many perennial species and most individual plants complete their phenological cycle entirely between fires (Morgan 1999), and also because of the ability of perennial species to regenerate rapidly through vegetative means after fire.

In the False Thornveld of the Eastern Cape, frequent burning favoured *Themeda triandra*, and had a negative effect on the abundance of *Cymbopogon plurinodis* (Frost and Robertson 1985; Trollope 1999; Uys et al 2004), and *T. triandra* also increased in frequently burned areas in Australia (Morgan and Lunt 1999; Lunt and Morgan 1999). It has been suggested that inter-fire intervals of ≤ 5 years would appear necessary to maintain the health and competitiveness of *T. triandra* (Morgan and Lunt 1999). The abundance of *T. triandra* in a study conducted in Australia was found to be 22% in rarely burned areas and 63% in frequently burned zones (Lunt and Morgan 1999); similarly in the False Thornveld Uys et al. (2004) found *T. triandra* was greater than 80% in annually burned areas and less than 20% in unburnt areas. Frost and Robertson (1985) reported that species that are dependent on seeds for their survival in recurrent fires must be able to establish, grow and reproduce in the interval between successive fires. Less frequently

burns favours species such as *C. plurinodis*, *Sporobolus fimbriatus* and forbs (Frost and Robertson 1985; Trollope 1999; Uys et al. 2004). In southern Africa, grass species such as *Diheteropogon amplexans* and *Koeleria capensis* consistently increased as fire became more frequent, meanwhile *Tristachya leucothrix* and *Aristida junciformis* consistently decreased with increasing fire frequency (Uys et al. 2004).

In a study conducted in Australia it was found that some perennial exotic species were more abundant in the long-unburned area, but were rare or absent in frequently burned zones (Lunt and Morgan 1999). Frequent burning did not prevent invasion of other species, but their cover was less. Changes in fire frequency can shift an area between fire tolerant species and fire intolerant species (Nuzzo et al. 1996; Bond and van Wilgen 1996; Morgan and Lunt 1999; Trollope 1999; Uys et al. 2004). Exclusion of fire for a long time would likely result in the loss of fire tolerant species. The reason has been accredited to the constant accumulation of dead or moribund material (Everson et al. 1988; Morgan and Lunt 1999; Lunt and Morgan 1999; Zimmermann et al. 2009).

According to Frost and Robertson (1985) savanna herbaceous communities are less affected by fire than are the woody communities. In addition Morgan (1999) and Uys et al. (2004) found that there were minor effects of fire frequency on herbaceous species composition. In the study conducted at Matapos Research Station, Zimbabwe in savanna vegetation (Furley et al. 2008), fire affected the composition of the herbaceous plant community, but not the number of species, because by the end of the experiment some grass and sedge species had flourished while others revealed greater susceptibility to fire. The most obvious change occurred at extremes of fire, which is annual burning (Frost and Robertson 1985; Furley et al. 2008).

2.3 Effect of burning frequency on woody vegetation

Fire is a natural factor in the savannas of southern Africa, and its exclusion leads to an encroachment of bush. Bush encroachment is an increase in woody plant density (Peterson and Reich 2001; Russell-Smith et al. 2003; Wiegand et al. 2006), basal area and canopy cover (Peterson and Reich 2001), typically resulting in impenetrable thickets suppressing palatable grasses and herbs (Wiegand et al. 2006). The use of savanna for domestic livestock has facilitated shrub invasion through associated overgrazing (Archer 1995; Wiegand et al. 2006) and other factors associated with mismanagement of rangelands, although other studies do not support this theory (Scholes and Archer 1997; Higgins et al. 2000). High frequency fires have been credited with creating and maintaining savannas (Trollope 1983, 1999; Peterson and Reich 2001) and the prolonged absence of fire allows the herbs and small shrubs to decrease in abundance, while large shrubs increase in abundance (Morrison et al. 1995; Bond and van Wilgen 1996).

Annual and biennial fires produce the most reduction in canopy density and help to keep its size to a browsable height for goats, but they do not eradicate trees or shrubs (Trollope 1983; Peterson and Reich 2001; Heisler et al. 2003; Furley et al. 2008). Triennial burns yield higher woody density probably due to longer fire return periods, which presumably allow some tree species recruitment (Enslin et al. 2000). In other areas of semi-arid savanna it has been shown that a single prescribed burn is insufficient to cause a transition from a shrub encroached site to one of low shrub cover within grassland (Havstad and James 2010).

Frequent fires in semi-arid savannas results in high number of “gullivers” (non-productive plants) (Higgins et al. 2000), and recruitment into the adult stage is reduced, as a result of relatively intense fires. The high number of “gulliver” stem in the semi-arid are due to relatively high establishment rates, coupled with slow growth rate that prevent many smaller gulliver stems from

resprouting after topkill (Trollope 1983; Higgins et al. 2000; Enslin et al. 2000). Fire frequency, fire season and complete exclusion from burning did not affect the size of tree populations and there was no decrease in tree density with increasing fire frequency (Furley et al. 2008). Apparently the increase in tree density has been attributed to the ability of the woody species to resprout from the base (Trollope 1983; Peterson and Reich 2001; Heisler et al. 2003; Furley et al. 2008).

Some general observations were made by Furley et al. (2008) in a study conducted in Zimbabwe on the results of frequent burning: (1) Vegetation structure is strongly affected, lowering the proportions of trees to shrubs and herbaceous plants and reducing ground cover; irregular fire behaviour leads to patchiness; ground layer plants change from perennials to a dominance of annuals. (2) Tree height decreases inversely with fire frequency; total above-ground biomass is severely reduced. (3) Tree and woody shrub density remains fairly constant through seedling recruitment and resprouting, though numbers of individual species may be affected. The ability of stems that are killed in fire to resprout is a key life-history trait that promotes the persistence of trees in savanna. In a study conducted by Russell-Smith et al. (2003) in *Eucalyptus* dominated open forest and woodland in Northern Australia, significant changes were observed between burned and unburned treatments specifically in the development of a denser midstorey in both open-forest and woodland unburned treatments.

On One hand, Enslin et al. (2000) found no evidence of species composition changes in line with the ordination results of frequency and season of burning, suggesting that there might be other environmental gradients responsible for variation. Furthermore, Trollope et al. (1995) indicated that changes in woody vegetation do not involve a decrease in diversity or composition, but primarily a change in structural diversity. On the contrary annual burning effectively prevented the

recruitment of species (Heisler et al. 2003), hence some species are fire tolerant and others are fire intolerant (Bond and van Wilgen 1996; Nuzzo et al. 1996; Morgan and Lunt 1999; Trollope 1999; Uys et al. 2004). On the other hand, most of *Acacia* species are fire tolerant (Burke 2006), and encroachment by species of *Acacia* has been reported in a number of countries after fire (Abule et al. 2007). However a no-burn area or a long fire-return interval has been shown to recruit different species. Fire frequency might be selective on species, with some species disappearing faster than others and protection from fire results in an increase in tree density, particularly of fire sensitive species (Frost and Robertson 1985).

2.4 Species diversity Indices

Spellerberg (1991) wrote that diversity could refer to species diversity, habitat diversity or diversity of resources in a niche. In simple terms, maximum diversity exists if each individual belongs to different species; whereas minimum diversity exists if all individuals belong to one species (Spellerberg 1991). Thus, within a given patch, the response of any community to a disturbance is determined by the response of component species. This suggests that species composition changes with time since disturbance and many species require some time after disturbance to reach reproductive maturity (Hobbs and Huenneke 1992). While disturbance is important for maintaining diversity both within communities and at landscape level, it may also have undesirable effects (Hobbs and Huenneke 1992). In addition, Spellerberg (1991) suggested that some communities naturally have low species diversity; therefore it is always useful to calculate the theoretical extremes of a diversity index via the collection of simple, hypothetical data.

The Intermediate Disturbance Hypothesis [IDH] suggests that highest community diversity occurs at intermediate disturbance regimes, with low richness under low and high disturbance frequencies

(Connell 1978; Huston 1979; Hobbs and Huenneke 1992). Even so high fire frequencies can result in high species diversity (Tester 1989; Nuzzo et al. 1996). However, high fire frequency has been found to decrease species diversity (Collins et al. 1995) and limit population growth rate (Garnier and Dajoz 2001). In a study conducted in South African grassland, there was no consistent response of species richness to either burning frequency or season of burn (Uys et al. 2004). Similarly in a study conducted in Florida Pine savanna, no relationship was found between species richness, diversity or flowering stem density and fire frequency (Beckage and Stout 2000).

Short-fire intervals are associated with a reduction in the number of plant species (Gary and Morrison 1995; Bond and van Wilgen 1996; Trollope 1999), although Furley et al. (2008) found that fire affected the composition of the herbaceous plant community, but not the number of species. Annual and biennial burns led to low vegetation cover and high species numbers, but the mid-fire intervals (5-8 years) allowed perennial highly competitive species to dominate and led to a low species number (Heinl et al. 2005). Species richness increases with the time between fires and herbaceous species composition consistently changes as fire becomes more frequent (Uys et al. 2004; Heinl et al. 2005). It has been shown that changes in ecosystem functioning associated with variations in the diversity of species are not simple cause-effect relationship, but often depend on the particular species involved (Aarssen 1997). Species vary in their response to fire, fire may favour one set of species over the other (Hobbs and Huenneke 1992).

2.5 The role of soil seed banks on vegetation

Plants establish themselves by the expansion and subsequent fragmentation of vegetation parts such as tillers, rhizomes, runners or by successful establishment of a soil seed bank (Solomon et al. 2006). Soil seed banks are an important component of the dynamics of plant populations (Auld 1995). An understanding of the soil seed bank process is crucial for understanding vegetation

dynamics, particularly in ecosystems experiencing frequent disturbance (Scott et al. 2010). Soil seed banks are defined as the store of viable as well as non-viable seeds buried in the soil, composed of seeds produced in the area and partly of seeds brought from elsewhere (Harper 1977; Kellerman 2004; Snyman 2006a). The dormant seeds need to await for stimuli before they can germinate or else further dormancy is imposed upon them by the experience they meet in the soil, while others are consumed by predators, decay or die (Harper 1977) (Figure 2.1).

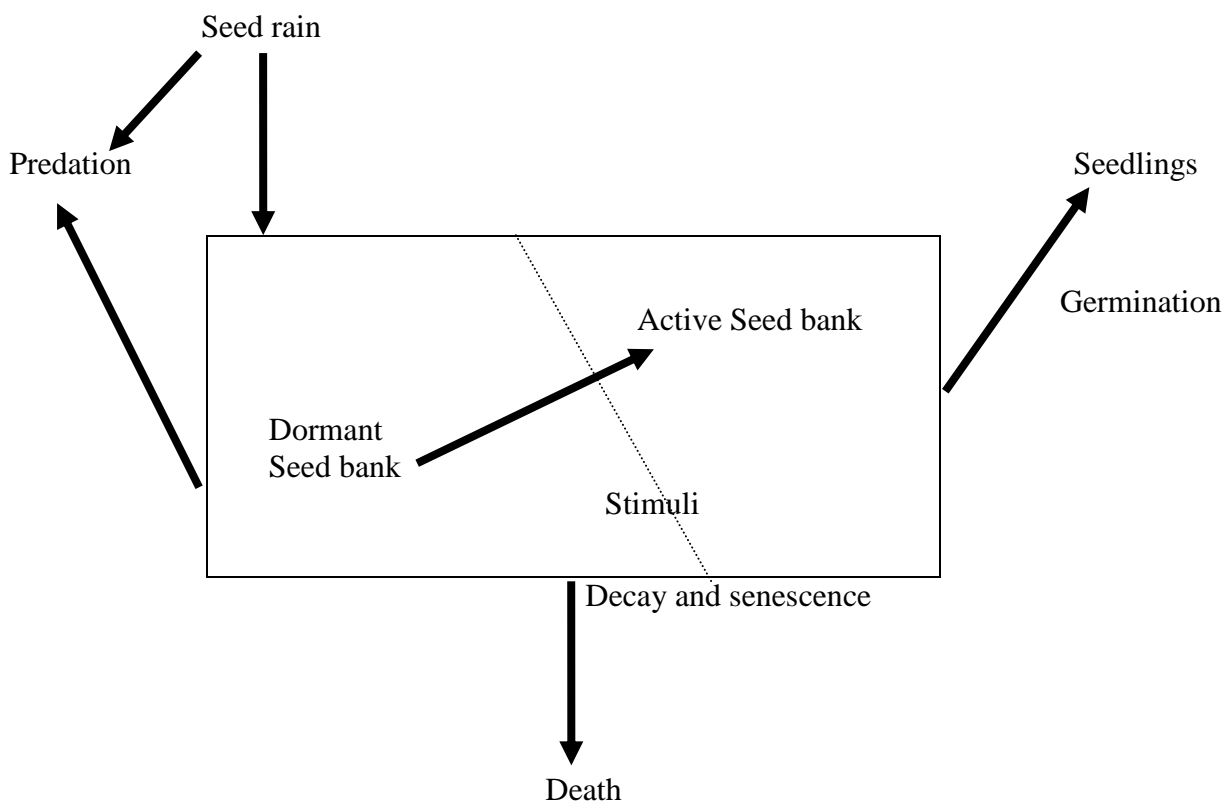


Figure 2. 1 Schematic diagram showing flow chart for the dynamics of the population of soil seed bank (Harper 1977).

The period of time that the seeds remain viable in the seed bank varies among species (Williams et al. 2005). Soil seed banks play an important role in maintaining the ecological and genetic diversity of populations (Auld 1995; Tekle and Bekele 2000). Seeds are considered essential constituents of plant communities, as they contribute significantly to the ecological process of

recovery (O'Connor 1996; Tekle and Bekele 2000; Luzuriaga et al. 2005). It is well known that the resilience of vegetation depends upon soil seed banks, but an understanding of the dynamics of soil seed banks has become a great challenge to plant community ecologists (Luzuriaga et al. 2005). This understanding is necessary to enable the determination of the role of soil seed banks in community traits of ecosystem functioning and to improve the integrated management of ecosystems. Emergence of new plants from the soil seed bank may reduce soil erosion and nutrient loss following disturbance and help in site stabilization, although the process of site stabilization and ecosystem development may depend primarily on the nature and severity of the disturbance (Tekle and Bekele 2000). Some species recover from disturbances through resprouting, seeding, or a combination of these.

Seed banks are described as transient, or persistent. Transient seeds are those that are capable of germinating within the same year and persistent seed are those that can persist in the soil for more than one year (Bond and van Wilgen 1996). Tree seed banks tend to form transient seed banks, because their large seeds are lost through predation, decaying, and by other means, while the herbaceous layer form a persistent seed bank because of small seeds it contains (Bond and van Wilgen 1996).

2.6 Fire and soil seed banks

Fire may have a positive effect on vegetation by reducing litter cover and a negative effect by reducing belowground physical and chemical characteristics, and by altering the size and composition of the soil seed bank. Fire may therefore have a range of effects on the mortality of adult plants, seedling establishment, release of germinal seeds and flowering (Tekle and Bekele 2000). The effect of fire may also depend on the plant's life cycles. Richardson and Kluge (2008) point out that fire can be applied to reduce seed numbers in the leaf litter and upper seed bank in

some cases, although there are serious problems associated with high fire intensities. The effect of fire on seed dormancy can be indirectly assessed through experimental treatment of soil seed banks, exposing them to heat shock and smoke (Williams 2002). Soil seed banks that persist after a fire are important in fire-prone habitats as they minimize the risk of decline or local extinction in plants (Tekle and Bekele 2000; Auld and Denham 2006). However, the ability of species within soil seed banks to maintain a seed bank after a fire will be influenced by the impact of high fire frequencies. Replenishment of the seed bank through flowering and seed production is expected to be most limited with frequent fires (Auld and Denham 2006).

The key area where knowledge is limited is the extent to which fires may deplete existing soil seed reserves (Auld and Denham 2006). Fire results in an increased water intake, gas exchange and enhanced germination, but some of the seeds are killed by fire (Mucunguzi and Oryem-Origa 1996). In fire-prone communities, obligate seeders are killed by each fire but may recolonize through germination of dormant seeds, and resprouters are resistant to frequent burning but sometimes may be killed by exceptionally severe fire (Hawkes and Menges 1995). At high fire frequencies, a lack of time between fires prevents replenishment of seed banks (Auld and Denham 2006). For species with canopy seed banks, except in patchy fires, the entire seed bank may be exhausted after a single fire, thus they might be at risk of decline under frequent fire (Auld and Denham 2006). During the passage of a fire, depletion of the soil seed bank is dependent on the magnitude of germination cues and the location of seeds in the soil profile. Snyman (2006a) indicated that high intensity fires close to the soil surface kill the most seeds. However it has been shown that some seeds are expected to remain as residuals in the soil after the passage of any single fire (Auld and Denham 2006).

2.6.1 The role of fire on seed dormancy and germination

One way in which fire stimulates the germination of seeds is by reducing seed dormancy; hence the dormancy-breaking mechanism must overcome factors that impose dormancy on seeds (Thomas 2004). Dormancy entails constraints that reside in the embryo itself (embryo dormancy) or belong to the enclosing structures (coat-imposed dormancy), that prevent growth of the embryonic axis (Thomas 2004). Dormancy strengthens as the environment becomes less conducive to seedling survival and, as dormancy strengthens, the range of environmental conditions over which germination is possible becomes narrower. Fire breaks hard seed coat dormancy by the physical burning of the seed coat. Some seeds in fire prone areas are protected by a hard coat which promotes their survival (Arianoutsou and Margaris 1981; Menassie and Michelsen 2002). Conversely, dormancy weakens as the environment becomes more conducive to seedling survival (Thomas 2004).

Dormant seeds germinate only with a certain probability, even if optimal physical conditions for germination are met (Valleriani and Tielbörger 2006). Not all seeds are expected to germinate following fire except for the species that form transient soil seed banks. The effect of fire regime on seedling emergence is subject to the availability of seeds and safe sites which provide moisture, light and temperature regimes appropriate for germination (Williams 2002). Seeds can delay their germination for several years, thus structuring the seed banks.

Factors affecting germination and early seedling growth are often the primary determinants of the distribution of adult plants (Snyman 2006b). It is sometimes possible to predict the response of vegetation to various types of management from knowledge of the composition of the accompanying seed bank. A phenomenon common to many of these communities is the flush of germination and growth that follows a burn. Fire produces the postburn flush of seedlings by

several direct and indirect means. These include direct heating of the soil and seed banks, thereby affecting seed germination, changing soil structure and nutrient levels: or temporary reduction in competition by removing above-ground vegetation, thereby allowing seedlings greater access to light and water, and reducing allelopathic influences (Tyler 1995; Garnier and Dajoz 2001; Snyman 2004). Heat, smoke, ashes, charred wood, charcoal and nitrogenous compounds released during plant combustion may act, individually or in combination, as a cue for post-fire seed germination

2.7 Floristic composition between standing vegetation and soil seed banks

According to Harper (1977) and Falińska (1999), soil seed bank floristic composition is apparently both a product of the species composition of standing vegetation and a record of the long term substitution of species. The size, species richness and species composition of the seed bank are important variables as they reflect the past, current and the future condition of the ecosystem (Solomon et al. 2006). The floristic composition of the seed bank at a particular time is not the mirror reflection of the aboveground vegetation (Harper 1977; Abrams 1988; Leck et al. 1989; Morgan 1998; Falińska 1999; Tekle and Bekele 2000; Solomon et al. 2006), and at some points the similarities may be very low (Morgan 1998; Lyaruu and Backéus 1999; Solomon et al. 2006).

A number of different reasons have been put forward to explain why the above ground vegetation is not well represented in the soil seed bank. Morgan (2001) indicated that in the recruitment of seed, exotic annuals exploited an available 'niche' that is not well utilized by native species and native seedlings were observed in only small quantities and only represented a restricted number of the species present at a site. Many species were never seen as seedlings and a further 21% of the perennial species recorded only one seedling in a single year, suggesting that some of the species were able to spread vegetatively (Abrams 1988; Morgan 2001). The abundance of

perennial grasses is gradually decreasing as they are known to have low seed production (Lyaruu and Backéus 1999). Seeds might be present in the soil seed banks but were not likely to germinate (Tekle and Bekele 2000). In the case of the rehabilitation of degraded areas it is unlikely that soil seed banks will serve as the only solution (Tekle and Bekele 2000), as they will contribute poorly to the vegetation recovery after fire (Valbuena and Trabaud 2001). Therefore integration with other methods such as reseeding and plant propagation are also important as an effective mechanism of rehabilitation.

2.8 The effect of smoke on soil seed banks

Smoke generated from fire plays an important role in re-establishing many plant communities in semi-arid regions such as Californian chaparral (Keeley 1991; Keeley and Fotheringham 1998), fynbos South African (Brown 1993), and *Banksia* woodland in Australia (Dixon et al. 1995). Smoke is highly effective, sometimes inducing 100% germination in a deeply dormant seed population (Keeley and Fotheringham 1998). Since its discovery by De Lange and Boucher (1990), positive effects of smoke have resulted in it being used as a seed pre-treatment (Brown and van Staden 1997). The application of smoke technology can be adopted to achieve high vigour seedlings.

There are several methods that have been used as a smoke inducer (Brown and van Staden 1997), including aqueous or gaseous treatments (Keeley and Fotheringham 1998; Sparg et al. 2005; Kulkarni et al. 2007; Dayamba et al. 2010). The aqueous smoke solution is obtained by forcing smoke generated in a drum to bubble through distilled water using compressed air (Brown and van Staden 1997). According to Kulkarni et al. (2007) butenolide, a compound found in smoke has been found to be responsible for the germination of some species. They discovered a significant effect on the post-fire ecology of *Acacia* species. Smoke-treated seeds have been shown to

germinate more quickly than untreated ones (Dayamba et al. 2008). Smoke is clearly an important environmental cue that can travel over long distances and response to smoke may have evolved as part of the survival strategies of fire-climax species (Brown and van Staden 1997). The effectiveness of using smoke will depend on the species composition of the topsoil seed bank (Read et al. 2000). Therefore, in some instance smoke might not enhance the germination of other species.

Dayamba et al. (2008, 2010) found no smoke effect on grass species in Burkina Faso. This could be related to exposure time and dosage of smoke produced under field conditions, which can be different from those of simulated smoke treatment in a laboratory experiment. Some of the grasses favoured by fire failed to germinate irrespective of the smoke treatments applied, including that of no smoke. The positive field response of seeds to fire might be due to the space and related favourable conditions provided by post fire environment and not to stimulation by cues such as smoke (Dayamba et al. 2010). Smoke had an inability to break seed coat imposing dormancy, which might be the cause of leguminous trees failing to respond positively (Dayamba et al. 2008, 2010). In addition the interaction between smoke and heat did not influence germination of the grass species (Dayamba et al. 2008).

Heteropogon triticeus in Cape Cleveland, Australia, was reported to be stimulated by smoke (Williams et al. 2005), and in South Africa grasses such as *T. triandra* and some *Acacia* seeds have been stimulated by smoke (Kulkarni et al. 2007). Twenty-five of the 32 species studied responded positively to smoke treatment; the findings were particularly significant as many of the Restionaceae species responding to smoke had previously been difficult or impossible to germinate (Brown et al. 1994). Overall some seeds can be stimulated by smoke to germinate or

break their dormancy but others may not respond at all. The different methods used to induce smoke in laboratory experiments are also an important factor in influencing seed germination.

2.9 The effect of heat on soil seed banks

Buried seeds have different tolerances to heating that may enhance germination (Garnier and Dajoz 2001). Heat has been shown to enhance the germination of some species. Species of *Acacia* are widely distributed in arid and semi-arid regions, where fire plays an important role in breaking hard seed coat dormancy and stimulating seed germination. Temperature or heat shocks, generated from fires, are reported to play a major role in releasing seed dormancy of legumes in arid and semi-arid regions (Kulkarni et al. 2007). Heat shock triggers germination of certain species but also has no stimulatory effect on a great many other species.

Post fire species are chemically stimulated by combustion products (Keeley and Fotheringham 1998). Extremely high temperatures and high temperatures may be applied to a suite of horticulturally and ecologically important species in an effort to improve germination (Tieu et al. 2001). Some savanna species were found to be stimulated by heat (Gashaw and Michelsen 2002), while others were not stimulated (Mucunguzi and Oryem-Origa 1996). In addition, Dayamba et al. (2008) found that heat did not affect the germination parameters in grass species, suggesting that seeds would be able to germinate after a fire event and colonise the field unless they are situated at ground level where lethal temperatures can be reached.

Naturally, heat and smoke occur simultaneously; and germination of some species is improved by the combination of the heat and the smoke (Tieu et al. 2001). Heat and smoke were reported to be complementary triggers of soil-stored seeds (Read et al. 2000). Some of the species showed increased germination with smoke and did not germinate with heat, while other species that

required heat to germinate showed no response to smoking effect (Grant and Macgregor 2001). Heat and smoke have a different effect on range of emergence (Read et al. 2000). In this regard, there is a need for deeper understanding of fire effects on vegetation and soil seed banks in order to fill the gaps or iron-out inconsistencies in the use of fire as a management tool. This study was conducted as an attempt to contribute to the body of knowledge in addressing challenges associated with the use of fire as a range management tool in the False Thornveld of the Eastern Cape.

CHAPTER 3 MATERIALS AND METHODS

3.1 The study area

This study was conducted at the Honeydale section of the University of Fort Hare Research farm, situated 3 km outside Alice town in the Eastern Cape Province of South Africa. The Research farm is located at 32° 47'S, 26° 52' E, and Altitude ranges from 500 m to 600 m above sea level. The mean annual rainfall is 500 mm of which 70% occurs between October and March. The rainfall distribution pattern is irregular and varies from year to year. The temperature regimes are moderate with cold winters, and the maximum ranges between 26 - 41°C and the minimum ranges between 5 - 11°C (ARDRI 1989). The vegetation is classified as a semi-arid savanna referred to as the False Thornveld of the Eastern Cape (Acocks 1975). It consists of grasses interspersed with *Acacia karroo*. The dense sward is dominated by *Themeda triandra*, *Panicum maximum*, *Digitaria eriantha* and *Sporobolus* species. The soil at the site is a silty loam of the Glenrosa form (Soil Classification Working Group, 1991) or Ochric Cambisol (FAO/UNESCO) and is characteristically shallow with a stony surface.

3.2 The long term fire trials

The study was conducted within a long term burning trials established in 1980 to investigate the effect of burning frequency on species composition and biomass production. The experiment consists of six treatments: no burn (K), annual burn (B1), biennial burn (B2), triennial burn (B3), quadrennial burn (B4) and sexennial burn (B6). The treatments are replicated twice in a completely randomized design, on plots measuring 50 m x 100 m, and separated from each other with a border space of 5 m. Burning of plots takes place every July - August after the first spring rains. Table 3.1 shows the burning history of different fire treatments, while figure 3.1 illustrates the arrangement of fire treatments in the field.

Table 3. 1: Burning history of the trial from 1980 to 2010.

Year	Burning treatments											
	I/B ₁	II/B ₁	I/B ₂	II/B ₂	I/B ₃	II/B ₃	I/B ₄	II/B ₄	I/B ₆	II/B ₆	I/K	II/K
1980	B	B	B	B	B	B	B	B	B	B	NB	NB
1981	B	B									NB	NB
1982	B	B	B	B							NB	NB
1983	B	B			B	B					NB	NB
1984	B	B	B	B			B	B			NB	NB
1985	B	B									NB	NB
1986	B	B	B	B	B	B			B	B	NB	NB
1987	B	B									NB	NB
1988	B	B	B	B			B	B			NB	NB
1989	B	B			B	B					NB	NB
1990	B	B	B	B							NB	NB
1991	B	B									NB	NB
1992	B	B	B	B	B	B	B	B	B	B	NB	NB
1993	B	B									NB	NB
1994	B	B	B	B							NB	NB
1995	B	B			B	B					NB	NB
1996	B	B	B	B			B	B			NB	NB
1997	B	B									NB	NB
1998	B	B	B	B	B	B			B	B	NB	NB
1999	B	B									NB	NB
2000	B	B	B	B			B	B			NB	NB
2001	B	B			B	B					NB	NB
2002	B	B	B	B							NB	NB
2003	B	B									NB	NB
2004	B	B	B	B	B	B	B	B	B	B	NB	NB
2005	B	B									NB	NB
2006	B	B	B	B							NB	NB
2007	B	B			B	B					NB	NB
2008	B	B	B	B			B	B			NB	NB
2009	B	B									NB	NB
2010	B	B	B	B	B	B			B	B	NB	NB

B1 = Annual burn; B2 = Biennial; B3 = Triennial; B3 = Triennial; B4 = Quadrennial; B6 = Sexennial; K=Control. B = burn, NB = no burn.



Figure 3. 1: Experimental layout of burning experiment at University of Fort Hare Research farm (Source: Google Earth, 2008 Europa Technologies).

3.3 Determination of species composition

Herbaceous species composition was determined using the step point method for assessing the condition of the veld (Trollope 1986). Two hundred step points were conducted along two 100 m line transects located 25 m apart on each plot. A pointer was dropped on the ground and the nearest herbaceous species to the pointer was identified and recorded to species for grasses, or classed as a forb or a sedge for non-grasses. To determine composition of woody plants, a pointed iron rod measuring 2 m was laid perpendicular to a 100 m tape. All the woody plants (seedlings, shrubs and trees) occurring within the strip of 1 m on the either side of the 100 m line transect were identified and recorded by species (Trollope 1986). The data were collected during the dry season in August 2009, before the application of the fire treatments.

3.4 Collection of soil samples

Soil samples were collected in August 2009 before application of the treatments. The soils were collected at 10 cm depth using a soil auger from each of the 12 plots, along the two 100 m line transects at intervals of 13.3 m. A total of 15 soil cores were collected from each plot and composited to give one representative sample per plot. The samples were taken into the laboratory and kept until commencement of the germination experiment.

3.5 Germination experiments

3.5.1 Seedling emergence from the long-term trial

The seedling emergence method was used for germination of viable seeds contained in the soil samples (Kellerman 2004; Williams et al. 2005). The soil samples collected from 12 plots were sub-sampled using a glass beaker. A total of six sub-sample soils were obtained from each of the 12 plots. 250 *ml* of sub-sample soils were each spread evenly on 25 cm plastic pots containing 4000 *ml* of

Hygromix growth medium, and a thin layer of the hygromix was spread on top to gently cover the soil. Other pots containing only growth medium were used as a control for any contamination that might arise from the growth medium or seed rain. Each treatment was replicated six times making a total of 72 pots. Temperatures in a glass house ranged between 10°C at night and 24°C during the day. Plants were watered daily and observations were made twice a day. Emerging seedlings were recorded and tagged to avoid repeated counting. As soon as seedlings could be identified, they were recorded and then removed from the pots. Seedlings which could not be easily identified were transplanted into a separate pot and observed until flowering. Plants also received a dose of 200 cm³ of Hoagland's complete nutrient solution (Hewitt 1952) twice a week. This was to replace nutrients loss through leaching in order to reduce mortality of seedlings. The germination experiments were started in January and were terminated at the end of April 2010. Specimens of each representative species were then pressed and taken to the Selmar Schonland Herbarium in Grahamstown for identification and verification.

3.5.2 Heat and smoke pre-treatments

A second germination experiment was ran concurrently with the one described in 3.5.1. Heat, smoke, heat and smoke were used as pre-germination treatments on soils from unburned plots of the long term trials. Soil samples were collected in August 2009 from the control plots. The soils were collected at 10 cm depth using a soil auger from two unburned plots, along the two 100 m line transect at the interval of 13.3 m. A total of 15 soil cores were collected from each plot and composited to give a representative sample of the plot. The sample bags were kept safely in paper bags until the commencement of the germination experiment.

The soil samples collected were mixed together and divided into four equal portions using a weighing scale. Each of the samples were allocated to one of four pre-treatments (1) Heat (2) Smoke (3) Heat

and Smoke (4) the control. For the heat pre-treatment, soil was spread on an aluminium tray and placed in an oven at 85°C for 45 minutes. After the first 20 minutes in the oven, the samples were mixed to aid heat penetration through the soil and spread the heating effect through the seed banks (Williams et al. 2005). After heating the soil, it was allowed to cool. Six, 250 cm³ samples were measured from the heated soil. The soils were evenly spread on six 25 cm plastic pots containing 4000 ml of hygromix growth medium, and a thin layer of hygromix was spread on top of the soils to cover them. Williams et al. (2004) indicated that temperatures that break seed dormancy of several tropical legumes (i.e 80-100°C) occur in the top soil during the passage of both early and late dry season heat.

An instant smoke plus seed prima was used for the smoke treatment. Twenty-five packets of instant smoke plus seed prima containing five discs of dehydrated germination stimulators each of which had been patented and marketed as “Kirstenbosch Instant Smoke “Plus” Seed Primer by the South African National Biodiversity Institute at Kirstenbosch in Cape Town were used (Brown and van Staden 1997). Instant smoke plus seed primer was prepared by adding 500 ml water to a 1L beaker and placing the discs to remove smoke from the paper discs. After 15 minutes the paper discs were removed from the containers. Two hundred and fifty cm³ of soil sample was added into each of the containers with the instant smoke plus seed primer. The soils were soaked for a night in the solution. The samples were thoroughly mixed in the containers then spread on six 25 cm plastic pots containing 4000 ml of hygromix growth medium. A thin layer of hygromix was spread evenly to cover the soil sample in each pot.

For heat and smoke pre-treatment, the soil samples were heated following the same procedure described by Williams et al. (2005). Six, 250 cm³ soils were obtained from heated soils. The smoke pre-treatment was then applied after the soil had cooled down, and germination conducted on six

plastic pots. For the control treatment, a total of six sub-sample soils were obtained from soil samples. The soils were spread on six 25 cm plastic pots containing 4000 *ml* of hygromix growth medium, and a thin layer of hygromix was spread on top of each pot. All pots were watered daily and as soon as emergent seedlings could be identified, they were removed, counted and recorded. Seedlings which could not be easily identified were transplanted and observed until flowering. The plants also received Hoagland's complete nutrient solution (Hewitt 1952).

3.6. Data analyses

The Shannon-Weaver Diversity Index (Shannon and Weaver 1962) was used to compute diversity indices for standing vegetation and germinated seedlings (Magurran 2004). The diversity index was calculate using the formula:

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

Where by:

P_i is the proportion of individuals found in the i th species,

s is the total number of species found in the community, and

$\ln P_i$ is the natural logarithm.

The diversity indices of standing vegetation (woody and herbaceous) were combined and analysed as one dataset. The data for all abundances were tested for normality log transformed prior to statistical analysis. Two-way Analysis of Variance (ANOVA) was applied to test treatment effects and type of species on germinated seedlings and species abundance. A One-way Anova was used to test treatments effects on diversity indices for both standing vegetation and soil seed banks. The pre-

treatments diversity indices were not statistically tested because the seedlings were too few to provide a large enough sample size. Significant differences between treatment means were determined by *post hoc* tests using Fischer's Least Significant Difference test at $\alpha = 0.05$. The Pearson Moment Correlation test was also conducted to determine the relationship between the standing vegetation and soil seed bank diversity. All data was analysed using GenStat Discovery Edition 3 (2008).

CHAPTER 4 RESULTS

4.1 Treatment effects on herbaceous species abundance.

Burning frequency had significant effects on the abundance of herbaceous species ($P < 0.05$). Species abundances were significantly different amongst burning treatments ($P < 0.05$) (Table 4.1). The interaction between treatments and herbaceous species was also significant ($P < 0.05$) (Table 4.1).

Table 4. 1: Analysis of variance for the effect of burning treatments and species type on herbaceous species abundance ($P \leq 0.05$; $n = 300$)

Source of Variation	DF	MS	F-cal	P-value
Treatment	5	0.14259	2.92	0.015*
Species	24	2.06826	42.42	0.001**
Treatment * Species	120	0.12841	2.63	0.001**

*= significant **= highly significant

There were no significant difference between the annual, biennial, triennial and the no burn treatments on species abundance ($P > 0.05$), while the quadrennial and sexennial burns had significantly higher herbaceous species abundance ($LSD = 0.08$; $\alpha = 0.05$) (Figure 4.1). The annual, biennial and triennial burns significantly increased the abundance of *T. triandra* ($P < 0.05$), while *S. fimbriatus* species and *M. decumbens* were significantly higher in the sexennial burn and the no burn treatments ($P < 0.05$).

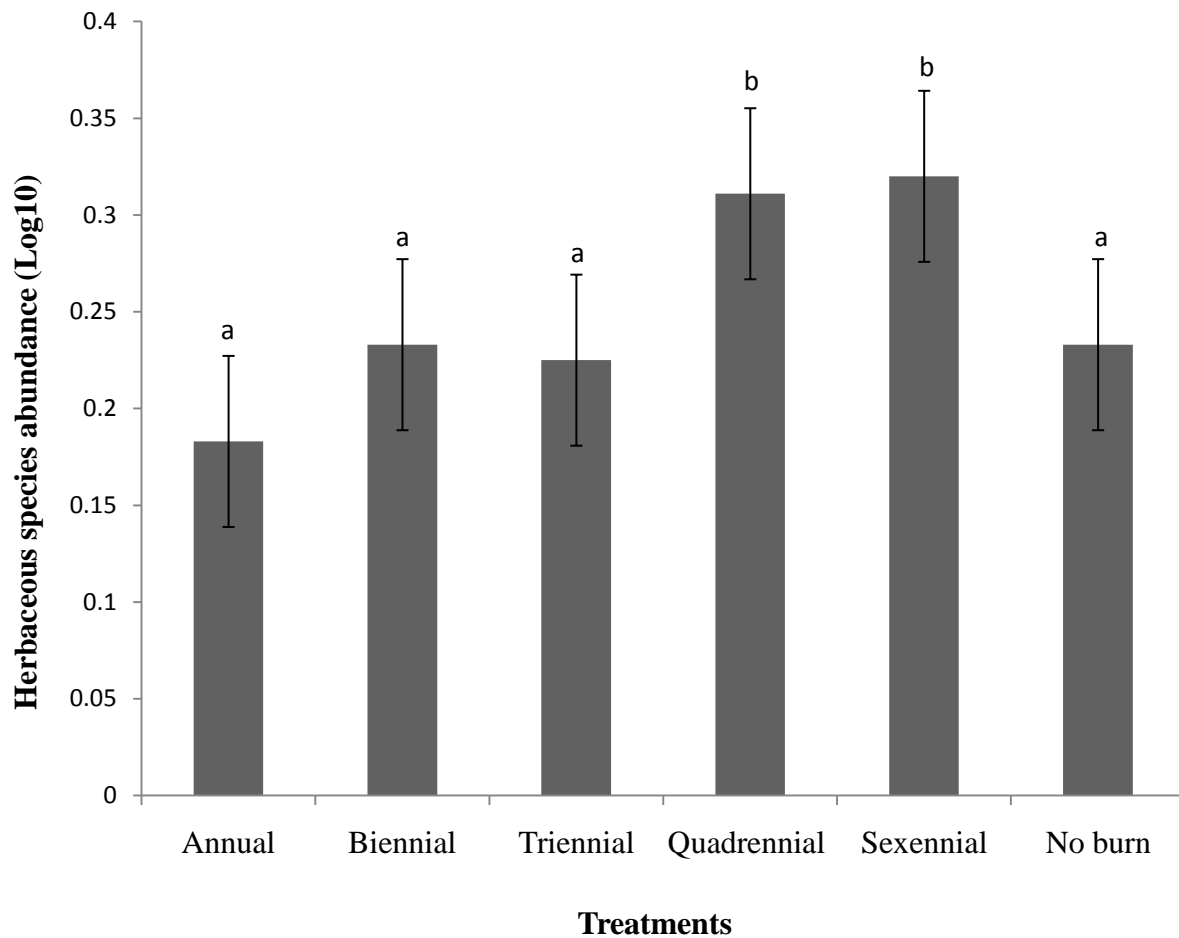


Figure 4. 1: Mean (log10) \pm SE abundances of herbaceous species across burning treatments (LSD = 0.08, $\alpha = 0.05$). Means with the same letters are not significantly different.

4.1.1 Relative abundance of herbaceous species

The annual, biennial and triennial burns were dominated by *T. triandra* with (57%), (65%) and (50%) respectively (Table 4.2). The sexennial and the no burn treatments were dominated by *S. fimbriatus* with (23%) and (38%) respectively, and *M. decumbens* (16% and 27%). *C. plurinodis* and *D. eriantha* were also abundant on both frequently burned plots and less frequently burned plots (Table 4.2).

Only five grass species recorded more than 10% in abundance. *T. triandra* recorded more than 10% in all burning treatments except in the no burn treatment. *C. plurinodis* had more than 10% abundance in all treatments, *D. eriantha* was recorded in the quadrennial burn only, *S. fimbriatus* was recorded in triennial burn, quadrennial burn, sexennial burn and the control treatment. *M. decumbens* was recorded in the sexennial burn and the no burn (Table 4.2). A forb, *P. reniforme* was recorded more than 10% in abundance in the annual burn.

T. triandra was the only species that increased with fire frequency, while *S. fimbriatus* and *M. decumbens* decreased with increasing fire frequency. Other grass species had an inconsistent abundance with the frequency of burning. *Trachyandra* spp also decreased with increasing burning frequency while other forbs had an inconsistent response to burning frequencies. The relative abundance of herbaceous species are presented in table 4.2.

Table 4. 2: Relative abundances (%) of herbaceous species across burning treatments.

Species	Treatments					
	Annual	Biennial	Triennial	Quadrennial	Sexennial	No burn
	Relative Abundances (%)					
Grasses						
<i>Cymbopogon plurinodis</i>	15	10	11	18	12	10
<i>Cynodon dactylon</i>	-	2	-	2	-	1
<i>Digitaria eriantha</i>	7	3	8	10	6	5
<i>Eragrostis capensis</i>	-	-	-	-	-	-
<i>Eragrostis chloromelas</i>	1	-	-	3	3	-
<i>Eragrostis congesta sub barbecolis</i>	-	-	-	-	-	-
<i>Eragrostis curvula</i>	-	2	2	2	2	3
<i>Eustachys muticus</i>	1	-	1	-	2	-
<i>Heteropogon contortus</i>	-	-	-	-	-	-
<i>Melica decumbens</i>	-	-	2	8	16	27
<i>Microchloa caffra</i>	-	-	-	1	-	-
<i>Panicum maximum</i>	1	6	2	2	8	2
<i>Panicum stapfianum</i>	1	3	6	5	2	1
<i>Setaria neglecta</i>	-	-	1	1	4	-
<i>Sporobolus africanus</i>	-	-	-	-	-	-
<i>Sporobolus fimbriatus</i>	3	3	15	15	23	38
<i>Themeda triandra</i>	57	65	50	23	18	8
Forbs						
<i>Protasparagues</i>	2	1	-	-	-	-
<i>Pelargonium reniforme</i>	11	3	-	-	2	-
<i>Cheilanthes viridus</i>	-	-	-	-	-	5
<i>Trachyandra</i> spp	-	2	-	9	1	-
<i>Bulbine abyssinica</i>	-	-	2	-	-	-
<i>Albuca setosa</i>	1	-	-	-	-	-
<i>Hibiscus</i> spp	-	-	-	1	-	-
Karroid shrub	-	-	-	-	1	-
Total	100	100	100	100	100	100

4.2. Effects of fire frequency on woody species abundance

Burning frequency had significant effects on woody species abundance ($P < 0.05$). There was a significant difference in the abundances of different woody species among the burning treatments ($P < 0.05$) (Table 4.3). The interaction between treatments and type of species was not significant ($P > 0.05$) (Table 4.3).

Table 4. 3: Analysis of variance for the effect of treatment, species and their interaction on woody species abundance ($P \leq 0.05$; $n = 192$)

Source of Variation	DF	MS	F-cal	P-value
Treatment	5	0.2557	4.77	0.001**
Species	15	2.81378	52.48	0.001**
Treatment * Species	7	0.05648	1.05	0.402 ns

ns= not significant, ** highly significant.

The mean separation ($LSD = 0.11$, $\alpha = 0.05$) indicated significant differences between the burning treatments on woody species abundance (Figure 4.2). The no burn treatment had significantly higher woody species abundance than all burning treatments ($P < 0.05$).

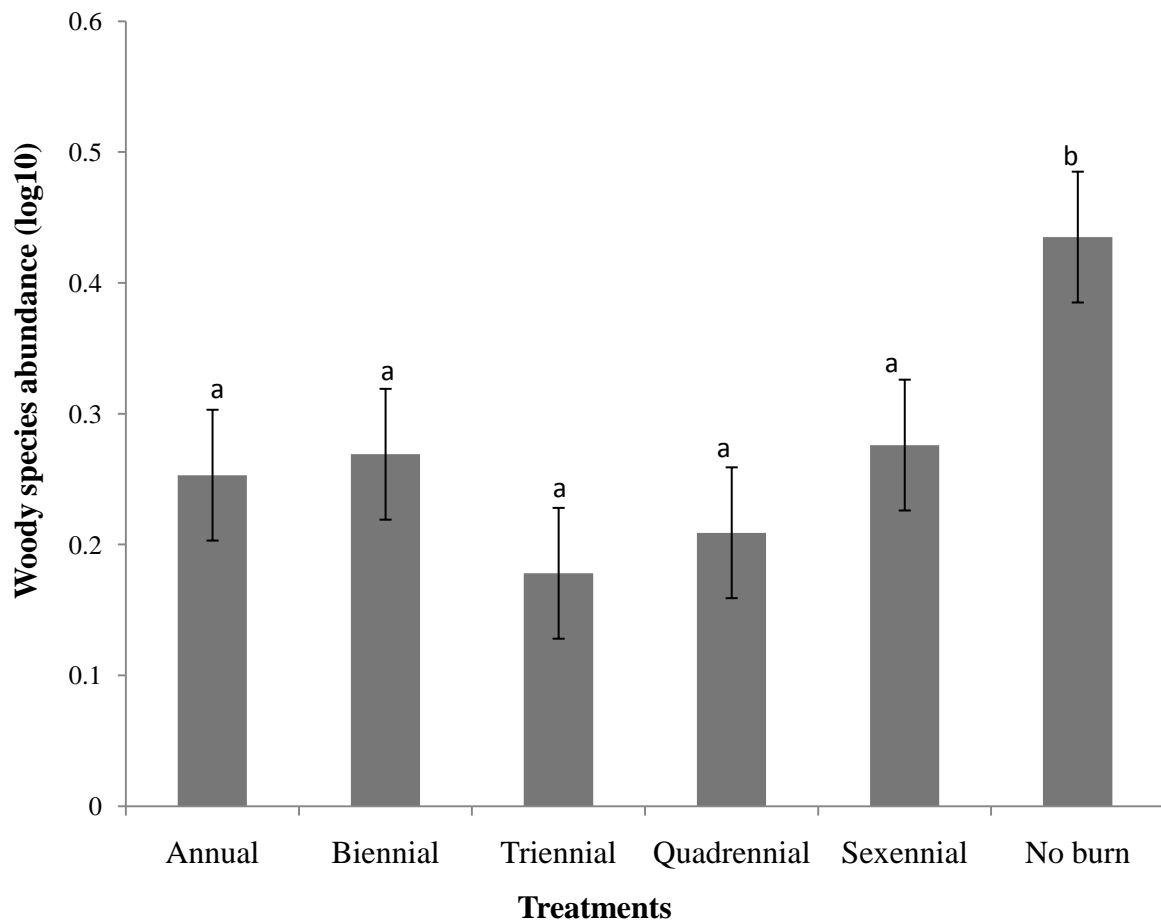


Figure 4. 2: Mean (log 10) \pm SE abundance of different fire treatments for woody species across burning treatments, (LSD = 0.11, α = 0.05). Means with the same letters were not significantly different.

4.2.1 Relative abundance of woody species

Acacia karroo was more abundant in the annual (80%), biennial (72%), triennial (89%), quadrennial (72%) and sexennial (80%) burns as compared to the no burn treatment with only 48% (Table 4.4). *Ehretia rigida* was more abundant in the quadrennial and the no burn treatments with 10% and 15% abundances respectively. *Diospyros lycioides* was more abundant in the no burn with (12%), and *Lycium ferosisinum* was abundant in the annual (9%), quadrennial burn (8%) and the no burn with (8%) (Table 4.4).

Only five woody species were recorded with more than 8% in abundance. *A. karroo* was recorded more than 8% in all burning treatments. *E. rigida* recorded more than 8% in the quadrennial burn and the no burn, *L. javanica* recorded more than 8% in the biennial burn (Table 4.4). *Lycium ferocissimum* and other species had an inconsistent abundance with the frequency of burning (Table 4.4).

Table 4. 4: Relative abundance (%) of woody species across burning treatments.

Species	Treatments					
	Annual	Biennial	Triennial	Quadrennial	Sexennial	No burn
Relative abundances (%)						
<i>Acacia karroo</i>	80	72	89	72	80	48
<i>Brachylaena eleptica</i>	-	-	-	-	1	5
<i>Diospyros lycioides</i>	3	4	3	3	5	12
<i>Ehretia rigida</i>	5	7	5	10	6	15
<i>Grewia occidentalis</i>	-	1	1	2	2	1
<i>Jasminum angulare</i>	-	1	-	-	-	3
<i>Lantana camara</i>	-	-	-	-	1	-
<i>Lippia javanica</i>	-	8	-	3	-	-
<i>Lycium ferocissimum</i>	9	3	2	8	4	8
<i>Maytenus heterophylla</i>	-	3	-	-	1	5
<i>Opuntia spp</i>	-	-	-	-	-	3
<i>Rhus longispina</i>	2	1	-	1	-	-
<i>Rhus refracta</i>	1	-	-	-	-	-
<i>Ziziphus mucronata</i>	-	-	-	1	-	-
Total	100	100	100	100	100	100

4.3 Treatments effects on species diversity

Burning treatments had a significant effect on species diversity ($P < 0.05$). The quadrennial, sexennial burns had the same highest diversity of 2.4 and no burn had a diversity of 2.3. The mean separation ($LSD = 0.388$, $\alpha = 0.05$) indicated no difference among the means of annual, biennial and triennial burns, while quadrennial, sexennial and the no burn had higher diversity ($P < 0.05$) (Figure 4.3).

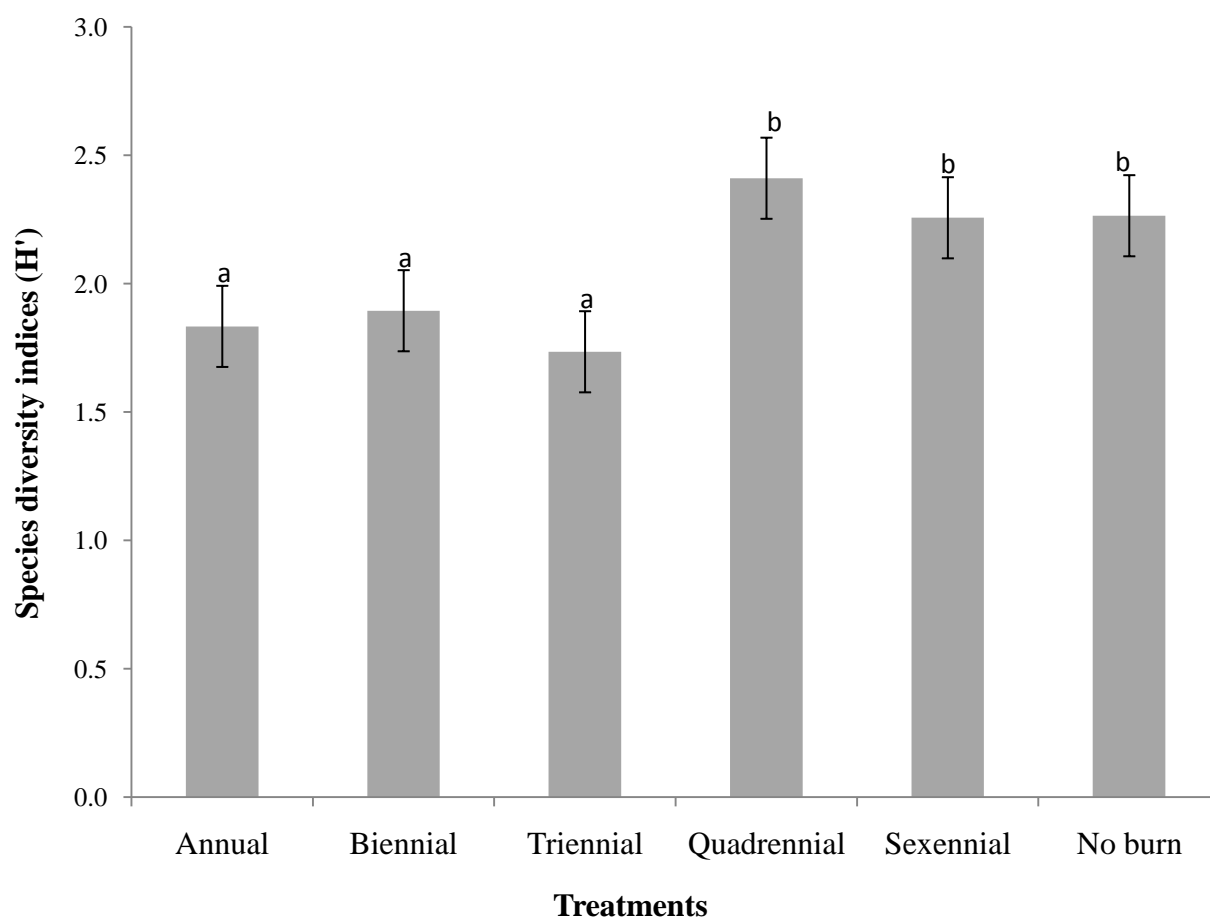


Figure 4. 3: Mean (\pm SE) diversity indices of standing vegetation for burning treatments, ($LSD = 0.388$, $\alpha = 0.05$). Means with the same letters were not significantly different.

4.4 Treatments effects on soil seed bank composition and diversity.

Burning frequency had no significant effect on the composition of soil seed banks ($P > 0.05$). There was a significant difference on the abundances of individual species across the burning treatments ($P < 0.05$) (Table 4.5). The interaction between treatments and species was not significant ($P > 0.05$) (Table 4.5)

Table 4. 5: Analysis of variance for the effect of treatments, species and their interaction on soil seed bank species abundances ($P \leq 0.05$; $n = 312$).

Source of variation	DF	MS	F- cal	P-value
Treatment	5	0.0909	1.27	0.279 ns
Species	25	1.55998	21.8	0.001**
Treatment * Species	125	0.06228	0.87	0.79 ns

ns= not significant, ** highly significant,

4.4.1 Relative abundance of soil seed bank species across burning treatments.

Only herbaceous species emerged during the course of the germination experiment and no woody component had emerged. Eight grasses and 19 forbs and sedges emerged from the experiment, and there was no mortality encountered during the emerging process. During the germination trial the highest emergence was observed in the triennial, quadrennial, sexennial and the no burn treatments, while the lowest emergence occurred in the annual and biennial burns. *S. fimbriatus* was more

abundant in the quadrennial (86%), sexennial (80%), triennial (78%) and the no burn (76). *Pennisetum purpureum* was more abundant in the annual (31%) and biennial burns (11%). The forb, *Arctotis arctotoides* was more abundant in the annual burn (17%) (Table 4.6).

Only three grass species were recorded more than 8% in burning treatments. *S. fimbriatus* was the only grass species that was recorded 8% in burning and no-burn treatments. *Eragrostis* spp was recorded in biennial burn and *P. stapfianum* was recorded in the annual burn. The forb, *A. arctotoides* was recorded in annual, biennial and the no burn with more than 8% (Table 4.6). Three grass species that increased with increased burning frequencies were *P.purpureum*, *P. stapfianum* and *Eragrostis* spp. Other species were present in all treatments with no consistent trends across burning frequencies (Table 4.6).

Table 4. 6: Relative abundance (%) of soil seed bank species across burning treatments.

Species	Treatments					
	Annual	Biennial	Triennial	Quadrennial	Sexennial	No burn
Relative abundances (%)						
Grasses						
<i>Chloris gayana</i>	3	-	-	-	-	-
<i>Digitharia eriantha</i>	-	2	-	-	-	-
<i>Eragrostis</i> spp	-	2	8	-	2	-
<i>Panicum maximum</i>	-	2	2	1	3	1
<i>Panicum stapfianum</i>	8	3	-	-	1	1
<i>Paspalum notatum</i>	-	-	-	-	-	1
<i>Pennisetum purpureum</i>	16	6	5	1	-	1
<i>Sporobolus fimbriatus</i>	47	58	78	86	80	76
Forbs and Sedges						
<i>Arctotis arctotoides</i>	17	9	2	2	3	9
<i>Conyza c.f albida</i>	3	2	-	-	2	-
<i>Cyphia sylyvatica</i>	-	-	2	-	-	-
<i>Erodium</i> spp	-	-	2	-	2	-
<i>Erythrina caffra</i>	-	-	-	-	1	-
<i>Leucas martinicensis</i>	-	3	-	-	1	-
<i>Malva cf parvifolia</i>	-	-	1	-	-	-
<i>Pseudognaphalium</i> spp	3	-	-	1	2	4
<i>Pseudognaphalium</i> <i>luteo-album</i>	3	-	-	-	-	-
<i>Poa prutensis</i>	-	2	-	-	-	-
<i>Solanum lycopersicum</i>	-	-	-	1	-	-
<i>Solanum mauritianum</i>	-	3	-	3	3	-
<i>Solanum nigrum</i>	-	5	-	2	-	1
<i>Solanum retroflexum</i>	-	-	-	1	-	-
<i>Solanum seafarhianum</i>	-	-	-	-	-	1
<i>Sutera campanulata</i>	-	2	-	1	-	2
<i>Verbesina encelioides</i>	-	2	-	1	-	2
<i>Verbesina tenuisecta</i>	-	-	-	-	-	1
Total	100	100	100	100	100	100

4.4.2 Species diversity indices of soil seed banks across fire treatments.

There were no significant differences in the species diversities of soil seed banks among the burning frequencies ($P > 0.05$). The annual burn and the biennial burn had the highest diversity 1.32 and 1.41 respectively, as compared to other treatments. Post-hoc analyses ($LSD = 1.049$; $\alpha = 0.05$) indicated no significant differences between the means of different treatments (Figure 4.4).

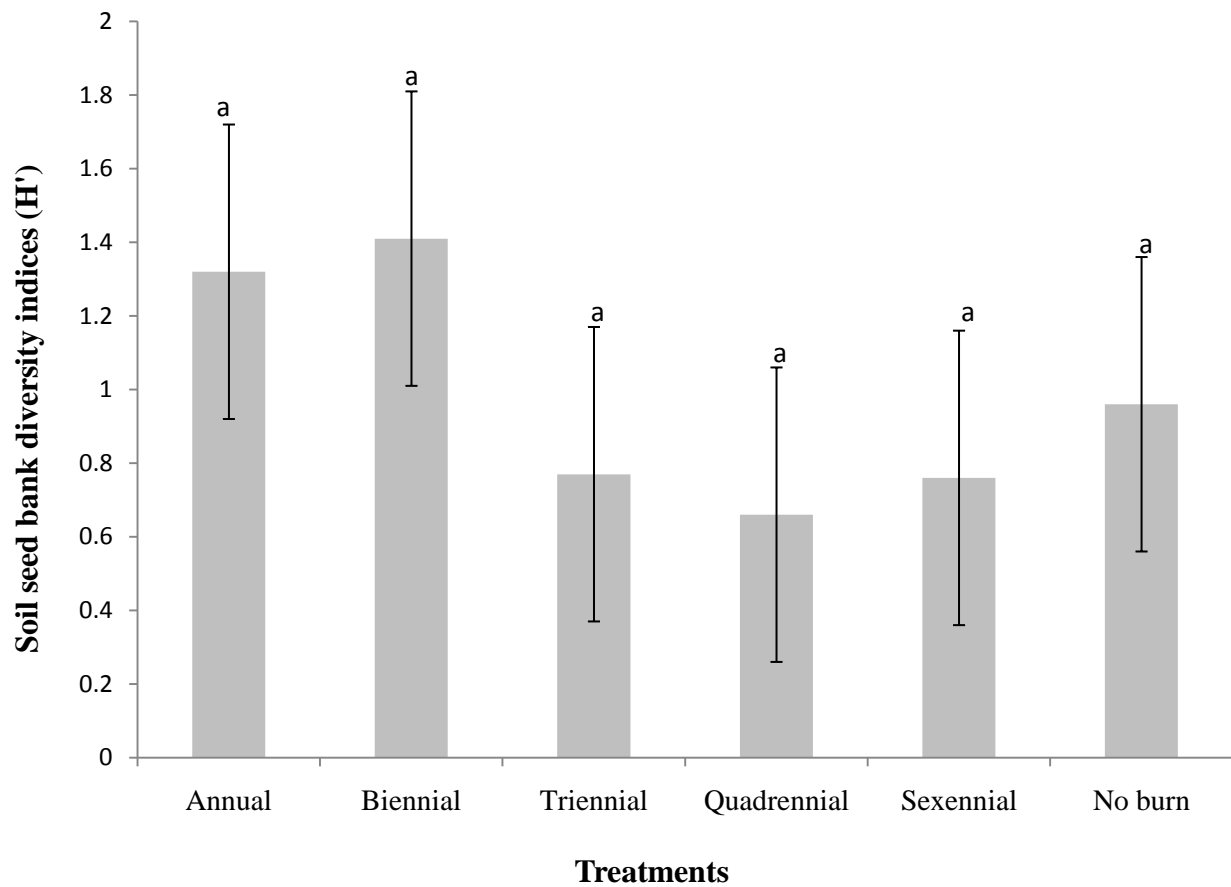


Figure 4. 4: Mean (\pm SE) diversity indices of soil seed banks for different burning treatments, ($LSD = 1.049$, $\alpha = 0.05$). Means with the same letters were not significantly different.

4.5 Correlation between standing vegetation and the soil seed bank diversity

There was no significant correlation between standing vegetation and the soil seed banks $R^2=0.0961$ ($P > 0.05$).

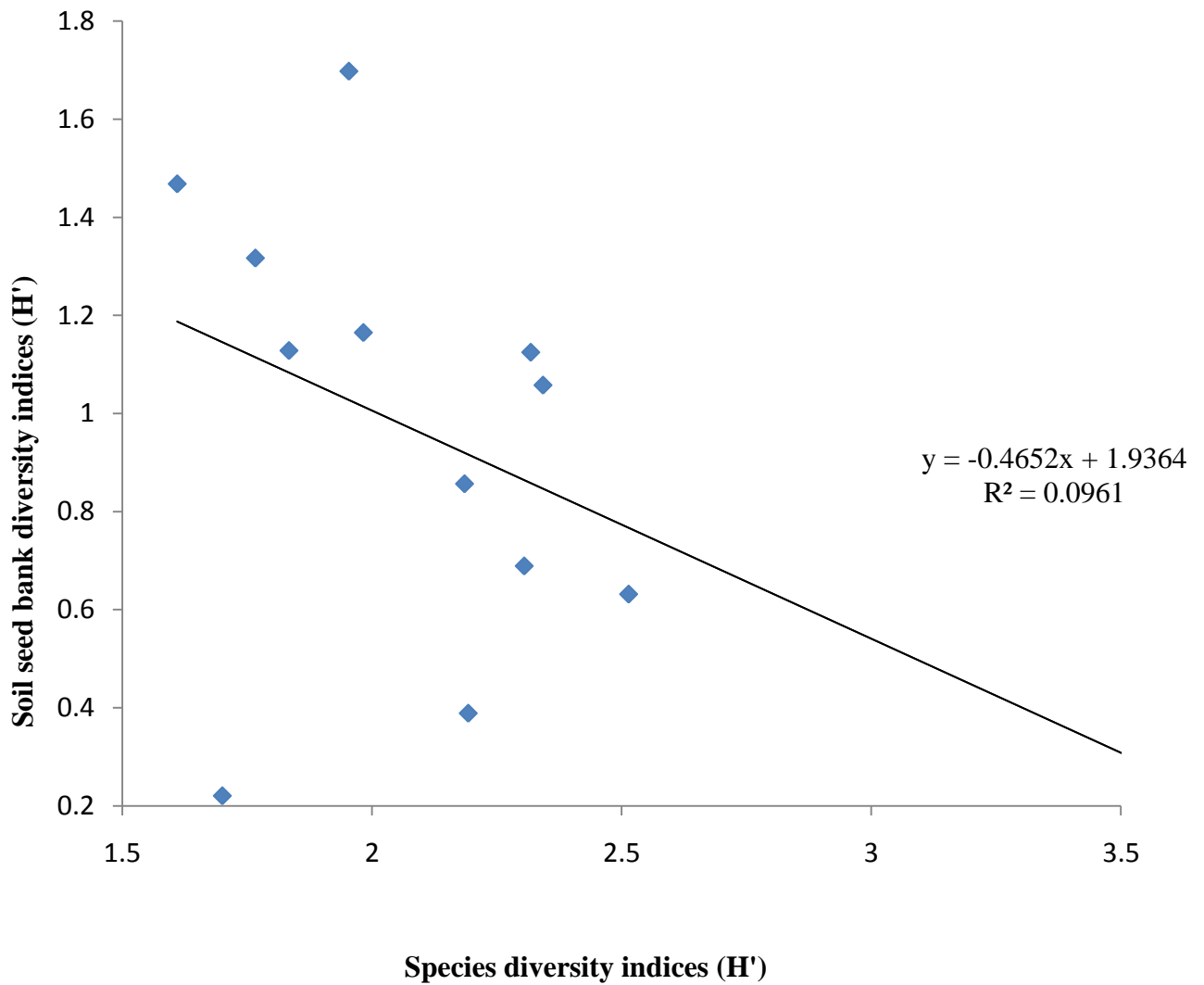


Figure 4. 5: Correlation between diversity indices of standing vegetation and the soil seed bank diversity indices.

4.6 Effects of heat and smoke treatments on seed germination.

Heat and smoke did not significantly affect seed germination ($P > 0.05$). There was a significant difference in the abundances of species between pre-germination treatments ($P < 0.05$), and the interaction was not significant ($P > 0.05$) (Table 4.7).

Table 4. 7: Analysis of variance for the effect of treatments, species type and their interaction on species abundances of seedlings ($P \leq 0.05$; $n = 312$).

Source of variation	DF	MS	F-Cal	P-value
Treatment	3	0.03	0.66	0.579 ns
Species	12	1.457	31.91	0.001***
Treatment & Species	36	0.061	1.35	0.098 ns

ns= not significant, *** = highly significant.

4.6.1 Relative abundance of species for pre-germination treatments

S.fimbriatus was the most abundant species in all the different pre-germination treatments. It recorded (78%) in the control and (83%) in the heat pre-treatments (Table 4.8). The forb *Sutera campanulata* was more abundant in the heat (32%), heat and smoke (20%), and *Solanum nigrum* was more abundant in heat treatment with (10%).

Only one grass species was recorded with 8% abundance, namely *S. fimbriatus* recorded more than 8% abundance in all treatments (Table 4.8). For the forbs, *A. arctotoides* was abundant in the control with more than 8%, *Pseudognaphalium* species recorded in heat and smoke, while *S. campanulata* was recorded in both the smoke and the heat and smoke pre-treatments. In general the heat and smoke, control and smoke treatments had the highest seedling emergence than heat treatments. Four grasses, nine forbs emerged from the experiment. There were no mortalities observed during the experiment.

Table 4. 8: Relative abundance (%) of soil seed banks species from pre-germination treatments.

Species	Treatments			
	Control	Heat	Smoke	Heat & smoke
Relative abundance (%)				
Grasses				
<i>Panicum maximum</i>	2	-	5	-
<i>Paspalum notatum</i>	2	-	-	-
<i>Pennisetum purpureum</i>	-	3	-	-
<i>Sporobolus fimbriatus</i>	79	84	48	56
Forbs and Sedges				
<i>Arctotis arctotoides</i>	9	-	5	-
<i>Cirsium vulgare</i>	-	-	5	-
<i>Erythrina caffra</i>	-	-	-	4
<i>Mariscus congestus</i>	-	-	-	4
<i>Pseudognaphalium spp</i>	4	-	-	8
<i>Solanum lycopersicum</i>	-	-	-	4
<i>Solanum nigrum</i>	-	10	-	-
<i>Sutera campanulata</i>	4	3	32	20
<i>Verbesina encelioides</i>	-	-	5	4
Totals	100	100	100	100

4.6.2 Species diversity indices of pre-treatments.

The highest diversity indices were recorded in the smoke and the combination of heat and smoke treatments, while the control and the heat treatments had the lowest species diversity indices (Figure 4.6).

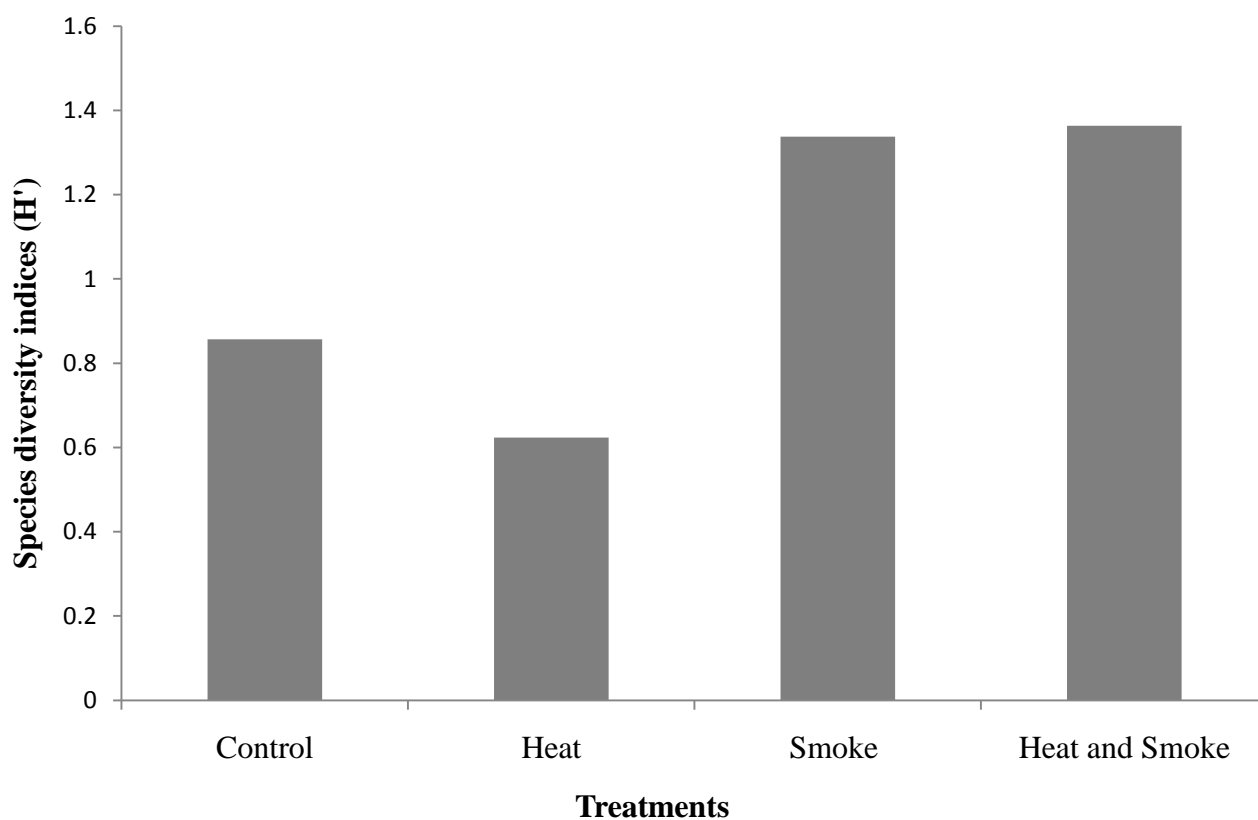


Figure 4. 6: Mean diversity indices (H') for different pre-germination treatments.

CHAPTER 5 DISCUSSION

This chapter will discuss the results obtained and indicate whether the specific key questions were addressed.

The key questions to be addressed in the study were as follows:

1. How does fire frequency affect species abundance in the False Thornveld of the Eastern Cape?
2. How does fire frequency affects species diversity in the False Thornveld of the Eastern Cape?
3. Is there any difference in species diversity and species composition of soil seed banks and above ground vegetation across fire treatments?
4. Does smoke, heat or both enhance seed germination?

5.1 Effect of burning frequency on herbaceous species abundances

The results of this study indicate that burning frequency had a significant impact on herbaceous species abundance (Table 4.1). The impacts of burning frequency on vegetation have also been reported by others (Trollope 1999; Furley et al. 2008). The annual, biennial, triennial burns and the no burn had the most pronounced effects on herbaceous species abundance (Figure 4.1). These results indicate that some of the herbaceous species have developed mechanisms of tolerance or adaptation to fire frequency. Therefore, the most likely influence of burning frequency on species was to increase the abundance of fire tolerant species and decrease that of fire intolerant species. Studies have indicated differences in species tolerances at different fire frequencies, emphasising that some of the species benefit from high frequent fires while others from less frequent fires (Nuzzo et al. 1996; Morgan and Lunt 1999; Trollope 1999; Uys et al. 2004).

The abundance of herbaceous species differed with varying frequencies of burn (Table 4.2). *T. triandra* dominated the frequently burned plots i.e the annual, biennial and triennial burns. The results are consistent with other findings which also reported an increase in the abundance of *T. triandra* in frequently burned areas (Trollope 1999; Morgan and Lunt 1999; Uys et al. 2004). The increase of *T. triandra* in frequently burned areas could be attributed to the constant removal of dead material or tussocks by fire and the elimination of self-shading (Everson et al. 1988; Morgan and Lunt 1999). Exclusion of fire for a long time would likely result in a potential loss of *T. triandra*, probably due to the accumulation of dead material (Morgan and Lunt 1999). The decrease of *T. triandra* was evident in the quadrennial, sexennial burned plots and control plots due to the high accumulation of biomass. The results of the study are in conformity with the findings of other scholars regarding the increase of *T. triandra* in frequently burned areas. The study was conducted almost 29 years since the start of the experiment and the abundance of *T. triandra* is still high in frequently burned plots (Table 4.2).

In this study the sexennial and the no burn plots were dominated by *S. fimbriatus* and *M. decumbens* (Table 4.2). Uys et al. (2004) observed that bunched or tufted grasses consistently increased as fire became more frequent, while sod-forming species consistently decrease with increasing fire frequency. The abundance of *S. fimbriatus* in less frequently and unburned areas was also reported in south and east African savannas by Frost and Robertson (1985). *M. decumbens* was not recorded in frequently burned plots, but its high abundance in the sexennial burn and no burn treatments (Table 4.2) provides evidence that the species is more tolerant to shading and undisturbed conditions than other grass species. Only five grass species recorded more than 10% in abundance across all burning frequency. This indicates that these species contribute more than others to botanical composition and they are also influenced by burning frequencies. There was no consistent trend for grasses such *C. plurinodis*, *D. eriantha*, *P. maximum* and *P. stapfianum* which neither increased nor decreased across

burning treatments. These species appear to be little affected by fire frequency. Lunt and Morgan (1999) report that while frequent burning does not prevent the abundance of some species, it can reduce their cover was reduced.

The interaction between treatments and type of species was highly significant (Table 4.1), indicating that the abundance of some species depends on the level of disturbance. This is supported by the fact that species like *T.triandra* could be maintained by frequent burning while others species like *M. decumbens* and *S. fimbriatus* could be maintained through less frequently burning and no burning treatments. The current results indicate that the abundance of herbaceous species in the False Thornveld of the Eastern Cape falls under three categories: those that are fire tolerant, fire intolerant and those that are inconsistent or little affected with burning frequency.

5.2 Effects of burning frequency on woody species composition.

Fire has been a driving force for savanna vegetation; hence it has been used in the control of bush encroachment (Trollope 1983). The results of the study indicate that different burning treatments significantly affected woody species composition and the abundance of individual species (Table 4.3). *A. karroo* was more abundant in burnt plots than in control plots (Table 4.4). This species is regarded as one of the main encroaching species in the False Thornveld of the Eastern Cape (Trollope 1999). The abundance of *A. karroo* shrubs coppicing growth from resprouters in both frequently and less frequently burnt plots suggests that frequent burning does control the phytomass of the shrub by reducing it to a browsable height for goats, but it does not reduce its density (Scholes and Archer 1997). Most of *A. karroo* in the study was coppice growth from resprouters. Figure 3.1 might give the impression that frequently burnt plots had lower bush density, while in fact it is the bush biomass that has been reduced, and not density. Conversely, frequently burnt plots have a

higher density than less frequently burnt plots. The sexennial and no burn plots have taller, wider trees while those frequently burnt have lower bush biomass but higher density.

The existence of high tree density may be accounted for their ability to coppice from the base after fire (Trollope 1999; Higgins et al. 2000). Most *Acacia* species are reported to be fire tolerant (Burke 2006), the current study confirms the reports of fire tolerance of *Acacia* species. Encroachment by species of *Acacia* has been reported in number of countries (Abule et al. 2007). The study also indicates that *A. karroo* did not have a consistent trend with burning frequency and its control through burning does not necessarily reduce its abundance (Table 4.4). The abundances of *D. lycioides* and *E. rigida* were high in the quadrennial and control treatments (Table 4.4), but these species were also abundant in all burning treatments, indicating that burning frequency did not affect them consistently.

The abundance of woody species was comparatively low across all treatments (Table 4.4). In a study conducted at the Prairie C₄ dominated grassland, Heisler et al. (2003) reported that annual burning could effectively prevent recruitment of native shrub species. The current study showed that no significant differences in the species abundance between frequently and less frequently burned plots, while the no burn had relatively higher species abundance (Figure 4.2). Enslin et al. (2000) found no evidence of compositional changes in woody species with frequency and season of burning, implying that there might be other environmental factors responsible for the observed variations. The current study is in agreement with the findings of Enslin et al. (2000) who reported no significant differences in species abundance across different burning treatments. Moreover, in a study conducted at the Kruger National Park, South Africa by Trollope et al. (1995), it was reported that changes in woody vegetation due to fire frequency did not involve a decrease in diversity or composition, but primarily a change in structural diversity. The low abundance of woody species in frequently burned verses

less frequently burned areas suggests that different burning frequencies do not increase or reduce species recruitment, but species that are able to persist in frequent or less frequent fires are able to maintain their existence.

5.3 The diversity indices of standing vegetation

The results of this study indicate that burning frequency had a significant effect on the diversity of aboveground vegetation, as it was high in the quadrennial, sexennial and the no burn treatments (Figure 4.3). These results indicate that species diversity of the False Thornveld increases with either longer fire intervals or with absence of fire. Similar reports occur from Bond and van Wilgen (1996) with Hobbs and Huenneke (1992) stating that sites with low fire frequency and long fire intervals were more heterogeneous than annually burnt sites, which were found to be more homogenous in appearance. In addition, in a study conducted at Konza Prairie Research Natural Area Collins et al. (1995), it was found that high fire frequency decreased species diversity and limited population growth rate (Garnier and Dajoz 2001). On the contrary, some studies reported high plant species diversities at high fire frequencies (Tester 1989; Nuzzo et al. 1996). Elsewhere in Australia (Morgan 1999) and South Africa (Uys et al. 2004), reports have indicated minor effects of fire frequency on species composition due to the general dominance of fire-tolerant species and the loss of disturbance-intolerant species in the flora.

Post-hoc analysis indicated significant differences between treatment means (Figure 4.3). The highest species diversity was found in the quadrennial, sexennial and the no burn treatments. Spellerberg (1991) stated that when considering species diversity it must be taken into account that some communities naturally have low species diversity. Therefore, the scenario in this study may be that diversity indices decrease with high frequent burning and increases with less frequent burning.

5.4 Effect of burning frequency on soil seed bank

Burning frequencies did not have a significant impact on soil seed bank composition (Table 4.5). These results imply that there are some underlying factors that might have a bigger impact on soil seed banks than fire frequency. In a study conducted at Newholme by Grant and McGregor (2001), the results showed that fire was not likely to stimulate the germination of a large number of seeds. Bond and van Wilgen (1996) also reported that fire frequency might have less of an influence on seed banks of perennial species that rely heavily on annual inputs. Lunt (1990) stated that low seedling recruitment rates are not a consequence of annual burning per se since seedling recruitment is generally a rare event in most years for most perennial species of *T. triandra* dominated grasslands, regardless of the time since the last burn. In addition Snyman (2006a) and Morgan (1998) indicated that for most perennial grasses, especially the larger-seeded species, their seeds do not form a persistent seed bank even in the absence of seed predation due to poor survival. At times predation of *T. triandra* seeds is also reported to be very high (Everson et al. 2009; O'Connor and Pickett 1992). In this study seed predation did not form part of the assessment. The above ground species composition for the annual, biennial and triennial burns was dominated by perennial specie *T. triandra* (Table 4.6) one can say that this species does not have a persistent seed bank.

On the contrary, in studies conducted in South Africa (Everson et al. 2009), Australia (Auld and Denham 2006) and Ivory Cost (Garnier and Dajoz 2001), results have indicated that massive amounts of seeds were consumed by frequent fires, as a result frequent burning reduced the soil seed banks. The annual burn had a detrimental effect on seed production as compared to longer burning intervals, which had higher seed production (Everson et al. 2009). Therefore, at high fire frequency, a lack of time between fires prevents replenishment of seed banks and for canopy seed banks the entire seed bank may be exhausted after a single fire (Auld and Denham 2006).

However, even though frequent fires might consume seeds in the soil, it was not evident from this study. There are several factors that might account for non-significance of burning frequency on soil seed banks. A possible explanation might be the inability of the species to produce high outputs of seeds dispersal, as it has been stated that areas that are dominated by perennial species do not have persistent seed banks, as they are vegetatively propagated (Abrams 1988; Morgan 2001). Moreover, availability of microsites for soil seeds banks may not be suitable for these seeds to remain dormant and persistent in the soil leading to death of these seeds. Moreover, some of the seed banks are buried deep in the soil and may not have been sampled. In addition sample size was too small to accommodate enough variations due to low replication of the burning treatments.

Savannas and grasslands, with the long history of the occurrences of surface fires, have few if any species with fire-stimulated seed germination or seed release (Bond and Parr 2009), but in the Mediterranean area seeds can be stimulated by fire to release their dormancy (Bond and van Wilgen 1996). The scarcity of viable buried seeds for the dominant vegetation may occur because most of vegetation is highly dependent on vegetative propagation (Abrams 1988; Morgan 1999). In general burning frequency did not promote the germination of the seeds that were present in the soils seed bank of the False Thornveld.

5.4.1 Species abundances of soil seed banks

The results illustrate that the abundances of species found in the soil seed banks were significantly different among the treatments, with *S. fimbriatus* (80%) being the most dominant species in the seed pool (Table 4.6). This was probably because of its ability to produce small seeds that persist in the soil seed banks, as the species was also abundant in the standing vegetation. *P. purpureum*, a weedy species which was also dominant in the annually burnt treatment (Table 4.6), might probably have been brought from elsewhere through pollen or wind since it is not considered as part of the natural

vegetation. It may also have an adaptation to high burning frequency. The species is used commonly in cultivated pastures (van Oudtshoorn 2004), and is an important fodder crop in East Africa, particularly in Kenya and is indigenous to the Zambezi Valley of Africa (Farrell et al. 2002). *Arctotis arctotites* was the dominant forb in the soil seed bank, indicating its ability to form a persistent seed bank and it was also abundant in the annually burn plots (Table 4.6). The seed bank had less floristic variation compared to the standing vegetation. However the absence of some of the species occurring in vegetation from the soil seed bank has also been reported in Australia (Morgan 1998, 2001), in the Orange Free State (Snyman 2006a) and in KwaZulu Natal (Everson et al. 2009).

S. fimbriatus, *Eragrostis* spp and *P. stapfianum* recorded more than 8% in relative abundance in the soil seed bank on different burning treatments (Table 4.6) and they were also promoted by the increase in burning frequency. The abundance of other grass species and forbs were inconsistent with the burning frequency. Since their abundance might not be explained by burning frequency, fire frequency does not seem to have a high impact on soil seed bank species abundance (Table 4.6). Williams (2002) suggested that a low and moderate density of soil seed was a contributing factor that limits seedling emergence. Tree seedlings were not recorded in the study probably due to a number of reasons such as scarcity of seeds, short lived seeds, predation of seeds and short duration of the experiment or insufficient scarification (Higgins et al. 2000).

5.4.2 Fire and seed bank diversity

There were no significant treatment effects on the diversity of soil seed banks, indicating that fire frequency alone does not significantly impact soil seed banks. Thus, one could say that there are some underlying factors that are responsible for the diversity indices of soil seed banks. Aboveground vegetation plays an important role in soil seed bank composition and diversity. Most of the perennial species are vegetatively propagated, indicating the limited output of seeds from such

species (Abrams 1988; Morgan 1999). The other factor might be the low input of seed from elsewhere (seed rain) and the limited availability of suitable microsites for the seeds to germinate and successfully establish.

Though treatments did not have a statistically significant effect the trend showed that annual and biennial burns had higher diversity indices as compared to other treatments (Figure 4.4), suggesting that high burning frequencies may increase the diversity of the soil seed bank to some extent, by enhancing the recruitment of some species. In a study conducted in Mason County Illinois Nuzzo et al. (1996), found that at high fire frequency species diversity was high. Morgan (2001) conducted a study in Australia within an experiment of long-burning history from 1 - 4 years, and found that floristic composition and recruitment of seedlings did not appear to be different between treatments. Seedling recruitment is either fire stimulated or not (Snyman 2006b). This may imply that the investment of aboveground vegetation towards seed production could be very low.

5.5 The relationship between vegetation and soil seed bank diversity.

According to this study, no significant correlation exists between the diversity of the soil seed bank and the standing vegetation (Figure 4.5). A number of researchers have found that the floristic composition of the seed bank at a particular time is not the mirror reflection of the aboveground vegetation (Abrams 1988; Leck et al. 1989; Morgan 1998; Falińska 1999; Tekle and Bekele 2000; Solomon et al. 2006). The results of this study support the statement that aboveground vegetation is not a mirror reflection of soil seed banks. The observation might be ascribed to the low seed input from the standing vegetation observed in this study, low seed rain, insufficient microsites and other environmental factors. It has been suggested that soil seed bank floristic composition is both a product of the species composition of the current vegetation and a record of the long term

substitution of species (Falińska 1999). The abundance of perennial grasses gradually decreases as they are known to have low seed production (Abrams 1988; Lyaruu and Backéus 1999; Morgan 2001). Therefore, the soil seed bank depends largely upon the supply from the standing vegetation and seed rain.

5.6 Effects of smoke and heat on soil seed germination

Smoke and heat have been known to induce the germination of many plants communities such as chaparral in Californian (Keely 1991; Keeley and Fotheringham 1998), Fynbos in South African (Brown 1993), and Banksia woodland in Australian (Dixon et al. 1995). By contrast, in this study neither of the treatment methods had a significant effects on seed germination (Table 4.7). Smoke treatment did not induce germination of seeds from the soil seed bank and this could imply that seeds present in the soil are not stimulated by smoke. Similarly, Dayamba et al. (2008, 2010), found that smoke did not significantly affect grass species germination. Also in a study conducted in Mediterranean Matorral of central Chile, Gómez-González et al. (2008) found that smoke-stimulated germination was poorly represented. Only two species were abundant in the smoke treatment (*S. fimbriatus* and a forb *S. campanulata*) (Table 4.8). This might be due to the high abundance of seeds of *S. fimbriatus* and a forb *S. campanulata* present in seed bank.

The fact that heat treatment did not significantly affect seed germination in this study implies that heat produced during the passage of fire does not have a pronounced stimulus as an enhancer for seeds germination in the False Thornveld. Williams et al. (2005) reported that heat shock significantly increased species richness and total density of seedling from the seed bank. However, other studies by Mucunguzi and Oryem-Origa (1996); Dayamba et al (2008) reported no heat effect on the seeds. Dayamba et al. (2008) suggested that seeds would not be able to germinate after a fire

event and colonise the field unless they are situated at ground level where lethal temperatures can be reached, and this is also a possible explanation for the observed results.

The combination of heat and smoke treatment also had no significant effect on seed germination (Table 4.7). Smoke and heat did not interact to influence germination of seeds in the soil, implying that these species seem to have adapted to the independent effect of these fire related cues (Dayamba et al. 2008). The diversity indices indicate that smoke alone and its combination with heat resulted in higher diversity compared to the control and heat treatments (Figure 4.6). This suggests that diversity can be promoted by these fire cues even though they were not tested statistically because of the small sample size.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

The purpose of the study was to investigate the long term effect of burning frequency on vegetation and soil seed banks. The hypothesis that frequent burning increases the abundance of fire tolerant species and decreases the fire intolerant species was supported by the results of the study. Frequent burning resulted in an increase in abundance of *T. triandra*, while *S. fimbriatus* and *M. decumbens* increased with less frequent burning or no burning. Therefore, the use of frequent burning in the False Thornveld of the Eastern Cape as a management tool could possibly result in range degradation as they promote the abundances of fire tolerant species in frequent fires and reduce species that are fire intolerant.

Fire frequency had profound effects on woody species composition and species abundances. The use of fire in semi-arid savanna is to reduce bush density; however it was unclear on how burning frequency affects woody plants density based on this study. However, *A. karroo* density increased with fire frequency. The results show that in the False Thornveld, fire does not reduce bush density, but reduces bush phytomass to a browsable height. With the use of fire as a management tool in the False Thornveld of the Eastern Cape it should be noted that fire increases the abundance of fire tolerant species such as *Acacias* and others savanna species. Fire and goats can control bush encroachment.

The hypothesis that frequent burning reduces species diversity is rejected as supported by the results from the study. The diversity in the False Thornveld can be promoted by applying less frequent burning i.e quadrennial and sexennial burns as well as providing for no burning. In addition management according to robust indicators of biodiversity condition would obviate the need for detailed empirical or theoretical insight (O'Connor et al. 2010). This study has shown that fire does not necessarily have profound effects on soil seed banks. The soil seed banks are important as they

indicate the recovery ability of an area after disturbance, but based on these results, it can be concluded that fire is not the sole cause of low soil seed banks diversity in areas where it is applied. *S. fimbriatus* was the only grass species found in both aboveground and soil seed banks. This supports the notion that vegetation is not a mirror image of the soil seed banks.

The hypotheses that heat and smoke increases germination from the soil seed bank is rejected, they did not have a significant effect on seedling emergence. This might be due to the inability of some species to produce persist seed banks especially species that are promoted through vegetative propagation. Furthermore, the aboveground vegetation might not be well represented in the soil seed banks. Proper management is crucial for species that do not rely on seed banks for their persistence. The hypothesis that there is no difference between the aboveground species diversity and that of viable soil seed bank is therefore rejected. With the evidence from the study it is therefore recommended that the False Thornveld of the Eastern Cape, be burned with less frequent fires as they increase aboveground species diversity.

The study had some limitations. The method used for germination allows only the viable seed in the soil to germinate, and thus some of the seeds might be present but were unable to germinate with this type of method. Therefore seed extraction methods will also assist in seeds estimations. Conducting the experiment for a longer period might allow more seeds to germinate. Seed predation did not also form a part of the assessment. Future studies should incorporate both the use of fire and grazing and their impact on vegetation and soil seed banks as well as level of seedling recruitment among different species, and whether fire provides suitable microsites for seedling establishment in the False Thornveld of the Eastern Cape.

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