THE EFFECTS OF FIRE AND GRAZING MANAGEMENT ON

UNPALATABLE CLIMAX GRASSLANDS DOMINATED BY

HYPARRHENIA HIRTA AND *CYMBOPOGON VALIDUS*

by

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Abstract

Fire alone, and in combination with grazing, influence established individual plants, and their respective regeneration potential variously with consequences on species dynamics. This study gives attention to the effects of fire alone, and in combination with grazing in underutilized, "problem" rangeland communities. Firstly, the question exists whether annual fire in "fire prone" *Hyparrhenia hirta* dominated veld could be one of the factors that promote the persistence of this veld type in the Gauteng Highveld. Secondly, the impacts of fire and heavy grazing on species and associated changes in veld condition characteristics are documented in *Cymbopogon validus* dominated veld in the Eastern Cape.

The grazing value of *Hyparrhenia hirta* dominated rangelands is often managed through frequent burning aimed at encouraging palatable re-growth. Despite this widely adopted practice, research on the effects of fire on *H. hirta* seed production (seed banks) and seed dynamics and therefore its regeneration potential, is lacking in South Africa. This study quantified and compared *H. hirta* soil seed bank density, and seedling emergence in the field in an annually burned site versus a > 2 year fire return interval site. It was hypothesized that *H. hirta* seed bank densities and seedling emergence would be greater in annually burned veld compared to > 2 year fire return interval veld. The seedling emergence method was used to determine seed bank densities of soil samples collected from the two sites. Seedling emergence was quantified and monitored under individual treatments within burn (clipping, soil disturbance, control) and unburned sites (soil disturbance, litter, clipping, and control) over a

single growing season. Results revealed that *H. hirta* seed bank densities were nearly two fold higher in the annually burned site but not significantly so. In the seedling emergence trial, no consistent trend was identified in individual treatments but emergence was generally favored in control plots (associated with standing vegetation), and reduced in clipped plots (associated with a short sward). However, analysis of the pooled data (annually burned site versus > 2 year fire return interval site) revealed a significant increase ($p < 0.0001$) in emergence in the annually burned site. It was concluded that frequent burning of *H. hirta* dominated stands may be one of the factors that facilitates its dominance, through increasing seed additions to the seed bank. This is likely the case where *H. hirta* is underutilized after burning, therefore allowing seed to set and encouraging its availability in the seed bank. Furthermore, underutilization inadvertently results in burning in subsequent years with accumulative effects on the soil seed bank, and subsequent emergence patterns.

In the high rainfall, sourveld grasslands of the Eastern Cape, the eradication of underutilized stands of *Cymbopogon validus* has been directed through burning and intensive grazing on the farm Glen Gregor, outside Bedford. At this study site, species composition of standing vegetation, basal cover, tuft diameter and standing biomass were sampled in top and bottom slopes of five camps representing a gradient of fire and grazing management intensity. Additionally, the composition of the soil seed bank was determined through the seedling emergence method from soil collected from the same sites. Results showed that the success of *C. validus* eradication was not determined by burning alone, as burning without the required post fire grazing maintained a dominance of *C. validus. Cymbopogon validus* decreased along the grazing gradient according to the total number of seasons that a camp was grazed after burning. Heterogenous topography in camps with steep top slopes and gentle bottom slopes meant grazing was concentrated in bottom areas, reflected by significant reductions of *C. validus* compared to top slopes. In contrast, even utilization in camps of uniform topography reduced the prevalence of *C. validus* over the whole camp, reflected by similar frequencies in top and bottom slopes. *Cymbopogon validus* dominated sites were associated with large areas of bare ground between large tufted individuals. In contrast, *C. validus* eradication through fire and intensive grazing went hand in hand with the occupation of large bare spaces by other

species, predominantly *Sporobolus africanus, Cynodon dactylon* and other subclimax species which lead to increases in basal cover. *Cymbopogon validus* was increasingly absent from the seed bank as its frequency was reduced in the sward. The presence of other species in the seed bank, regardless of *C. validus* dominance could indicate a highly functional role of the seed bank in this mesic environment. It is proposed that once established (as *C. validus* is suppressed) it is these individuals that will provide the source of additional seed for subsequent population establishment. Windows of opportunity for establishment are facilitated by cycles of intense grazing that prevent *C. validus* from "growing out" and dominating the canopy. After 17 years, the sward is increasingly composed of a variety of species with favorable grazing characteristics. Prior to targeting *C. validus* with fire and heavy grazing, areas occupied by *C. validus* dominated veld were in a poor condition and offered zero contribution to livestock production. Through burning and intense grazing, management was primarily able to make use of underutilized *C. validus* swards. Veld condition improved as the consequent species replacement that followed now caters for breeding stock, thus increasing livestock production in previously unavailable rangelands.

Both *H. hirta* and *C. validus* are competitive Increaser I species (species increasing in underutilized veld) that dominate in end point or climax grassland states. That these species are prone to underutilization (low quality mature sward) means fire is a common and often necessary tool used to stimulate higher quality forage. However, this study has shown that annual burning of *H. hirta* (without grazing) increases seed banks and therefore maintains a consistent source of seed to maintain its dominance. The value of burning *C. validus* veld is only realized when combined with intense and efficient post fire grazing. A sustained cycle of heavy grazing and rest eliminates this unpalatable climax community and facilitates the development of a sub climax sward with improved veld condition characteristics favoring livestock production. In conclusion, both studies emphasize the importance of post fire grazing to manage and control unpalatable climax swards.

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ACKNOWLEDGEMENTS

DECLARATION

I, Robin Maurice Ford declare that the dissertation, which I hereby submit for the degree MSc (Agric): Pasture Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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INTRODUCTION

1. Background

Research informing best practice for the control and subsequent elimination of unpalatable grass communities through the use of fire and grazing management is limited in South Africa. The poor grazing value of unpalatable communities renders them prone to underutilization, which in turn, favors their persistence, and often leads to increased frequency of fire use, particularly in the absence of effective grazing following burning. Heavy grazing after fire can suppress established individuals; it also limits seed set and additions to the seed bank, thereby limiting re-establishment of the species in question. In contrast, fire influences species variously and can increase seed production in some species, which, in the absence of post fire grazing may lead to increased seed availability and re-establishment of undesirable grazing species.

Generally, both *Hyparrhenia hirta* and *Cymbopogon validus* are undesirable from a livestock production point of view because these species provide palatable forage for only part of the year, or following burning, after which the plant matures and becomes unacceptable to livestock (Rethman and Booysen 1967; Van Oudtshoorn 2002). This occurs over a single season in the absence of grazing or under low grazing intensity (Bond et al. 2003; Archibald et al. 2005) suggesting that areas dominated by these species are effectively unavailable for animal production for extended periods. Additionally, underutilization favors increases in both species. In fact, the large quantity of underutilized, poor quality forage that is often a feature in these communities indicates inefficient utilization, resulting in losses in animal production. This situation also explains the customary practice of frequent veld burning in these communities which is controversial (Tainton 1999). The latter notwithstanding, *H. hirta* and *C. validus* dominated communities are commonly viewed as unproductive landscapes with low conservation priority status due to few co-occurring species (Shackleton 1989; Van Oudtshoorn 2002; Bredenkamp and Brown 2003). It follows that understanding how fire alone, and in

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combination with grazing influences species dynamics in these communities, is critical for designing management tactics that can control and ideally reduce the abundance of these species, and facilitate change to a more productive sward.

The interaction between fire and grazing has been argued to have a greater influence on species composition and species dynamics in mesic rangelands compared to the individual effects of fire and grazing (Fuhlendorf et al. 2009; Allred et al. 2011). Prescribed fire followed by heavy cyclical grazing has been successfully applied to control and eradicate problematic communities (unacceptable) and facilitate the establishment of more desirable species (Edroma 1981; Westoby et al. 1989; Ramirez-Yanez et al. 2007). Key to the success of these tactics is keeping the target species in a "grazeable condition" (short and palatable) through heavy cyclical grazing. This negatively effects root reserves and reduces the vigour of established individuals while limiting re-establishment of the species by preventing seed set and additions to the seed bank (O'Connor 1991; Kemp et al. 1996). Nonetheless, fire alone has been shown to modify species composition by favoring certain species over others. The persistence of some grass populations, i.e. *Themeda triandra* and *Heteropogon contortus* has been shown to be dependent on annual or more frequent burning in the Highland Sourveld (Everson et al. 2009). Some grass species increase under more frequent burning (Campbell et al. 1996; Smith et al. 2012) and part of this association is due to annual fire or fire in general stimulating seed production and improving micro site conditions for germination and establishment.

2. Problem statement

Frequent burning of *Hyparrhenia hirta* is widely adopted to promote the growth of palatable forage in spring (Van Oudtshoorn 2002). However, it has never been explored whether fire stimulates seed production and promotes seedling germination in this species, therefore buffering *H. hirta* populations in the long term. Such information is lacking for *H. hirta*, and could be one of the "unintended consequences" of burning, particularly in the absence of effective post fire grazing. Therefore, this research has relevance for both the efficiency of post fire grazing in grazed environments and protection against unintentional fires in ungrazed areas. Increases in *H. hirta* dominance is a major risk to the conservation of the threatened

Egoli Granite Grassland (Bredenkamp et al. 2006). Despite these concerns, there is relatively little published ecological research on *H. hirta* in South Africa as opposed to New South Wales, Australia, where the plant has also infested large areas (Lodge et al. 1994; Chejara et al. 2008; 2012). This is probably because southern Africa has such a wide diversity of plants species, and because research has often focused on production characteristics of the more palatable species (O'Connor 1991). Furthermore, this species generally occupies land regarded as having low agricultural potential, such as previously cultivated lands and overgrazed rangelands (Tainton 1999), and therefore, there appears little economic reason to utilize or improve its current state. Yet, its abundance in communities is a major threat to livestock production, biodiversity and natural ecosystems worldwide (Mack et al. 2000; Williams and Baruch 2000).

In Chapter 3, compositional changes were documented in *Cymbopogon validus* dominated veld that has undergone varying degrees of fire and grazing management over 17 years on Glen Gregor Farm, Eastern Cape. The results of targeting *C. validus* communities with fire followed by intensive grazing on Glen Gregor Farm are well recognized amongst farmers and researchers in the Eastern Cape region. The burning and grazing program adopted on Glen Gregor formed part of work by Trollope (1989) on burning in the Eastern Cape but to date; compositional and structural changes and associated changes in veld condition characteristics have never been quantified. The principles of burning *C. validus* and the novel approach of using mature oxen to graze the highly unpalatable *C. validus* were also first explored on Glen Gregor Farm. Observations of radical veld improvement on Glen Gregor with fire and oxen have informed further research by Trollope and co-workers, working on other undesirable species such as *Cymbopogon plurinodis* and *Seriphium plumosum*.

3. Aims

The broad aim of this study was to expand the understanding of the effects of burning, and burning in combination with grazing in specific communities under specific conditions. Much of the literature deals with burning and grazing regimes in broadly classified veld types, and principles for managing unpalatable "unimportant" species seem limited despite their importance in some rangelands.

With regard to *Hyparrhenia hirta*, the aim of this study was to compare soil seed bank densities and seedling emergence in the field at two adjacent sites; annually burned versus > 2 year fire return interval. The hypothesis that the annually burned sward would support higher soil seed bank densities and increased seedling emergence was based on clear observational differences between seed bearing culms in the two sites. Numerous seed bearing culms observed in *H. hirta* in the annually burned site were markedly absent or fewer in the > 2 year fire return interval (Chapter 2). While burning can increase seed production in certain species, the absence of defoliation (either by burning or grazing) can lead to reduced plant growth and vigour where reproductive potential is also decreased. In Chapter 3, the focus of the study is on the second aim where *C. validus was* examined in the Eastern Cape and involved documenting compositional differences and associated changes in veld condition characteristics in five camps reflecting a gradient of fire and grazing intensity. Fire and grazing management in the five camps ranged from fire/no grazing to various degrees of fire and intensive grazing.

To summarize, this research will contribute to an increased understanding of the effects of fire on the reproductive biology of *H. hirta*. The results will be applicable to management that considers the effect of burning on regeneration strategies that may or may not promote the persistence of *H. hirta* dominated communities. The principles of fire and grazing in the case of *C. validus* are not new but they do validate important concepts of fire and grazing in counteracting succession. It is proposed that these principles may be applied in similar, unpalatable, single species communities in the more mesic, sour grasslands.

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4. LITERATURE REVIEW

4.1. Concepts of vegetation succession and climax communities

Vegetation communities are continuously changing in response to abiotic and biotic pressures and this process is referred to as succession. Succession describes the series of species replacement occurring between a simple, pioneer based "origin" and a theoretical, stable "climax". Climax implies a "peak" and suggests a final stage in community development occupied by designated climax species. The preceding communities are also defined by particular suites of species that reflect the general state of the grassland, i.e. its ecological (successional) status relative to the climax (or benchmark). Not by coincidence, the ecological or successional status of the community is based on species specific responses to defoliation, or the increaser-decreaser concept forwarded by Foran et al. (1978).

In short, this concept emphasizes the role of grazing and fire in counteracting the natural tendency for vegetation to develop toward climax. Knowing the climax community of a given area allows assumptions to be made on the historical disturbance regimes (climate, fire and grazing), based on the presence of indicator species whose response to fire and grazing is standardized. The generality is that increased grazing leads to the replacement of grazing sensitive, generally climax species with grazing tolerant, sub climax and pioneer species in the same way that reduced grazing (or fire) induces the opposite effect (Dyksterhuis 1958; Archer and Smeins 1991; Belsky 1992).

The problem with this concept is that it assumes the climax community to be the most stable and productive and therefore the most desirable. Similarly, categorization of species into defoliation responses presumes that all species are equally predisposed to grazing which is not true (Tainton 1999). While a number of climax species offer good forage (eg. *Themeda triandra*, *Panicum maximum*) and the loss of these species through heavy grazing can result in a theoretically poorer sward (due to the loss of climax species), climax species such as *C. validus* are unpalatable and are not desirable for livestock grazing. In such cases, the sub climax or pioneer state can be more productive in terms of forage value to the grazier (Tainton 1999). In the next section on Models of Vegetation Change, contemporary understanding of vegetation

changes (succession) is discussed where the perceived linear relationship between fire and grazing and succession does not always occur. Instead, greater recognition of abiotic factors and/ or in combination with fire and grazing are suggested to explain vegetation change.

It follows that in the absence of grazing and/or fire, the progressive development of vegetation is limited by climate (particularly moisture and temperature), i.e. climatic climax (Krebs et al. 1994), or soil fertility, and characteristics such as topography, aspect and slope, referred to as edaphic climax (O'Connor and Bredenkamp 1997). In southern African, rangelands are broadly distinguished on the basis of the major factor that limits succession; or the factor that prevents vegetation development beyond the "known" or expected climax. The climatic climax grassland (Tainton 1994) covering the arid, western parts of the country, referred to as Climate Dependent Ecosystems (CDE's) are restrained by precipitation (see Table 1.). The wet fire climax grasslands in the east, also known as Fire Dependant Ecosystems (FDE's) are maintained by fire (Bond et al. 2003). This distinction largely mirrors previous separation of southern African grasslands into sweet and sour veld respectively (Ellery et al. 1995). Both *H. hirta* and *C. validus* form important components of grasslands in the sourveld region (Fire Climax Grasslands) which illustrates their close association with fire.

Table 1. Primary determinants of Fire Climax and Climatic Climax Grasslands and the distinction between dominant characteristics of sour and sweet veld (compiled from Ellery et al. 1995; Tainton 1999; Bond et al. 2003).

Fire Climax Grasslands	Climatic Climax Grasslands
- >650mm (mesic grasslands)	- <650mm (semi-arid and arid grasslands)
- Succession limited by fire	- Succession limited by rainfall
- Prone to bush encroachment (no fire and grazing)	- Less prone (bush encroachment does occur, combination grazing, climate)
Sourveld	Sweet veld
- High rainfall, fire maintains grasslands	- Low rainfall generally precludes fire
- Leached soils	- Mineralized soils
- Loses palatability over growing season (sour)	- Maintains palatability (sweet)

4.1.1. Models of vegetation change

The inability of vegetation to return to previous states after the removal of the major disturbance factors has challenged the traditional view of a definitive return of vegetation to previous states (composition and structure), i.e. the Range Model (Dyksterhuis 1958). Contemporary models such as the State and Transition Model (Westoby et al. 1989) acknowledge reversible changes (Figure 1.) but only up to a point. That is, changes in the dominance of grassland species (annual versus perennial, pioneer:sub-climax:climax) can occur provided the unique set of ecological processes which support the grass layer are not altered beyond the point of natural restoration (internal regulation). Theoretically, continuous heavy grazing of climax communities can limit seed production and exhaust seed banks with irreversible consequences for natural regeneration potential. Furthermore, concomitant soil erosion, loss of vegetation cover and compaction can contribute to highly unfavorable conditions for recovery to previous states.
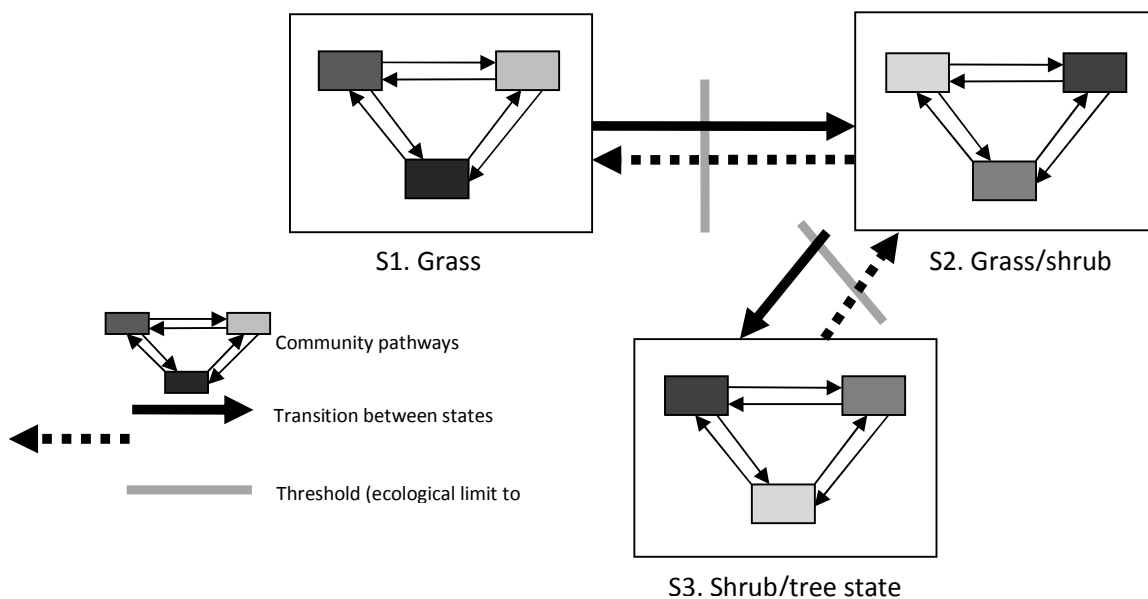
Figure 1. Multiple steady states (S1-S3) where communities can remain in equilibrium with their environment. Changes within states (S1-3) are usually reversible through management regimes (fire and grazing). Breaching of thresholds between S1 and S2, and between S2 and S3 are not reversible except with mechanical/ chemical interventions (Stringham et al. 2001).

In effect, disruption of processes beyond a critical point (grassland threshold) sets off a cascade of site modifications in which grasslands "lose" character entirely and switch to alternative growth forms representing a transition between states, which is irreversible (Westoby et al. 1989). The unique ecological processes which supported the maintenance of grasslands are breached to favor establishment of alternative states (i.e. shrubs, sub climax and/ or pioneer grass species) at the expense of grasses. Importantly, the process can be a gradual, or sudden and dramatic (Stringham et al. 2001) implying that different combinations of causative factors (fire, grazing, climate) can take place over different time scales.

The significance of models of vegetation change is that they serve as a guide for interpreting and predicting vegetation response to management and environment (Briske et al. 2003). To be of practical value for a specific site, the model "requires an understanding of the multiple ecological mechanisms underlying transitions" (Bestelmeyer et al. 2003). Therefore, models that do not fully identify the range of factors acting on the system, and how they interact (i.e. how the system works) to influence vegetation change, might result in ill-informed management decisions and unpredictable consequences (Mentis et al. 1989). For example, a manager subscribing to the Range Model in climatically variable environments, limits his predictive capacity, management options, and therefore control, by assuming continuous and reversible vegetation dynamics in response to grazing pressure alone (Mentis et al. 1989). Without a good understanding of thresholds or possible indicators of impending transitions the manager is vulnerable to a misguided grazing or burning schedule that might be compounded by drought or other climatic changes.

Considering the above theoretical discussion regarding transitions, for southern African rangelands, O'Connor (1985) contends that over the long term vegetation does in fact return to pre-disturbance states, but that this is more controlled by broad scale climatic factors rather than through the manipulation of fire and/or grazing. In his synthesis of experimental work, fire and grazing have resulted in species losses but long term experiments suggests that these losses are not permanent. Tainton (1972) offers the only example where heavily overgrazed rangelands do not return to original states. In conclusion, fire and grazing are secondary factors

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working within the bounds of climate, particularly rainfall and soils.

4.2. Fire and Grazing Interactions in Grasslands

Fire and grazing interact closely with climate in humid, seasonal environments (Archibald et al. 2005; Teague et al. 2008; Fuhlendorf et al. 2009), such as the sourveld regions of South Africa (Tainton 1999). Typically, high and relatively reliable annual rainfall leads to fast growth (Tainton 1999) and an extended growing season (Teague et al. 2008). This results in higher and consistent grass yields (Kirkman and Carvalho 2003), compared to the drier (sweetveld) regions (Tainton 1999). Although seemingly favorable, these characteristics present a significant management challenge to the sourveld grazier in terms of utilization efficiency with important implications for fire and burning management.

Forage quality in sour veld drops from a high value early in the season (grasses are short and vegetative) to a low quality toward the end of the season and into winter (Figure 2.) (Trollope 1989; Tainton 1999; Teague et al. 2008).
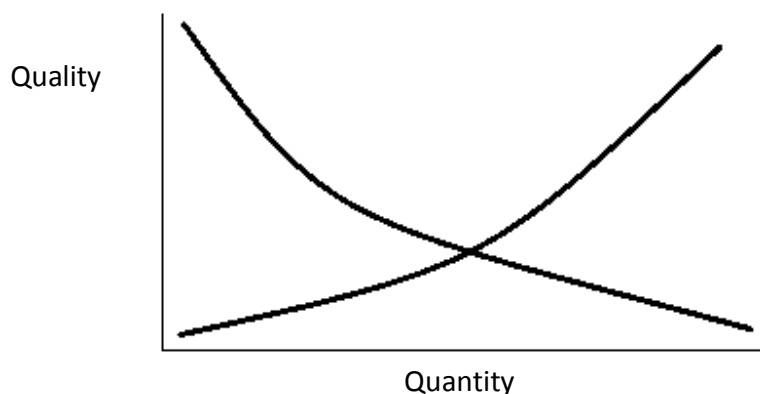
Figure 2. Inverse relationship between forage quality and quantity over the growing season (Tainton 1999).

This process is hastened when early season growth is left ungrazed, or undergrazed and grasses are allowed to mature. Under these conditions, the non-growing season (winter) is characterized by an accumulation of "fire-favorable" dried and unpalatable material (Figure 3.1.

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- 2) (Trollope 1989; Tainton 1999). The less veld is utilized, the more grass is allowed to accumulate during the season and successive seasons (value decreases over the season and between seasons), and a shorter time interval between fires will occur (Figure 3.1. - 2) (Trollope 1989). This will lead to increased fire frequency.
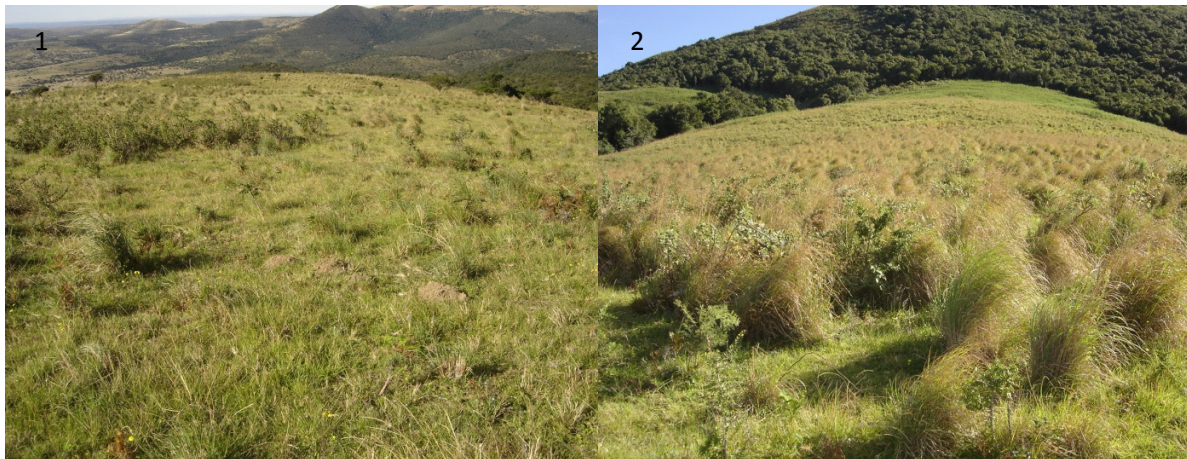
Figure 3. 1. A heavily grazed fire "unfavorable" sward at the bottom slope where grazing is concentrated. 2. Accumulation of a fire "favorable" sward on steep top slopes where grazing is light. Photos taken at Glen Gregor December 2013.

Conversely, efficient utilization during the growing season creates a "fire-unfavorable" sward due to the absence of burnable material (Figure 3.1.-2) (Trollope 1989; Taylor 2006). This is because the likelihood of fire is primarily precluded by the accumulation of a combustible fuel load (Trollope 2008) which is dependent on rainfall and grazing intensity, amongst other factors, influencing site productivity (Trollope 1989; Grace et al. 2000; Leonard et al. 2010). Since these factors vary from year to year, fire intensity and frequency are seldom regular.

However, rainfall is the primary driver of grassland production and therefore determines broad scale fire probability. High rainfall is concentrated in the eastern parts of the country and corresponds to high production characteristics of sourveld. In contrast, low rainfall corresponds to low production characteristics of sweet veld in the central and western parts (Dent et al. 1987) (Figure 4). Therefore, it is the high rainfall sourveld areas which experience the highest frequency of fire. In the National Veldfire Risk Assessment report, Forsyth et al. (2010) showed

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that Sour Grassland areas supported the highest incidence of fire over the period 2001 – 2008. As discussed, this is due to a favorable climate for grass growth interacting with the degree of grazing intensity, which is influenced by grass maturation.
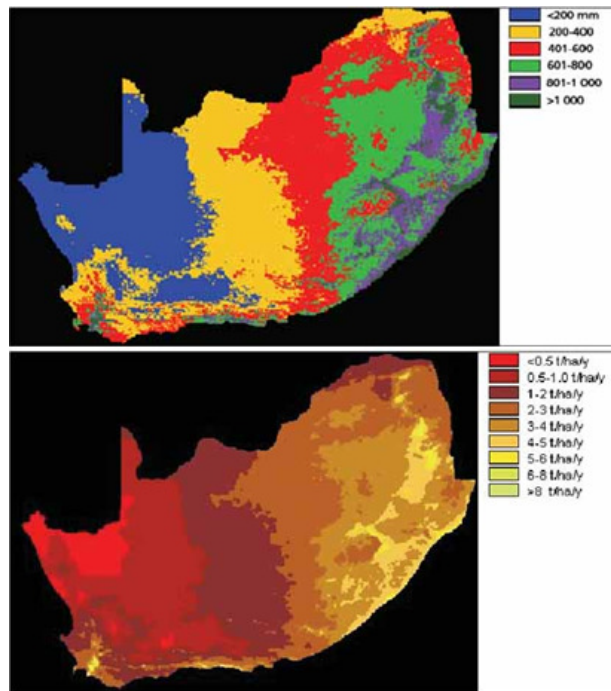
Figure 4. Mean annual rainfall for South Africa (mm/year) and veld production characteristics (ton/ ha/ year) (from Dent et al. 1987).

"The grass is getting away"

The phrase "The grass is getting away and the grass has grown out" describes one of the primary challenges experienced by livestock farmers not only in sour veld but also in dealing with unpalatable communities. As suggested earlier, it is forage quality (not quantity) that limits animal production in sourveld (Hardy and Tainton 1995), and maintaining quality means keeping the sward short and vegetative. This is particularly important for inherently unpalatable species, such as *C. validus* and mature *H. hirta.* Underutilized grass "grows out" and the opportunity for sustained heavy grazing and subsequent control of these species is forfeit. Furthermore, the particular area and the forage that is potentially available for animal production is effectively lost for the remainder of the season. Seen in this light, underutilization

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can be just as bad for animal production as overutilization (Savory and Butterfield 1998) and both reduce carrying capacity (Mentis et al. 1989).

"Keeping ahead of the grass" is emphasized to keep grasses short and in a more palatable condition for livestock. Since changes in quality are predictable (Danckwerts et al. 1993), this concept is mostly achieved through increased grazing pressure and rotational grazing systems where cattle are reintroduced into a previously grazed camp before grass has matured (Teague et al. 2008). Fast growth and reduced forage quality means that this situation is common and is the principal reason for the need for periodic burning in sourveld and mesic grasslands in general (Trollope 1989; Teague et al. 2008; Forsyth et al. 2010).

Regardless, successfully "keeping ahead of the grass" implies efficient utilization over the whole grazing area and this depends on carefully matching livestock numbers to available forage, and knowing when to move them and how long to rest. The following study clearly illustrates the practical value of "keeping ahead of the grass", or keeping the grass "down" in terms of utilization efficiency. Morris (2002) tested utilization during the season after burning under three levels of grazing pressure (high, medium, and low) at a constant stocking density of 4.85 LU/ha^{-1} in the Southern Tall Grassveld (Acocks 1988). The high grazing pressure treatment was grazed early, 29 days after the burn. The medium grazing pressure treatment was grazed to the recommended sward height of 10 – 15cm (44 days after the burn). Low grazing pressure was achieved 80 days after the burn, because most grass had accumulated relative to the standard number of animals. Two important spatial concepts of standing crop were revealed that directly relate to management and utilization. Firstly, before cattle were introduced, the early – high pressure treatment was most palatable and uniform in height, in contrast to the late grazing - low pressure treatment, where the sward had matured and height was most uneven. As a consequence of forage equality (and high grazing pressure), the early grazed treatment was most efficiently and uniformly utilized. This significantly improved utilization in subsequent grazing periods as compared to medium and late grazing treatments where utilization decreased relative to the developing patchiness of the sward. Barnes et al. (2008) also showed that utilization is improved under increased grazing pressure, especially when swards were

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regrazed prior to sward maturation.

4.3. The objectives of prescribed burning

Prescribed fire is probably the most important management tool in mesic grasslands for two related reasons. Firstly, burning allows livestock to graze areas and species that would otherwise be avoided due to underutilization and/or inherent anti-herbivory traits. Underutilized and moribund material is replaced by palatable re-growth (Edroma 1981; Barnes et al. 1984, Trollope 1989, Ramirez-Yanez et al. 2007), of increased preference and value to livestock (Duvall and Whitaker 1964; Barnes and Dempsey 1992). Studies have shown re-growth to contain higher crude protein, nutrients and digestibility values (Tainton et al. 1977; Snyman 2004b), relating to superior livestock performance on burned veld compared to unburned veld (Zacharias 1994).

In contrast, fire exclusion combined with inefficient and underutilization leads to tall, lignified tufts of unpalatable material which are avoided by livestock (O'Connor 1992; Teague et al. 2008). Excess accumulation of unutilized matter also reduces vigor and suppresses new growth, particularly in the more desirable species (Everson et al. 1988; O'Connor and Bredenkamp 1997). In contrast, certain undesirable species are favored to increase with underutilization and veld in this condition (due to the exclusion of fire which precludes grazing) is not only unpalatable but it is also especially prone to encroachment by shrub and tree species (Titshall et al. 2000).

Appropriate burning contributes to controlling the natural tendency for woody species establishment. In fact, Bond et al. (2003) emphasized the role of fire in determining vegetation patterns by demonstrating that fire prone areas supporting grassland and savanna (mesic grasslands) had the "climatic attributes suited or otherwise favorable" to the development of a closed canopy. In effect, the transition to shrub and tree dominated states was prevented by fire, resulting in the present day Fire Climax Grasslands. Lastly, the influence of fire on characteristics of grass re-growth seems to determine the primacy for herbivore selection of burned grass over unburned grass. This simple interaction has clearly had major impacts on the distribution of vegetation communities.

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4.3.1 Fire/grazing interaction

Allred et al. (2011) suggest that the interaction between fire and grazing is ecologically more significant than the independent effects of fire and grazing, and that the combination should be viewed as a single disturbance responsible for markedly different effects on vegetation compared to fire and/or grazing alone. Similar sentiments are shared by southern African range scientists working in sourveld and mesic environments (Tainton and Mentis 1984; Trollope 1989; Morris et al. 1992). Nevertheless, understanding the independent effects of fire and grazing on particular species should hint toward species vulnerability (or proliferation), and will aid in deciding the optimal combination of these two factors to achieve management objectives.

4.3.2. The application of fire/ grazing interaction in undesirable grassland communities

Both prescribed fire and very heavy grazing have been used to improve rangeland dominated by undesirable species in certain cases (Heady and Child 1994; Tainton and Camp 1999; Launchbaugh et al. 2006). Naturally, these strategies adopt an opposite approach to the majority of principles aimed at favoring or maintaining desirable plant populations (Ramirez-Yanez et al. 2007). These strategies generally include conservative stocking rates/densities relating to lenient to moderate use, adequate rest to restore plant vigor, root reserves and to allow seed set (Tainton 1999).

In contrast, prescribed fire and cyclical heavy grazing are managed to suppress the competitive influence of dominant species by depleting root and carbohydrate reserves, negatively affecting vigour and effectively overgrazing the target plant. Another noteworthy side effect of heavy cyclical grazing is that it prevents seed set, thereby limiting the addition of seeds to the seed bank (Kemp et al. 1996) which reduces the chances of re-establishment in the long term. The term Targeted Grazing (Launchbaugh et al. 2006) has recently been coined to describe intensive management based on the above principles.

Prescribed burning, followed by intensive grazing, successfully reduced invasive Guinea grass (*Panicum maximum*) in the Rio Grande Sand Plains, Texas, USA (Ramirez-Yanez et al. 2007). Native species richness increased from 1 to 4.3 species/m² (330% increase) in plots where Guinea grass invaded areas were exposed to a combination of burning and intensive grazing. In this study, cattle grazed Guinea grass plots in cyclic graze and rest periods when forage reached 30 cm. In tropical Rwenzori National Park, Uganda, Edroma (1981) showed that *Imperata cylindrica* dominated stands can be controlled and reduced by burning, followed by intensive grazing. Without burning, old growth of unpalatable *I. cylindrica* develops a thick litter layer that inhibits the establishment and co-existence of other species. Burning removes this barrier and herbivores focus on the palatable re-growth of established plants.

Locally, heavy utilization of *Pospiclillii plurinodis* dominated veld after burning was successful in reducing its abundance in the False Thornveld of the Eastern Cape (Trollope 1989). In northern Nevada, USA, Diamond et al. (2012) reduced seed rain and seed bank density of *Bromus tectorum* (Downy Brome) with two consecutive seasons of heavy grazing just before seed maturation, followed by burning. This combination proved to be more effective than the grazing only or fire only treatments.

The above studies support the notion of fire and grazing as a single disturbance producing unique effects as described by Allred et al. (2011). It is unlikely that fire alone could produce these significant effects. On the contrary, it is possible that these species could be "grazed out" by livestock; however forcing livestock onto mature stands of low quality grass would present a different challenge in itself. Fire "makes" species available and vulnerable to the cumulative negative effects of heavy grazing. This statement by no means plays down the distinct effects and relevance of fire in grasslands, which are described in the following section to aid in placing the "burning" issue into context.

4.4. Fire and species

Like grazing, plant responses to fire varies between species (Trollope 1989; McPherson et al. 1995) to the extent that species favored by fire (fire tolerant) increase at the expense of fire intolerant species (Everson and Tainton 1984, Furley et al. 2008). For example, Everson and Tainton (1984) report decreases in *Tristachya leucothrix*, *Alloteropsis semialata* and *Harpochloa falx* while *T. triandra* and *Heteropogon contortus* increased in Highland Sourveld under more regular burns (2 year cycle). The maintenance of *T. triandra* populations under more frequent burns is widely recognized. In a long term burning study conducted in Kruger National Park, *Heteropogon contortus* was found to increase in frequently (annually) burned sourveld areas as opposed to fire exclusion areas where it decreased (Smith et al. 2012). Studies in Hawaii and in Australia also revealed increases in *Heteropogon contortus* under annual burning compared to less frequent burns (Shaw 1957; Orr et al. 1991; Daehler and Goergen 2005). The above studies reveal the reliance of *T. triandra* and *Heteropogon contortus* on regular burning; but subsequent studies based on these findings have gone further; seeking to establish the mechanisms through which fire favors these species.

These studies focussed on the effect of fire on the reproductive dynamics; including seed production, seed banks, and seedling germination of *T. triandra* and *Heteropogon contortus* to explain the observed increases in response to frequent fire. The next section and the corresponding chapter on the effects of fire on seed banks and seedling emergence in *H. hirta* dominated veld follows this line of thinking.

4.5. The role of seed banks in Grassland dynamics

4.5.1. The maintenance of plant populations: Seed availability, micro sites and recruitment from the soil seed bank

Seed banks are directly implicated in the maintenance of plant populations. Vegetation communities are continuously exposed to perturbations or disturbances of different intensities and frequencies that can cause small to large scale mortality. Plant re-establishment will depend on the presence of seed produced prior to disturbances which is present in the soil seed bank (Grubb 1977; Olff and Ritchie 1998). At the local scale, plant recruitment, or the replacement of individuals of the same species (or different species) following a disturbance is primarily dependent on seed abundance and micro site availability (Kinucan and Smeins 1992; Edwards and Crawley 1999). This suggests that the likelihood of recruitment is low when seed is scarce, whereas increasing seed availability favors increased likelihood of germination and establishment (recruitment) when conditions are favorable (Eriksson and Ehrlen 1992).

Therefore, determining the quantity of seed available in the seed banks gives valuable insight to both the vulnerability of a species to local extinction (absence of a species in the seed bank) (O'Connor and Pickett 1992), as well as the likelihood of species maintenance and/or invasion (increasing dominance of a species in the seed bank) (DiTomaso 2009). In a similar way, the composition of the soil seed bank becomes a crucial indicator of possible successional trends (Snyman 2004a) and for the long term survival and resilience of plant populations (O'Connor 1991; Dreber et al. 2011). Both grazing and fire can influence the amount of seed that sets and the conditions under which seed can emerge (micro-site modification), therefore influencing seed availability, seed banks and recruitment, with possible implications for species dynamics and successional trends, and ultimately management and achievement of objectives (Kinucan and Smeins 1992). Before discussing how grazing and fire can influence seed availability and micro-site suitability, it is necessary to elaborate on the characteristics of grass species seed banks and the implications of this concept in range management studies.

4.5.2. Soil seed banks in perennial grass species

Seed banks are formed when established plants release seed that incorporates into the soil. Here, seeds are exposed to an array of biotic (predators, herbivory) and abiotic (wind, fire, soil) factors (Schupp and Fuentes 1995). The characteristics of a species such as the amount of seed produced, seed longevity, seed morphology (size, shape, appendages) and dormancy mechanisms interact with the surrounding environment to determine seed bank persistence and abundance (O'Connor and Picket 1992; Bekker et al. 1997; Snyman 2010). As a result, seed bank sizes vary in time and space, and are either short lived or long term species dependent, forming transient (1-2 years) or permanent seed banks (> 5 years), respectively.

In perennial grass species annual seed output is generally low while seed lifespan is also limited. Recruitment from the seed bank is therefore highly reliant on seed additions from seed production of the current and previous seasons' seed output, i.e. perennial species form transient seed banks (O'Connor and Picket 1992; Edwards and Crawley 1999; Zimmerman et al. 2008). Seed production and therefore maintenance of a soil seed bank in perennial grass species may collapse when established plants are exposed to processes which limit or prevent seed production and seed set in the short term (O'Connor and Picket 1992; Holmes and Cowling 1997; O'Connor 1997). By the same token, seed production may also increase, leading to increased seed availability in the seed bank.

4.5.2.1. Does grazing decrease seed availability?

Additions to the seed bank can be reduced by the prevention of seed set through management strategies such as heavy grazing (Crawley 1983; O'Connor and Picket 1992; Kemp et al. 1996; Snyman 2010), as well as mowing and herbicide treatments (Chejara et al. 2012). Snyman (2010) and Chejara et al. (2012) showed that seed banks of certain perennial species can be completely eliminated by preventing seed set for two consecutive years. The study by Chejara et al. (2012) was conducted on invasive populations of *H. hirta* in New South Wales, Australia. Subsequent seedling emergence was completely arrested after two years in both these studies. In further support, Orr (2004) revealed that stocking rate (high versus low) had a significant

effect on seed production and seed bank densities in *Heteropogon contortus* dominated grassland in southern Queensland. Strategic burning at or before seed maturation on the plant has also been demonstrated to reduce seed bank densities (DiTomaso 2009).

4.5.2.1. Does fire increase seed availability?

Research in southern Africa has seemingly ignored the effects of fire on grass seed production despite the frequent burning of many grassland communities. Research on this topic appears to be largely restricted to north and south America where fire either decrease or increase seed production (Majerus and Bridger 1988).

Direct mechanisms through which this phenomenon occurs are limited in the literature; however it is suggested that increased resource availability brought about by the removal of competing vegetation (Heady and Child 1994), and adaptation of tall bunch grasses to fire through a close evolutionary relationship (Uys et al. 2004) play a role where increases are observed. Above average rainfall events following burning also increase seed production significantly, compared to drier years where seed production is limited (O'Connor 1991).

Nevertheless, studies have generally shown that the effects of burning on seed production are species dependant (Knapp et al. 2009) with stimulatory responses associated more with tropical and subtropical species (Daubenmire 1968). This is illustrated where fire increased seed production compared to fire exclusion plots in *Hyparrhenia diplandra* (Garnier and Dajoz 2001), *Andropogon gerardii* (Logan et al. 2009), *Trachypogon plumosus* (Baruch and Bilbao 1999), *T. filifolius* (Parron and Du Vall 1997) and *Themeda triandra* and *Cymbopogon validus* (Harrington and Thornton 1969). Orr (2004) also found increased seed production and higher seed bank densities of *Heteropogon contortus* in annually burned southern Queensland grasslands. Other studies have demonstrated decreased seed production following annual burning in *Themeda triandra* (Everson et al. 2009).

Similarly, studies have documented that flowering and seed production are highest in the year after the burn, and that seed production generally decreases with time after fire. This has been demonstrated for *Hyparrhenia hirta, Merxmuellera disticha and T. triandra* (Ligavha-

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Mbelengwa and Bhat 2013) where flowering in all species was highest 9 months after burning, and decreased linearly 21 months after burning. Other researchers have demonstrated similar findings for *Schizachyrium rhizomatum* (Main and Barry 2002), *Agropyron spleatum* and *Stipa columbiana* (Patton et al. 1988) and *Andropogon semiberbis* (Silva et al. 1990). This contrasts findings on *T. triandra* in the Drakensberg Montane grasslands by Everson et al. (2009) who showed seed production to increase with increasing time after burning.

In summary, seed bank densities may therefore vary as a function of species specific seed production responses to frequent fire or fire exclusion. Consequent increases or decreases in soil seed bank densities have important implications for regeneration potential of a particular species, with consequences on species dynamics.

4.6. Effects of fire and grazing on micro-sites and recruitment

Regardless of seed availability and/or the presence of a seed bank, seed will not establish unless favorable conditions for germination are present. Although broad scale climatic factors (rainfall and temperature) are most important for recruitment events (O'Connor 1985; Bond et al. 2003; Orr 2004), small scale environmental alterations within the sward can be influenced by fire and grazing to favor or inhibit recruitment (Olff and Ritchie 1998; Zimmerman et al. 2008). There is, however, a paucity of evidence on ways in which management can encourage seedling recruitment within an existing sward (Thapa et al. 2011), particularly in the southern African context (Adams 1996). Based on this literature review there is even less information available on the suppression of seedling recruitment of less desirable species. This gap is probably because grassland research has often focused on the biomass produced by palatable species with little emphasis on life history characteristics (O'Connor and Pickett 1992), particularly for less palatable species. A further challenge is that recruitment depends on a range of environmental factors (light, moisture and temperature) being simultaneously favorable for germination and recruitment and these factors are often difficult to isolate and replicate under field conditions (O'Connor 1996).

Therefore, depending on whether the sward is grazed or not and likewise if it is burned or not burned therein opportunities for recruitment will differ. This is primarily due to changes in structural characteristics created by disturbances that modify competitive hierarchies (light, nutrient, moisture and temperature regimes) within the sward and at the soil surface. For example, seedling recruitment is often limited within dense, undisturbed vegetation (Grubb 1977; Bakker et al. 1996; Bartha et al. 2003). Here, old, underutilized material form a restrictive litter layer and standing, mature plants overshadow and outcompete establishing species for all major resources (Moloney 1990; Olff and Ritchie 1998). Thus, by removing the impeding canopy or litter layer, by way of grazing and/or fire, conditions for recruitment are modified through an array of environmental changes that influence germination and subsequent recruitment.

Research conducted in the Southern Tall Grassveld showed that recruitment was significantly favored when standing mature vegetation was removed, either by clipping or soil disturbance (Adams 1996). Similar results were found in swards kept short through clipping in the Pampa region of Brazil (Focht and Medeiros 2012), where recruitment was favored while it was limited in taller swards. In a nine year grazing trial in Germany, Wrage et al. (2012) showed that intensively grazed paddocks (and short sward paddocks) experienced increased recruitment and reduced established dominant species, compared to less intensively grazed and taller swards.

While the removal of the competitive canopy may favor competitive release to favor recruitment, other environmental factors such as increased evaporation, and reduced soil moisture can act to limit subsequent recruitment. By implication, this re-iterates the importance of prevailing rainfall and temperature patterns. For example, in West Africa, Garnier and Dajoz (2001) showed that recruitment in the dominant species *Hyparrhenia diplandara* was favored in unburned sites associated with standing vegetation, citing improved moisture retention provided by canopies of established vegetation. In this study, recruitment was reduced in annually burned cites where fire killed a large proportion of small seedlings and reduced soil moisture. Similarly, Fowler (1986) attributed reduced emergence in arid Texas

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rangelands due to the removal of standing cover and its effect on soil moisture in the absence of good rainfall.

In conclusion, the objective of this research is to understand the condition or state of the sward (i.e. presence of canopy/ litter, canopy/litter removal, burn and no burning) that favors or limits seedling recruitment. The preceding discussion illustrates that disturbance (grazing, clipping, fire) and no disturbance (underutilization) influences species recruitment variously, being dependent on the qualities of the species or sward itself and/or prevailing weather (climate). Little information exists in this regard for *Hyparrhenia hirta.* In terms of disturbance regimes, *H. hirta* communities persist arguably in either highly disturbed states, through frequent fire and different degrees of grazing or in undisturbed/ underutilized states where mature unpalatable forage exempts them grazing. Finally, even though recruitment patterns are primarily constrained by climate, understanding conditions of the sward that promote or inhibit seedling emergence, and how these conditions can be managed, enables management to "prime" the targeted species or sward to either promote or inhibit recruitment during the main recruitment periods.

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CHAPTER 2

SOIL SEED BANK DENSITY AND SEEDLING EMERGENCE OF *HYPARRHENIA HIRTA* IN ANNUALLY BURNED VERSUS > TWO YEAR FIRE RETURN INTERVAL IN *HYPARRHENIA* DOMINATED VELD IN THE GAUTENG HIGHVELD

Prepared according to the format guidelines of the African Journal of Range and Forage Science

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Abstract

Despite frequent burning of underutilized *Hyparrhenia hirta* dominated swards, little is known regarding the influence of fire on the reproductive potential (seed banks) of this species and whether fire has any influence on seedling emergence. In the first part of this study, the seedling emergence method was used to quantify and compare seed densities of *H. hirta* in the soil seed bank of soils collected from frequently burned (annual) versus infrequently burned (> 2 year fire return interval) sites in *H. hirta* dominated veld in the Gauteng Highveld. Seedling emergence was also monitored, denoted here as burned (frequent burn) and unburned (infrequent burn) sites under different treatments (biomass removal, soil disturbance, litter). Results revealed that *H. hirta* dominated the seed bank in both sites, with densities of *H. hirta* in the annually burned site containing nearly twice as many seeds as found in > 2 year fire return interval (not significant). Seedling emergence in the field was similar across all treatments, however pooled data revealed that seedling emergence was significantly greater in burned versus unburned sites (p<0.0001). These results may indicate that the persistence of *H. hirta* populations are favorably buffered by the dominance of *H. hirta* seed in the seed bank and that annual burning may in fact lead to increases in soil seed bank densities. Although emergence was significantly higher in the burned sites, this study could not determine whether this was a direct result of fire enhancing germination of this species or because of higher soil seed bank densities in the annually burned site. This research demonstrates that further investigation is required to increase our understanding of the influence of fire on the ecology and life history characteristics of *H. hirta*.

Keywords: fire, *Hyparrhenia hirta*, seed banks, seedling emergence

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1. Introduction

Burning to remove underutilized, moribund, low quality grass material and promote palatable re-growth is a well-established management tool in rangelands (Trollope 1989; Trollope et al. 1990). However, it follows that if post fire grazing pressure is low or absent, the sward quickly "grows out" and reverts to its initial underutilized condition by the end of the growing season. Conceptually, this process might result in an enforced reliance on annual or more frequent burning, creating a situation in which fire becomes a "bad master" associated with an array of unintended consequences (Phillips 1936).

This study seeks to gain insight into the less obvious effects of fire in the reproductive potential of *Hyparrhenia hirta,* which is often overlooked when burning to promote new re-growth. Anecdotal evidence suggests conflicting effects of fire on *H. hirta*; where both increases and decreases in abundance have been reported under varying conditions. Burning in these instances has almost certainly been followed by grazing to different degrees; which makes distinguishing the effect of fire from grazing a challenge. Varying responses have also been attributed to different effects of fire in Climatic climax and Fire Climax grassland zones, although this has never been tested. Studies in Mediterranean environments have shown that *H. hirta* tends to increase with increasing fire frequency (Papanastasis 1980), and that burning appears to increase flowering and seed production of this species (Watrous et al. 1993). Reports from Australia also suggest increases in abundance following fire (McArdle et al. 2004). Despite a close association with burning, the influence of fire on the reproductive potential of *H. hirta* has not been quantified, and therefore the relationship between fire and *H. hirta* dynamics remains poorly understood.

Plant reproductive potential is closely linked to a species particular life history strategy, in other words, its inherent ability to produce seed, persistence of these seeds and their accumulation in the soil seed bank, as well as the subsequent germination and establishment of that seed under specific conditions (O'Connor 1991). Therefore, reproductive potential (seed and seedling dynamics) is commonly assessed by determining species specific seed production (O'Connor and Pickett 1992; Everson et al. 2009), the abundance of seed in the soil seed banks

(O'Connor and Pickett 1992; Snyman 2004a; Dreber et al. 2011), seedling recruitment and species composition as measured by germination, emergence and survival of seedlings (Vila et al. 2001; Everson et al. 2009). The emphasis on seed dynamics (production, seed bank, seedlings) is based on the idea that recruitment (seed to plant) is largely influenced by seed availability (Zimmerman et al. 2008), i.e. the seed production of a species, and/or the availability of suitable micro-sites for establishment (Oesterheld and Sala 1990; Kinucan and Smeins 1992; Edwards and Crawley 1999) or a combination of both (Eriksson and Ehrlen 1992). Micro-sites refer to the local scale environmental condition that the seed is exposed to, which is influenced by competing vegetation to favor or inhibit germination and establishment. In effect, seed may be amply present but establishment can be limited by unfavorable conditions or micro-sites. Nevertheless, the above discussion implies that if the probability of recruitment is reduced when seed and micro-site is scarce or unfavorable, then chances for recruitment are favored by increasing seed availability (seed rain and seed bank) and/or improving micro-site suitability (Eriksson and Ehrlen 1992). Fire and grazing can impact these factors through defoliation.

A species may cease to recruit when established plants are exposed to processes that prevent seed production and seed set, resulting in the collapse of the soil seed bank (O'Connor and Pickett 1992; Holmes and Cowling 1997; O'Connor 1997). Perennial grass species are especially at risk because annual seed output is generally low and seed lifespan limited. This makes the seed bank highly reliant on seed additions from seed rain of the current and previous seasons' seed output, i.e. perennial species form transient seed banks (O'Connor and Pickett 1992; Edwards and Crawley 1999; Zimmerman et al. 2008). Additions to the seed bank can be reduced by preventing seed set through management strategies such as heavy grazing (Crawley 1983; O'Connor and Pickett 1992; Kemp et al. 1996), mowing and herbicide treatments (Chejara et al. 2012). The study by Chejara et al. (2012) demonstrated that preventing seed set (by repeated clipping) decreased soil seed bank of *H. hirta* by 95% over two years. Emergence of *H. hirta* in the field ceased completely after 14 months.

In comparison, a number of artificial sowing and/or restoration experiments have established that higher seed availability can increase recruitment (Zobel et al. 2000; Wilsey and Polley 2003), depending on the presence of suitable micro-sites (Eriksson and Ehrlen 1992). Fire can influence both seed availability (Vila et al. 2001) and micro-site suitability (Zimmerman et al. 2008). Several studies have shown that fire promotes flowering and seed production, particularly in the season after burning (Lazarides et al. 1965; Majerus and Bridger 1988; Orr 2004; Ligavha-Mbelengwa and Bhat 2013). Stimulatory responses are associated more with tropical and subtropical species (Daubenmire 1968), which include *Hyparrhenia* species. Fire can also improve micro-site conditions by removing the suppressive effects of canopy and litter layer, thereby increasing light and relaxing seedling competition for water (Keeley and Fotheringham 2000). Smoke and heat generated by combustion have also been shown to stimulate germination for some species (Baxter et al. 1994; Brown and van Staden 1997) but annual burning can also destroy seedlings in some grasslands (Zimmerman et al. 2008). Fire could therefore influence recruitment, or the dynamics of plant populations depending on positive or negative response. Overall, burning appears to have variable effects on reproductive potential of the various grass species and these are generally species specific (Knapp et al. 2009). Little information in this regard is known for *H. hirta.*

In this study, the first objective was to quantify and compare the density of *H. hirta* seed in the soil seed bank of frequently burned (annually) versus infrequently burned (>2 year fire return interval) *H. hirta* dominated veld. The second objective was to compare *H. hirta* seedling emergence in the field at the same sites; burn (frequent) versus unburned (infrequent). In this experiment the influence of soil disturbance and canopy removal on seedling emergence in the burned site, and soil disturbance and litter in the unburned site were also tested. These factors are common grassland disturbances associated with livestock grazing that have been shown to influence micro site characteristics, and seedling emergence (Grubb 1977; Belsky 1986; Ruyle et al. 1988; Facelli and Pickett 1991; Adams 1996; Maret and Wilson 2005).

In the area under study, there was a perception that *H. hirta* tufts and stands in annually burned veld supported more reproductive culms and seed bearing flowers than tufts or stands

of the same species in an adjacent area that had not been burned for at least two seasons. Mature plants in the unburned area appeared to have little new season growth (culms and inflorescences) in contrast with an abundance of culm and inflorescence development in the burned area. This concurs with Majerus and Bridger (1988), who suggest a strong negative relationship between stand age or maturity and seed production (seed production decreases with increasing stand age). This tenet is further supported by the established theory of decreased plant vigor and annual primary production with fire exclusion (mature, moribund stands) (Kirkman and de Faccio Carvalho 2003) and time after fire (Morgan and Lunt 1999).

2. Materials and methods

2.1. Experimental Site description

This study was conducted at the Agricultural Research Councils', Irene experimental farm (25°54'E, 28°13'E, altitude 1467 m), located approximately 15 km south east of Pretoria, Gauteng Province. Rainfall is strongly seasonal, occurring during the summer months of October through February (mean annual rainfall = 620 – 800mm). Summer months are warm (summer and winter maximum and minimum) contrasting cool winters with frequent frost typical of the Highveld region.

2.2. Vegetation and soils

The area lies in the transitional zone between the Carletonville Dolomite Grassland and the threatened Egoli Granite Grassland (Mucina and Rutherford 2006). The red, well-formed soils of the Hutton and Clovelly types found at the site tend toward classification under Carletonville Dolomite, particularly given the close local proximity and similarity in species composition between the two types. *Hyparrhenia hirta* is an important species in both vegetation types, probably due due to high rates of transformation in the surrounding urban environment and the species close association with disturbed areas (Tainton 1999; Van Oudtshoorn 2002). As a result, botanical composition of the area bears similarity to the *H. hirta* anthropogenic grassland described by Bredenkamp and Brown (2003).

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2.3. Species and community description

Hyparrhenia hirta (L) Stapf is a summer active, C4 perennial tufted grass, native to southern and East Africa, Mediterranean regions and in Pakistan (Van Oudtshoorn 2002; Chejara et al. 2006). In southern Africa, it is widely distributed, naturally occupying a broad range of soil types and climatic conditions. Single species swards are particularly prominent in disturbed areas, such as along road sides, in previously cultivated ("old lands") and overgrazed areas (Tainton 1999). Strictly speaking these are secondary grasslands recovering from prior disturbances, where the process of succession is apparently ongoing. Briefly, annual and grassy weeds are replaced by *Sporobolus* and *Eragrostis* species, followed by the invasion of a stable, persistent community of *Hyparrhenia hirta.* The community appears to remain in stasis as *H. hirta* dominates for extended periods (10 to 30 years) with the grassland community seldom advancing past this stage to return to pre-disturbance states (Tainton 1999). For this reason, these communities are considered climax or "end point" vegetation in this dissertation. Lastly, *H. hirta* is more stem than leaf. Booysen et al. (1963) found the ratio of flowering to non-flowering parts to be as high as 11.5: 1, thus highlighting the importance for grazing this species early in the season before stem development occurs and palatability decreases.

2.4. Sampling procedure

2.4.1. Soil seed bank collection

A high abundance of flowering (and associated culm/ tiller development) following fire in the burned site (annually burned), and a lack thereof in the infrequently burned site (> 2 seasons since burning), provided the basis for analyzing the seed bank since it was assumed that these differences would be detected in the soil.

Ernst et al. (1992) cautioned that increased flowering does not necessarily relate to higher seed yields. Seed only forms a small part of the flower with a large proportion made up of non-reproductive structures. Based on this understanding, direct counting of flowers was not considered appropriate. Furthermore, seeds may already have aborted within the flower (Veenendaal et al. 1996). Therefore, the primary observation that flowering (and seed

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production) was highest in burned *H. hirta* could be flawed. Thus, by assessing the seed bank, this study measured the proportion of viable, readily germinable seed.

In July 2013 soil samples were collected from frequently burned and adjacent infrequently (> 2 year fire return interval) burned *H. hirta* dominated plots. The criterion for plot selection was that plots needed to contain >75% *H. hirta* densities since seed production (seed banks are assumed) is directly related to the abundance of established individuals (O'Connor 1991). *Hyparrhenia hirta* seed had already set with a mass of seed evident on the soil surface, particularly in the burned sites, and to a lesser extent in the unburned sites. A soil auger was used to collect soil samples from twenty sites each in the burned and unburned treatments. Five soil auger samples were taken per sampling site and combined. The samples were taken to a depth of 5 cm below the surface where most seeds are located (Everson 1999). A single 250 g soil sample was extracted from the five soil auger composite for germination in one pot. Therefore, twenty pots were evaluated under the same greenhouse conditions as the first evaluation for each burn and unburn treatment (40 pots in total).

Emerging seedlings were transferred to new pots where they were allowed to grow until identification at the species level was possible. The abundance of developing grass species was recorded for analysis (forbs were excluded).

2.4.2. Field Treatments and in-field seedling emergence sampling

Burned H. hirta plots

Four treatments (including a control) were assigned in burned *H. hirta* dominated veld.

(T1 to 4=Treatment 1 to 4)

T1. Clipping × soil disturbance

T2. Clipping only,

T3. Soil disturbance only, and

T4. Control (no clipping, no disturbance).

The four treatments were replicated five times and applied in a randomized complete block design (RBCD; plot size 1m² with 0.5m buffer zones to prevent shadowing and edge effects). The plots were intentionally positioned in portions of the sward that had > 75% *H. hirta*. Soil disturbance was carried out with a hand held harrow. Bare soil interspaces were loosened with the harrow up to a depth of 1 cm. The sward in the clipping treatments was kept short (15cm) by repeated clipping with garden shears throughout the duration of the study. Given the sometimes patchy distribution of *H. hirta* clumps and the need to adhere to the RCBD, plots were never closer than 3m and not further than 6 m apart. The same experimental design was used for treatments established in the unburned *H. hirta* plots described below**.

Figure 1. Experimental lay out in (a) burned site, Treatments 1 – 4, where T1 = Clipping × soil disturbance, T2 = Clipping only, T3 = Soil disturbance only and T4 = Control (b) Unburned site, Treatments 1 – 5, where T1 = Soil disturbance × litter, T2 = Soil disturbance only, T3 = Litter only, T4 = Clipping only, T5 = Control

Unburned H. hirta plots

Five treatments in adjacent non-burned *H. hirta* veld were designed to simulate soil and sward conditions relevant to unburned and/or underutilized *H. hirta* veld. The treatments therefore represent various states of the soil surface and the sward under grazed and ungrazed conditions. Treatments 1 – 3 were kept short (15cm) by repeated clipping throughout the study.

Treatments

T1. Soil disturbance × litter,

T2. Soil disturbance only

T3. Litter only

T4. Clipping only

T5. Control (no clipping, no litter, and no surface disturbance)

Before treatments were applied, all seedlings that had germinated and established prior to the treatments were removed. Burned and unburned treatments were applied at the same time in midsummer (21-23 December 2012). From this date new emerging seedlings were recorded at the same time in burned and unburned sites at three week intervals. New seedlings were marked with colored pins, corresponding to the week in which new seedlings emerged. Seedling emergence was therefore examined five times over a period of fifteen weeks. The study was terminated on 15 May 2004, following the cessation of all seedling emergences.

2.5. Statistical analysis

Soil seed bank densities were tested with the use of a one tailed t-test in R version 3.08, testing the hypothesis that the seed densities were greater in the frequently burned sites. Non-normally distributed seedling emergence data in burned and unburned treatments was tested, using non parametric analysis. The Friedman's test for repeated measures was used, as the same plots were re-sampled over the study period. Subsequent pair wise differences between pooled data (burned and unburned sites) and the individual treatments were tested using Mann Whitney test.

3. Results and discussion

3.1. Soil seed bank in annually burned and infrequently burned H. hirta veld

The seedling emergence method revealed almost two fold higher *H. hirta* seed bank densities in

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the frequently burned sites (127±28 seedlings/m²) compared to infrequently burned sites (75±16 seedlings/m²) (Figure 2). Results of a one tailed paired t-test revealed no significant difference between individual species in the frequently burned versus infrequently burned sites (p>0.05). *H. hirta* was dominant in the seed bank at both sites, with relatively small seed bank densities of other grass species. *Eragrostis curvula* was common in frequent and infrequently burned sites; *B. biflora* and *P. natalensis* emerged only in the frequently burned whereas *C. dactylon* emerged in the infrequently burned site alone.
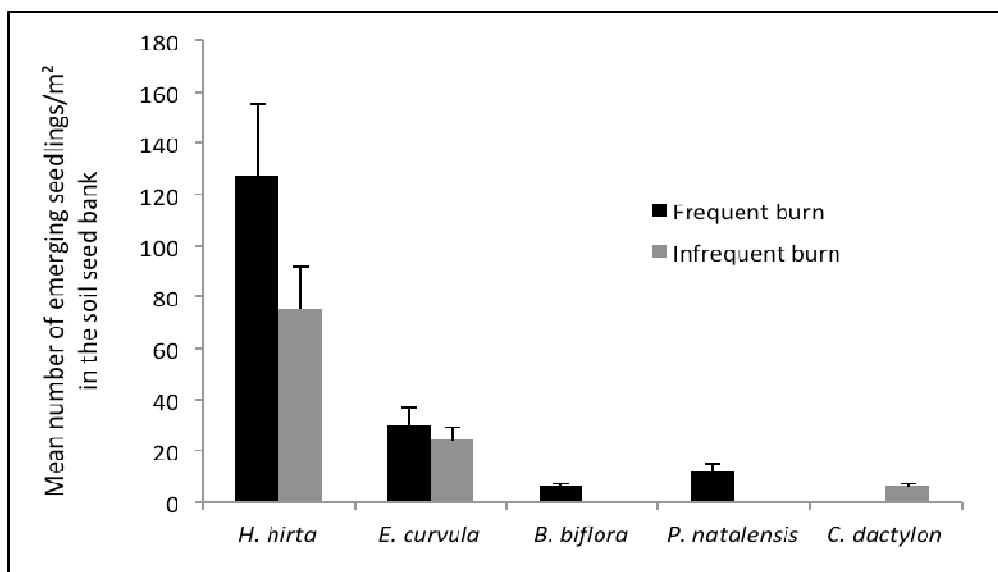
Figure 2. Mean number of seedlings/m² (±SE) obtained through the seedling emergence method (*n=20*). No significant difference between treatments (p>0.05)

In this study, annual burning led to increases in the *H. hirta* seed bank (Figure 2.). This supports the assumption that fire increased seed production of *H. hirta* at this site, which was based on initial observations of an abundance of flowering in the burned site compared to unburned *H. hirta* site. Increased seed production and flowering following fire have been reported for a number of other C4 species, i.e. *Andropogon gerardii* (Logan et al. 2005), *Trachypogon plumosus* (Baruch and Bilbao 1999), *T. filifolius* (Parron and Du Vall 1997) and *T. triandra* and *C. validus* (Harrington and Thornton 1969). These studies did not include the seed bank analysis. The results of this study are similar to Orr (2004), who showed that annual burning increased seed production in *Heteropogon contortus* and that these increases related to increased seed

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bank densities. In this study, fire in the previous seasons could have increased flowering in *H. hirta*, leading to the accumulation of higher seed bank densities in the annually burned site compared to the less frequently burned site.

With regard to a smaller seed bank found in the infrequently burned site, a number of studies, mostly conducted in North and South America, but also one study in South Africa that included *H. hirta*, have drawn a relationship between decreased flowering and time since burning. These studies found that flowering and reproductive allocation is highest in the year after the burn and steadily decreases in the years thereafter. This trend has been observed in *Schizachyrium rhizomatum* (Main and Barry 2002), *H. hirta* (Ligavha-Mbelengwa and Bhat 2013) and *Agropyron spleatum* and *Stipa columbiana* (Patton et al. 1998) and *Andropogon semiberbis* (Silva et al. 1990). In Australia, Orr (2004) also revealed decreased seed production and smaller seed banks in *H. contortus* grasslands sites excluded from fire compared to annually burned sites. The exclusion of fire can decrease culm/ tiller development (increase mortality) (Everson et al. 1988; Shackleton 1989), as unutilized material stifles and suppresses new growth (Morgan and Lunt 1999; Tainton 1999). Since tillers support flowers, the inhibition of new tillers leads to reduced flowering, and less seed reaching the seed bank. Therefore, the differences observed in this study were due to fire increasing seed production in annually burned veld and fire exclusion associated with reduced seed production.

Hyparrhenia hirta was by far the most abundant species present in the seed bank at both sites due to seed density being closely related to abundance of standing vegetation (O'Connor and Picket 1992; Bekker et al. 1997; Maret and Wilson 2000). Seed bank samples were intentionally taken from patches where > 75% *H. hirta* cover occurred. This would translate to dominance of *H. hirta* in the seed bank. Fire (or no fire) did not have a marked effect on the occurrence of other species, although their presence does signal opportunities for recruitment and potential species change within the sward.

3.2. Seedling emergence of H. hirta and other grass species: Field experiment in an annually burned and infrequently burned (> 2 year fire return interval) site

3.2.1. Seedling emergence; frequently burned versus infrequently burned

Overall, this study demonstrated significantly higher *H. hirta* and other grass species seedling emergence in the burned sites, compared to unburned sites. Pooled data (burn versus >2yr fire return) revealed that both *H. hirta* and other grass species seedlings were significantly more (p<0.0001) in the burned sites compared to the unburned sites. There was no significant difference between individual treatments in the burned site, and only small differences within the unburned site; suggesting that fire (or no fire) was more important than the individual treatments.

Table 1. Test result between pooled data, burned (n=25) versus unburned (n=20) using the Mann Whitney test. Treatments with no common letter are significantly different (p<0.0001).

Species	Burn		No burn	
	Total	Mean±SE	Total	Mean±SE
H. hirta	218	10.9±0.47a	132	5.28±0.35b
Other grass *spp.*	48	2.4±0.17c	10	0.4±0.06d

Firstly, seedling emergence between burning and fire exclusion is discussed in general. Secondly, the lack of observed treatment effects between individual treatments (burned and unburned sites) is discussed with explanations.

Emergence in the field appears to be in line with results obtained from the soil seed bank and seedling emergence method (Table 1.). Higher seedling emergence in the burned site could be explained by the increase in available seed found in the seed bank at this site. Experimental studies have shown that seedling emergence increases with increasing seed availability (Wilsey and Polley 2003; Zimmerman et al. 2008). Similarly, according to Capon and O'Connor (1990), seedling emergence rates are reduced when seed production is limited, as was found in this study where fire was excluded for more than two years.

Seed availability aside, seedling emergence increased in the season directly after the burn, and that fire appeared to have a further positive influence on emergence in the field. Conditions for recruitment can be favored by fire through the removal of competing vegetation (Snyman 2004b), increasing irradiance at the soil surface (Keeley and Fotheringham 2000), and

accelerating the rate at which plant available nutrients are returned to the soil (Wells et al. 1979). Zacharias et al. (1988) demonstrated that heat and smoke from fire directly stimulated *H. contortus* seedling emergence in southern Africa.

Therefore, these results were similar to studies in *H. contortus* rangelands in Australia (Campbell et al. 1996; Orr 2004) and *T. triandra* rangelands (Morgan 2001) where increased seedling emergence occurred after fire compared to fire exclusion plots. In disagreement, Snyman (2004) found that fire had a negative effect on emerging seedlings in drier semi-arid South African rangelands, but in this study, and according to Orr (2004), seedling emergence was higher in the burned sites (where seed production and seed bank densities were increased) compared to unburned sites. In the study by Orr (2004), measurement of seed production, seed banks, and seedling emergence in study was informed by large scale burning (and grazing exclusion) trials conducted over a number of years on a number of study sites (Paton and Rickert 1989; Orr et al. 1991) where it became apparent that *H. contortus* increased under annual burning. These increases were therefore explained by fire stimulating seed production, increasing seed bank densities, and favoring recruitment of the desirable *H. contortus*, particularly in good rain years.

3.2.2. Treatment effects in annually burned and infrequently burned (>2 year fire return interval) H. hirta dominated veld

There was no difference in *H. hirta* emergence between treatments in the annually burned site (p>0.05). In the infrequently (un)burned site, emergence in the cutting only and disturbance only treatments were slightly lower than other treatments (p<0.05) (Figure 3.). Overall, results indicated that *H. hirta* emergence was highest in the control treatments in both sites. The emergence of other grass species was no different between treatments in the annually burned site (p>0.05) (Figure 4). Disturbance + litter and disturbance treatments increased emergence of other species only slightly compared to the other treatments, while no emergence was found in the cutting treatments.
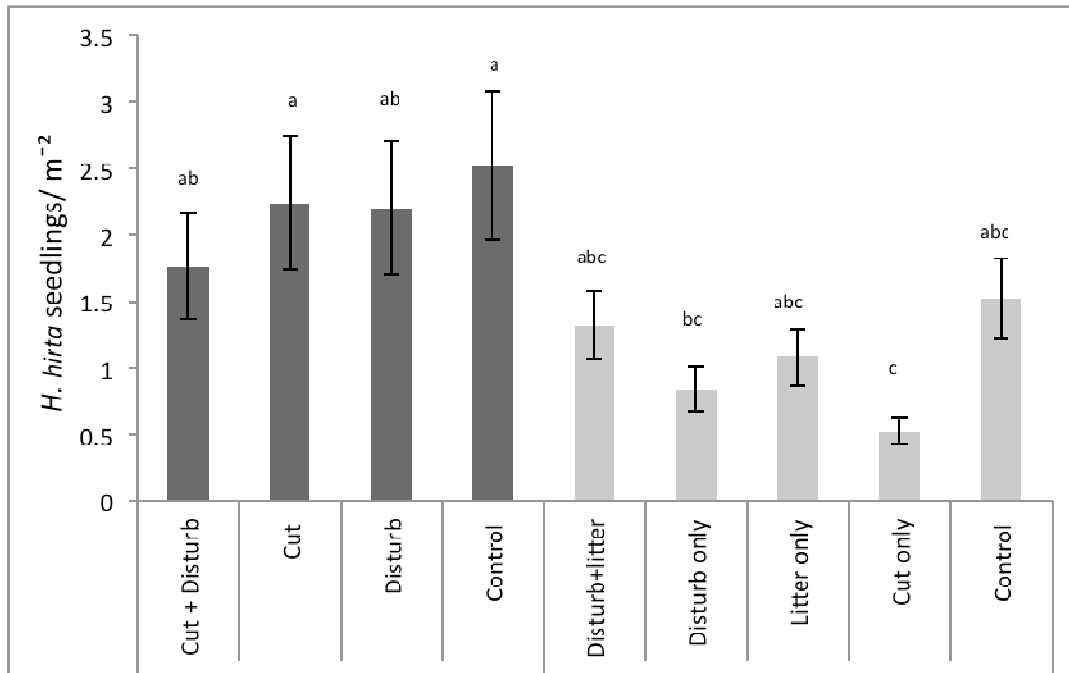
Figure 3. Means (±SE) of *H. hirta* seedling emergence in burned and unburned treatments. Treatments with no common letter are significantly different (p<0.05).
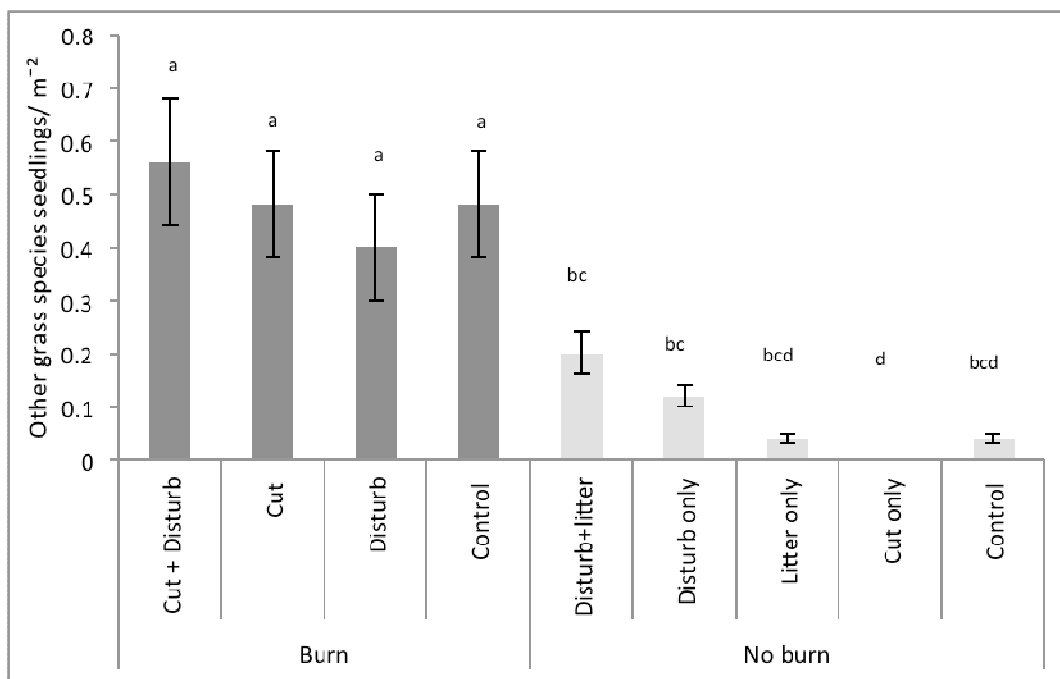
Figure 4. Means (±SE) of emergence of other species only in burned and unburned treatments. Treatments with no common letter are significantly different (p<0.05).

The absence of a consistent response to individual treatments within burned and unburned experiments could be due to two related factors; one includes the seed biology of *H. hirta* and the other is a methodological consideration. Considering that *H. hirta* germinates over a very wide range of light intensities, temperatures, as well as water deficits (Chejara et al. 2008), it is possible that the respective treatments did not alter these limits substantially enough to illicit a measurable difference. For example, Van Oudtshoorn (2007) demonstrated consistent increases in *H. hirta* to more intense soil disturbances, i.e. mechanical ripping and ploughing. Clearly, soil surface disturbance (1cm below surface) treatments did not reveal strong trends in either burned or unburned sites in this study.

In contrast to other studies, which suggest negative effects of competing cover (standing vegetation and litter) on emergence, this study indicated that the litter and control treatments appeared to promote emergence, particularly in *H. hirta.* Emergence was higher in unburned plots that were disturbed and had litter compared to disturbance alone (Figure 3 and 4). Similarly, emergence increased where plots were clipped and had litter, compared to plots that were clipped only (Figure 3 and 4). While litter acts as a physical barrier to emerging seedlings (Chambers 2000, Ruprecht et al. 2010) and reduces light availability (Knapp and Seastedt 1986, Facelli and Pickett 1991), it also conserves soil moisture (Savory and Butterfield 1998; Snyman 1998), which may have led to the higher seedling emergence.

Litter and standing vegetation in the unburned site may have had a comparably larger influence on seedling emergence (via water retention) because of the timing of the study and the prevailing weather conditions. Treatments were initiated in late December; coinciding with the wettest and warmest time of the year which are also the most favorable conditions for seedling emergence in C4 grass species (Kemp et al. 1996). Furthermore, the relative prevalence of *H. hirta* emergence in the control treatments (Figure 3 and 4) indicates that established *H. hirta* plays a facilitative role in seedling emergence, rather than a competitive role as often suggested in the literature (Grubb 1977; Moloney 1990; Adams 1996). Mature plants take on the function of "nurse plants" whereby the cover they provide helps to keep the soil moist in a similar manner as litter (Holmgren et al. 1997). Readings undertaken after this study was completed

confirmed that *H. hirta* is able to germinate and establish within a dense sward (Gibss Russell et al. 1991). Similarly, in West African savanna, Garnier and Dajoz (2001) found that recruitment in the dominant species, *Hyparrhenia diplandra,* was favored in fire exclusion plots associated with standing cover. This supports the findings of this study, where the control and litter plots (associated with underutilization and fire exclusion) and control plots in the annually burned sites were those where highest *H. hirta* seedling emergence occurred.

In direct contrast to treatments that provided cover, the removal of cover through clipping reduced emergence in all other treatments. This result contrasts a number of studies where emergence and recruitment were favored through the creation of gaps within the sward, either by clipping and/or soil disturbance (Adams 1996; Focht and Medeiros 2012). In this study, treatment gaps were created by repeatedly clipping the sward to 15 cm throughout the study, alone, and in combination with soil disturbance or litter. Against expectations, seedling emergence was markedly reduced in these treatments compared to control treatments, especially in the unburned site (Figures 3 and 4). Fowler (1986) found similar results which were explained by increased evaporation and water shortages in the absence of vegetative cover.

4. Conclusion

This study shows that the reproductive potential, i.e. the seed bank densities and subsequent emergence of *H. hirta* is increased under annual burning. Within treatments, increased emergence was associated with underutilization in both burned and unburned sites. That is, seedling emergence increased in burned veld when *H. hirta* was left to regrow and re-establish cover for emerging seedlings. Similarly, in the unburned site, emergence increased in control plots associated with standing cover and litter. In contrast, emergence was reduced or limited through the removal of cover by repeated clipping throughout the study. This means that maintaining a short sward limits *H. hirta* emergence, and prevents seed additions to the seed bank, both of which could practically be achieved through mowing or intense grazing. Research on *H. hirta* in Australia showed that the seed bank and subsequent emergence of *H. hirta* can be completely eliminated over a two year period through repeated clipping. Intense and efficient defoliation of *H. hirta* is suggested to be the objective of grazing to control recruitment

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in this species. A final by product of such a regime would subsequently reduce the need for fire, or reduce the frequency of fire, which in this study, was shown to favor *H. hirta*.

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CHAPTER 3

THE USE OF FIRE AND GRAZING IN THE REHABILITATION OF

CLIMAX *CYMBOPOGON VALIDUS* DOMINATED VELD IN THE EASTERN CAPE, SOUTH AFRICA

Prepared according to the format guidelines of the African Journal of Range and Forage Science

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Abstract

The grazing value of areas supporting low quality, high production climax veld such as *Cymbogon validus* is extremely low and practical interventions are required to benefit from this generally unutilized resource. This study demonstrates the combination of fire and grazing as tools in the management and subsequent eradication of *Cymbopogon validus* veld on Glen Gregor Farm, Bedford, Eastern Cape. Five camp sites were chosen, representing a gradient of management intensity which reflect different stages of succession following the suppression of climax *C. validus* veld. An untreated control camp was included as a reference point for comparison between treatment camps. Species composition, veld condition index, basal cover, seed banks and primary productivity were determined in the top and bottom slope sites in each camp. Results show that *C. validus* diminished significantly according to the total number of seasons that a camp was grazed after burning, and not necessarily the number of burns. A lack of grazing after burning maintained a dominance of *C. validus,* which represented a poor veld condition. Species richness, diversity and basal cover was significantly lowered (p<0.05) in the climax state, while seed banks were also poorly represented based on few co-occurring species. In contrast, veld condition improved as *C. validus* was replaced with sub climax and pioneer species which colonized wide bare ground spaces characteristic of the climax sward. As a result, species richness, diversity and basal cover increased significantly (p<0.05) as *C. validus* declined. Therefore, contrary to predictions of veld condition index, *C. validus* veld is in a poor condition which improves under increased grazing pressure. The presence of similar species in each camp, but different proportions, indicates a single relatively predictable sequence of succession as *C. validus* is suppressed. Species including *Sporobolus africanus, Eragrostis curvula, Cynodon dactylon,* and *Paspalum dilatatum* are dominant in the sub climax state and contribute to improved soil surface coverage and provide improved forage availability, compared to the unpalatable *C. validus* swards. Therefore, it can be concluded that the combination of fire and grazing as management tools, has delivered significant benefits in improving the grazing value of *C. validus veld*.

Keywords: climax community, fire, high density grazing, plant diversity

1. Introduction

In rangeland management, grasses are valued according to their contribution to animal production (Trollope et al. 1990). The determination of veld condition is implicit in this approach. It is a valuable measurement since it directly relates the capacity of a sward to provide for animal production in the long term (Trollope et al. 1990; Danckwerts and Tainton 1996), i.e. veld condition directly influences animal production (Danckwerts and Tainton 1996), and therefore gross farm income (Snyman 1998). This may explain why the various methods prescribed for assessing veld condition, eg. Ecological Index (Vorster 1982), Weighted Key Species (Heard et al. 1986) all use species composition as a primary criterion. Simply stated, species with high grazing value represents rangelands in good condition and the potential to carry higher numbers of livestock (Rethman and Booysen 1967; Stuart-Hill and Mentis 1982; Tainton and Camp 1999; Van Oudtshoorn 2002).

The broad assumption of veld condition assessments is closely linked to the climax concept in that veld in good condition is often associated with climax species representing a well developed vegetation state. However, not all climax species offer nutritious forage, as is the case for *Cymbopogon validus.* The ecological method used to determine veld condition in this study scores *C. validus* based on its successional status (increaser/decreaser classification). According to the Foran et al. (1978) classification, *C. validus* is a Increaser 1 climax species indicating a well developed successional stage associated with veld in good condition. However, to farmers, unpalatable, low diversity *C. validus* dominated veld (Shackleton 1989) represent a good example of rangeland that has deteriorated (Danckwerts and Tainton 1996); posing a threat to both animal production and biodiversity in rangelands.

Although a highly productive grass (Shackleton 1990); *C. validus* contains high concentrations of plant secondary metabolites (turpenes and phenols) which are bitter and function effectively as a plant defence (Rethman and Booysen 1967; Stuart-Hill and Mentis 1982). This trait, as well as a robust growth form (Rethman and Booysen 1967) contributes to avoidance by livestock and where dominant to a potentially reduced intake rate (Provenza 1991; Laca et al. 1991; Van Oudtshoorn 2002) and loss in livestock production. Thus, the species forms an unwanted

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component in grazing lands, and a target for management strategies (fire and grazing) aimed at reducing its abundance.

Previous studies on *C. validus* suggest that it is sensitive to both over (frequent and severe defoliation) and under-utilization (protection from defoliation) (Shackleton 1989, Shackleton and Mentis 1991). This is illustrated by a 96-100% die-back of tillers when *C. validus* was clipped short at 2, 4 and 8 week frequencies over a period of 17 months in Mkambathi Game Reserve, Eastern Cape. Zero defoliation suppressed tillering and increased tiller mortality (Shackleton 1989, Shackleton and Mentis 1991). Studies have also shown relatively consistent positive response of *C. validus* to burning frequency. Tiller production was promoted by annual and biennial burns in Mkambati Game Reserve, Transkei (Shackleton 1989). Similarly, *C. validus* and *C. excavatus* increased in dominance in the Tall Grassveld of KwaZulu Natal under more frequent burns (Tainton 1999).

Fire is well established as an essential tool in the management of mesic rangelands (Trollope 1989), where it used primarily to remove moribund grass material and control woody species encroachment (Trollope 1989, Trollope 2008). However, where shifts in species composition are desired, burning regimes alone appear insufficient (Tainton and Mentis 1984). More emphasis is placed on post fire grazing strategies (Morris et al. 1992) since management has direct control over the timing, frequency and severity of these grazing regimes (Heitschmidt and Walker 1983, Liedloff et al. 2001) and it is the combination of these tools (fire and grazing) that are most likely to cause species shifts in mesic rangelands (Trollope 1989; Westoby et al. 1989; Fuhlendorf et al. 2009).

Livestock are increasingly recognized as potential management tools driving vegetation change (Belsky 1992; Olff and Ritchie 1998; Bakker et al. 2006). Short periods of heavy grazing following fire, has been recommended as a mean of controlling *C. validus* (Trollope 1989) and have proven effective in the control and reduction of other undesirable species (Launchbaugh et al. 2006; Ramirez-Yanez et al. 2007; DiTomaso 2009). However, predicting the success of these strategies is dependent on informed manipulation of the temporal and spatial aspects of grazing behavior (DiTomaso 2009). Here, success is defined in terms of uniformity of grazing

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effects (and associated vegetation changes) in a land unit, i.e. fenced camps, since the dominance of superior competitors and/ or species that increase in the absence of grazing can be suppressed under increased grazing pressure (Briske 1991).

Uniform utilization is rarely achieved in innately heterogenous rangelands and is reflected by patches that are grazed more often than others (Bailey et al. 1996). Utilization of less desirable species can be achieved by increasing grazing pressure (Trollope 1989; Morris 2002; Teague et al. 2008) and by limiting sward maturation through grazing and rest cycles that keep target species short and palatable (Teague et al. 2008). Furthermore, in mountainous terrain, such as Glen Gregor Farm situated in the southern extreme of the Amathole-Winterberg range, there is a tendency for grazing to be concentrated in the flatter bottom land areas as opposed to the steep upper slopes (Cook 1966; Ganskopp et al. 2007). Unequal sward use is even more apparent when slope differences occur within the same camp, and is illustrated by the underutilization of steep slopes compared to heavy use in the bottom land areas (Mueggler 1965). Considering Trollope's (1989) suggestion that two to three seasons of heavy use is required for *C. validus* suppression, it could be expected that over this time the unequal selection between sites will result in compositional differences between underutilized and heavily grazed sites. Management at Glen Gregor have observed no reduction in *C. validus* in underutilized areas, which contrasts Shackleton and Mentis' (1991) earlier finding that *C. validus* dies out under zero defoliation. Anti-herbivory qualities and decreasing acceptability of *C. validus* over the season and between seasons (increased chemical compounds and lignification), makes maintaining grazing pressure on *C. validus* a particular challenge. This is fundamental and requires a suitable choice of animal type and strategy.

Research has often focused on the varying, and clearly different effects of animal type (cattle and sheep) on plant species (O'Reagain et al. 1996) and structure selection (O'Reagain and Grau 1995; O'Reagain and Owen-Smith 1996), as well as on rangeland condition (Morris et al. 1999; Kirkman 2002). However, there remains a distinct lack of reference to the role of mature oxen, particularly their potential in circumstances where both sheep and cattle (breeding herds) are unsuitable. Because the reproductive success in livestock is closely linked to feed quality and

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female condition (Adams et al. 1996; Paterson et al. 2001), the utilization of low quality *C. validus* veld for breeding stock is unviable. Mature oxen are known to have lower maintenance requirements and are well suited to utilizing poor quality forage.

This study records site specific decline of *C. validus*, and accompanying changes in veld condition associated with an increasingly sub climax dominated sward, along a gradient of fire and heavy oxen use over time. Variation in species composition influences other characteristics of veld condition which include basal cover (Van der Westhuizen et al. 1999), primary production (Tainton 1999), and soil seed banks (Snyman 2004; Dreber et al. 2011). Deterioration in veld condition, indicated through the loss of climax species, increases in bare ground and the loss of soil seed banks, is generally associated with reduced ecosystem function amounting to loss of grassland sustainability and potential animal production. This study seeks to understand how the above veld condition characteristics change with the elimination of *C. validus* dominated veld under fire and heavy grazing. This information will provide important principles for improving the species composition of *C. validus* veld for livestock grazing and for understanding the sustainability of such management over 17 years of fire and grazing use.

Therefore, the aim of this study was to document differences in species composition of standing vegetation and soil seed bank, basal cover, and productivity in top and bottom slopes of five camps in different stages of retrogressive succession.

1.1. The management regime applied to Cymbopogon validus rangeland

Strategic targeting of *Cymbopogon* camps began in 1997, under the following burning and grazing regime

- Prescribed burns are ignited in mature *Cymbopogon* swards from mid to the end of August.

- Mature oxen (3AU/ha) are introduced once *C. validus* regrowth has reached 10–15 cm in height. The sward is heavily grazed (complete utilization) for two weeks and rested for three weeks (Figure 3), rainfall dependent. Uniform removal during the first grazing period is critical to ensure a sward of uniform height, and therefore, of equal

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acceptability, at the time of the second grazing period.

- Graze and rest cycles are repeated throughout the growing season, and the non growing season as *C. validus* continues to grow through winter.

- Toward the end of the third season grazing after the burn, *C. validus* plant hardens and is completely avoided by oxen

- *C. validus* camp is left to rest between three to five years until enough biomass (>5000kg/ha) has accumulated to support subsequent prescribed burn.

- Failure to "keep ahead" of *C. validus* results in sward maturation (arrow line in Figure 3.), whereby further utilization of that camp is inhibited. The camp is rested as above until a subsequent burn is possible.
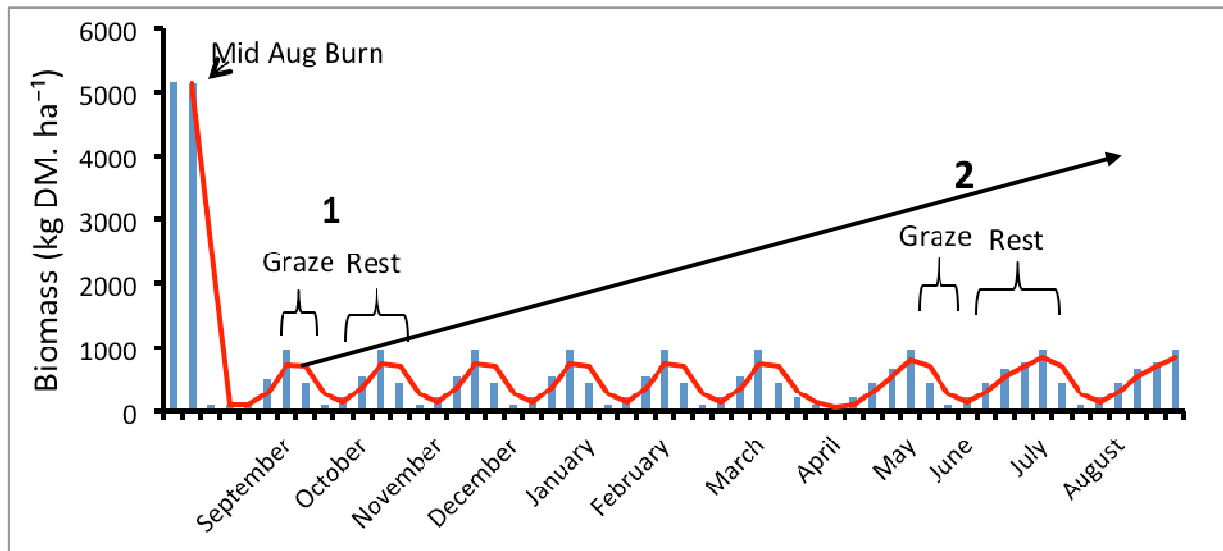
Figure 1. Hypothetical diagram representing the management regime on *C. validus* veld during 1. growing season and 2. non growing season. The arrowed line represents *C. validus* "growing out" (maturing) which occurs through under-utilization.

Management focused on individual camps independently of one another over time, and this is reflected in the way the data is analyzed and interpreted. For example, a newly burned camp

becomes the focus of cyclical graze and rest periods, for as long as oxen are able to utilize *C. validus* effectively. Although, the following text emphasizes the role of maintaining grazing pressure on burned *C. validus,* and its importance for facilitating vegetation change; there are management factors that influence realized grazing pressure (see notes *1, *2 and *3 on Table 1). As a result, we also discuss how these factors vary between sampled camps, to eventually influence the desired grazing pressure, and subsequent vegetation change.

Table 1. Sample camp name, number of burns, number of seasons that pressure was maintained after each burn, calculated Fire/grazing intensity Index and slope (%) of assessed camps. Fire/grazing intensity Index was based on information provided by management and calculated as follows: Fire/Grazing intensity Index = Number of burns × Total number of seasons of pressure since 1997. Slope (%) indicates the angle of the slope in relation to the horizontal, and was calculated by dividing the altitudinal difference between the slope extremes with the measured distance between the two extremes of the slope.

Camp name	Number of burns	Number of seasons that pressure was maintained after each burn	Total number of seasons of grazing since 1997	Fire/grazing intensity Index	Slope (%)	
					Top	Bottom
Mbabaleng	3	1st burn - 0 2nd burn - 0 3rd burn - 0	0	0	6.8	9.7
*[1]Ridges	3	1st burn - 1 2nd burn - 1 3rd burn - 1	3	6	15.3	13.2
*[2]Bushpig	2	1st burn - 3 2nd burn - 2	5	10	12.5	13.5
*[3]Willows	3	1st burn - 3 2nd burn - 3 3rd burn - 2.5	8.5	25.5	13.5	5.8
Station	4	1st burn - 3 2nd burn - 3 3rd burn - 3 4th burn - 2	11	44	10.3	8.6

*[1]Ridges is distinguished by steepest slopes overall. Difficulty containing oxen with Ridges lead to low grazing pressure. *[2]Water limitations lead to premature withdrawal of oxen following the second burn and graze cycle. *[3] Large differences in slope (%) between top and bottom slopes.

Mbabeleng camp

This camp served as a reference site depicting the original condition of *Cymbopogon* veld in the absence of prescribed fire and grazing management (Figure 2). This camp has been burned every six years to control shrub encroachment, but *C. validus* had never been targeted for grazing oxen, as a direct result of management. However, *C. validus* was targeted for the first time following prescribed burning in August 2011. Heart water (Ricketsial) outbreaks lead to the early withdrawal of oxen from the camp by January 2012.

Figure 2. Google earth image of reference control site; Mbabaleng camp. This camp is representative of the ecological veld type of targeted camps in their original condition.

Ridges

The long, steep slope of Ridges camp has burned three times in the last fifteen years (Figure 3). Management achieved little success in containing oxen in this camp and the desired grazing of *C. validus* was limited on each occasion. As a result, Ridges camp became unpalatable in the first season following the burns. Due to difficulty with fence breakages and containment, the burning of this camp has largely been carried out to reduce woody encroachment. The absence of fire for extended periods led woody ingress, and subsequent smothering of *C. validus.* In terms of *C. validus* control, management views this camp as a challenge.

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Figure 3. Ridges camp, characterized by long uniformly steep slopes.

Bushpig

Bushpig has been burned twice in the last fifteen years. Following the first burn, oxen were effectively maintained for three seasons and subsequently rested for required time to burn again. Due to water limitation following the second burn, the desired utilization of *C. validus* was not achieved. In contrast to the other camps with steep, upper slopes and gentle, bottom slopes, this camp is of a uniform slope from top to bottom (Figure 4). Oxen have not grazed newly burned *C. validus* for approximately five years in this camp. Management perceives this camp to be returning back to its initial composition.

Figure 4. Bushpig camp is characterized by uniform slopes.

Willows

Willows camp has burned three times and heavily grazed for three seasons on each occasion. Topography is characterized by steep top slopes and gentle bottom slopes (Figure 5). The camp has been heavily grazed in this manner for the past five seasons, with grazing concentrated in the favorably accessible bottom slopes.

Figure 5. Steep top slopes and gentle bottom slopes emphasize differences in grazing pressure in Willows camp.

Station

Station camp represents achievement of management objectives with near complete elimination of *C. validus*. The camp has been burned on four occasions and heavy grazing had been successfully maintained following each burn. In contrast to Willows and Ridges, Station camp shows small variation in topography. Furthermore, it occupies the bottom of the valley, and adjoins the long steep slope of Ridges.

Figure 6. Station camp represents ideal management objective of suppression of *C. validus* and the establishment of favorable species composition.

2. Materials and methods

2.1. Experimental site description

This study was carried out on Glen Gregor, a 4300 ha multi–stock farming operation, located near Bedford in southern extremes of Amathole - Winterberg range in the Eastern Cape, South Africa (Figure 7).
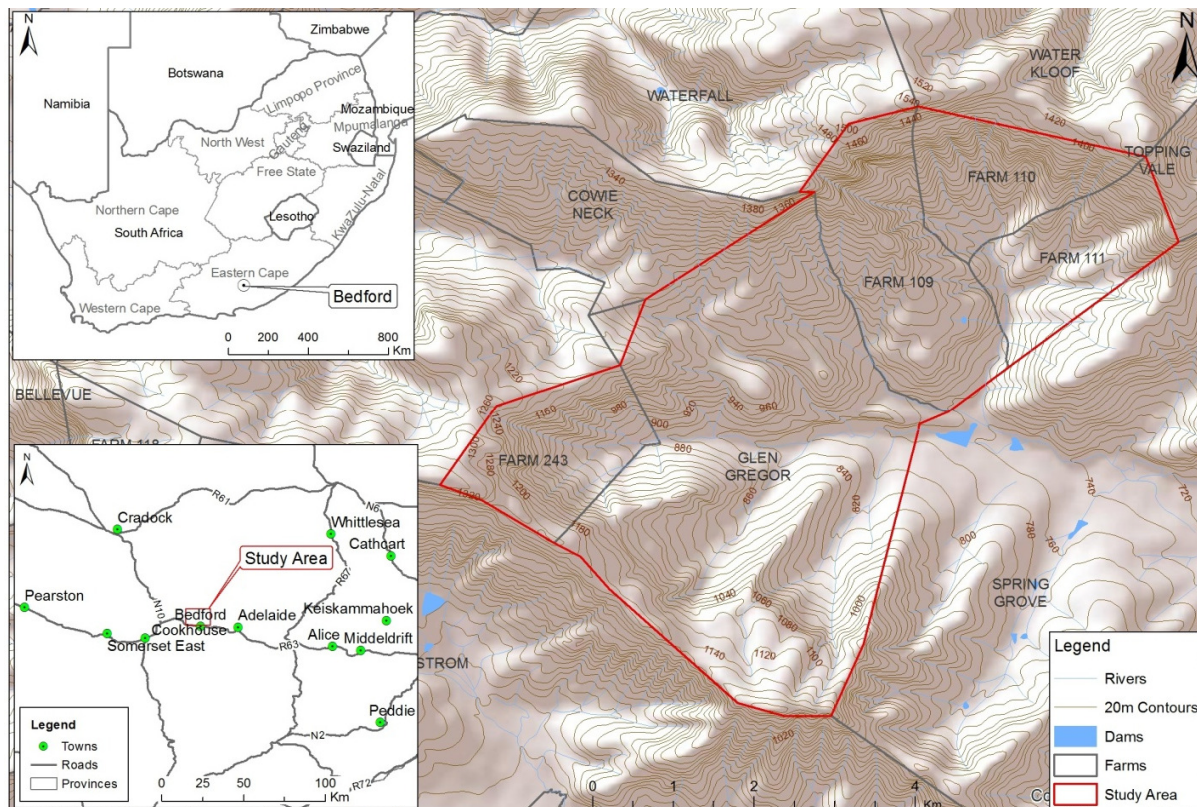
Figure 7. Location of study site, Glen Gregor Farm, Bedford, Eastern Cape

2.2. Climate

Regional climate is semiarid and characterized by bimodal rainfall in spring and late summer (mean annual precipitation is 310 mm to 550 mm), thus a summer rainfall region with hot dry spells commonly occurring between major rainfall periods. At the study site, local climate varies considerably between cool high and warm lower lying landscape features. The high lying plateau marks the southern bounds of the Amathole – Winterberg range and creates a unique climate. The nearest weather station based in Adelaide bears no similarity to climatic conditions at this specific site. Rainfall on the plateau and along the descending mountains folds (occupied

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by *C. validus*) is considerably higher (>1000mm/annum) compared to drier conditions in low lying valleys. Rainfall in the upper slopes is supplemented by coastal mists and dew formation throughout spring/summer months.

2.3. Topography, Soils and Vegetation

Topography ranges from a high lying plateau (approx. 1500 masl) along the northern and eastern boundaries to undulating flats in the low lying valleys (800 masl). Dominant soil types are classified as loam to clay loam of the Glenrosa and/or Mispah form (Mucina and Rutherford 2006). Differences in vegetation types are largely determined by landscape and climatic features which are discussed below. The stocking rate of the mixed *Bos indicus* and *Bos taurus* oxen herds on *C. validus* veld is 3 Au/ha managed on a rotational grazing basis.

2.4. Species and community description

The moist, high lying escarpment is associated with typical Dohne Sourveld (Acocks 1988). Mucina and Rutherford (2006) classified this short structured grassland as Amathole Mistbelt Grassland. Important grass taxa include *Tristachya leucothrix, Heteropogon contortus, Elionorus muticus, Eragrostis capensis, Microchloa caffra and Festuca* spp.

Cymbopogon validus grassland dominates the extent of the descending mountain folds, from steep upper slopes to the flatter, bottom sites (Figure 8). *Cymbopogon validus* slopes are separated by "fire shadow" crevices and generally surrounded by a closed woodland community similar to Eastern Cape Escarpment thicket which on the study site, and as described, grades into thornveld (*Vachellia karroo* dominated) as the landscape descends. Important species in the community proper include *Olea europaea* subsp. *africana, O. capensis, Rhus* spp. and multi stemmed shrubs such as *Scutia myrtina* and *Euclea crispa*. Tall structured Southern Mistbelt forest have developed along the Cowie River at the bottom of the valley. *Podocarpus falcatus* and *P. latifolius* both occur, and along with *Celtis africana* form important and distinctive canopy species in these forests.

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Figure 8. Study site at Glen Gregor, Bedford. *Cymbopogon validus* dominated areas occupy the extent of the descending mountain slopes in the middle of the landscape.

The dry lower lying areas consist of a mixed and sweet veld type with savanna – like vegetation. Important taxa include *Sporobolus fimbriatus*, *Sporobolus africanus, Setaria sphacelata, Eragrostis* spp. and *C. plurinodis*. Acocks (1988) classified these vegetation types as False Karroid Broken veld and False Thornveld. Bush encroachment and infiltration of *Vachellia Karoo* into these grazing areas is a recent and serious management issue. More recent classification refers to the veld as Bedford Dry Grassland (Mucina and Rutherford 2006).

2.5. General description of C. validus communities

Cymbopogon validus (Stapf) Stapff ex Burtt Davy, commonly known as Giant Turpentine Grass, is a tall, robust, aromatic perennial grass (Shackleton 1989; Van Oudtshoorn 2002). The grass behaves as a typical Increaser I and climax grass species in mountainous, high rainfall regions where it displays a tendency for high moisture sites (Killick 1963; Hilliard and Burtt 1987), particularly on south facing slopes (Camp 1997). These are potential forest areas with climatic conditions conducive to woody development, especially in the absence of fire or grazing

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(Tainton and Camp 1999, Titshall et al. 2000). Underutilization, i.e. the absence of defoliation promotes the dominance of *C. validus* and other tall forest margin grass species (*C. excavates, Miscanthus capensis, Hyparrhenia rufa, H. dregeana*).

Similarly, on the study site, mature, unmanaged *C. validus* areas are characterized by the encroachment of woody elements and other characteristics of potentially forested areas. *Searsia* spp., Bracken fern (*Pteridium aquilinum*), Black berry (*Rubus* spp.), Ouhout (*Leucosidea sericea*), Worm wood (*Artemisia affra*), *Helichrysum* spp. and *Buddleja* spp. are prominent, and indicative of the need of fire in order to prevent woody encroachment. *Cymbopogon validus* dominates the sward, and due to low acceptability this area is little utilized by grazers, fire being the only consumer. Few grass species co-occur within the dominant *C. validus* stands.

2.6. *Sampling procedure*

Six (50m) transects were randomly established in the top and bottom slopes of each camp (n=300). Species composition was determined by recording the nearest plant encountered at 1m intervals; measurements of point to nearest tuft distances and tuft diameter were also included. The species data was used to determine veld condition index according to Foran et al. (1978 increaser/decreaser classification system). According to Heard et al. (1986), N=200 is sufficient to determine veld condition score in a homogenous land unit. The inclusion of top and bottom slopes was based on assessing homogenous land units individually , and due to the marked effect of slope differences and its influence on grazing distribution (Cook 1966; Bailey et al. 1996).

The soil seed bank was assessed at five random sampling locations within each site (top and bottom). Five soil cores were bulked to form one composite, thus totaling five composites per site. Seeds were germinated at University of Pretoria's Experimental Farm in a greenhouse environment, following same procedures as in Chapter 2.

Basal cover was directly estimated using a 1m^2 quadrate, placed at 10 m intervals along each transect. The 1m^2 quadrate was divided into 20 x 20 cm^2 blocks and each block estimated in terms of percentage (%) rooted cover. Biomass production was measured by destructive

sampling. Fifteen 1 m² samples were randomly taken in each top and bottom slope per camp, therefore thirty samples per camp and 150 samples in total were collected. The samples were transported to the University of Pretoria, where samples were oven dried and weighed. Initial attempts with a calibrated rising plate meter were deemed inappropriate, given the high incidence of woody growth within the sward, reasoning that this would lead to overestimations of sward height.

2.7. Statistical analysis

Normality of the data was tested, using the Shapiro-Wilk normality test. Species composition, biomass, seed bank densities and basal cover data were not normally distributed. Therefore, the following non parametric methods of analysis were used.

- The Kruskal-Wallis test to test for the presence of significance in groups; species composition, basal cover, seed banks, and biomass.

- The Mann Whitney U test was first used to compare differences between groups, i.e. top vs top and bottom vs bottom, and secondly within groups, i.e. top vs bottom.

3. Results

3.1. Changes in Cymbopogon validus

Overall, results indicate large differences in *C. validus* between camps (Figure 9.1). These decreases followed increases in the total number of seasons that a camp was grazed (increasing from left to right) and not necessarily the number of burns. Overall, *C. validus* decreased significantly in top and bottom slopes of Ridges, Bushpig, Willows and Station when compared to the top and bottom slopes of the benchmark ($p < 0.05$).

Within camps, *C. validus* frequency was similar between top and bottom slopes in three camps ($p > 0.05$), namely Mbabaleng, Bushpig and Station. This contrasted significant reductions in the bottom slopes compared to top slopes ($p < 0.05$) of Ridges and Willows (Figure 9.1).

Decreases in *C. validus* runs parallel to increases in *S. africanus, P. dilatatum, C. dactylon, E.*

curvula, and *S. sphacealata* which are skewered to the right of the graphs (Figure 9.2-8) where camps were exposed to increased grazing episodes (total number of grazing seasons after each fire). *Dactylis glomerata* and *P. sphacelata* were unique to Bushpig (Figure 9.1-9-8).
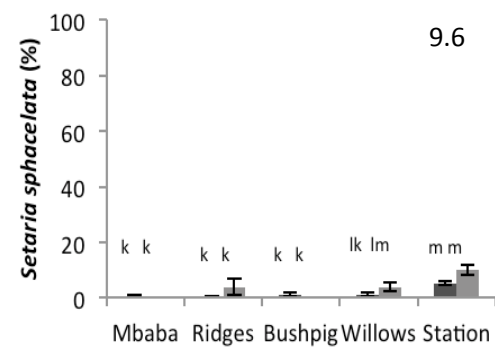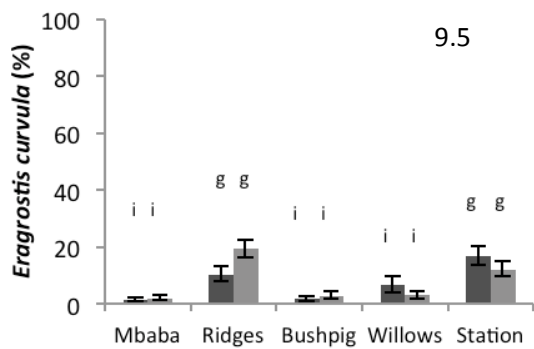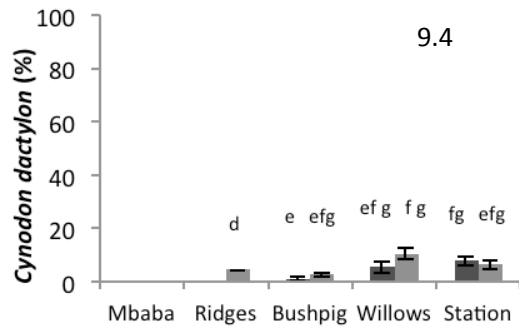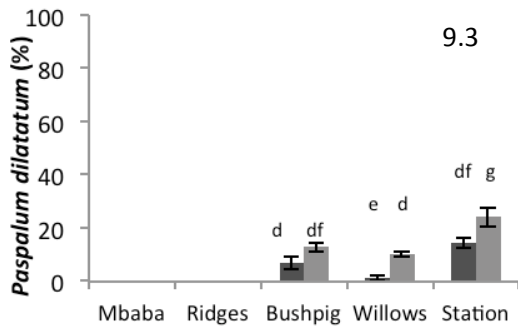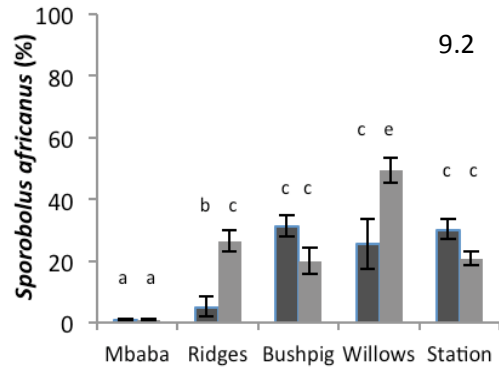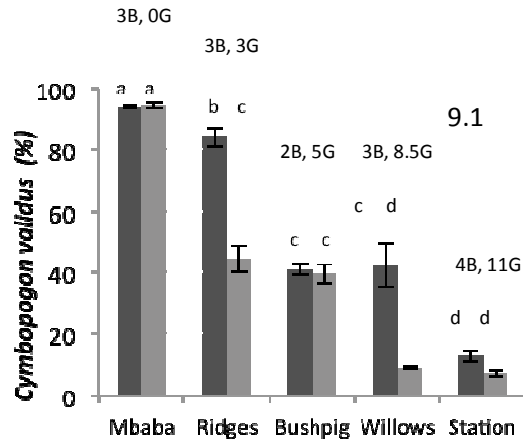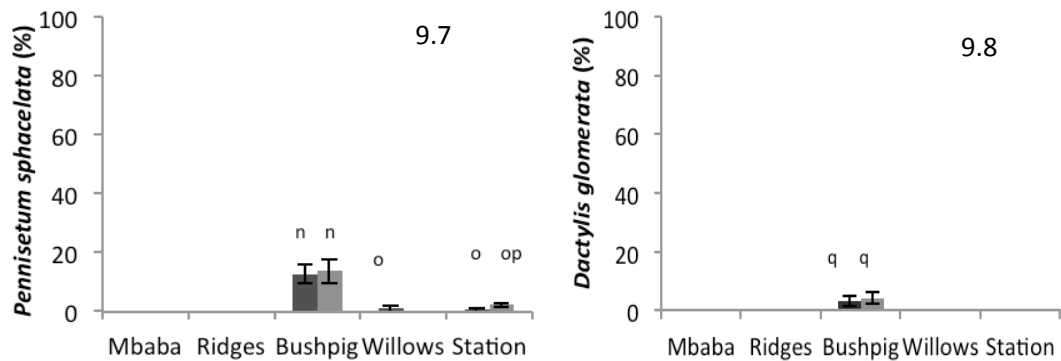
Figure 9.1-9.8. Relative frequency (%) of important forage species in top (▮) and bottom (▮) slopes calculated from 300 points per site. Insert at top of column indicates the number of times a camp has been burned (B) and the total number of season that it was grazed (G). Columns with different letters are statistically different (p < 0.05).

3.2. Species richness and diversity

Species richness and diversity followed a similar trend and increased along a gradient of increasing grazing and *C. validus* reduction (Table 2). The topographically isolated top slope of Ridges supported the least number of species; which was similar to Mbabaleng (p>0.05) but was significantly lower (p<0.05) than the bottom slopes of Ridges. Diversity was significantly low (p<0.05) in Mbabaleng and top slopes of Ridges compared to camps experiencing increasing number of grazing cycles. Bushpig top and bottom were similar to each other, and to Willows top and bottom. In contrast, Station supported significantly more species and higher diversity (p<0.05) compared to all other camps.

Table 2. Mean species richness (S) and diversity (H) per transect in top and bottom slopes of sampled camps. Groups with no common letter are significantly different (p<0.05)

	Richness (S)		Diversity (H)	
	Top	Bottom	Top	Bottom
Mbabaleng	3.33±0.33a	3±0.36a	0.11±0.05a	0.12±0.04a
Ridges	2.67±0.33a	5.17±0.31b	0.27±0.33a	0.67±0.03b
Bushpig	6±0.26bc	6.67±0.33bc	0.69±0.01bc	0.73±0.02bc
Willows	7.67±0.42bc	8.5±0.62c	0.66±0.04bc	0.7±0.03c
Station	9±0.58d	10.67±0.33d	0.81±0.01d	0.83±0.02d

3.3. Soil seed bank

Overall, *C. validus* was only found in soil seed banks in less intensively grazed sites (where *C. validus* persisted in the standing vegetation) of Mbabeleng, Ridges and Bushpig (Table 3). *Sporobolus africanus* was the most abundant species in the seed bank of heavily grazed camps of Willows and Station. Station top and bottom were similar ($p > 0.05$), but *S. africanus* was significantly higher ($p < 0.05$) in Station bottom compared to Willows top and bottom and Ridges bottom. Bushpig top and bottom was similar ($p > 0.05$) to Willows, Ridges (bottom) and Station while *S. africanus* was absent in Mbabaleng and Ridges top. In general, seed banks were composed of the same pioneer and sub climax species of which *S. africanus, P. dilatatum,* and *D. ternata* were the most conspicuous (Table 3).

Table 3. Species abundance in soil seed banks obtained in the seedling emergence method from soil samples collected in January 2012. Treatments with no common letter are significantly different (p<0.05).

Species	Mbabaleng		Ridges		Bushpig		Willows		Station	
Climax	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Andropogon appendiculatus										0.4±0.8
Cymbopogon validus		0.2±0.4a	1±0.7b	0.4±0.9ab	0.6±0.8ab	0.4±0.89ab				
Sub climax										
Eragrostis curvula			0.8±1.1							
Sporobolus africanus			0.2±0.4a	3±1bc	3.2±1.7bc	2.4±2.3bc	1±1.4b	2±1.8b	5.8±4.3bc	5±2.1c
Dactylis glomerata						0.4±0.8				
Pioneer										
Bromus spp.	0.4±0.5a					0.4±0.9a	0.4±0.89a	1.4±1.3a	0.2±0.4a	
Cynodon dactylon								0.6±1.3		
Digitaria ternata				1.2±1.3a	5.2±2.2b	4.2±4.4b		0.8±1.1ad	1.8±1.3d	1.6±1.1d
Eragrostis obtusa							1±1.14	0.4±.8		
Paspalum dilatatum				1.4±1.3a	0.8±1.3a	0.6±0.8a		0.4±.8a	2.4±2.1a	1.6±1.5a
% Climax		100a	50b	6.6b	2b	4.7b				4.6b
% Sub climax			50c	50c	38c	33.5c	41.6c	30.7c	57cd	58.2d
% Pioneer	100a			43.4d	60c	61.8cd	58.4d	69.3cd	43cd	37.2d
Total	100	100	100	100	100	100	100	100	100	100

3.4. Veld condition characteristics

3.4.1. Veld condition Index

The *C. validus* dominated swards of Mbabaleng and the top slopes of Ridges ranked the highest according to the Veld Condition Index based on the Foran et al. (1978) classification (Figure 10). As a result, veld condition declined as the climax species *C. validus* diminished. It was replaced with lower scored, lower successional sub climax and pioneer species.
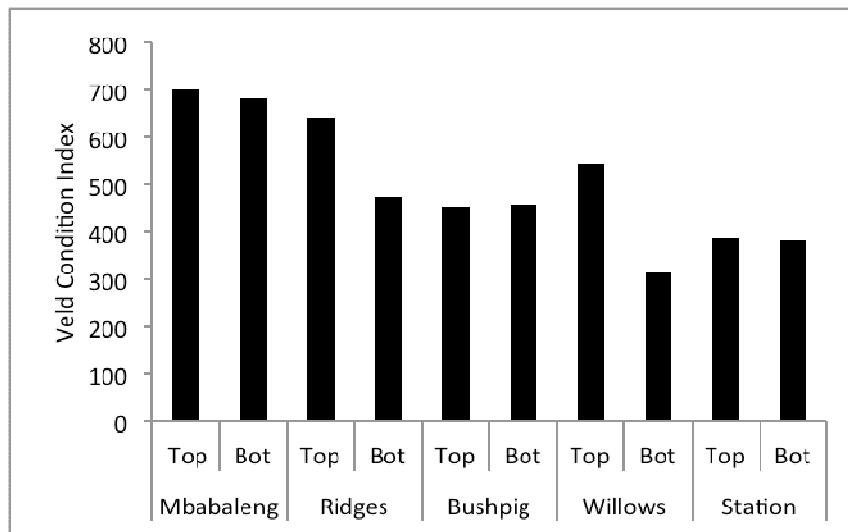
Figure 10. Veld Condition Index (n=300) for top and bottom slopes of camps on Glen Gregor.

3.4.2. Basal cover

Basal cover was poorest where the veld was in the climax condition (Mbabaleng and Ridges), and increased significantly (p<0.001) in Bushpig, Willows bottom, and Station camps (Figure 11). Basal cover in the top slopes of Willows was similar to that of the climax community of Mbabaleng and Ridges. In contrast, basal cover was highest in the top and bottom slopes of Station sites where *C. validus* diminished, and was replaced with a sub climax dominated sward. Similar basal cover values are noted in the uniform slopes of Bushpig (Figure 11).

Figure 11. Basal cover (%) box plots indicating differences within and between camps and top and bottom slopes. Columns with different letters are statistically different (p< 0.001).

3.4.3. Cymbopogon validus (%), average point to tuft distances, and average tuft diameter

Average tuft diameter decreased through the replacement of *C. validus* with smaller tufted sub climax and pioneer species. Average point to tuft distances were relatively variable, but showed marked decreases in Willows bottom, and Station where basal cover was highest (Table 4).

Table 4. Relationship between frequency of *C. validus*, average point to tuft distances, and average tuft diameter.

Camps	Slope	*C. validus* (%)	Ave. Distance to tuft	Ave. Tuft diameter
Mbabaleng	Top	94 ± 0.51	5.72 ± 0.61	10.02 ± 0.9
	Bot	94.3 ±0.8	7.67 ± 1.19	12.28 ± 1.05
Ridges	Top	84 ± 3.14	11.3 ± 1.26	9.9 ± 1.01
	Bot	44.3 ± 4.3	4.9 ± 0.74	7.54 ± 0.21
Bushpig	Top	40.67 ± 1.76	5.04 ± 0.38	7.6 ± 0.6
	Bot	39.7 ± 3.02	4.58 ± 0.67	8.02 ± 1.01
Willows	Top	41.67 ± 7.08	6.785 ± 0.74	5.67 ± 0.57
	Bot	9 ± 0.44	1.73 ± 1.42	4.12 ± 0.45
Station	Top	12.67 ± 1.9	2.44 ± 0.25	4.69 ± 0.42
	Bot	7 ± 1.12	1.71 ± 0.05	3.93 ± 0.21

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3.4.4. Standing biomass

Low biomass was recorded in Mbabaleng following a burn in August 2012, where measurements were collected in December 2012 (Figure 12). The short regrowth of the *C. validus* sward was similar to the heavily grazed sub climax sward of Willows bottom. High biomass was present in the underutilized *C. validus* dominated slopes of Ridges. Similar quantities were found in Ridges bottom (*C. validus* %F = 44.3±4.3), Bushpig top (40.67±1.76) and bottom (39.7±3.02) and Willows top (41.67±7.08) which reflected similar frequencies of *C. validus.* In contrast, Station top (*C. validus* %F 12.67±1.9) and bottom (7±1.12) supported a similar quantity however *C. validus* did not contribute to this based on its limited frequency in this camp (Figure 12).

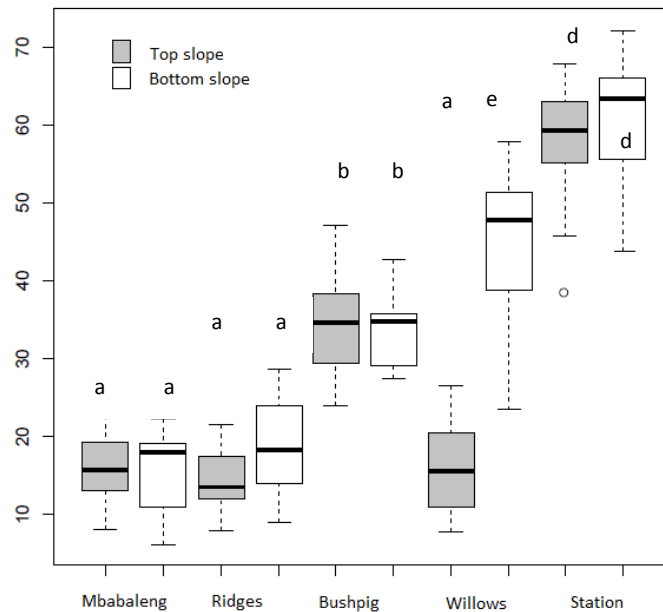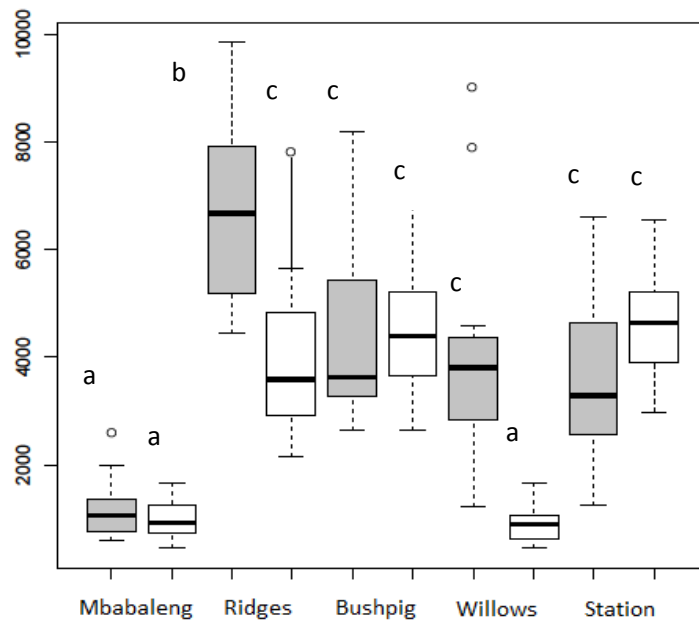Figure 12. Standing biomass (kg. DM. ha⁻¹) boxplots indicating differences within and between camps and top and bottom slopes. Columns with different letters are statistically different (p < 0.01).

4. Discussion

4.1. Changes in C. validus

In this study, the effect of burning on *C. validus* was dependent on the effectiveness of post fire grazing, keeping *C. validus* short and palatable through heavy utilization grazing cycles. Decreases in *C. validus,* and subsequent species replacements, were related to the total number of seasons that a camp was grazed after burning, and not the number of times it has been burned (Figure 9.1). Two to three seasons of cyclical grazing and rest periods are only possible if the sward is heavily and efficiently grazed at the outset and returned to throughout, before grasses have matured. The importance of uniform, heavy grazing and its influence on improving utilization in subsequent grazing periods has been documented (Morris 2002; Barnes et al. 2008), and forms the guiding management principle on this study site.

Significant decreases in *C. validus* were evident where grazing pressure was maintained for three consecutive seasons after each burn, as found in Bushpig (2 burns, 5 seasons grazing pressure), Willows (3 burns, 8.5 seasons grazing pressure), and Station camps (4 burns, 11.5 seasons grazing pressure). In these camps, the number of grazing episodes that *C. validus* has been exposed to is markedly greater than 17 months reported by and 2-3 seasons for controlling *C. validus* reported by . The absence of grazing after burning (i.e. Mbabeleng) or a single season grazing after burning (i.e. Ridges) means that grazing was not effective and *C. validus* was able to mature and resume dominance.

According to management, controlling *C. validus* in steep slopes of Willows and Ridges has been a major challenge since the beginning of the programme. Livestock avoidance of steep slopes is well documented (Mueggler 1965; Cook 1966) particularly when flatter, bottom slopes occur within the same grazing area (Willms 1990; Ganskopp et al. 2007; Allred et al. 2011). Biomass left uneaten at one grazing event will grow out further, and become less acceptable after each successive grazing event that it is left uneaten (Barnes and Dempsey 1992; Morris 2002). Livestock return to previously grazed plants and areas (flat bottom slopes), and avoid previously ungrazed areas (Ring et al. 1985; Fuls 1992; Bailey et al. 1996). This scenario is suggested to have caused the higher decrease of *C. validus* in bottom slopes of Ridges and Willows.

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Essentially, the steep slopes divided the grazing pressure; instead of grazing occurring equally over the whole camp, it is concentrated at the bottom slopes. This also means that stocking densities on bottom slopes are likely to be much higher than stocking density over the whole camp; implying that top slopes are not effectively stocked at 3 AU/ha. In comparison, the uniform slope of Bushpig and Station camps, allowed uniform grazing distribution, supported by similar *C. validus* abundance and species composition in top and bottom slopes.

4.2. Species richness and diversity

The influence of *C. validus* on the presence of other grass species was most evident in Mbabaleng and the top slope of Ridges. Species richness and diversity were lowest in these sites (Table 4). In the absence of sustained post fire grazing, the dense canopy of *C. validus* was able to recover quickly and probably out competed potential seedlings for all major resources ie. light, water, and nutrients (Grubb 1977; Bartha et al. 2003). Underutilized *C. validus* form an impenetrable mass of vegetation, in the top slopes of Ridges (Figure 12) and Mbabeleng, and to a lesser extent in the top slopes of Willows. In contrast, conditions for establishment were improved where post fire grazing pressure kept *C. validus* short, while the cumulative effect of intense, repeated defoliation reduced its abundance. The suppression of *C. validus* observed in Bushpig, Willows, and Station went hand in hand with increased species richness and diversity (Table 4.). Species typically favored under heavy grazing became increasingly important, including *S. africanus*, *P. dilatatum*, *C. dactylon* and *E. curvula,* which established in the wide, bare interspaces distinct in *C. validus* dominated veld (Figure 13). In agreement with this study, prescribed burning followed by cyclical heavy grazing have been used to reduce invasive populations of *P. maximum* in Texas, USA (Ramirez-Yanez et al. 2007) and *Imperata cylindrica* dominated stands in Rwenzori National Park, Uganda (Edroma 1981), with subsequent increases in species richness and diversity.

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Figure 13 (left) & 14 (right). Few grass species can compete below a dense, competitive canopy of *C. validus* and shrub species. Wide bare ground interspaces typical where *C. validus* dominates.

4.3. Soil seed bank

Soil seed banks play an important role in arid regions where plant populations are vulnerable to collapse under drought, and drought in combination with overgrazing (O'Connor 1991). Re-vegetation will depend on the persistence of seeds in the soil to recover, following large scale disturbances (Bakker et al. 1996). In contrast, the functional role of seed bank in mesic grasslands is suggested to be less clear because plant populations are generally more stable and resilient to disturbance (Bullock 1995). This is not the case for *C. validus*, and likely for other grazing intolerant climax communities subjected to fire and intense grazing, which has been emphasized thus far. Analysis in this study suggests a highly functional role of the seed bank similar to that commonly associated with arid environments. Sustained heavy grazing on *C. validus* would have significantly depressed seed reserves in this species, while also reducing established plants. Recruitment in the arising community would have been highly dependent on seed of other species present in the soil seed bank of the climax community.

This study showed that *C. validus* was eliminated from the seed bank in camps that had experienced heavy grazing in the past (Willows and Station), but was present where *C. validus* persisted in the standing vegetation (Mbabaleng, Ridges and Bushpig). This finding is supported by other studies that have showed that a species seed bank can be reduced, or eliminated,

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when established individuals are heavily grazed thereby preventing seed set and limiting additions to the seed bank (O'Connor and Pickett 1992; Bekker et al. 1997). The death of established individuals under sustained heavy grazing ultimately leads to the deterioration of the seed bank, and the species ability to recover. In contrast, the replacement of *C. validus* in the standing vegetation with sub climax and pioneer species lead to a dominance of these species in the seed bank. The extreme of this is evident in the most heavily grazed site, Station, where the seed bank comprised 57% and 43% (top) and 58.2% and 37.2% (bottom) sub climax and pioneer species, respectively (Table 3.). Sub climax species in Station bottom was similar to Station top but significantly higher ($p<0.05$) than all other camps.

Despite poor representation of *S. africanus, P. dilatatum,* and *E. curvula* in the climax condition where *C. validus* dominates (Mbabaleng, Ridges), it is suggested that these individuals will most likely provide the seed source for subsequent species replacement as *C. validus* is suppressed. Besides being tolerant of grazing, these species are prolific seeders (Stuart-Hill and Mentis 1982); their small, hard seed germinate profusely and generally persist in the soil seed bank longer than climax species (Snyman 2010).

4.4. Veld condition and status of the soil surface

Foran et al. (1978) classification ranks communities according to their successional status (grazing responses) and by implication assumes that the climax state is the most desirable community. The problem with this classification, which is highlighted in these results, is that not all climax species provide desirable forage and not all climax communities are in a state conducive for livestock grazing. For grazers, a community dominated by *C. validus* surely limits animal production yet *C. validus* dominated veld found in Mbabaleng and Ridges scored the highest veld condition index (VCI=700 and VCI=641) associated with veld in good condition. Furthermore, *C. validus* dominated veld (Mbabaleng and Ridges) had the poorest basal cover values indicative of poor veld condition. This finding contradicts the linear relationship between veld condition index and basal cover found in semi-arid regions (basal cover is high, intermediate, and low in veld in good, moderate and poor condition) (Snyman and Fouche 1993). In support of these findings, Danckwerts and Barnard (1981) contend that basal cover

does not relate to veld condition in high rainfall regions, which is what was found in this study. This study found an inverse relationship between veld condition and basal cover where the climax community supported poorest basal cover.

The replacement of large tufted *C. validus* populations by numerous, but smaller sized sub-climax and pioneer species lead to a tighter spaced grass population associated with increased basal coverage (Figure 13). This also resulted in smaller average plant diameters along the fire/ grazing gradient (Table 1). There was a strong negative relationship between *C. validus* occurrence and point to tuft distances (df = 58, Spearman's correlation coefficient = 0.801). The extremes of this are observed in Mbabaleng and Ridges (lowest basal cover, high point to tuft distances, *C. validus* dominant) and in Station (highest basal cover, lowest *C. validus*). According to Stoddart et al. (1975), increases in basal cover as veld condition decreases is not unusual as the presence of low growing, stoloniferous species generally increase under increased grazing pressure. These species cover relatively greater proportions of soil compared to tall, erect species. In this study, favorable grazing species such as *P. dilatatum* and *C. dactlyon* increased in occurrence as veld condition decreased according to the increaser/decreaser concept.

4.5. Veld productivity: quantity versus quality

The persistence of *C. validus* dominated swards represents inefficient conversion of primary rangeland resources (nutrients, sunlight, and water) because the large quantity of unpalatable forage in these climax communities is essentially unavailable to livestock without burning. Even with burning, these swards are not considered desirable for breeding stock, which is why oxen were introduced in the first place. The establishment of more desirable species, despite their sub climax status, allows for the conversion of these resources into a more productive sward capable of supporting animal production in the long term. The improved quality of the sub climax sward is such that management now uses these camps for breeding cow herds, thus increasing the area of desirable grazing available for breeding stock.

A low quantity of palatable *C. validus* is evident in Mbabaleng after being burned in August 2012. This contrasts the abundance of underutilized forage in Ridges, and to certain extents in

Bushpig and the top of Willows. *Cymbopogon validus* composition was 84 and 44% in Ridges top and bottom, 40 and 39% in Bushpig top and bottom, and 41% in Willows. Effectively, this implies that these percentages are unavailable for utilization. In fact, given higher biomass production per *C. validus* plant compared to lower yielding sub climax species, the actual percentage of unavailable forage is probably greater. This is extremely significant from a utilization point of view.

5. Conclusion

In this study, the effectiveness of oxen keeping *C. validus* short and palatable through intense graze and rest cycles (after burning) appears to dictate the different successional stages observed in camps and between top and bottom slopes. The successive replacement of *C. validus* by similar species in each camp, but different proportions of these species indicates a single, relatively predictable sequence of regression that is dependent on the total number of grazing episodes and not necessarily burning alone.

Fire alone maintained the typical climax *C. validus* community observed in Mbabaleng and the top of Ridges. Without heavy grazing pressure to suppress adult plants and create gaps, and/or opportunities for establishment of other species, *C. validus* dominated swards quickly become unpalatable and the potential benefits of burning are lost. In disagreement with the climax concept and veld condition index, the substituted sub-climax and pioneer sward, composed of *S. africanus, E. curvula* and prostrate grass *C. dactylon* and *P. dilatatum,* offer considerably better forage for livestock production compared to *C. validus* dominated veld in this region. The size and species composition of the soil seed bank also increased in the sub climax state compared to the poor condition of soil seed banks in *C. validus* dominated veld. Furthermore, basal cover was significantly improved in the sub-climax state. Populations of the palatable *Setaria spaceleata* were also increasingly frequent in Willows and Station, which further justifies the desirability of this veld for management. In conclusion, the presence of other grass species in the soil seed bank, regardless of their low occurrence in the climax condition, is suggested to play an increasingly important role in the re-organization of the arising community

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as *C. validus* is eliminated.

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

In Chapter 2, results indicate that annual burning of *H. hirta* dominated veld promotes its regeneration through increasing seed availability in the soil seed bank, and thereby facilitates the dominance of this species in the Gauteng Highveld*.* Seed densities were nearly two fold higher in the seed bank of annually burned veld versus a > 2 year fire return interval site whereas seedling emergence in the field was significantly higher in the annually burned site. It is postulated that seed production in *H. hirta* is stimulated by fire and that fire could have a positive influence on seedling emergence**.** It must be noted that although emergence was significantly higher in the burned sites, this study could not determine whether this was a direct result of fire enhancing germination of this species or because of higher soil seed bank densities in the annually burned site.

On the other hand, low seed availability associated with fire exclusion (>2 years) could be explained by *H. hirta* demonstrating decreased flowering/ seed production with time since fire. In management terms, if the exclusion of fire for a number of years leads to successively smaller seed inputs as seed production/ flowering decreases with time since burning, then the size of the germinable seed bank, and therefore potential for *H. hirta* recruitment, would be reduced. Prescribed burning of the sward at this stage, in combination with subsequent defoliation (either by mowing or intensive grazing) to prevent further seed set (and seed additions) could prove a useful tactic to inhibit *H. hirta*. Studies conducted in semi-arid Free State rangeland and *H. hirta* infested rangeland in New South Wales, Australia, showed that after three years, new seedling emergence can be arrested by eliminating species seed banks through preventing seed additions. Therefore, the process of suppression of this undesirable species would be further assisted by effective post fire grazing which keeps the plant in a vegetative state and prevents seed setting. In contrast, annual burning of *H. hirta* without effective post fire grazing to limit seed additions could aid in buffering population regeneration.

For farmers, the protection from fire for a number of years may not be a practical solution as the targeted area would need to be exempted from grazing during those years. In terms of

short term animal production requirements, most farmers would prefer to burn mature *H. hirta* to make use of high quality forage following fire. But the fact that burning (annual burning in particular) is required implies that utilization of *H. hirta* is not optimal in the first place. Therefore, the extent to which post fire grazing is maintained on these areas will influence the success of these strategies in terms of managing seed (and limiting regeneration potential) and reducing the need for frequent burning. Frequent burning is controversial in its' own right. Annual removal of protective standing vegetation (by fire) exposes the soil surface to increased temperatures and evaporation, limits soil moisture penetration, and promotes soil losses. Improving utilization, thereby limiting fire frequency, may limit these negative effects on ecosystem function. The timing, intensity and frequency of the grazing regime would need to be closely monitored in order to meet livestock dietary preferences while preventing seed setting. Grazing *H. hirta* heavily may satisfy both these requirements.

The persistence of established individuals remains a challenge; as there is evidence to suggest that *H. hirta* is extremely difficult to eradicate in areas where it has established and dominates. The deep roots of *H. hirta* confer a competitive advantage over other species particularly in drought years. In southern Africa, its dominance of previously disturbed areas such as cultivated lands and over grazed areas also shows its competitive superiority in marginal areas. However, conclusions drawn from this study and others, demonstrate that limiting seed additions is the first step in control of this species. Management of seed is particularly important as *H. hirta* germinates over a wide range of temperatures and water deficits which means that available seed is very likely to emerge and contribute to population maintenance. This study showed that annual fire increases seed availability and emergence which demonstrates that burning programmes for *H. hirta* dominated veld need to consider the effects of fire on seed dynamics, and subsequent grazing pressure for long term control. Given the increasing prevalence of low diversity within *H. hirta* dominated grasslands, alternative fire and grazing regimes need to be tested, over a number of years, focusing on its reproductive biology. As far as is known population response (seed banks, seedling recruitment, established individuals) of *H. hirta* to fire and heavy grazing has not been tested, and remains a knowledge gap of importance.

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The primary objective in Chapter 2 was to quantify and compare seed bank densities and seedling emergence of *H. hirta* between frequently burned and infrequently burned *H. hirta* veld. This was assessed over a single season due to time constraints, so variability between seasons cannot be accounted for, and therefore generalities are limited from these results. In hindsight, the inclusion of additional treatments (soil disturbance, litter, cutting to mimic grazing) to assess seedling emergence within these sites diluted the main aim, and affected subsequent data analysis and results. Despite the absence of treatment effects between sites, the low number of repetition per treatment also probably masked any possible effects that may have been revealed with more replicates.

With regards to the overall aims of this study, future work on improving understanding of fire effects on life history characteristics of *H. hirta* should include assessing actual seed production/flowering directly from established plants as well as monitoring establishment and survival of seedlings post emergence stage. This information combined with soil seed bank analysis would have given more information, particularly given the short duration of the study.

The elimination of *Cymbopogon validus* was assessed under fire and heavy grazing in the high rainfall regions of the Amathole mountain range. The species is known to be sensitive to grazing, but requires burning to promote heavy utilization of a sward that is generally not grazed at all. This study showed that although fire has a short term negative effect on *C. validus,* its primary influence is to render the plant vulnerable to the accumulative effects of intensive grazing. Burning without effective post fire grazing maintained a dominance of *C. validus*. In contrast, results show significant reductions of the targeted species related to the total number of seasons of grazing (after burning), with subsequent increases in diversity and related improvements to veld condition. The total number of seasons of grazing achieved was contingent on timeous management of oxen.

Therefore, contrary to predictions made by the veld condition assessment, *C. validus* dominated climax rangeland is in poor condition, which improves under increased grazing pressure. At this study site, climax *C. validus* communities were characterized by poor basal cover and low species richness and diversity of standing vegetation. Soil seed bank composition

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also reflected a dominance of *C. validus* with few co-occurring species. Under increased grazing pressure, *C. validus* dominated climax veld was replaced by a productive sub-climax sward, supporting a wider diversity of grasses which occupy the wide bare ground spaces characteristic of the climax condition. This increased soil surface coverage, thereby generally improved ecosystem functions such as enhanced infiltration and increased stability and soil organic matter conditions.

Stocking densities in *C. validus* veld were 3AU/ha, grazing for approximately two weeks, which, while not particularly high, was offset by the duration of the grazing which ensured that the oxen returned to previously grazed plants for a "second bite" within the same grazing period. This would mean that the vigor of the plant, which was still recovering from its first grazing and drawing on limited root and carbohydrate reserves, would be further stressed by the "second bite". The continuation of cyclical grazing through winter months, on account of high moisture availability on mountain slopes is of note, as growth in most grasses ceases in winter. It is suggested that extended periods of growth in high rainfall regions increases opportunities for sustained targeting of problem plants.

As mentioned above, the main objective of intense cyclical grazing is to overgraze and kill established plants. Intense grazing also prevents seed additions, thereby limiting regeneration potential in *C. validus*. Furthermore, the maintenance of a shortly grazed sward, which amounts to two to three years without the competitive dominance of a *C. validus* canopy, is a major secondary consequence which facilitated colonization by other species. The creation of gaps (removal of standing vegetation) is a major driver of species change in mesic rangelands and was likely the case in this study. The high rainfall *C. validus* sites provide optimal conditions for germination and establishment (as soil moisture is the major determinant of recruitment events) of new species especially when *C. validus* is suppressed. Analysis of the seed bank in *C. validus* dominated camps (especially Ridges top) showed that subclimax species (*S. africanus*, *E. curvula*) were present in the seed bank. The enforced rest applied to heavily grazed camps (after two to three years grazing) provided favorable conditions for these species to establish, reproduce, and gain a competitive dominance in the seed bank.

Increases in diversity following the removal of competing vegetation (canopy and/or litter) through fire and grazing has been found in *P. maximum* invaded rangeland in Texas, USA and *Imperata cylindrica* in Uganda. Like *C. validus*, mature *P. maximum* has a large, competitive, canopy that out-competes other species. Similarly, mature swards of *I. cylindrica* deposit a thick mass of litter on the ground which has a similar effect as dense canopies, and is removed by fire. More recent research showed that burning followed by 18 months of cyclical grazing with oxen did not reduce *C. plurinodis* dominated veld in the eastern Free State. According to Trollope (*pers comm.)*, this was due to the use of immature oxen (1½ - 2 years old) and lower stocking density (1.5 AU/ha), being less suited to deal with *Cymbopogon,* and as a consequence, the pressure on *Cymbopogon* was never achieved.

This study highlights the importance of timing in post fire grazing management of *C. validus* dominated rangelands. While results showed that *C. validus* is eradicated under increased grazing pressure, they also demonstrate that *C. validus* dominated rangeland can support livestock production (oxen in particular) in the short term (two to three years after burning) under cyclical grazing and rest periods. This supports the notion that species composition becomes less important in high rainfall, sourveld areas where plant size, or stage of plant maturity at grazing become more important for livestock production. The principles of keeping *C. validus* short and palatable for as long as possible has potential applications in other areas with similar dominant undesirable species.

Further, the influence of slope on grazing distribution had important consequences for achieving *C. validus* eradication over the entire site. In this study, topographical variation in the camps with steep top slopes and gentle bottom slopes seemed to override forage uniformity in determining the distribution of grazing. Comparatively less intense utilization in steep top slopes lead to *C. validus* "growing out" quicker and resuming its unpalatable nature, in contrast to the bottom slopes where intense utilization maintained *C. validus* in a grazeable condition and promoted faster rates of species change. It is therefore proposed that fencing off steep top slopes from gentle bottoms would improve utilization of top slopes, and facilitate subsequent species replacement. Past management experience with patch burning in the steep upper

slopes, was not successful as the favorable changes in species composition in bottom slopes continued to attract oxen. Therefore, fencing is likely the only solution. Finally, the use of mature oxen is a novel approach to utilize unproductive rangelands dominated by unpalatable communities. Further research is required on the use of oxen for other problem plants.

To summarize, this study showed that while general management principles are applicable to rangeland management at a broad scale it is imperative that each situation be addressed in a unique way. For example, fire and grazing management to control undesirable species is a proven strategy. However, as this study has shown, the specific management applications will differ between *H. hirta* and *C. validus* communities.

Even in the absence of grazing after burning, annual or biennial burning in *C. validus* dominated swards is not realistic in the environment of the study site. *Cymbopogon validus* retains its greenness throughout the winter fire seasons for two or three years after a fire (rainfall dependent). In contrast, annual burning is possible in *H. hirta* dominated veld in the Highveld where grasses are fully matured and dried in the fire season. High rainfall in *C. validus* environments meant fast grass regrowth such that more grazing cycles are possible in a growing season amounting to greater accumulative effect of grazing. Conceptually, less rainfall in the Highveld relates to relatively slower growth and fewer grazing cycles which may limit the impact of intense grazing on *H. hirta. Cymbopogon validus* is sensitive to repeated biomass removal however this does not seem to be the case for *H. hirta*. However, the latter is more palatable and without the chemical defense of *C. validus* which could allow cyclical grazing to occur over longer periods than the maximum of three seasons in *C. validus* rangeland.

In conclusion, there is a close relationship between fire and species prone to underutilization that seems unaccounted for in southern African rangeland research. This study does not dispute the adherence of *H. hirta* and *C. validus* to Increaser 1 species characteristics (species that increase with underutilization) but this classification ignores the effect of fire on species dynamics and the close association between fire and underutilization. That being, rangelands prone to underutilization (which favors Increaser I species) are also likely to burn more frequently. This especially is the case for *H. hirta* in the Gauteng Highveld, that is capable of

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supporting annual fires in the absence of grazing (under-utilization) and the effects of annual fire on seed availability, as demonstrated in this study.