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Influence of livestock grazing on plant diversity of Highland Sourveld grassland in KwaZulu-Natal

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ABSTRACT

The effect of livestock type (cattle-to-sheep ratio) and stocking rate on grassland species richness and vegetation composition were tested using two long-term trials in Highland Sourveld Grassland at the Kokstad Agricultural Research Station in KwaZulu-Natal.

The two-paddock trial (initiated 1996) was grazed by sheep at three different stocking rates, each of which was replicated twice. The simulation trial (initiated 1989) simulated a four-paddock rotational grazing system in which one paddock was rested for the entire grazing season and the other three were rotationally grazed according to a fixed schedule. It consisted of two stocking rates and five ratios of cattle-to-sheep.

Plant diversity and species composition were sampled using a Modified-Whittaker Plot in December 2005. For each trial, differences among treatments in species richness, diversity and evenness were analysed using analysis of variance. Differences in botanical composition were evaluated using canonical correspondence analysis.

The results from the two-paddock trial suggested that the responses had been confounded by burning, and by environmental and possibly historical variables. Lower species richness, especially of non-graminoid species was recorded for treatments that had been burnt during the preceding September. Despite these issues, an effect of grazing regime was apparent. There was an increase in mean number of species per $1m^2$ quadrat in the treatments grazed at the high stocking rate compared to those grazed at the low and medium stocking rates, which were associated with changes in species composition that enabled species suited to disturbed areas to colonise these treatments. As expected, species such as *Themeda triandra* declined in abundance with increasing grazing pressure whilst weedy species such as *Senecio speciosus* increased in abundance.

A higher mean number of non-graminoid species were found in the simulation trial in the treatments grazed at the low stocking rate but the converse was true of the graminoid species. Unpalatable species such as *Sporobolus africanus* and *Eragrostis plana* increased in response to increasing grazing intensity. *Senecio retrorsus*, which is known to increase in grassland that is over-utilised and *Tolpis capensis*, which is often found in disturbed places, increased in response to grazing intensity. Consistent with the findings in the other trial, *Helichrysum nudifolium* and *Vernonia natalensis* declined in response to grazing intensity. A general decline in the mean number of species per $1m^2$ quadrat and in the total number of species in all $1m^2$ quadrats was detected in response to an increasing proportion of sheep in the cattle-to-sheep ratio. The abundance of *Alloteropsis semialata* increased significantly at both stocking rates at low ratios of cattle-to-sheep whilst *Pentanisia angustifolia*, *Aster bakerianus* and *Monsonia angustifolia* declined dramatically in abundance with decreasing ratios of cattle-to-sheep, in some instances disappearing altogether. The results suggest that the ratio of cattle-to-sheep influenced both the species composition and species richness in the trial, resulting in a lower overall species richness at lower ratios of cattle-to-sheep and lower overall non-graminoid species richness at higher grazing intensities.

A major shortcoming of the data was the lack of statistical replication available to accurately determine trends and patterns associated with the different grazing regimes. This could have been overcome by establishing baseline conditions at the start of the trials and monitoring changes over time. This would have enabled trajectories of change associated with particular plant species to be identified and a clearer understanding could have been developed of the influence of different ratios of cattle-to-sheep and of different grazing intensities on species composition and richness over time.

The results of the study illustrate that sheep are not an ideal choice of livestock for maintaining plant diversity when grazing humid grasslands in KwaZulu-Natal, for which the best choice is a mixed-species grazing regime, consisting of a relatively high ratio of cattle-to-sheep.

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I dedicate my research to Wilma Martindale, my wife, who gave up her Christmas holidays to help me with my fieldwork in December 2005 and without whose love and support I would not have been able to complete this work.

DECLARATION

I Gregory Martindale declare that this research report is my own, original and unaided work. It is being submitted for the Degree of Master of Science (Resource Conservation Biology) in the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

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(Signature of Candidate)

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(Date)

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1) INTRODUCTION

Livestock agriculture in South Africa is heavily dependent on grassland, which supports over 150 000 head of cattle and 1.5 million sheep (Reyers and Tosh 2003), and is the foundation of the country's dairy, beef and wool industries. The grassland biome, which is the second largest biome in South Africa, at approximately 350 000 km^2, includes the country's main economic centre, the Witwatersrand, which is its most populous, rapidly urbanising and industrialising region. Due to this, and other pressures such as crop production and the operations of several key industries including mining and forestry, approximately 60% of the biome has been irreversibly transformed (Reyers and Tosh 2003). Levels of transformation and these intense and growing pressures are of particular concern because it comprises a centre of diversity with an estimated 3 788 plant species (Gibbs Russell 1987) and only 2% of it is formally conserved (Low and Rebelo 1996; O'Connor and Bredenkamp 1997).

Almost the entire area of the biome that has not been irreversibly transformed is used for livestock agriculture (Reyers and Tosh 2003). It is therefore important to develop an appropriate understanding of the impacts of livestock grazing in an effort to implement sound management practices aimed at maintaining grassland biodiversity. Although considerable knowledge exists about the ecology and functioning of grasslands in South Africa, most research has focussed on their production potential for livestock agriculture and most management strategies have been aimed at maintaining a species composition dominated by palatable grasses. To a large extent this has ignored the broader importance of the diversity of the biome, which is considered second only in species diversity in South Africa to the fynbos biome and is characterised by a number of rare and endangered species, most of which are endemic geophytes or dicotyledonous herbaceous plants (Low and Rebelo 1996). This study attempts to contribute towards a better understanding of the influence of livestock grazing, particularly in commercial agricultural operations, on the broader biodiversity of grasslands.

The impacts of grazing on grasslands are influenced by the intensity of grazing activity, as determined by stocking rates (Tainton 1999). As stocking rates increase, changes in grassland species composition occur, resulting in an increased abundance of species that are considered to be resistant to grazing and decreased abundance of species that are susceptible to its impacts, which are usually considered favourable for animal production. The type of animal utilised in grazing systems is also known to have different impacts (Hardy and Tainton 1995), as cattle are considered to be bulk grazers that are not overly selective in their grazing habits whereas sheep are considered to be selective grazers that will favour plant species that are more palatable, over those that are not. Consequently sheep and cattle are utilised to differing degrees in different grassland vegetation types, in which they are believed to be more suited to the conditions and perform better. Mixed grazing systems utilising sheep and cattle are also considered to result in better animal production and fewer impacts on grassland systems, as the grazing behaviour of the animals is considered to complement each other (Hardy and Tainton 1995).

The study examined the influence of stocking rates and ratios of cattle-to-sheep, on grassland species richness and vegetation composition at the Kokstad Agricultural Research Station in KwaZulu-Natal with the purpose of addressing the following questions:

(i) What effects do different stocking rates of cattle and sheep have on grassland plant diversity?

(ii) What effects do different ratios of cattle-to-sheep have on grassland plant diversity?

(iii) What broader conclusions can be drawn about the effects of stocking rates and stocking ratios on humid grasslands in southern KwaZulu-Natal?

(iv) What broader conclusions can be drawn about the role of livestock grazing in determining structure, composition and ecological functioning in South African grasslands?

2) THE ECOLOGY OF GRASSLANDS

The determinants of the extent of the grassland biome and the ecological processes that underpin it involve a complex inter-relationship of abiotic and biotic factors, which include plant-herbivore interactions such as livestock grazing. In order to understand the ecological implications of grazing, it is necessary to examine the current thinking on grassland ecological theory.

The following section outlines the broad ecological principles that are believed to underpin grassland dynamics, which are based on ecological equilibrium and non-equilibrium paradigms. Following this, the role of grazing in the ecology of South African grasslands is discussed within the context of such factors as climate and the influence of fire. Finally, the ecology of sourveld grassland, and the principal notions upon which the management of its grazing systems are based, are described and discussed.

2.1 Ecological theory and grasslands

Traditional notions of grassland vegetation dynamics have embraced concepts of Clementsian succession in which vegetation progressively develops through a series of plant communities from discrete pioneer stages to a climax stage (Tainton and Hardy 1999; Briske *et al.* 2003; O'Connor and Bredenkamp 1997). The development of vegetation through these stages is thought to be directional and reversible meaning that interventions such as fire or grazing will counteract with secondary succession, influencing the speed and direction of the successionary sequence (Tainton and Hardy 1999; Fynn and O'Connor 2000; Briske *et al.* 2003). This is thought to occur primarily though the influence of herbivores on the competitive abilities of the plants within a grassland community, alternately favouring certain species and reducing the competitive ability of others (Howe 1994; Crawley 1997; Olff and Ritchie 1998; Ritchie and Olff 1999; Tainton and Hardy 1999). This in turn has given rise to the increaser-decreaser concept in which plant species are classified on the basis of their response to defoliation (Foran *et al.* 1978).

This model of grassland vegetation dynamics is conceptually linked to the ecological equilibrium paradigm that contends that ecosystems are internally self-regulating through a number of negative feedback mechanisms that are predictable and directional, leading through a series of successional stages to an equilibrium point (Briske *et al*. 2003). The importance of grazing is emphasised in the model as a feedback mechanisms that influences competitive interactions of plants and is a key driver of ecosystem dynamics (Crawley 1997; Olff and Ritchie 1998; Cauldwell *et al.* 1999; Ritchie and Olff 1999; Tainton and Hardy 1999; Briske *et al.* 2003).

Contemporary notions of grassland ecology have challenged the Clementsian-based model as an over-simplification of vegetation dynamics (Ellis and Swift 1988), arguing that models based on discontinuous and non-reversible vegetation dynamics are more appropriate (Briske *et al.* 2003; O'Connor and Bredenkamp 1997; Smet and Ward 2005). Such models, which are conceptually linked to the ecological non-equilibrium paradigm, emphasise the role of external disturbance and contend that the capacity for internal regulation in ecosystems is limited (Briske *et al.* 2003). These systems are considered more dynamic and less predictable than equilibrium systems because their ecological drivers are thought to be primarily periodic and stochastic climatic events (Briske *et al.* 2003). Although some proponents for these models have argued that the effects of grazing on grassland productivity and ecology are negligible (Scoones 1994; Abel 1993), as the interactions between plant and animal populations becomes unimportant in the face of sufficiently large climatic variation (Ellis and Swift 1988), most contemporary non-equilibrium models do not discard the importance of grazing but attempt to include greater levels of complexity in the interactions of such factors as climate with grazing and fire.

Several non-equilibrium models, which are applicable to various environments and ecological conditions, have been developed. Arid grasslands systems are thought to conform to persistent non-equilibrium models in which rainfall variability is the primary driver of

vegetation dynamics and drought can result in marked changes in community composition, which may be significantly exacerbated by grazing (Briske *et al.* 2003; O'Connor and Bredenkamp 1997). Threshold models apply when a disturbance pushes a system across a threshold into a new stable state, which persists after the disturbance has been removed (Briske *et al.* 2003). In South Africa examples of threshold models have been found in areas of *Hyparrhenia hirta* tall grassland in KwaZulu-Natal, with instances recorded in which the primary palatable species, *Themeda triandra*, did not return following the removal of grazing, providing evidence that a threshold had been crossed (O'Connor and Bredenkamp 1997). Further examples of threshold models are thought to apply when grasslands become dominated by woody plants, usually due to changes in the frequency and intensity of fire, often as a result of high grazing intensity, which influences the availability of fuel and reduces the competitive suppression of woody species (Briske *et al.* 2003). The removal of grazing would not be expected to reverse the dominant pattern of the woody plants (Briske *et al.* 2003). This has been seen in South Africa in the interface between the grassland and savanna biomes, with the invasion and establishment of *Acacia karroo*, which often facilitates the invasion of bird-dispersed species (O'Connor and Bredenkamp 1997). A third non-equilibrium model is the state-and-transition model, which allows for greater complexity than the Clementsian-based model, by considering issues such as fire and climate, in addition to grazing, and eases the assumptions about the predictability of the system and its stability (Westoby *et al.* 1989, Briske *et al.* 2003). Unlike the Clementsian model, the state-and-transition model does not anticipate gradual transitions of vegetation states in a successional sequence but rather it envisages transitions between vegetation states that are induced by perturbations such as drought or grazing, or a combination of both (Fynn and O'Connor 2000).

In determining the merits of the two paradigms, their accompanying models and their applicability to grassland vegetation dynamics, it is important to consider that ecological patterns will vary across different temporal and spatial scales. Much of the empirical and theoretical evidence suggests that equilibrium and non-equilibrium dynamics operate simultaneously within ecosystems at different spatial and temporal scales (Illius and O'Connor 1999; Briske *et al.* 2003). This is because vegetation dynamics across spatial scales are characterised as a shifting mosaic of patches at various stages of succession that represent a complex response to disturbance regimes, resource heterogeneity, historic land uses and inter-specific competitive interactions (Stohlgren *et al.* 1999; Briske *et al.* 2003). At localised spatial scales, extinctions may arise from small perturbations but stability may still exist at the broader community level (Illius and O'Connor 1999). Similarly although animal population densities may not be dependent on plant productivity during the growing season, in seasonal systems that are continuously grazed, and may be considered non-equilibrial, mammalian herbivore populations are usually limited by their ability to survive periods of mass loss during the plant's dormant season (Illius and O'Connor 1999). On this basis equilibrium and non-equilibrium models may be equally applicable within ecosystems, depending on the spatial and temporal scale that is applied. For example, the Clementsian-based model arose out of rangeland management tools developed to evaluate sites that were defined on the basis of the homogeneity of local topo-edaphic conditions and rainfall regimes, which would not be applicable across broader scales in which successional rates and patterns may differ (Briske *et al.* 2003).

In this context, Whittaker *et al.* (2001) have developed a hierarchical theory of diversity, in which grazing is thought to have the greatest influence at local scales, affecting species richness and community composition within patches. This is supported by Stohlgren *et al.* (1999) who found that significant differences in species richness between grazed and ungrazed sites at the $1m^2$ scale were insignificant at the $1\ 000m^2$ scale in Rocky Mountain grasslands in the United States. The type of management regime applied within a grassland system may however influence the scale at which grazing influences species richness. The majority of the grazing systems evaluated in Stohlgren *et al.*'s (1999) study involved largely free roaming herbivores with access to various plant communities, able to optimise their nutrient intake. In contrast, confined livestock in intensive commercial grazing systems, provided with adequate

water, veterinary care and supplemental feeding have a far greater potential to impact on vegetation dynamics and alter species composition (Briske and Heitschmidt 1991; Briske *et al.* 2003).

Influences that are considered to operate at broader landscape scales than grazing include topography, catenal effects, soils and disturbance (such as fire), which affect the turnover of species between patches (Whittaker *et al.* 2001). This is supported in South Africa by O'Connor and Bredenkamp (2003) who contend that soil type has an important influence at the local or regional scale on plant species composition. Influences operating at the regional scale include climate, water energy-dynamics and residual historical patterns, which affect the differential overlap of species and their ranges (Whittaker *et al.* 2001). Whittaker *et al.* (2001) postulate that the influence of biological mechanisms, such as grazing, are either local in scale, or if regional, arise secondarily due to climate and are therefore 'linking mechanisms' rather than constituting first-order independent controls that set the pattern. Several South African studies support this claim (O'Connor 1994; Fynn and O'Connor 2000; Archibald *et al.* 2005), as does the conclusion by O'Connor and Bredenkamp (2003) that the overall extent of grassland in South Africa, appears to be primarily determined by climatic variables, although fire and grazing exert considerable influence over the biome's boundaries. Similarly Stohlgren *et al.* (1999) concluded that climate, soil fertility and other factors have a greater effect on plant species diversity than grazing and that species richness at landscape and regional scales may be largely controlled by climate rather than grazing.

It appears that both equilibrium and non-equilibrium dynamics operate in grassland ecosystems, at various spatial and temporal scales, to produce a broadly equilibrial pattern at the macro-scale, within which local areas may be non-equilibrial (Whittaker *et al.* 2001; Briske *et al.* 2003). The implications of this are that grassland communities may be structured by a complex interaction of processes that are both internal and external to an ecosystem, such as grazing and climate, and that the relative expression of equilibrium and non-equilibrium dynamics will be dependent on the time period following successive disturbances (Briske *et al.* 2003). It therefore appears that stochastic climatic variation does not maintain a system in a state of perpetual non-equilibrium, but rather that it superimposes fluctuations on the patterns of vegetation dynamics and species composition, which are responding to such factors as grazing intensity (Briske *et al.* 2003).

2.2 The ecology of South African grasslands

The South African grassland biome encompasses a wide range of rainfall and temperature variation, which suggests that the influence of equilibrium and non-equilibrium dynamics will vary across it. The implications of this are that effects of grazing, in combination with perturbations such as drought and fire, will vary across different regions of the biome, implying that the impact of grazing may be greater in some areas than in others. Consequently, it is argued that the more arid regions of the biome appear more susceptible to grazing induced compositional changes, following drought events, than do the higher rainfall areas that experience a reasonably consistent year-to-year rainfall regime (Ellis and Swift 1988; O'Connor 1994, Fynn and O'Connor 2000, O'Connor and Bredenkamp 1997). It is also likely that the complex relationship between grazing, fire, soils, topography and climatic variables, will differ across the biome, in some instances amplifying the role of one and in others reducing it.

Traditionally the grassland biome has been divided into two categories, climatic climax and fire climax grasslands (Acocks 1988, Tainton 1999), but it appears more likely that its overall distribution and extent is primarily determined by climatic variables, in particular rainfall, and to a lesser extent by temperature and soil properties (O'Connor and Bredenkamp 1997, Archibald *et al.* 2005). Although fire, like grazing, plays an important role in the ecological dynamics of grasslands, it does not appear to be a primary determinant of the distribution and extent of the biome but rather its influence appears to be a secondary determinant that is largely driven by climate (O'Connor and Bredenkamp 1997). Nevertheless interactions between fire

and grazing have important effects on vegetation composition, primary productivity and nutrient cycling, particularly in the more humid regions, where fire appears to play an important role in grassland ecological dynamics (O'Connor and Bredenkamp 1997, Snyman 2004, Archibald *et al.* 2005).

A number of plant species in areas that are prone to frequent intense fires, such as the Drakensberg and most of the humid grassland regions of KwaZulu-Natal, appear to have evolved adaptations in response to fire, indicating its historical evolutionary role (Hilliard and Burtt 1987; Trollope 1999, O'Connor 2005). The interaction between fire and grazing is primarily determined by the influence of fire on large-scale forage patterns and by the influence of grazing on fire fuel loads (Archibald *et al.* 2005). Fire appears to affect a number of aspects of the ecology of grasslands, including seedling establishment and survival and the effects of fire appear not only to be short-term, but may be longer-lasting, depending on subsequent climatic conditions and grazing regimes (Snyman 2004). The influence of the interaction between grazing regimes and fire is further affected by its frequency and the season in which a burn occurs (Trollope 1999, Snyman 2004, Archibald *et al.* 2005). For example, the effects on grassland that is burnt early before spring rains and then grazed heavily and continuously before it can produce substantial re-growth may include a substantial decline in plant vigour and changes in species composition (Trollope 1999). Similarly, burning in late spring or early summer, after active plant growth has commenced, may result in substantial impacts on plant productivity and vigour, and may substantially alter species composition (Trollope 1999).

Fire has been shown to be a potentially useful management tool for grazing systems, as it can be used to overcome issues of grazing selectivity and it may be used to control the invasion of undesirable species or the abundance of palatable and non-palatable grass species. For example, in humid grasslands in KwaZulu-Natal, it has been used to reduce the incidence of encroachment of undesirable fynbos species such as *Helichrysum aureum* and *Leucosidea sericea* as well as encouraging desirable grass species such as *Themeda triandra* and *Heteropogon contortus* while reducing the abundance of undesirable grass species such as *Alloteropsis semialata* and *Harpochloa falx* (Trollope 1999).

Fire appears to play an important role in the ecological dynamics of South African grasslands, particularly in the more humid regions, which experience frequent, intense fires. Together with climate, fire appears to be an important factor that interacts with grazing to produce substantial changes in grassland species composition and diversity.

A further concept that is considered to be important is the differentiation between sour and sweet grasslands. To a large extent, this is an arbitrary categorisation as many of the same species occur in both types of vegetation and in most instances it relates more to the ability of a region to support livestock production (O'Connor and Bredenkamp 1997). The primary difference between the two vegetation types is that sweetveld is able to provide grazing throughout the year while sourveld loses nutritional value rapidly in autumn and winter and is only able to provide grazing that can sustain livestock during the growing season. Sourveld largely corresponds to areas that have traditionally been described as fire climax grassland, which occur in regions of higher rainfall and cooler growing seasons, on relatively infertile, leached soils that are derived from parent material that is of intermediate to low base status and on soils derived from sandstones and quartzites in lower rainfall areas (Tainton 1999, O'Connor and Bredenkamp 1997). Sweetveld largely corresponds to areas that have traditionally been described as climatic climax grassland, which occur in more arid regions on soils that have not been substantially leached and are derived from parent material of an intermediate to high base status (Tainton 1999, O'Connor and Bredenkamp 1997). Sweetveld also occurs in wetter environments on soils that are derived from basic igneous materials (O'Connor and Bredenkamp 1997). The Kokstad Agricultural Research Station, where this study was undertaken, is located in a region of the grassland biome that is recognised as sourveld.

2.3 Sourveld ecology and management

Most sourveld communities are thought to be relatively ecologically stable, generally having a dense grass cover, soils that are not particularly susceptible to erosion and a relatively high and reliable rainfall regime (Hardy *et al.* 1999, O'Connor and Bredenkamp 1997, Snyman 2004). Although sourveld grasslands are now largely utilised for livestock farming, it is unlikely that grazing was historically a major factor affecting the plant dynamics of these areas (Hardy *et al.* 1999, O'Connor 2005). This is because the density of herbivores before European colonisation was in all likelihood substantially lower than it is today, primarily because of the poor quality of forage during the winter months (Hardy *et al.* 1999, O'Connor 2005). O'Connor (2005) estimates that current livestock stocking rates are six to 20 times greater than they were during pre-settlement times and grazing regimes are no longer dominated by small-bodied antelope species but by livestock that are substantially larger and spatially restricted in their movements in the landscape. As a result, most sourveld areas of grassland now experience markedly greater grazing and trampling pressure than would previously have been the case (O'Connor 2005). Due to increased grazing pressures, and possibly altered frequencies and intensities of fires, the community composition and ecological structure of many sourveld areas may have been significantly altered (Hardy *et al.* 1999).

Once unpalatable and grazing tolerant species dominate in sourveld, it is very difficult to return it to a state in which palatable species dominate, even when grazing is removed, suggesting that it has low resilience to grazing pressures (Hardy *et al.* 1999). *Themeda triandra* is thought to have dominated sourveld grassland communities in conditions of low grazing pressure and frequent fire (Hardy *et al.* 1999). Sustained high grazing intensities in these environments is believed to lead to a loss in abundance of palatable species such as *T. triandra* and an increase in the abundance of unpalatable species such as *Eragrostis curvula*, *Eragrostis plana*, *Sporobolus africanus* and *Sporobolus pyramidalis* (Hardy *et al.* 1999). Heavy grazing, which results in low fuel loads and prevents the occurrence of intense fires, is also thought to favour the increase of fynbos species in certain areas of sourveld (Hardy *et al.* 1999). In contrast, selective grazing, which is considered to occur more intensely with sheep than cattle, appears to result in an increase in the abundance of 'wire' grasses such as *Aristida junciformis*, *Elionurus muticus* and *Diheteropogon filifolius* (Hardy *et al.* 1999). Clearly grazing intensity, and the type of animal that is utilised for livestock grazing, has an impact on grassland ecology, which may result in substantial changes in species composition. For example, studies conducted in the Highland Sourveld of KwaZulu-Natal have shown that differences in stocking rates can result in dramatic impacts, with high stocking rates resulting in rapid changes in the grass sward to one that is dominated by unpalatable, grazing tolerant species, when compared with grassland that is grazed at low stocking rates and is dominated by palatable species (Hardy *et al*. 1999). O'Connor (2005) has argued however that although the grazing regime that is applied may influence species composition, it does not appear to have a substantial effect on species richness. In a study conducted in Highland Sourveld grasslands in the southern Drakensberg, he found that a protected site, which had only been lightly grazed by horses for the previous 50 years, supported twice the species richness of the grazed sites that he examined, which included communal and commercial areas as well as conservation areas, stocked with game. On this basis, he concluded that all forms of grazing under the different land use types, which are all at substantially higher stocking rates than would historically have been the case, have decreased plant diversity rather than the type of grazing regime applied.

Management for livestock production in sourveld regions conventionally involves a focus on four aspects: the use of fire as a management tool; the type of animal utilised, whether sheep or cattle, or both; the stocking rate; and the grazing management regime applied (Hardy *et al.* 1999).

The use of fire usually involves controlled burning during the dormant season or early spring in an effort to remove all dead and moribund material, to maintain the vigour of the desirable grass species and to avoid or minimise patch grazing (Hardy *et al.* 1999).

The use of sheep or cattle has markedly different effects. Grassland that is stocked with cattle tends to be more evenly and less closely grazed than that stocked with sheep so the impacts of cattle grazing in sourveld are thought to be less than those with sheep (Hardy and Tainton 1993, Hardy and Tainton 1995, Hardy *et al.* 1999). Generally, sheep grazing is highly selective and has been shown to result in a dramatic reduction in the vigour and ultimately the abundance of palatable species, and an increase in less palatable, grazing tolerant species (Hardy and Tainton 1993, Hardy *et al.* 1999). As a result, it has been recommended that a mix of cattle and sheep be utilised in sheep production systems on sourveld, preferably at a narrow ratio of cattle-to-sheep (Hardy and Tainton 1993, Hardy and Tainton 1995, Hardy *et al.* 1999). The rationale behind this approach is that the grazing behaviour of cattle complements that of sheep, as the cattle remove most of the bulk material, allowing the sheep to graze on shorter, leafy material, which they prefer (Hardy and Tainton 1993, Hardy and Tainton 1995, Hardy *et al.* 1999).

The aim of the stocking rate applied in sourveld is to maintain it in a state in which palatable grass species dominate. If such grasslands are under-stocked, or infrequently burnt, moribund material accumulates, which is thought to lead to undesirable changes in species composition (Hardy *et al.* 1999). At the other extreme, overstocking has been shown to result in the replacement of palatable species with less palatable or unpalatable ones (Hardy *et al.* 1999).

The choice of grazing management regime typically involves variations of rotational or continuous grazing systems and is usually determined by the type of animal utilised. In systems that utilise cattle and sheep together, it is generally considered necessary to burn or rest the grassland not more than once in four years (Hardy and Tainton 1993, Hardy and Tainton 1995, Hardy *et al.* 1999). In systems that utilise sheep alone, a different approach is applied, for example burning and grazing intensively in one year and providing a full season's rest in the following year (Hardy and Tainton 1993, Hardy and Tainton 1995, Hardy *et al.* 1999).

Two categories of plants that encroach into sourveld are recognised: those that increase when the grassland is under-utilised and infrequently burnt, most of which are forest-margin plants; and those that increase when the grassland is over or selectively-utilised (Hardy *et al.* 1999). The species in the latter category include *D. filifolius*, *E. muticus*, and *Senecio retrorsus* (Hardy *et al.* 1999). A number of fynbos species, including *Stoebe vulgaris* and *Leucosidea sericea*, are known to increase in both situations (Hardy *et al.* 1999).

It is clear that a reasonably comprehensive understanding of the ecology and management of sourveld grasslands has been developed. The use and management of cattle and sheep in livestock production systems has been well studied and their influence on the ecology of the grasslands from an agricultural production perspective is well documented. This study further examined these conclusions and the influence of the accepted grazing management practices on the species diversity within these grasslands.

3) STUDY AREA

The study was conducted at the Kokstad Agricultural Research Station in KwaZulu-Natal. It is operated and managed by the KwaZulu-Natal Department of Agriculture and Environmental Affairs that runs a number of agricultural field trials including grazing trials, which were established between 1989 and 1996 and have been designed to examine the effects of different grazing management regimes on grassland condition and stability, and animal performance. The site was selected for the study because the grazing trials provide a valuable source of consistent, reliable data that has been collected as part of a carefully controlled experiment.

3.1 Climate, soils and vegetation

The Kokstad Agricultural Research Station (30°31'S, 29°25'E) has a mean annual rainfall of 790mm and experiences cold winters from May to August with regular frost (mean daily minimum of 2.1°C) and a warm growing season (mean daily maximum of 24.5°C) from October to February. The research station ranges in altitude from 1 344 metres above sea level at its offices to 1 651 metres above sea level at its highest point, straddling two vegetation types, described as Highland Sourveld and Dohne Sourveld by Acocks (1988) which are grouped into Moist Upland Grassland by Low and Rebelo (1996). In the most recent vegetation map of South Africa (Mucina and Rutherford 2006), the research station falls within the vegetation type Drakensberg Foothill Moist Grassland, which is considered to be rich in non-graminoid species and is dominated by short bunch grasses including *Themeda triandra* and *Tristachya leucothrix*. The vegetation at the research station is characterised by short, dense grassland that seldom reaches a height in excess of 0.5m (Hardy and Tainton 1995). It generally occurs adjacent to Afromontane forest, which is common in valleys and sheltered areas, in the Drakensberg foothills of the Eastern Cape and KwaZulu-Natal (Low and Rebelo 1996).

The climate in which this vegetation type occurs is temperate and moist with a rainfall of between 605 to 1 000mm per year, which falls mainly in summer, and a temperature range of -3°C to 40°C, with an average of 16°C. Soils in this vegetation type are derived from the Karoo sequence sediments and are often shallow, rocky and leached (Low and Rebelo 1996). Within the research station, the soils on the lower, flatter parts of the site are relatively deep (90 – 120cm) and moderately to well drained. The dominant soil forms are Hutton soils with a luvic B-horizon, which indicates a higher clay content than in the A or E horizons. Other soil forms that occur in these areas include Clovelly, Avalon and Westleigh soils also with luvic B horizons. On the upper slopes of the site in which the two-paddock trial is located, the soils are predominantly shallow (30 – 90cm) and the dominant soil forms are Oakleaf and Hutton soils with luvic B-horizons. Other soil forms that occur in this area include Glenrosa and Mispah soils with a non-calcareous B-horizon and Clovelly soils with a luvic B-horizon.

A diversity of commonly occurring non-graminoid monocotyledons and dicotyledons species are found in this vegetation type and dominant grass species include *Themeda triandra*, *Heteropogon contortus*, *Tristachya leucothrix*, *Eragrostis curvula*, *Trachypogon spicatus*, *Diheteropogon filifolius*, *Alloteropsis semialata* and *Elionurus muticus* (Acocks 1988, Low and Rebelo 1996). Selective grazing and overgrazing of this vegetation type is known to result in an increase in the abundance of *Elionurus muticus* and substantial increases in the abundance of *Senecio retrorsus*, a poisonous Asteraceae (Acocks 1988, Low and Rebelo 1996). Acocks (1988) has also recorded that trampling and selective grazing by cattle results in a significant increase in *Eragrostis plana* in Highland Sourveld and that overgrazing by sheep results in significant increases in the abundance of *Acalypha schinzii*.

4) METHODS

4.1 The two-paddock trial

Two grazing trials at the Kokstad Agricultural Research Station were examined in this study. A two-paddock trial was established to examine the effects of sheep grazing on grassland condition, animal performance and soil loss. It was established in 1996 on a steep (30%) west-facing slope and consists of three different stocking rates (Figure 4.1) with each stocking rate replicated twice in a randomised blocks design (Michener 2000). The stocking rates were intended to be low (1.0 Au/ha), medium (1.5 AU/ha) and high (2.0 Au/ha) and the mean stocking rates reflect this (Table 4.1) but the actual stocking rates (Figure 4.2(a)) varied somewhat from this, from year to year. An animal unit (AU) represents a steer with a mass of 450 kg, which gains 0.5 kg per day on forage with a digestible energy percentage of 55% (Tainton 1999). The animals used in the trial were weaned merino lambs, approximately six of which equate to 1AU. As a result, a mean number of 7 sheep/ha were grazed in the paddocks stocked at the low stocking rates, a mean number of 11 sheep/ha were grazed in the paddocks stocked at the medium stocking rate and a mean number of 15 sheep/ha were grazed in the paddocks stocked at the high stocking rate, over the life of the trial.

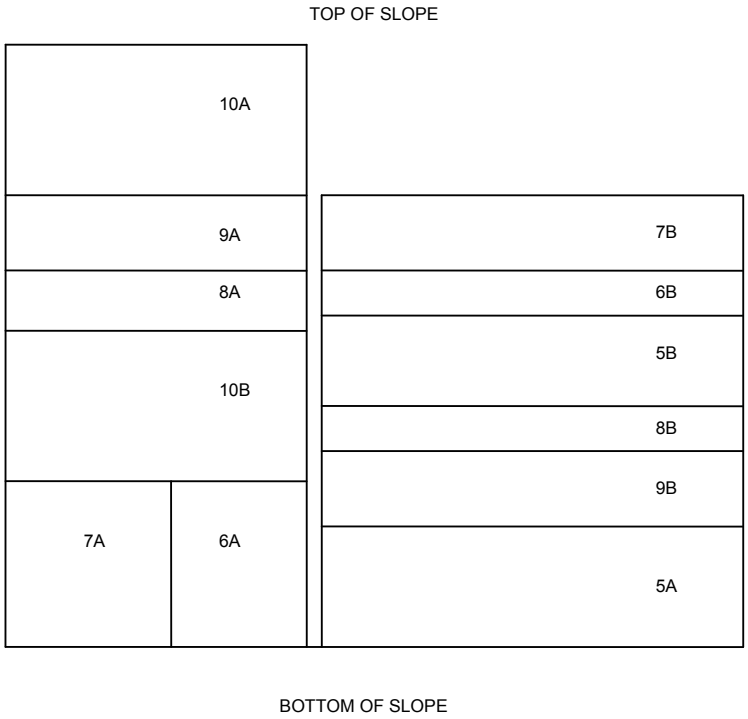


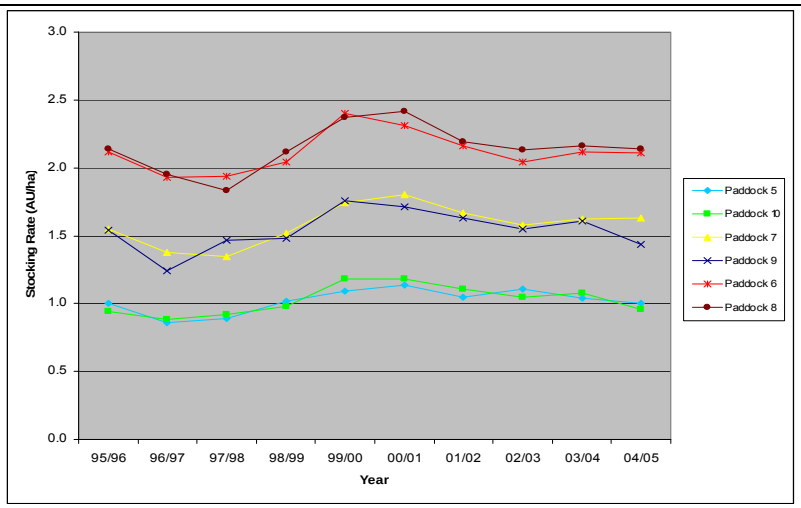
Figure 4.1 Two-paddock trial site plan (numbers indicate paddock numbers)

One of each replicate is burnt at the beginning of each growing season, shortly after the first rains, stocked as soon as possible thereafter and grazed continuously for the growing season. The sheep are then removed from the paddock at the end of the growing season in March or April. The second replicate is rested for the entire growing season. In the following growing season, the grazed paddock is rested and the procedure is repeated in the second paddock. The stocking rates shown in Table 4.1 do not refer to the mean of both occupied and rested paddocks but refer only to the occupied paddocks.

Table 4.1 Configuration of the two-paddock trial grazing regime during the 2005/06 season

Paddock number	Treatment	Stocking rate	Mean stocking rate (AU/ha)	Replicate	Burnt	Paddock Area (ha)
10A	Grazed	Low	1.03	1	Yes	1.09
10B	Rested	Low	1.03	1	No	1.11
5A	Grazed	Low	1.02	2	Yes	1.14
5B	Rested	Low	1.02	2	No	1.13
9A	Grazed	Medium	1.55	1	Yes	0.70
9B	Rested	Medium	1.55	1	No	0.74
7A	Grazed	Medium	1.59	2	Yes	0.72
7B	Rested	Medium	1.59	2	No	0.71
8A	Grazed	High	2.15	1	Yes	0.52
8B	Rested	High	2.15	1	No	0.52
6A	Grazed	High	2.12	2	Yes	0.52
6B	Rested	High	2.12	2	No	0.52

a)



b)

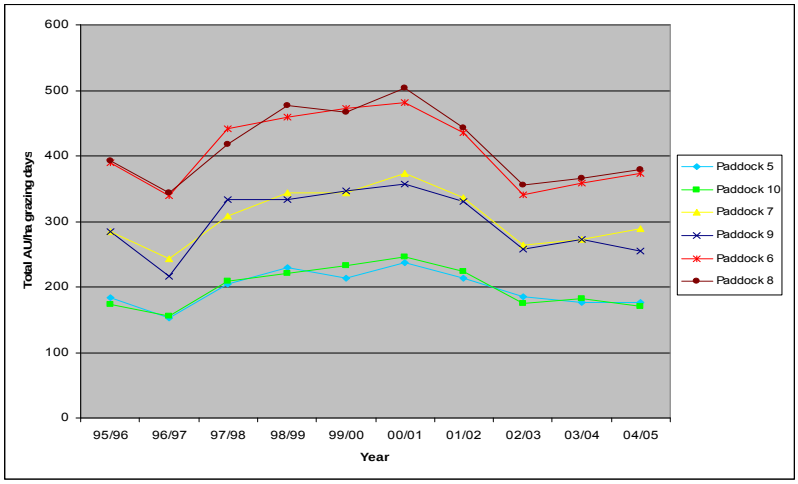


Figure 4.2 (a) Actual stocking rate and (b) Total number of grazing days per year in AU/ha in each of the paddocks (A and B replicates) from 1995/96 to 2004/05 (paddocks 5 and 10 – low stocking rate, 7 and 9 – medium stocking rate, 6 and 8 – high stocking rate)

The variation in the stocking rate from year to year resulted in considerable variation in the total number of grazing days per AU per hectare per year (Figure 4.2(b)). There was nevertheless a consistent and considerable difference in the grazing intensities between the paddocks stocked at the low, medium and high grazing intensities.

4.2 The simulation trial

The second trial simulated a four-paddock rotational grazing system, with two stocking rates and five ratios of cattle-to-sheep (Figure 4.3; Table 4.2) and was established in 1989. The actual mean stocking rates have varied somewhat from the intended 1.0 and 0.5 AU/ha (Table 4.2) and have also varied from year to year (Figure 4.4). The five ratios of cattle-to-sheep, measured in animal units, are 1:0, 3:1, 1:1, 1:3 and 0:1. Sheep and cattle are grazed together in the trial, and all animals on the different treatments are moved simultaneously.

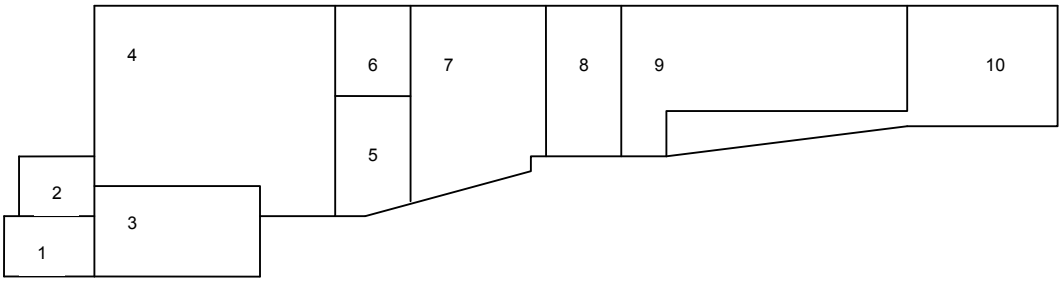


Figure 4.3 Simulation trial site plan (numbers indicate paddock numbers)

The trial simulates a four-paddock rotational grazing system, in which one paddock is rested for the entire grazing season and the other three are rotationally grazed according to a fixed schedule. The trial is a simulation trial, as only one paddock is used to create the conditions of a four-paddock rotational system. Animals are moved onto the paddock according to the schedule for two weeks and then moved off of it to an adjacent open area of grassland until the next grazing session. The paddock is burnt in early spring, rested and burnt again the following spring, once every four years. The paddocks were rested in the 2000/01 and 2004/05 seasons and grazed again in the 2005/06 season.

Table 4.2 Grazing regime of the simulation trial

Paddock number	Stocking rate	Mean stocking rate (AU/ha)	Cattle/sheep ratio	Paddock Area (ha)
10	Low	0.59	1:0	0.54
3	Low	0.66	3:1	0.81
9	Low	0.69	1:1	1.08
4	Low	0.72	1:3	2.16
5	Low	0.73	0:1	0.40
1	High	0.90	1:0	0.29
6	High	1.44	3:1	0.36
8	High	1.31	1:1	0.54
7	High	1.41	1:3	1.08
2	High	1.47	0:1	0.20

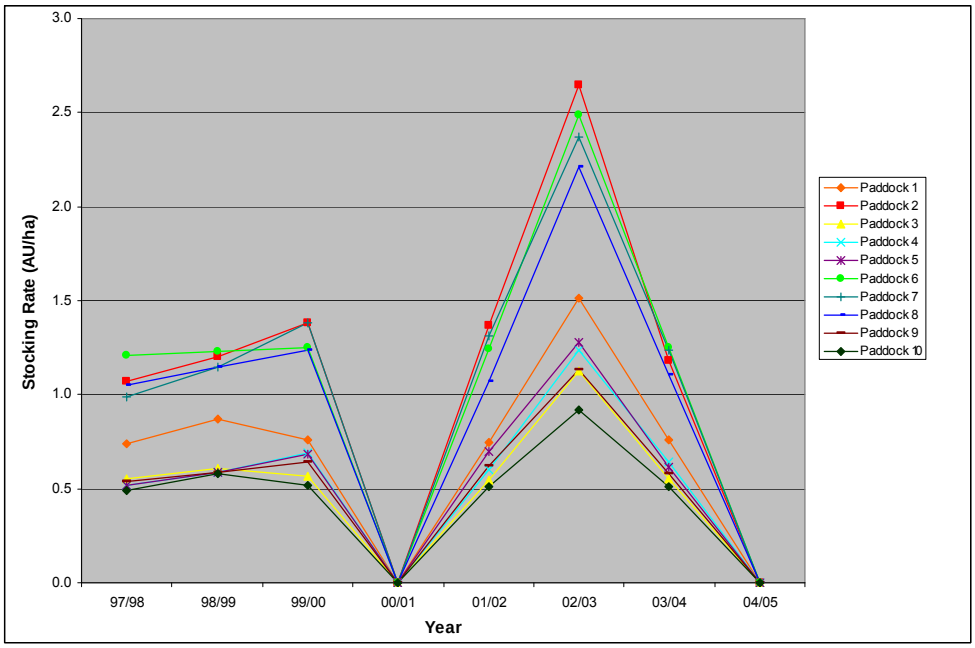


Figure 4.4 Actual stocking rates in AU/ha in each of the paddocks from 1997/98 to 2004/05 (paddocks 10, 3, 9, 4 and 5 – low stocking rate, 1, 6, 8, 7 and 2 – high stocking rate)

Originally the animals spent two weeks in the paddock and four weeks out of it, but since 2001 the animals have spent two weeks in it and only three weeks out, which constitutes a substantial increase in grazing intensity and total number of grazing days per AU per hectare per season. As in the two-paddock trial there has nevertheless been a consistent and considerable difference in grazing intensity between the high and low stocking rates.

The animals used in the trial are yearling steers and two-toothed merino sheep. Animals are supplemented and dosed according to the recommendations of the Animal Science section of the KwaZulu-Natal Department of Agriculture at Cedara and the State Veterinarian at Allerton.

4.3 Experimental design

The two grazing trials analysed in this study have been established as experiments, designed to determine the effects of livestock grazing on the ecology of the grassland in which they are located. In this study the response variables of interest in the two trials are plant species composition and diversity. The predictor variables, or factors, which have been controlled to determine their effects on the response variables, are grazing intensity and ratios of cattle-to-sheep in the simulation trial. In the two-paddock trial, the factor is the grazing intensity applied, which occurs at three different levels. The factors in both trials are quantitative and discrete.

Tilman (1989) has identified four conceptual issues that may affect the data generated in ecological experiments. These include transient dynamics, which relate to the changes brought about in a system from its original to experimentally altered state; indirect effects; environmental variability; and site history. These issues may lead to the misinterpretation of experimental results, which may in turn limit the ability to predict responses to grazing ratios and intensities (Michener 2000). They must therefore be borne in mind in interpreting the outputs of the data analysis.

There were several sources of variability within the design of the two trials that may have influenced the data that was collected. In both trials there was considerable variability in the dimensions of the paddocks. For example paddock 1 in the simulation trial was only 0.29

ha compared with paddock 4, which was 2.16 ha. Furthermore paddocks 9 and 10 in the simulation trial each described a dogleg shape, with a long narrow section that ran off one end of them, compared with the other paddocks, which were all a square or oblong shape. The differences in the dimensions in the two-paddock trial were not as marked as those in the simulation trial but they were nonetheless substantial. Although aspect and topography were all reasonably similar in the paddocks in the two trials, there were some differences in soil characteristics, which may also have introduced a degree of variability that may have influenced the data. Soil fertility and moisture are issues that greatly affect the distribution and physiology of plants, which may confound the results obtained from data. In an effort to overcome the sources of variability, plots in which data were collected, were located in each paddock down the slope, in areas of uniform appearance, away from drainage lines and other features that may have introduced unnecessary variability.

4.4 Data collection

Plant diversity and species composition were sampled based on a standardised technique developed by Stohlgren *et al.* (1995), known as a Modified-Whittaker plot, which was adapted from an earlier method developed by Whittaker (Shmida 1984). It samples plant diversity through systematic surveys at multiple spatial scales (nested quadrat sizes that can extend from $1m^2$, $10m^2$ and $100m^2$ within a 1 $000m^2$ area – Table 4.3), which enables the evaluation of spatial scale on local species richness patterns and allows for more meaningful comparisons of community richness than are provided by single-scale measurements (Stohlgren *et al.* 1995). Furthermore, multiple-scale sampling techniques enable the development of species-area curves, which can be used to estimate species richness at larger scales (Stohlgren *et al.* 1995).

The Modified-Whittaker plot is similar to the original Whittaker plot in that the total size of the plot is 20m x 50m but unlike the Whittaker plot, the $1m^2$ and $10m^2$ quadrats are arranged systematically within the perimeter of the 20m x 50m plot and are not abutting onto each other. As a result the quadrats are independent and non-overlapping.

Table 4.3 Dimensions of the subplots within the Modified-Whittaker plot

Dimensions	Configuration
Twenty $1m^2$ quadrats	1m x 1m (systematic, outer-perimeter, not contiguous)
Two $10m^2$ quadrats	2m x 5m (systematic, outer-perimeter, non-overlapping)
One 1 $000m^2$ plot	20m x 50m (overlapping)

Stohlgren *et al.* (1995) recommend the use of a third $100m^2$ quadrat, located in the centre of the 1 $000m^2$ plot, but studies undertaken in grasslands in South Africa have shown that this quadrat does not greatly contribute towards the development of species-area curves in Highland Sourveld (O'Connor 2005). As a result, the plot has been configured with two $10m^2$ quadrats in opposite corners and 10 $1m^2$ quadrats down each of the long axes of the plot (Figure 4.5).

Stohlgren *et al.* (1995) identified several critical design flaws in the original Whittaker plot that the Modified-Whittaker plot overcomes. The original Whittaker plot introduces problems of autocorrelation. In the original plot, there are 10 contiguous $1m^2$ quadrats, and the successively larger quadrats are superimposed on the smaller quadrats, which means that they are not independent in terms of species richness. A species rich area in one of the $1m^2$ quadrats will therefore affect the species richness in one of the larger sized quadrats (Stohlgren *et al.* 1995). The Modified-Whittaker plot overcomes this problem by ensuring that the quadrats are independent and non-overlapping.

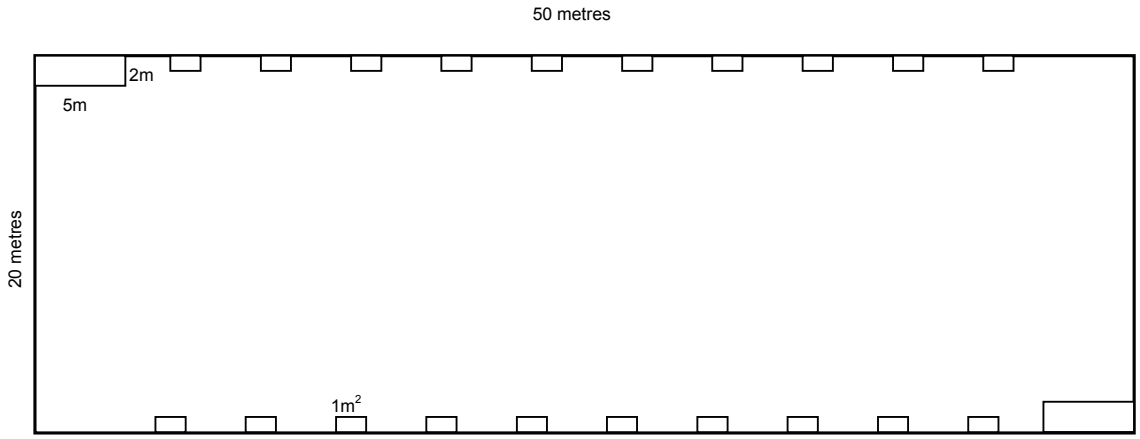


Figure 4.5 Study plot design

Prior to undertaking the sampling, initial fieldwork was conducted in November 2005 to collect and identify as many plant species as possible in an effort to develop a voucher specimen collection to be used for plant identification during the sampling process. Where possible specimens were identified in the field, otherwise they were taken to the Moss Herbarium at the University of Witwatersrand or submitted to the herbarium at the South African National Biodiversity Institute in Pretoria, for identification to the species level. During the sampling process, plants that could not be identified were pressed, mounted in a large scrapbook and assigned a number to ensure that they could be consistently identified when they were re-encountered during further sampling. A separate sample of each unidentified plant was collected, pressed and sent to the KwaZulu-Natal Nature Conservation Department for identification following completion of the sampling process.

Table 4.4 Cover scores assigned in the Domin scale

Score	Percentage cover/vegetation composition	Converted percentage
1	A species that occurs singly and occupies less than 1% of the quadrat.	0.1%
2	More than one specimen of a species but occupies less than 1% of the quadrat.	0.5%
3	A species that occupies approximately 1% of the quadrat.	1.0%
4	A species that occupies 1-2% of the quadrat.	1.5%
5	A species that occupies 3-5% of the quadrat.	4.0%
6	A species that occupies 5-10% of the quadrat.	7.5%
7	A species that occupies 11-25% of the quadrat.	18%
8	A species that occupies 26-50% of the quadrat.	38%
9	A species that occupies 50% or more of the quadrat.	65%

Each paddock in the simulation and two-paddock trials was sampled over a two and a half week period in December 2005 using a Modified-Whittaker plot. A reasonably uniform area that ran down the slope, capturing the elevation or moisture gradient of the paddock to maximise plant diversity in the plot, was selected. The 20m x 50m plot was then pegged. A $10m^2$ quadrat (5m x 2m) was marked in two of the corners (diagonally opposite), and all species within each quadrat were recorded. Ten 1m x 1m quadrats were sampled along each 50m axis

of a plot with quadrats spaced at intervals of 3m. Each species in each quadrat was recorded and its aerial cover estimated using the Domin scale (Jager and Looman 1987). A small 10cm x 10cm frame was used to assist the estimation of the aerial cover, as this provided a measure of 1% of the area of the quadrat. The Domin scale provides a score between 1 and 9, on the basis of the estimated percentage of aerial cover. For the purposes of the analysis, the values obtained from the Domin scale were converted to a middle percentage point (Table 4.4). The use of a measure of cover abundance was selected as it provides a greater indication of the dominance of a plant species within its community than a simple presence/absence measure.

Once the fieldwork was completed and all the data had been collected, the remaining plants that were unidentified were sent for identification.

4.5 Data analysis

Data type

The data collected for the study are discrete, which means that they can only take on specified values. In the case of the $10m^2$ quadrats, the data are presence/absence data, making them binary data, whereas the data collected in the $1m^2$ quadrats identify the presence of a species and assign a score to it on the basis of its aerial cover using the Domin scale, which approximates a log transform of percentage cover data (Jager and Looman 1987).

Diversity indices

There are several ways of defining species diversity. The simplest measure is species richness, which is a count of the number of species in a community. This measure often provides the most biologically meaningful results, particularly as there are frequently problems in the measurement of diversity and evenness indices. Other measures consider both evenness and richness and are referred to as heterogeneity (Ludwig and Reynolds 1988, Krebs 1989, Magurran 2004). The concept of evenness is based on the phenomenon that most ecological communities contain a few dominant species and many species that are uncommon. Evenness measures attempt to quantify this unequal representation in a community against a hypothetical community in which all species are equally common (Krebs 1989). Diversity indices, which provide an indication of heterogeneity, attempt to combine measures of both richness and evenness into a single value (Ludwig and Reynolds 1988, Magurran 2004).

The relative abundances of a large assemblage of species are conventionally the result of the interaction of a number of relatively independent factors that may be multiplicatively compounded (Ludwig and Reynolds 1988). Such species-abundance relationships are usually lognormally distributed, according to the statistical central limit theorem and may be graphically depicted by plotting the frequency of species against the logarithms of the abundance measures (Ludwig and Reynolds 1988, Magurran 2004). Although these techniques may be used to examine patterns of species abundance in communities, there is a lack of theoretical justification in their use, as their patterns may only be the result of the law of large numbers (Ludwig and Reynolds 1988, Krebs 1989). As a result, a number of non-parametric measures of heterogeneity that do not make assumptions about the shape of species abundance curves have been developed (Ludwig and Reynolds 1988, Krebs 1989; Magurran 2004, Williams *et al* 2006).

The Shannon index is based on information theory and measures the uncertainty in the question “how difficult would it be to predict correctly the species of the next individual collected?” (Krebs 1989). This uncertainty increases as the number of species increases and as the distribution of individuals among species becomes even (Ludwig and Reynolds 1988, Magurran 2004). Therefore *H*’ (the index of species diversity) increases and attains a maximum only when all the species in a sample are represented by the same number of individuals, which means that there is a perfectly even distribution of abundances (Ludwig and Reynolds 1988).

The Shannon index is thus a measure of the abundance of all species in a community and emphasises the rare species in a community (Ludwig and Reynolds 1988, Krebs 1989). The equation used to calculate the Shannon index for this study was:

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

where s is the number of species and p_i is the proportion of the total sample belonging to the ith species. H' increases with the number of species in a community and can theoretically reach very high values but in practice the values do not appear to exceed 4.0 or 5.0 (Krebs 1989, Magurran 2004). The Shannon index for diversity was calculated using the percent cover scores converted from the Domin scale for the $1m^2$ quadrats.

The primary criticism of such diversity indices is that because they combine variables such as the number of species and their evenness, this makes interpretation of their statistics problematic (Ludwig and Reynolds 1988, Krebs 1989, Magurran 2004). This is because a given value of a diversity index may be obtained for a community with a low richness and high evenness or for a community with high richness and low evenness. In order to ensure that the statistical outputs were accurately interpreted, it was therefore necessary to calculate an evenness index and compare this with the Shannon index to determine how meaningful the measures were.

Evenness indices

Two evenness indices were calculated. The first was derived from the Shannon index, which as a heterogeneity measure includes a degree of evenness (Magurran 2004). The maximum diversity that could be calculated for a Shannon index would be found in a situation where all species had equal abundances, where $H' = H_{max} = \ln S$ (Magurran 2004). This means that the ratio of observed diversity to maximum diversity can be used to measure evenness (Pielou's J') (Magurran 2004). This was calculated as:

$$J' = H'/H'_{max} = H'/\ln S$$

The second evenness measure calculated was Heip's index of evenness, which is not as dependant on species richness as Pielou's J' and is intended to reflect a low value where evenness is obviously low (Magurran 2004). The equation used to calculate this index was:

$$E_{Heip} = \frac{(eH' - 1)}{(S - 1)}$$

The maximum value of Heip's measure is 0 and it registers 0.006 for an extremely uneven community (Magurran 2004).

The diversity and evenness indices were calculated for each $1m^2$ quadrat rather than as a pooled value for the entire study plot, as the same values were used in the analysis of variance, which required a calculation for each of the $1m^2$ quadrats. Accordingly, for the sake of consistency, the same values were used, which led to somewhat small diversity and evenness indices values due to the small area used in the calculations.

Canonical correspondence analysis

The species composition of the two trials was analysed with the ordination technique, canonical correspondence analysis (CCA), using the CANOCO 4.5 package. CCA is an extension of correspondence analysis, a graphical ordination technique that is applicable to categorical data (Ter Braak 1986). It is a multivariate direct gradient analysis technique that is capable of

directly relating a set of environmental variables to a set of species (Ter Braak 1986). It does this by identifying the patterns of variation in community composition that can best be explained by the environmental variables (Ter Braak 1986). Accordingly, CCA analysis was undertaken on the two-paddock trial data to determine if the applied grazing treatments had an effect despite the influence of environmental variables on compositional variation, which appeared to have considerably influenced the data that was obtained. CCA is able to filter out the various abiotic factors that may influence composition to determine whether the grazing treatments were having an effect and what the relative effect of that influence was in the face of the other factors. CCA was also applied to the data collected in the simulation trial in an effort to determine the different effects of the stocking rates and ratios of cattle-to-sheep on compositional variation.

The data used in the analysis consisted of two separate data sets, an environmental and a species data set. The 25 species with the highest cover abundance scores were selected, as this accounted for approximately 97% of the total cover abundance. Three environmental data categories were used in the two-paddock trial – the three grazing intensities applied, the fire regime in which half of the paddocks had been burnt in the 2005/06 season and an apparent topographical effect in which it appeared that a pediment existed at the bottom of the slope in which material was being deposited, not eroded. This appeared to be influencing the species composition of the trial, as the drainage and soil characteristics appeared different down the slope. The paddocks were divided into those in the top half of the slope and those in the bottom half. Two environmental categories were used in the simulation trial – the two grazing intensities applied and the five ratios of cattle-to-sheep.

The data were analysed with canonical correspondence analysis, further subjected to a Monte Carlo permutation test (199 permutations). The Monte Carlo permutation test determines the statistical significance of the relation between the species and the set of environmental variables. Two tests were applied, one based on the first canonical eigenvalue, which determines the significance of the first ordination axis, and a second one based on the sum of all canonical eigenvalues, which determines the significance of all canonical axes together. The canonical correspondence analysis was first applied to untransformed data. The species data were then square root transformed to down-weight high abundances (Ter Braak 1986) and the analysis was performed again.

The ordination diagram produced through the application of the technique displays species and sites as points and environmental variables as arrows (Ter Braak 1986). The diagram displays the primary patterns of variation in community composition that can most effectively be explained by the environmental variables (Ter Braak 1986). It also reflects the distributions of the species along each environmental variable (Ter Braak 1986). The technique is based on the rationale that species are assumed to have Gaussian-shaped responses to compound environmental variables (Ter Braak 1986). The main advantage of the technique is that it allows a preliminary appraisal of how community composition varies with the environment (Ter Braak 1986).

Analysis of variance

Analysis of variance (ANOVA) is a statistical technique that tests for a significant difference between independent groups of data. Accordingly, it was an appropriate method for statistically comparing the differences between the various types of grazing regimes applied in the two trials.

ANOVA provides an overall test of the hypothesis that all the samples come from the same population, at the chosen level of significance, which in this case was $p \leq 0.05$, versus the alternate hypothesis that two or more of the varieties differ. The test concerns differences in means – the variances of the populations are assumed to be the same, or at least comparable (Sokal and Rohlf 1995, Galpin unpublished). If the overall test is significant, so that it is known that at least two of the groups differ from each other, follow-up tests (multiple comparison tests)

are performed at a more stringent level, in order to detect where the differences lie. The test used was the Tukey procedure, which was selected because it had been used as an appropriate technique in a similar study undertaken by Stohlgren *et al.* (1999).

The ANOVA test is based on a comparison of the response to different levels of a factor, on the groups of data, as arising from the application of a treatment (Sokal and Rohlf 1995, Galpin unpublished). The ANOVA test compares the variability between the levels of the factor to the variability within the groups or samples to see if there is a difference (Sokal and Rohlf 1995, Galpin unpublished). This means that the variability between the means for the groups of data is examined to determine if it is greater than the overall random variability within the groups of data (Sokal and Rohlf 1995, Galpin unpublished). The following variables were analysed using ANOVA:

- Total species richness and species richness of non-graminoid monocotyledons and dicotyledons, and grass species.
- The Shannon (*H'*) indices.
- Cover scores (Domin scale) and frequency occurrence (expressed as a percentage) of key individual species.

A three-way ANOVA was applied to the two-paddock trial data, using grazing intensity, the 2005/06 burning programme and the apparent pediment effect between the upper and lower slope, as the three factors. These three factors were applied, as there were obvious differences as a result of the burning programme and the apparent pediment effect that had to be considered in addition to the influence of the different stocking rates. A two-way ANOVA was applied to simulation trial data, the two factors being the grazing intensity applied and the different ratios of cattle-to-sheep in the trial. The ANOVA tests were conducted using Enterprise Guide 3.0, the user interface for the statistical package SAS 9.1. The data were first imported from Microsoft Excel, where they had been compiled.

Before conducting the ANOVA tests, the data were analysed to determine if they were normally distributed around the mean of the factor level using the Shapiro-Wilk test in SAS 9.1, which is an appropriate test of normality if the sample size is less than or equal to 2 000. Residuals were also plotted against the factor levels to check the ANOVA assumption of equal error variances. If the data were not normally distributed and error variances were not equal, appropriate data transformations were applied before conducting the ANOVA.

Species richness was analysed by comparing the number of species per $1m^2$ quadrat of each study plot. Cover types were analysed by first converting the cover scores, obtained from the Domin Scale, to percentage estimates (Table 4.4). Because the data approximate a log transform of percentage cover data (Jager and Looman 1987), an appropriate data transformation is the arcsine:

$$A = \arcsin \sqrt{p}$$

where p is proportion. Species diversity indices were analysed using the *H*' values obtained for each $1m^2$ quadrat. Differences in cover types and differences in the frequency of occurrence per 20 $1m^2$ quadrats of key individual species were analysed to determine if significant differences between the treatments could be identified.

Comparison of quadrats

In order to test the spatial differences in sampling between the $10m^2$ and $1m^2$ quadrats, a paired sample t-test was conducted of the total number of species collected in the 20 $1m^2$ quadrats and the total number of species collected in the two $10m^2$ quadrats in each paddock. The data are comparable as the total area of each of the types of quadrats is $20m^2$.

5) RESULTS

A total of 183 species from 39 families were found in the two-paddock (Appendix A) and simulation trials (Appendix C). Of these 19 species were not identified to the family, genus or species level and were simply assigned a specimen number. The families most strongly represented in the two trial areas were the Poaceae with 37 species and the Asteraceae with 35 species.

5.1 The two-paddock trial

Community composition

Plant cover

The grass *Diheteropogon filifolius* was dominant in most paddocks frequently contributing 65% or more to aerial cover. *Alloteropsis semialata* and *Themeda triandra* were the next most dominant species although they generally contributed considerably less to aerial cover than *D. filifolius*. Variation in total cover across treatments therefore reflected variation in cover of *D. filifolius* (Figure 5.1).

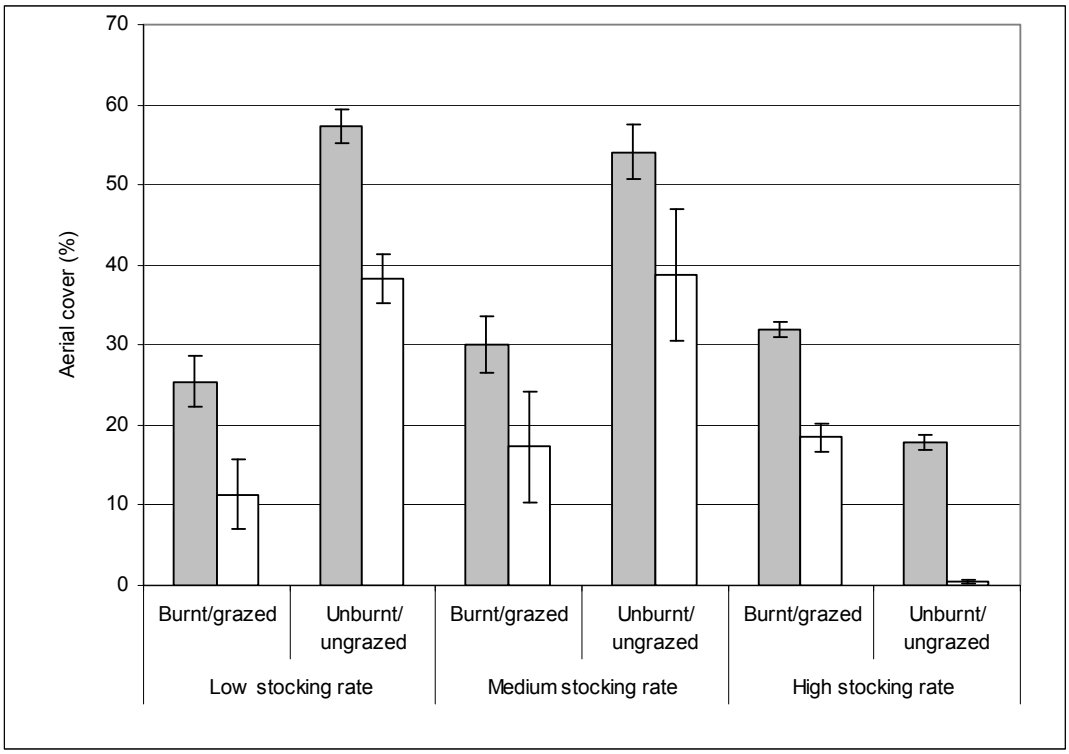


Figure 5.1 Comparison between the mean cover scores and standard deviation for all species (shaded columns) and *Diheteropogon filifolius* (open columns)

Analysis of variance ($F_{1,228}$ = 14.26, P = 0.002) and CCA confirmed that aerial cover of *D. filifolius* was inversely related to the visible pediment that existed at the bottom of the slope, in which material was being deposited, not eroded. This agreed with the observation that low cover abundance scores were recorded in paddocks grazed under all three stocking rates and in a number of instances paddocks located in similar areas within the trial site had similar cover abundance scores. The three paddocks located on the bottom-most part of the site, which were grazed at the low, medium and high stocking rates all recorded very low cover abundance percentages for *D. filifolius*, with paddocks grazed at the low and medium stocking rates having

mean cover abundances of less than 10% whilst the paddock grazed at the high stocking rate had a mean cover abundance of 20%. Similarly, the paddocks with the three highest mean cover abundance scores, one of which was grazed at the low stocking rate and the other two of which were grazed at the medium stocking rate and had mean cover abundances ranging from 33% to 50%, were located in a similar position higher up the slope in the trial site. Differences in soil types and soil moisture, associated with the pediment effect, may thus have influenced the distribution of *D. filifolius* and other species across the trial site.

Although in many instances *D. filifolius* appeared to almost completely dominate the vegetation cover in the trial, numerous species did occur under all of the grazing treatments, usually at very low cover abundances. The mean cover abundance scores for the 50 most abundant species after *D. filifolius*, *T. triandra* and *A. semialata* are presented in Appendix B.

Species richness

A marked divergence was evident in the results obtained for the paddocks that were burnt and grazed compared with those that were unburnt and rested in the 2005/06 season (Figure 5.2). Results of the analysis of variance (Table 5.1) confirmed a clear statistically significant difference in the number of species per $1m^2$ quadrat between those paddocks that were burnt and those that were not in the 2005/06 season. These differences were strongly reflected in the analysis of the number of non-graminoid monocotyledons and dicotyledons per $1m^2$ quadrat (Figure 5.2(d)) but were not reflected in the analysis of the graminoid species, suggesting that the non-graminoid monocotyledons and dicotyledons may have been more heavily influenced by the timing of the burning of the trial area in September 2005 or by the immediate impacts of grazing by the sheep than the grass species were.

Despite the influence of the burning programme, the stocking rate did have a statistically significant effect on the number of species per $1m^2$ quadrat, which was reflected in both the graminoids and non-graminoid monocotyledons and dicotyledons (Table 5.1). A statistically significant difference was detected in the analysis of all species and the non-graminoid monocotyledons and dicotyledons between paddocks grazed at the high stocking rate and those grazed at the low and medium stocking rate but no difference was detected between the low and medium stocking rates. This is reflected in Figure 5.2((a) and (d)), which show a considerably higher number of species in the paddocks that were not burnt and rested in the 2005/06 season that were grazed at the high stocking rate, compared with all other treatments. The results obtained in the analysis of the graminoids were due to a single statistically significant difference between paddocks grazed at the low and medium stocking rates. This is reflected in Figure 5.2(d), which shows a considerably lower number of graminoids in the paddocks grazed at the medium stocking rate compared with those grazed at the low stocking rate.

Table 5.1 P values from the three-way ANOVAs of grazing intensity, burning and the pediment effect on species richness data

Species richness variables	Fire	Stocking rate	Pediment	Stocking rate/ fire	Pediment/ fire	Stocking rate/ pediment
No. species per $1m^2$ quadrat	<0.0001	0.0097	0.2061	0.1510	0.0159	0.7751
No. graminoids per $1m^2$ quadrat	0.9851	0.0147	<0.0001	0.0578	0.0086	0.5463
No. non-graminoid monocotyledons and dicotyledons per $1m^2$ quadrat	<0.0001	0.0003	0.2599	0.5679	0.1477	0.6480

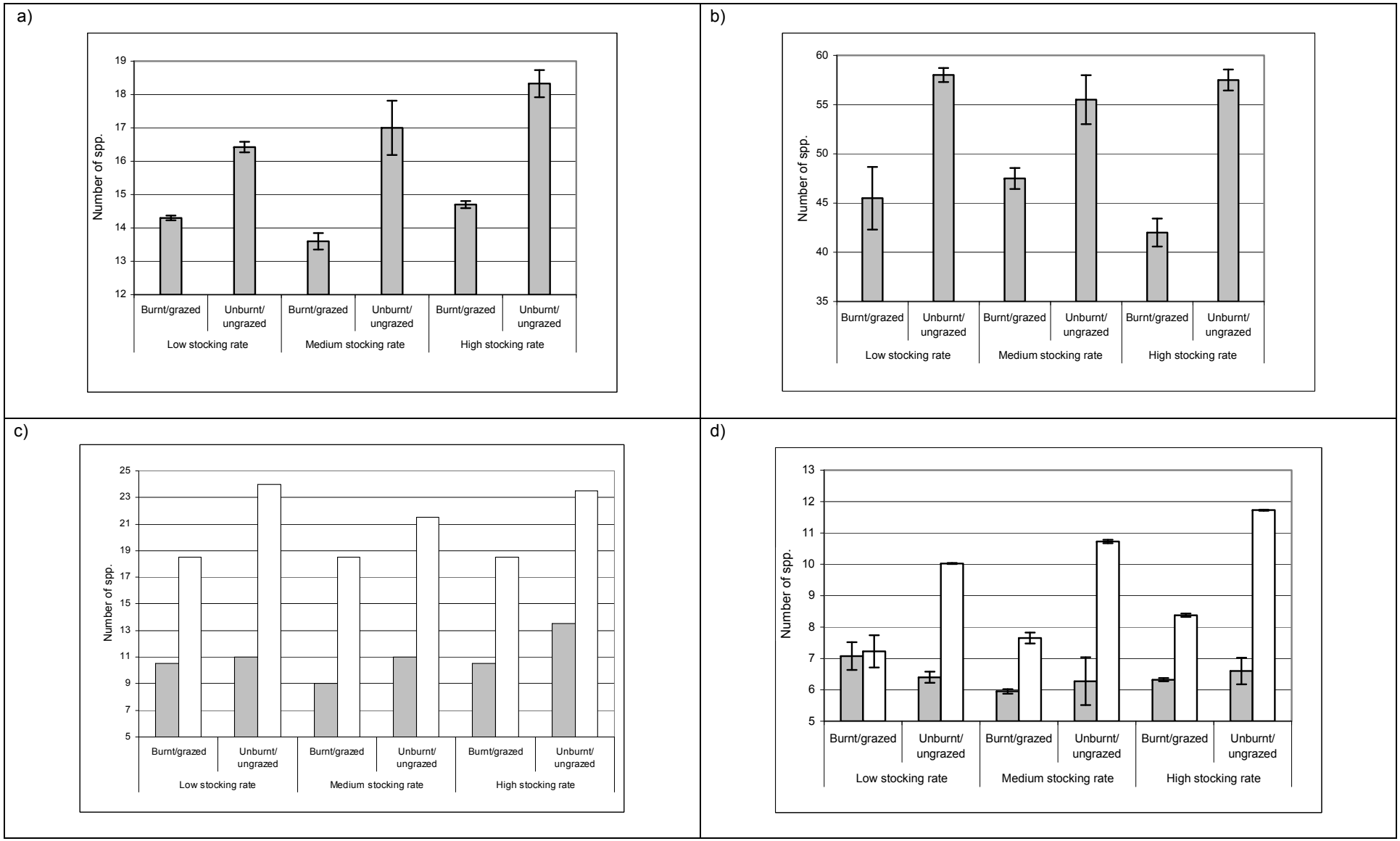


Figure 5.2 (a) Mean number of species per 1m^2 quadrat and standard deviation; (b) total number of species in all 1m^2 quadrats and standard deviation; (c) minimum (shaded) and maximum (open) number of species per 1m^2 quadrat; (d) mean number of graminoid (shaded) and non-graminoid monocotyledons and dicotyledons (open) per 1m^2 quadrat and standard deviation

A statistically significant difference was detected in the analysis of the pediment effect on the number of graminoids per $1m^2$ quadrat (Table 5.1). This was the result of considerably lower numbers of graminoids per $1m^2$ quadrat in the paddocks located on the upper slope of the trial site compared with those located on the lower slope. The three paddocks located uppermost on the slope of the trial site that were grazed at the low and medium stocking rates had mean numbers of graminoids per $1m^2$ quadrat of 6.45, 6.05 and 5.20 respectively, which compared with the three lowermost paddocks that were grazed at the medium and high stocking rates and had mean numbers of graminoids per $1m^2$ quadrat of 7.20, 7.70 and 7.35 respectively.

Although statistically significant differences were detected for all species and the graminoids in the interaction between the burning programme and the pediment effect, these appeared to reflect the statistically significant differences that had been detected as a result of the burning programme in all species and the pediment effect in the graminoids.

The results suggest that factors other than the different stocking rates may have strongly influenced the species composition and diversity of the flora within the trial. The most noticeable influence appears to have been the timing of the burning programme, which seems to have affected the non-graminoid species, resulting in a lower number of species and lower cover scores in the paddocks that were burnt and grazed in the 2005/06 season compared to those that were not burnt and were rested, at the same stocking rates. Differences associated with the pediment effect and possibly historical influences appear also to have affected the composition and cover abundance of the different species.

CCA of the cover abundance data confirmed a statistically significant relationship between the species and the set of environmental variables, as shown by the Monte Carlo test, in the test applied on the untransformed (first canonical axis: $F = 8.653$, $P < 0.005$; all canonical axes: $F = 6.407$, $P < 0.005$) and the transformed data (first canonical axis: $F = 16.864$, $P < 0.005$; all canonical axes: $F = 12.341$, $P < 0.005$). The first two axes accounted for 85.9% of the variation in the untransformed data and 80.6% of the variation in the transformed data. The relatively large eigenvalue of axis 4 (Table 5.2) however indicates that most of the variation in species composition was a result of environmental factors that were not included in the CCA. This is because only three factors were included in the analysis so only the first three axes are constrained.

Table 5.2 Summary of the CCA of the grazing intensities, burning regime and pediment effect on grassland composition in the two-paddock trial using transformed cover abundance data

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
Eigenvalues	0.069	0.044	0.027	0.184
Species-environment correlations	0.701	0.570	0.709	0.000
Cumulative percentage variance:				
of species data	6.7	10.9	13.6	31.4
of species-environment relation	49.2	80.6	100.0	0.0
Canonical coefficients:				
Grazing	0.5206	0.0101	0.4746	
Fire	-0.4000	0.3232	0.4212	
Pediment	0.2281	0.4559	-0.3510	

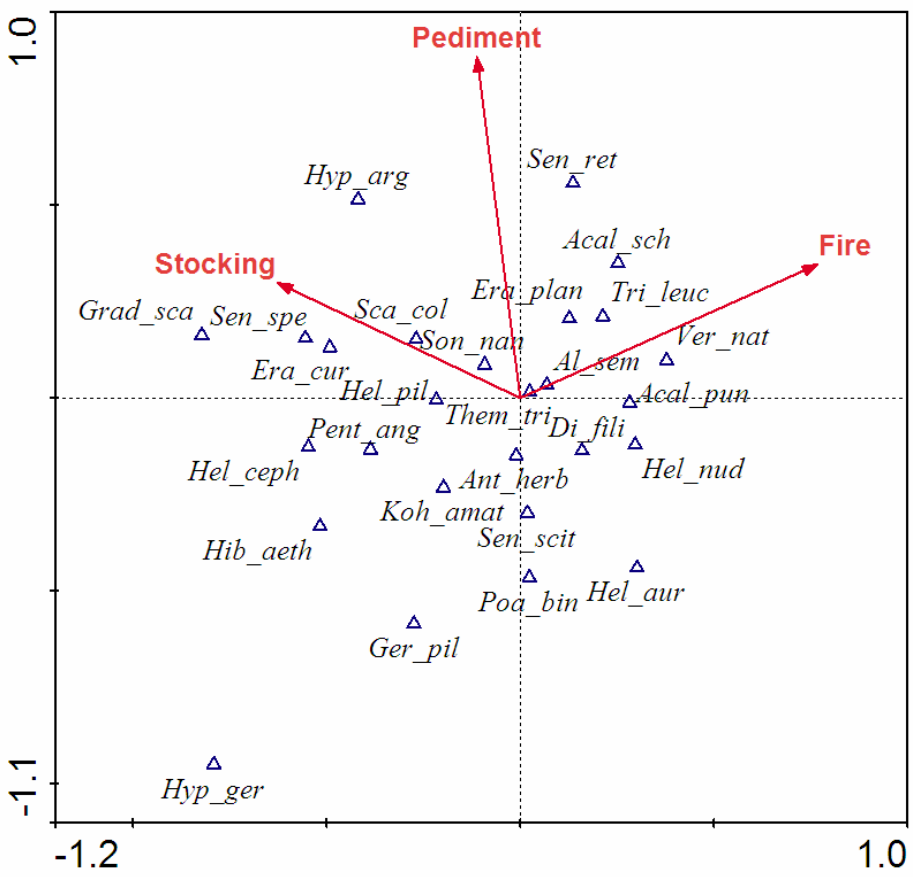


Figure 5.3 Canonical correspondence analysis plot of transformed cover abundance data from the two-paddock trial showing species responses to the influences of fire, the pediment effect and grazing

The burning regime applied in 2005/06 and the pediment effect appeared to have a strong effect on species such as *Vernonia natalensis* (Figure 5.3), which occurred more abundantly in paddocks that had been burnt in 2005/06 and *Pentanisia angustifolia* and *Helichrysum cephaloideum,* which occurred at far lower abundances in paddocks that had been burnt. *Themeda triandra* and *Alloteropsis semialata*, which occurred at relatively high densities in all paddocks are centrally located in the diagram, reflecting that their abundance is poorly explained by the ordination, as little of their variance has been accounted for by the fitted model.

CCA of the species composition data also confirmed a statistically significant relationship between the species and the set of environmental variables, as shown by the Monte Carlo test, in the test applied on the untransformed data (first canonical axis: F = 15.620, P <0.0050; all canonical axes: F = 11.757, P <0.0050) and the transformed data (first canonical axis: F =15.620, P <0.0050; all canonical axes: F = 11.757, P <0.0050). The first two axes accounted for 78.2% of the variation in both the transformed and untransformed data. The relatively large eigenvalue of axis 4 (Table 5.3) also indicates however that most of the variation in plant species composition was a result of environmental factors that were not included in the CCA.

Table 5.3 Summary of the CCA of the grazing intensities, burning regime and pediment effect on grassland species composition in the two-paddock trial using transformed species composition data

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.066	0.042	0.030	0.096
Species-environment correlations	0.744	0.656	0.656	0.000
Cumulative percentage variance:				
of species data	6.2	10.2	13.0	22.0
of species-environment relation	47.7	78.2	100.0	0.0
Canonical coefficients:				
Grazing	-0.3902	0.1203	-0.5458	
Fire	0.4948	-0.3361	-0.3567	
Pediment	-0.4237	-0.5290	0.1038	

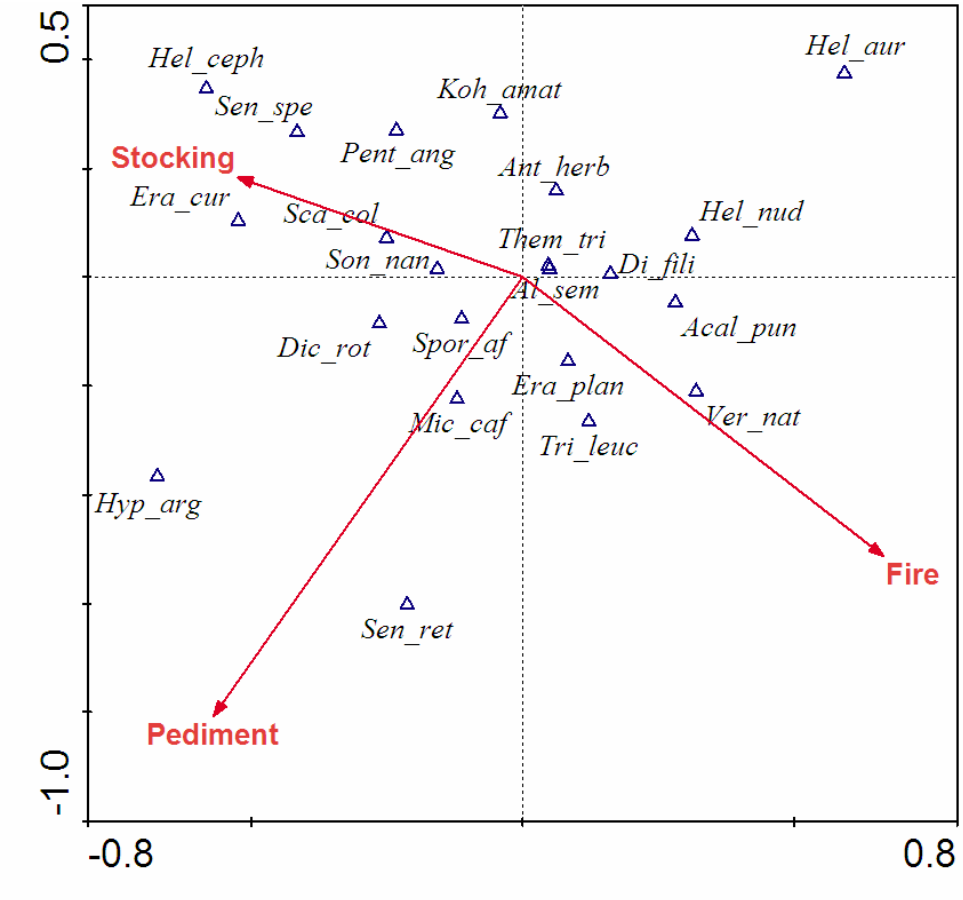


Figure 5.4 Canonical correspondence analysis plot of transformed species composition data from the two-paddock trial showing species responses to the influences of fire, the pediment effect and grazing

The burning regime applied in 2005/06 and the pediment effect appeared to have a strong effect on the species composition data, resulting in similar effects on *Vernonia natalensis*, *Pentanisia angustifolia* and *Helichrysum cephaloideum* (Figure 5.4). *Themeda triandra* and *Alloteropsis semialata* were again centrally located in the diagram whilst species such as *Senecio retrorsus* showed a similar response to the pediment effect. Overall the results obtained from the analysis of both the cover abundance values and the species composition data, appear to reflect similar trends.

Species diversity and evenness

The highest *H'* values were obtained for the treatment grazed at the lowest stocking rate that was unburnt and ungrazed in the 2005/06 season (Figure 5.5(a)). A high mean *H'* value was also obtained for the treatment grazed at the medium stocking that was unburnt and ungrazed in the 2005/06 season, although there was considerable variation within this treatment, as one of the two paddocks had the lowest *H'* value in the entire trial. The high *H'* values reflect relatively high species richness values (Figure 5.2(a)) and relatively high evenness values (Figure 5.5(b and c)). In contrast, despite relatively high species richness values (Figure 5.2(a)), low *H'* values were obtained for the unburnt and ungrazed treatment that was grazed at the highest stocking rate, because of low evenness values (Figure 5.5(b and c)).

The low evenness values in this treatment appear to be the result of very low cover values obtained for *D. filifolius*, which were less than 1% cover abundance for both of the paddocks in the treatment. As a result, instead of three species with relatively high cover abundance values, only two occurred in this treatment (*T. triandra* and *A. semialata*), which led to the low evenness indices. In contrast, the paddock grazed at the medium stocking rate that was not burnt or grazed in the 2005/06 season, which had a low *H'* value, had an extremely high cover abundance score for *D. filifolius* and very low scores for *T. triandra* and *A. semialata*, which led to its low evenness value and low *H'* value. This is reflected in the diversity and evenness values for graminoid species (Figure 5.5(d)).

It appears therefore that the cover abundance of *D. filifolius* may have had a significant effect on the results obtained in the analysis of the diversity and evenness indices. A one-way ANOVA applied to the *H'* values for each paddock found a statistically significant difference between the different paddocks ($F_{2,228}$ = 12.25, P < 0.0001), which revealed that the two paddocks grazed at the highest stocking rate, which were unburnt and ungrazed in the 2005/06 season and the paddock grazed at the medium stocking that was unburnt and ungrazed in the 2005/06 season were statistically significantly different from all the other paddocks. The low *H'* Values were the result of the lowest evenness values (Figure 5.5(b and C)). It is likely that the diversity and evenness indices may thus be a reflection of the environmental variability at the site rather than a result of the different grazing intensities applied in each of the treatments.

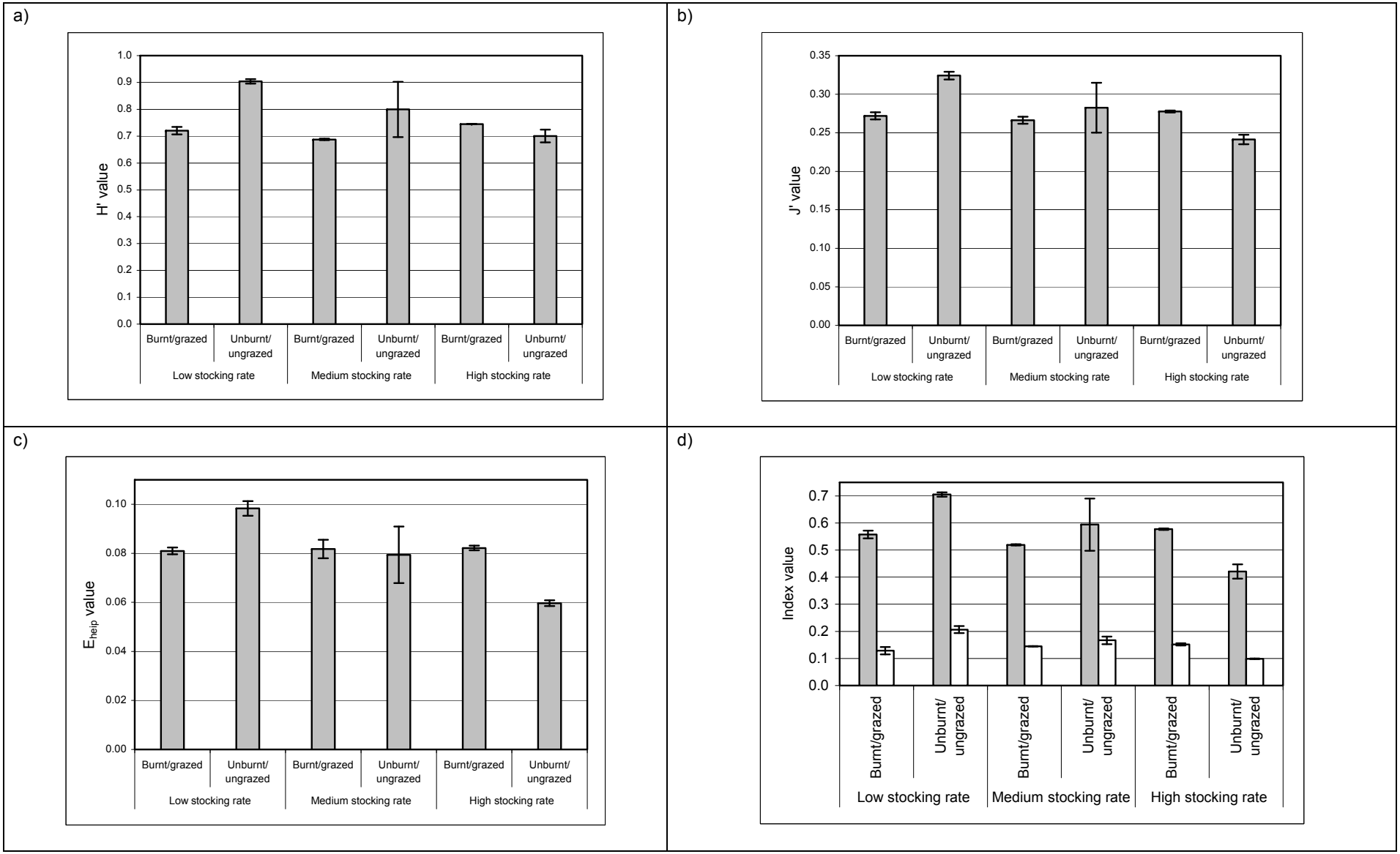


Figure 5.5 Mean values and standard deviation for all species per 1m^2 quadrat for (a) *H'*; (b) *J'*; (c) E_{Heip}; and (d) mean *H'* value (shaded) and standard deviation and E_{Heip} value (open) and standard deviation for graminoids

Individual species responses

There was considerable variation in the response of individual species to the different stocking rates in the trial, the 2005/06 burning programme and the apparent pediment effect, which is reflected in their mean percentage aerial cover abundance (Table 5.4) and mean frequency occurrence (Table 5.5). Analysis of the aerial cover (Table 5.6) and frequency occurrence data (Table 5.7) using three-way ANOVA revealed a number of statistically significant responses in the individual species.

Response to the 2005/06 burning programme

The aerial cover abundances of *Vernonia natalensis* (Figure 5.6(a)), *Helichrysum nudifolium*, *Acalypha punctata*, *Eragrostis plana*, *Elionurus muticus*, *Helichrysum aureum*, *Senecio retrorsus* and *Scabiosa columbaria* were statistically significantly higher in the treatments that were burnt in the 2005/06 season compared with those that were not (Table 5.6). The frequency occurrences of these species, which all occurred at relatively low aerial cover abundances, reflect similar results (Table 5.5 and 5.7) and in some cases the differences, were particularly evident. The mean frequency occurrence of *V. natalensis* in treatments that were burnt was 75.8% compared to 36.6% in those that were not burnt. In *E. plana* it was 47.5% compared to 27.5% and in *A. punctata* it was 72.5% compared to 45.8%.

The aerial cover abundance of *D. filifolius*, *T. triandra*, *Heteropogon contortus*, *Anthospermum herbaceum*, *Pentanisia angustifolia*, *Senecio speciosus*, *Eragrostis curvula*, *Helichrysum cephaloideum*, *Polygala ohlendorfiana* and *Stachys sessilis* was statistically significantly lower in the treatments that were burnt in the 2005/06 season compared with those that were not.

Although there was a marked difference in *D. filifolius* in the mean aerial cover between the treatments that were burnt (15.7%) and those that were not (25.8%), it is notable that the mean aerial cover in the unburnt treatment that was grazed at the high stocking rate was only 0.5% (Table 5.4). The frequency occurrence of *D. filifolius* in this treatments was also noticeably lower (Table 5.5), suggesting that there was a strong interaction with one or more of the other factors, which is confirmed in the results of the ANOVA (Table 5.6 and 5.7). The two paddocks in which these low aerial cover abundance scores were recorded occurred close to each other on the lower parts of the slope, suggesting that the interaction with the pediment effect may have led to the results that were obtained.

The higher mean aerial cover of *T. triandra* in the treatments that were burnt compared with those that were unburnt appears to have been the result of an interaction with other factors. A clear interaction was detected between the burning programme and the stocking rate (Table 5.6) and this is reflected in the data, which shows a substantially higher aerial cover abundance in the treatment that was grazed at the low stocking rate that was unburnt (Figure 5.6 (b)).

A particularly strong pattern emerged in the response of *P. angustifolia* to the burning programme (Figure 5.6(c)), in which it occurred at considerably higher abundances in the unburnt treatments. There was also a clear interaction between the burning programme and the grazing intensity, in which all treatments that were unburnt were statistically significantly different from each other but there was no difference between the treatments that were burnt.

An interaction in *E. curvula* was detected between the stocking rate and the burning programme as a result of a statistically significant difference between the treatment that was grazed at the high stocking rate and was unburnt, which had considerably higher aerial cover abundance values than all other treatments, suggesting that both factors influenced its aerial cover abundance.

Table 5.4 Mean percentage aerial cover abundance and standard deviation of species per 1m^2 quadrat per treatment

Species	Low grazing intensity				Medium grazing intensity				High grazing intensity			
	Burnt/grazed		Unburnt/ungrazed		Burnt/grazed		Unburnt/ungrazed		Burnt/grazed		Unburnt/ungrazed	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Diheteropogon filifolius	11.4	4.9	38.2	11.5	17.3	7.4	38.8	12.1	18.5	7.2	0.5	0.3
Alloteropsis semialata	4.5	1.6	5.0	2.1	3.7	1.2	5.7	2.4	5.2	1.7	2.9	1.1
Themeda triandra	3.1	1.7	8.2	3.1	3.5	1.5	3.4	1.3	3.0	1.7	4.3	1.9
Helichrysum herbaceum	0.5	0.1	0.5	0.0	0.4	0.1	0.4	0.1	0.3	0.1	0.3	0.1
Heteropogon contortus	0.2	0.2	0.4	0.2	0.2	0.2	0.3	0.2	0.1	0.2	1.1	1.1
Sporobolus africanus	0.3	0.3	0.1	0.1	0.4	0.4	0.2	0.2	0.5	0.3	0.6	0.3
Anthospermum herbaceum	0.3	0.2	0.4	0.2	0.2	0.1	0.3	0.1	0.3	0.1	0.4	0.2
Pentanisia angustifolia	0.1	0.1	0.3	0.2	0.0	0.0	0.5	0.1	0.1	0.1	0.8	0.3
Vernonia natalensis	0.5	0.2	0.2	0.1	0.5	0.1	0.2	0.1	0.3	0.1	0.2	0.1
Acalypha punctata	0.5	0.2	0.2	0.1	0.3	0.1	0.2	0.1	0.3	0.1	0.2	0.1
Senecio retrorsus	0.3	0.1	0.2	0.1	0.5	0.3	0.3	0.1	0.2	0.1	0.1	0.1
Eragrostis plana	0.2	0.2	0.2	0.1	0.3	0.2	0.2	0.1	0.4	0.2	0.2	0.2
Scabiosa columbaria	0.0	0.0	0.1	0.1	0.2	0.1	0.3	0.1	0.3	0.1	0.4	0.2
Senecio speciosus	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.2	0.1	0.8	0.2
Eragrostis curvula	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.7	0.4
Helichrysum nudifolium	0.2	0.1	0.3	0.1	0.3	0.1	0.1	0.1	0.2	0.1	0.0	0.0
Panicum ecklonii	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.2	0.0	0.0	0.0	0.0
Helichrysum aureum	0.1	0.0	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.0	0.0
Trachypogon spicatus	0.2	0.1	0.2	0.2	0.1	0.1	0.2	0.2	0.0	0.0	0.0	0.0
Helichrysum cephaloideum	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2
Acalypha schinzii	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.2	0.1	0.0	0.0
Polygala ohlendorfiana	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.1
Asteraceae sp.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Festuca scabra	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0
Stachys sessilis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Ajuga ophrydis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Elionurus muticus	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0

Table 5.5 Mean percentage frequency occurrence and standard deviation of species per 20 1m^2 quadrats per treatment

Species	Low grazing intensity				Medium grazing intensity				High grazing intensity			
	Burnt/grazed		Unburnt/ungrazed		Burnt/grazed		Unburnt/ungrazed		Burnt/grazed		Unburnt/ungrazed	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Diheteropogon filifolius	87.5	17.7	100.0	0.0	70.0	42.4	95.0	0.0	92.5	3.5	42.5	24.7
Alloteropsis semialata	97.5	3.5	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0
Themeda triandra	100.0	0.0	100.0	0.0	92.5	3.5	100.0	0.0	95.0	7.1	100.0	0.0
Helichrysum herbaceum	90.0	14.1	95.0	7.1	75.0	14.1	77.5	24.7	62.5	10.6	67.5	10.6
Heteropogon contortus	27.5	31.8	65.0	21.2	27.5	17.7	32.5	24.7	12.5	10.6	52.5	38.9
Sporobolus africanus	30.0	35.4	12.5	10.6	35.0	14.1	30.0	28.3	62.5	24.7	52.5	31.8
Anthospermum herbaceum	55.0	21.2	72.5	10.6	42.5	24.7	57.5	17.7	62.5	3.5	62.5	3.5
Pentanisia angustifolia	30.0	14.1	62.5	3.5	35.0	0.0	90.0	7.1	45.0	0.0	85.0	0.0
Vernonia natalensis	77.5	10.6	42.5	17.7	87.5	3.5	35.0	7.1	62.5	3.5	32.5	3.5
Acalypha punctata	82.5	3.5	45.0	28.3	57.5	24.7	60.0	7.1	77.5	3.5	32.5	3.5
Senecio retrorsus	52.5	67.2	50.0	0.0	52.5	67.2	40.0	49.5	37.5	53.0	40.0	21.2
Eragrostis plana	32.5	10.6	25.0	21.2	42.5	3.5	30.0	21.2	67.5	3.5	27.5	3.5
Scabiosa columbaria	12.5	10.6	35.0	7.1	55.0	14.1	60.0	0.0	70.0	7.1	72.5	3.5
Senecio speciosus	2.5	3.5	17.5	3.5	25.0	28.3	32.5	10.6	70.0	0.0	87.5	17.7
Eragrostis curvula	10.0	7.1	27.5	24.7	7.5	10.6	20.0	14.1	22.5	3.5	52.5	3.5
Helichrysum nudifolium	50.0	49.5	65.0	14.1	72.5	17.7	55.0	28.3	55.0	7.1	20.0	14.1
Panicum ecklonii	25.0	28.3	25.0	14.1	10.0	14.1	40.0	14.1	7.5	10.6	7.5	3.5
Helichrysum aureum	40.0	56.6	35.0	42.4	42.5	60.1	42.5	53.0	40.0	49.5	5.0	0.0
Trachypogon spicatus	25.0	35.4	20.0	14.1	7.5	10.6	22.5	3.5	2.5	3.5	2.5	3.5
Helichrysum cephaloideum	2.5	3.5	55.0	0.0	7.5	10.6	25.0	35.4	12.5	3.5	70.0	21.2
Acalypha schinzii	0.0	0.0	27.5	38.9	25.0	35.4	0.0	0.0	27.5	38.9	0.0	0.0
Polygala ohlendorfiana	5.0	7.1	5.0	7.1	2.5	3.5	35.0	21.2	10.0	14.1	52.5	3.5
Asteraceae sp.1	0.0	0.0	5.0	7.1	5.0	7.1	10.0	7.1	35.0	42.4	32.5	3.5
Festuca scabra	15.0	7.1	5.0	7.1	2.5	3.5	7.5	10.6	0.0	0.0	2.5	3.5
Stachys sessilis	2.5	3.5	7.5	10.6	5.0	7.1	5.0	7.1	2.5	3.5	30.0	0.0
Ajuga ophrydis	2.5	3.5	5.0	0.0	5.0	7.1	7.5	10.6	12.5	3.5	30.0	14.1
Elionurus muticus	2.5	3.5	0.0	0.0	2.5	3.5	0.0	0.0	10.0	7.1	2.5	3.5

Table 5.6 P values from the three-way ANOVAs of grazing intensity, burning and the pediment effect on species aerial cover abundance data

Species	Fire	Grazing	Pediment	Grazing/ fire	Pediment/ fire	Grazing/ pediment	Grazing/ pediment/ fire
Diheteropogon filifolius	**0.0018**	**<0.0001**	**0.0002**	**<0.0001**	**0.0444**	**<0.0001**	**0.0434**
Alloteropsis semialata	0.6134	0.6363	**0.0107**	**0.0011**	0.7647	**<0.0001**	0.1030
Themeda triandra	**<0.0001**	**0.0003**	**<0.0001**	**0.0012**	0.1384	**<0.0001**	**0.0069**
Helichrysum herbaceum	0.5139	**<0.0001**	**0.0134**	0.7522	0.0597	0.0621	0.3007
Heteropogon contortus	**<0.0001**	0.3543	0.3783	**0.0059**	**0.0003**	0.1025	0.2774
Sporobolus africanus	0.0968	**<0.0001**	0.1207	0.2382	0.1337	**<0.0001**	0.2536
Anthospermum herbaceum	**0.0033**	0.0618	**0.0065**	0.7381	0.5796	0.2366	0.5118
Pentanisia angustifolia	**<0.0001**	**<0.0001**	0.6686	**0.0033**	0.8322	0.6909	0.5098
Vernonia natalensis	**<0.0001**	**0.0253**	0.8053	0.0975	0.3684	0.4380	0.3144
Acalypha punctata	**<0.0001**	0.0815	0.0599	**0.0064**	0.1945	**0.0227**	**0.0064**
Senecio retrorsus	**0.0368**	**0.0004**	**<0.0001**	0.3259	**<0.0001**	**<0.0001**	**0.0137**
Eragrostis plana	**0.0010**	0.0592	0.2593	0.0960	0.2771	0.2483	**0.0393**
Scabiosa columbaria	**0.0439**	**<0.0001**	0.1393	0.5964	0.7148	0.8802	0.8554
Senecio speciosus	**<0.0001**	**<0.0001**	**0.0343**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Eragrostis curvula	**<0.0001**	**<0.0001**	**0.0373**	**0.0314**	0.3197	0.0680	0.4976
Helichrysum nudifolium	**0.0005**	**<0.0001**	**0.0156**	**0.0003**	**0.0245**	**0.0278**	**<0.0001**
Panicum ecklonii	0.0813	**0.0011**	0.3846	**0.0049**	**0.0299**	**0.0195**	**0.0010**
Helichrysum aureum	**0.0031**	**0.0115**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0004**
Trachypogon spicatus	0.4084	**0.0002**	0.7760	0.1099	**0.0200**	0.0508	**<0.0001**
Helichrysum cephaloideum	**<0.0001**	**<0.0001**	0.7231	**0.0005**	**0.0300**	**0.0002**	**0.0002**
Acalypha schinzii	**0.0035**	0.8044	**0.0472**	**<0.0001**	**0.0041**	**<0.0001**	**<0.0001**
Polygala ohlendorfiana	**<0.0001**	**<0.0001**	**0.0487**	**0.0001**	0.5804	0.1508	0.1239
Asteraceae sp.1	0.6683	**<0.0001**	**0.0005**	0.4095	**0.0089**	**0.0002**	**0.0094**
Festuca scabra	0.8785	**0.0439**	0.3722	0.0990	0.3722	0.0692	0.1836
Ajuga ophrydis	0.2025	**0.0006**	0.3989	0.4849	0.6705	0.2556	0.4849
Stachys sessilis	**0.0015**	**0.0233**	0.2389	**0.0049**	0.4052	0.7033	**0.0441**
Elionurus muticus	**0.0480**	0.1282	**0.0480**	0.5599	0.1929	0.5599	0.9801

Table 5.7 P values from the three-way ANOVAs of grazing intensity, burning and the pediment effect on species frequency occurrence data

Species	Fire	Grazing	Pediment	Grazing/ fire	Pediment/ fire	Grazing/ pediment	Grazing/ pediment/ fire
Diheteropogon filifolius	0.2971	**<0.0001**	0.0613	**<0.0001**	**<0.0001**	**<0.0001**	0.1552
Alloteropsis semialata	0.3184	0.3695	0.3184	0.3695	0.3184	0.3695	0.3695
Themeda triandra	**0.0233**	0.2340	0.6482	0.2340	0.6482	0.2340	0.2340
Helichrysum herbaceum	0.4146	**<0.0001**	**0.0059**	0.9736	0.2537	0.0902	0.2720
Heteropogon contortus	**<0.0001**	**0.0325**	**0.0467**	**0.0143**	**<0.0001**	**0.0050**	0.4181
Sporobolus africanus	0.0508	**<0.0001**	0.1754	0.6489	0.4509	**<0.0001**	0.1278
Anthospermum herbaceum	0.0836	0.1399	**0.0240**	0.4649	0.1428	0.1989	0.3038
Pentanisia angustifolia	**<0.0001**	**0.0161**	0.4680	0.2661	0.6632	0.8626	0.4399
Vernonia natalensis	**<0.0001**	0.1102	0.8875	0.2628	0.3225	0.6062	0.2333
Acalypha punctata	**<0.0001**	0.4805	**0.0496**	**0.0023**	0.5374	0.1315	0.0517
Senecio retrorsus	0.3699	0.0855	**<0.0001**	0.4017	**<0.0001**	**0.0041**	**0.0068**
Eragrostis plana	**0.0010**	**0.0383**	0.4048	0.0602	0.5785	0.2365	0.0559
Scabiosa columbaria	0.0944	**<0.0001**	0.1630	0.3292	0.2640	0.7754	0.8719
Senecio speciosus	**0.0074**	**<0.0001**	0.7358	0.6905	**0.0074**	0.1073	0.0768
Eragrostis curvula	**0.0001**	**0.0004**	**0.0233**	0.3559	0.3287	0.0666	0.5727
Helichrysum nudifolium	**0.0308**	**0.0007**	**0.0004**	**0.0018**	0.1935	0.1329	**<0.0001**
Panicum ecklonii	**0.0359**	**0.0027**	0.1607	**0.0126**	0.0799	**0.0329**	**0.0055**
Helichrysum aureum	**0.0010**	**0.0002**	**<0.0001**	**0.0008**	**<0.0001**	**<0.0001**	**<0.0001**
Trachypogon spicatus	0.4109	**0.0003**	1.0000	0.1126	**0.0142**	**0.0300**	**<0.0001**
Helichrysum cephaloideum	**<0.0001**	**0.0001**	0.1121	**0.0010**	0.8595	**0.0005**	**0.0105**
Acalypha schinzii	**0.0122**	0.9382	**0.0122**	**<0.0001**	**0.0027**	**<0.0001**	**<0.0001**
Polygala ohlendorfiana	**<0.0001**	**<0.0001**	**0.0225**	**0.0002**	0.7020	0.2413	0.0709
Asteraceae sp.1	0.5275	**<0.0001**	**0.0066**	0.67050	**0.0018**	**0.0112**	**0.0006**
Festuca scabra	0.7716	**0.0458**	0.3842	0.0752	0.3842	0.1046	0.1721
Stachys sessilis	**0.0020**	**0.0102**	0.8103	**0.0030**	0.8103	0.6680	0.0611
Ajuga ophrydis	**0.0485**	**0.0003**	0.8257	0.1762	0.5091	0.0821	0.1762
Elionurus muticus	0.0544	0.0936	0.0544	0.5505	0.2471	0.5505	1.0000

Response to the different stocking rates

Aerial cover of *E. curvula*, *Sporobolus africanus* and *H. contortus* was directly related to the stocking rate. Frequency occurrence of *Eragrostis plana* was also directly related to the stocking rates. A statistically significant difference was detected in the aerial cover of *E. curvula* between the treatments grazed at the high stocking rate and those grazed at the medium and low stocking rates, which were not different from each other. All stocking rates for *S. africanus* were statistically significantly different from each other, as the result of progressively higher cover abundance associated with grazing intensity. An interaction was detected between the stocking rate and the pediment effect as a result of a statistically significant difference between paddocks grazed at the medium stocking rate on the upper and lower slopes of the site, suggesting that the pediment effect also had an influence on the aerial cover abundance of *S. africanus*. A statistically significant difference was detected in the frequency occurrence of *E. plana* between the treatments grazed at the high stocking rate and those grazed at the medium and low stocking rates, which were not different from each other.

Aerial cover of *T. triandra*, *Panicum ecklonii*, *Trachypogon spicatus*, and *Festuca scabra* was inversely related to the stocking rate. There was a statistically significant difference in the aerial cover of *T. triandra* between the treatments grazed at the high stocking rate and those grazed at the medium and low stocking rates, which were not different from each other, but the interaction with the burning programme was again evident (Figure 5.6(b)), as the unburnt treatment, grazed at the low stocking rate was statistically significantly different from all other treatments. There were statistically significant differences in the aerial cover of *T. spicatus,*
F. scabra and *P. ecklonii* between the treatments grazed at the high stocking rate and those grazed at the medium and low stocking rates, which were not different from each other.

An interaction in *P. ecklonii* was detected between the stocking rate and the burning programme as a result of a statistically significant difference between both treatments that were grazed at the low stocking rate, suggesting that fire may have had an influence on its aerial cover abundance.

Aerial cover of *H. herbaceum*, *H. nudifolium* and *V. natalensis* was inversely related to grazing intensity. There was a statistically significant difference in the aerial cover of *H. herbaceum* between the treatments grazed at the low stocking rate and those grazed at the medium and high stocking rates, which were not different from each other. There was a statistically significant difference in the aerial cover of *H. nudifolium* between the treatments grazed at the high stocking rate and those grazed at the medium and low stocking rates, which were not different from each other. The only statistically significant difference in the aerial cover of *V. natalensis* was between the treatments grazed at the low and high stocking rates.

Although a statistically significant difference was detected in *S. retrorsus* between the treatments grazed at the medium stocking rate and all other treatments, it is likely that this was the result of the statistically significant interaction with the pediment effect, as three of the lowermost paddocks of the site that were grazed at the medium and low stocking rates, had considerably higher aerial cover abundance scores than all of the other paddocks (Figure 5.6(d)).

Aerial cover of *P. angustifolia*, *Scabiosa columbaria*, *Ajuga ophrydis*, *S. speciosus*, *H. cephaloideum*, *S. sessilis* and *P. ohlendorfiana* was directly related to grazing intensity. There were statistically significant differences in the aerial cover of *A. ophrydis*, *H. cephaloideum* and *S. sessilis* between the treatments grazed at the high stocking rate and those grazed at the medium and low stocking rates, which were not different from each other. *A. ophrydis* occurred at particularly low cover abundances but a marked increase in its frequency occurrence, associated with increasing grazing intensity, was evident (Figure 5.7(a)). An interaction was detected in *H. cephaloideum* between the stocking rate and the burning programme as a result of a statistically significant difference between the unburnt treatment that was grazed at the high stocking rate and all other treatments.

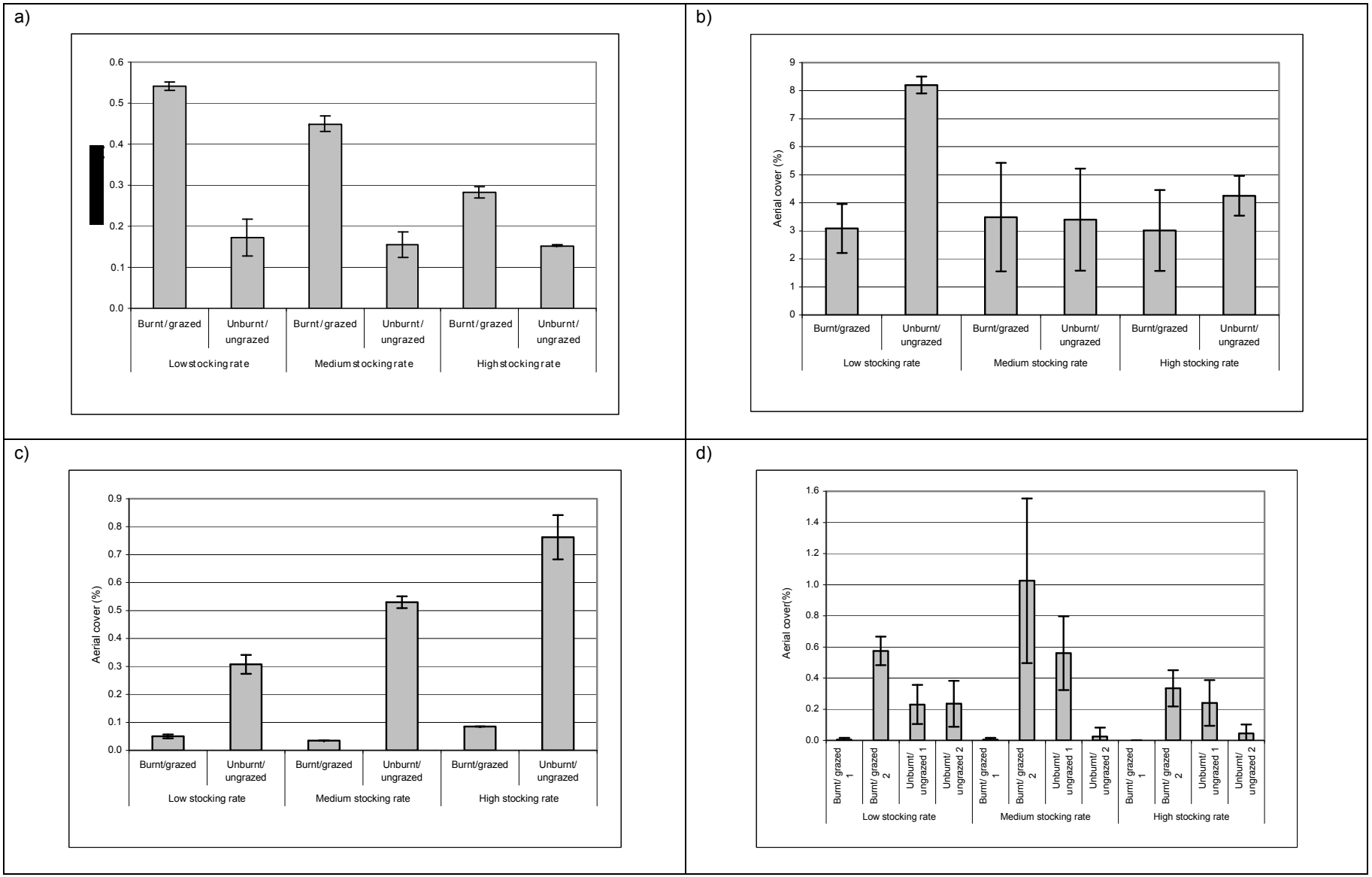


Figure 5.6 Mean aerial cover scores and standard deviation for (a) *Vernonia natalensis*; (b) *Themeda triandra*; (c) *Pentanisia angustifolia*; (d) *Senecio retrorsus*

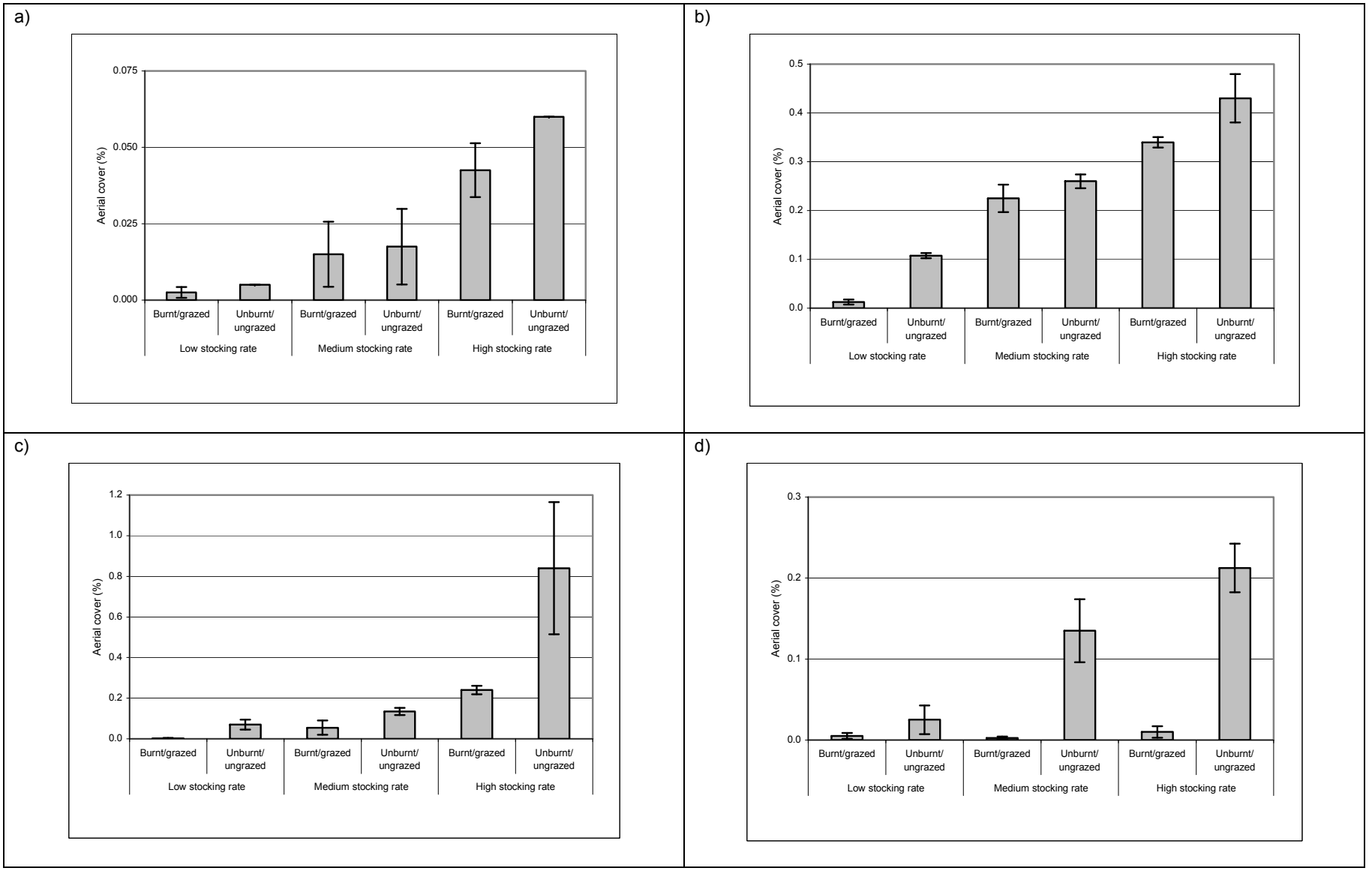


Figure 5.7 Mean aerial cover scores and standard deviation for (a) *Ajuga ophrydis*; (b) *Scabiosa columbaria*; (c) *Senecio speciosus*; (d) *Polygala ohlendorfiana*

There was a statistically significant difference in the aerial cover of *P. angustifolia* between the unburnt treatments grazed at all stocking rates, which reflected a progressively higher cover abundance associated with increasing grazing intensity (Figure 5.6(c)).

There were statistically significant differences in the aerial cover of *S. columbaria* (Figure 5.7(a)), *Senecio speciosus* (Figure 5.7(b)) and *Polygala ohlendorfiana* (Figure 5.7(c)) between all stocking rates, as a result of progressively higher cover abundance associated with increasing grazing intensity. A clear interaction was evident between the stocking rate and the burning programme in *S. speciosus*. Although an interaction was also detected between the stocking rate and the pediment effect, this was a result of statistically significant differences between the treatment grazed at the high stocking rate on the upper and lower parts of the slope and all other treatments, suggesting that the stocking rates had a marked influence on its aerial cover abundance than the pediment effect. A clear interaction was also evident between the stocking rate and the burning programme in *P. ohlendorfiana*.

Response to the pediment effect

The aerial cover abundances of *D. filifolius*, *Anthospermum herbaceum*, *Helichrysum aureum*, *Helichrysum herbaceum*, *H. nudifolium* and *H. cephaloideum* were statistically significantly higher in the paddocks on the upper slope of the trial site compared with the lower slope (Table 5.6 and 5.7). The mean aerial cover abundance of *D. filifolius* on the upper slope was 24.2% compared with 17.35% on the lower slope. The other species occurred at very low cover abundances but marked differences were evident in the mean frequency occurrence of *H. aureum*, which was 55.0% on the upper slope compared with 13.3% on the lower slope and in *H. nudifolium* it was 63.3% compared with 42.5%.

An interaction was detected between the burning programme and pediment in *H. aureum* as a result of a statistically significant difference between the burnt paddocks on the upper slope of the trial site and all other paddocks.

The aerial cover abundances and frequency occurrences of *T. triandra*, *Alloteropsis semialata*, *E. curvula*, *E. muticus*, *S. retrorsus*, *S. speciosus*, *A. schinzii* and *P. ohlendorfiana* were statistically significantly lower in the paddocks on the upper slope of the trial site compared with the lower slope. Similar mean aerial cover abundances were recorded on the upper and lower slope for *T. triandra* (3.3% and 5.2% respectively) and *A. semialata* (4.0% and 5.0% respectively). The other species occurred at very low cover abundances but marked differences were evident in the mean frequency occurrence of *S. retrorsus*, which was 15.0% on the upper slope compared with 75.8% on the lower slope, *E. curvula*, which was 17.5% compared with 29.2% and *E. muticus*, which was 0.8% compared with 5.0%.

Although statistically significant interactions were detected between all of the factors in *A. schinzii*, this appears to have been due to the fact that its presence was only recorded in three paddocks, all of which were at different stocking rates, one had been burnt and two were unburnt.

Comparison between quadrat sizes

There was an obvious difference in the cumulative total number of species collected in the $1m^2$ quadrats compared with the $10m^2$ quadrats (Figure 5.8). In all cases the cumulative number of species collected in the $1m^2$ quadrats was greater than the cumulative number of species collected in the $10m^2$ quadrats. One of the unburnt/ungrazed paddocks grazed at the high stocking rate, had a similar number of species in both sets of quadrats but there were still more species collected in the $1m^2$ quadrats (56) than in the $10m^2$ quadrats (55). The largest difference between the sets of quadrats was in an unburnt/ungrazed paddock grazed at the low stocking rate, in which 17 more species were collected in the $1m^2$ quadrats than in the $10m^2$ quadrats.

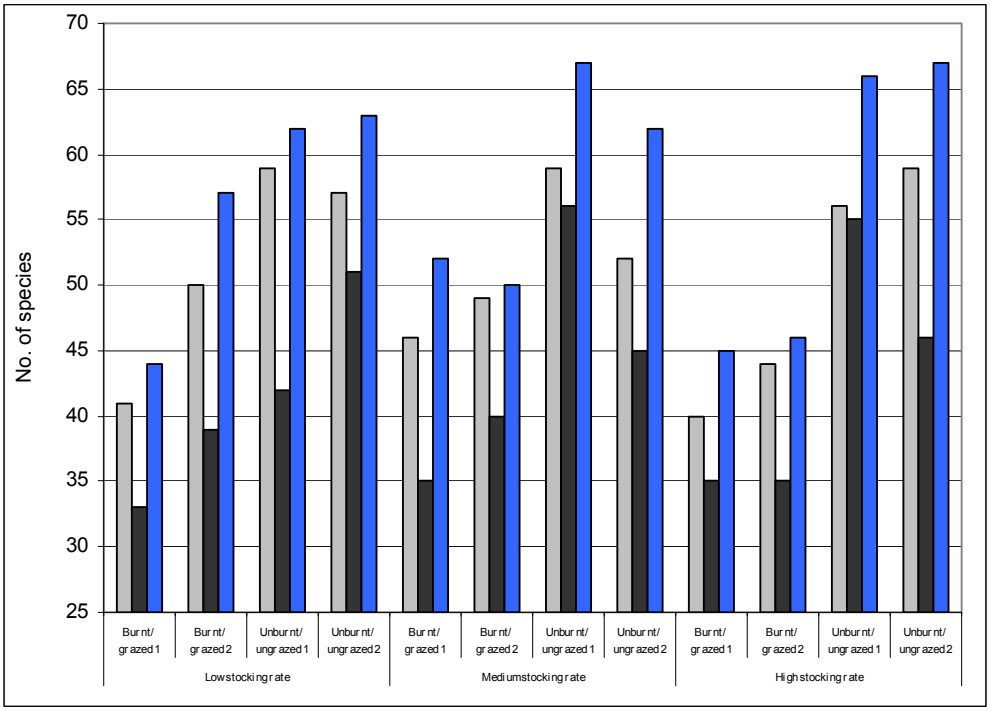


Figure 5.8 Total cumulative number of species in all $1m^2$ (grey-shaded columns) and $10m^2$ (black columns) quadrats and in each paddock (blue-shaded columns)

In all instances species were recorded in one of the sets of quadrats but not the other. A mean of 12.8 species was recorded in the $1m^2$ quadrats only compared with a mean of 5.8 species that was recorded in the $10m^2$ quadrats only. The differences between the cumulative number of species collected in the different quadrats were found to be statistically significant ($t = -6.57$, $P < 0.0001$).

5.2 The simulation trial

Community composition

Plant cover

The three most dominant species in the trial were the grasses *Themeda triandra*, *Alloteropsis semialata* and *Microchloa caffra*. To a large extent, the fluctuations in the aerial cover of *T. triandra* were reflected in the fluctuations of mean cover scores for all species, illustrating its dominance in the overall vegetation cover of the trial (Figure 5.9). Although *T. triandra*, followed by *A. semialata* and *M. caffra* were largely dominant in the trial, numerous species did occur under all of the grazing treatments, usually at very low cover abundances. The mean cover abundances for the 50 most abundant species after *T. triandra*, *A. semialata* and *M. caffra* are presented in Appendix D.

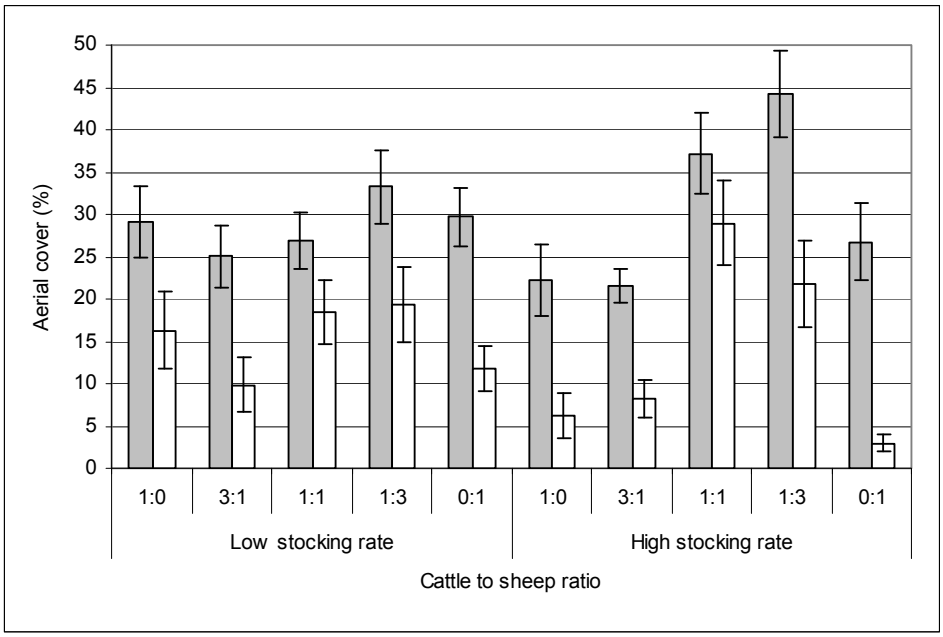


Figure 5.9 Comparison between the mean cover scores and standard deviation for all species (shaded columns) and *Themeda triandra* (open columns)

Species richness

A statistically significant trend (Table 5.8) of declining number of mean species per $1m^2$ quadrat, as the ratio of cattle decreased and the ratio of sheep increased, was evident in the results (Figure 5.10(a)). The two highest mean values obtained for the number of species per $1m^2$ quadrat were 20.75 and 21.30 for the low and high stocking rates respectively, which were grazed at a ratio of cattle-to-sheep of 1:0, and were statistically significantly different from all other ratios of cattle-to-sheep. Considerably lower mean values were obtained for treatments grazed under both the low and high stocking rates that included sheep in them but no further statistically significant differences were detected.

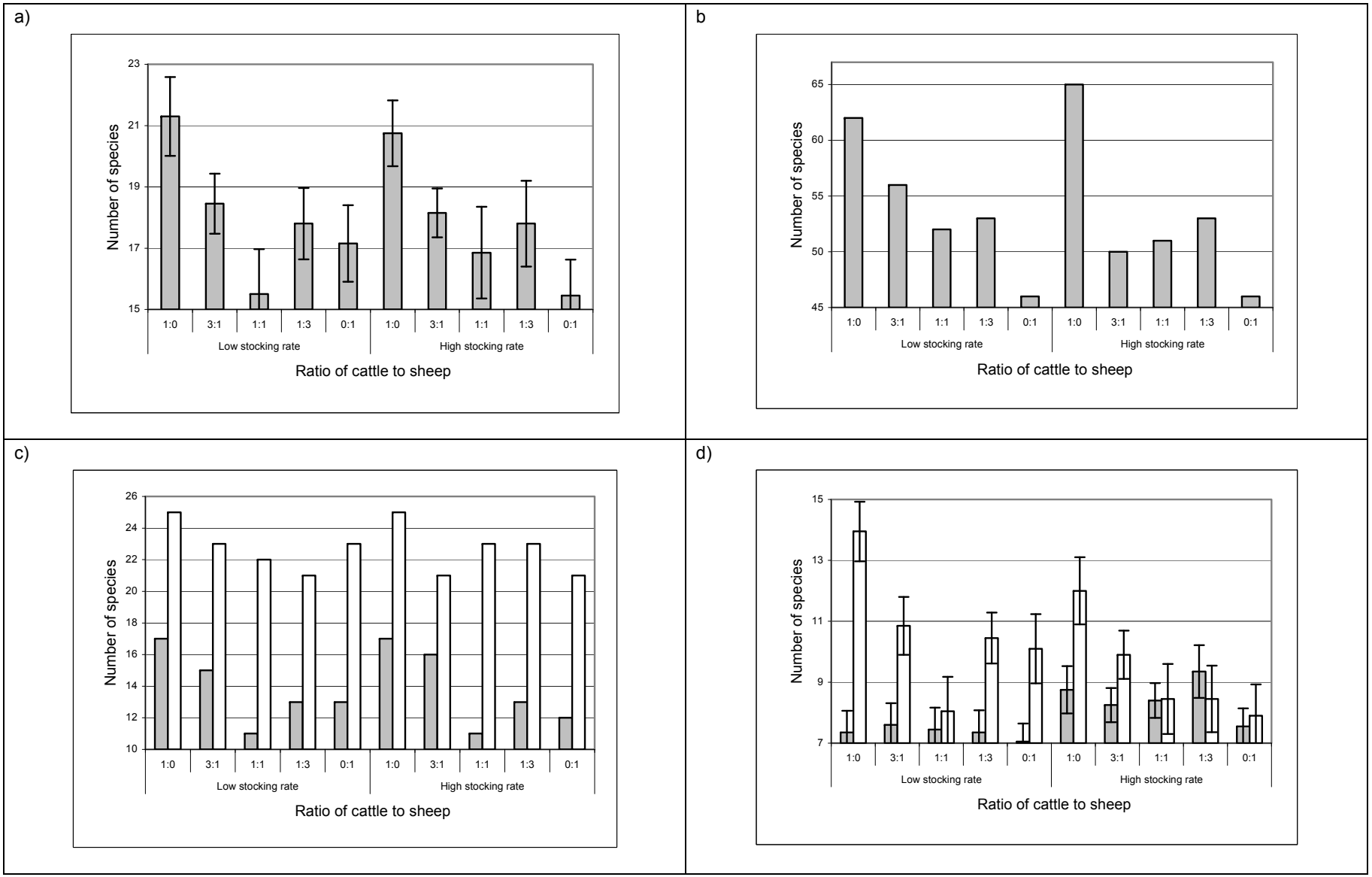


Figure 5.10 (a) Mean number of species per $1m^2$ quadrat and standard deviation; (b) total number of species in all $1m^2$ quadrats; (c) minimum (shaded) and maximum (open) number of species per $1m^2$ quadrat; (d) mean number of graminoids (shaded) and non-graminoid monocotyledons and dicotyledons (open) per $1m^2$ quadrat and standard deviation

The trend was largely reflected in the total number of all species in the $1m^2$ quadrats and in the minimum and maximum number of species per $1m^2$ quadrat, per treatment (Figure 5.10(b) and (c)). No noticeable difference was evident in the mean number of species per $1m^2$ quadrat as a result of the different stocking rates, which was confirmed in the statistical analysis (Table 5.8).

Table 5.8 P values from the two-way ANOVAs of grazing intensity and cattle-to-sheep ratio

Species richness variables	Stocking rate	Cattle : sheep ratio	Stocking rate/ratio
No. species per $1m^2$ quadrat	0.4902	<0.0001	0.0964
No. graminoids per $1m^2$ quadrat	<0.0001	0.0174	0.1037
No. non-graminoid monocotyledons and dicotyledons per $1m^2$ quadrat	<0.0001	<0.0001	0.0271

A similar statistically significant trend (Table 5.8) was found in the mean number of non-graminoid monocotyledons and dicotyledons per $1m^2$ quadrat, which was particularly evident when plotted along a continuum (Figure 5.11). The analysis revealed similar statistically significant differences between the ratio of cattle-to-sheep of 1:0 and all other ratios. In addition, a ratio of cattle-to-sheep of 3:1 was found to be statistically different from a ratio of 1:1 but not with any of the other ratios. A statistically significant difference (Table 5.8) was also found between the different stocking rates in the analysis of the non-graminoid monocotyledons and dicotyledons, which was the result of a higher mean number of non-graminoid species per $1m^2$ quadrat at the low stocking rate (10.68) compared to the high stocking rate (9.34).

The interaction between the stocking rate and the cattle-to-sheep ratios revealed statistically significant differences between the treatments grazed at the low stocking rate and a ratio of cattle-to-sheep of 1:0 all other treatments except that grazed at the high stocking rate, at the same ratio of cattle-to-sheep. The treatment grazed at the high stocking rate and a ratio of cattle-to-sheep of 1:0 was statistically significantly different from all other treatments grazed at the high stocking rate and the treatment grazed at the low stocking rate at a ratio of cattle-to-sheep of 1:1. Several other treatments were also statistically significantly different, as a result of lower numbers of species at the lower ratios of cattle-to-sheep and the high stocking rate, indicating that both the ratio of cattle-to-sheep and the stocking rate influenced the mean number of non-graminoid monocotyledons and dicotyledons per $1m^2$ quadrat in the trial.

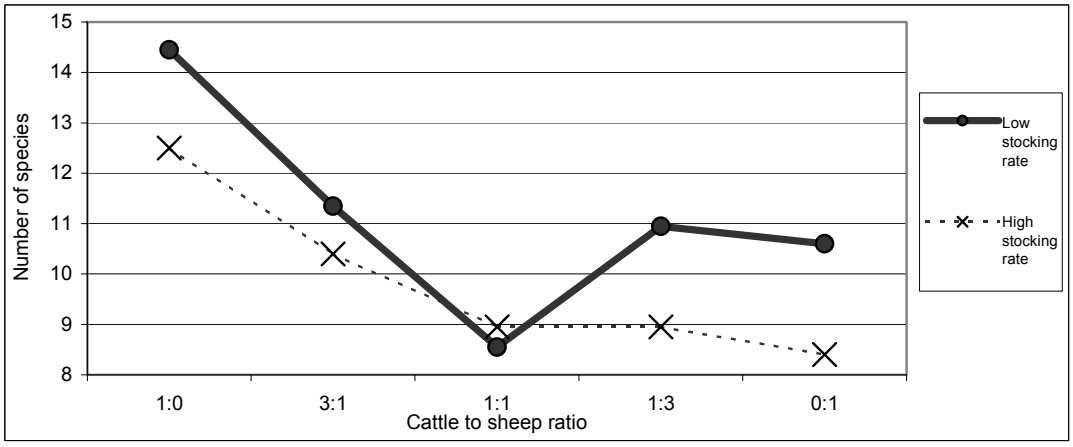


Figure 5.11 Mean number of non-graminoid monocotyledons and dicotyledons per $1m^2$ quadrat at low stocking and high stocking rates

A statistically significant difference was found in the mean number of grass species per $1m^2$ quadrat, as a result of the different stocking rates but not the ratios of cattle-to-sheep (Table 5.8), which was the result of a lower mean number of graminoids per $1m^2$ quadrat at the low stocking rate (7.36) compared to the high stocking rate (8.46).

The pattern detected as a result of the ratio of cattle-to-sheep suggests grazing intensity has considerably less impact than a high proportion of sheep to cattle, which suggests that there may be some facilitation between sheep and cattle in terms of a negative impact on particular species.

CCA of the cover abundance data confirmed a statistically significant relationship between the botanical composition of the trial and the stocking rate and cattle-to-sheep ratio, as shown by the Monte Carlo test, in the test applied on the transformed (first canonical axis: F = 12.28, P <0.005; all canonical axes: F = 12.27, P <0.005) and the untransformed data (first canonical axis: F = 13.23, P <0.005; all canonical axes: F = 12.13, P <0.005).

Table 5.9 Summary of the CCA of the grazing intensities and cattle-to-sheep ratio on grassland composition in the simulation trial using untransformed cover abundance data

	Axis 1	**Axis 2**	**Axis 3**	**Axis 4**
Eigenvalues	0.103	0.048	0.103	0.097
Species-environment correlations	0.846	0.761	0.000	0.000
Cumulative percentage variance:				
of species data	8.0	11.7	19.7	27.2
of species-environment relation	68.5	100.0	0.0	0.0
Canonical coefficients:				
Grazing	-0.5538	-0.5754	0.0000	
Cattle	0.6529	-0.4841	0.0000	
Sheep	-0.6529	0.4841	0.0000	

The cattle-to-sheep ratio appeared to have a strong influence on species such as *Pentanisia angustifolia*, *Aster bakerianus* and *Acalypha punctata* (Figure 5.12), which occurred at greater abundances in the treatments grazed at higher proportions of cattle-to-sheep. The cover abundances of species such as *Themeda triandra* and *Diheteropogon amplectens* were inversely related to the stocking rate, as they occurred at lower abundances in the treatments grazed at the high stocking rate. In contrast, the cover abundances of species such as *Tolpis capensis*, *Senecio retrorsus*, *Eragrostis curvula* and *Eragrostis plana* were directly related to the stocking rate, as they occurred at higher abundances in the treatments grazed at the high stocking rates. Species such as *Sporobolus africanus* and *Crabbea acaulis* responded to both the stocking rate and the cattle-to-sheep ratio, as they both occurred at higher cover abundances in treatments grazed at the high stocking rate, at lower ratios of cattle-to-sheep. In contrast, species such as *Monsonia angustifolia* and *Helichrysum miconiifolium* were absent in a number of the treatments grazed at the high stocking rate at lower ratios of cattle-to-sheep.

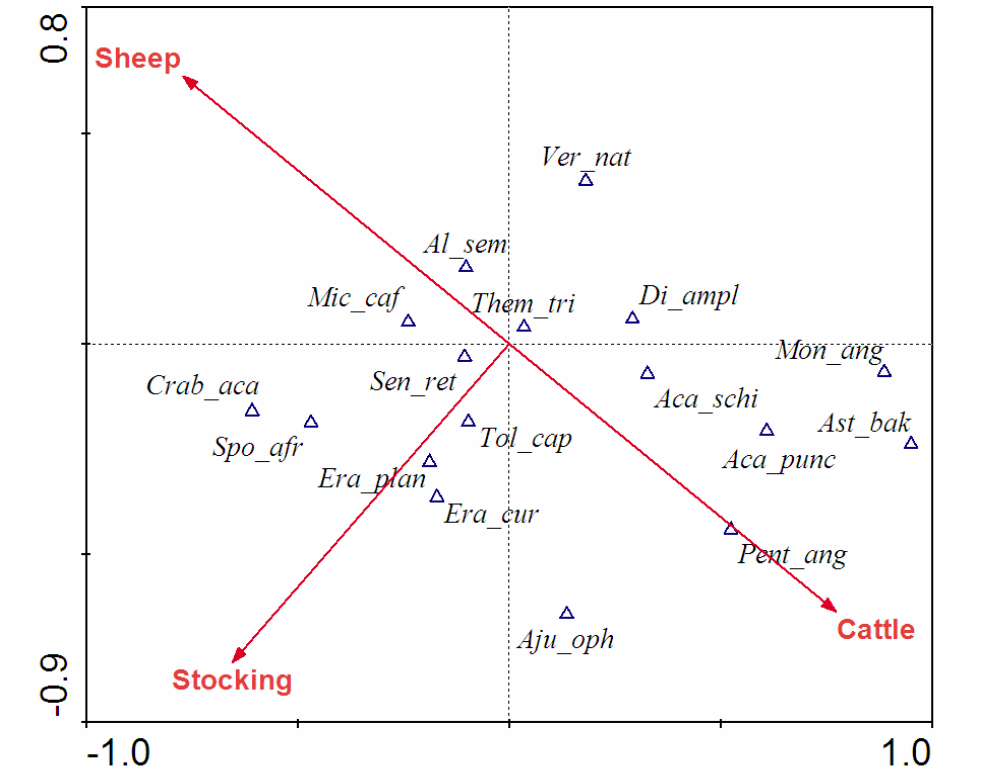


Figure 5.12 Canonical correspondence analysis plot of untransformed cover abundance data from the simulation trial showing species responses to the influences of sheep, cattle and stocking rates

CCA of the species composition data also confirmed a statistically significant relationship between the botanical composition of the trial and the stocking rate and cattle-to-sheep ratio, as shown by the Monte Carlo test, in the test applied on the untransformed (first canonical axis: F = 15.67, P <0.005; all canonical axes: F = 10.82, P <0.005) and the transformed data (first canonical axis: F = 15.67, P <0.005; all canonical axes: F = 10.82, P <0.005).

Table 5.10 Summary of the CCA of the grazing intensities and cattle-to-sheep ratio on grassland composition in the simulation trial using untransformed species composition data

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.067	0.023	0.094	0.083
Species-environment correlations	0.781	0.619	0.000	0.000
Cumulative percentage variance:				
of species data	7.4	9.9	20.2	29.3
of species-environment relation	74.4	100.0	0.0	0.0
Canonical coefficients:				
Grazing	0.6401	-0.3547	0.0000	
Cattle	-0.4316	-0.5157	0.0000	
Sheep	0.4316	0.5157	0.0000	

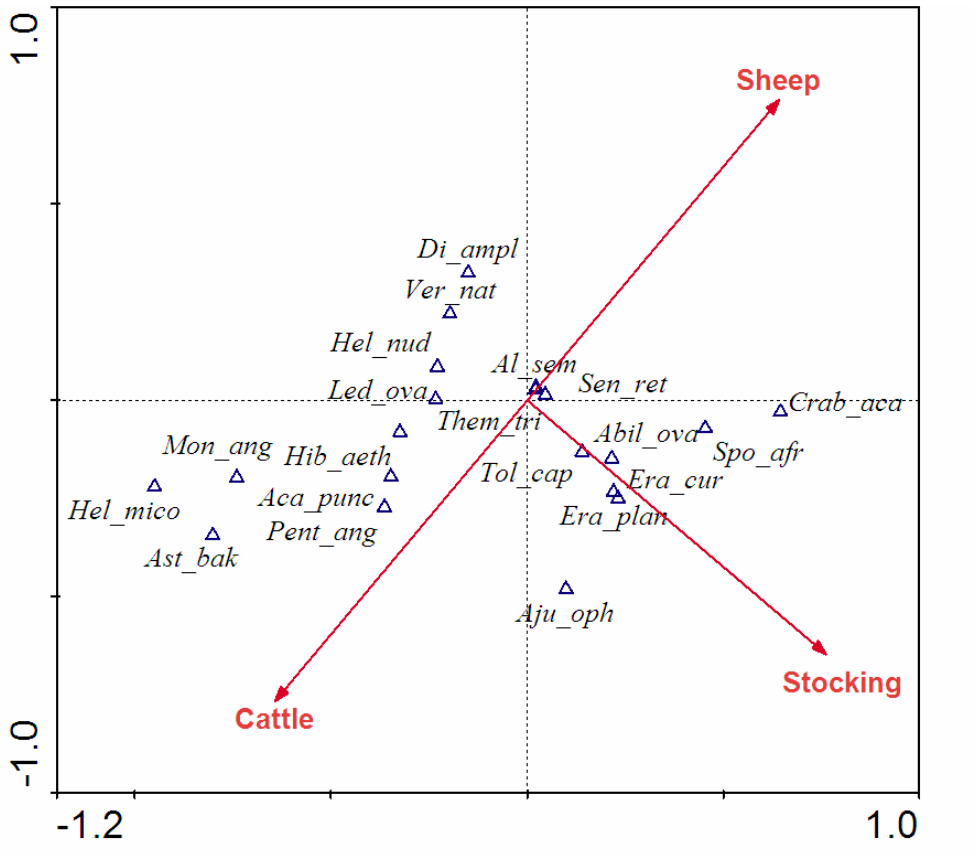


Figure 5.13 Canonical correspondence analysis plot of untransformed species composition data from the simulation trial showing species responses to the influences of sheep, cattle and stocking rates

The cattle-to-sheep ratio appeared to have a strong influence on the species composition data, resulting in similar effects on *Pentanisia angustifolia*, *Aster bakerianus*, *Acalypha punctata* and *Diheteropogon amplectens* (Figure 5.13). In contrast, although the cover abundance of species such as *Themeda triandra*, *Senecio retrorsus* and *Alloteropsis semialata* appeared to be influenced by factors such as the stocking rate, they were present in most quadrats, no matter what the treatment, resulting in them being centrally located in the diagram. Overall however, the results obtained from the analysis of both the cover abundance values and the species composition data, appear to reflect similar trends.

Species diversity and evenness

The highest *H'* values were obtained for the treatment grazed at the high stocking rate and a ratio of cattle-to-sheep of 1:3 (Figure 5.14(a)). The remaining *H'* values are fairly similar, except for the treatment grazed at the low stocking rate and a cattle-to-sheep ratio of 1:1. The high *H'* value is associated with high evenness values (Figures 5.14(b) and (c)) that were recorded for the same treatment, which appear to be the result of the high cover of the vegetation in the paddock in which this treatment was applied (Figure 5.9). High abundance values were recorded in this treatment for *T. triandra*, *Alloteropsis semialata*, *Senecio retrorsus*, *Sporobolus africanus*, *Setaria nigrirostris*, *Koeleria capensis* and *Heteropogon contortus*, which is reflected in its diversity and evenness values for graminoid species (Figure 5.14(d)). These

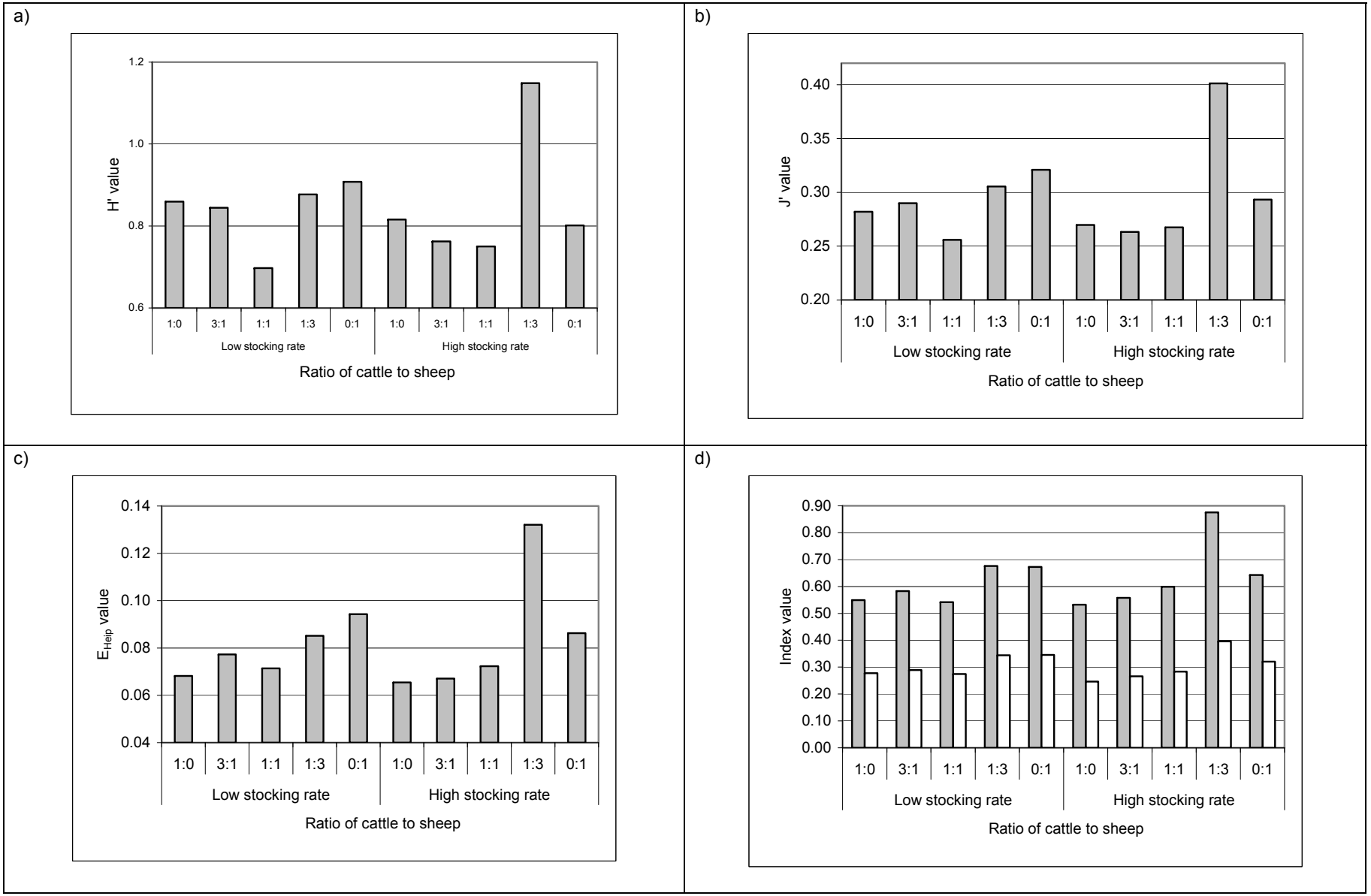


Figure 5.14 Mean values for all species per 1m^2 quadrat for (a) *H'*; (b) *J'*; (c) E_{Heip}; and (d) mean *H'* value (shaded) and E_{Heip} value (open) for graminoids

high abundance values probably contributed towards the high values in the evenness indices, which in turn contributed towards the high diversity index obtained for the paddock.

The low *H'* value recorded in the treatment grazed at the low stocking rate and a cattle-to-sheep ratio of 1:1, appears to be the result of the low species richness value that was recorded (Figure 5.10(a)), which was the second lowest overall. This treatment also had a relatively low evenness value, which may have been a result of relatively low cover abundance scores for most of the dominant species, except for *T. triandra*, which was particularly dominant (Figure 5.9).

As in the two-paddock trial, the diversity and evenness indices appear primarily to reflect differences in cover between the different paddocks, which may be the result of environmental variability or historical influences. They thus provide little indication of the influence of the stocking rates or ratios of cattle-to-sheep on plant diversity within the trial.

Individual species responses

A number of species responded to the different stocking rates and ratios of cattle-to-sheep in consistent ways. Despite this there was considerable variation in the responses of individual species, which is reflected in their mean percentage aerial cover abundance (Table 5.11) and mean frequency occurrence (Table 5.12). Analysis of the aerial cover abundance (Table 5.13) and frequency occurrence data (Table 5.14) using two-way ANOVA revealed a number of statistically significant responses in the individual species.

Response to the different stocking rates

The aerial cover abundance of *T. triandra*, *A. semialata*, *Tristachya leucothrix*, *Elionurus muticus*, *A. schinzii*, *H. nudifolium*, *Bulbostylis oritrephes*, *Diheteropogon amplectens*, *Acalypha punctata*, *Cyperus* sp.1, *Vernonia natalensis*, *Eulalia villosa*, *Aster bakerianus*, *Helichrysum miconiifolium* and *Monsonia angustifolia* was inversely related to stocking rate. The frequency occurrence of *Kohautia amatymbica* was also inversely related to stocking rate.

Although an interaction was detected between the stocking rate and the cattle-to-sheep ratio in the analysis of *T. triandra*, no discernible pattern emerged and it appears to have been primarily due to the high aerial cover abundance values recorded in the treatments grazed at the high stocking rate at ratios of cattle-to-sheep of 1:1 and 1:3. Similarly the interaction detected in the analysis of *T. leucothrix* appears to have been the result of a particularly high aerial cover abundance score in the treatment grazed at the low stocking rate and a ratio of cattle-to-sheep of 3:1 and a particularly low score in the treatment grazed at the same stocking rate and a ratio of 1:1. The interactions detected in the analysis of *E. muticus*, *H. nudifolium*, *B. oritrephes*, and *V. natalensis* were the result of particularly low or high aerial cover abundance scores recorded in one or more treatments and did not display a discernible pattern.

The interaction detected between the stocking rate and the ratio of cattle-to-sheep in the analysis of *A. semialata* was a result of statistically significant differences between the treatment grazed at the low stocking rate at a ratio of cattle-to-sheep of 0:1 and all other treatments. Similarly, the treatment grazed at the high stocking rate at a ratio of cattle-to-sheep of 0:1 was statistically significantly different from all other treatments and differences were also found between the treatments grazed at the low and high stocking rates at ratios of cattle-to-sheep of 1:3 and those grazed at higher ratios of cattle-to-sheep, suggesting that both grazing intensity and the ratio of cattle-to-sheep had an influence on its aerial cover abundance.

The interaction detected in *A. schinzii* was the result of very low aerial cover abundance scores in the treatment grazed at the low stocking rate and a cattle-to-sheep ratio of 0:1 and the treatments grazed at the high stocking rates and cattle-to-sheep ratios of 0:1, 1:3 and 3:1, suggesting that both grazing intensity and cattle-to-sheep ratio had an influence on its aerial cover abundance.

Table 5.11 Mean percentage aerial cover abundance and standard deviation of species per 1m^2 quadrat per treatment

Ratio of cattle to sheep	Low stocking rate										High stocking rate									
	1:0		3:1		1:1		1:3		0:1		1:0		3:1		1:1		1:3		0:1	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Themeda triandra	16.3	8.9	9.9	6.4	18.4	7.7	19.4	8.9	11.7	5.3	6.3	5.4	8.3	4.5	29.0	10.2	21.8	10.3	3.0	2.0
Alloteropsis semialata	2.1	1.2	2.4	2.2	1.9	1.7	3.0	1.7	7.5	3.9	0.9	0.3	0.8	0.3	0.8	0.4	3.6	2.1	7.0	3.1
Microchloa caffra	0.3	0.2	1.1	1.2	0.4	0.2	1.5	1.8	1.9	1.9	1.3	1.3	2.1	4.1	0.3	0.3	1.3	1.3	10.1	10.8
Tristachya leucothrix	0.9	0.8	2.5	1.8	0.5	0.3	1.3	0.7	1.1	0.3	1.0	0.3	0.9	0.4	0.8	0.8	0.9	0.8	0.8	0.3
Elionurus muticus	1.6	3.9	2.0	3.9	0.4	0.9	0.7	0.5	0.1	0.9	2.0	4.0	0.8	0.5	0.5	0.4	0.3	0.4	0.1	0.2
Senecio retrorsus	0.5	0.1	0.4	0.3	0.7	0.8	0.4	0.2	0.5	0.1	0.5	0.1	0.5	0.0	0.6	0.2	3.3	1.9	0.6	0.2
Eragrostis curvula	0.1	0.2	0.5	1.0	0.0	0.0	0.2	0.4	0.2	0.9	0.6	1.0	2.6	2.4	0.2	0.5	1.4	2.0	0.5	1.0
Sporobolus africanus	0.0	0.0	0.0	0.1	0.2	0.4	0.0	0.0	0.2	0.4	0.4	0.9	0.4	0.6	0.3	0.4	4.0	4.0	0.4	0.4
Pentanisia angustifolia	0.5	0.3	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	2.1	5.5	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Acalypha schinzii	0.3	0.2	0.5	0.2	0.5	0.1	0.3	0.2	0.0	0.0	0.5	0.2	0.0	0.1	0.5	0.0	0.0	0.0	0.0	0.0
Abildgaardia ovata	0.0	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.2	0.5	0.3	0.3	0.3	0.4	0.4	0.3	0.4
Helichrysum nudifolium	0.4	0.2	0.6	0.3	0.1	0.2	0.1	0.1	0.3	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.0	0.0	0.1	0.1
Bulbostylis oritrephes	0.1	0.3	0.4	0.9	0.1	0.2	0.4	0.5	0.6	0.6	0.1	0.3	0.1	0.2	0.0	0.1	0.0	0.0	0.1	0.2
Diheteropogon amplectens	0.3	0.4	0.3	0.4	0.2	0.3	0.5	0.9	0.0	0.0	0.1	0.2	0.2	0.3	0.1	0.2	0.0	0.0	0.1	0.3
Acalypha punctata	1.2	1.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.3	0.3	0.3	0.0	0.0	0.0	0.1	0.0	0.0
Cyperus sp.1	0.3	0.2	0.3	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.0	0.1	0.2	0.2	0.1	0.2
Vernonia natalensis	0.2	o.2	0.1	0.2	0.0	0.0	0.3	0.3	0.5	0.5	0.0	0.1	0.1	0.2	0.1	0.2	0.0	0.1	0.0	0.1
Eragrostis plana	0.2	0.3	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.2	0.3	0.4	0.6	0.2	0.4
Eulalia villosa	0.2	0.2	0.2	0.4	0.2	0.3	0.3	0.3	0.1	0.2	0.0	0.0	0.1	0.3	0.1	0.2	0.0	0.0	0.0	0.0
Brachiara serrata	0.0	0.1	0.1	0.2	0.1	0.2	0.0	0.1	0.0	0.0	0.3	0.3	0.1	0.4	0.2	0.3	0.1	0.2	0.1	0.2
Anthospermum rigidum	0.0	0.1	0.1	0.3	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.2	0.0	0.1	0.1	0.2	0.2	0.3	0.1	0.3
Hermannia depressa	0.2	0.2	0.0	0.1	0.0	0.0	0.1	0.2	0.0	0.1	0.1	0.2	0.0	0.0	0.1	0.2	0.0	0.1	0.0	0.1
Diclis rotundifolia	0.1	0.2	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.2	0.0	0.0
Crabbea acaulis	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0
Tolpis capensis	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.2	0.0	0.0	0.0	0.1
Kohautia amatymbica	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Aster bakerianus	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hibiscus aethiopicus	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Ajuga ophrydis	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Helichrysum miconiifolium	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monsonia angustifolia	0.1	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.12 Mean percentage frequency occurrence and standard deviation of species per 20 1m^2 quadrats per treatment

Ratio of cattle to sheep	Low stocking rate										High stocking rate									
	1:0		3:1		1:1		1:3		0:1		1:0		3:1		1:1		1:3		0:1	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Themeda triandra	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0
Alloteropsis semialata	100	0.0	90.0	30.8	100	0.0	100	0.0	100	0.0	100	0.0	95.0	22.4	90.0	30.8	100	0.0	100	0.0
Microchloa caffra	65.0	48.9	75.0	44.4	80.0	41.0	95.0	22.4	85.0	36.6	80.0	41.0	85.0	36.6	50.0	51.3	85.0	36.6	100	0.0
Tristachya leucothrix	95.0	22.4	100	0.0	80.0	41.0	100	0.0	100	0.0	95.0	22.4	95.0	22.4	85.0	36.6	90.0	30.8	100	0.0
Elionurus muticus	80.0	41.0	95.0	22.4	40.0	50.3	70.0	47.0	80.0	41.0	70.0	47.0	85.0	36.6	70.0	47.0	35.0	48.9	15.0	36.6
Senecio retrorsus	95.0	22.4	80.0	41.0	95.0	22.4	85.0	36.6	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0	100	0.0
Eragrostis curvula	5.0	22.4	30.0	47.0	0.0	0.0	15.0	36.6	5.0	22.4	40.0	50.3	70.0	47.0	15.0	36.6	55.0	51.0	30.0	47.0
Sporobolus africanus	0.0	0.0	5.0	22.4	20.0	41.0	0.0	0.0	25.0	44.4	30.0	47.0	40.0	50.3	35.0	48.9	100	0.0	55.0	51.0
Pentanisia angustifolia	90.0	30.8	35.0	48.9	20.0	41.0	20.0	41.0	5.0	22.4	65.0	48.9	40.0	50.3	0.0	0.0	15.0	36.6	0.0	0.0
Acalypha schinzii	65.0	48.9	90.0	30.8	95.0	22.4	75.0	44.4	0.0	0.0	90.0	30.8	10.0	30.8	100	0.0	0.0	0.0	0.0	0.0
Abildgaardia ovata	0.0	0.0	20.0	41.0	30.0	47.0	30.0	47.0	45.0	51.0	80.0	41.0	95.0	22.4	50.0	51.3	65.0	48.9	40.0	50.3
Helichrysum nudifolium	95.0	22.4	95.0	22.4	50.0	51.3	70.0	47.0	80.0	41.0	70.0	47.0	40.0	50.3	20.0	41.0	5.0	22.4	35.0	48.9
Bulbostylis oritrephes	20.0	41.0	35.0	48.9	10.0	30.8	45.0	51.0	65.0	48.9	20.0	41.0	15.0	36.6	5.0	22.4	0.0	0.0	10.0	30.8
Diheteropogon amplectens	45.0	51.0	40.0	50.3	30.0	47.0	45.0	51.0	0.0	0.0	10.0	30.8	35.0	48.9	25.0	44.4	0.0	0.0	15.0	36.6
Acalypha punctata	90.0	30.8	5.0	22.4	15.0	36.6	0.0	0.0	20.0	41.0	15.0	36.6	50.0	51.3	0.0	0.0	15.0	36.6	0.0	0.0
Cyperus sp.1	65.0	48.9	80.0	41.0	15.0	36.6	35.0	48.9	40.0	50.3	15.0	36.6	15.0	36.6	20.0	41.0	40.0	50.3	10.0	30.8
Vernonia natalensis	55.0	51.0	25.0	44.4	0.0	0.0	55.0	51.0	60.0	50.3	5.0	22.4	35.0	48.9	15.0	36.6	10.0	30.8	0.0	0.0
Eragrostis plana	35.0	48.9	0.0	0.0	10.0	30.8	0.0	0.0	0.0	0.0	10.0	30.8	40.0	50.3	40.0	50.3	35.0	48.9	30.0	47.0
Eulalia villosa	30.0	47.0	20.0	41.0	35.0	48.9	50.0	51.3	15.0	36.6	0.0	0.0	15.0	36.6	10.0	30.8	0.0	0.0	0.0	0.0
Brachiara serrata	5.0	22.4	20.0	41.0	15.0	36.6	5.0	22.4	0.0	0.0	40.0	50.3	15.0	36.6	35.0	48.9	15.0	36.6	15.0	36.6
Anthospermum rigidum	10.0	30.8	20.0	41.0	10.0	30.8	5.0	22.4	10.0	30.8	15.0	36.6	10.0	30.8	25.0	44.4	35.0	48.9	30.0	47.0
Hermannia depressa	50.0	51.3	5.0	22.4	0.0	0.0	30.0	47.0	5.0	22.4	20.0	41.0	20.0	41.0	15.0	36.6	10.0	30.8	25.0	44.4
Diclis rotundifolia	20.0	41.0	0.0	0.0	5.0	22.4	5.0	22.4	0.0	0.0	10.0	30.8	20.0	41.0	15.0	36.6	30.0	47.0	0.0	0.0
Crabbea acaulis	0.0	0.0	5.0	22.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	80.0	41.0	0.0	0.0
Tolpis capensis	5.0	22.4	0.0	0.0	20.0	41.0	20.0	41.0	0.0	0.0	10.0	30.8	25.0	44.4	45.0	51.0	0.0	0.0	10.0	30.8
Kohautia amatymbica	35.0	48.9	15.0	36.6	5.0	22.4	5.0	22.4	20.0	41.0	5.0	22.4	15.0	36.6	0.0	0.0	5.0	22.4	10.0	30.8
Aster bakerianus	50.0	51.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.0	30.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hibiscus aethiopicus	40.0	50.3	0.0	0.0	20.0	41.0	20.0	41.0	0.0	0.0	20.0	41.0	5.0	22.4	5.0	22.4	5.0	22.4	5.0	22.4
Ajuga ophrydis	5.0	22.4	0.0	0.0	5.0	22.4	0.0	0.0	0.0	0.0	30.0	47.0	0.0	0.0	10.0	30.8	0.0	0.0	10.0	30.8
Helichrysum miconiifolium	40.0	50.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monsonia angustifolia	25.0	44.4	10.0	30.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	22.4	0.0	0.0	0.0	0.0	0.0	0.0

Table 5.13 P values from the two-way ANOVAs of grazing intensity, burning and the pediment effect on species aerial cover abundance data

Species	Grazing	Ratio of cattle sheep	Grazing/ratio
Themeda triandra	**0.0033**	**<0.0001**	**<0.0001**
Alloteropsis semialata	**0.0002**	**<0.0001**	**0.0137**
Microchloa caffra	**<0.0001**	**<0.0001**	**<0.0001**
Tristachya leucothrix	**0.0058**	**<0.0001**	**<0.0001**
Elionurus muticus	**0.0096**	**<0.0001**	**0.0097**
Senecio retrorsus	**<0.0001**	**<0.0001**	**<0.0001**
Eragrostis curvula	**<0.0001**	**<0.0001**	**0.0186**
Sporobolus africanus	**<0.0001**	**<0.0001**	**<0.0001**
Pentanisia angustifolia	0.9406	**<0.0001**	0.8167
Acalypha schinzii	**<0.0001**	**<0.0001**	**<0.0001**
Abildgaardia ovata	**<0.0001**	**0.3045**	**<0.0001**
Helichrysum nudifolium	**<0.0001**	**<0.0001**	**0.0038**
Bulbostylis oritrephes	**<0.0001**	**0.0058**	**0.0015**
Diheteropogon amplectens	**0.0046**	**0.0489**	**0.0050**
Acalypha punctata	**0.0007**	**<0.0001**	**<0.0001**
Cyperus sp.1	**<0.0001**	**0.0038**	**0.0008**
Vernonia natalensis	**<0.0001**	**0.0030**	**<0.0001**
Eragrostis plana	**<0.0001**	0.8782	**0.0009**
Eulalia villosa	**<0.0001**	0.1990	0.1293
Brachiara serrata	**0.0022**	0.1140	0.2000
Anthospermum rigidum	**0.0318**	0.7147	**0.0269**
Hermannia depressa	0.3471	**0.0021**	**0.0054**
Diclis rotundifolia	0.0577	0.1176	0.0891
Crabbea acaulis	**<0.0001**	**<0.0001**	**<0.0001**
Tolpis capensis	0.0560	**0.0002**	0.0992
Kohautia amatymbica	0.2102	0.0721	0.5425
Aster bakerianus	**0.0056**	**<0.0001**	**<0.0001**
Hibiscus aethiopicus	0.0890	**0.0010**	0.0834
Ajuga ophrydis	**0.0179**	**0.0006**	**0.0034**
Helichrysum miconiifolium	**0.0013**	**<0.0001**	**<0.0001**
Monsonia angustifolia	**0.0214**	**0.0120**	**0.0199**

Table 5.14 P values from the two-way ANOVAs of grazing intensity, burning and the pediment effect on species frequency occurrence data

Species	Grazing	Ratio of cattle sheep	Grazing/ratio
Alloteropsis semialata	0.6482	0.0840	0.2902
Microchloa caffra	1.0000	**0.0073**	**0.0374**
Tristachya leucothrix	0.5463	**0.0115**	0.6676
Elionurus muticus	**0.0031**	**<0.0001**	**<0.0001**
Senecio retrorsus	**0.0018**	0.1571	0.1571
Eragrostis curvula	**<0.0001**	**<0.0001**	0.5521
Sporobolus africanus	**<0.0001**	**0.0003**	**<0.0001**
Pentanisia angustifolia	0.0555	**<0.0001**	0.3516
Acalypha schinzii	**<0.0001**	**<0.0001**	**<0.0001**
Abildgaardia ovata	**<0.0001**	0.3214	**<0.0001**
Helichrysum nudifolium	**<0.0001**	**<0.0001**	0.1604
Bulbostylis oritrephes	**<0.0001**	**0.0145**	**0.0036**
Diheteropogon amplectens	**0.0100**	**0.0236**	**0.0073**
Acalypha punctata	**0.0250**	**<0.0001**	**<0.0001**
Cyperus sp.1	**<0.0001**	**0.0142**	**0.0003**
Vernonia natalensis	**<0.0001**	**0.0231**	**<0.0001**
Eragrostis plana	**<0.0001**	0.7737	**0.0007**
Eulalia villosa	**<0.0001**	0.2507	0.0612
Brachiara serrata	**0.0036**	0.1321	0.1664
Anthospermum rigidum	**0.0239**	0.8738	0.1578
Hermannia depressa	1.0000	**0.0125**	**0.0039**
Diclis rotundifolia	**0.0339**	0.0919	0.0592
Crabbea acaulis	**<0.0001**	**<0.0001**	**<0.0001**
Tolpis capensis	**0.0493**	**0.0013**	**0.0119**
Kohautia amatymbica	**0.0425**	0.0637	0.1170
Aster bakerianus	**0.0032**	**<0.0001**	**<0.0001**
Hibiscus aethiopicus	0.0692	**0.0005**	0.1998
Ajuga ophrydis	**0.0131**	**0.0035**	0.0817
Helichrysum miconiifolium	**0.0005**	**<0.0001**	**<0.0001**
Monsonia angustifolia	**0.0229**	**0.0048**	**0.0098**

The interaction detected in *D. amplectens* was the result of particularly low aerial cover abundance values in the treatments grazed at the low stocking rate at a ratio of cattle-to-sheep of 0:1 and at the high stocking rate at a ratio of cattle-to-sheep of 1:3. Consistently lower aerial cover abundance scores were recorded in the paddocks grazed at the high stocking rate, suggesting that both grazing intensity and cattle-to-sheep ratio had an influence on its aerial cover abundance.

The interaction detected in *A. punctata* was the result of a particularly high aerial cover abundance value in the treatment grazed at the low stocking rate at a ratio of cattle-to-sheep of

1:0 and a relatively high aerial cover abundance value in the treatment grazed at the high stocking rate at a ratio of cattle-to-sheep of 3:1 suggesting that both grazing intensity and cattle-to-sheep ratio had an influence on its aerial cover abundance.

The interaction detected in *Cyperus* sp.1 was the result of relatively high aerial cover scores in the treatments grazed at the low stocking rate at ratios of cattle-to-sheep of 1:0 and 3:1 and consistently low cover scores in the treatments grazed at the high stocking rate, suggesting that both grazing intensity and cattle-to-sheep ratio had an influence on its aerial cover abundance.

The interactions detected between the stocking rate and the ratio of cattle-to-sheep in *A. bakerianus, H. miconiifolium* and *M. angustifolia* were the result of a statistically significant difference between the treatment grazed at the low stocking rate at a ratio of cattle-to-sheep of 1:0 and all other treatments, which suggests that both grazing intensity and cattle-to-sheep ratio had an influence on their aerial cover abundance.

Aerial cover of *Microchloa caffra*, *Senecio retrorsus*, *Eragrostis curvula*, *Sporobolus africanus*, *Abildgaardia ovata*, *Eragrostis plana*, *Brachiara serrata*, *Anthospermum rigidum*, *Crabbea acaulis* and *Ajuga ophrydis*, was directly related to stocking rate. The frequency occurrence of *Tolpis capensis* and *Diclis rotundifolia* was also directly related to stocking rate.

The interactions detected in *S. retrorsus*, *E. curvula*, *S. africanus*, *A. ovata*, *E. plana*, *A. rigidum*, *C. acaulis*, *A. ophrydis* and T. capensis were the result of relatively low or high aerial cover abundance scores recorded in one or more treatments and did not display a discernible pattern.

The interaction detected in *M. caffra* was the result of a relatively high aerial cover score in the treatment grazed at the high stocking rate at a ratio of cattle-to-sheep of 0:1. This together with the relatively high aerial cover abundance scores in the treatments grazed at the high stocking rate suggests that both grazing intensity and cattle-to-sheep ratio had an influence on its aerial cover abundance.

Response to the cattle-to-sheep ratio

Although statistically significant differences were detected in a number of species as a result of the different cattle-to-sheep ratios, in many instances they were the result of particularly high or low aerial cover abundance scores in one or more of the treatments and did not display consistent responses to the increasing proportions of sheep to cattle. Species that did display consistent responses to the proportion of sheep to cattle and whose aerial cover abundances were inversely related to the proportion of sheep to cattle included *P. angustifolia*, *A. schinzii*, *D. amplectens*, *A. punctata*, *H. nudifolium*, *A. bakerianus*, *H. miconiifolium* and *M. angustifolia*.

Although a particularly high aerial cover abundance score was recorded for *P. angustifolia* in the treatment grazed at the high stocking rate at a ratio of cattle-to-sheep of 1:0 the treatment at the same ratio that was grazed at the low stocking rate had the second highest aerial cover score and this ratio was statistically significantly different from all others (Figure 5.15(a)). The next highest aerial cover abundance scores were recorded in the treatments grazed at a cattle-to-sheep ratio of 3:1, which compared with very low scores in the paddocks grazed at higher proportions of sheep to cattle.

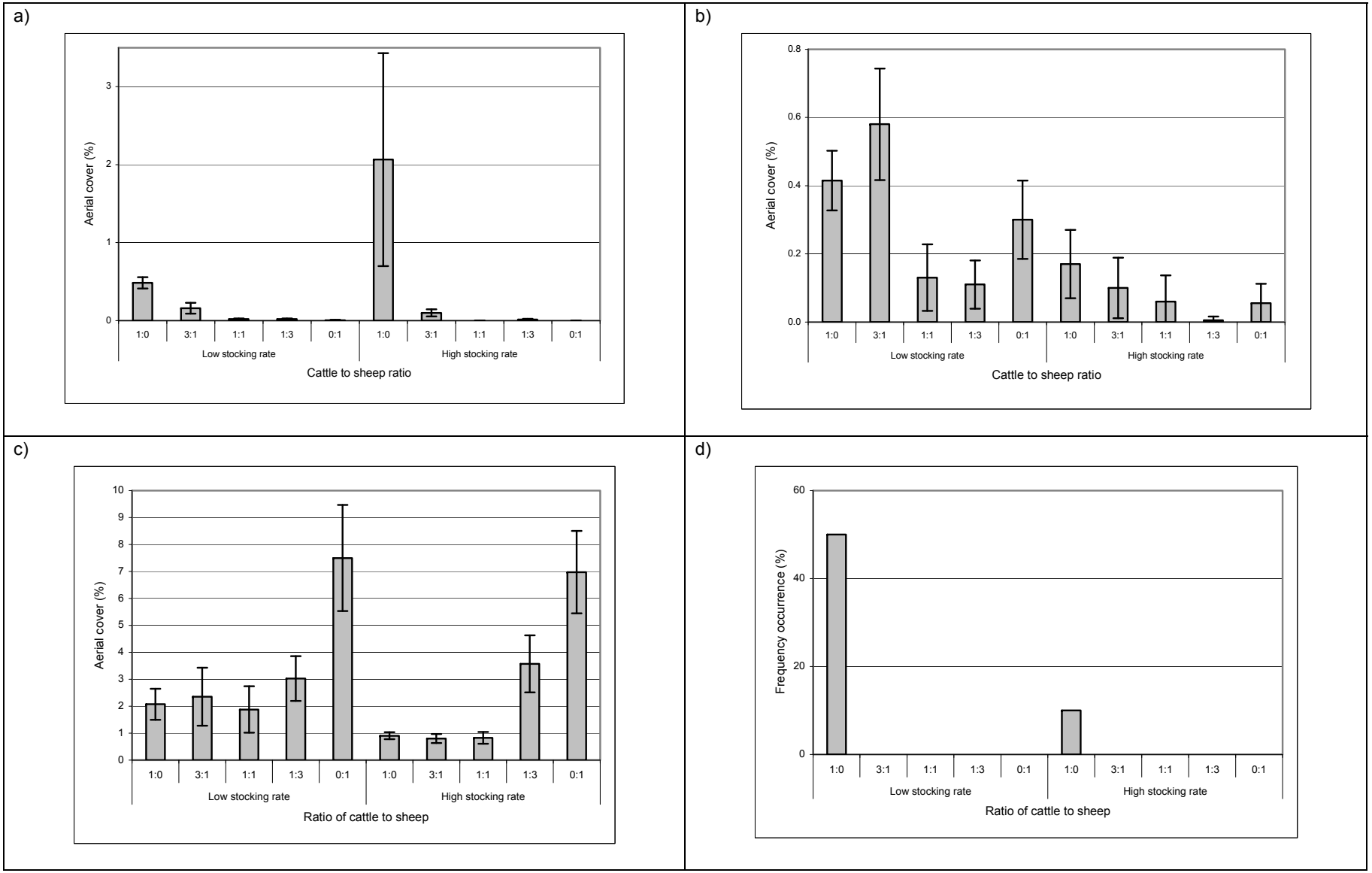


Figure 5.15 Mean aerial cover scores and standard deviation for (a) *Pentanisia angustifolia*; (b) *Helichrysum nudifolium*; (c) *Alloteropsis semialata*; and (d) mean frequency occurrence of *Aster bakerianus* per treatment

Although the pattern detected in *A. schinzii* was not as clear, there was a trend of decreasing cover abundance with an increase in the proportion of sheep to cattle and the treatment grazed at a cattle-to-sheep ratio of 0:1 was statistically significantly different from all other treatments.

The pattern detected in *D. amplectens* was also not particularly clear, but there was a trend of decreasing cover abundance with an increase in the proportion of sheep to cattle and an interaction with the stocking rate. The treatment grazed at a cattle-to-sheep ratio of 0:1 was statistically significantly different from the treatment grazed at a cattle-to-sheep ratio of 3:1, which reflected the relatively high cover abundance at the ratio of 3:1 and the significantly lower cover abundance at the ratio of 0:1.

Although a particularly high cover abundance score was recorded for *A. punctata* in the treatment grazed at the low stocking rate at a ratio of cattle-to-sheep of 1:0, there was a clear trend of decreasing cover abundance with an increasing proportion of sheep to cattle. The treatment grazed at a ratio of cattle-to-sheep of 1:0 was statistically significantly different from all other treatments.

A clear pattern was detected in *H. nudifolium*, in which there was a clear trend of decreasing cover abundance with an increasing proportion of sheep to cattle (Figure 5.15(b)). The treatments grazed at ratios of cattle-to-sheep of 1:0 and 3:1 were statistically significantly different from all other treatments but not from each other.

A. bakerianus, *H. miconiifolium* and *M. angustifolia*, which occurred at particularly low cover abundance scores, displayed a strong response to the ratio of cattle-to-sheep. *A. bakerianus* (Figure 5.15(d)) did not occur in any of the treatments but the one grazed at a ratio of cattle-to-sheep of 1:0 and displayed a strong interaction with the stocking rate as it occurred at a higher frequency occurrence in the treatment grazed at the low stocking rate. Similarly, *H. miconiifolium* only occurred in the treatment grazed at a ratio of cattle-to-sheep of 1:0 and displayed a strong interaction with the stocking rate as it only occurred in the treatment grazed at the low stocking rate. *M. angustifolia* occurred in the treatments grazed at ratios of cattle-to-sheep of 1:0 and 3:1 but not in any of the other treatments. The treatment grazed at a ratio of 1:0 was statistically significantly different from all other treatments expect the treatment grazed at a ratio of 3:1.

Species whose aerial cover abundance was directly related to the proportion of sheep to cattle included *A. semialata* and *M. caffra*. *A. semialata* displayed a particularly clear trend (Figure 5.15(c)), as it increased in aerial cover abundance significantly at ratios of cattle-to-sheep of 1:3 and 0:1. The treatments grazed at these ratios were statistically significantly different from each other and from all the other treatments.

The trend displayed by M. caffra was similar to that of A. semialata except that it displayed a strong interaction with stocking rate and only increased significantly in aerial cover abundance at the high stocking rate and a ratio of cattle-to-sheep of 0:1. The treatments grazed at this ratio were statistically significantly different from all other treatments.

Paired sample t test

As with the two-paddock trial there was an obvious difference in the total cumulative number of species collected in the $1m^2$ quadrats compared with the $10m^2$ quadrats (Figure 5.16). Except for the paddock grazed at the low stocking rate and a cattle-to-sheep ratio of 0:1 and the paddock grazed at the high stocking rate and a cattle-to-sheep ratio of 3:1, the cumulative number of species collected in the $1m^2$ quadrats was greater than the cumulative number of species collected in the $10m^2$ quadrats. The paddock grazed at the low stocking rate and a cattle-to-sheep ratio of 0:1 had three more species in the $10m^2$ quadrats than in the $1m^2$ quadrats and the paddock grazed at the high stocking rate and a cattle-to-sheep ratio of 3:1 had 50 species in both the $10m^2$ and $1m^2$ quadrats. The largest difference between the quadrats was in the paddock that was grazed at the high stocking rate and a ratio of cattle-to-sheep of 1:0, where 23 more species were collected in the $1m^2$ quadrats than in the $10m^2$ quadrats. The

differences between the cumulative numbers of species collected in the different quadrats were found to be statistically significant ($t = -3.31$, $P < 0.009$).

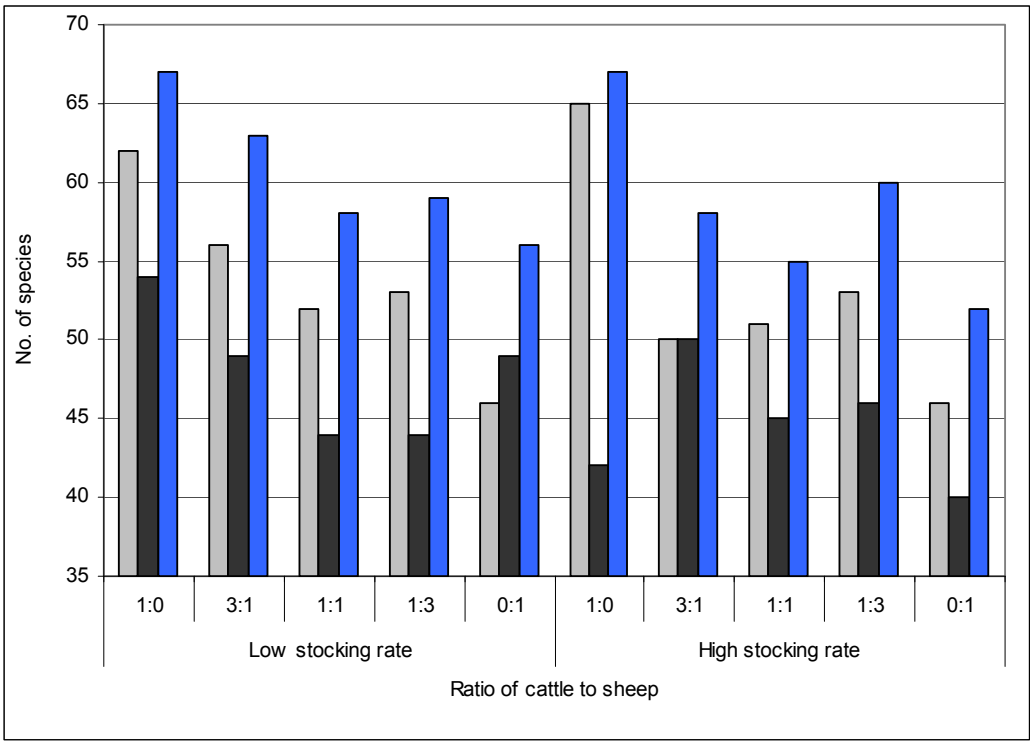


Figure 5.16 Total cumulative number of species in all $1m^2$ (grey-shaded columns) and $10m^2$ (black columns) quadrats and in each paddock (blue-shaded columns)

As in the two-paddock trial, in all instances species were recorded in one of the sets of quadrats but not the other. A mean of 11.6 species was recorded in the $1m^2$ quadrats only compared with a mean of 6.0 species that were recorded in the $10m^2$ quadrats only.

6) DISCUSSION

Analysis of the data in the two-paddock trial suggests that the community composition of the trial has been affected by varying environmental conditions and possibly by historical grazing patterns at the site. Despite this the different stocking rates applied in the trial did appear to influence its community composition and the abundance and presence of a number of individual species. Unexpectedly, the 2005/06 burning programme appears to have had a particularly strong influence on the results that were obtained from the data, which was collected in December 2005, suggesting that undertaking the data collection later in the season, in February or March, may have been more appropriate.

A clearer picture of the influence of the different grazing regimes on the community composition and individual species emerged in the analysis of the data collected in the simulation trial. Although the two stocking rates appear to have affected community composition, the ratio of cattle-to-sheep appears to have had a stronger impact, resulting in decreased species richness among non-graminoid monocotyledons and dicotyledons in the treatments grazed at higher proportions of sheep to cattle.

The results of the analysis of the diversity and evenness indices appeared to largely reflect differences in cover between the different paddocks in the two trials, which appeared to be the result of environmental variability or historical influences. Because of this, they did not provide any indication of the influence of stocking rates or ratios of cattle-to-sheep on plant diversity. CCA and ANOVA of species richness and individual species in both trials produced far more meaningful results that provided a clearer picture of the dynamics between the grazing regimes and the grassland diversity.

The comparison of the spatial differences in sampling between the $1m^2$ and $10m^2$ quadrats revealed that significantly more species were cumulatively captured in the $1m^2$ than in the $10m^2$ quadrats. Although the total area of the two types of quadrats is the same, this was the result that was expected, as the $1m^2$ quadrats covered a more varied area than the $10m^2$ quadrats, capturing more of the spatial variation and heterogeneity of the individual paddocks. For this reason the $1m^2$ quadrats formed the primary focus for the analysis of the data and the results that were generated.

6.1 The two-paddock trial

From the results it is apparent that the influence of the different stocking rates in the trial has been confounded by spatial variation within the site and possibly historical variables that make it challenging to draw meaningful conclusions about the influence of the grazing regime on the diversity of the grassland in the trial. Much of the apparent variation found within the trial appears to be the result of environmental variability. It is also possible that the trial area may have been affected by historical grazing practices that occurred before the trial was initiated. Furthermore, the data seems to have been confounded by the burning programme, in which one of each of the replicates was burnt in September 2005. It appears that the low species richness encountered in the burnt replicates may have been due to an inadequate amount of time for the plants, in particular the non-graminoid species, to recover and germinate or re-sprout by the time the data collection was undertaken in December 2005.

Despite these issues some patterns emerged in the analysis of the data and it is worthwhile examining them in the context of the influence of the burning programme and the apparent pediment effect that exists at the trial site.

Influence of the burning programme

A clear difference existed between those replicates of each treatment that had been burnt in September 2005 compared with those that had not. The burnt replicates had noticeably lower mean and total numbers of species per $1m^2$ quadrat than their corresponding replicates, which had been burnt the previous spring and rested for the 2005/06 season. It seems unlikely that

the influence of grazing alone would result in such marked differences between the replicates in only a three month period, which is supported by the mean cover scores, in which most of the burnt replicates had considerably lower total aerial cover scores than the unburnt replicates, with the exception of the replicates grazed under the high stocking rate, which may have been the result of an environmental influence rather than the grazing regime.

CCA showed that a number of species were influenced by the burning programme, in most cases resulting in decreased aerial cover abundance, as in *Pentanisia angustifolia*, but aerial cover abundance did increase in some species such as *Vernonia natalensis*. Analysis of species richness, using a three-way ANOVA, further confirmed the statistically significant differences as a result of the burning programme, which arose from a greater number of species in the unburnt replicates compared with those that were burnt. In general the non-graminoid species exhibited a strong inverse relationship to the burning programme, as there was a noticeably lower mean number of these species in the burnt replicates compared with those that were unburnt. Conversely, the graminoids did not appear to be as strongly affected, as a reasonably consistent number of grass species were found in the $1m^2$ quadrats across all treatments and in some instances a higher number of grass species occurred in the replicates that had been burnt.

Unfortunately the life history attributes of many of the species that occurred in the trial are not known in detail, as it is likely that they could, to some extent, explain the responses that the individual species exhibited towards the burning programme. For example the aerial cover abundance of *Elionurus muticus* was statistically significantly higher in the replicates that had been burnt compared with those that were unburnt, which may have been because it is one of the first grass species to sprout in spring following a fire (Tainton *et al* 1990; van Oudsthoorn 1992). *Helichrysum nudifolium*, which is a perennial herb, spreads by underground runners, which may enable it to re-sprout faster than other species resulting in a higher abundance in the burnt replicates than in those that were not burnt. In contrast *Diheteropogon filifolius* is acceptable only to animals for grazing when it is young but once mature, animals will select strongly against it (Tainton *et al* 1990). As it was dominant across most of the trial site, it is understandable that it would occur at higher cover abundances in the replicates that were unburnt, as the sheep would generally not select it in their grazing behaviour resulting in the accumulation of large amounts of moribund material. This would be burnt off in the burnt replicates enabling the sheep to graze on the young, more palatable re-growth. It is possible that this was the case for a number of the grass species such as *Themeda triandra*, *Heteropogon contortus* and *Eragrostis curvula* that would be most palatable early in the season following the fires that had been put through the burnt replicates. This may to some extent also have been the case with *Pentanisia angustifolia*, which occurred at very low aerial cover abundances in the replicates that were burnt and grazed in the 2005/06 season, as there was visible evidence that the plants of this species were being grazed by the sheep. As a result, maximum aerial cover abundance scores of 0.1% or 0.5% were recorded in these replicates compared with a number of aerial cover abundance scores of 1.0% or 1.5% in the unburnt replicates.

Other factors that may have influenced the aerial cover abundance of particular species in the trial include soil moisture. Species such as *Anthospermum herbaceum*, *Senecio speciosus*, *Stachys sessilis* and *Polygala ohlendorfiana* commonly occur in moist soil conditions (Pooley 1998, Hilliard and Burrt 1987). In the exposed environment of the areas that had been burnt, in which there was considerably lower cover abundance, these species may not have been fully capable of re-establishing themselves until sufficient re-growth had occurred to make conditions more suitable, which is further supported by the growth forms of these species. *A. herbaceum* is a straggling herb that may form a cushion-like mat and is commonly found in moist thickets and on forest margins (Pooley 1998). *S. speciosus* is a fleshy, upright perennial herb that is commonly found in damp grassland and marshy places (Pooley 1998). *Stachys sessilis* is a slender, upright perennial herb commonly found in moist ground (Pooley 1998) and

P. ohlendorfiana is a small herb commonly found under shady rocks and in marshy ground (Hilliard and Burtt).

Influence of the apparent pediment effect

The influence of the apparent pediment effect was not as clear in the data analysis as the influence of the 2005/06 burning programme but it was confirmed in the CCA, which found a strong influence on species such as *D. filifolius* and *Helichrysum herbaceum*, which occurred at a considerably higher occurrences and cover abundances on the upper slope of the site compared to the lower slope. The analysis may also have been overly simplistic, as although there was a clear visible difference between the upper and lower slope, it did not appear to be uniformly defined by the upper and lower paddocks and may also have been influenced by drainage lines and differences in topography running down the slope.

Many of the graminoids, including *T. triandra*, *Alloteropsis semialata*, *E. curvula* and *E. muticus*, exhibited clear responses to the apparent pediment effect, occurring at greater cover abundances and frequency occurrence on the lower slopes of the site. In contrast four *Helichrysum* species occurred at greater cover abundances and frequency occurrences on the upper slopes of the site – *H. aureum*, *H. herbaceum*, *H. nudifolium* and *H. cephaloideum*. One of the most marked contrasts occurred in *Senecio retrorsus*, which was absent in many of the paddocks on the upper slope but occurred at considerably higher cover abundances on the lower slope, particularly in the lowermost paddock that was grazed at the medium stocking rate and had been burnt in the 2005/06 season, where it received cover abundance scores as high as 4.0% compared with scores between 0.1% and 1.0% in other paddocks in which it did occur.

From the analysis it is clear that there was a difference in the environmental conditions between the upper and lower parts of the trial site. This was clearly evident in the almost complete dominance of *D. filifolius* in many of the paddocks on the uppermost parts of the site and its marked reduction in cover abundance on the lowermost parts of the site. It is possible that these differences were the result of different soil types, soil moisture or drainage conditions that enabled various species to flourish in different parts of the trial site but the conditions also appear to have been more complex than could be explained by a division of paddocks into the upper and lower slope. These conditions make it difficult to draw conclusive findings from the analysis of the influence of the different stocking rates as the effects of grazing appear to have been confounded by the position of the paddocks within the trial site, which has in turn influenced their species composition.

Influence of the grazing regime

Despite the influences of the 2005/06 burning programme and the apparent pediment effect, some meaningful patterns emerged from the statistical analysis as a result of the different stocking rates in the trial site. The CCA identified an inverse relationship between *T. triandra* and the stocking rate and a direct relationship in species such as *E. curvula* and *S. speciosus*. These results were largely as would be expected, as *T. triandra* is a Decreaser species that would be expected to decline in abundance with increasing grazing pressure, whilst *E. curvula* is generally associated with overgrazed and trampled grassland and is classified as an Increaser IIb species that would be expected to increase in abundance with moderate overgrazing (van Oudtshoorn 1992).

It was not expected that there would be a higher mean number of species per $1m^2$ quadrat in the treatments grazed at the high stocking rate compared to those grazed at the low and medium stocking rates, but it is possible that this was the result of changes in the species composition as a result of the stocking rates that enabled undesirable or weedy species, which would ordinarily grow in disturbed areas, to colonise the treatments grazed at the high stocking rate.

The response of *T. triandra* was largely expected although a particularly low cover

abundance score recorded in one of the paddocks grazed at the medium stocking rate that was not burnt in the 2005/06 season may have been an anomaly, as a considerably higher score was recorded in the other unburnt paddock grazed at this stocking rate. Despite this, the response detected in the cover abundance and frequency occurrence data for *T. triandra* appears to be consistent with the findings of Peddie *et al.* (1995), who found that the two-year management cycle implemented in the trial resulted in a substantial increase in the abundance of *T. triandra*, compared with grazing regimes in which a full year's rest is not provided.

The results obtained for *D. filifolius* were not as expected as it is a 'wire grass,' classified as an Increaser IIb species that is expected to increase in cover abundance when grassland is overgrazed (Tainton *et al* 1990; van Oudtshoorn 1992; Hardy *et al.* 1999). As discussed above, it appeared to be strongly influenced however by the pediment effect that appeared to affect its occurrence and cover abundance across the site.

Other graminoids exhibited responses to the different stocking rates that would be expected. *Eragrostis plana* and *Sporobolus africanus* are classified as Increaser IIc species that increase in cover abundance with severe overgrazing (van Oudtshoorn 1992). *E. plana* in particular is considered an indicator of grassland that has been severely overgrazed or selectively grazed (Acocks 1988) and there was a markedly higher occurrence of the species in the paddocks grazed at the high stocking rate compared to the low stocking rate. In contrast analysis of the data for species such as *Panicum ecklonii* which is classified as a Decreaser species demonstrated statistically significant differences as the result of decreasing occurrence and cover abundance scores, associated with increasing grazing pressure.

The responses of the non-graminoid monocotyledons and dicotyledons to the different stocking rates were also variable with some species increasing in abundance and other decreasing in response to increasing grazing pressure. Species that exhibited a statistically significant decline in frequency occurrence and cover abundance with an increasing stocking rate included *V. natalensis*, *H. herbaceum* and *H. nudifolium*. *P. angustifolia* exhibited a highly statistically significant response to the grazing regime, increasingly markedly in cover abundance from the low to the high stocking rate in the treatments that were unburnt in the 2005/06 season, in a strong interaction with the burning programme. There was clear visible evidence that plants of this species had been grazed upon when the data was collected, suggesting that it may be palatable after it has been burnt but that it grows back strongly later in the season.

Senecio speciosus also exhibited a highly statistically significant response to the grazing regime, occurring at a mean frequency occurrence of 10.0% in the treatment grazed at the low stocking rate compared to a mean frequency occurrence of 78.8% in the treatment grazed at the high stocking rate. Other species that increased in occurrence and cover abundance with increasing grazing pressure included *Scabiosa columbaria*, *Ajuga ophrydis*, *Helichrysum cephaloideum*, *P. ohlendorfiana* and *S. sessilis*.

It is possible that the increase that occurred in the cover abundances and frequency occurrences of some of these species was the result of conditions at the high stocking rate that enabled the colonisation of opportunistic or weedy species and the replacement of agriculturally desirable species such as *T. triandra*, which would be expected to be considerably more dominant under lower grazing pressure.

The findings of the analysis of the effects of the stocking rate on the grassland in the trial support the findings of O'Connor (2005) who concluded that different grazing regimes influence the species composition of grasslands but have little effect on species richness. Clearly the different stocking rates had an effect on the species composition of the trial, resulting in an increase in the cover abundance of some species and decrease in the cover abundance of others.

6.2 The simulation trial

The results of the analysis of the data collected in the simulation trial show a strong response as

result of the ratio of cattle-to-sheep and, to a lesser extent, several significant patterns emerge as a result of the different stocking rates.

Influence of the stocking rate

The analysis of the mean number of non-graminoid species per $1m^2$ quadrat revealed a statistically significant difference as a result of the stocking rate that was due to a higher mean number of species in the paddocks grazed at the lower stocking rate compared with those grazed at the higher stocking rate. There was also a strong interaction between the stocking rate and the ratio of cattle-to-sheep, which suggested that whilst the stocking rate had a statistically significant influence, the ratio of cattle-to-sheep appeared to be the strongest influence. In contrast the analysis of the mean number of graminoids per $1m^2$ quadrat revealed a statistically significant difference as a result of the stocking rate that was due to a lower mean number of species in the paddocks grazed at the low stocking rate compared with those grazed at the high stocking rate. The influence of the stocking rate is however shown more clearly in the analysis of many of the individual species.

The response of *T. triandra* to the stocking rate indicated a statistically significant difference in the analysis of the cover abundance data. This was due to a higher cover abundance of the species in the paddocks grazed at the low stocking rate compared to those grazed at the high stocking rate, despite particularly high values being recorded in the treatments grazed at the high stocking rate at ratios of cattle-to-sheep of 1:1 and 1:3. Nevertheless, the mean cover abundance value was substantially lower at the high stocking rate, the lowest mean score of just 3.0% being in recorded in the treatment grazed at the high stocking rate with sheep only.

Other grass species that declined in response to increasing grazing intensity included *Tristachya leucothrix*, *E. muticus*, *Diheteropogon amplectens*, *A. semialata* and *Eulalia villosa*. Although only *D. amplectens* is classified as a Decreaser species (van Oudtshoorn 1992), *E. villosa* is known to become more abundant when grassland is leniently grazed and infrequently burnt (Tainton *et al.* 1990) and it, *A. semialata* and *T. leucothrix* are classified as Increaser I species that increase with understocking or selective grazing (van Oudtshoorn 1992). On the other hand, the results for *E. muticus* were not expected as it is classified as an Increaser IIb species that increases with severe overgrazing and indicates grassland that has been over-utilised (van Oudtshoorn 1992).

Grass species that increased in abundance in response to increasing grazing intensity included *Microchloa caffra*, *E. curvula*, *S. africanus*, *E. plana* and *Brachiara serrata*. Of these species, *B serrata* would not be expected to increase in abundance with increasing grazing intensity, as it is classified as a Decreaser species, but it occurred at considerably lower cover abundance across all treatments than most other grass species in the trial. The remainder of the species would be expected to increase within increasing grazing intensity. *E. curvula* is an Increaser IIb species that increases with moderate overgrazing and is generally associated with overgrazed and trampled grassland (van Oudtshoorn 1992). *E. plana*, *M. caffra* and *S. africanus* are classified as Increaser IIc species that increases with severe overgrazing and *S. africanus* and *M. caffra* occur in disturbed areas and in grassland that has degenerated from overgrazing (Tainton *et al.* 1990; van Oudtshoorn 1992).

Non-graminoid species that increased in frequency occurrence and cover abundance in response to grazing intensity included *S. retrorsus*, *Anthospermum rigidum*, *Tolpis capensis*, *Diclis rotundifolia*, *Crabbea acaulis*, *Abildgaardia ovata* and *Ajuga ophrydis*. *S. retrorsus* is a poisonous plant species that is known to increase in grassland that is over or selectively-utilised and it would be expected to increase in abundance in response to increasing grazing pressure (Hardy *et al.* 1999). Despite a particularly high mean cover abundance score for *S. retrorsus* in the treatment grazed at the high stocking rate and a ratio of cattle-to-sheep of 1:3, most of the cover abundance values at the high grazing intensity were higher than those at the low grazing intensity. The frequency occurrence of *T. capensis*, which was as high as 45% in some of the

treatments grazed at the high stocking rate, compared with a range of 0% to 20% in the treatments grazed at the low stocking rate was also expected, as it is a perennial herb with a stout woody rootstock that is often found in disturbed places (van Wyk and Malan 1997).

Non-graminoid species that declined in cover abundance and frequency occurrence in response to grazing intensity included *H. nudifolium*, *Bulbostylis oritrephes*, *V. natalensis*, *A. schinzii*, *Cyperus* sp.1, *A. punctata*, *K. amatymbica*, *A. bakerianus* and *M. angustifolia*. The decline in the abundance of *H nudifolium* and *V. natalensis* reflects the findings of the two-paddock trial in which these species also declined in response to the increasing sheep grazing intensity. The results for *A. schinzii* were unexpected, as it was expected to increase in abundance with increasing grazing pressure (Acocks 1988). It is notable that considerably more non-graminoid species declined in abundance in response to increasing grazing intensity within the trial than those that increased in abundance with increasing grazing pressure.

Influence of the ratio of cattle-to-sheep

A clear difference, as a result of the ratio of cattle-to-sheep was apparent in the plots. A similar pattern appeared in the plots of the mean number of species, the total number of species and the mean number of non-graminoid species per $1m^2$ quadrat (Figures 5.9 and 5.10). A general decline in the mean and total number of species as the proportion of sheep increased in the cattle-to-sheep ratio was evident and was confirmed in the statistical analysis. One notable anomaly in the data was that at both stocking rates, the mean number of species, the total number of species and the mean number of non-graminoid species per $1m^2$ quadrat increased from a ratio of cattle-to-sheep of 1:1 to a ratio of 1:3. No clear pattern emerged in the analysis of the mean number of graminoids per $1m^2$ quadrat however.

The results of the analysis are interesting to compare with the findings of Hardy and Tainton (1993) who found that sheep production declined as the proportion of sheep increased in the cattle-to-sheep ratio and that the poorest performance was recorded when only sheep were grazed (a ratio of 0:1). This may be a reflection of the selective feeding of sheep and their reported propensity to reduce the number of palatable species in grassland. Tainton and Hardy (1993) concluded that cattle through their bulk grazing habits should be used to “condition” grasslands to provide the short, leafy grazing material preferred by sheep.

The analysis of the effects of the cattle-to-sheep ratio on *T. triandra* produced statistically significant results but it was difficult to identify a discernible pattern as the particularly high cover abundance scores recorded in the treatments grazed at the high stocking rate and ratios of cattle-to-sheep of 1:1 and 1:3 appeared to be anomalies. In contrast analysis of the cover abundance data for *A. semialata* produced a strong statistically significant pattern associated with the cattle-to-sheep ratio, in which there was a marked increase in its cover abundance at ratios of cattle-to-sheep of 1:3 and 0:1, at both stocking rates. This response is largely what would be expected, given that *A. semialata* is classified as an Increaser I species, meaning that increases in abundance in grassland that is selectively grazed (van Oudtshoorn 1992).

Although a number of other statistically significant differences were detected as a result of the cattle-to-sheep ratio in individual species, most of these were associated with one or two paddocks with unusually high or unusually low cover abundance scores or frequency occurrences and it was difficult to draw meaningful conclusions about them based on the different ratios.

Statistically significantly higher cover abundance scores were recorded for *P. angustifolia* in the treatments in which there was a higher proportion of cattle in the cattle-to-sheep ratio. This response is in contrast to the two-paddock trial, which showed increasing cover abundance with increasing grazing pressure, but it is notable that its cover abundance in the treatments that had been burnt and were being grazed was considerably lower, suggesting that the effects of grazing, at least temporarily result in its decline.

The results produced in the analysis of the cover abundance and frequency occurrence

data for *H. nudifolium* also appear to reinforce the findings of the two-paddock trail which found a statistically significant decline in the cover abundance of *H. nudifolium*, associated with increasing grazing pressure from sheep.

Species that occurred at very low frequencies in the trial that appeared to show a strong response to the cattle-to-sheep ratio included *A. bakerianus* and *M. angustifolia*. These species largely disappeared as the proportion of sheep in the cattle-to-sheep ratio increased. In all treatments in which sheep were present, *A. bakerianus* was absent, occurring only in the treatments grazed with cattle. This result compared with the findings of the two-paddock trial, in which *A. bakerianus* occurred very scarcely, only having been recorded on four occasions throughout the trial. *A. bakerianus* is a perennial herb with hairless stems and bracts that grows up to 450mm (Pooley 1998) and it is difficult to explain the reasons for its disappearance when sheep are present unless if is heavily grazed on by sheep, resulting in its disappearance under these treatments.

In contrast to the two-paddock trial, the results of the simulation trial suggest that the different grazing regimes, particularly the different ratios of cattle-to-sheep influenced both the species composition of the grassland and its species richness, resulting in a lower overall species richness at higher proportions of sheep in the cattle-to-sheep ratio and lower overall non-graminoid species richness at higher grazing intensities.

6.3 Shortcomings of the data

Although the two-paddock and simulation trials had been running for 10 and 17 years respectively when the data was collected, there were several shortcomings in both the trials and the data capture methods that could have been improved to produce more meaningful results. In regard to what is practicable for such field trials, in terms of human and financial resources, the trials were well designed but the confidence one can draw from the statistical analysis is hindered by the lack of statistical replication. Although the two-paddock trial consisted of two replicates of each treatment and each stocking rate was grazed in a total of four paddocks, the results were significantly influenced by the environmental variability within the trial area. In contrast there was only one replicate of each treatment in the simulation trial and the highly varied sizes and dimensions of the paddocks used in it may have influenced the data that was collected.

The influence of the burning programme in which half of the paddocks had been burnt in September 2005 had a strong effect on the data, which was collected in December 2005. This problem and the lack of replicate treatments in the simulation trial may have been overcome by collecting a baseline dataset and then re-collecting data several times, at different times of the year over a period of two years or more in an effort to create a dataset with adequate statistical replication that encompassed the variability that would occur in the species composition and cover associated with the burning regime and the different stages of growth and dormancy in the plants. This approach would have provided a clearer indication of the changes in vegetation over time associated with the grazing regimes in each of the trials rather than the simple snapshot that was provided by the approach that was taken. This would also have overcome temporary fluctuations or localised changes in the abundance or presence of particular species, associated with temporal influences such as rainfall, uncontrolled fires or unusual fluctuations in temperature. Through such a process, trajectories of change associated with particular plant species could be identified and a clearer understanding could be developed of the influence of different ratios of cattle-to-sheep and of different grazing intensities on species composition and richness over time.

Despite these shortcomings the results obtained from the analysis of the data provided an indication of the influence of different grazing intensities on the species composition and richness of the grasslands in which the trials have been performed, from which some broad conclusions may be drawn about such grazing regimes in Highland Sourveld generally.

7) CONCLUSION

The purpose of the study was to examine the influence of stocking rates of cattle and sheep, and ratios of cattle-to-sheep on grassland species richness and vegetation composition at the Kokstad Agricultural Research Station. To some extent the research questions raised have been answered through the study but the results that have emerged from the data analysis are not unequivocal, particularly in the study of the two-paddock trial in which a number of confounding factors appear to have blurred the impact of the different stocking rates. The different stocking rates of sheep do however appear to have had an influence on the species composition of the grassland at the site. As O'Connor (2005) found however there does not appear to have been an effect, as a result of the different grazing intensities, on overall species richness, associated with increasing grazing intensity. It is possible that this is the result of conditions that enable the colonisation of pioneer or weedy species at high grazing intensities.

In contrast to the two-paddock trial, the results of the simulation trial suggest that the ratio of cattle-to-sheep, more so than the stocking rate, has had a powerful influence on both the species composition and the species richness of the trial site. The results of the study make an interesting comparison with the results of animal production studies that have been conducted at the trial site (Hardy and Tainton 1993; Hardy and Tainton 1995), which concluded that sheep performance was poorest when sheep grazed alone and that the optimal ratios of cattle-to-sheep were those with high ratios of cattle, in terms of AU, to sheep. Despite the influence of the cattle-to-sheep ratio, stocking rate remained nonetheless important, as there was a statistically significant difference in non-graminoid species richness between the two grazing intensities, with a higher number of species occurring in those paddocks grazed at the lower stocking rate compared with those grazed at the high stocking rate.

The results of the study reinforce the notion that sheep are not an ideal choice of livestock for maintaining plant diversity when grazing humid grasslands in KwaZulu-Natal, despite the fact that they are widely farmed in these areas, as these grasslands do not appear particularly well adapted or resilient to grazing by sheep (Hardy *et al.* 1999). The results of the study further reinforce the conclusion that in circumstances when sheep are to be farmed commercially in these grasslands, this should be undertaken using a mixed-species grazing regime, consisting of cattle and sheep with a relatively high ratio of cattle-to-sheep. Furthermore, stocking rates equivalent to the low stocking rate in the simulation trial appear to be more suitable in maintaining the structure and composition of these grasslands than the high stocking rates utilised in the two trials. The lower stocking rate and high ratio of cattle-to-sheep appears not only to result in better animal performance in the sheep but it also appears to be a more suitable approach in terms of maintaining the structure, composition and diversity of such grasslands.

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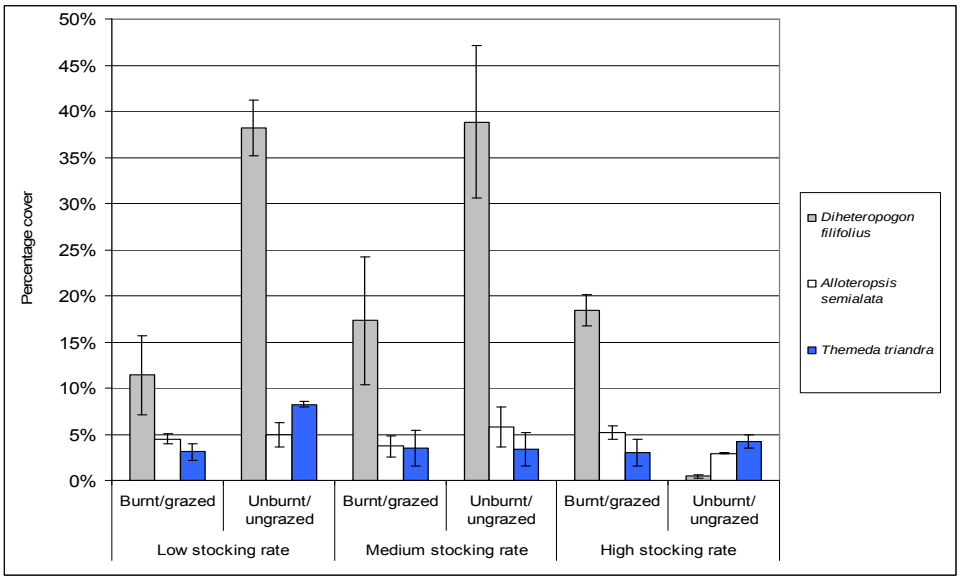
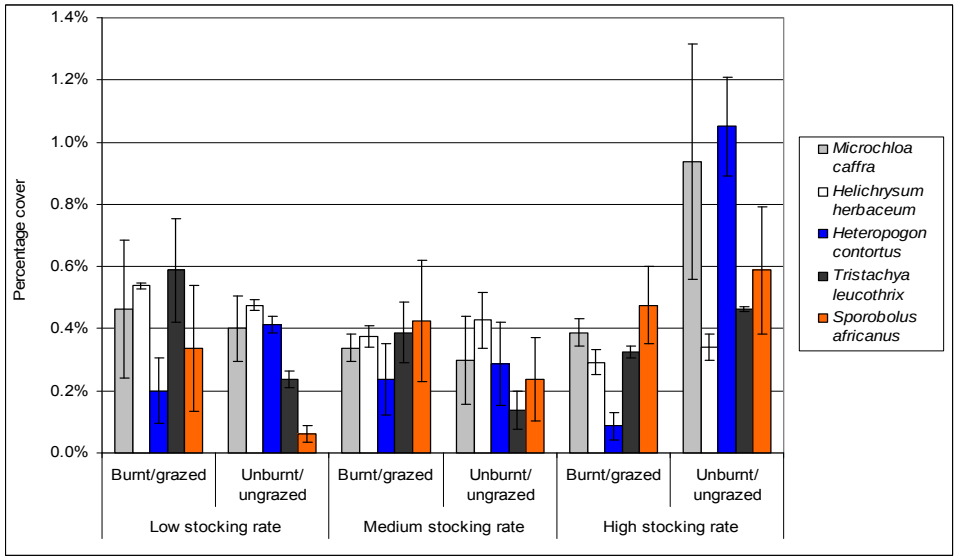
Appendix A – Two-paddock trial community composition

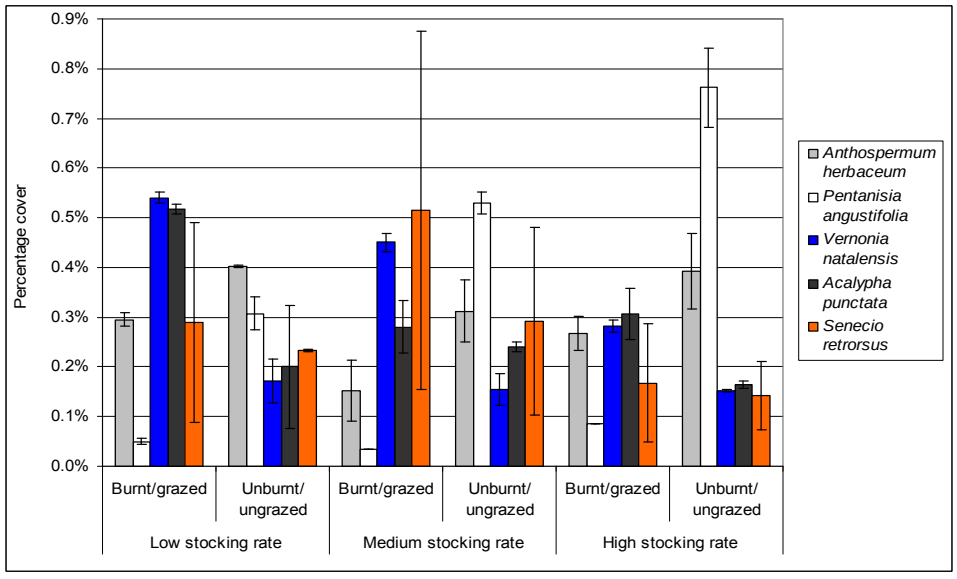
A total of 122 species, from 33 families were found in the trial. Of these, 8 species were not identified to the family, genus or species level and were simply assigned a specimen number. The families most strongly represented were the Asteraceae with 31 species and the Poaceae with 30 species. The species list is presented below.

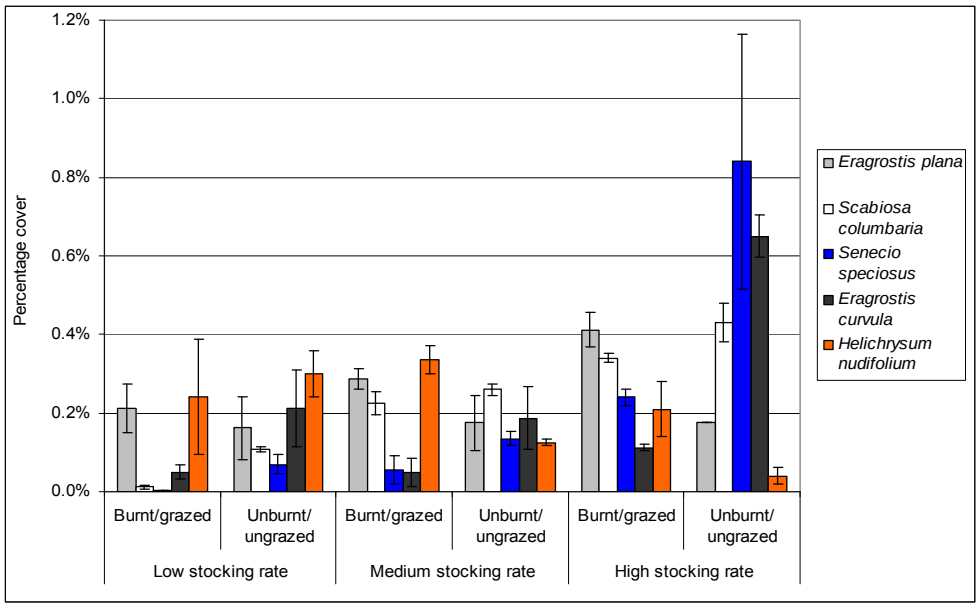
Acanthaceae	**Asclepiadaceae**	*Hypoxis rigidula*	*Panicum ecklonii*
Barleria sp.1	*Schizoglossum cordifolium*	**Juncaceae**	*Poa binata*
Anacardiaceae	*Xysmalobium involucratum*	*Juncus* sp.1	*Setaria nigrirostris*
Rhus dentata	**Boraginaceae**	**Lamiaceae**	*Setaria sphacelata*
Rhus discolor	*Cynoglossum hispidum*	*Ajuga ophrydis*	*Sporobolus africanus*
Apiaceae	*Cynoglossum lithospermum*	*Stachys sessilis*	*Themeda triandra*
Centella asiatica	**Campanulaceae**	**Linaceae**	*Trachypogon spicatus*
Asteraceae	*Wahlenbergia undulata*	*Linum thunbergii*	*Tristachya leucothrix*
Aster bakerianus	**Commelinaceae**	**Malvaceae**	Poaceae sp.4
Athrixia phylicoides	*Commelina africana*	*Hibiscus aethiopicus*	Poaceae sp.5
Berkheya rhapontica	**Cucurbitaceae**	**Orchidaceae**	Poaceae sp.6
Conyza sp.1	*Cucumis hirsutus*	Orchidaceae sp.1	**Polygalaceae**
Felicia muricata	**Cyperaceae**	**Oxalidaceae**	*Polygala ohlendorfiana*
Gerbera piloselloides	*Abildgaardia ovata*	*Oxalis smithiana*	**Rosaceae**
Helichrysum aureum	*Bulbostylis oritrephes*	*Oxalis* sp.1	*Leucosidea sericea*
Helichrysum cephaloideum	*Cyperus sphaerocephalus*	**Periplocaceae**	**Rubiaceae**
Helichrysum herbaceum	*Cyperus* sp.1	*Raphionacme hirsuta*	*Anthospermum herbaceum*
Helichrysum miconiifolium	Cyperaceae sp.1	**Plantaginaceae**	*Anthospermum rigidum*
Helichrysum nudifolium	Cyperaceae sp.2	*Plantago virginica*	*Kohautia amatymbica*
Helichrysum pilosellum	**Dipsacaceae**	**Poaceae**	*Pentanisia angustifolia*
Helichrysum thalypterum	*Scabiosa columbaria*	*Alloteropsis semialata*	**Scrophulariaceae**
Pseudognaphalium sp.1	**Euphorbiaceae**	*Brachiara serrata*	*Diclis rotundifolia*
Senecio baurii	*Acalypha punctata*	*Digitaria setifolia*	*Graderia scabra*
Senecio brevidentatus	*Acalypha schinzii*	*Diheteropogon amplectens*	**Sterculiaceae**
Senecio coronatus	**Fabaceae**	*Diheteropogon filifolius*	*Hermannia depressa*
Senecio retrosus	*Indigofera fristis*	*Elionurus muticus*	**Thymelaeaceae**
Senecio scitus	*Lotonis corymbosa*	*Eragrostis capensis*	*Gnidia caffra*
Senecio speciosus	**Geraniaceae**	*Eragrostis curvula*	*Gnidia kraussiana*
Senecio striatifolius	*Monsonia angustifolia*	*Eragrostis plana*	**Verbenaceae**
Sonchus nanus	*Pelargonium sp. 1*	*Eragrostis racemosa*	*Verbena brasiliensis*
Sonchus sp.1	**Hyacinthaceae**	*Eulalia villosa*	**Other**
Taraxacum sp.1	*Albuca setosa*	*Festuca costata*	Specimen 4
Tolpis capensis	*Ornithogalum graminifolium*	*Festuca scabra*	Specimen 11
Vernonia capensis	*Scilla nervosa*	*Harpochloa falx*	Specimen 14
Vernonia natalensis	**Hypericaceae**	*Heteropogon contortus*	Specimen 15
Asteraceae sp.1	*Hypericum lalandii*	*Koeleria capensis*	Specimen 16
Asteraceae sp.2	**Hypoxidaceae**	*Microchloa caffra*	Specimen 17
Asteraceae sp.3	*Hypoxis argentea*	*Monocymbium ceresiiforme*	Specimen 18
Asteraceae sp.4	*Hypoxis gerrardii*	*Panicum aquinerve*	Specimen 19

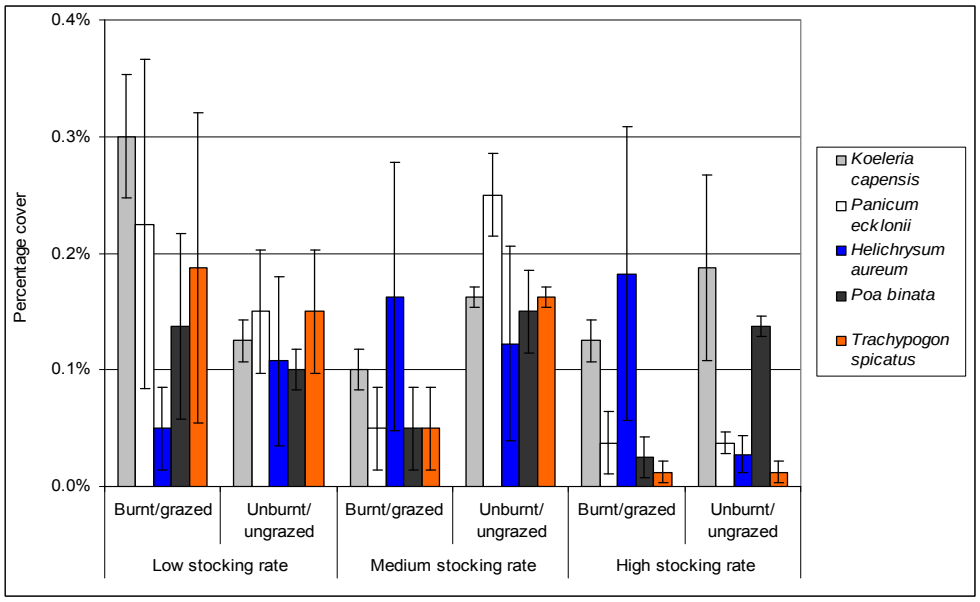
Appendix B – species mean cover abundances in the two-paddock trial

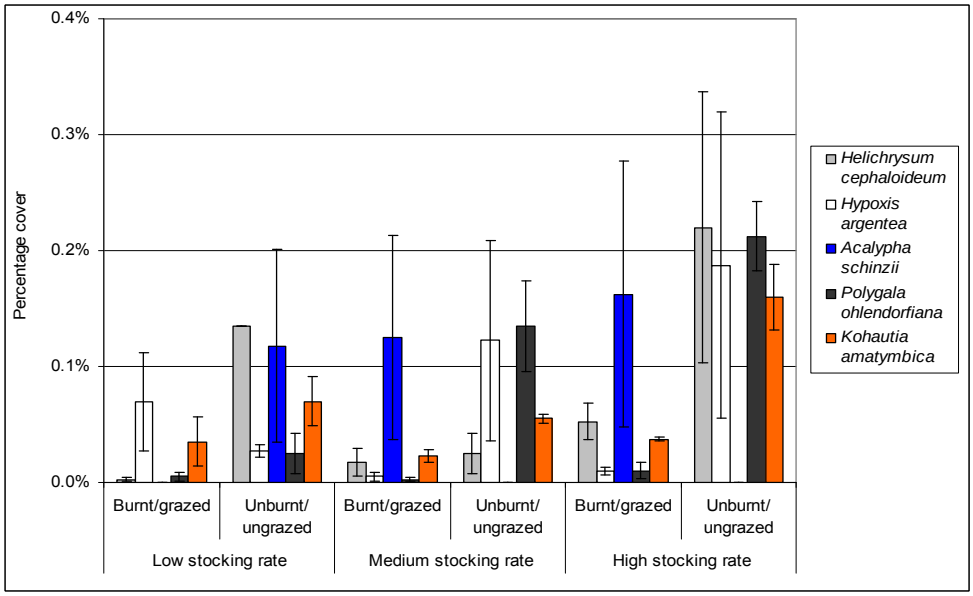


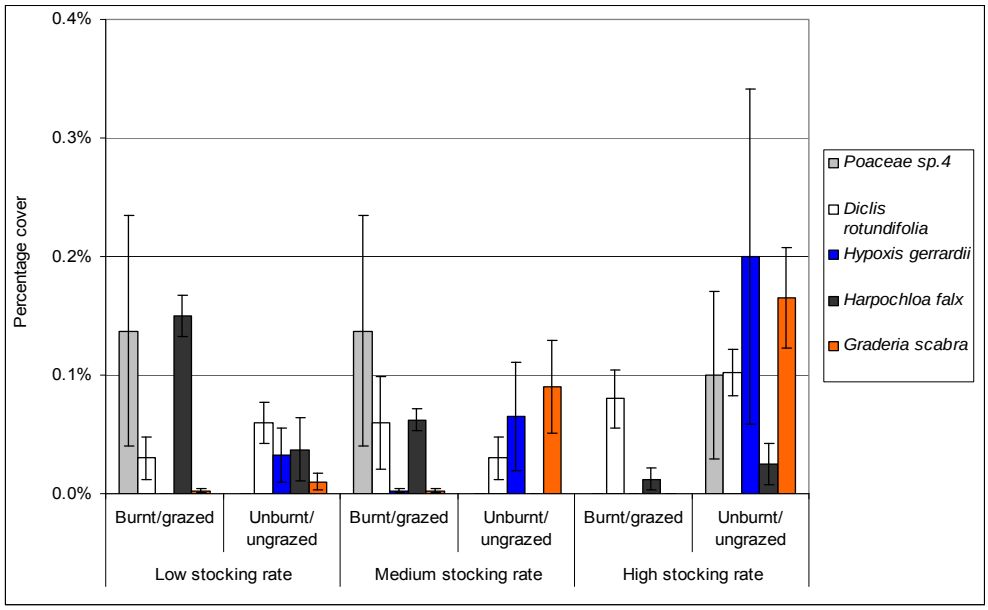


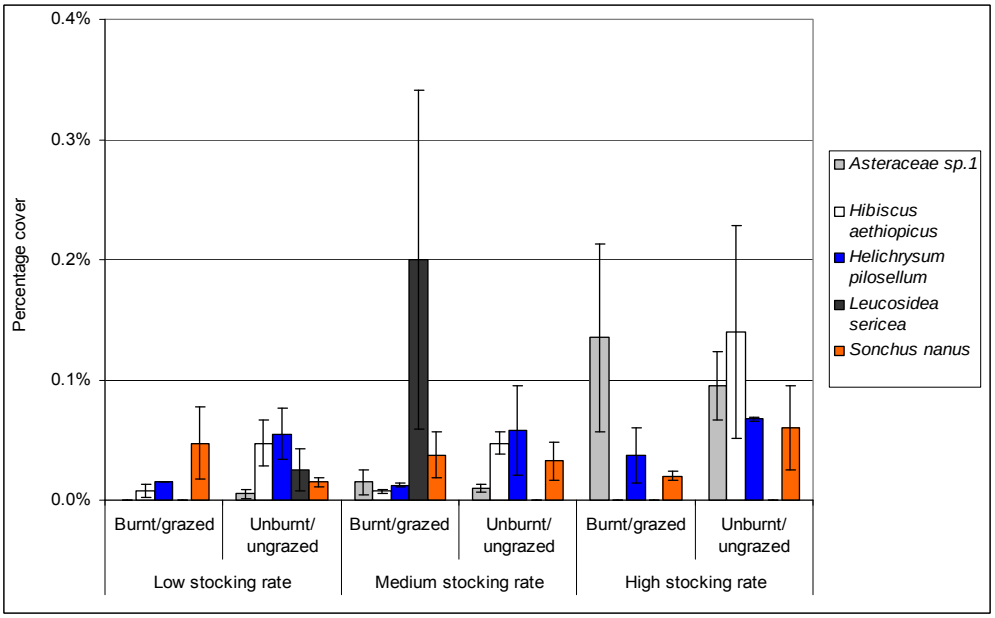


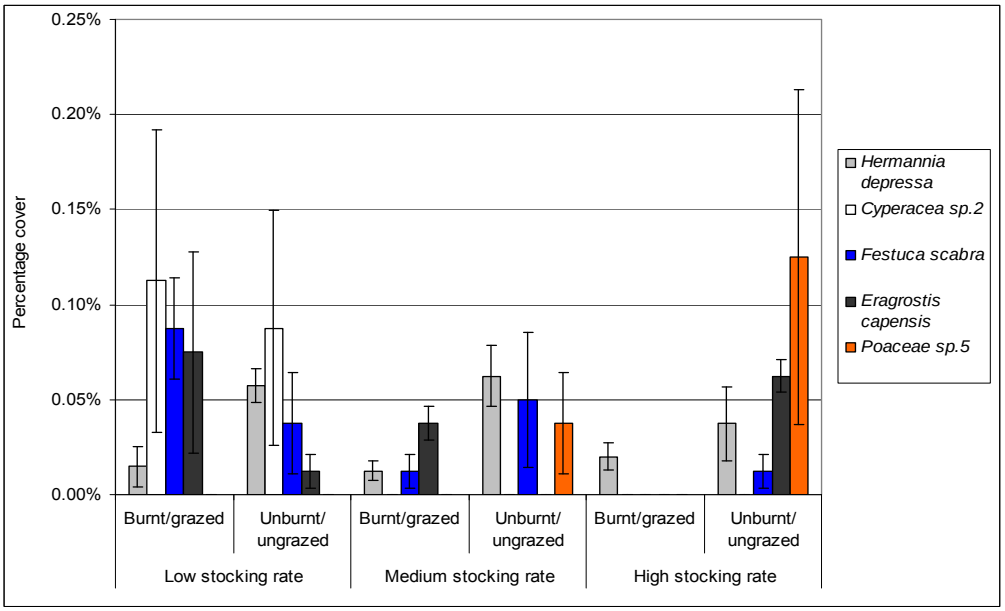

1.2%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
Percentage cover
Eragrostis plana
Scabiosa columbaria
Senecio speciosus
Eragrostis curvula
Helichrysum nudifolium
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate

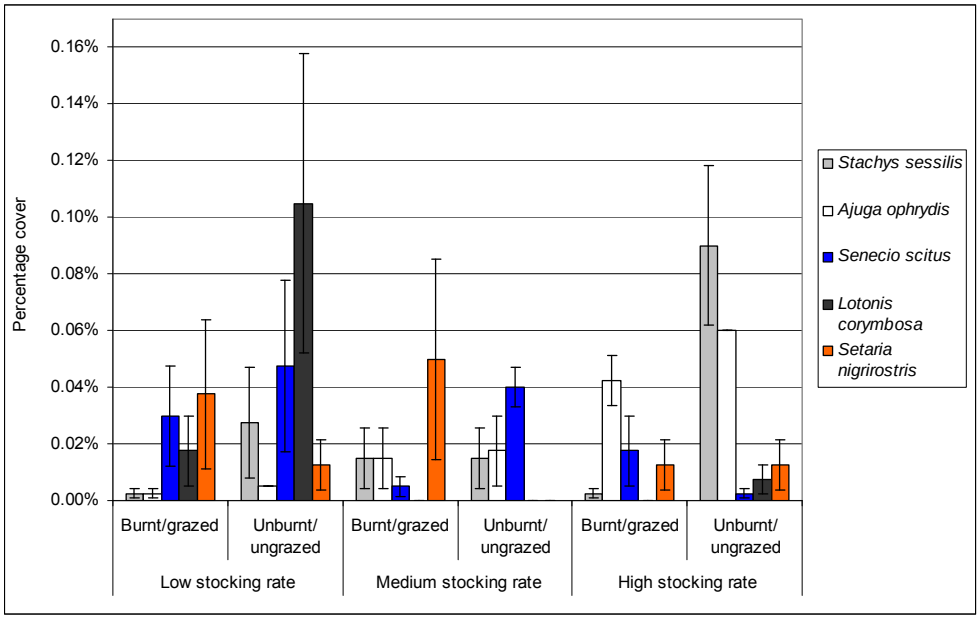

0.4%
0.3%
0.2%
0.1%
0.0%
Percentage cover
Koeleria capensis
Panicum ecklonii
Helichrysum aureum
Poa binata
Trachypogon spicatus
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate

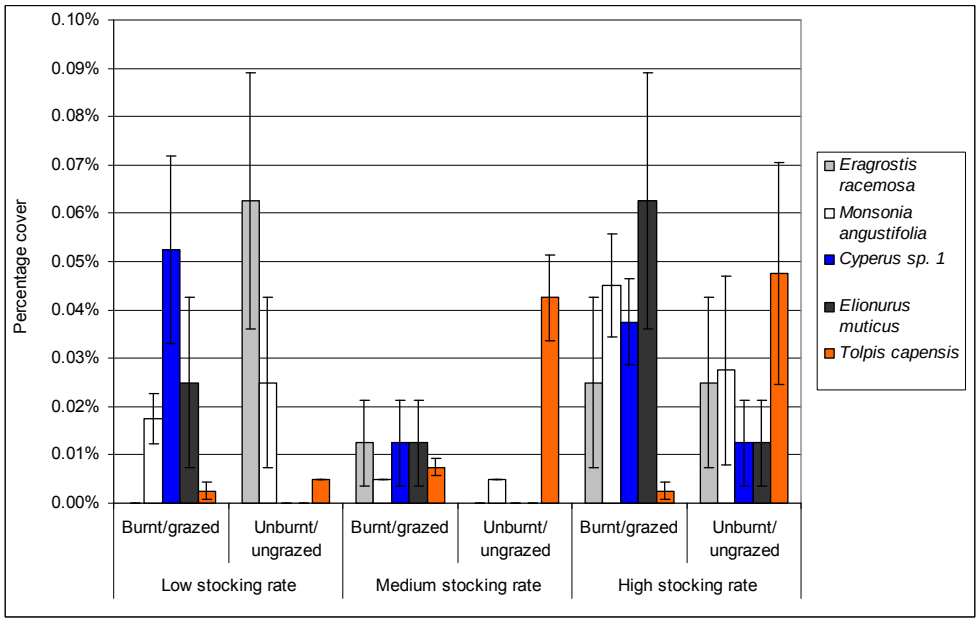

0.4%
0.3%
0.2%
0.1%
0.0%
Percentage cover
Helichrysum cephaloideum
Hypoxis argentea
Acalypha schinzii
Polygala ohlendorfiana
Kohautia amatymbica
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate


0.4%
0.3%
0.2%
0.1%
0.0%
Percentage cover
Poaceae sp.4
Diclis rotundifolia
Hypoxis gerrardii
Harpochloa falx
Graderia scabra
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate


0.4%
0.3%
0.2%
0.1%
0.0%
Percentage cover
Asteraceae sp.1
Hibiscus aethiopicus
Helichrysum pilosellum
Leucosidea sericea
Sonchus nanus
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate


0.25%
0.20%
0.15%
0.10%
0.05%
0.00%
Percentage cover
Hermannia depressa
Cyperacea sp.2
Festuca scabra
Eragrostis capensis
Poaceae sp.5
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate


0.16%
0.14%
0.12%
0.10%
0.08%
0.06%
0.04%
0.02%
0.00%
Percentage cover
Burnt/grazed
Unburnt/ ungrazed
Burnt/grazed
Unburnt/ ungrazed
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate
Stachys sessilis
Ajuga ophrydis
Senecio scitus
Lotonis corymbosa
Setaria nigrirostris

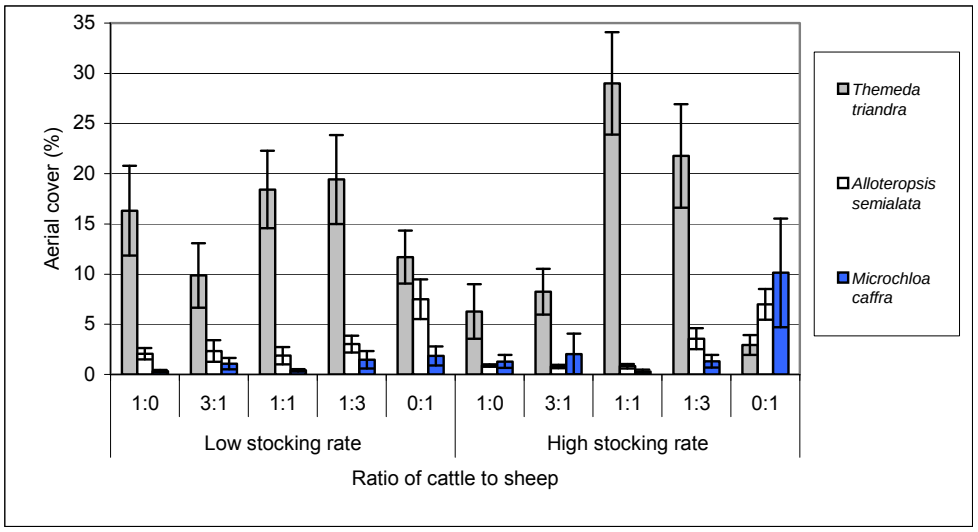

0.10%
0.09%
0.08%
0.07%
0.06%
0.05%
0.04%
0.03%
0.02%
0.01%
0.00%
Percentage cover
Burnt/grazed
Unburnt/ ungrazed
Burnt/grazed
Unburnt/ ungrazed
Burnt/grazed
Unburnt/ ungrazed
Low stocking rate
Medium stocking rate
High stocking rate
Eragrostis racemosa
Monsonia angustifolia
Cyperus sp. 1
Elionurus muticus
Tolpis capensis

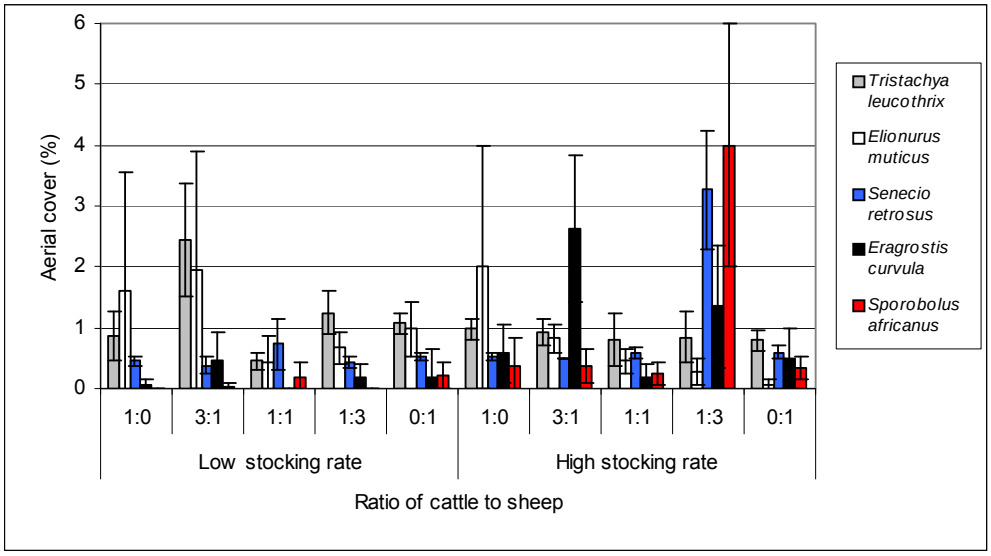
Appendix C – Simulation trial community composition

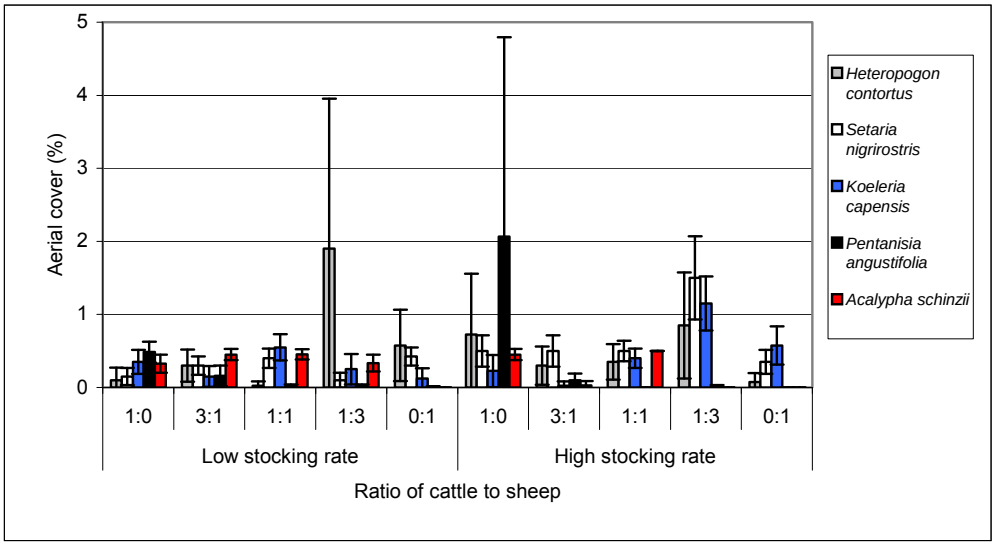
A total of 113 species from 31 families were found in the simulation trial. Of these, 7 species were not identified to the family, genus or species level and were simply assigned a specimen number. The families most strongly represented were the Poaceae with 30 species and the Asteraceae with 20 species. The species list is presented below.

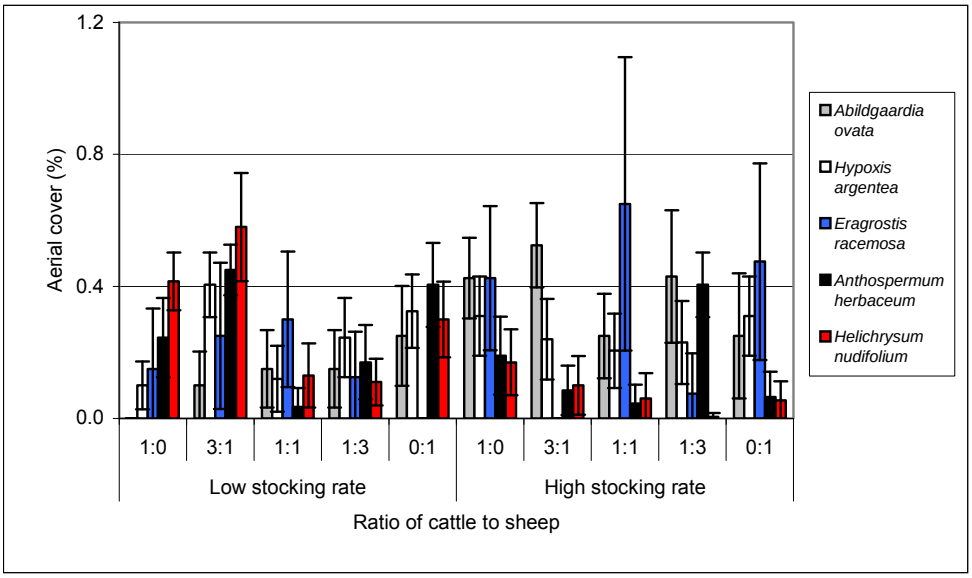
Acanthaceae	**Cyperaceae**	**Oxalidaceae**	**Polygalaceae**
Barleria sp.1	*Abildgaardia ovata*	*Oxalis smithiana*	*Polygala amatymbica*
Crabbea acaulis	*Bulbostylis oritrephes*	*Oxalis* sp.1	*Polygala gerrardii*
Anacardiaceae	*Cyperus sphaerocephalus*	**Periplocaceae**	*Polygala ohlendorfiana*
Rhus dentata	Cyperus sp.1	*Raphionacme hirsuta*	**Ranunculaceae**
Anthericaceae	**Dipsacaceae**	**Plantaginaceae**	*Ranunculus meyeri*
Chlorophytum cooperi	*Cephalaria oblongifolia*	*Plantago virginica*	**Rubiaceae**
Asteraceae	*Scabiosa columbaria*	**Poaceae**	*Anthospermum herbaceum*
Aster bakerianus	**Euphorbiaceae**	*Alloteropsis semialata*	*Anthospermum rigidum*
Gerbera piloselloides	*Acalypha punctata*	*Brachiara serrata*	*Kohautia amatymbica*
Helichrysum cephaloideum	*Acalypha schinzii*	*Cynodon dactylon*	*Pentanisia angustifolia*
Helichrysum herbaceum	**Fabaceae**	*Digitaria setifolia*	*Pentanisia prunelloides*
Helichrysum miconiifolium	*Lotonis corymbosa*	*Digitaria tricholaenoides*	**Scrophulariaceae**
Helichrysum nudifolium	*Rhynchosia totta*	*Diheteropogon amplectens*	*Diclis rotundifolia*
Helichrysum pilosellum	**Geraniaceae**	*Diheteropogon filifolius*	*Graderia scabra*
Lactuca capensis	*Monsonia angustifolia*	*Elionurus muticus*	*Striga bilabiata*
Senecio coronatus	**Hyacinthaceae**	*Eragrostis capensis*	**Sterculiaceae**
Senecio retrosus	*Albuca setosa*	*Eragrostis curvula*	*Hermannia depressa*
Senecio scitus	*Ledebouria ovatifolia*	*Eragrostis plana*	**Thymelaeaceae**
Senecio speciosus	*Scilla nervosa*	*Eragrostis racemosa*	*Gnidia capitata*
Senecio striatifolius	**Hypoxidaceae**	*Eulalia villosa*	*Gnidia kraussiana*
Sonchus nanus	*Hypoxis argentea*	*Festuca scabra*	**Other**
Tolpis capensis	*Hypoxis obtusa*	*Harpochloa falx*	Specimen 1
Vernonia capensis	*Hypoxis rigidula*	*Helictotrichon turgidulum*	Specimen 2
Vernonia natalensis	**Iridaceae**	*Helictotrichon* sp.1	Specimen 4
Asteraceae sp.1	Iridaceae sp.1	*Heteropogon contortus*	Specimen 5
Asteraceae sp.2	**Juncaceae**	*Koeleria capensis*	Specimen 6
Asteraceae sp.3	*Juncus* sp.1	*Microchloa caffra*	Specimen 7
Asclepiadaceae	**Lamiaceae**	*Panicum ecklonii*	Specimen 9
Asclepias flexuosa	*Ajuga ophrydis*	*Setaria nigrirostris*	
Xysmalobium involucratum	*Solanum* sp.1	*Setaria sphacelata*	
Boraginaceae	*Stachys sessilis*	*Sporobolus africanus*	
Cynoglossum hispidum	**Linaceae**	*Themeda triandra*	
Cynoglossum lithospermum	*Linum thunbergii*	*Trachypogon spicatus*	
Commelinaceae	**Malvaceae**	*Tristachya leucothrix*	
Commelina africana	*Hibiscus aethiopicus*	Poaceae sp.1	
Cucurbitaceae	**Orchidaceae**	Poaceae sp.2	
Cucumis hirsutus	*Eulophia calanthoides*	Poaceae sp.3	
Cucumis zeyheri	Orchidaceae sp.1		

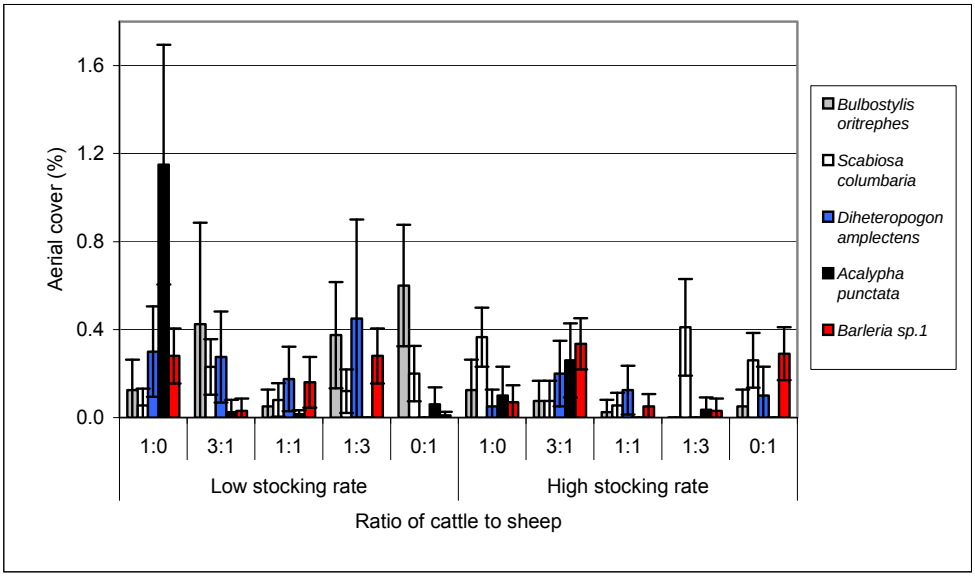
Appendix D – species mean cover abundances in the simulation trial

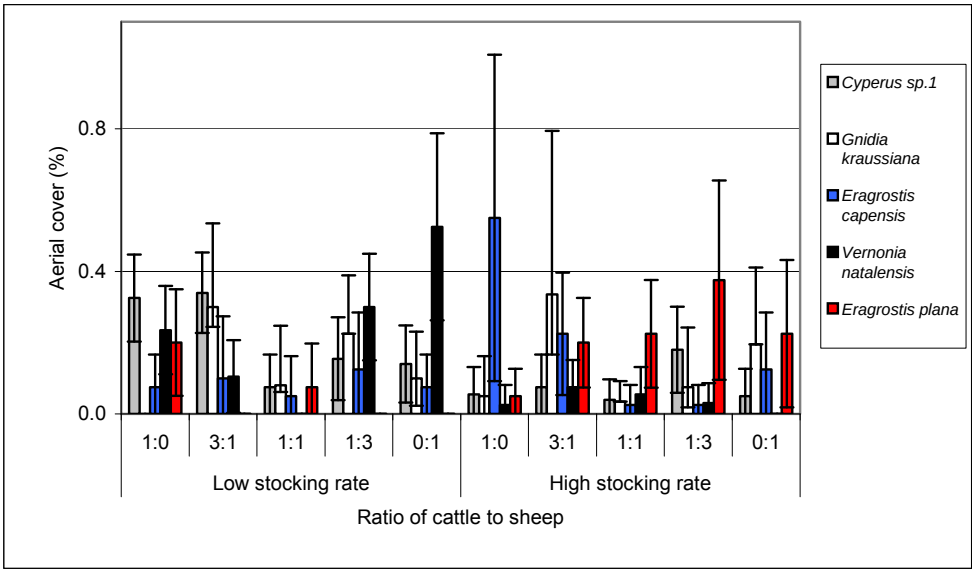


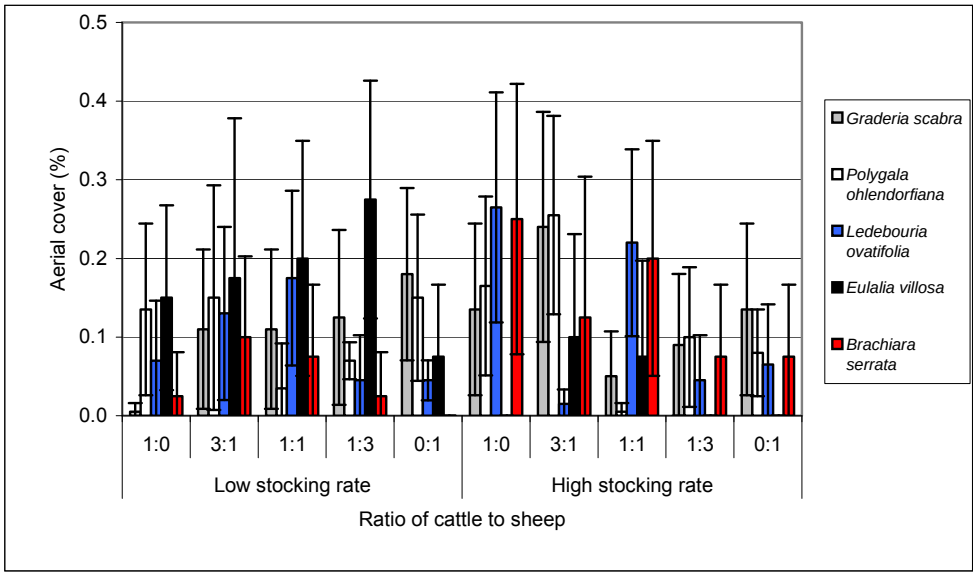


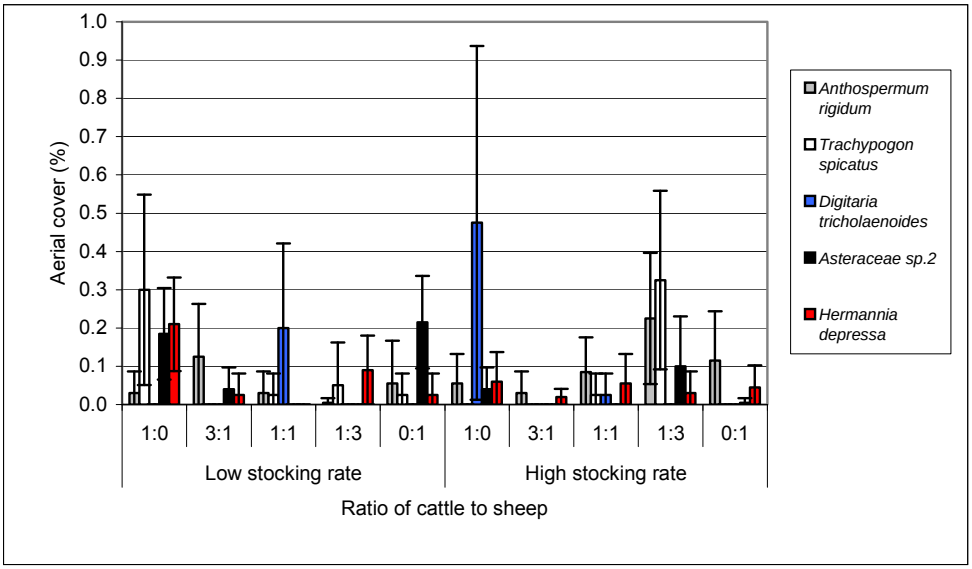


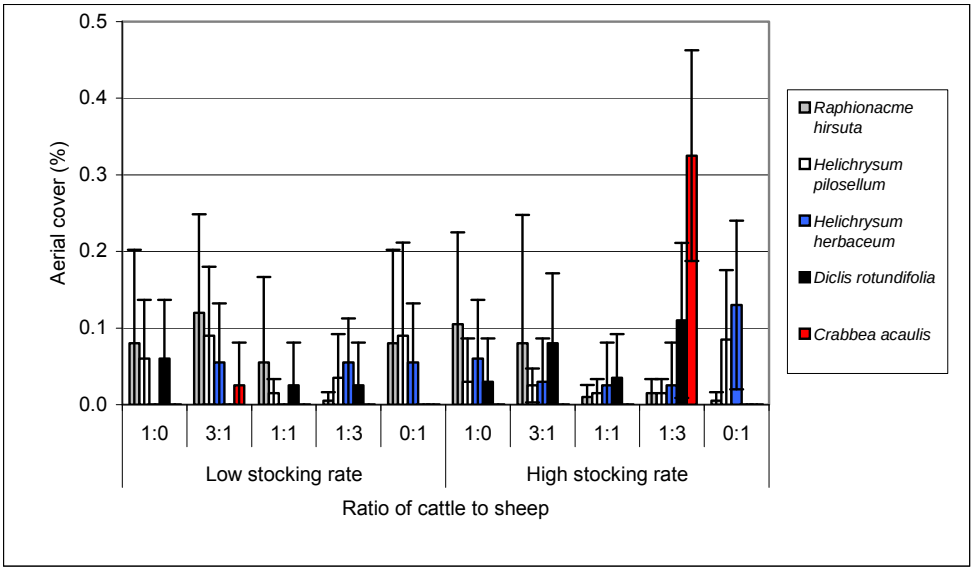

1.2
0.8
0.4
0.0
Aerial cover (%)
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep
Abildgaardia ovata
Hypoxis argentea
Eragrostis racemosa
Anthospermum herbaceum
Helichrysum nudifolium

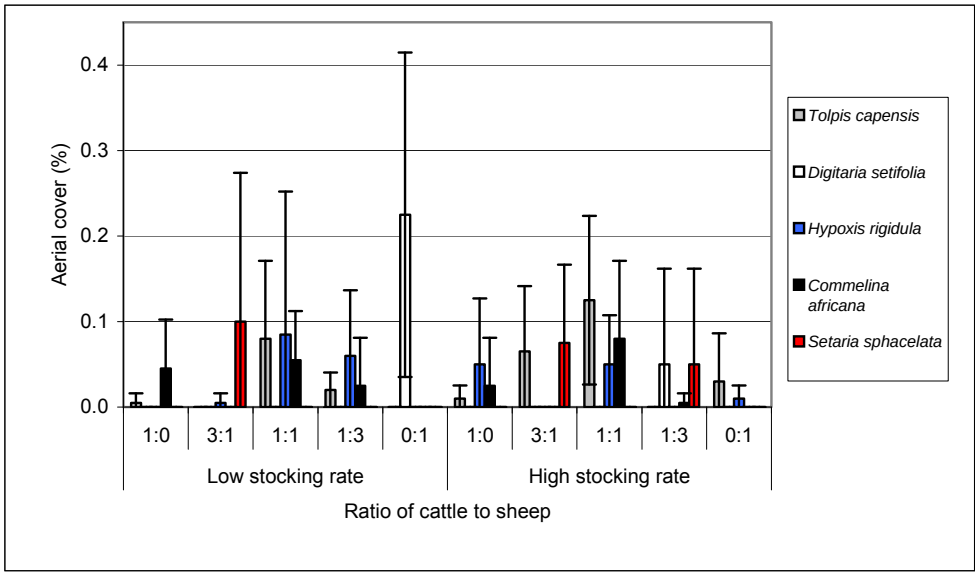

1.6
1.2
0.8
0.4
0.0
Aerial cover (%)
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep
Bulbostylis oritrephes
Scabiosa columbaria
Diheteropogon amplectens
Acalypha punctata
Barleria sp.1

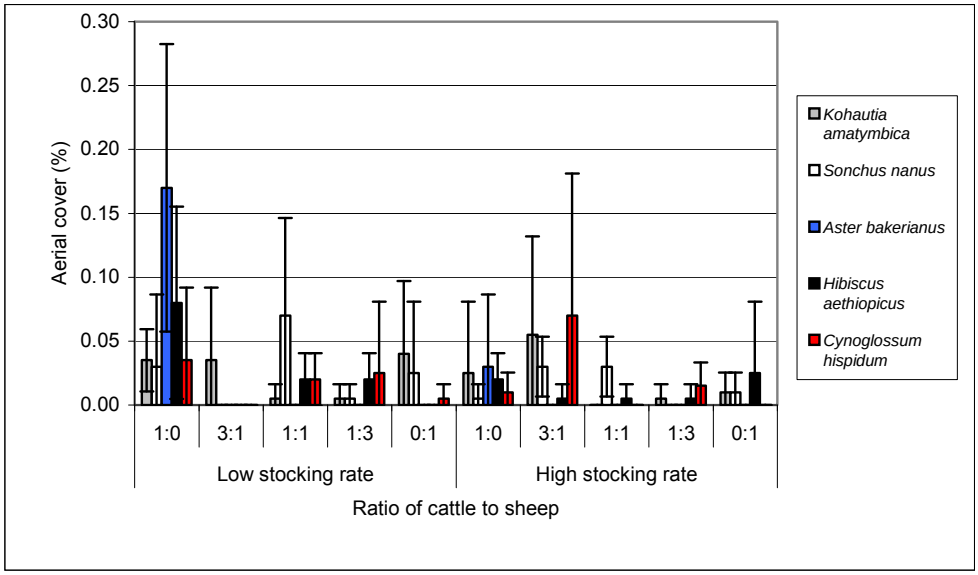

0.8
0.4
0.0
Aerial cover (%)
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep
Cyperus sp.1
Gnidia kraussiana
Eragrostis capensis
Vernonia natalensis
Eragrostis plana


0.5
0.4
0.3
0.2
0.1
0.0
Aerial cover (%)
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep
Graderia scabra
Polygala ohlendorfiana
Ledebouria ovatifolia
Eulalia villosa
Brachiara serrata


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Aerial cover (%)
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep
Anthospermum rigidum
Trachypogon spicatus
Digitaria tricholaenoides
Asteraceae sp.2
Hermannia depressa


0.5
0.4
0.3
0.2
0.1
0.0
Aerial cover (%)
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep
Raphionacme hirsuta
Helichrysum pilosellum
Helichrysum herbaceum
Diclis rotundifolia
Crabbea acaulis


0.4
0.3
0.2
0.1
0.0
Aerial cover (%)
Tolpis capensis
Digitaria setifolia
Hypoxis rigidula
Commelina africana
Setaria sphacelata
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep


0.30
0.25
0.20
0.15
0.10
0.05
0.00
Aerial cover (%)
Kohautia amatymbica
Sonchus nanus
Aster bakerianus
Hibiscus aethiopicus
Cynoglossum hispidum
1:0
3:1
1:1
1:3
0:1
1:0
3:1
1:1
1:3
0:1
Low stocking rate
High stocking rate
Ratio of cattle to sheep