

The coastal grasslands of Maputaland, South Africa: Effects of fire and grazing on vegetation structure, diversity, and composition.

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Abstract

A series of trials and investigations were implemented to address concerns surrounding the dynamics of the fire-climax wooded/edaphic grasslands within the iSimangaliso Wetland Park, northern KwaZulu-Natal, South Africa. The research problem surrounded inadequate historical evaluations of changes in vegetation structure, grasslands progressing to a woody dominated composition, and increases in *Helichrysum kraussii* (Curry bush).

These were addressed as follows: Firstly, the recovery of vegetation in response to different periods of fire exclusion in different communities along a topographical gradient of a coastal dune area, was assessed over a two year period. Secondly, the regeneration after wildfire of the persistent, stress tolerant shrub *H. kraussii*, was studied on different catenal positions with differing fire exclusion periods and with and without defoliation of surrounding plant biomass in the coastal edaphic grasslands north of Manzengwenya, South Africa. Thirdly, aerial photography from 1937, 1975, and 2000 was georectified, digitised and analysed using a Geographic Information System to examine broad vegetation changes in response to different management regimes for a site on the Eastern Shores of Lake St Lucia and a site within the Tewater Wilderness Area.

In the absence of fire, the coastal edaphic grasslands progressed to a closed canopied scrub forest within six years. An increase in fire exclusion period resulted in a decrease in species abundance, an increase in woody height, and a decrease in plant density. Richness increased initially but declined marginally with increased fire exclusion period. Higher lying east and west facing sites had a better veld condition index compared with bottom sites and had an increased response (vigour) to defoliation but were far more likely to succeed through to woody scrub forest. Woody plant biomass vigour was greater for west facing sites.

Ordination of species composition across sites in response to fire exclusion and catenal position revealed greater similarities within exclusion periods than between. Bottom sites were more similar with similarity decreasing for east and west facing sites. Fire exclusion resulted in an initial increase in woody species and a subsequent increase in herbaceous species.

Growth response of *H. kraussii* was unaffected by catenal position and fire exclusion period, whereas defoliation of surrounding grass tended to increase in size ($P < 0.05$). Density and height for this species however increased with increasing fire exclusion. An increase in soil moisture negatively affected *H. kraussii* growth indicating susceptibility to high water tables. The number of other woody species establishing beneath *H. kraussii* may be due to changes in the transmission of light through the canopy where an increase in canopy diameter resulted in an increase of photosynthetically active radiation at the soil surface.

The effects of fire on landscape change were investigated for the Eastern Shores and Tewate Wilderness Area, iSimangaliso Wetland Park, South Africa using aerial photography. Changes to historical disturbance regimes largely through active exclusion of fire resulted in the majority of the higher lying coastal grasslands changing to savanna scrub or closed canopied forest within 63 years on the Eastern Shores. The degree of fragmentation of these grasslands was greatly reduced within the Tewate Wilderness Area where disturbance regimes included greater frequencies of fire. Hygrophilous grasslands remained largely unaffected by woody encroachment but did not preclude woody species establishment indicating possible susceptibility during long drier periods.

Frequent fires result in the maintained distribution of the higher grasslands. This vegetation type is a system which becomes resilient in response to fire, whereas in the absence of fire readily progresses to Dune Forest. The coastal grasslands above the high water table are therefore highly unstable and transformed easily in the absence of regular disturbance. It would appear that a threshold of approximately six years exists, after which substantial management intervention may be required to reverse the succession back to grassland.

The growth of *H. kraussii* was unaffected by fire and remained persistent irrespective of fire exclusion period. An ability to attain size (height and canopy diameter) was limited with increased soil moisture but density was reduced through regular burning. Frequent fires are necessary to reduce density of *H. kraussii* and reduce the competitive advantage gained with age.

Preface

The experimental work described in this dissertation was carried out in the Discipline of Grassland Science, School of Biological and Conservation Sciences, Faculty of Science and Agriculture, University of KwaZulu-Natal, Pietermaritzburg, from January 2004 to October 2007, under the supervision of Professor Kevin Kirkman and co-supervision of Dr. Ricky Taylor.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.

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Mr. Brian Patrick Alexander Dalton (candidate).

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Prof. Kevin Kirkman (supervisor).

Signed:

Dr. Ricky Taylor (co-supervisor).

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Isaiah 40:28-31. Have you not known? Have you not heard? The LORD is the everlasting God, the Creator of the ends of the earth. He does not faint or grow weary; His understanding is unsearchable. He gives power to the faint, and to him who has no might He increases strength. Even youths shall faint and be weary, and young men shall fall exhausted; but they who wait for the LORD shall renew their strength; they shall mount up with wings like eagles; they shall run and not be weary; they shall walk and not faint (ESV).

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List of acronyms

ANOVA – Analysis of variance

Aspect – Refers to the topographical position of a site along the catena

BRG – Bioresource Group

BRU – Bioresource Unit

Canopy – Unless context indicates otherwise, is the position for the light meter reading within the canopy of *H. kraussii*

Chi. Pr. – Chi-square probability

Clip – Refers to the removal of biomass surrounding *H. kraussii*

Cp – Mallows Cp test statistic is related to adjusted R-squared, but includes a heavier penalty for increasing the number of independent variables. Cp is not measured on a 0 to 1 scale. Rather, its values are typically positive and greater than 1 and lower values ‘are better’.

DCA – Detrended Correspondence Analysis

d.f. – Degrees of Freedom: An estimate of the number of independent categories in a particular statistical test or experiment.

DM – Dry matter and unless otherwise indicated is expressed as kg ha⁻¹

Dpi – Dots per square inch referring to image pixel resolution

DPM – Disc Pasture Meter

E, T, W, or B – Are four catenal positions for sites north of the Manzengwenya Offices, east, top, west, and bottom facing respectively

EIM – Ecological Index Method

EKZNW – Ezemvelo KwaZulu-Natal Wildlife

ESG – Eastern Shores Grassland site from trial one

ESP – Eastern Shores clear felled pine plantation site from trial one

F.pr. – F probability. For a set of scores divided into groups, it is defined as the total variance or mean square between groups divided by the total variance or mean square within groups. Also called the F ratio.

FExcl – Fire exclusion period and not to be confused with fire frequency

GIS – Geographical Information System

GPS – Global Positioning System

Grass – Unless indicated otherwise refers to undisturbed edaphic grassland

Ground - Unless context indicates otherwise, is the position for the light meter reading at ground level of *H. kraussii*

IWP – iSimangaliso Wetland Park

KZN – KwaZulu-Natal

LO33 – A South African co-ordinate system with an ability to preserve both area and angular distance. It is a meters-based system which uses a Cape Transverse Mercator projection, the Cape datum and longitude 33° East as the central meridian.

MBP – Manzengwenya Burning Plots north of the Manzengwenya Offices

Moisture – Unless indicated otherwise refers to the % moisture contained within the soil

M.s. – Used in ANOVA and is another term for variance. Computed by dividing the S.S. by the appropriate D.F.

NMDS – Non-metric Multidimensional Scaling

NUFU – The Norwegian Programme for Development, Research and Education

One year, three year, and six year – refers to the three fire exclusion periods north of the Manzengwenya Offices, unless indicated otherwise

P2P – Point-to-plant distance calculated as the distance from a point to the nearest plant for that quadrat using the PCQ method

PAR – Photosynthetically Active Radiation

PCA – Principal Components Analysis

PCQ – Point Centred Quarter Method

Pine – Refers to the *Pinus* plantations previously established within the IWP

RMS – Residual Mean Square error

S.S. – Sum of Squares. It is an unscaled, or unadjusted measure of dispersion (also called variability).

TWA – Tswane Wilderness Area

Unclip or Unclipped – Refers to no removal of biomass from around the *H. kraussii* plant

UNESCO – United Nations Educational, Scientific and Cultural Organisation

VegT – Refers to the vegetation type within the different burning trials

VCI – Veld Condition Index

V.r. – Variation ratio. A technique for comparing the spreads or variabilities of two sets of figures to determine whether the two sets of figures were drawn from the same population. Also known as F test.

1. Introduction

The iSimangaliso Wetland Park (IWP) (formerly the Greater St Lucia Wetland Park) has a long history of conservation, with Ezemvelo KwaZulu-Natal Wildlife (EKZNW) primarily responsible for management oversight and intervention. The Park presents a unique challenge to environmental managers due to its rich cultural and natural heritage earning this region recognition as South Africa's first World Heritage site (UNESCO 1999) and it would be unrealistic to attempt to uncouple the ecological diversity of this region from the environmental conditions and cultural history. The passage of time has seen a change in land use for the Eastern Shores of Lake St Lucia (Eastern Shores) from rural shifting agricultural practices and regular point source burning (resulting in frequent, low intensity fires), to commercial pine plantations and conservation, and ultimately it will be developed as a high density tourist area (Taylor 2003). The northern sections of the IWP have changed little in terms of historical management regimes, these being governed largely by residents in and around these areas. The resultant interplay of tall, forested dune cordons, large estuarine lake system, mosaics of wetlands, grasslands, forests and savanna with varying environmental gradients and disturbance regimes has led to a complex system. Of these vegetation types however, the coastal non-hygrophilous grasslands are probably the most prone to change and thus require a greater level of management intervention.

Fire and groundwater have been recognised as the main determinants of the coastal grasslands (Taylor 2003) where regular inundation encourages a sedge rich hygrophilous grassland and above this, exclusion of fire results in succession through to forest scrub savanna and Dune Forest (Weisser & Marques 1979; Weisser & Muller 1983). The regional effects of fire within this system is generally well appreciated, however the dynamics of the coastal grassland at a local scale in response to fire or its exclusion is not so (Taylor 2003). Increasing both the local and regional understandings surrounding the dynamics of these coastal grasslands in response to fire will greatly improve the short term management interventions by EKZNW and contribute to the broader understandings for the system.

1.1. RESEARCH PROBLEM

Fire-climax wooded/edaphic grasslands, coastal dune and sand forests, and intermediate woody vegetation characterize the humid northern KwaZulu-Natal coastal region between the Eastern Shores of Lake St Lucia and Bhanga Nek, Kosi Bay. This region can be divided into four major areas, namely the Eastern Shores of Lake St Lucia, Tewate Wilderness area, Ozabeni and Kosi (which includes the Coastal Forest Reserve).

These areas form part of the iSimangaliso Wetland Park (IWP). The Eastern Shores of Lake St Lucia has been marked for development as a high-density tourist area and Ozabeni will have a number of game species reintroduced (Taylor 2003). There is currently a lack of detailed research and understanding of the sand/dune forest and grasslands of the Maputaland Coastal region, which have been referred to as wooded and edaphic grasslands (Moll 1980) or dwarf shrub grasslands. There are also few historical records of changes in vegetation structure over time. This contributes to the current concerns for management of this region.

The role that fire season and frequency plays in maintaining a dominant grassland structure is generally well appreciated throughout the Maputaland region. Previously however, large areas of the Eastern Shores were afforested with *Pinus elliottii*, thus effectively excluding the use of fire in the surrounding grasslands. The pine plantations have been clear felled (completed in 2006), allowing the unconstrained use of fire. Management of this area revolves principally around conserving the grasslands from bush encroachment and progression to a woody dominated vegetation type.

The eastern grasslands of the Ozabeni region were largely protected from regular, low intensity fire when the South African Defence Force removed people and their cattle so as to use the area for weapon training purposes (Bainbridge *et al.* 1986). Uncontrolled fires were therefore generally less frequent but more intense, depending on previous season's rainfall and fuel loads. This impacted heavily upon the coastal dune forests, these being recognised as important from a forest biodiversity perspective. The impacts of fire on these forest margins and their spatial, structural, and proportional changes over time are poorly understood.

The Tewate Wilderness Area is in direct contrast with the other sections of the IWP in terms of recent human utilisation and management. This section of Maputaland was set

aside and managed as a Wilderness Area and was later added to the UNESCO list in 1999. Once the area was proclaimed in 1956 people were actively excluded and this dramatically changed the disturbance regimes (Taylor 1982b; Thompson 1996).

The northern areas have been intensively utilised by the Thembe-Thonga and fire regimes have been governed by their traditional practices. There is therefore a diverse pattern of fire usage within the Maputaland grasslands. Management is also concerned with reductions in coastal dune forest of the Coastal Forest Reserve due to frequent fires.

Issues of concern pertaining to the Maputaland region in general are a poor understanding of interactions between fire and stocking rate and the establishment of a persistent and long-lived species, *Helichrysum kraussii* Sch.Bip., which coppices readily after defoliation and dominates higher lying areas above the influences of the water table. This shrub is thought to be a key species in the successional process from grassland to tree dominated communities (Owen 1992) through the facilitation of other taller woody species.

The research problem is therefore threefold:

1. Inadequate historical evaluations of changes in vegetation structure over time
2. Grasslands progressing to a woody dominated composition and
3. Increases in *H. kraussii*.

Therefore in an effort to address some of these concerns surrounding the management of the IWP a series of trials and investigations were implemented. Burning and clipping trials were established in an effort to investigate the dynamics of *H. kraussii*. The influence of fire exclusion period and topography on plant density, composition, veld condition, and diversity was assessed within a section of the coastal grasslands at Manzengwenya. Historical changes to vegetation in response to disturbance regimes were assessed with the use of aerial photography. The aim of these investigations was ultimately to provide some practical insights into the role of fire in these coastal dune communities and provide some management recommendations on the use of fire as a management tool for the manipulation of *H. kraussii*.

2. Literature review

2.1. INTRODUCTION

Disturbance in the form of natural and anthropogenic fire has been shaping and manipulating the vegetation of South Africa since time immemorial (Hall 1984; Tainton 1999b). The type, timing, intensity, frequency, and spatial distribution of disturbance on plant communities coupled with interspecific competition for resources (particularly soil nutrients), and the system's stability and resilience in relation to disturbance, has been identified as key variables in predicting plant competitive ability, community organisation, trait trade-offs, and succession (Belsky 1992; Fynn *et al.* 2005; Grime 1977, 1979; Huston 1979; McKenzie 1982; Sousa 1984; Tilman 1984, 1987a, 1987b, 1988; Walker 1980). These are important factors to consider, particularly where habitat modification and management practices result in a change to the functional diversity and composition as there is potential for large impacts on ecosystem processes (Tilman *et al.* 1997).

Depending on the management objectives for the vegetation community, bush encroachment of savanna and grassland can pose a serious problem to vegetation managers (Sweet 1982; Trollope 1980). In 'moist' savannas, accumulated grass fuel loads are often sufficient to support a frequency of burning that enables the control of woody species encroachment by fire (Trollope 1980). The disturbance regime has an important affect on the distribution of African savannas where the mean annual precipitation is greater than 650mm and is a crucial factor in preventing savanna succession through to a closed woody canopy (Sankaran *et al.* 2005).

Soil nutrient and light availability are important resources affecting succession in coastal sand dunes (Olf *et al.* 1993; Tilman 1984). In general, nitrogen accumulation is accompanied by an increase in biomass, a decrease in light at the soil surface, a decreased root/shoot ratio, increasing dominance of tall species, and a decreasing abundance of small, short-lived species (Olf *et al.* 1993; Sieman & Rogers 2003). Succession on sandy dunes may be closer in dynamics to that of primary succession (Gleeson & Tilman 1990) due to inherently impoverished nutrient status (Olf *et al.* 1993). A progression of

transient to soil-driven dynamics may be a more suitable predictor model for associations within such habitats (Gleeson & Tilman 1990). A change in resources may facilitate the invasion of woody species through competitive release (Sieman & Rogers 2003) and in the absence of disturbance (discontinuity) or some other form of management intervention, result in retrogression across a threshold (Friedel 1991). Under changing disturbance regimes, vegetation communities may shift toward an alternate stable state, depending on system stability and resilience to the type of disturbance (Cingolani *et al.* 2005; May 1977; McKenzie 1982).

Therefore, the effective management of plant communities requires an understanding of both the historical and current disturbance regimes and its use as a significant tool (Belsky 1992; Bond & Keeley 2005; Noy-Meir 1995; Pyne *et al.* 2004; Tainton 1999b; Titshall *et al.* 2000). This review will focus on disturbance within coastal dune communities typical of those found within Maputaland, South Africa, which forms the southern limit of the Mozambique coastal plain, as well as its subsequent affect on community organisation.

2.2. THE VEGETATION OF THE COASTAL DUNES OF MAPUTALAND

The vegetation of Maputaland is of considerable ecological interest, diverse in structure and variable in formation with at least fifteen broad vegetation types described for the KwaZulu-Natal portion of the region (Matthews *et al.* 2001). This area is recognised as a Centre of Plant Endemism, namely the Maputaland Centre (Matthews *et al.* 2001), with approximately 40 % of the woody species being endemic (Moll 1980). This is partly attributed to the topology and geology of this region, a distinct biogeographical transformation of both plants and animals, and differences in climatic and edaphic factors (Moll 1980) coupled with salt sea spray and hydrological interactions. The Maputaland Centre lies between the tropical biome, which extends down the coastal plain from equatorial, East Africa and the temperate biome, which extends northwards from the south-western Cape (Bainbridge 1991). There are connections with several other phytochoria, including Somalia-Masai, Zambezian, Guineo-Congolian, Karoo-Namib, Cape, Malagasy and Afromontane (Moll 1980).

The dune vegetation of the Maputaland plain has been broadly classified into Coastal Forest and Thorn-veld communities (Acocks 1988) otherwise known as Zululand Palm veld (Veld type 1) and the grass/shrubland communities into dune dwarf shrublands, and low-lying dwarf shrublands (van Wyk 1991), or otherwise referred to as edaphic grasslands, and hygrophilous grasslands (Moll 1980) and is associated with sandy soil on a badly drained coastal plain. These woody grasslands are endemic to the Mozambique coastal plain (Siebert *et al.* 2004). The transition of these woody grasslands to secondary dune scrub is usually abrupt and a number of woody communities have been identified as precursors, through which these grasslands may progress to dune forest, in the absence of defoliation (Weisser 1980). Of particular interest is the *Helichrysum kraussii-Diospyros lycioides* High Water Table Community. Similarly, Camp (1997) classified the vegetation into Bioresource Units (BRU) based on similar environmental conditions such as soil, vegetation and climate in order to assess the magnitude of crop yields. There are three BRU's within Maputaland, namely: (i.) Moist Coast Forest, Thorn and Palm Veld (BRG 1), (ii.) Dry Coast Forest, Thorn and Palm Veld (BRG 2), and (iii.) Sandy Bushveld (BRG 23). Camp (1997) regards the Moist Coastal Forest, Thorn and Palm Veld of particular importance as it supports the largest population of people in the Province and with an approximate area of 1 006 858 hectares, constitutes the largest BRG in the Province.

Proximity to the groundwater table is an important factor delineating the hygrophilous grasslands from the establishment of dune and low-lying dwarf shrublands, and woody species (Pickett & Bazzaz 1978; Scheffer *et al.* 2005; Taylor 2003; Weisser 1991). The vegetation types in this area can be described as a complex mosaic, with the fire climax grasslands constituting a major portion of the dune vegetation of the southern section of the Mozambique Plain (Moll 1980), the management of which represents the main intervention by Ezemvelo KZN Wildlife (Taylor 2003).

For the purposes of this review, the vegetation of the Maputaland coastal plain will be divided broadly into the three predominant vegetation types, namely: coastal dune forest, bushveld/savanna (secondary dune scrub) and edaphic, fire climax or 'false' grasslands (Acocks 1988) situated above the influence of the water table. Of these, only coastal dune forest is extremely intolerant of fire (Tainton 1999b). Disturbance and succession will

then be discussed with particular relevance to these vegetation types, however an exhaustive review of the general impact of disturbance and role of succession is not attempted.

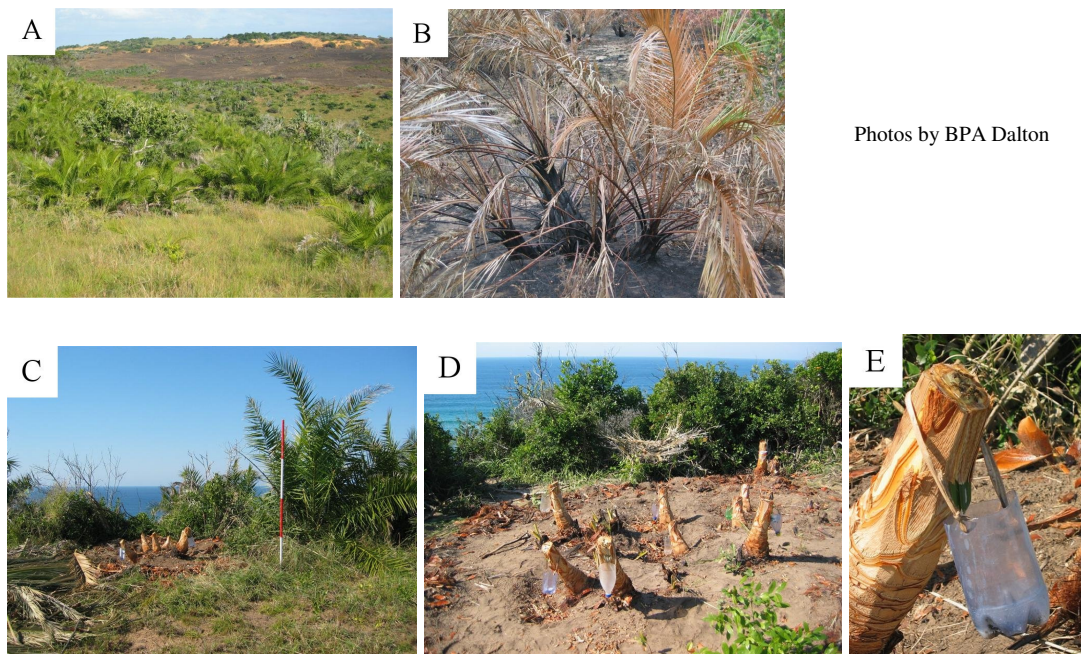
2.3. HISTORICAL DISTURBANCE REGIMES WITHIN MAPUTALAND

Historically, the vegetation of the Maputaland Centre has been heavily impacted upon by past human utilization. These people are generally believed to have originated near the Bight of Benin on the west coast of Africa, south of the Sahara Desert (Mountain 1990). These people are referred to as the Tembe-Thonga and are a culturally diverse group, consisting many mixed ethnic origins (Felgate 1982). Poor soils, together with harsh climatic conditions, geographical isolation and high water tables render this region agriculturally unproductive and therefore suited to shifting agriculture practices (Felgate 1982; Mountain 1990). Of particular importance was the use of fire to clear agricultural land and improve grazing for their cattle. Agricultural success in the lowlands of Maputaland fluctuated widely from year to year due to flooding, drought and/or very hot summers (Bruton *et al.* 1980). The number of people inhabiting Maputaland varied considerably as a direct influence of proximity to Eastern civilizations, environmental factors, expansionist policies of the Zulu kings Shaka and Dingaan, Arab and Portuguese trading, ivory and game hunting, Nagana, rinderpest, nature conservation, agriculture and forestry, and more recently, the development of harbours, townships and tourism (Bruton *et al.* 1980). An increase in population density from north to south existed and therefore an associated gradient in intensity of disturbance (Bruton *et al.* 1980; Hall 1980; Taylor 1982b).

More recently, Weisser and Muller (1983) examined the gross vegetation changes within Richards Bay, south of St Lucia from 1937 to 1974. Major changes occurred within the 37 year period, most notably within the Secondary Dune Grasslands, decreasing from 2 829 ha in 1937 to 399 ha in 1974. This was attributed to the removal of the local population (Thembe-Thonga), along with their cattle, clearing, cultivation, and frequent veld burning practices for the establishment of both *Eucalyptus* spp and *Pinus* spp plantations and consequent exclusion of fire.

Another important disturbance is the frequent and intense use of fire to defoliate *Phoenix reclinata* which occurs throughout Maputaland but is concentrated on the margins of coastal dune forest. The xylem sap of this palm is tapped and left to ferment to form an intoxicating drink (Moll 1980; Pooley 1980, 1997). (Refer to Plate 2.3.1).

The coastal dune communities of Maputaland have therefore been shaped and notably influenced by disturbance.



Photos by BPA Dalton

Plate 2.3.1 Burning and tapping of *Phoenix reclinata* for sap at Bhanga Nek, north-eastern KwaZulu-Natal, South Africa. Note the density and proximity of these palms to the dune forest (A). This area in particular is regularly burnt to improve grazing and stimulate sap for tapping (B). Therefore, these palms are generally short and only those protected from defoliation reach heights of up to 10m (C). Defoliation by cutting is generally localised to individual plants but intense (D). Tapping is done simply and the locals use the materials available to them (E).

2.4. DISTURBANCE OF PLANT COMMUNITIES

It is clear that portions of the vegetation communities of the Maputaland coastal plain have been subjected to a diversity of both type and intensity of disturbances, including fire, grazing, and cultivation. Therefore, large areas of these communities are unlikely to

have achieved equilibrium but are recovering from some level of disturbance (secondary succession). Frequency of disturbance in these communities may have an important influence on species richness (Beckage & Stout 2000; Grime 1973; Huston 1979) by influencing the transient dynamics of vegetation life history and trade-offs between colonization and competitive ability (Gleeson & Tilman 1990; Huston 1979; Tilman 1988).

Abrupt changes to the disturbance regime may also alter competitive advantages (Juttila & Grace 2002) but in unproductive habitats, phenology and morphogenetic plant responses may be more adapted to stress-avoidance whereby inter- and intra-specific competition for resources is less important than being capable of tolerating stress (Grime 1979). Alternatively, periodic stress may be important in maintaining vegetation resilience (not stability), with future abrupt changes in stress resulting in a continual return to equilibrium (Walker 1980). Depending on the properties of the vegetation and disturbance, systems may be discontinuously stable (Noy-Meir 1975) and lie along some transition between alternative stable states (Westoby *et al.* 1989) with continuous variation in disturbance resulting in discontinuous effects (May 1977). A threshold (boundary between two states) may preclude the vegetation's ability to return to a previous state of equilibrium without significant management effort (Friedel 1991). Facilitation in establishment of later-successional species by early-successional species, particularly after a perturbation, may influence the direction of vegetation response, assist the transcending of a threshold between two communities and ultimately alter the end stable state (Connell & Slatyer 1977).

Therefore, the understanding of disturbance is complex yet crucial due to its ability to significantly impact vegetation communities. Of these disturbances, fire and grazing present managers with an important selective force for the manipulation of these moist, coastal dune communities and may be difficult to isolate from their associations (Tainton 1999b; Trollope 1974). These two agents of change will be explored further.

2.5. DISTURBANCE BY FIRE

The interaction between environmental factors, vegetation, and disturbance on nutrient poor soils is generally well understood (Bond 2003; Carson & Pickett 1990;

Fynn *et al.* 2005; Gleeson & Tilman 1990; Pickett & Bazzaz 1978; Wilson & Tilman 1993). However, in anthropogenic landscapes, where fire is a key tool for modifying the environment, these interactions may be less pronounced, with structure and fire-related properties differing from the 'natural vegetation' (Vázquez *et al.* 2002). It is evident from Section 2.3 above that the coastal dune vegetation of Maputaland has been drastically altered by anthropogenic fire regimes and fire has therefore played an integral role in shaping the vegetation communities of this region. However, at a finer temporal and spatial scale, where environmental factors do not vary considerably, what is the effect of fire on species diversity, composition and structure? To attempt to answer this question requires an understanding of fire behaviour and the factors influencing this behaviour, crucial information to effective veld management (Trollope 1978).

2.5.1. Factors influencing fire and its behaviour

Fundamentally fire is an oxidation process during which heat energy is generated by the combustion of plant material (Trollope 1999a). At the risk of oversimplifying, this process of energy release is affected largely by, amongst other things, fuel load, fuel size, moisture content, fuel distribution, air temperature, relative humidity, wind, and terrain slope (Trollope 1999a). In Africa however, there is a serious lack of quantitative data on the effect of various factors on fire behaviour (Scott 1984; Trollope 1978; Trollope *et al.* 2004).

From the factors listed above, fuel load is one of the more important factors affecting fire behaviour and intensity (Trollope 1999a) and largely determines the amount of energy available for release (Trollope *et al.* 2004). All else being equal, fire intensity is directly proportional to the amount of fuel available (Brown & Davis 1973). Fuel size and its distribution and compaction affects the drying rate of the fuel, fire intensity, rate of spread, and completeness of burn (Trollope 1999a; Trollope *et al.* 2004). Fuel moisture content will vary depending on air humidity, which in turn is affected largely by air temperature, wind, precipitation, time of day, and topography (Trollope *et al.* 2004). This affects fuel ignition and combustion rates (Trollope 1999a). Wind, depending on speed, affects fire intensity through the replenishment of oxygen and promotes a more efficient pre-heating of the fuel in the case of head-fires, thus increasing the rate of spread

(Trollope 1999a). Type of fire, head- or back-fire, will affect vegetation differently. The significance being it determines the height, distribution, and duration of heat experienced in relation to the meristematic sites where plants recover after burning (de Ronde *et al.* 2004). Head-fires compared with back-fire duration has been found to be significantly different, resulting in a reduction in the time shoot apices of the grass sward experienced critical threshold temperature (temperature above which mortality occurs, regarded as 95°C) (Trollope 1978).

These factors all interact to significantly influence fire intensity (Trollope *et al.* 2004). The following sub-section will review the effect fire has on vegetation communities akin to those found on the Maputaland coastal plain.

2.6. FIRE AND ITS EFFECT ON COASTAL DUNE COMMUNITIES

The reaction of vegetation to burning is significantly correlated to the intensity of a fire which, as outlined above, is largely determined by a number of interacting factors. The majority of these factors are external to the influence of management but are nevertheless crucial to document in order to evaluate vegetation responses to burning (Trollope 1978). Other important aspects of fire besides the intensity are its frequency, or time since last burnt (exclusion period), seasonality, and timing.

The Maputaland coastal plain is characterized by impoverished sandy soils (Maud 1980). Nutrient-deficient soils may result in a uniformity of plant morphology, for example, narrow-leaved and creeping grasses, and sclerophyllous shrubs (Klemmedson & Tiedemann 1995) but plants may differ in strategy in response to this stress (Grime 1977). Sequestered nutrients in the above-ground biomass can also magnify this stress on plants (Klemmedson & Tiedemann 1995). These porous and deficient soils may positively influence grass species abundance but conversely so with woody species (Ben-Shahar 1991). In any event, defoliation of the above-ground biomass is important in the cycling of these nutrients (Klemmedson & Tiedemann 1995) and patchiness of both the disturbance and resource may promote plant coexistence and spatial heterogeneity (Carson & Pickett 1990; Hester & Hobbs 1992).

2.6.1. Fire effects on bushveld/savanna and edaphic, fire climax grasslands

The vegetation of coastal dune communities, excluding dune forest, is generally well adapted to regular disturbance by fire (O’Leary 1990; Pierce & Cowling 1991; Seligman & Henkin 2000; Vestergaard & Alstrup 2001), of which the Maputaland vegetation is no exception. Grassland species have their apical portions encased and near the soil surface, thus well suited to ‘escape’ defoliation (Danckwerts & Stuart-Hill 1987). Of the three broad vegetation types outlined in Section 2.2, both bushveld/savanna and edaphic, fire climax grasslands owe their existence primarily to current and historical anthropogenic fire regimes (Bruton *et al.* 1980). These mesic grasslands and savannas are however more likely prone to a relatively high fire frequency, when compared with more arid areas (Trollope 1980).

Generally, fire enhances the concentration of nutrients in grasses (Tainton & Mentis 1984), however this depends on vegetation type and nutrient investigated (Shackleton & Mentis 1992). This may not be the case for the sclerophyllous shrubs found in these grasslands (e.g. *H. kraussii*) (Vestergaard & Alstrup 1996). Crude protein of the grass layer has been found to be three times greater following burning when compared to the adjacent control (Shackleton & Mentis 1992). Dry matter digestibility initially increases following fire but decreases again with plant maturation (Shackleton & Mentis 1992). This general increase in forage quality is associated with a reduction in quantity available to the herbivore and necessitates an increase in their ingestion and bite size (O’Reagain & Mentis 1990).

It is important to note that exclusion of disturbance generally results in a decrease of species diversity with successional age in grasslands (de Ronde *et al.* 2004; Debussche *et al.* 1996; Short *et al.* 2003), a loss of tufted species that require defoliation (Short *et al.* 2003), and may promote the ingress of woody elements (Titshall *et al.* 2000; Trollope 1974) or species more tolerant of moribund conditions (Short *et al.* 2003). Variability in fire intensities however, may provide an opportunity for woody tree stems to avoid exposure to intense burning and recruit into larger, more fire-resistant height classes where they are less susceptible (Higgins *et al.* 2000). This has been described as a “fire-mediated recruitment bottleneck” and may be central to understanding how fire directs grass and tree coexistence (Higgins *et al.* 2000 Pp. 225).

As mentioned earlier, type of fire will be an important factor and can affect the vegetation differently. For example, heat distribution of back-burns increases the exposure and duration of the shoot apices to critical threshold temperature (95°C) and thus adversely affecting the grass plants when compared with head-burns (de Ronde *et al.* 2004; Trollope 1978). Trollope and Tainton (1986) found fire intensity of head-fires during the dormant season to have no significant effect on grass recovery following a fire but veld condition was variably affected. Fire has been found to reduce plant cover and height in Mediterranean coastal grasslands but these affects were reduced in the second growing season after fire (Noy-Meir 1995). Fire generally has a negative affect on grass seed germination unless germination and establishment, or seed burial occurs before exposure to the fire (Zacharias *et al.* 1988).

Completeness of defoliation by fire may prevent root growth but stimulate lateral tillering through the removal of apical meristems and therefore apical dominance which suppresses tillering (Wolfson 1999). Increased light availability may have an important influence on species richness. An increase in the frequency and severity of defoliation may result in reduced vigour and therefore a reduced capacity for the grass plant to regrow following subsequent defoliation (Kirkman & Moore 1995; Wolfson 1999), however this varies considerably from species to species (Wolfson 1999). Frequent, as well as the absence of burning may significantly reduce species diversity when compared to infrequent burning (Belsky 1992; McNaughton 1983).

On nutrient impoverished soils, disturbance produced quadratic variation in richness due to persistent, short perennials and colonization by annuals (Wilson & Tilman 2002) and may cause a reduction in tall perennials (Belsky 1992). Certainly, grasslands dominated by persistent perennials have been found to consistently increase in diversity and richness in response to fire and grazing when compared to a variable response in ungrazed, predominantly annual grasslands (Noy-Meir 1995). The edaphic grasslands have been found to be rich in perennial grass species when compared to the hygrophilous grasslands (Siebert *et al.* 2004). However, in mediterranean-type shrublands, species richness peaked the first two years following a fire but subsequently decreased to a constant level (O'Leary 1990).

Fire frequency in these coastal dune communities generally peaks from July to October (de Ronde *et al.* 2004) due to an increase in both moribund material and conducive conditions for fire. Season of burning is controversial (de Ronde *et al.* 2004; Trollope 1987) but in general, fire during the dormant period (mid-winter) compared with after the first spring rains has no negative affect on grass recovery (de Ronde *et al.* 2004; Trollope 1987). However, burning during the growing season seriously retards growth (Trollope 1987). Grass species composition may also be affected by season of burning, where *Themeda triandra* declined after an autumn burn when compared with burning in winter and spring (de Ronde *et al.* 2004).

Certain grass species favour regular defoliation, such as *T. triandra*, whereas *Tristachya leucothrix* increases with a decrease in defoliation. However, interval dependent effects, such as an increase in time since last burnt, causes a decrease in *T. triandra* due to sensitivity of low light conditions (de Ronde *et al.* 2004).

2.6.2. Fire effects on woody coastal dune communities

The woody component of the coastal dune communities of Maputaland can be divided into two broad categories. These being, woody species associated with the mature, climatic-climax dune forest, or woody savanna/scrub species occurring within the edaphic grasslands. These two categories response to fire will differ due to a mixture of fuel types that exist within the coastal edaphic grasslands owing to their diversity in composition, which in turn will influence fire intensity (Trollope 1999b). Type of fire will affect the heat distribution of the fire vertically and therefore affect the topkill of stems and branches (de Ronde *et al.* 2004; Trollope 1999b). Head fires result in a greater topkill of stems and branches when compared to back fires (de Ronde *et al.* 2004; Trollope 1978, 1999b) and topkill of bush tends to increase with increasing fire intensity (de Ronde *et al.* 2004).

In comparison to grass species, woody species are generally poorly adapted and detrimentally affected by fire intensity but fire season has little to no effect (de Ronde *et al.* 2004). Additionally, depending on the intensity of the fire and structure of the woody component, after a certain height, woody plants remain relatively unaffected by fire (Jordaan 1995). Dune forests are generally protected by a relatively inflammable margin

(Tainton 1999a) (Plate 2.6.1) however drastic reductions to the dune forest within Maputaland has occurred due to cultivation and slash-and-burn agriculture seriously impacting these margins (Weisser & Muller 1983).



Plate 2.6.1 *Phoenix reclinata* tolerates regular burning and often forms a fire retardant protective edge to Dune Forest where fire is frequent. This species is also actively burnt to harvest xylem sap for fermenting into wine (Plate 2.3.1) which promotes its establishment.

The effects of fire frequency on vegetation depends on the environmental conditions and physiological state of the vegetation and the conditions influencing growth experienced during intervals between burning. These two overall effects tend to confound the effect of frequency of burning. (Bond & van Wilgen 1996). Event-dependent effects, for example type and intensity of fire tend to have an overriding influence on woody vegetation as opposed to direct effects of frequency (de Ronde *et al.* 2004). Biomass production (although initially reduced) and woody seedling establishment are generally stimulated by fire (Oddvar *et al.* 1998; Trollope & Tainton 1986). The development of

seedlings is however retarded by fire (Scott 1984). In Hawi'i Volcanoes National Park, Tunison, D'Antonio, & Loh (2001) found that the invasion of Hawi'i by non-native fire promoting grass species resulted in a three-fold increase in fire frequency and 60-fold increases in fire size. This significantly impacted the indigenous woody vegetation and severely degraded the biodiversity.

The disturbance caused by fire therefore varies according to type, frequency, intensity, and season and may allow the establishment of shrub species due to changes in resources, particularly nutrients and light (Olf *et al.* 1993). These shrub species generally resprout/coppice vigorously after defoliation (de Ronde *et al.* 2004; Henkin *et al.* 1999; Veblen *et al.* 1992) but may however be short-lived and replaced within a few decades by more dominant tree species (Veblen *et al.* 1992).

2.7. DISTURBANCE BY HERBIVORY

Shackleton & Mentis (1992) reported grazing effects in coastal grassland to be similar to that of burning. Consequently, grass plant nutrient quality is influenced more by the magnitude of defoliation as opposed to the type itself. As mentioned above (Section 2.6.1 Page 12) exclusion of disturbance has a consistent negative effect on the vegetation and there is little difference with grazing. Conversely, intense defoliation by grazing may severely reduce a grass plants productivity in the following growing season (vigour) (Kirkman & Moore 1995).

The complicated interactions between herbivory, fire and other environmental factors are well recognised (Bergström *et al.* 2000; McNaughton 1983; Owen-Smith 1999). Some examples of studies highlighting these interactive effects are between fire and goat browsing (Trollope 1980), precipitation and different grazing intensities (Fuhlendorf & Smeins 1997), and grazing, resting and fire (Morris *et al.* 1992) to mention but a few.

Weber & Jeltsch (2000) investigated the long-term impacts of livestock herbivory on herbaceous and woody vegetation in semiarid savannas and found that herbivory effects may influence the threshold of response of vegetation change through utilisation intensities which negatively affect herbaceous productivity. This in turn influences diet selection, the level of spatial heterogeneity of the grazing impact, and thus at the local scale, the defoliation regime. This utilisation intensity may result in a micro-pattern or

mosaic of heavily grazed patches with lightly grazed or ungrazed patches (non-patch), becoming reinforced over time (Fuls 1992; McNaughton 1984; Teague & Dowhower 2002).

Utilisation of these patches results in a change in composition, plant phenotypic expression and production (Hatch & Tainton 1990; McNaughton 1984). Degradation is associated with an increase in pioneer, less productive and low ecologic status species (Fuls 1992). Archibald and Bond (2003) modelled interactions between fire, rainfall, and grazing. Results highlighted the importance of fire frequency in reducing patch heterogeneity and therefore decreasing the amount of time spent grazing in these patches. The increase in homogeneity as a result of fire is important as this will increase the area available for grazing and reduce over utilisation of the patches. Species that were not being selected for due to unpalatable tufts and high lignin content, have this moribund material removed and more palatable forage regenerates. Heavy grazing on sites within the grasslands of the Eastern Shores of Lake St Lucia resulted in a greater proportion of palatable material when compared with ungrazed sites (Conlong & Breen 1982).

Van de Koppel and Prins (1998) investigated the importance of herbivore interactions in the dynamic transitions between savanna grasslands and woodlands in Africa. Large herbivores may play an essential role in maintaining natural grazing systems, particularly in savanna areas with high annual rainfall, through the removal of dense vegetation, thereby facilitating an increase in small herbivores and gaining control of the vegetation. In some instances, these savannas are arrested as a sub-climax by herbivory (Jeltsch *et al.* 2000) which act as a buffering mechanism, moderating changes of too great a magnitude, and therefore preventing a shift towards an alternate stable state. Grazing intensity has been identified as having an important influence on long-term variations in species composition (Fuhlendorf & Smeins 1997) with fire frequency inversely correlated to an increasing stocking rate (Weber & Jeltsch 2000) due to an associated reduction in fuel load.

The effects of selective grazing will vary in different systems and within and between plant communities and species (Tainton *et al.* 1996). Where rainfall is relatively consistent and predictable and where communities are comprised predominantly by perennial plants, as is the case with the humid coastal communities of Maputaland,

Tainton, Morris, and Hardy (1996) contend that equilibrium dynamics may be more appropriate in system stability. In other words, grazing intensity accounts for the majority of the variation influencing plant-herbivore dynamics. The spatial and temporal availability of graze may then largely be determined by management.

It is therefore difficult to divorce herbivory from other environmental and disturbance factors affecting the coastal dune communities of Maputaland. It is therefore important to consider the role of disturbance in affecting community associations. An exhaustive review of succession and competition is not attempted. A brief review of some of the more contemporary theories that have particular relevance to further understanding the dynamics in coastal dune communities on impoverished sandy soils follows.

2.8. COMMUNITY ORGANISATION

Although many theories postulated regarding community succession and organisation agree on a few basic underlying assumptions and emergent properties to community associations (Golley 1977), such as spatial and temporal species heterogeneity, and a certain amount of predictability (Clements 1916; Margalef 1968; Odum 1977; Sousa 1984), there is still no single general model that encompasses the complexity of vegetation dynamics, interactions and succession (Fynn *et al.* 2005; Huston & Smith 1987; Sheil 1999).

There is little doubt that the study of the environment and how it affects plant associations (synecology) has progressed from a simple condition into a complex state (Gleason 1977). The continued measurement, description, correlation and historical appreciation of associations, whether emphasis be spatially or temporally broad or species specific, contributes to furthering the knowledge of each association (Gleason 1977). With the improved description and understanding of community associations and succession came a shift away from broad, holistic interpretations (equilibrium models) towards localised, simplistic approaches (reductionist), where predictions apply to a specific habitat, from the empirical data on the mechanisms (mechanistic) of vegetation change (Glenn-Lewin *et al.* 1992).

2.8.1. Succession, competition and stability on poor soils

Clements (1916) introduced the theory of vegetation development (succession) as a complex super organism akin to the life-history of an individual organic entity, through a number of seral or developmental stages, to a climax community indicative of a regions long-term climatic conditions. The principle being vegetation succession “*terminates in the community capable of maintaining itself under a particular climate*”, unless disturbed (Clements 1949). Although Clements recognises that most associations are dynamic and never in complete equilibrium, all associations are complex, repeatable and definite in formation, and must terminate in the highest stage possible (Clements 1916).

Although this model of vegetation change has been widely challenged (Gleason 1977; Golley 1977; Grime 1977; Huston 1979; MacArthur & Wilson 1967; May & MacArthur 1975; McCook 1994; Odum 1977; Tilman 1984; Whittaker 1977; Whittaker & Levin 1975) the tendency of ecosystems to develop towards greater homeostasis, being both progressive and convergent in nature is still widely embraced. However, Glenn-Lewin, Peet and Veblen (1992) contend that by the early 1970s, the Clementsian synthesis was recognised as inadequate and this necessitated the need for site-specific information and understanding the mechanisms or proximate causes of vegetation change.

Grime (1977) outlines three primary strategies in plants relating to particular combinations of competition, stress, and disturbance. He recognises that plant competitive ability varies according to the conditions in which it is growing and these variable conditions (stress), impact on species composition and structure due to the direct effects on survival and reproduction. This may result in a shift from species with high competitive ability to species that tolerate stress. In infertile soils, woody and herbaceous species tend to be reduced in stature, leaf form and potential growth rate, purportedly for survival under conditions of low nutrient supply, highlighting important phenotypic response to stress.

Conversely, Tilman (1984) proposed that a trade-off between biomass allocation and nutrient availability exists, depending on the productivity of the environment. In unproductive environments where soil nutrients and soil water are often limiting, biomass is allocated to below ground structures to maximize resource uptake. An increase in habitat productivity may shift this biomass allocation to aboveground structures for

improved light interception. Therefore, an inverse correlation exists between soil resource supply and light intensity at the soil surface. Succession depends then on the factors influencing and controlling resource supply rates.

Another important consideration when examining successional pathways, through pioneer, sub-climax to climax vegetation and their reversal due to disturbance, is the system's stability and resilience to the type, timing and intensity of the disturbance, as this may direct succession into one or more stable or unstable states (Tainton *et al.* 1996). This threshold level of disturbance is the limit above which vegetation will move through to an alternate stable state or below which will return back to a 'regional climax' or equilibrium point (May 1977). System stability (degree of change in response to disturbance) and resilience (vegetation remains attracted towards its equilibrium) will determine the successional direction and ultimate response to disturbance regimes (McKenzie 1982; Walker 1980).

It is clear that the historical and current disturbance regimes as well as the type, timing and intensity of the disturbance are crucial factors influencing community organisation within the coastal dunes of Maputaland. More importantly, changes in these regimes may result in a shift in stable state, after which significant amounts of input would be needed to direct succession back to a previous condition. Additionally, the mesic conditions and impoverished soils on which these communities exist may further complicate interactions between disturbance and the vegetation.

Therefore, information that permits a greater appreciation of the interactive effects between grazing, fire, and various environmental factors will prove invaluable for the effective future management of these communities.

3. Study area

The coastal grasslands of Maputaland are situated in northern KwaZulu-Natal, on the east coast of South Africa. The grasslands in question extend southwards from Banga Nek ($27^{\circ} 00' 17.4''$ S and $32^{\circ} 51' 44.1''$ E) approximately 16.8 kilometres south of the Mozambique border, to the St Lucia Estuary ($28^{\circ} 22' 56.2''$ S and $32^{\circ} 25' 30.7''$ E) and are restricted to the eastern sections (from north to south) of the Kosi Lake system, Manzengwenya plantation, Lake Sibaya, Sibaya and Mbazwana plantation, Mosi swamp, Mkuze river and Lake St Lucia (Refer to Figure 3.1.1).

3.1. CLIMATE

The climate of this region can be described as warm to hot, humid and sub-tropical (Schultze 1982), with considerable variation in an east to west direction (Maud 1980). January temperatures range from 22 to 30°C , with a mean of 25°C while July temperatures range between $12\text{--}23^{\circ}\text{C}$, with a mean of 18°C (James 1998).

Relative humidity values on average across this area are high, averaging 76.5 % at 08h00 at Otobotini. Lake Sibaya Research Station maximum and minimum relative humidity figures for the winter months of 1973 were 88 and 56 % respectively. Summer month values for the same period were 83 and 60 % respectively (Maud 1980). Average annual relative humidity for St Lucia is 80 % at 08h00 and 60 % by 14h00 (Crass 1982).

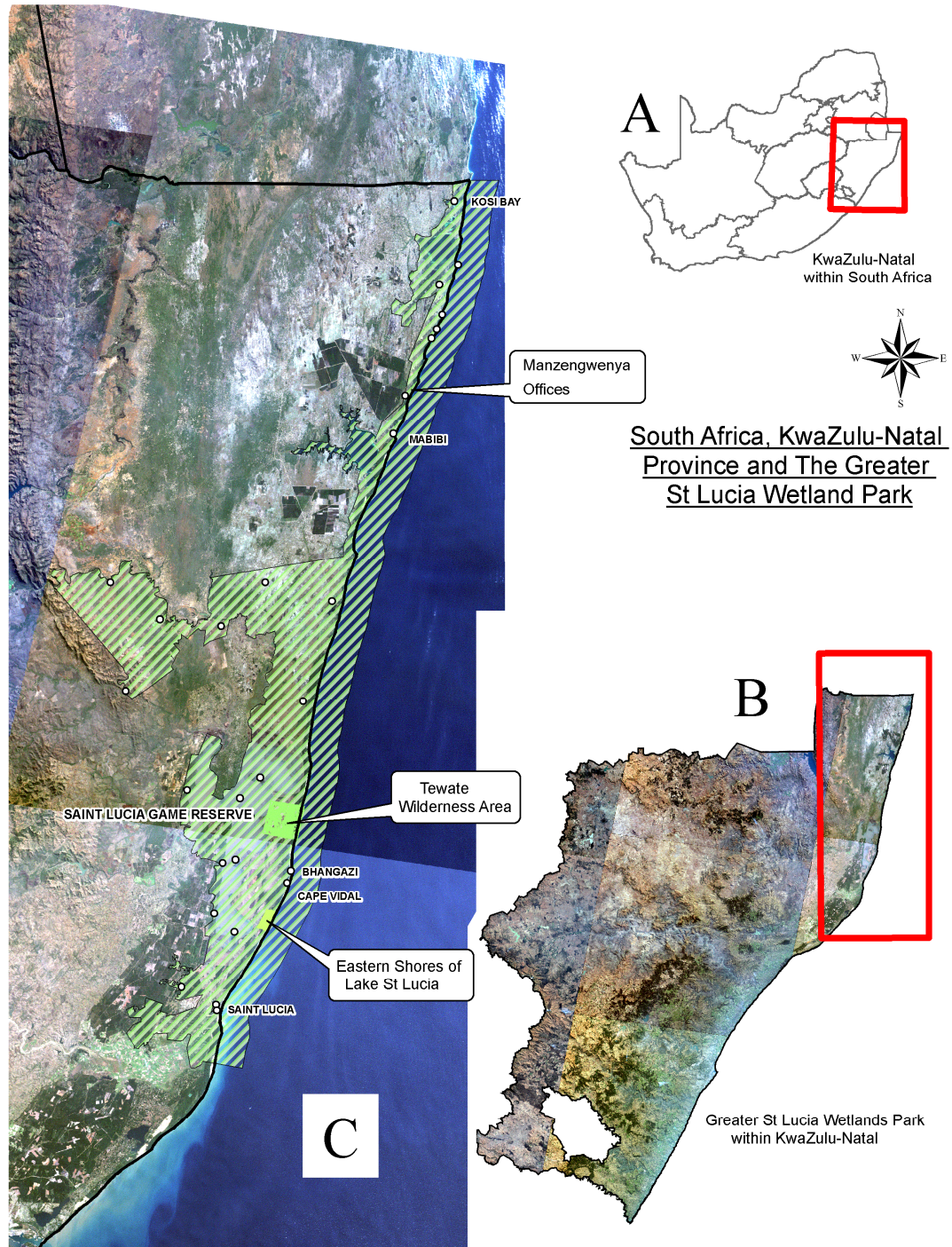


Figure 3.1.1 Map using Landsat imagery to depict the location of the iSimangaliso Wetland Park (IWP) within South Africa (A) and KwaZulu-Natal (B). Study sites within the IWP have been labeled accordingly (C).

Rainfall for the Maputaland region averages between 1000 to 1100 mm annually, but this declines progressively westwards to approximately 600 mm annually at the western margin of the region, the foothills of the Lebombo Range (Maud 1980). The average annual rainfall for St Lucia has been estimated at around 1026mm (Taylor 1982a) but there is a considerable amount of variation. Most rain falls during summer whilst the winter mean is never lower than 40mm (Taylor 1982a). This high rainfall is due in part to the warm Mozambique current and the coastal dunes, which are up to 200m in height in some areas (Crass 1982), providing a mechanism for orographic rainfall.

North-easterlies and South-westerlies are the two main prevailing winds along the KwaZulu-Natal coast (Crass 1982; Tinley 1958). Due to the proximity of Maputaland to the sea and absence of prominent physical barriers, winds are generally strong, accounting for a relatively high evaporative loss, estimated to be 1500 mm per year (Crass 1982).

3.2. TOPOGRAPHY AND GEOLOGY

“The Zulus call Maputaland *uMhlaba’yalingana*, which translated means ‘the earth which is flat’.” (Mountain 1990). Maputaland is located on the southern most portion of the Mozambican Coastal Plain and is bordered by the Lebombo Mountains to the west and the Indian Ocean to the east (Matthews *et al.* 2001), with a coastal dune range present along the entire coastal margin (Tinley 1985). The region is mostly flat, between 50 and 130 meters above sea level, with undulating sand ridges (Matthews *et al.* 2001). Maud (1980) provides a succinct summary of the succession of both rocks and unconsolidated sediments underlying the Maputaland region and is presented in Table 3.1.

Very young coastal dune ridges exist along the shoreline and these overlie the Port Durnford Beds or sandy limestone. These are some of the youngest formations in southern Africa (Matthews *et al.* 2001).

Table 3.1 Stratigraphic succession of the rocks and unconsolidated sediments underlying Maputaland (Adapted from Maud 1980 Pp. 3).

Alluvium Grey aeolian sands Coastal dunes	Recent Quaternary
Coastal dunes Alluvial terrace gravels Reddish-brown and red sands (Berea red sands) White and grey sandy limestones Grey and white consolidated Aeolian sands, clayey sands and lacustrine deposits (Port Durnford Beds)	Pleistocene Quaternary
White sandy limestone with basal conglomerate	Pliocene – Miocene Tertiary
Yellowish brown and grey siltstone, shale, sandstone and limestone	Upper and Middle Cretaceous
Yellowish brown and grey siltstone, shale, sandstone and conglomerates	Lower Cretaceous
Rhyolites, dacites, andesites and pyroclasts	Stormberg-Lebombo Karoo

3.3. SOILS

The greater portion of Maputaland comprises recent wind-redistributed grey sand. Soils are therefore, in general very sandy and infertile with low agricultural potential. High rainfall exacerbates this through leaching, particularly in the dune areas. There is however an east-west gradient, in that the soils of western Maputaland are in general inherently fertile to very fertile (Maud 1980). The lower lying areas west of the coastal dunes represent degraded, low dunes and are moderately well drained. High water tables within the lower lying interdune depressions result in bleached, grey soil profiles. Lateral ground water movement towards these interdune depressions has resulted in clay-rich, slightly saline or calcareous duplex soils forming in low-lying sites (Matthews *et al.* 2001).

3.4. HYDROLOGY

Water table and associated ground water movements play an integral role in determining vegetation patterns in the majority of the Maputaland region. Water table depths are considerably variable across the region and can in some places exceed 90m, there are however many seasonal pans throughout. During periods of rainfall, variable fluctuations in local water levels exist, with permeability varying depending on the east-west lateral variability in Pleistocene sediments (Matthews *et al.* 2001). The coastal dunes play an integral role in augmenting ground-water through lateral percolation and in times of severe drought can produce as much as ten percent of freshwater entering Lake St Lucia (Hutchinson & Pitman 1976). A reduction in ground water levels has the potential to modify plant communities and is therefore important to understand (Tinley 1985).

4. Trials

The coastal dwarf edaphic grasslands located to the north of the Manzengwenya KZN Wildlife Management Office, hereafter referred to as ‘Manzengwenya Offices’, (Figure 3.4.1) presented an ideal opportunity to examine the questions outlined in the aforementioned section 1.1. This area has been variably impacted upon by different burning regimes, largely governed by local people. To a somewhat lesser degree, grazing interacts with burning to produce a variable grazing pressure within the area. In order to protect the developments and infrastructure at Manzengwenya and adjacent pine plantation (west) from the regular fire regimes north of this area, a mown firebreak (Figure 3.4.1) was established.

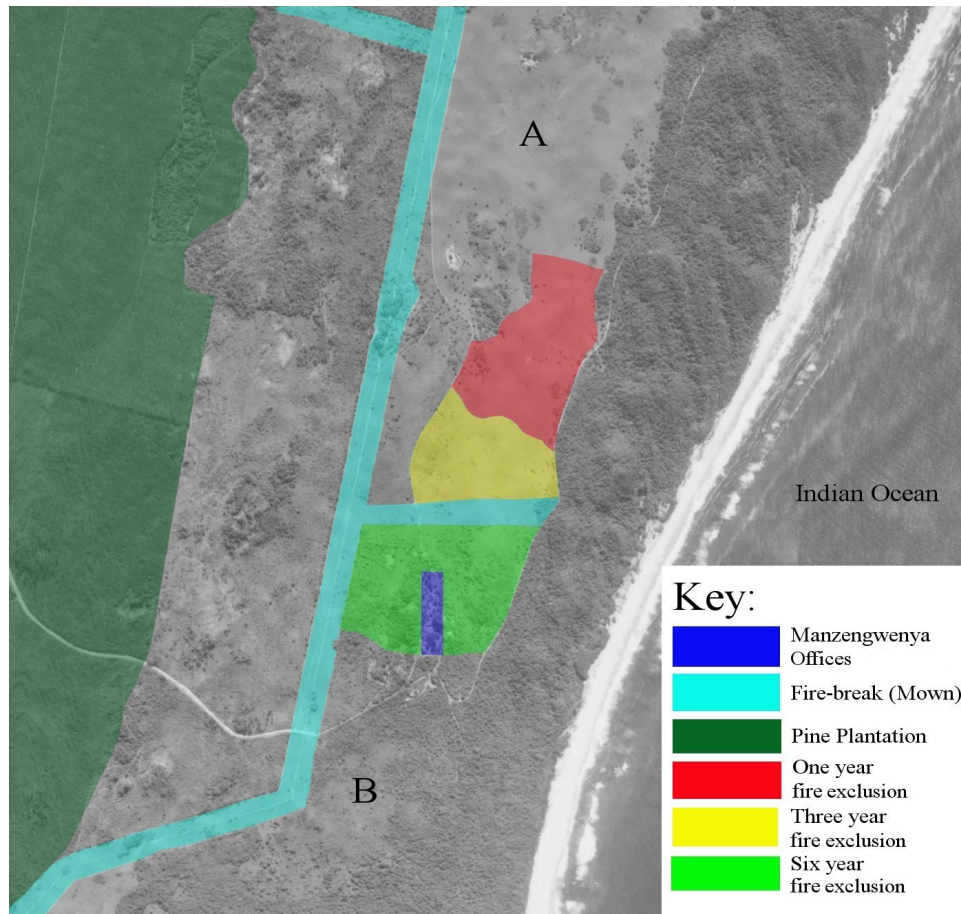


Figure 3.4.1 Ungeorectified aerial photo (2002) mapped to indicate different fire exclusion periods and management practices in proximity to the Manzengwenya Offices,

Maputaland, South Africa. Note the appreciable north-south difference (A versus B) in vegetation structure due largely to increased fire exclusion at B.

This effectively excluded two zones from fire for three and six years respectively. Immediately north of this, the edaphic grasslands continued to be burnt regularly, largely to improve grazing quality for livestock (Section 2.3). However, more recently, another smaller section of grassland has had fire excluded for a period of time. This has resulted in three distinct sections in terms of management. At the time of initial survey (June 2004) these sections consisted of the following fire exclusion periods (or time since last burnt) (Refer to Figure 3.4.1):

1. A six year exclusion of fire, restricted to immediately adjacent the Research Station,
2. A three year exclusion, and
3. A section burnt annually, possibly even more than once a year in certain years but referred to as one year fire exclusion period.

4.1. RESEARCH PURPOSE

The purpose of this research is twofold:

1. Describe some of the effects of and interactions between fire, defoliation and the environment on selected sandy dune vegetation communities within Maputaland, South Africa.
2. Produce recommendations on the use/role of fire and possible effects of stocking levels on grassland biomass and composition to allow future effective management and conservation of these vegetation communities.

4.2. RESEARCH OBJECTIVES AND KEY QUESTIONS

1. Describe the effects of fire exclusion period in determining vegetation biomass, diversity, botanical composition, and structure.
 - i. Does the period of fire exclusion interact with environmental factors such as topography, soil moisture, and light, influence vegetation biomass, diversity, botanical composition, and structure?

2. Evaluate the interactive effects of fire and subsequent defoliation of surrounding grass on *H. kraussii* growth.
 - i. Does fire, the removal of vegetation around *H. kraussii*, environmental factors, and interactions amongst the latter aspects affect growth and persistence of this species?

4.3. METHODOLOGY

4.3.1. Manzengwenya burning and defoliation trial (Trial One)

In order to effectively address the second objective and associated key question outlined in Section 4.2 above, a trial was established within the edaphic grasslands north of the Manzengwenya Offices (Figure 4.3.1) to investigate the interactive effects of defoliation by fire, defoliation by clipping as influenced by topographical position. The trial design is as follows:

1. Time since last burn applied non-randomly at two levels, namely Annual and Three year (Whole plot factor). Although a third fire exclusion period existed, it was not possible to incorporate this period into the trial as the preparation of adequate firebreaks was prohibited due to the extent of woody species. However, preliminary data was still collected for this treatment on three different catenal positions.
2. Due to topographical differences within the two fire exclusion periods, sites were blocked according to its catenal position. These being: West, East, Top, and Bottom (Sub-plot factor).
3. Defoliation was implemented at two levels, namely Clipped and Unclipped, with the unclipped plots serving as the control (Sub-sub-plot factor). This sub-sub-plot factor was then repeated six times.

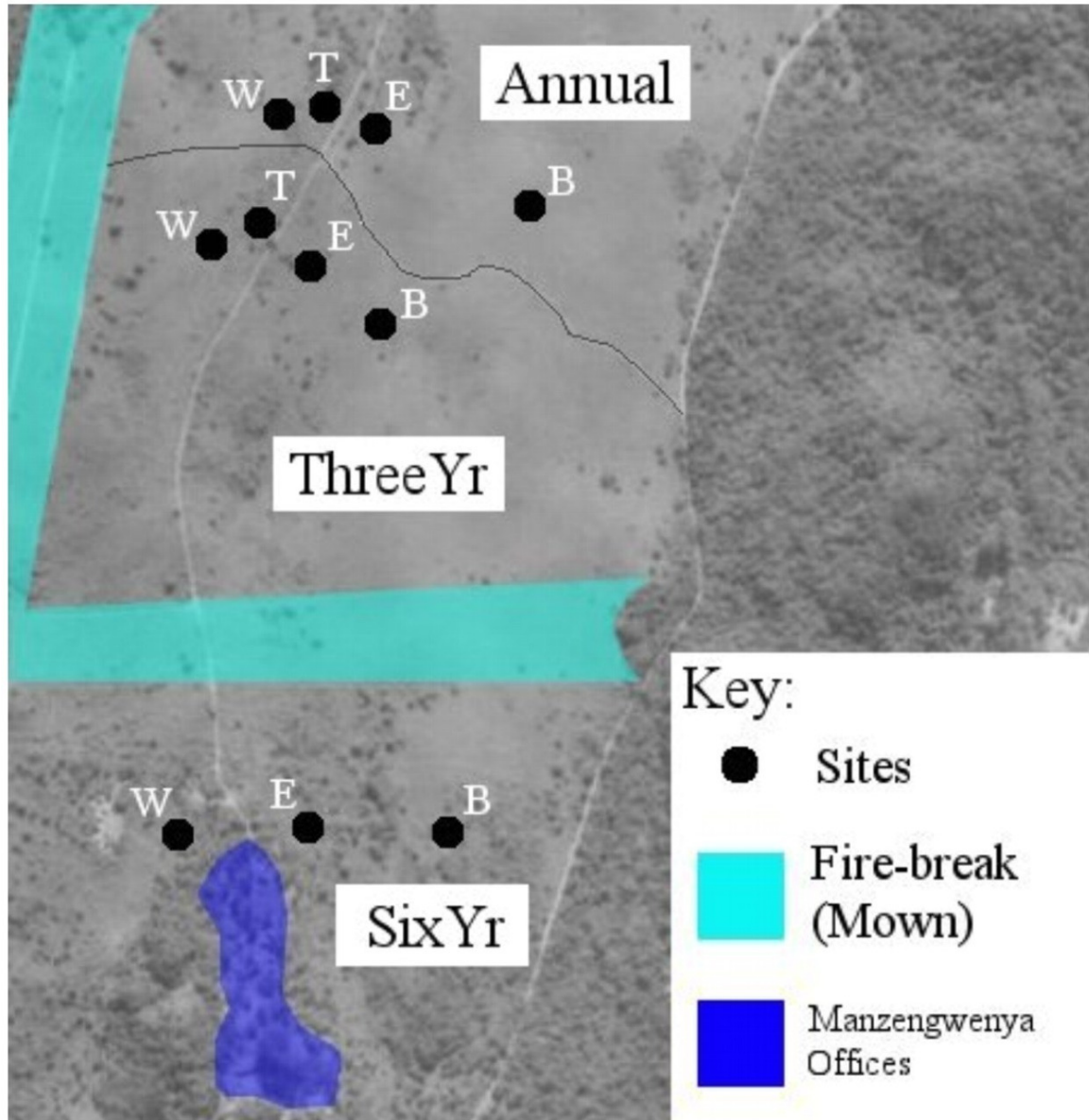


Figure 4.3.1 Ungeorectified aerial photograph (2002) indicating approximate plot location within the three fire exclusion periods north of the Manzengwenya Offices. Catenal positions (E) East, (T) Top, (W) West, and (B) Bottom, are illustrated.

From the onset of the trial, it was clear that there were a number of considerations and limitations to the implementation of the trial and therefore the interpretation and applicability of the data. These being:

1. Historical fire regimes and time since last burnt are clearly not applied randomly between the different plots;

2. Although clipping was carried out on replicated plots within each topographic position, these plots do not constitute formal replication and therefore comprise samples for reasons outlined in point one above;
3. Due to differences in *H. kraussii* distribution and density, individual plots had differing numbers of *H. kraussii* plants within them. This has resulted in an unbalanced treatment design and requires specialised analysis techniques (Restricted Maximum Likelihood) as opposed to the more formal analysis of variance (ANOVA); and
4. The intention for this particular trial was to incorporate defoliation by fire randomly into the treatment design. However, just prior to the implementation of this treatment (10th October 2004), wildfire burnt through all the plots before firebreaks could be adequately prepared. It is important to note that this fire burnt through these plots during the early hours of the morning when temperatures, relative humidity, and wind speeds were low when compared with midday temperatures. As a result, fire intensity and rate of spread would more than likely have been reduced and consequently, effects on vegetation may differ to that of an intense fire.

As a result of wildfire prematurely burning the plots and preventing its random application, a second burning trial was planned and established further south, on the Eastern Shores of Lake St Lucia.

4.3.2. Eastern Shores burning and clipping trial (Trial Two)

Ideally, sight selection was to allow comparisons with the Manzengwenya trial and therefore represent replication. This, however, was not possible for the Eastern Shores of Lake St Lucia has had a number of pine plantations in the past at various stages of being clear felled. This difference in management presented an opportunity to investigate the effects of previous management regimes on *H. kraussii* along with defoliation.

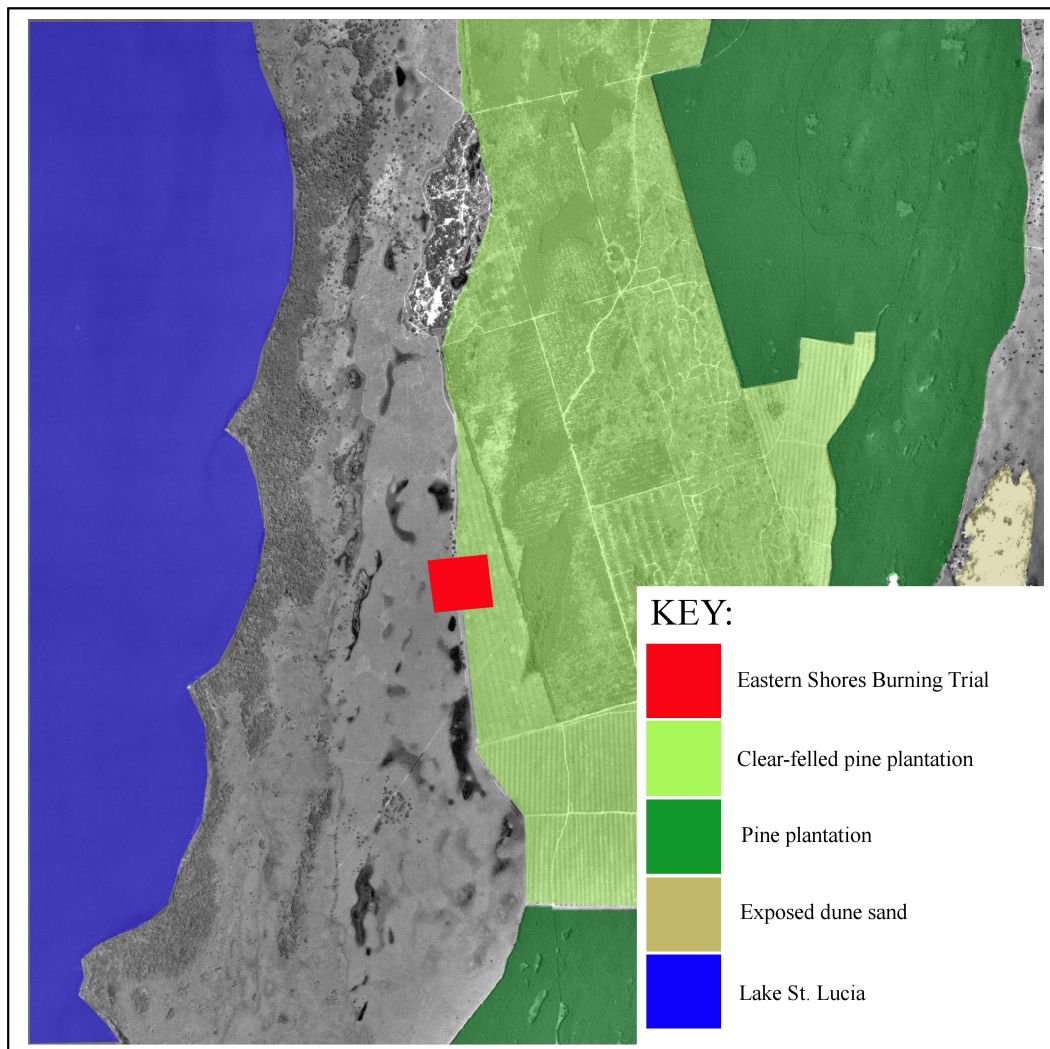


Figure 4.3.2 Ungeorectified aerial photo (2000) indicating the location of the burning trial on the Eastern Shores of Lake St Lucia, South Africa.

The trial on the Eastern Shores of Lake St Lucia was therefore established within edaphic grassland adjacent to a clear felled pine plantation (Figure 4.3.2). The trial design is as follows:

1. Different management regimes (grassland versus pine plantation) were applied at two levels (or occurred twice within the trial), namely relatively undisturbed edaphic grassland (Grass) and clear felled pine plantation (Pine).

2. Two defoliation treatments, namely clipped (Clip) and unclipped (Unclip), with the unclipped plot serving as the control. This treatment was then repeated over five plots.
3. Additionally, the area was divided into three sections (blocks) to serve as replications.
4. As with the Manzengwenya trial, fire treatments were intended to be applied randomly. However, burning was conducted to coincide with the burning of the recently clear felled pine plantation block within which the trial is located. Burning conditions for this plantation were selected specifically to ensure an intense fire and therefore achieve sufficient topkill of any remaining woody plantation species (E.g. *Pinus elliotii*). As a result, the mown fire breaks were not adequate enough to exclude fire and all but one grassland block within the trial burnt. This perpetuated the inability to investigate the treatment effect of fire on *H. kraussii* due to the non-random application of this treatment.

Although greater effort was used in site selection and trial design based on the lessons learnt previously, this trial still suffers problems similar to those experienced with the Manzengwenya trial. This is as a result of the inability to randomly apply management regime to each plot and an unbalanced treatment design owing to differing densities of *H. kraussii* within each plot. Additionally, one block (block two) had to be excluded due to one section remaining unburnt.

As opposed to implementing a third ‘burning’ and clipping trial in another location within the iSimangaliso Wetland Park (IWP), use was made of the unburnt portion of block two on the Eastern Shores mentioned above. This therefore constitutes the third and final burning and clipping trial.

4.3.3. Eastern Shores burning and clipping trial (Trial Three)

Within the unburnt block (Plate 4.3.1 below) of the existing trial (Trial Two) on a section of the Eastern Shores of Lake St Lucia (Figure 4.3.2 above) six plots, each consisting of a clipped and unclipped subplot were paired along the perimeter of the unburnt block (Figure 4.3.3 below).

Due to differing numbers of *H. kraussii* plants within each plot, the treatment structure is unbalanced, requiring more rigorous methods of analysis. Therefore, two burning treatments were applied and two clipping treatments with six replications and totalling 24 plots.



Plate 4.3.1 Southern view of the unburnt block (A) and plot ESG 3a (B) (pegs delineating the plot being marked above and below with a white marker) in the edaphic grassland, many hours after burning (1st November 2004).

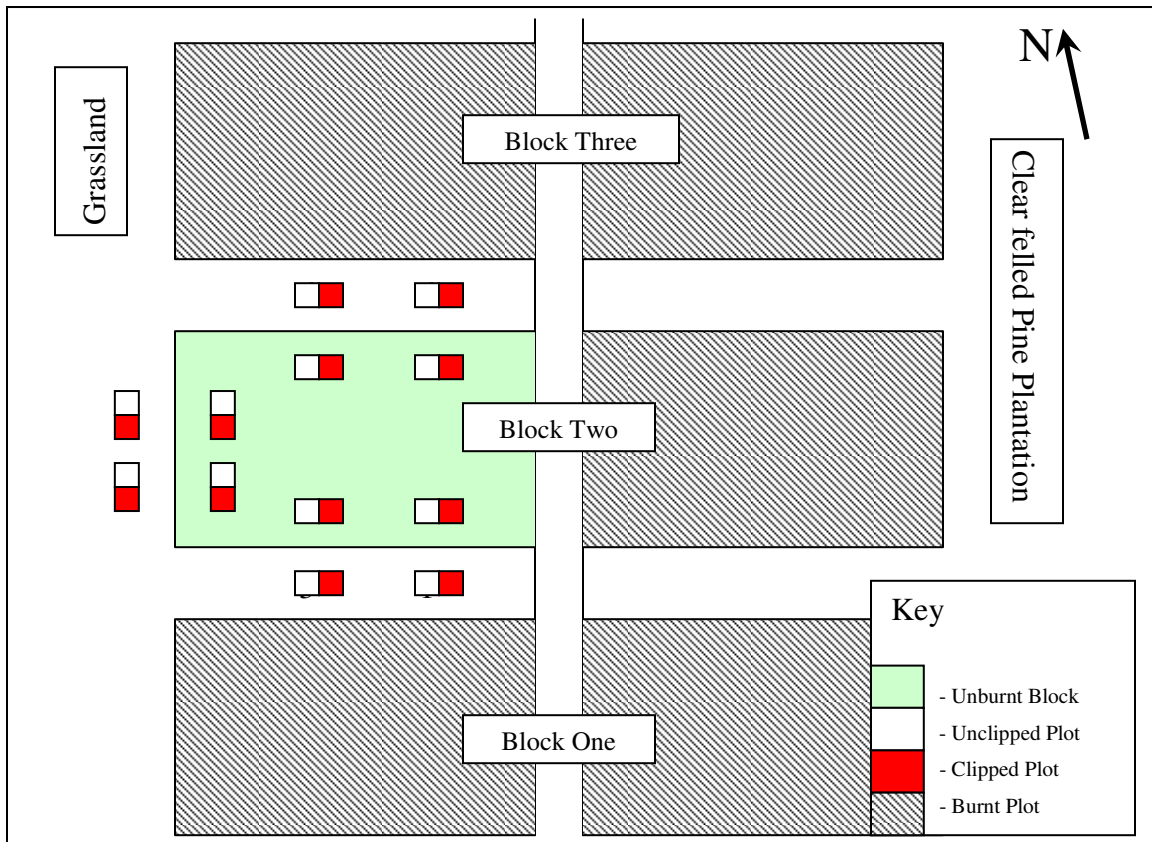


Figure 4.3.3 Diagrammatic representation of Trial Three. Numbers indicate the paired plots located within the unburnt block and adjacent burnt grassland. Diagram not drawn to scale.

4.4. DATA COLLECTION

4.4.1. *Examination of the effects of fire exclusion period and catenal position on the coastal dune communities of Maputaland*

As mentioned in Section 4, the grasslands immediately north of the Manzengwenya Offices have had three different fire exclusion periods (Figure 3.4.1) and occur on a

series of smaller parallel dune ridges extending from the main fore dune cordon. This allowed for the evaluation of the fire exclusion period and topography's influence, as mediated by aspect/catenal position on the composition, structure, and diversity of these coastal dune communities.

Within each fire treatment, three catenal positions (West, East, and Bottom) (Figure 4.3.1) were chosen. A 500m² plot (25 by 20m) was demarcated. The location of each plot was chosen to best represent the vegetation that was based on structure (homogeneity) for that specific aspect. Within each plot the grass, herbaceous, and woody component of the dune communities, were separately identified and measured by using an adapted version of the point-centred quarter method (PCQ) (Whalley & Hardy 2000). The PCQ is a plotless method where the distance is measured from a random point to the nearest plant in each of four 90° quadrants. The PCQ method was adapted to include an extra two plants per quadrant, thus each point effectively sampled 12 plants. This was done to better determine species composition within each plot.

Within each quadrant, the distance to the centre of the nearest grass species, herbaceous species, and woody species was recorded, along with species name and woody plant height. Fifty points were taken within each plot, totalling a sample of 600 individual plants (200 grasses, 200 herbaceous non-grasses and 200 woody). Data were collected for two sampling periods, one prior to wildfire in May 2004 and another after, in April 2005.

During the initial sampling period, it was noted that due to the presence of many dwarf woody species within the grassland (less than 80cm), the PCQ method was not adequately sampling the taller woody species present in the three year and six year fire exclusion treatments. Additionally, the classification of a woody species based on lignification and height (greater than 50cm) was effectively excluding a large number of short woody species. For this reason, sampling methodology was altered for the second sampling period post burning. Woody species were classified by lignification of the stem, where plant stems that retained their shape after bending or alternatively snapped due to bending were considered woody. A third optional category was included for woody species with a height greater than one meter and within a five meter radius of each point.

This change in methodology and a number of difficulties experienced during sampling are important to highlight and consider in the interpretation of the results. These considerations relate to the following:

1. Comparisons between the two sampling intervals are not plausible due to differences in sampling methodology.
2. A number of herbaceous species exhibited degrees of lignification and were therefore classified as woody. However, plant height was not recorded for these species (Appendix 3).
3. Within this list of ‘woody’ herbaceous species, a number of woody species were included (e.g. *Dichrostachys cinerea*, *Diospyros lycioides*, and *Strychnos spinosa*). These species, particularly *D. lycioides*, when young, or dwarfed due to regular defoliation, exhibit growth forms akin to that of ‘woody’ herbaceous species. Initial misidentification meant height for these woody species was not recorded. This may influence differences in height distributions in response to fire exclusion period.

For these reasons, no comparisons were made between sampling intervals and inferences of the effects of fire exclusion period and catenal position on these coastal dune communities were confined to the second sampling interval (April 2005). With these data collected it was possible to examine the following differences for three fire exclusion periods and catenal positions:

1. Total plant, grass, herbaceous, and woody density.
2. Structure of the woody component.
3. Composition, diversity, richness, evenness, site similarity, and a relative index of veld condition.

From point one above, an average density (A) (Table 4.4) for the j^{th} site was calculated using the average point-to-plant distance (X) for the i^{th} species, as follows:

$$A = \frac{10000}{\sum_{i=1}^n x_{ij}^2} \quad (1)$$

The density per species is presented in Appendix 4 for further referral. In order to calculate the density per species (C), a relative density (B) for each species was used as follows:

$$B = \frac{\sum_i x_{ij}}{\sum_j n_j} \times 100 \quad (2)$$

where x is the count of the number of individuals for the i^{th} species at the j^{th} site and n the total number of species for the sample at the j^{th} site. The density per species is then calculated as:

$$C = \left(\frac{B}{100} \right) \times A \quad (3)$$

The structure of the woody component (point two above) was evaluated qualitatively through the graphical representation of average height for selected woody species at each site. This was further separated out into height classes where the numbers of individuals for a number of different heights were presented.

From point three above, the spatial relations in composition sampled for each site using the PCQ method were projected using an unconstrained ordination analysis to best represent these relations and reduce any distortion (Lepš & Šmilauer 2003). The choice of ordination procedure and interpretation of the ordination diagrams is discussed further in section 4.5.5 below.

The Shannon diversity index (H') (Shannon & Weaver 1949) which was compared with site richness and evenness was calculated using the statistical package PRIMER 5 for Windows (PRIMER-E 2002). Additionally, a two-dimensional non-metric multidimensional scaling (NMDS) ordination, a distance-based ordination using Bray-Curtis similarity measures (e.g. Greig-Smith 1983), was used to evaluate measures of association along the two most important gradients of change in a Principal Components Analysis (PCA) (discussed further in section 4.5.8 below).

The Bray-Curtis coefficient of similarity was calculated as follows:

$$BC = \frac{\left(\sum_i |x_{ij} - x_{ik}| \right)}{\left[\sum_i (x_{ij} + x_{ik}) \right]} \quad (4)$$

where X is the standardised species density value (mean of density) of species I on stands j and k . This index is easily interpreted with a maximum value of 1.0 for gaps with no species in common and 0.0 when gaps share the same species with the same density (Kupfer & Runkle 1996).

Veld condition was assessed using the Ecological Index Method (EIM) (Vorster 1999), where a Veld Condition Index (VCI) was compared for each site and calculated as the sum of the products of the abundance value contributed by a species and the relative index values assigned to each species (refer to section 4.5.7 for results).

4.4.2. Additional variables collected: Standing fuels

Prior to the wildfire, surface fuel biomass comprised of the standing grass sward was determined using the disc pasture meter (DPM) (Bransbury & Tainton 1977) for a site both on the Eastern Shores of Lake St Lucia and north of the Manzengwenya Offices. Above-ground standing grass sward or average dry matter per site is a key component in determining fire intensity and therefore was measured in an effort to describe the burning fuels available. However, accidental burning of the sites prevented collection of all necessary variables for the calculation of fire intensity at Manzengwenya but this was not the case for the Eastern Shores. The following two sections have been included here as the accidental burning of the plots has rendered an understanding of intensity unnecessary but may be useful for later examination.

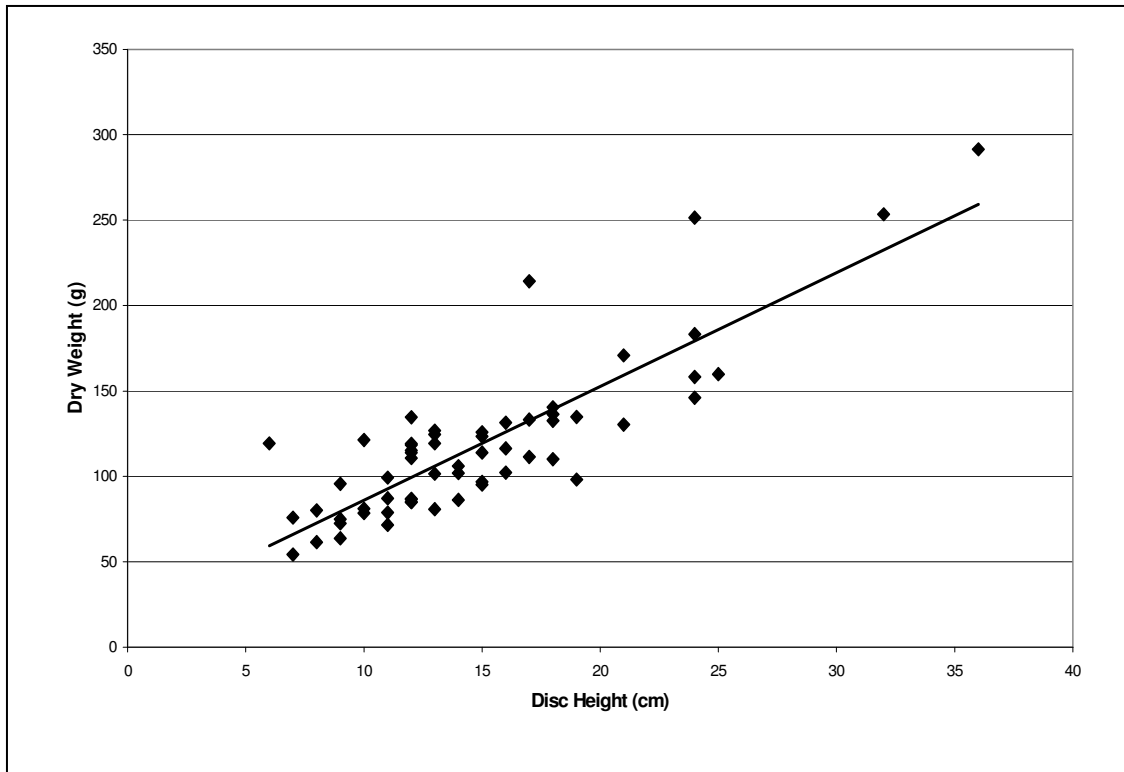


Figure 4.4.1 The relation between the calibration curve for above-ground standing grass sward (dry weight in grams) and compressed disc pasture meter height (cm) for the unburnt grassland site on the Eastern Shores of Lake St Lucia, South Africa. Regression equation was calculated as $y = 6.6663x + 19.332$ and this accounted for 72 % of the variation.

Calibration of the DPM was conducted within the grassland section of Trial Two (Figure 4.4.1) and the annually burnt grassland north of the Manzengwenya Offices (Figure 4.4.2) so as to better calculate standing fuels for each site. None of the sites average grass height exceeded 260 mm (Table 4.1) and therefore separate calibrations for each fire treatment was not necessary (Zambatis *et al.* 2003). The standing fuels directly below 60 and 75 discs were clipped for the Eastern Shores (Appendix 5) and Manzengwenya (Appendix 6) respectively. These were then weighed and a grab sample taken, weighed and oven-dried at 100°C for seven days to ensure complete desiccation. The percentage moisture loss was then used to calculate total dry matter for each sample from its associated grab sample.

Table 4.1 Summary of disc pasture meter (DPM) heights from Appendix 7 and Appendix 8 and associated dry matter (DM) for both the sites north of Manzengwenya and on the Eastern Shores of Lake St Lucia, South Africa

Site	Average Height (cm)	kg DM ha ⁻¹
ESP	14.74	7075.82
ESG	13.05	6397.92
MBP 1 (W)	9.89	4046.42
MBP 2 (E)	11.42	4462.79
MBP 3 (B)	11.08	4370.26
MBP 4 (W)	23.27	7687.65
MBP 5 (E)	24.57	8041.43
MBP 6 (B)	20.99	7067.17
MBP 7 (W)	19.41	6637.19
MBP 8 (E)	16.25	5777.23
MBP 9 (B)	14.74	5366.30

Dry matter was never less than 4 000 kilograms per hectare (Table 4.1) and therefore 100 samples within each site was sufficient to estimate fuel load (Brockett 1996). An additional variable was collected during sampling of the grasslands. This was an estimate of the degree to which the grass sward directly beneath the DPM was lignified. Above a certain height (approximately 260 mm) the lignified grass culms result in a poor correlation between DPM height and above-ground standing grass sward (Zambatis *et al.* 2006). As average DPM height did not exceed 260 mm, the calculation of a second calibration equation was deemed unnecessary however these data are presented in Appendix 7 and Appendix 8 should this method of calibration be re-evaluated in the future. The regression equations estimating dry matter from DPM height for the two sites differed in their slope but only marginally so for their x-intercept (Eastern Shores: $y = 6.6663x + 19.332$ and Manzengwenya: $y = 4.5227x + 22.518$). The percentage variation accounted for by each regression equation was 72 and 60 % respectively.

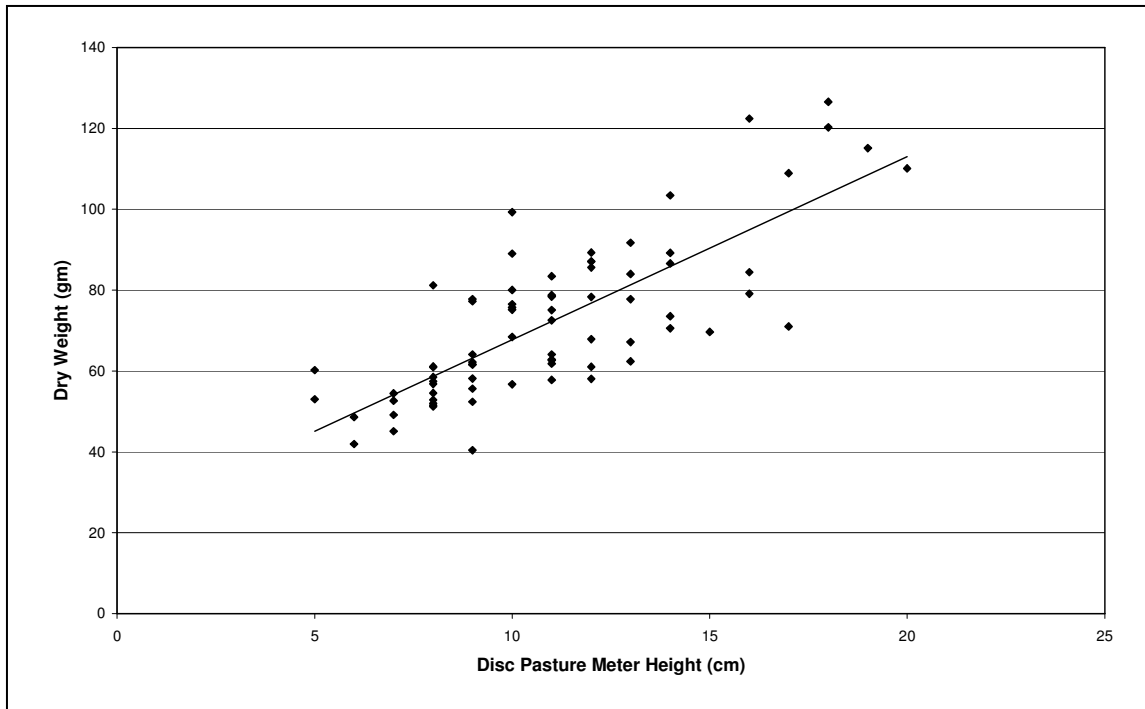


Figure 4.4.2 The relation between the calibration curve for above-ground standing grass sward (dry weight in grams) and compressed disc pasture meter height (cm) within annually burnt grasslands, north of the Manzengwenya Offices, Maputaland, South Africa. Regression equation was calculated as $y = 4.5227x + 22.518$ and this accounted for 60 % of the variation.

Surface fuels can be measured with the disc pasture meter and average sward height used to calculate dry matter (kgDM.ha^{-1}) using the following regression equation:

$$y = 401.125x + 1163.25 \quad (r^2 = 0.72)$$

Table 4.2 Average disc height (cm) and associated dry matter ($\text{kg ha}^{-1} \pm \text{SE}$) for three fire exclusion periods north of the Manzengwenya Offices, South Africa

Fire exclusion	Average Disc Height (cm)	DM kg ha^{-1}	Standard Error
1 Year	10.80	4293.16	± 219
3 Year	22.94	7598.75	± 493
6 Year	16.80	5926.90	± 649

The regression equation derived may need further comparison with different areas for a more general equation. It serves here to illustrate the relationship between disc height and associated dry matter (Table 4.2). From these data, average disc heights of between 12 and 22 cm indicate suitable surface fuel accumulation for burning. A height of 24 cm may be indicative of grassland urgently requiring burning and this height should not be exceeded. These data are restricted to higher lying grasslands and calibration may need to be conducted separately for lower lying areas. Although a six year fire exclusion is dominated by tall woody species, surface fuels available for combustion are still high but it is unclear what the effects of fire on the tall woody species would be.

4.4.3. Fire intensity

In order to better evaluate vegetation response to burning various factors were recorded at the time of burning to quantify fire intensity and characterise its behaviour. This was to form part of the analysis of trial two and assist explanation of any variation but due to complications with implementing, this treatment was excluded from further analysis. However, these data are presented should further research require this type of information.

Fire intensity was calculated as the product of heat yield (constant; kJ g^{-1}), mass of available fuel (kg m^{-2}), and rate of spread (m s^{-1}) (Trollope 1999a). Rate of spread was calculated as the area burnt (m^2) over the product of the time of flaming combustion (s) and the length of the fire front (m). Wind velocity and rate of spread were individually used to calculate fire intensity as way of comparison. For the calculation of wind velocity a wind cup was used to measure the distance traveled for a period of time. This was measured in feet and was converted to meters. An estimate of flame height for various lengths along the flame front was estimated with the use of a measuring pole placed in the path of the moving flame front. Temperature and relative humidity were also recorded. These data have been summarised in Table 4.3.

Table 4.3 Various factors used in the calculation of fire intensity for two sites on the Eastern Shores of Lake St Lucia

Date	01/11/2004	Site	Biomass	Fire Intensity (a)
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Wind Direction	Northerly	ESP	1.18 kg m ²	142 791.84 kJ s ⁻¹ m ⁻¹
Distance	48627"	ESG	1.06 kg m ²	129 111.63 kJ s ⁻¹ m ⁻¹
Time	2200 s			
Wind Reach	6.74 m s ⁻¹			
		Distance	Flame Height	Fire Intensity (b)
Heat yield	18024 kJ kg ⁻¹	10 m	70 cm	61 292.51 kJ s ⁻¹ m ⁻¹
Time of burn Start	9.05 am	20 m	190 cm	55 420.36 kJ s ⁻¹ m ⁻¹
Finish	9.49 am	30 m	320 cm	
Distance Peg A to Peg B	73m	40 m	280 cm	
Time Peg A to Peg B	142.11 s	50 m	410 cm	
Area	30000 m ²	60 m	330 cm	
Rate of Spread	2.89 m s ⁻¹	70 m	180 cm	
		80 m	140 cm	
Relative Humidity	60 %	90 m	320 cm	
Temp	19.04 °C	100 m	450 cm	

Fire intensity was greater for sites that were previously under pine plantation (ESP) compared to open grassland (ESG). Fires were intense due to unusually high wind velocities of nearly seven meters per second and high surface fuels available for consumption (Plate 4.4.1). Flame heights exceeded four meters in sections for biomass with heights of less than one meter. It is strongly recommended that these conditions be avoided for implementing a successful burning trial.



Plate 4.4.1 From top left clockwise: High wind velocities greatly increase rate of spread; burning conditions made fire control difficult; burning was part of a larger block burn for the Eastern Shores; fire affected *H. kraussii* variably; grass and herbaceous vegetation were largely consumed; intense fires left an unpatchy landscape.

4.4.4. Investigating the interactive effects of defoliation by fire and defoliation by clipping on Helichrysum kraussii

4.4.4.1. Manzengwenya burning and clipping trial (Trial One)

A total of 96 plots (Section 4.3.1 above) two by two metres each were located within the edaphic grasslands north of the Manzengwenya Offices. A clipped and unclipped plot were paired and located such that each plot had at least one *H. kraussii* plant within. Plot allocation within each catenal position is therefore not randomly allocated as the trial was concerned purely with the response of this persistent species to defoliation of surrounding grass and herbaceous vegetation. Each plot was demarcated using wooden stakes to increase the ease of identification. Care was taken to ensure *H. kraussii* plants within the unclipped plot were not immediately adjacent to the clipped plot. Clipping was conducted monthly from November 2004 to April 2005, totalling six clipping times during the growing season.

Clipping was conducted mechanically using a petrol brush-cutter and all biomass, other than that of the *H. kraussii* plants present in each plot, was removed, including a 300 mm buffer around each clipped plot to completely remove edge-effects on light availability amongst other influences. Defoliation of this surrounding plant biomass was complete and removal occurred down to the soil surface (Plate 4.4.2). Initial plant attributes were measured in November 2004, before clipping but one and a half months after the accidental burning, and again at the end of the trial in April 2005. Measurements included the number of stems, height, and minimum and maximum canopy diameter for each *H. kraussii* plant. Individual plants were distinguished on stem morphology as this species tends to coppice prolifically in response to defoliation from a localised area at ground level.

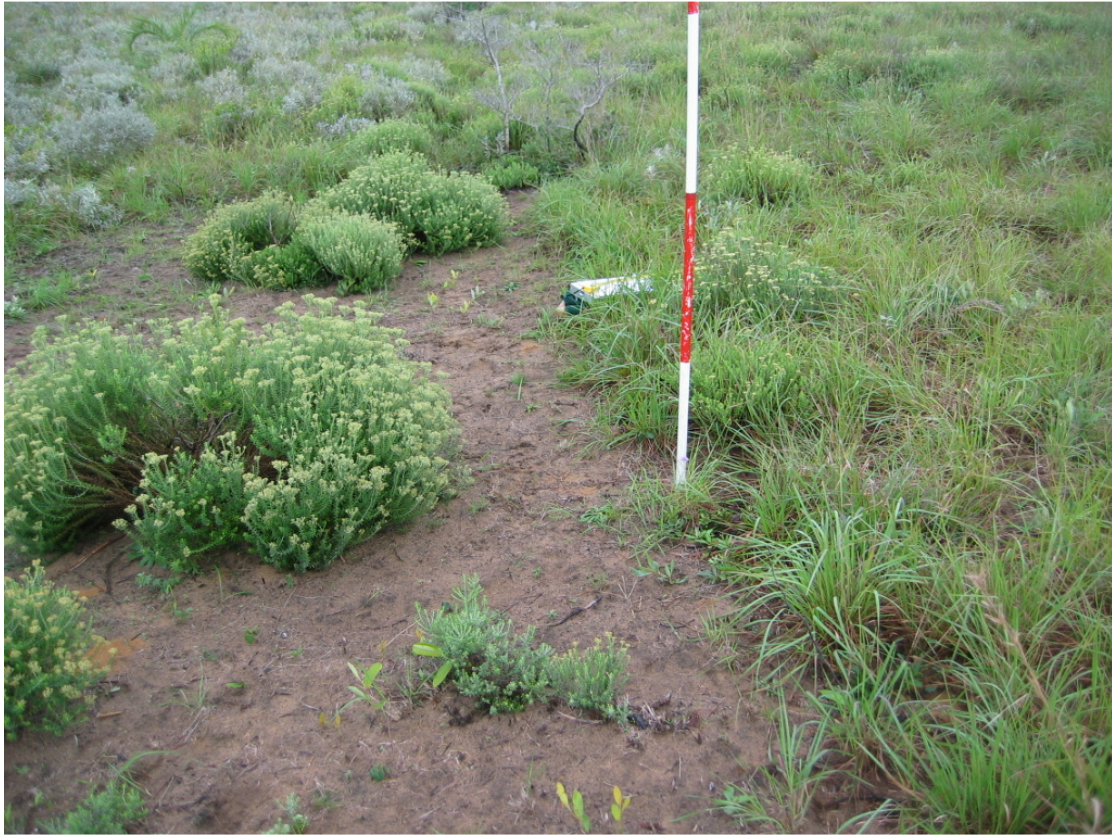


Plate 4.4.2 Typical plot with vegetation around the *Helichrysum kraussii* plants removed by clipping.

4.4.4.2. Eastern Shores burning and clipping trial (Trial Two)

The trial located on the Eastern Shores of Lake St Lucia consisted of a total of 60 plots, blocked three times across two vegetation types (VegT) and defoliated at two levels, clipped and unclipped. Plot sizes, method of clipping, and criteria for plot location are similar to those outlined for Trial One in Section 4.4.4.1 above. Differences in trial design and layout as well as important considerations can be summarized as follows:

1. To ensure similarity in topography between vegetation types it was not necessary to divide areas (blocks) for aspect and therefore comparisons between trials on the Eastern Shores and that north of the Manzengwenya Offices were limited.
2. Plots were located immediately adjacent to another in two groups of five and defoliation was carried out sequentially within each plot.

3. Clipping was conducted monthly from October 2004 to March 2005 but was conducted for a longer period (three months extra) for trials two and three. This was due to wildfire prematurely burning trial one and time needed for regeneration before implementing the clipping treatment.
4. Due to the grassland section of block two remaining unburnt, comparisons are limited to blocks one and three.

Measurements were taken immediately prior to defoliation and after completion of the defoliation treatment.

4.4.4.3. Eastern Shores burning and clipping trial (Trial Three)

The 24 plots (Section 4.3.3 above) located within the unburnt plot from Trial Two (Figure 4.3.3) on a section of the Eastern Shores of Lake St Lucia were established immediately following the complications experienced with Trial Two and the sampling and clipping dates therefore follow the same as those for Trial Two (Section 4.4.4.2). Methods of clipping and measurements taken during sampling follow those outlined for Trial One in Section 4.4.4.1 above. Plot location (as with Trial One and Two) was dependant on the presence of *H. kraussii* plants and the number of *H. kraussii* plants varied within each plot. A two by two meter clipped plot was located immediately adjacent to an equal sized unclipped plot. These were then paired across the different burning 'treatment' to allow for formal comparison (Figure 4.3.3 above).

4.4.4.4. Additional variables collected

On completion of the three trials in March 2005, additional environmental variables were collected so as to better evaluate and interpret some of the possible underlying effects of the environment on the response of *H. kraussii* other than that of defoliation by fire and clipping. These additional environmental variables included the following:

1. Soil moisture %
2. Photosynthetically active radiation (PAR)
3. Plant biomass response to defoliation by clipping.

Soil moisture was assessed for all plots within each trial where a 350 gram sample was collected from each plot and oven-dried at 150°C for 72 hours and the difference in mass converted to a percentage. All bulk organic matter was removed from the soil surface where the sample was to be collected and collection conducted adjacent to a *H. kraussii* plant, in between rooted plants. Any root material was excluded from the sample.

The transmission of photosynthetically active radiation (PAR) through the canopy of *H. kraussii* was measured at each plot on completion of the trials in September 2005. All measurements were taken between 9 a.m. and 3 p.m. under light conditions unaffected by cloudy conditions to minimize differences between and allow better comparisons across sites. The radiation within the 400 – 700 nm wavelengths (PAR) was measured with a Sunfleck Ceptometer (Decagon Devices Inc., Pullman, Washington, USA) consisting of 80 light sensors at one centimetre intervals along a metal probe. Each measurement represented the mean of eight readings. For each of the plots, the Ceptometer probe was inserted into the centre of the plant canopy at ground level and where the canopy extended to its maximum before closing at its height. The orientation of the probe during insertion was kept constant in an east to west direction. This was conducted five times within each plot and where only one *H. kraussii* plant was present in a plot, measurements were conducted only within that plant. The transmission of PAR to a certain height was calculated as the PAR reading at that height divided by the incoming PAR reading taken immediately before the canopy measurements and averaged over the five measurements per plot.

After several clipping events throughout the duration of the three trials, all biomass was clipped for a 0.5 m² quadrat and separated out into its three component categories, namely: grass, herbaceous, and woody species (Appendix 10). This was conducted for selected plots from the three trials where both the clipped and unclipped plots were sampled in a pair-wise fashion to allow for comparisons of plant biomass response to the various treatments in Manzengwenya and on the Eastern Shores of Lake St Lucia.

4.5. RESULTS

4.5.1. Examination of the effects of fire exclusion period and catenal position on the coastal dune communities of Maputaland: Density

On average, total plant density for sites burnt regularly (one year fire exclusion) was considerably greater ($359\,086 \pm 234$ plants ha^{-1}) than compared with those of a fire exclusion period of three ($76\,326 \pm 271$ plants ha^{-1}) and/or six years ($25\,837 \pm 115$ plants ha^{-1}) (Table 4.4 and Figure 4.5.1). This decrease in plant density with an increase in fire exclusion period is moderately exponential, where an initial increase in fire exclusion period results in a substantial reduction in the total average plant density (Table 4.4). A further increase in fire exclusion period results in a comparatively disproportionate reduction in the change in plant density. Therefore, when comparing fire exclusion periods on the basis of total plant density there is less variation between periods of three and six years when compared with one and six, and one and three years.

Table 4.4 Average point-to-plant distance (AveDist; m), total density (Density; ha^{-1}), separated out into component category density (Grass, Herbaceous, and Woody) and average density (AveDen; ha^{-1}) \pm SE for the three fire exclusion periods (Flnt) within sites (site acronym (W), (E), (B) refers to west, east, and bottom sites respectively) north of the Manzengwenya Offices, South Africa

Flnt	Site	AveDist	Density	Grass	Herbaceous	Woody	AveDen
1 Year	MBP 1 (W)	0.16 \pm 0.12	373346 \pm 234	11506 \pm 48	4588 \pm 21	13272 \pm 43	359086 \pm 234
1 Year	MBP 2 (E)	0.18 \pm 0.12	298388 \pm 234	10223 \pm 48	5218 \pm 21	10086 \pm 43	
1 Year	MBP 3 (B)	0.16 \pm 0.12	405524 \pm 234	14720 \pm 48	5386 \pm 21	13155 \pm 43	
3 Year	MBP 4 (W)	0.59 \pm 0.42	28841 \pm 271	909 \pm 50	377 \pm 36	869 \pm 44	76326 \pm 271
3 Year	MBP 5 (E)	0.51 \pm 0.42	38964 \pm 271	1332 \pm 50	576 \pm 36	1200 \pm 44	
3 Year	MBP 6 (B)	0.25 \pm 0.42	161174 \pm 271	5389 \pm 50	2653 \pm 36	4335 \pm 44	
6 Year	MBP 7 (W)	0.75 \pm 0.38	17702 \pm 115	448 \pm 22	192 \pm 17	493 \pm 21	25837 \pm 115
6 Year	MBP 8 (E)	0.73 \pm 0.38	18627 \pm 115	552 \pm 22	279 \pm 17	503 \pm 21	
6 Year	MBP 9 (B)	0.49 \pm 0.38	41183 \pm 115	1369 \pm 22	718 \pm 17	1237 \pm 21	

However, plant density as mediated by aspect (catenal position) differed across fire exclusion periods in its response. For all periods, total plant density was greatest in bottom sites when compared with west and east sites (Figure 4.5.1). For fire exclusion periods of three and six years, plant density was greater with a change in catenal position

from west, through east, to bottom sites. This trend differed however for sites with one year fire exclusion, where plant density for west sites was greater than that for east sites.

A reduction in regular burning therefore resulted in a reduction in plant density, with this reduction decreasing with increasing fire exclusion period and plant density becoming less variable down the catena however catenal position resulted in variable effects across fire exclusion period.

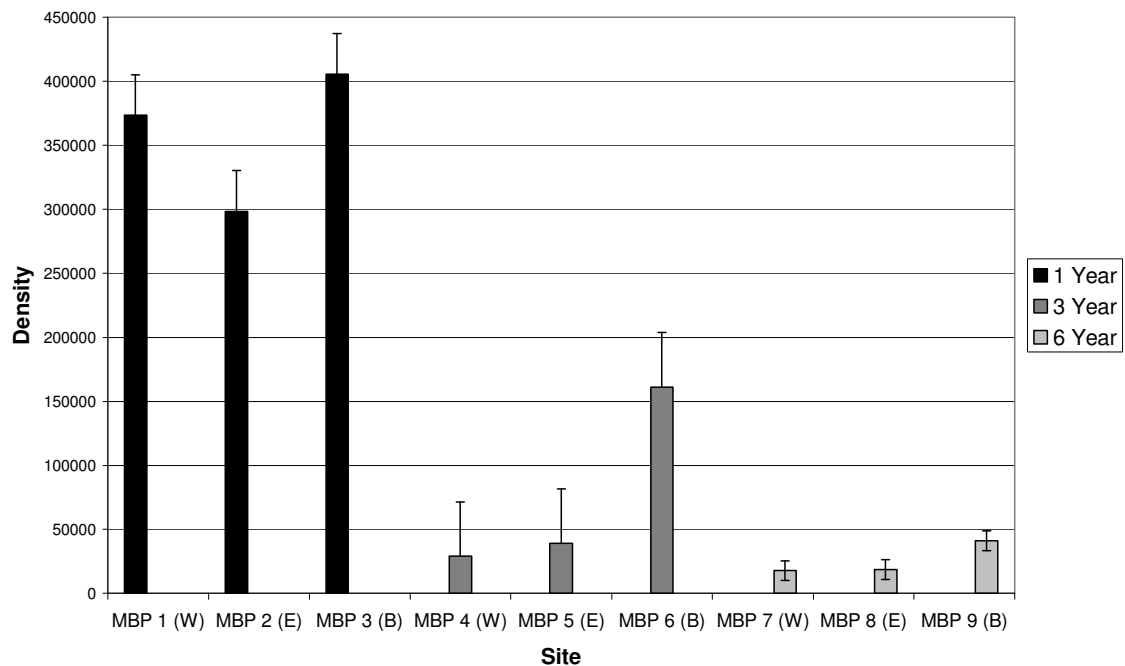


Figure 4.5.1 Total plant density (individuals per hectare (\pm SE)) for different catenal positions and fire exclusion periods within sites north of the Manzungwenya Offices, South Africa.

Total plant density per site was separated out further into distinct component physiognomic categories consisting of grass, herbaceous, and woody species (Table 4.4 and Figure 4.5.2). The relationship between fire exclusion period and plant density has been maintained where sites burnt frequently have the greatest plant density across all three physiognomic categories. Within this, grass species density is greatest for bottom sites and within these sites has the greatest density of the three categories. For west and east facing sites, grass and woody species density differ marginally and comprise the

majority of the plant density. This is however not the case for MBP 1 (W), a west facing site with a one year fire exclusion, where woody species density is substantially greater than the grass species. The herbaceous physiognomic category is consistently the lowest density throughout catenal position and fire exclusion period. This category is not affected to the same degree by catenal position as is the case for the other two categories but rather remains relatively consistent for the three fire exclusion periods.

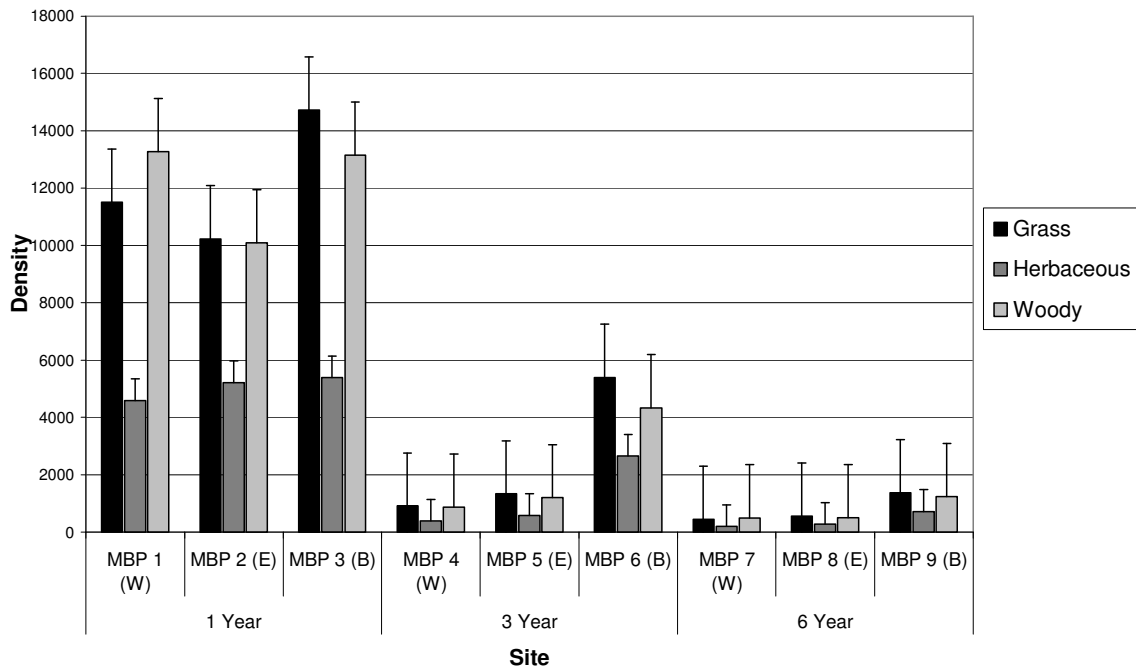


Figure 4.5.2 Total plant density (individuals per hectare (\pm SE)) separated according to physiognomic category for different catenal positions and fire treatments within sites north of the Manzengwenya Offices, South Africa.

These component categories have been expressed as a relative proportion of the total absolute density for each site to allow for comparisons between sites and highlight trends additional to the absolute density data (Figure 4.5.3). Although total density for all species is greatest in sites burnt regularly, with density decreasing with increasing fire exclusion period, the proportional density for the grass and woody categories for all sites differ only to a small degree (greatest difference less than 10 %). Within each fire treatment there is a general trend where proportionately both the herbaceous and grass

categories increase down the catena with the woody category exhibiting an opposite trend. However, comparing category density with the individual site density revealed consistent uniformity where grass and woody categories are on average 40 % of the density for all sites, regardless of catenal position and fire exclusion period. The same is true for the herbaceous category where each site is on average comprised of the remaining 20 %.

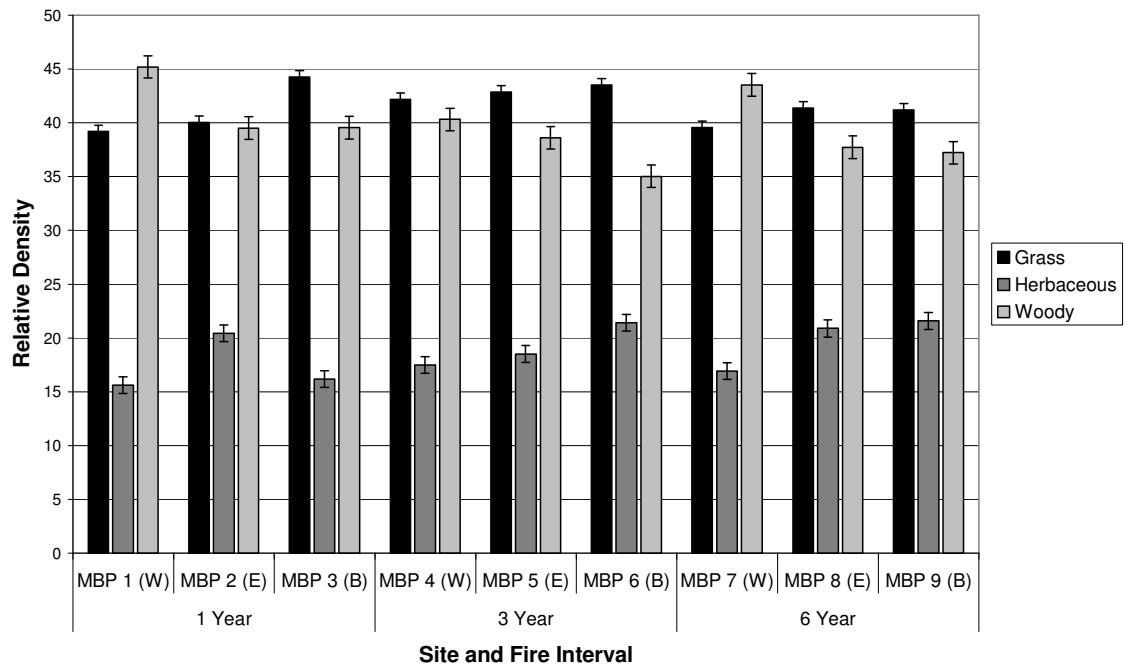


Figure 4.5.3 Relative category density (plants ha⁻¹) (Grass, Herbaceous, and Woody (\pm SE)) for different catenal positions and fire exclusion periods within sites north of the Manzengwenya Offices, South Africa.

Therefore regular burning would appear to have an over-riding influence on site density but with increased fire exclusion, catenal position has more of an influence (Figure 4.5.1). A decrease in fire exclusion period results in an increase in total plant density and within this overarching effect is another important, although less prominent trend relating to catenal position and physiognomic category response.

4.5.2. *Species density by physiognomic category and fire exclusion period*

The response in density of each species within the physiognomic categories (grass, herbaceous, and woody) within the three fire exclusion periods (one year, three year, and six year) was examined at a finer scale. This sub-section therefore presents a series of figures where each contains the species for each physiognomic category, separated by the fire exclusion periods. Additionally, species have been ordered by their local mean within each figure where total density has been divided by the number of sites in which present, giving more weight to dense species occurring in only one or two sites.

4.5.2.1. Grass species density

Of the grass species within sites with a one year fire exclusion period (Figure 4.5.4) *T. triandra* was on average the most prevalent species based on density. *Panicum deustum* was the only species not present for a one year fire exclusion. This species is particularly susceptible to regular burning due, in part, to a delay in tillering after rains (Jacobs & Schloeder 2002). *Setaria sphacelata*, *Digitaria eriantha*, *Urelytrum agropyroides*, *Cymbopogon validus*, and *Diheteropogon amplexans* were the next five most prevalent species. *Setaria sphacelata* had the greatest density of all the grass species for bottom and west facing sites and *T. triandra* for east facing sites. The higher total density for bottom sites (as depicted in Figure 4.5.2) was due largely to the greater densities of the species *S. sphacelata*, *D. eriantha*, *U. agropyroides*, and *C. validus*. These four species were consistently the dominant species across the three fire exclusion periods. Besides *S. sphacelata*, these species were not as dense for the remaining sites and therefore prevalent in bottom sites in comparison to east and west facing sites. *Diheteropogon amplexans* was the second densest grass species for east facing sites and is a species that is generally stimulated by regular burning (Belsky 1992; van Oudtshoorn 1999) but was substantially reduced for bottom sites where average plant density, soil moisture, and soil fertility tends to be greater. Of the three fire exclusion periods, one year fire exclusion had the most uniform spread of densities across the catenal positions with six of the ten species being established with substantial density.

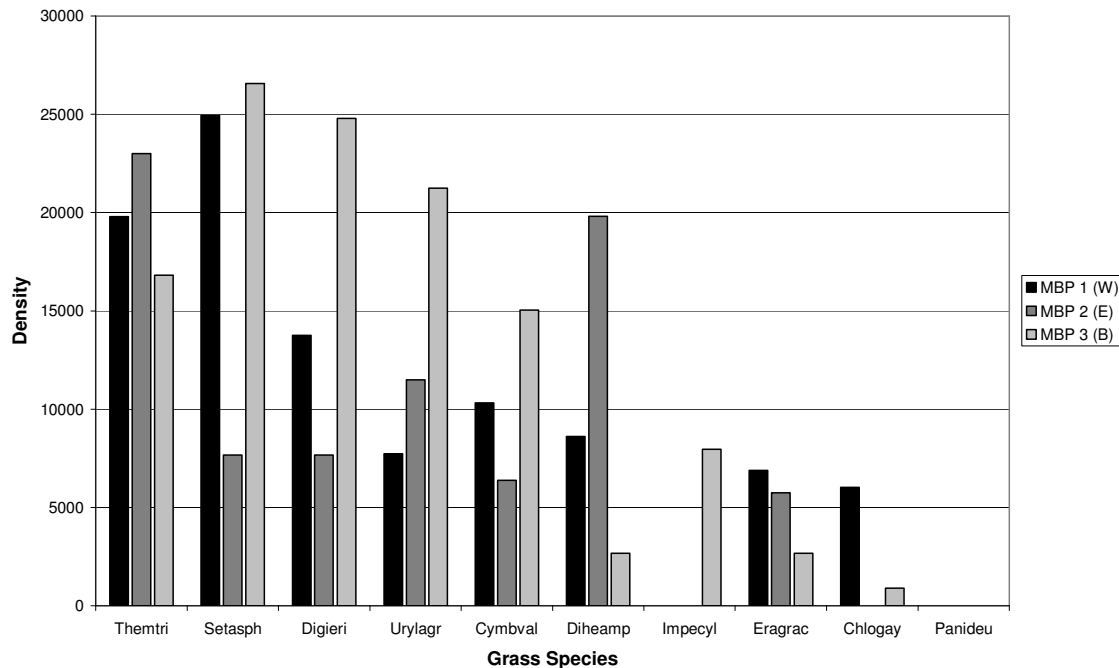


Figure 4.5.4 Density (plants ha⁻¹) for selected grass species (ordered by species site local mean) for sites with a fire exclusion period of one year, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the species acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

Grass species within sites with a three year fire exclusion period exhibit a different trend although a similar species response is evident. The major difference compared to sites with a one year fire exclusion period is the reduction in total plant density. Immediately obvious is the drastically increased densities for the prevalent grass species in bottom sites. This species response to catenal position was evident in sites with one year fire exclusion but not as distinct. *Setaria sphacelata*, *D. eriantha*, *C. validus*, and *U. agropyroides* remain the four dominant species in terms of density. *Themeda triandra* was the only species absent from the sward. This rapid loss of *T. triandra* has been well documented and attributed to increased shading and litter levels (Danckwerts & Stuart-Hill 1987; Fynn *et al.* 2004).

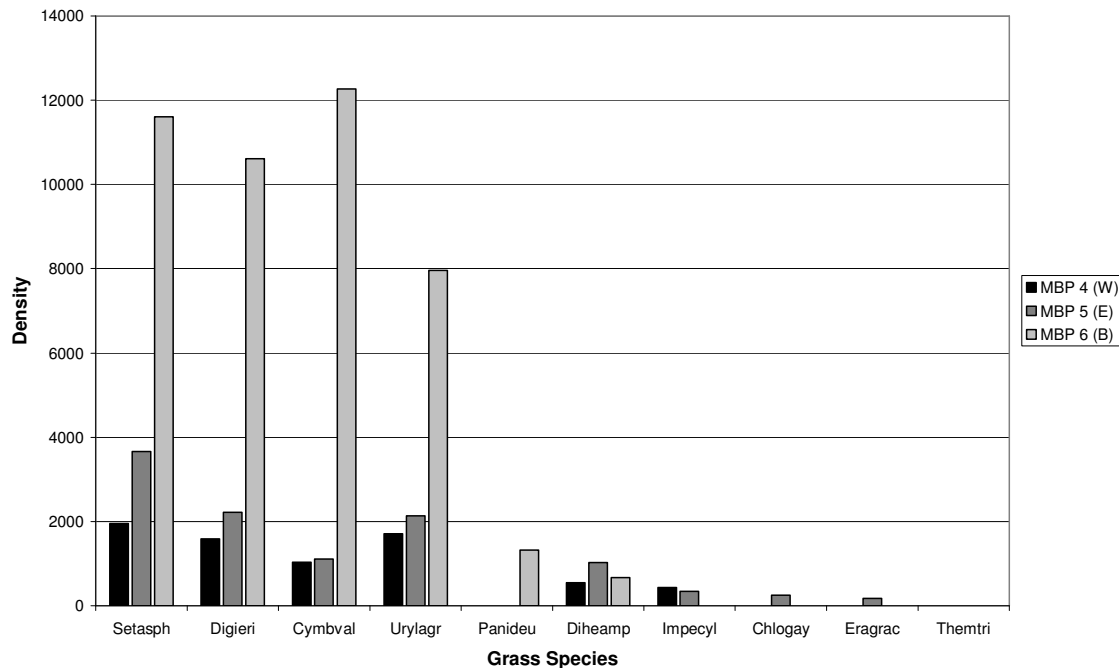


Figure 4.5.5 Density (plants ha⁻¹) for selected grass species (ordered by species site local mean) for sites with a fire exclusion period of three years, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the species acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

For sites with a fire exclusion period of six years, *U. agropyroides*, *S. sphacelata*, *C. validus*, and *D. eriantha* showed the greatest density (Figure 4.5.6). Grass species were consistently denser across all bottom sites with *P. deustum* being the only exception. *Eragrostis racemosa*, *Imperata cylindrica*, and *T. triandra* were all absent from the sward. Overall density decreased further with increasing fire exclusion and associated with this was a reduction in grass species (grass diversity).

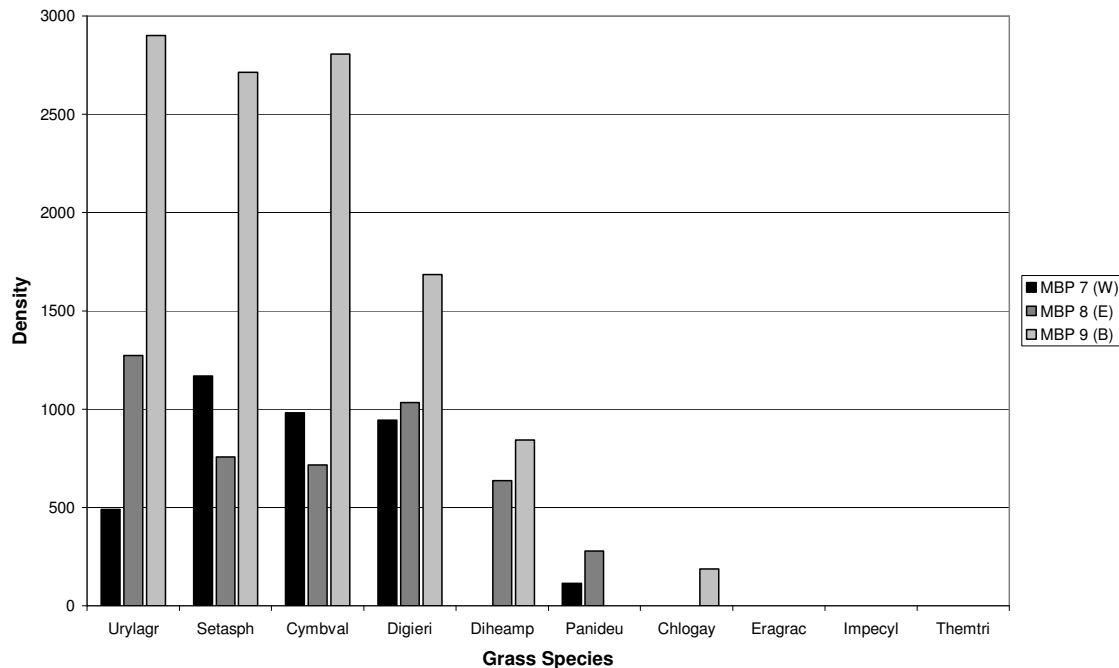


Figure 4.5.6 Density (plants ha⁻¹) for selected grass species (ordered by species site local mean) for sites with a fire exclusion period of six years, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the species acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

Focusing on the four main grass species across the three fire exclusion periods and three catenal positions (west, east, and bottom) reveals a consistency in the response of species to catenal position. For example, *U. agropyroides* increased in density from west facing to bottom sites in a consistent manner for the three fire exclusion periods. These trends for the four prevalent grass species were more entrenched for fire exclusion periods of one and six years, with some variation within the three year fire exclusion period. Overall however, grass diversity and density increased with a decrease in fire exclusion period.

From section 4.4.2 above, above-ground standing biomass was estimated using the disc pasture meter method for the calculation of fire intensity. Due to the premature burning of these sites, this calculation was not possible. However, from these data average biomass is greatest for a three year fire exclusion period (7599±493 kg ha⁻¹),

decreasing for a one ($4293 \pm 219 \text{ kg ha}^{-1}$) and six year ($5927 \pm 649 \text{ kg ha}^{-1}$) fire exclusion period. Variation increased with increasing fire exclusion due to differences between catenal positions (Refer to Table 4.1, page 40) where on average biomass was greatest for east facing sites. Therefore, biomass increased initially with an increase in fire exclusion but decreased where this exclusion period became prolonged due most likely to exclusion by taller woody species.

4.5.2.2. Herbaceous species density

Of the 25 herbaceous species recorded within the fire exclusion plots north of the Manzengwenya Offices (Figure 4.5.7), only 16 were present within sites with a one year fire exclusion period. *Lobelia coronopifolia*, a perennial shrublet prevalent in coastal grassland (Pooley 1998) dominated herbaceous density in two of the three catenal positions, west sites being the only exception. *Rhynchosia totta*, a slender creeper found throughout southern Africa (Pooley 1998) was the second densest species although only present in bottom sites.

The majority of the herbaceous species present have bulbous or woody rootstocks or woody rhizomes protected beneath the soil surface, allowing ready regeneration post defoliation by fire. The only exceptions are annual species such as *Bulbostylis contexta* a pioneer species establishing readily from the soil seed bank. *Cassytha filiformis*, a twining parasite that attaches itself to predominantly grass species by disc-like suckers (Pooley 1998), was effectively excluded from sites burnt regularly (one year fire exclusion).

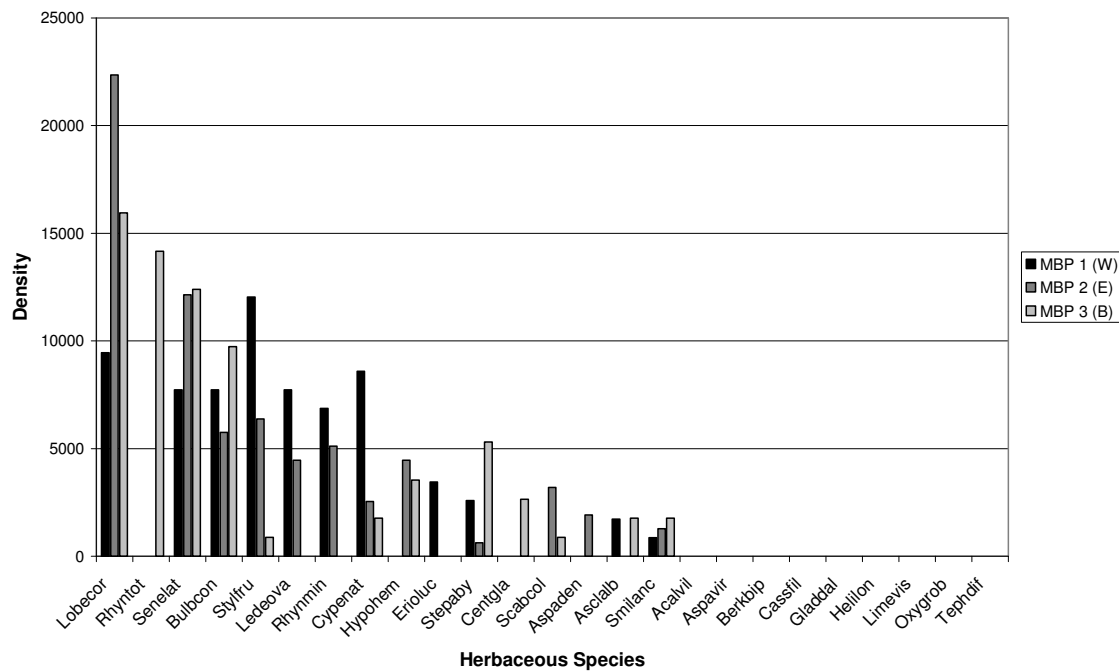


Figure 4.5.7 Density (plants ha⁻¹) for selected herbaceous species (ordered by species site local mean) for sites with a fire exclusion period of one year, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

Cyperus natalensis is a sedge-like herbaceous perennial species normally associated with moist sandy alluvium (Pooley 1998). Therefore, density for this species would be expected to be greatest for bottom sites where soil moisture conditions would be assumed to be more conducive for establishment. However, this species was more prevalent within east and west facing sites compared with bottom sites. *Bulbostylis contexta* is an annual sedge species conforming to this expectation where density was greatest for bottom sites.

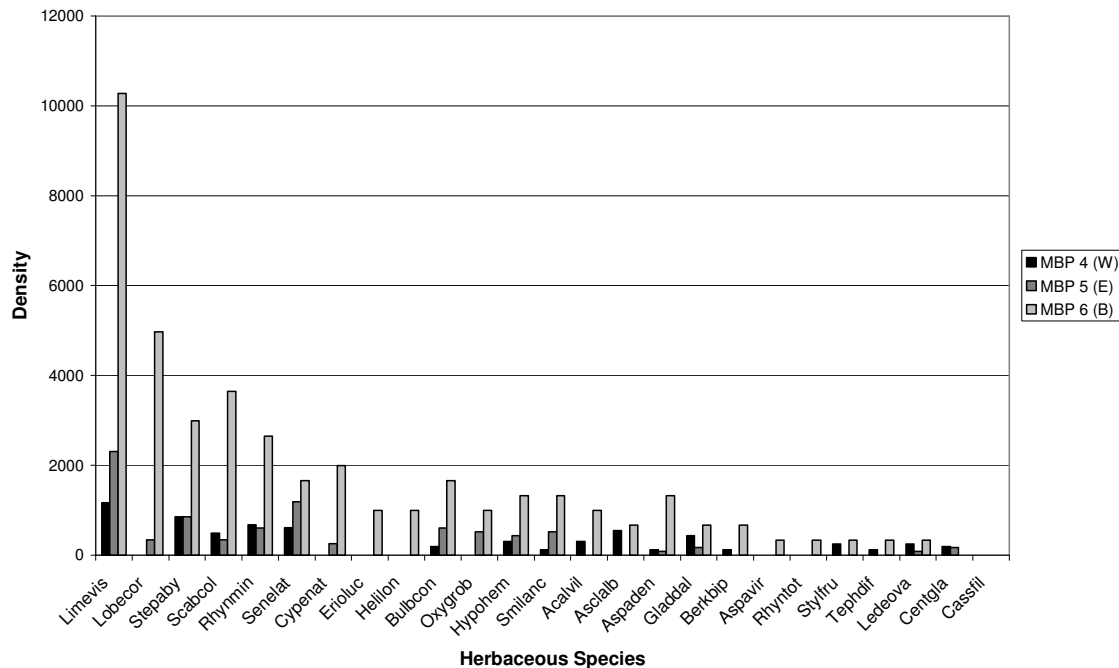


Figure 4.5.8 Density (plants ha⁻¹) for selected herbaceous species (ordered by species site local mean) for sites with a fire exclusion period of three years, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

The number of herbaceous species increased for sites with a fire exclusion period of three years (Figure 4.5.8) when compared with sites with one year exclusion. Immediately evident is the prevalence of all species across bottom sites with a number of species occurring only in this catenal position. The overall herbaceous density for these species is reduced in comparison with the one year fire exclusion sites. Of the 25 herbaceous species present across all sites *C. filiformis* was the only species absent. *Limeum viscosum* dominated herbaceous density particularly in bottom sites. This species tends to proliferate in disturbed veld (Strohbach 2000). *Lobelia coronopifolia* was the second most prevalent herbaceous species due largely to its density in bottom sites. *Stephania abyssinica* increased in prevalence when compared with one year fire exclusion, although density was reduced. This species is a perennial climber normally associated with woodland type habitat but for sites north of Manzengwenya occurs at

greater densities within grassland sites but increases in prevalence with an increase in fire exclusion period.

Cyperus natalensis had increased densities for bottom sites, a reversal when compared with one year fire exclusion. Absence from west facing sites could be due to a change in soil moisture conditions where bottom sites tend to be moist in comparison. *Rhynchosia totta* decreased in prevalence considerably and remained present in bottom sites only.

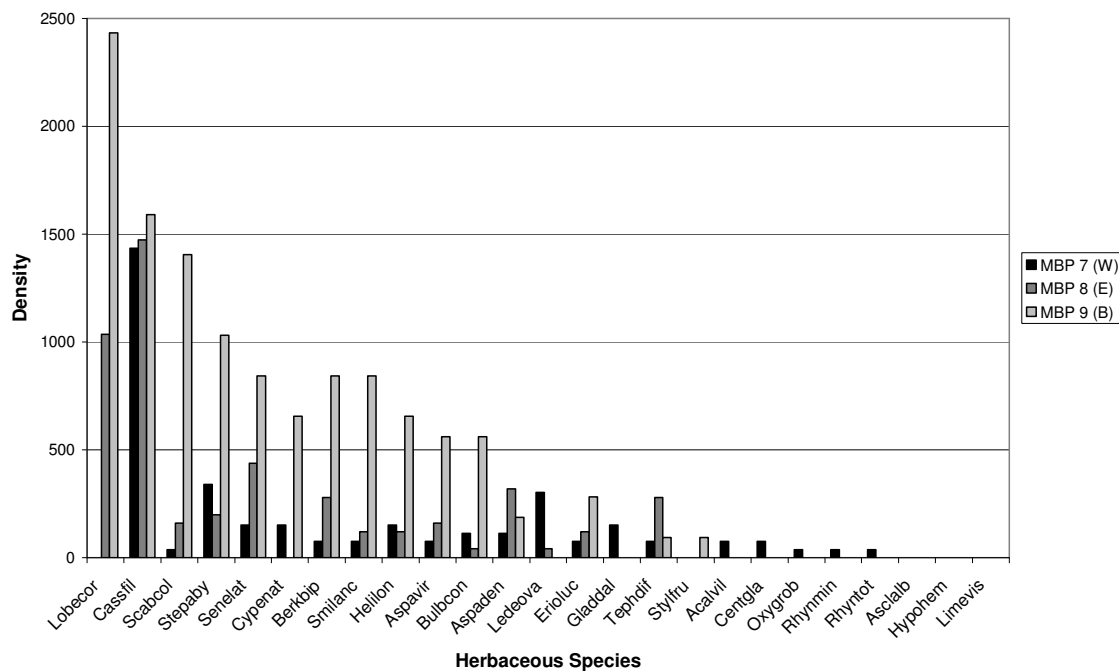


Figure 4.5.9 Density (plants ha⁻¹) for selected herbaceous species (ordered by species site local mean) for sites with a fire exclusion period of six years, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

Overall herbaceous density for six year fire exclusion was again reduced when compared with one and three year fire exclusion (Figure 4.5.9). The number of herbaceous species present within the six year fire exclusion was greater (22) when compared to one year fire exclusion (16) but reduced when compared with three year exclusion (24). Bottom sites were consistently greater in density across all species, the

only exceptions being *Asparagus densiflorus* and *Tephrosia diffusa*. These two species both had greater densities for east facing sites.

Lobelia coronopifolia although absent from west facing sites was ranked highest based on local mean and densest for bottom sites. The twining parasite, *C. filiformis*, was found consistently throughout the three catenal positions. This particular species was absent from the other fire exclusion periods and density for this species is therefore strongly positively correlated with fire exclusion period where an increase in exclusion period results in a drastic increase in density.

Although differences exist between total plant density for the three fire exclusion periods, there is a similar ordering of herbaceous species within each exclusion period. For example, herbaceous species ranked higher in one fire exclusion period will be more likely ranked high in another fire exclusion period. There are exceptions to this trend (*C. filiformis*) but these species tend to be absent in the other fire exclusion periods. *Berkheya bipinnatifida*, a perennial herb found predominantly on forest margins (Pooley 1998), is another example of an exception to this trend where presence and density is limited to sites with a six year fire exclusion. *Smilax anceps*, a scrambling climber in grassland, was present for all fire exclusion periods but increased in importance with increasing fire exclusion period. *Limeum viscosum* was only present in sites with a three year fire exclusion period and therefore effectively excluded by regular burning (one year fire exclusion) or prolonged absence of fire (six year fire exclusion).

4.5.2.3. Woody species density

A similar trend to total woody plant density is evident where density is greatest for the one year fire exclusion sites and this density decreases with increasing fire exclusion. This apparent anomaly is due to the type of sampling technique used and particular classification of woody species but it is important to note that this is not due to error or an unrealistic representation of conditions on the ground. This technique and classification included species with heights of less than 30cm and a number of woody species were recorded although no height was included due to their small stature. These individuals are normally excluded in sparse stands of savanna vegetation due to a minimum height qualification. For these coastal grasslands however, these dwarf species were perceived

to contribute substantially to plant density and sampling strategy was therefore adapted to include these. This aspect of the data has been further explored in section 4.5.4.1 below where density has been separated according to different height classes.

Twenty-three of the 28 woody species were present for sites with a fire exclusion period of one year (Figure 4.5.10). Across all fire exclusion periods *Diospyros villosa* was consistently ranked highest although various catenal positions had other woody species with greater densities. *Syzygium cordatum*, typically a medium sized evergreen tree was ranked second and was recorded for all three catenal positions. This species has previously been found as a low spreading shrub in coastal grasslands of Maputaland (Pooley 1998) and these data agree with this finding. This woody species is therefore able to establish in normally unfavourable conditions but possibly remain suppressed in dwarf or shrub form until an abrupt reduction in fire frequency results in a competitive release (Jutila & Grace 2002).

There are a number of other woody species which are typically represented by tall shrubs or sizeable trees present as dwarfs within the grasslands with a one year fire exclusion. A number of these being: *D. lycioides*, *Gymnosporia markwardii*, *D. cinerea*, *Eugenia albanensis*, and *S. spinosa*.

Other species included as woody but normally present as shrubs within the sward were *Parinari capensis*, *Tephrosia latifolia*, *Athrixia phyllicoides*, *Euphorbia dumosa*, *Abrus laevigatus*, and *Barleria meyeriana*. Note the presence of both *H. kraussii* and *Chrysanthemoides monilifera* within this fire exclusion period, albeit not ranked within the top 50 %. The following woody species were not present within the one year fire exclusion period: *Eriosema saligna*, *Isoglossa ovata*, *Kraussia floribunda*, *P. reclinata*, and *Vernonia oligocephala*. Of these species only *K. floribunda* is represented typically as a shrub or small tree where disturbance regimes allow. Therefore, woody species normally represented as tall trees were present across all fire exclusion periods in one form or another depending on severity of disturbance (exclusion period).

For the majority of woody species density was greater for bottom sites. Two species representing a reversal to this trend were *S. cordatum* and *Athrixia phyllicoides* where density was greatest for west facing sites.

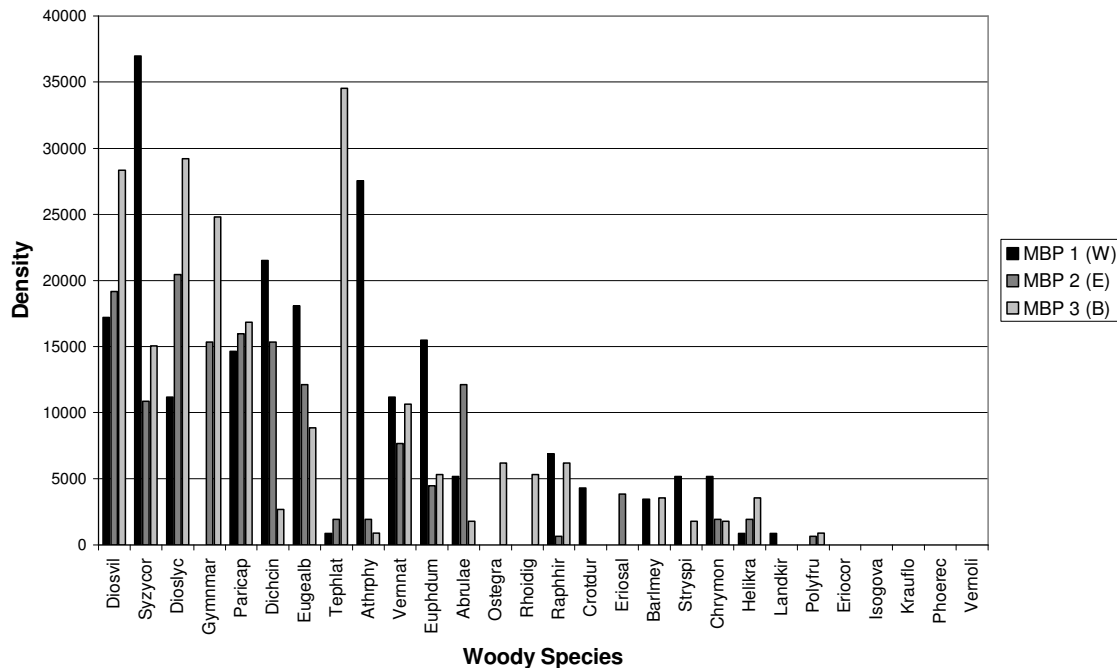


Figure 4.5.10 Density (plants ha⁻¹) for selected woody species (ordered by species site local mean) for sites with a fire exclusion period of one year, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

All 28 woody species were present within the three year fire exclusion period (Figure 4.5.11). Although differences in species ranking exist when compared with one year fire exclusion period, ordering of the dominant species differ only marginally. *Dichrostachys cinerea* increased in ranking with an increase in fire exclusion period as did *H. kraussii*. Bottom sites were considerably denser compared with a fire exclusion period of one year. Exceptions to this trend were due to absence of certain species from the other catenal positions. Individual species density in response to catenal position for these two fire exclusion periods varied considerably with very little consistency. This would indicate that the exclusion period from fire is the major influence on density but catenal position has a less consistent effect on this response.

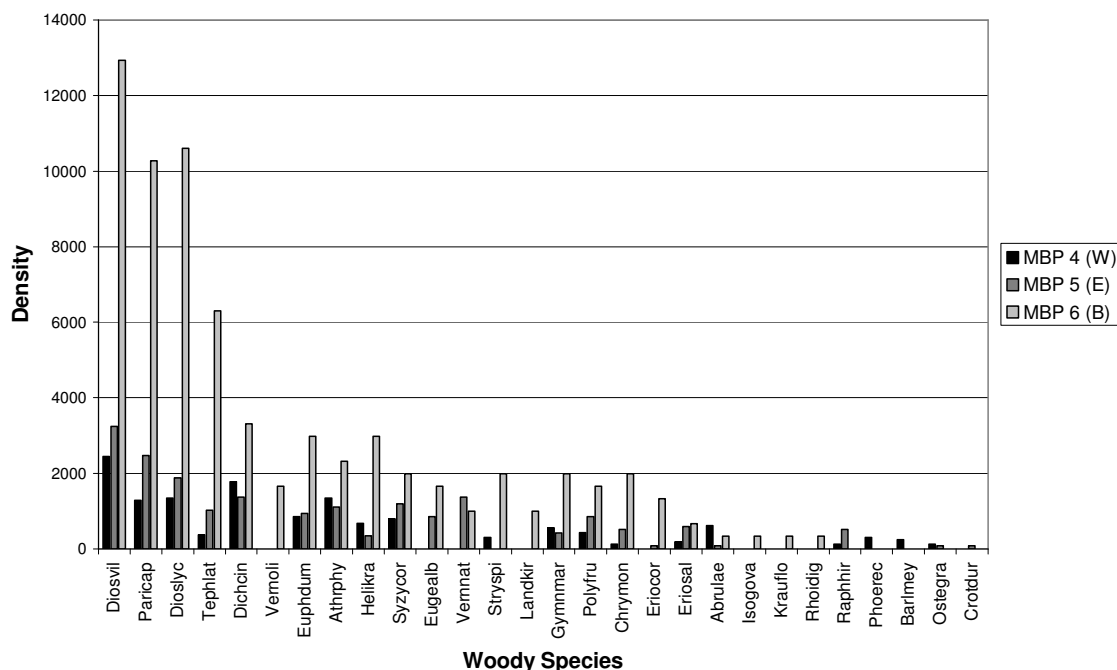


Figure 4.5.11 Density (plants ha⁻¹) for selected woody species (ordered by species site local mean) for sites with a fire exclusion period of three years, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

The number of woody species present for a fire exclusion period of six years decreased from sites with a three year fire exclusion to 26 species but was still less when compared with a one year fire exclusion period. The shorter shrub species such as *D. villosa* and *D. lycioides* remained dominant although at far reduced densities in comparison to three and one year fire exclusion periods. A similar trend observed for three year fire exclusion is evident where density for bottom sites was consistently greater.

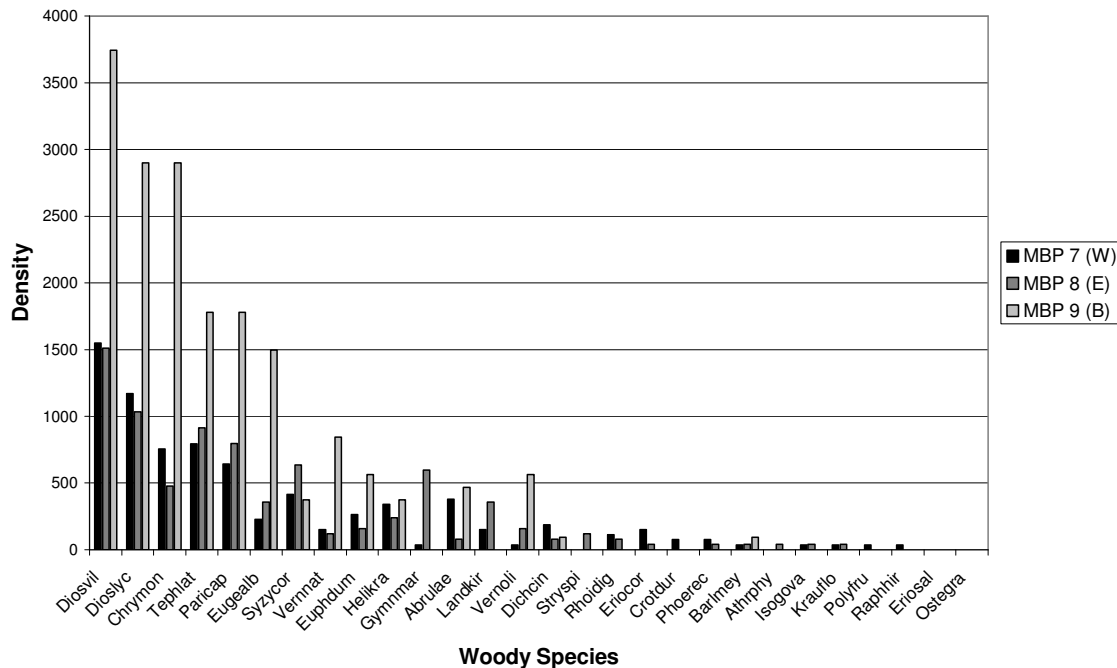


Figure 4.5.12 Density (plants ha⁻¹) for selected woody species (ordered by species site local mean) for sites with a fire exclusion period of six years, Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the acronyms used. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively.

4.5.3. *Helichrysum kraussii* density

Helichrysum kraussii density has been found to vary with topography where density decreases considerably for bottom lying areas. This has been attributed to an increase in soil moisture particularly where periodic inundation occurs (Owen 1992) and is regularly observed within the IWP (Plate 4.6.3 Pp. 114). Therefore density for this species has been presented to assess any possible trends in the data that may conform to this previous observation.

From Figure 4.5.13 density was on average greatest for a fire exclusion period of three years despite woody density being greatest for a one year fire exclusion period (section 4.5.2.3 above). This represents a peak in density after which further fire exclusion resulted in a decrease in density. Density was only greater for bottom sites with a six year fire exclusion period. For the other two exclusion periods density was greatly reduced in bottom sites. Variability between catenal positions indicates a response for

which an explanatory variable has not been accounted for. It is however possible to appreciate that density for *H. kraussii* is affected by fire exclusion period where a decrease in fire exclusion period reduces density. Initial response is more than likely due directly to fire frequency whereas the subsequent decline visible for a six year fire exclusion period may be a result of competitive exclusion through shading from taller woody species.

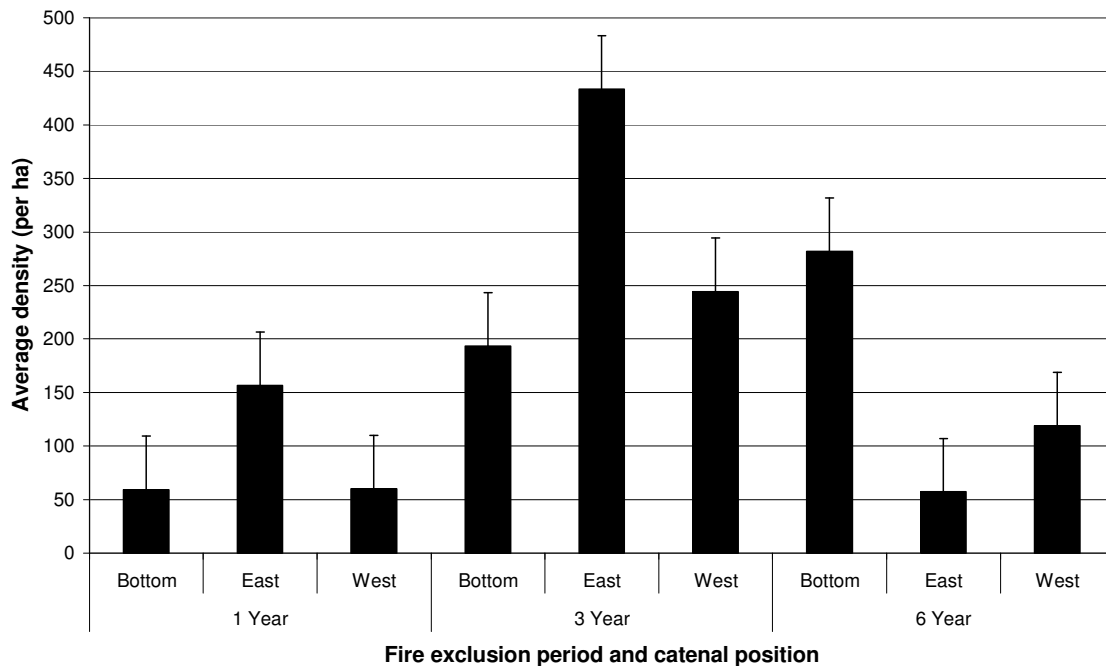


Figure 4.5.13 Average density (plants ha⁻¹ (±SE)) for *Helichrysum kraussii* for three fire exclusion periods and catenal positions for sites north of the Manzengwenya Offices, South Africa.

4.5.4. Height

As expected due to the obvious difference visually in vegetation structure mostly attributed to fire exclusion period (refer to Plate 4.5.1 Comparing position 1, 2, & 3 and Plate 4.5.2) average woody height increases with an increase in fire exclusion period (Figure 4.5.14) such that average woody height is greatest in sites with a fire exclusion period of six years. Regular burning has therefore resulted in a substantial decrease in

woody species height and this response to fire is comparatively uniform resulting in a decrease in variation with a decrease in fire exclusion period. However, within each fire exclusion period there is a variable response of woody height to fire exclusion period within the three catenal positions. For sites with a fire exclusion of three years, woody height was greatest in west facing sites however for sites with a fire exclusion of six years east facing sites had a greater woody height. Woody height for bottom sites was consistently the least for all fire exclusion periods.

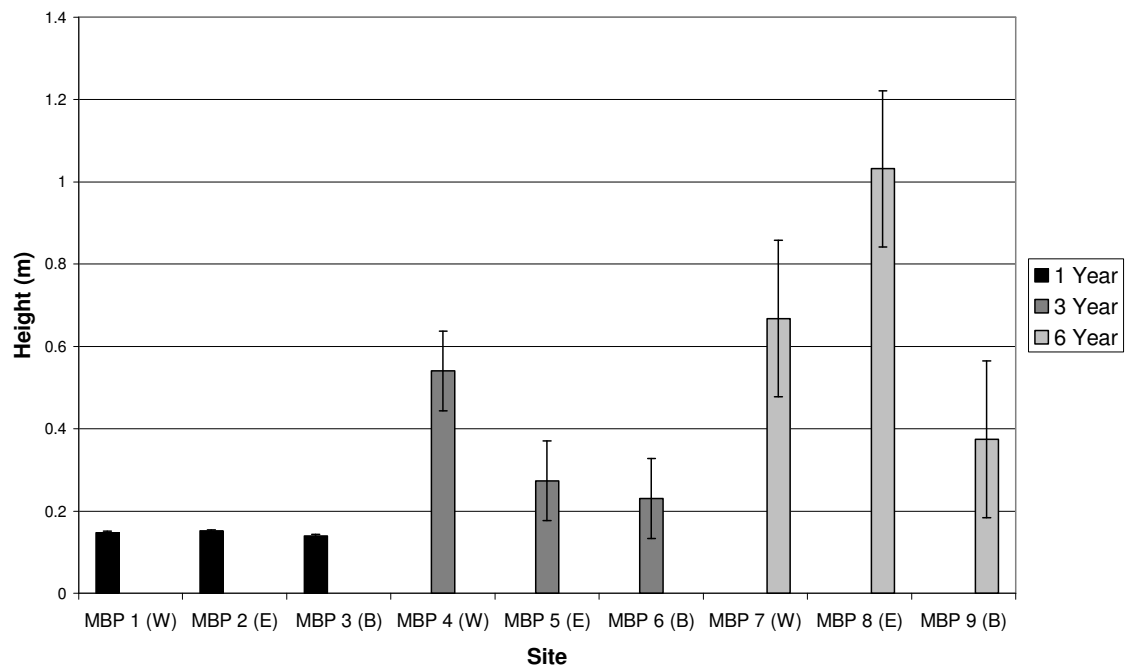


Figure 4.5.14 Average woody height (Height; m (\pm SE)) for different catenal positions and fire exclusion periods within sites north of the Manzengwenya Offices, South Africa.

Integrating the understanding gained from the woody density data above in Figure 4.5.1, Section 4.5.1, density is greatest for bottom sites and substantially lower for west facing sites. However although density is greatest in bottom facing sites, woody plant height is consistently the lowest for these sites. Again, as with density there is an overarching influence of fire exclusion on woody plant height but within this effect is a less constant and more variable influence of catenal position that is important to highlight. With no environmental variables having been collected to explain this variation and dataset it is not possible to determine other factors contributing to this trend in woody

plant height and density, however some proposals to explain these trends have been attempted which will require further evaluating.

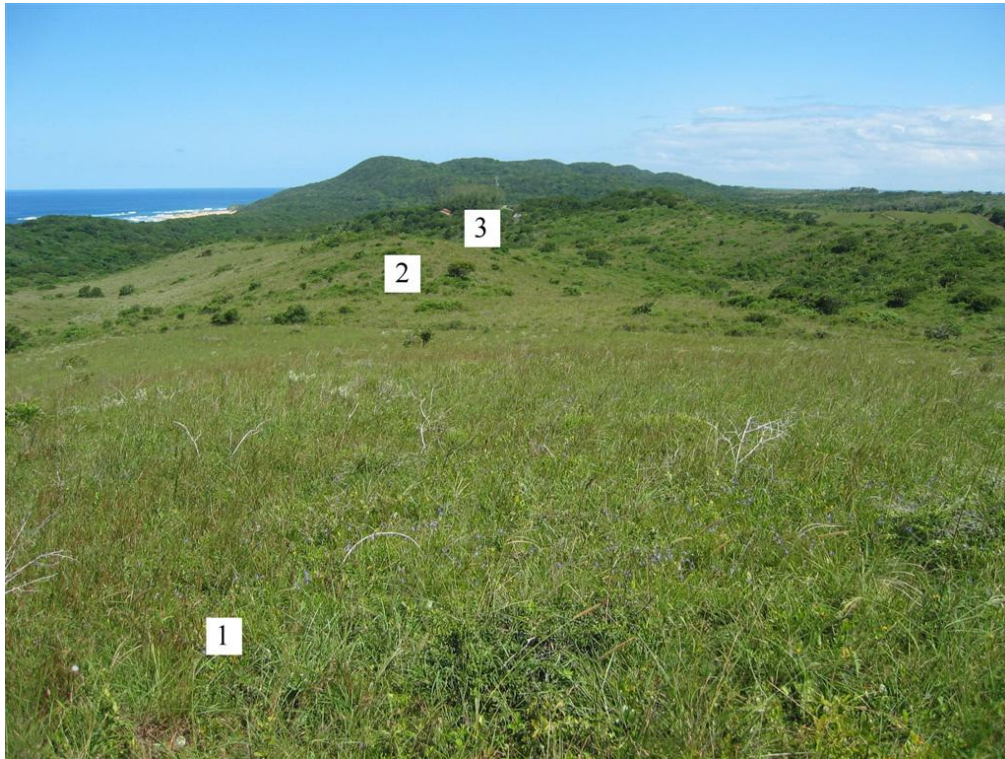


Plate 4.5.1 View south towards the Manzengwenya Offices (left of number 3). Note the appreciable difference in vegetation structure between annual burning (1), three year fire exclusion (2), and six year fire exclusion (3). Also important to note is the dwarf woody species (bottom right) and bare white branches of *D. cinerea* seen protruding out within the grassland.

Separating out average height for selected woody species according to fire exclusion period and catenal position further illustrates differences in the response of woody plant height (Figure 4.5.15). Woody species have been ordered according to their local mean which compares average heights for those sites in which present. Therefore, the first species, *Diospyros villosum*, is consistently short and *P. reclinata* is on average the taller species. Woody species were selected based on frequency and cover a spread of average heights from short to tall. From Figure 4.5.15 it is clear that sites with a one year fire exclusion period have short woody individuals and an increase in fire exclusion results in

an increase in average woody height for the majority of the woody species. This difference has already been adequately highlighted however previous illustrations have not covered differences for specific species across fire exclusion and catenal position. This enables illumination of an aspect of woody height not previously exposed due to the coarse scale of investigation.

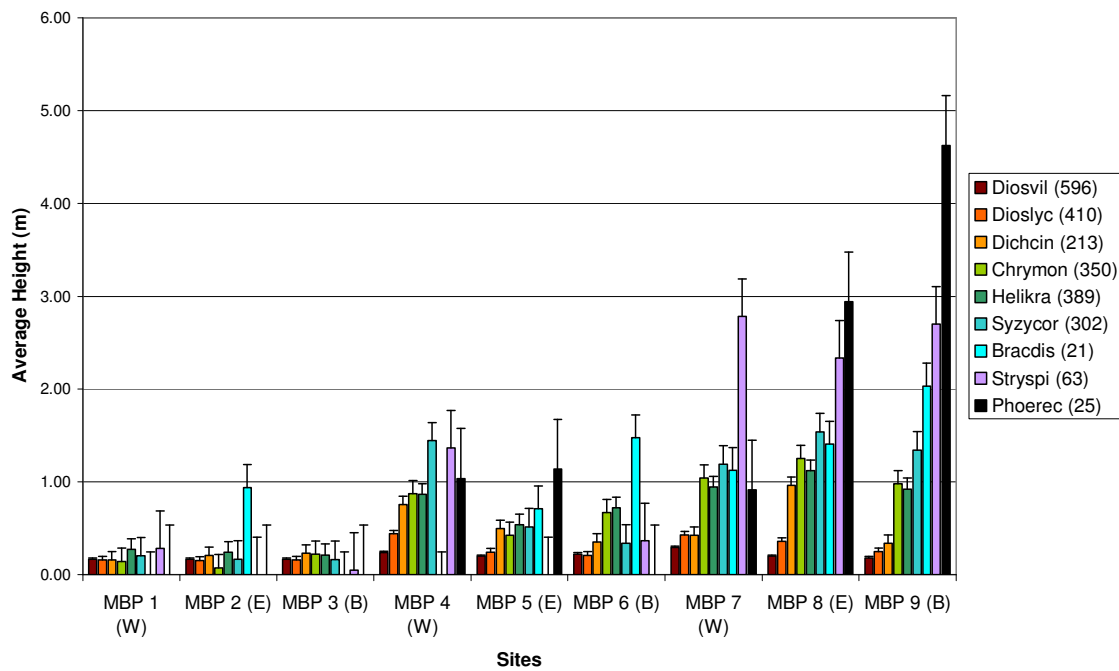


Figure 4.5.15 Average height (m (\pm SE)) of selected woody species for sites north of the Manzengwenya Offices, South Africa. Numbers following the label in the key indicate total individuals for that species used in calculating average height. Refer to Appendix 2 for an explanation of species acronym used.

Of the nine selected woody species *Brachylaena discolor*, *P. reclinata*, and *S. spinosa* are the only species not present for all fire exclusion periods and catenal positions. These three species are particularly absent for a one year fire exclusion period. *Brachylaena discolor* is only present for east facing sites and of these selected species was the tallest for a one fire exclusion period. *Phoenix reclinata* was absent from these sites and is ranked ninth in average height indicating its importance for sites with an increased fire exclusion period. This species is recorded as having the greatest average height for sites with a six year fire exclusion period where maximum average height is achieved for

bottom sites. *Strychnos spinosa* and *Brachylaena discolor* responded similarly and have their greatest average height for a six year fire exclusion period. It is important to note that variation is greater for these taller species due to their representation throughout the fire exclusion periods and are therefore present as both short and tall individuals.

Plate 4.5.2 One year (top left), three year (top right), and six year (bottom) fire exclusion sites north of Manzengwenya Offices. Note the difference in structure and increase in taller woody species.



A completely different response is evident for the species *Diospyros villosum*, *D. lycioides*, and *D. cinerea*. These three woody species are present for all three fire exclusion periods and catenal positions however there is very little difference in average height and this is indicated by the small size in variation. These three species therefore remain present and their average height relatively unchanged regardless of catenal position and fire exclusion period. The number of individuals used to calculate the

average heights have been included with the species acronym in the key. These figures relate back to density where it is clear that the shorter woody species are more prolific compared with the taller species. Interestingly the species, *S. cordatum* is numerous and present for all fire exclusion periods despite its classification as a medium sized tree (up to 15m) (Palgrave 2000) therefore displaying a fire tolerant strategy.

The woody species *C. monilifera*, *H. kraussii*, and *S. cordatum* present an intermediate type category where average height increases with increasing fire exclusion period but not as noticeably as the first three species discussed above. This is expected of the first two species due to biological constraints on maximum height achievable but *S. cordatum* is a woody species capable of far greater heights. It is possible that growth rates for this species are slower when compared with a soft wooded species such as *P. reclinata* and therefore difference in heights are due to a time lag where eventually these taller woody species should ultimately overtop the others. It is unclear what the competitive effects of these tall faster growing species are on the slower hard wooded species and whether these species therefore preclude the ability for these slower species to persist into the upper canopy.

The differing response of woody height and density may be due in part to increased moisture availability or increased soil fertility as finer colloidal material collects on lower sections of the catena. This increased soil fertility possibly creates a competitive advantage for bottom sites where compared with other catenal positions shorter, fire tolerant woody species establish and grow rapidly thus effectively ensuring sufficient resources such as light are attained. Due to the comparatively greater density for these woody species in bottom sites, the taller, slower growing woody species are excluded (density dependant effects). It is not possible to determine from these data how final this exclusion is however for the other two catenal positions taller woody species are able to establish and grow through to various heights. These taller species possibly reduce the establishment of other woody species beneath the canopy and thereby reduce overall plant density. Additional sampling will be needed to confirm this hypothesis.

4.5.4.1.Height classes

As discussed in section 4.5.2.3 above, woody density figures were somewhat exaggerated presenting an apparent fault with the dataset. However, sampling methodology involved the adaptation of the PCQ method and did not exclude woody species based on a minimum height. Juvenile woody species within the grass sward were included and in many instances did not have any substantial woodiness to their growth. Therefore, for these individuals height was not recorded. In other words a number of woody species have been included into a zero height class. Nine height classes were created to separate out all woody species measured for the three fire exclusion periods (Figure 4.5.16).

Immediately noticeable is the asymmetrical distribution of woody plants being skewed positively. The majority of the woody plants sampled across the three fire exclusion periods had heights of less than one meter. Above this height class only two woody individuals were recorded within a one year fire exclusion period, 23 for three year fire exclusion, and 131 for six year fire exclusion. If sampling methodology had introduced a minimum height of one meter for inclusion of a woody plant the average distance for the calculation of density would have been derived from these few individuals. Distances to these individuals varied but were generally far greater than for shorter, denser individuals and thus density would have been greatly reduced.

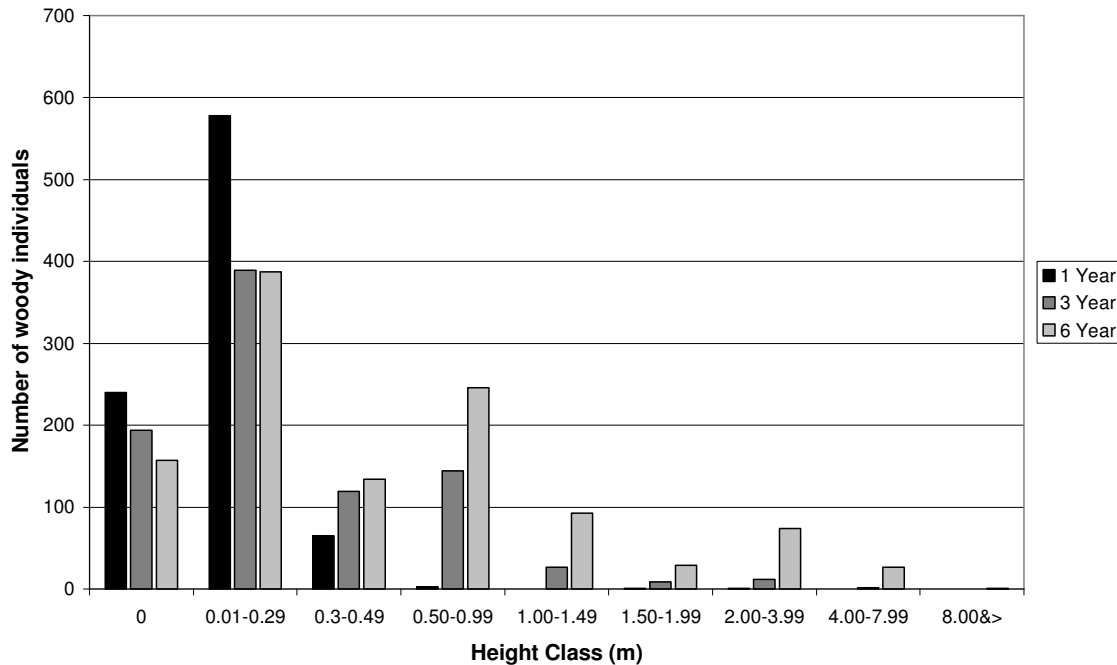


Figure 4.5.16 Total number of woody individuals per height class for three fire exclusion periods within sites north of the Manzengwenya Offices, South Africa.

Another noticeable influence of this particular sampling strategy is the apparent lack of tall woody species from the six year fire exclusion sites. Although not clear from Plate 4.5.1 this fire exclusion period appeared to be dominated by taller woody species however due to the density of the shorter woody species within the sites, these taller individuals were rarely encountered. Therefore, an adjustment was made to previous sampling methodology and a second category was introduced to better represent these individuals by introducing a minimum qualifying height for inclusion of one meter.

From Figure 4.5.16 the second height class (0.01-0.29m) had the greatest number of woody individuals across all three fire exclusion periods. Sites with one year fire exclusion were dominated by individuals within this height class. Subsequent increases to height class resulted in a rapid decline of the number of individuals present. Essentially these sites were occupied by predominantly short woody species.

Excluding fire for a further two years (three year fire exclusion) has resulted in a reduction to this second height class and an increase (shift) in the number of individuals for all bigger height classes. This is particularly evident for the 0.50 to 0.99m height class

which spikes again (144 individuals) before tailing off. Excluding fire again for another two years (six year fire exclusion) results in a substantial increase across the taller height classes particularly between 2.00 and 8.99m. Interestingly though, the second height class representing short individuals (less than 30cm) is still represented and is equivalent to the three year fire exclusion period. Therefore, these shorter woody species are persistent within the coastal dune vegetation despite length of fire exclusion and possible changes to resources such as light. For sites burnt regularly (one year fire exclusion) these shorter woody species dominate the vegetation in comparison to three and six year fire exclusion. However, from the third height class there is a switch where numbers are greater for a six year fire exclusion period. Therefore, woody height is reduced for one year fire exclusion and increases substantially with increasing fire exclusion.

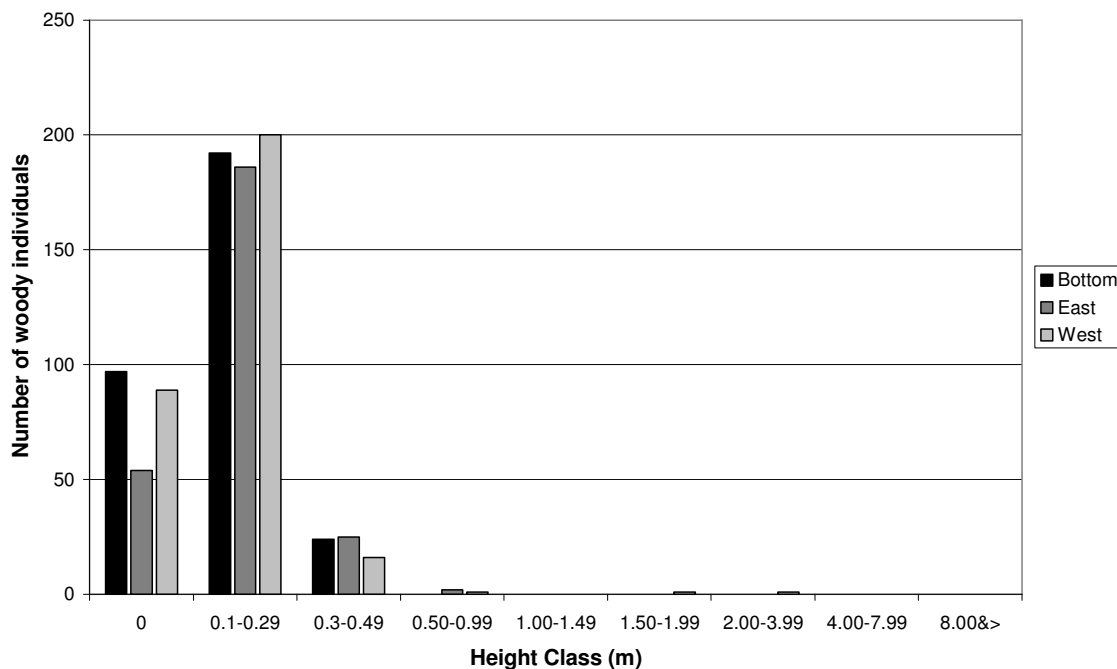


Figure 4.5.17 Total number of woody individuals per height class for three catenal positions of a one year fire exclusion period within sites north of the Manzengwenya Offices, South Africa.

Separating the height classes into the three fire exclusion periods and examining this change in height across the three catenal positions reveals further differences in the response of woody height. Sites with a fire exclusion period of one year are very clearly

dominated by short woody individuals and there was little variation in height between catenal positions within sites (Figure 4.5.17).

This consistency is not evident for the three year fire exclusion period (Figure 4.5.18) where some variation in woody height distribution exists. For example, west facing sites had fewer short woody individuals compared with bottom and east facing sites but had consistently more individuals in the larger height classes. Therefore, the response of woody plants in terms of increased height was more pronounced for west facing sites. Bottom sites had fewer taller woody individuals in comparison to east and west facing sites with no representation in classes greater than two meters.

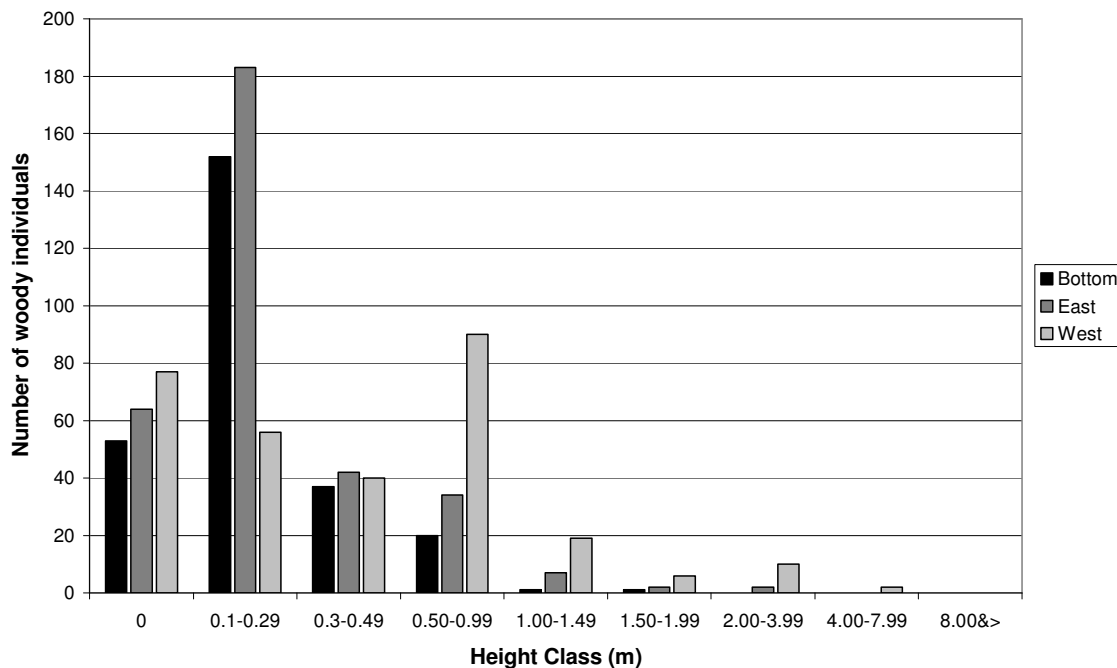


Figure 4.5.18 Total number of woody individuals per height class for three catenal positions of a three year fire exclusion period within sites north of the Manzengwenya Offices, South Africa.

This pattern of increased variation within catenal position with an increase in fire exclusion was furthered for the six year fire exclusion (Figure 4.5.19). Bottom sites were again not well represented in the taller height classes however substantially more plants were recorded with heights greater than half a meter in comparison to the three year fire exclusion sites. West facing sites had better representation for shorter height classes when

compared with east facing sites. East facing sites had a large number of woody plants greater than two meters and therefore differed structurally compared with the other two catenal positions. Note the persistence of the short individuals for this fire exclusion period which are still greater in number than for any other height class. Interestingly, these numbers are decreased for east facing sites which have a greater proportion of taller individuals indicating a possible correlation.

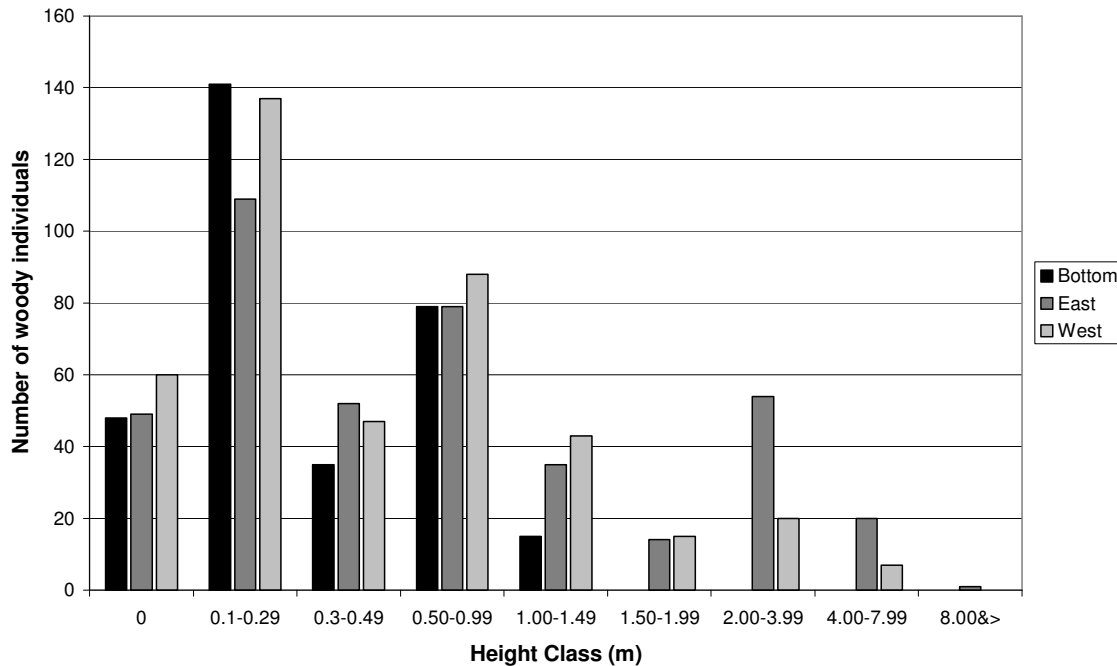


Figure 4.5.19 Total number of woody individuals per height class for three catenal positions of a six year fire exclusion period within sites north of the Manzengwenya Offices, South Africa.

4.5.5. Unconstrained linear ordination

To further explore and highlight trends in species response to fire exclusion and catenal position within sites north of the Manzengwenya Offices, South Africa average point-to-plant distance (P2P) was used to ordinate sites based on species composition. This measure was chosen over average density as this is a more direct measure of difference between sites and not susceptible to error in the calculation to convert to density. Additionally, all abundant species were included in the ordinating of sites (rare species were excluded based on frequency) thereby allowing a more detailed

investigation of the effect of fire exclusion and catenal position on composition. A Detrended Correspondence Analysis (DCA), an unconstrained ordination (method of gradient analysis) (Lepš & Šmilauer 2003) was conducted to evaluate lengths of gradient (Table 4.5). Due to the short lengths of gradient (less than three standard deviations) a linear, indirect ordination method was chosen, namely Principle Components Analysis (PCA) (Lepš & Šmilauer 2003) and the option of centering by species was selected to examine the pattern of the rarer species within the dataset.

Table 4.5 Summary of the Detrended Correspondence Analysis for the point-to-plant distances of species for sites north of the Manzengwenya Offices, South Africa

Axes	1	2	3	4
Eigenvalues	0.210	0.056	0.006	0.000
Lengths of gradient	1.322	1.071	0.825	0.915
Cumulative percentage variance of species data	31.6	40.0	40.9	40.9

The P2P distances for species ordinated using a PCA are presented in Figure 4.5.20. Immediately obvious is the ordination of sites where those with a one year fire exclusion period are located in close proximity to one another and sites for the other two fire exclusion periods are more variable in their distribution. The first axis describes the most amount of variation (approximately 34 %) and broadly separates sites with a one year fire exclusion from those with a three and six year fire exclusion. This separation includes differences in the number of species where there are far greater numbers of species to the right of the axis. The second axis separates one and three year fire exclusion sites from the six year fire exclusion sites. Two sites (MBP 6 B and MBP 9 B) have been ordinated close to one another, apart from the other sites and therefore are more similar compared with sites from their respective fire exclusion periods. These two sites are both bottom sites from a three (MBP 6 B) and six year (MBP 9 B) fire exclusion period. There is an above average abundance of the woody species *Vernonia natalensis* and the herbaceous species *C. natalensis* for these bottom sites. Note that the woody species *H. kraussii* has less than average abundance for these sites preferring higher lying east and west facing sites with a three year fire exclusion.

A one year fire exclusion period has resulted in uniformity of species composition indicated by proximity of these sites within the ordination diagram. These sites have an

above average abundance of the grass species *T. triandra* and herbaceous species *Stylosanthes fruticosa*. Grass species such as *D. eriantha*, *S. sphacelata*, and *U. agropyroides* and the woody species *P. reclinata* are some examples of species with less than average abundance for these sites. This separation is strongly correlated with the first axis and therefore represents the greatest variation. This can be attributed to fire exclusion period where these species decrease with a decrease in fire exclusion and therefore are not commonly associated with regular burning.

Three year fire exclusion resulted in an above average abundance for a number of woody species for east and west facing sites. The numbers of species increasing in abundance for these two sites are more numerous in comparison with sites of a one year fire exclusion indicated by the number of arrows spreading in that direction. The woody species *H. kraussii*, *S. spinosa*, and *S. cordatum* have increased in abundance for these two sites indicating a positive response to increased fire exclusion. Other woody species with greater than average abundance for these sites are *D. lycioides*, *C. monilifera*, and *D. cinerea* but are not restricted to these two sites. *Imperata cylindrica* and *D. amplexans* are the main grass species associated with this fire exclusion period however it is clear that an increase in fire exclusion favours woody species having greatly increased in number and abundance with fire exclusion.

For this fire exclusion period (three years) west sites (MBP 4 W) have a greater abundance of these species when compared with east facing sites (MBP 5 E) the greatest of which is the grass species *I. cylindrical*. The bottom sites (MBP 6 B) however have a less than average abundance of all these species that are associated with west and east sites. The herbaceous species *C. natalensis*, *Eriosema lucipetum* and the woody species *V. natalensis* and *E. albanensis* are greater in abundance for these sites.

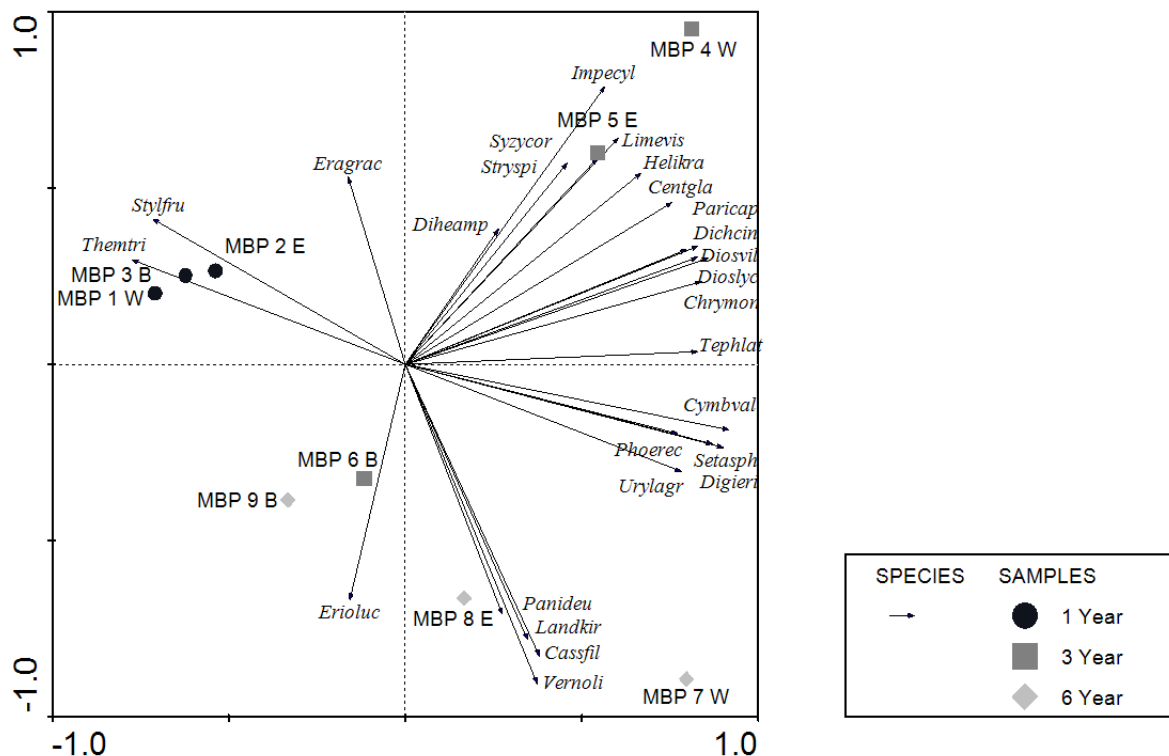


Figure 4.5.20 Plot of selected species point-to-plant distances along the first two axes of a Principal Components Analysis (PCA) for sites north of the Manzenzwanya Offices, South Africa. Eigenvalues for axis one and two are 0.336 and 0.242 respectively, representing 57.8 of the cumulative percentage variance accounted for. Refer to Appendix 2 for an explanation of the species acronyms. Site acronym component W, E, and B refers to catenal position west, east, and bottom, respectively. Species with an abundance less than 20 % have been excluded.

This difference between bottom sites and west and east sites was reiterated for sites with six year fire exclusion. Bottom sites (MBP 9 B) were separated from east (MBP 8 E) and west sites (MBP 7 W) having more species in common with bottom sites from the three year fire exclusion period (MBP 6 B) discussed in the previous paragraph. Excluding fire from the system for six years has resulted in a greater amount of variability between catenal positions compared with the previous fire exclusion periods indicated by increasing distance between sites. Additionally, a number of different grass,

herbaceous, and woody species are associated with this fire exclusion period. *K. floribunda* and *Rhoicissus digitata* are present in greater than average abundance for these sites indicating a preference for areas burnt less frequently. *Cassytha filiformis* and *Landolphia kirkii* are two herbaceous species with a strong positive correlation to these woody species the latter being a woody climber. *Panicum deustum* and *C. validus* are two grass species with increased abundance for these sites. *Panicum deustum* is a shade tolerant species but susceptible to regular burning.

The progressive exclusion of fire has resulted in a change in species composition from *Themeda* dominated grassland through to a mixed shrubland and juvenile dune forest within six years. Species composition became increasingly variable across catenal position with this variation becoming greater with increased fire exclusion. Fire exclusion had the greatest effect of driving this change in composition however it is important to note that this influence became less of a driving factor with increased fire exclusion. This is evident for bottom sites which increased in similarity. Integrating this with the understanding gained from density and woody plant height reveals some interesting and consistent relationships. From Figure 4.5.2 in sections 4.5.1 above plant densities were greater for bottom sites for all three physiognomic categories and from Figure 4.5.14 in sections 4.5.4 above woody plant heights were least for these bottom sites. Bottom sites for a one year fire exclusion period are similar in composition when compared with east and west facing sites however the bottom sites for a three and six year fire exclusion are similar to one another but different from sites from their respective fire exclusion periods. Certainly this difference is being expressed with plant density and woody height and this is due to a less than average abundance of woody species for these bottom sites. This response is not completely independent of fire exclusion period. Another important point is the differences in woody height for east and west facing sites of a three and six year fire exclusion period may be due to a different set of woody species within these sites. It would appear that certain species establish and persist within the dune communities regardless of fire exclusion period or catenal position and other species display traits either positively or negatively correlated to exclusion period and/or catenal position.

4.5.6. Richness, evenness, and diversity

Differences in fire exclusion period and catenal position can be explored further by examining biological diversity. Diversity can be further divided into two components, richness and evenness. Richness refers to the number of species present whereas evenness is a measure of the relative abundance for the different species for this richness estimate (Wolda 1981).

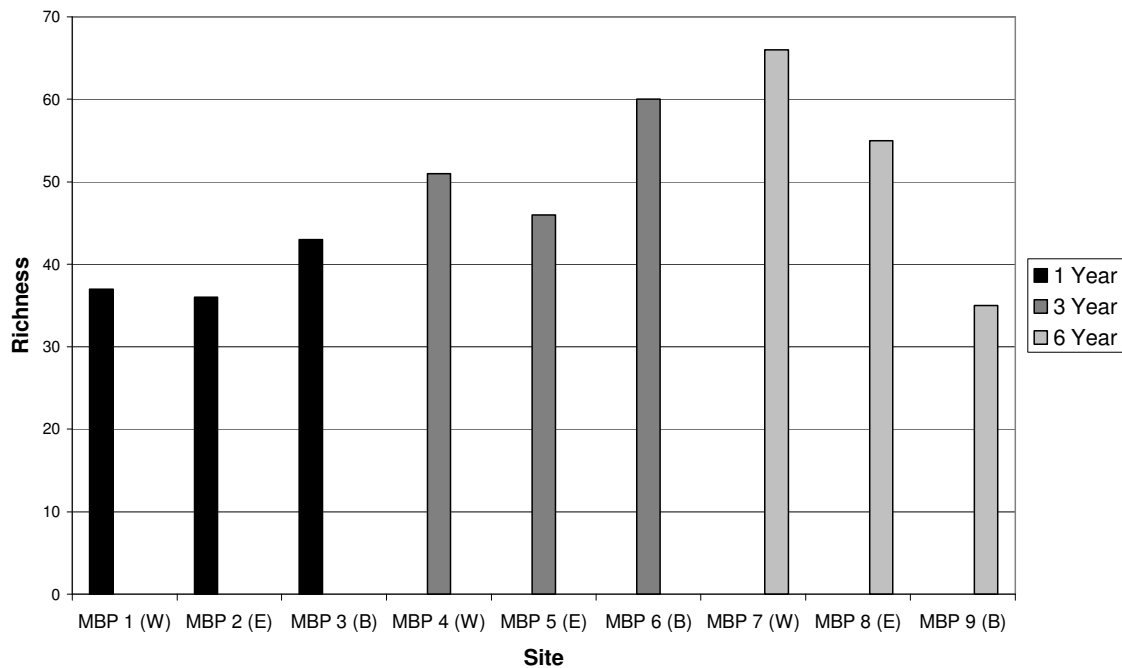


Figure 4.5.21 Richness indices for different catenal positions and fire exclusion periods for sites north of the Manzengwenya Offices, South Africa.

Richness varied both for fire exclusion and catenal position where an increase in fire exclusion period resulted in a general increase in richness. On average richness was greater for sites with three year fire exclusion but at a finer scale was greatest within west facing sites for a fire exclusion of six years. Except for the six year fire exclusion sites richness was greater for bottom sites within a one and three year fire exclusion period. A number of factors interact to affect community richness (Keeley *et al.* 2005) and possibly the increased density for these bottom sites is responsible for this as there would appear to be a positive correlation between the two. Richness for east and west facing sites with

three and six year fire exclusion differs marginally. However richness was greater on average for the three year fire exclusion. For a six year fire exclusion period this trend was reversed where richness was greater for west facing sites and decreased for bottom sites.

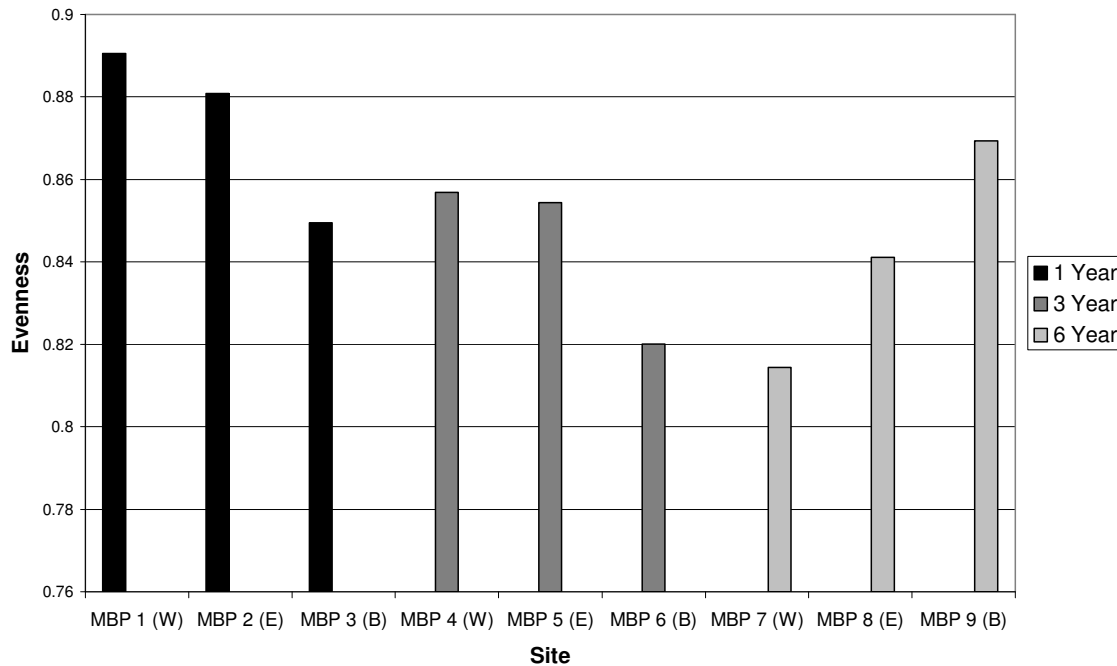


Figure 4.5.22 Species evenness for different catenal positions and fire exclusion periods for sites north of the Manzengwenya Offices, South Africa.

Evenness reveals an interesting difference between fire exclusion and catenal position (Figure 4.5.22). Sites with a one year fire exclusion period have a greater evenness compared to the other two fire exclusion periods. In other words the abundance for the species present is more evenly distributed. Compared with a three year fire exclusion period the one year fire exclusion sites are more even however evenness decreases from east to bottom sites. Therefore, although richness is greatest for bottom sites, evenness is the least. As with richness this trend is reversed for sites with a six year fire exclusion where richness is greater for bottom sites and decreases moving westwards up and over the catena. Note the difference in evenness for the bottom sites of a three and six year fire exclusion period which were ordinated in close proximity to one another (Figure 4.5.20). This indicates that although richness is greater for bottom sites with a three year fire

exclusion period there are fewer abundant species present. Bottom sites for a six year fire exclusion period however have fewer species but are more equally abundant.

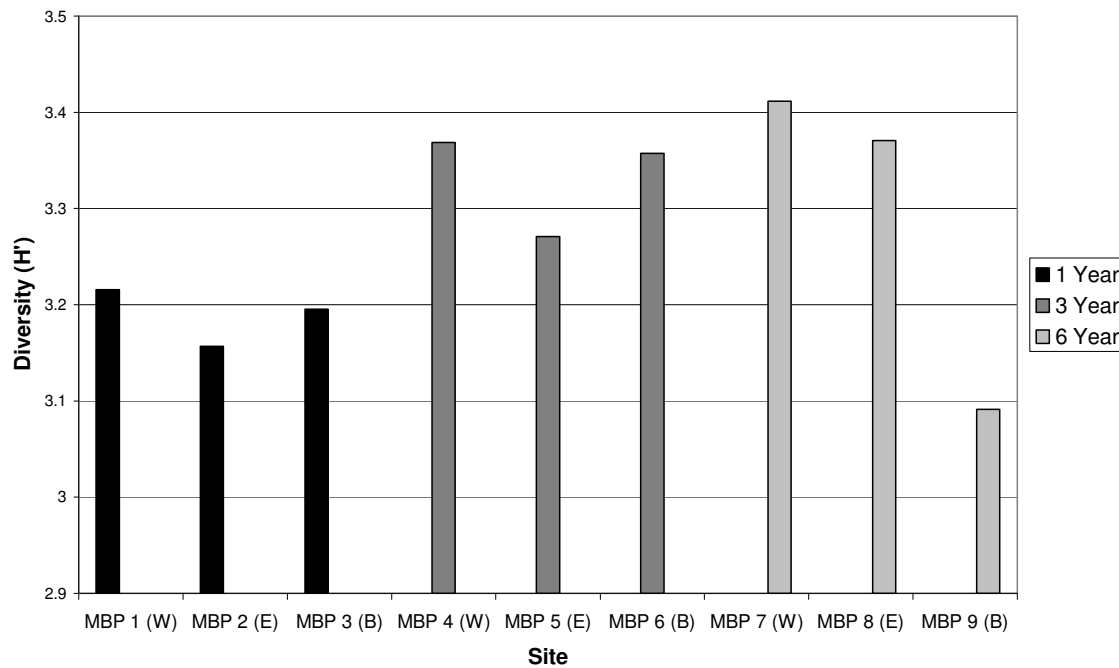


Figure 4.5.23 Shannon's diversity index (H') for different catenal positions and fire exclusion periods for sites north of the Manzengwenya Offices, South Africa.

Richness and evenness are then incorporated into the calculation of diversity. The pattern of response for diversity within these sites is very similar when compared with richness (Figure 4.5.23). Subtle but important differences exist where diversity is calculated as greater for west facing sites in a one year fire exclusion period even though richness was greater for bottom sites. This is due to the influence of evenness when calculating diversity. Generally, diversity was greatest for sites with six year fire exclusion and decreased with a decrease in fire exclusion. Additionally, diversity was consistently greater for west facing sites and east facing sites had the lowest diversity.

4.5.7. *An index of veld condition*

The ecological index method (EIM) (Vorster 1999) was selected to calculate a veld condition index (VCI) for sites north of the Manzengwenya Offices (refer to section 4.4.1 and Appendix 9). This index was calculated to give an indication of the change to

condition with a change in fire exclusion period. Comparisons using this method should be limited to between these plots as it is possible that the PCQ method may have over emphasized presence for the grass species as grass had to be located and sampled in each quarter. This methodology is however consistent across fire exclusion period and therefore permits an accurate comparison of trends.

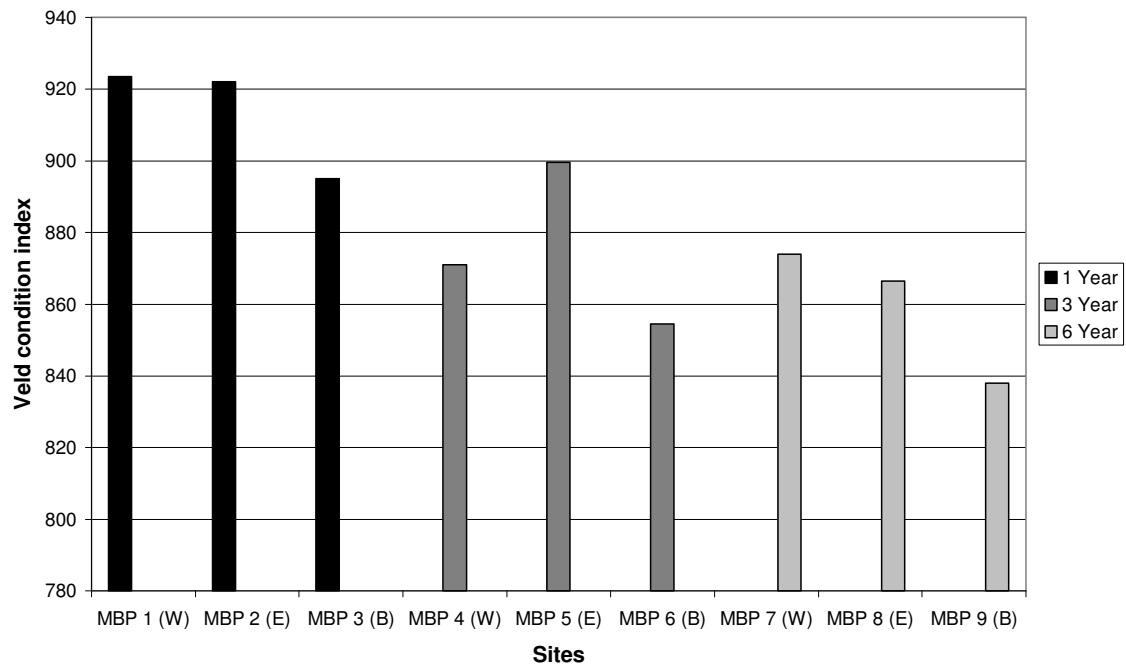


Figure 4.5.24 Veld condition index (VCI) calculated using the ecological index method (EIM) for sites north of the Manzengwenya Offices, South Africa. A full dataset is contained in Appendix 9 for the calculation of the VCI. Note the y-axis scale is not at zero.

The various VCI are presented in Figure 4.5.24 where an interesting response is evident. Veld condition has decreased with an increase in fire exclusion period in an almost linear fashion. There is some variability for sites with a three year fire exclusion period where condition is scored lower than the observed trend for the dataset. Condition was greatest for west facing sites and attained the lowest condition for bottom sites regardless of fire exclusion period. These differences in condition for the three catenal positions are important to note.

From these data it is clear that the fire exclusion period is the overarching influence on veld condition. The reduction in fire exclusion period results in an increase in cover and the grass species *T. triandra*, therefore resulting in high index scores. Within this influence of fire exclusion period on VCI is an underarching trend with catenal position. Using inference from these data the higher lying, west facing sites should receive more attention/weighting when determining grazing capacity whereas the lower lying areas are accompanied by a reduction in condition.

4.5.8. Non-metric Multi Dimensional Scaling

Non-metric Multidimensional Scaling (NMDS) is a multivariate ordination technique which configures samples such that distances between samples best represent the dissimilarities of their species composition (Lepš & Šmilauer 2003). This is based on 'stress' minimisation where stress is a measure of fit between the distances of sites within the ordination and original dissimilarity data (Kelly & Basford 2000). The lower this stress measure the more accurate the representation of the ordination. A principal components analysis was used to rotate these data such that the first axis represented the greatest amount of variation. Abundance data was used for the calculation of the Bray-Curtis similarity indices for the ordination of sites (e.g. Greig-Smith 1983). This is presented in Figure 4.5.25 and the species information used for the calculations presented in Figure 4.5.26 which have been taken from a separate principal components analysis.

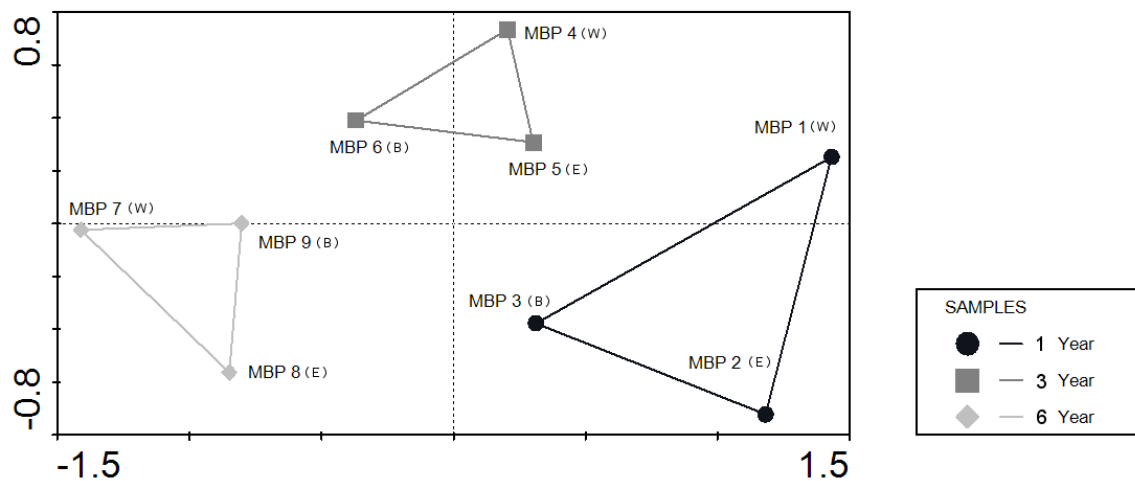


Figure 4.5.25 Two-dimensional non-metric multidimensional scaling (NMDS) ordination (rotated by principal components analysis) of Bray-Curtis distances of samples from three fire exclusion periods, each with three catenal positions (W-west, E-east, & B-bottom) using composition based on abundances. Stress= 0.03279.

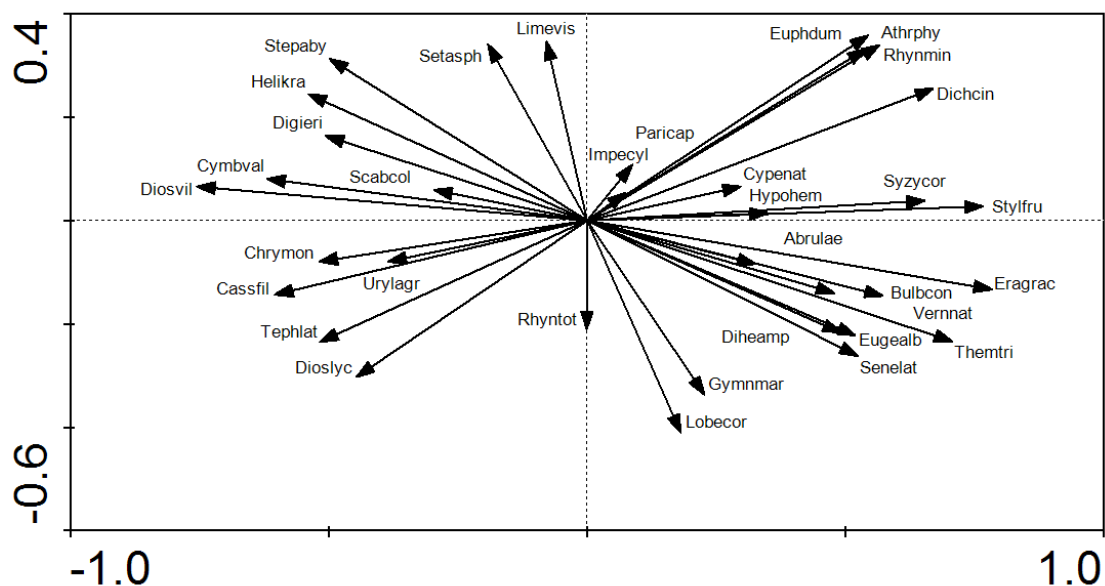


Figure 4.5.26 Scatter plot of the abundant species from a principal components analysis for sites north of the Manzengwenya Offices, South Africa. Refer to Appendix 2 for an explanation of the acronyms used.

The spatial structure of the underlying species composition has been adequately represented by the NMDS ordination (minimal stress achieved) and should be interpreted in conjunction with the species scatter plot (Figure 4.5.26). This ordination (Figure 4.5.25) has separated sites based on variation and in so doing has divided sites with a one and three year fire exclusion period from sites with six year fire exclusion. Therefore, the difference between six year fire exclusion and the other two fire exclusions is contributing to the main source of variation in species composition. Immediately noticeable is the distinct grouping of sites by fire exclusion period. Sites located within close proximity to one another indicate similarity in terms of species composition. Therefore, the three fire exclusion periods have resulted in a unique composition where differences are greater between fire exclusion periods than within. Some variation exists between the three catenal positions for each fire exclusion period and these differences

conform to some of the previous understandings gained from the density (section 4.5.1) and height data (section 4.5.4) collected using a modified PCQ method. Sites for a three and six year fire exclusion period are closer to one another compared with sites for a one year fire exclusion indicating a reduction in variation with an increase in fire exclusion.

Comparing Figure 4.5.25 with the species scatter plot (Figure 4.5.26) *T. triandra*, *D. amplexens*, and *Lobelia coronopifolia* are some of the species associated with a one year fire exclusion period. Consistent with the PCQ data is the above average abundance of the woody species *S. cordatum* and *D. cinerea* for this fire exclusion period. This unusual response indicates an affinity to regular burning that was not expected.

Two species are abundant for sites with a three year fire exclusion period. This does not indicate a fewer number of species present for these sites but merely a smaller number of species are present in these sites with a greater than average abundance. These species were the herbaceous species *Limeum viscosum* and the grass species *S. sphacelata*.

The number of species with an above average abundance increases again for sites with a six year fire exclusion being categorized by an increased number of woody species. *H. kraussii*, *Diospyros villosum*, and *D. lycioides* are examples of woody species increased in abundance for these sites. *Cymbopogon validus* and *Cassythia filiformis* are non-woody species increasing in abundance with an increase in fire exclusion period.

Table 4.6 Bray-Curtis similarity matrix for species composition based on abundance for sites north of the Manzengwenya Offices, South Africa

	MBP 1	MBP 2	MBP 3	MBP 4	MBP 5	MBP 6	MBP 7	MBP 8	MBP 9
MBP 1	0	0	0	0	0	0	0	0	0
MBP 2	59	0	0	0	0	0	0	0	0
MBP 3	55	58	0	0	0	0	0	0	0
MBP 4	55	49	57	0	0	0	0	0	0
MBP 5	56	55	62	76	0	0	0	0	0
MBP 6	47	47	60	67	71	0	0	0	0
MBP 7	37	35	49	51	51	58	0	0	0
MBP 8	39	48	54	53	53	60	64	0	0
MBP 9	44	45	58	54	57	64	65	68	0

Sites with the greatest dissimilarity are the two west facing sites for a one and six year fire exclusion period (MBP 1 and MBP 7, respectively). These two sites are 37 % similar

in terms of species abundance (Table 4.6) representing the smallest shared proportion compared with the other fire exclusion periods and catenal positions. From the orientation of the enclosed fire exclusion periods (indicated as triangles) bottom sites for the three fire exclusion periods are located in closer proximity to one another and are therefore more similar compared with the other catenal positions. Average similarity for these sites is approximately 60 %. Bottom sites for a three and six year fire exclusion are more similar (64 %) compared with bottom sites for one year fire exclusion.

4.5.9. *Burning and clipping trials*

The design methodology, motivation, and restrictions associated with the three burning and clipping trials established within the IWP is detailed within section 4.3 above. These three trials differ in their design due to previous management regimes and variation in location within the environment. However, all three trials suffer from an unbalanced treatment design due to variable numbers of *H. kraussii* plants within plots and fail to adequately replicate treatments due to limitations in size and location. These limitations therefore require the use of more rigorous methods of analysis because analysis of variance (ANOVA) for example is unable to handle unbalanced datasets (VSN International Ltd 2005). For unbalanced designs restricted maximum likelihood (Reml) is one of the more preferred methods of dispersion.

Table 4.7 Correlation matrix for *Helichrysum kraussii* attributes measured for trial one. Refer to Appendix 9 for an explanation of acronyms used. Figures highlighted in grey indicate correlation with the chosen response variable

Cvol2	1.000					
Dave2	0.941	1.000				
Dmax2	0.928	0.987	1.000			
Dmin2	0.926	0.983	0.942	1.000		
Ht2	0.795	0.793	0.801	0.759	1.000	
Stem2	0.580	0.597	0.575	0.603	0.504	1.000
	Cvol2	Dave2	Dmax2	Dmin2	Ht2	Stem2

Restricted maximum likelihood (Reml) (Patterson & Thompson 1971) improves on ordinary maximum likelihood estimation by taking into account the degrees of freedom used in estimating treatment effects where the average information method (AI) is the

standard optimisation method. Standard errors for fixed effects are therefore not underestimated and better inferences may be drawn from the data. This is particularly true for treatment effects in unbalanced designs with more than one source of error. (VSN International Ltd 2005). The Wald statistic is produced by Reml and corresponds to the treatment sum of squares divided by the stratum mean square. The statistic is asymptotically distributed as chi-square and is reliable where residual treatment degrees of freedom are large. (VSN International Ltd 2005).

The following three subsections discuss the output following the analysis used. A number of measurements were taken for each *H. kraussii* plant within these trials to broadly cover growth response to the various treatment effects. These treatment effects are not similar across trials, whereas, trial three is the only trial where fire has been applied albeit non-randomly. Maximum canopy diameter was selected due to consistency in use across the three trials and a strong positive correlation with the other attributes measured from trial one (Table 4.7). This was then adopted for the other two trials to ensure consistent comparisons between trials.

Additionally, to examine *H. kraussii* growth in response to treatments, initial maximum canopy diameter was subtracted from the final maximum canopy diameter leaving change for the period of the trials as the response variate.

4.5.9.1. Trial one: Manzengwenya clipping trial

Trial one was established in the edaphic grasslands north of the Manzengwenya Offices and was designed to investigate the effects of different historical fire exclusion periods (two levels), defoliation regimes (two levels), and catenal position (four levels) (refer to section 4.3.1 above for details on layout and design) on the growth of the woody shrub species *H. kraussii*.

Table 4.8 contains the chi square probabilities for the Wald test statistic of treatment effects on the change in maximum canopy diameter for *H. kraussii*. Generally, a change in maximum canopy diameter for *H. kraussii* was not associated with a particular catenal position, fire exclusion period, or defoliation. This remained unchanged for all treatment interactions. However clipping, which entailed removal of the surrounding biomass from each *H. kraussii* plant, approached significance at the ten percent level ($P < 0.10$) and this

will be considered further as a trend in the dataset. This treatment was applied in order to simulate grazing and gain an understanding of this effect on *H. kraussii*. Therefore, reducing the biomass around *H. kraussii* results in increased canopy growth most likely through reduced competition for light but this would need further assessment (refer to section 4.5.10 below).

Table 4.8 The Wald statistic (with a χ^2 distribution) for various factors included in the linear mixed model for trial one, Manzengwenya. Coefficients estimated by the restricted maximum likelihood method. Terms Aspect, Clip, and Flnt refer to four catenal positions, defoliation by clipping, and fire exclusion period, respectively

Fixed term	Wald statistic	d.f.	Wald/d.f.	chi pr
Aspect	0.21	3	0.07	0.976
Clip	3.30	1	3.30	0.069
Flnt	0.31	1	0.31	0.575
Aspect.Clip	0.40	3	0.13	0.941
Aspect.Flnt	0.17	3	0.06	0.982
Clip.Flnt	0.03	1	0.03	0.867
Aspect.Clip.Flnt	0.23	3	0.08	0.973

This response of *H. kraussii* to the three treatments has some important considerations for management. This woody shrub species responds with a similar rate of growth despite historical fire exclusion periods and its position along the catena. The growth rate increases where surrounding biomass is reduced and therefore areas grazed heavily or with a high stocking rate may promote growth and subsequent establishment of this species.

4.5.9.2. Trial two: Eastern Shores clipping trial

Trial two was established within the edaphic grasslands on the Eastern Shores of Lake St Lucia. This trial differs from trial one where plots are located on the same level and therefore there are no differences in catenal position. Additionally, plots were located within a clear felled pine plantation and the adjacent grassland. This presents different historical management regimes which is not similar to the fire exclusion periods for trial one. Refer to section 4.3.2 above for details on layout and design for this particular trial. This trial also focused on the response of *H. kraussii* to these treatments. Change in

maximum canopy diameter was kept as the response variate within the analysis for consistency. Table 4.9 contains the chi square probabilities for the Wald test statistic of treatment effects on the change in maximum canopy diameter for *H. kraussii* of trial two. Again, a change in maximum canopy diameter for *H. kraussii* was not associated with a particular management regime (VegT) or defoliation, consistent with trial one. Defoliation however did not have any affect on maximum canopy diameter as was evident for trial one. From this trial it is possible to establish that the growth of *H. kraussii* is unaffected by the previous management regime and in this case, defoliation. It is unclear what the reasons are for this differing response to defoliation is however, it is important to note that a non-significant response to management regime does not indicate difference in density or establishment due to disturbance but purely no difference in growth rate across treatments. Therefore, for the *H. kraussii* plants present growth rate (canopy spread) remains constant for the different treatments and this conforms with the results of trial one.

Table 4.9 The Wald statistic (with a χ^2 distribution) for various factors included in the linear mixed model for trial two, Eastern Shores. Coefficients estimated by the restricted maximum likelihood method. Terms Clip and VegT refer to defoliation by clipping and vegetation type, respectively

Fixed term	Wald statistic	d.f.	Wald/d.f.	chi pr
Clip	0.08	1	0.08	0.778
VegT	0.08	1	0.08	0.773
Clip.VegT	0.05	1	0.05	0.816

4.5.9.3. Trial three: Eastern Shores burning and clipping trial

Trial three was established within an unburnt block from trial two (this block had been excluded from analysis for trial two) and was designed to incorporate burning and defoliation to investigate treatment effects on *H. kraussii* growth. This trial therefore differs only marginally from trial two in terms of topography and is located within the grassland section adjacent the clear felled pine plantation. Section 4.3.3 above contains a more detailed discussion of trial layout and design. Note that burning has not been applied randomly as a treatment but considering the circumstances was the best alternative available to the study. Table 4.10 contains the chi square probabilities for the Wald test statistic of treatment effects on the change in maximum canopy diameter for *H. kraussii* of trial three. Defoliation and burning has not resulted in a significant change in maximum canopy diameter for *H. kraussii*, as has been established from trial one and two. Unexpectedly however, this growth rate has remained unaffected by different burning regimes. Therefore, although other characteristics of the plant are affected such as a reduction in height and total biomass, growth rate remains unaffected. Consistent with trial two is the non-significant response to defoliation of the surrounding plant biomass on maximum canopy growth.

Table 4.10 The Wald statistic (with a χ^2 distribution) for various factors included in the linear mixed model for trial three, Eastern Shores. Coefficients estimated by the restricted maximum likelihood method. The terms Clip and Fire refer to defoliation by clipping and burning, respectively

Fixed term	Wald statistic	d.f.	Wald/d.f.	chi pr
Clip	0.00	1	0.00	0.960
Fire	0.01	1	0.01	0.926
Clip.Fire	0.03	1	0.03	0.868

4.5.10. Light and soil moisture

In order to better account for variation present within trial one, soil moisture and a measure of light absorption (PAR) by *H. kraussii* were recorded. Refer to section 4.4.4.4 for an explanation of methodology used.

In order to examine which of the variables collected best account for variability within the dataset (including those already present within the trial), a linear multiple regression model was selected. For this purpose the forward stepwise selection approach was adopted to determine what the relevant variables of the dataset were. This procedure attempts to select those environmental variables which add significantly to the explanation of the observed variance in the response variable (Lepš & Šmilauer 2003). Therefore, a single predictor from the set of variables is added to the model individually to account for the greatest variation. Subsequent additions to the model continues with the remaining variables and selection terminates where its contribution no longer accounts for ‘enough’ variability. This procedure therefore presents a series of ‘best’ regression models for the data considering one, then two etc. independent variables (Zar 1999).

Note that the adoption of this procedure is not to derive the single most important equation describing maximum canopy diameter considering the available variables. Certainly inferring this type of equation would be limited in accuracy and usefulness (Mallows 1973) but rather it has been employed to examine some aspects of the data previously not achievable. As such no equation is formally presented or discussed but a comment on the output is however presented.

Table 4.11 Results from stepwise multiple regression analysis of the maximum canopy diameter of *H. kraussii* and several environmental related parameters obtained from the area north of the Manzengwenya Offices, South Africa. FExcl = fire exclusion period; Moisture = soil moisture percent; Ground and Canopy = PAR reading at ground and canopy level; Clip = defoliation by clipping; and Aspect = catenal position

	Adjusted R ²	Cp	d.f.	Moisture	Ground	FExcl	Clip	Aspect	Canopy
1 Term	25.82	21.96	2	-	-	0.026	-	-	-
2 Terms	47.36	12.38	3	-	-	0.011	0.022	-	-
3 Terms	59.15	9.36	6	-	-	0.007	0.015	0.145	-
4 Terms	71.51	6.39	7	-	0.046	0.002	0.007	0.05	-
5 Terms	71.73	7.4	8	0.331	0.035	0.003	0.008	0.17	-
6 Terms	69.42	9	9	0.282	0.104	0.006	0.017	0.249	0.549

In keeping with previous analyses of *H. kraussii*, maximum canopy diameter remained the response variable for examination. The variables considered by the forward stepwise procedure were those included by trial one (fire exclusion period, clipping, and catenal position) and the additional variables collected (PAR and soil moisture). Table 4.11 summarises the best subsets for each term added to the model. The full output is contained in Appendix 11 for further referral. Of interest is the order of selection as opposed to the probability of this selection.

Fire exclusion period was included first and therefore represents the variable accounting for the greatest amount of variation (an adjusted R² value of 25.82) when explaining maximum canopy diameter. This was followed by defoliation of the surrounding biomass (Clip) and catenal position (Aspect). Therefore, the three variables as part of the trial design were the first three variables selected by the procedure. The measure of photosynthetically active radiation (PAR) at ground level (Ground) was the first of the two light readings selected. Soil moisture was the fifth term added to the model and only accounted for a small increase in variability (0.22). Canopy (PAR reading for the canopy) was the sixth term considered but did not increase variability accounted for when considered with the five other terms in the model. Canopy was not included and five terms therefore presents the best predictor model for maximum canopy diameter of *H. kraussii*. The accumulated analysis of variance has been summarised in Table 4.12.

Table 4.12 Accumulated analysis of variance from stepwise multiple regression analysis of the maximum canopy diameter of *H. kraussii* and several environmental related parameters obtained from the area north of the Manzengwenya Offices, South Africa. FExcl = fire exclusion period; Moisture = soil moisture percent; Ground and Canopy = PAR reading at ground and canopy level; Clip = defoliation by clipping; and Aspect = catenal position

	d.f.	s.s.	m.s.	v.r.	F pr.
Fire Excl	1	0.28935	0.28935	16.32	0.004
Clip	1	0.22208	0.22208	12.53	0.008
Aspect	3	0.17297	0.05766	3.25	0.081
Ground	1	0.09533	0.09533	5.38	0.049
Moisture	1	0.01896	0.01896	1.07	0.331
Residual	8	0.14182	0.01773		
Total	15	0.94051	0.0627		

In terms of explaining the maximum canopy diameter of *H. kraussii* fire exclusion period accounted for a significant amount of the variation ($P < 0.01$). An increase in fire exclusion period resulted in both an increase in height and maximum canopy diameter of *H. kraussii* (Figure 4.5.27). Clipping of the surrounding biomass accounted for the second greatest portion of the variability where clipping resulted in an increased canopy diameter. This is consistent with the results from the Reml analysis for trial one (section 4.5.9.1 above). Individuals for *H. kraussii* had greater maximum canopies for top and west facing sites (Figure 4.5.28) and catenal position accounted for the third most variation in the dataset.

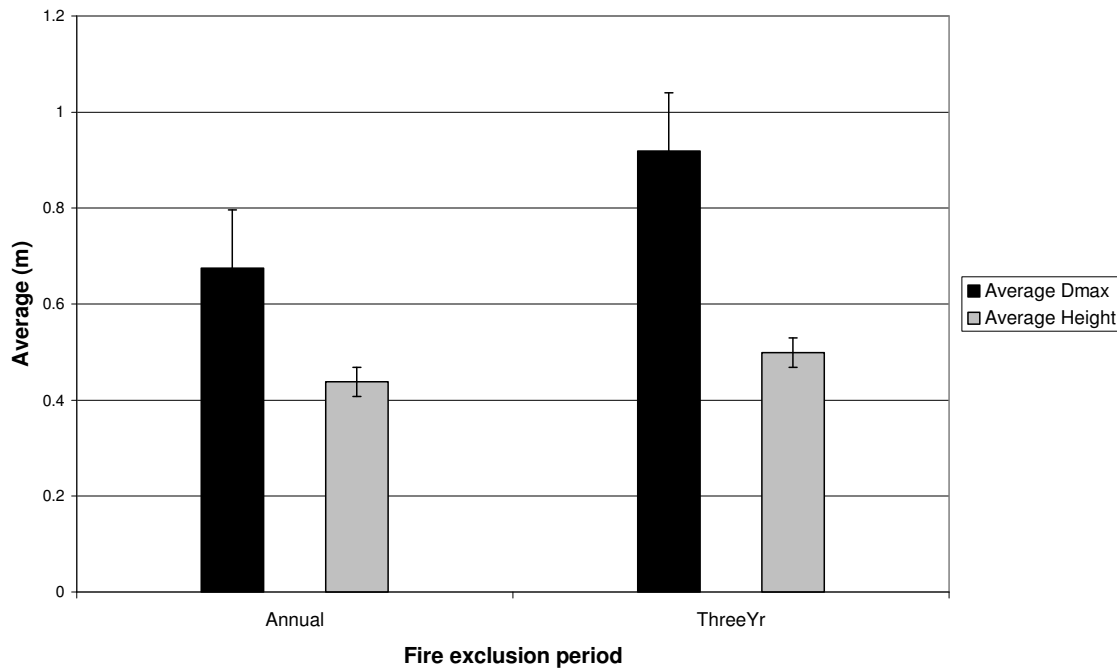


Figure 4.5.27 Average maximum canopy diameter (Dmax; m (\pm SE)) and height (Height; m (\pm SE)) of *Helichrysum kraussii* for two fire exclusion periods from trial one north of Manzengwenya Offices, South Africa.

Interestingly the environmental variables collected to help explain some of the variation within the data where all selected last and one of which were excluded from the final model. The PAR reading from within the upper canopy did not account for any additional variability. However, the reading taken at ground level did account for some variation in maximum canopy diameter. This variable was selected before moisture indicating a greater importance in terms of affecting response. It would therefore appear that although *H. kraussii* decreases in density with an increase in soil moisture (Owen 1992) maximum growth is unaffected.

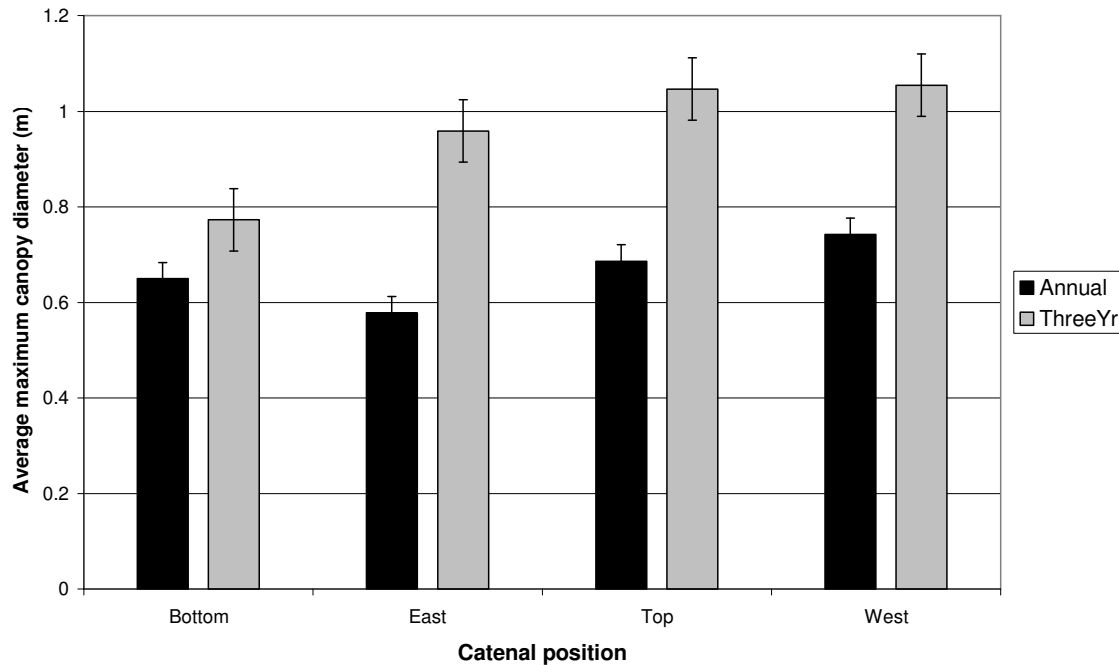


Figure 4.5.28 Average maximum canopy diameter (m (\pm SE)) for four catenal positions and separated further into fire exclusion period from trial one north of the Manzengwenya Offices, South Africa.

These data indicate the important influence of fire exclusion period and the interaction with clipping and catenal position on *H. kraussii* growth. This growth response represented by maximum canopy diameter is following wild fire where all plots were burnt. Therefore, the ability for *H. kraussii* to attain size is limited for areas burnt more frequently. This was not clear where the response variate is growth for a period of time as investigated for the analysis of trial one. It is important to highlight that although fire exclusion period has been used to indicate exclusion for one and three years, the annual burnt sites are in fact burnt annually and therefore represent frequency of burning. *Helichrysum kraussii* individuals were larger for areas higher up on the catena. This difference was in comparison with areas that are not periodically inundated and even still the ability for *H. kraussii* to attain size was limited for these lower lying areas. Areas of periodic inundation should greatly increase this difference as has been observed (Plate 4.6.3).

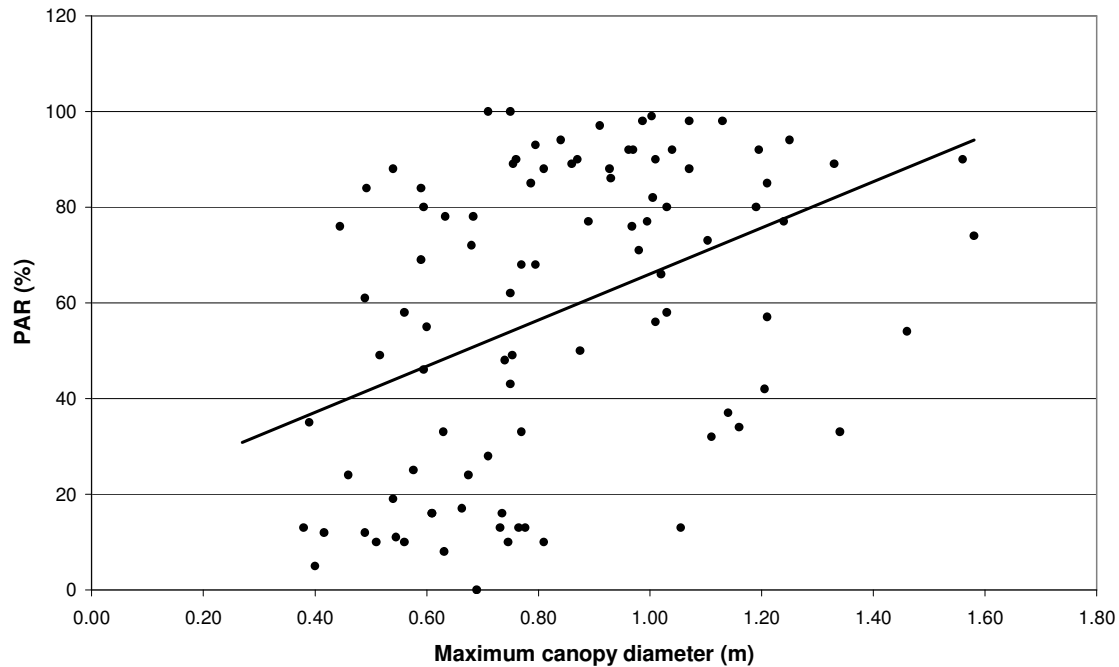


Figure 4.5.29 PAR taken at ground level (PAR; %) as a function of maximum canopy diameter (m) of *Helichrysum kraussii* for trial one across two fire exclusion periods. (The equation describing this function is $y = 48.254x + 17.809$ with an R^2 value of 0.1733 $P < 0.001$).

Although the canopy PAR reading was excluded from the model calculated by the forward stepwise selection procedure, the ground PAR reading was included on account of some explanation of the variation for maximum canopy diameter. When this trend was further explored with a simple linear regression (Figure 4.5.29) it was discovered that the percentage photosynthetically active radiation reaching the ground surface (transmission PAR) was greater for larger plants when compared with smaller ones as indicated by the positive slope to the regression equation. This is an interesting result and may account for the ability of other woody species to establish beneath *H. kraussii*. When the *H. kraussii* plant is still small it is able to secure space and dominate the undergrowth through effective competition for light. Therefore, as the plant grows the light availability changes where a release on the dominance permits light through to the soil surface thus initiating germination for some of the adapted woody species. These species in turn are permitted to grow through to a mature stand of tall individuals where the reverse is observed and

light becomes a limiting resource for *H. kraussii*. It is important to note that this is merely a trend in the dataset and will need further testing to establish the validity of the above.

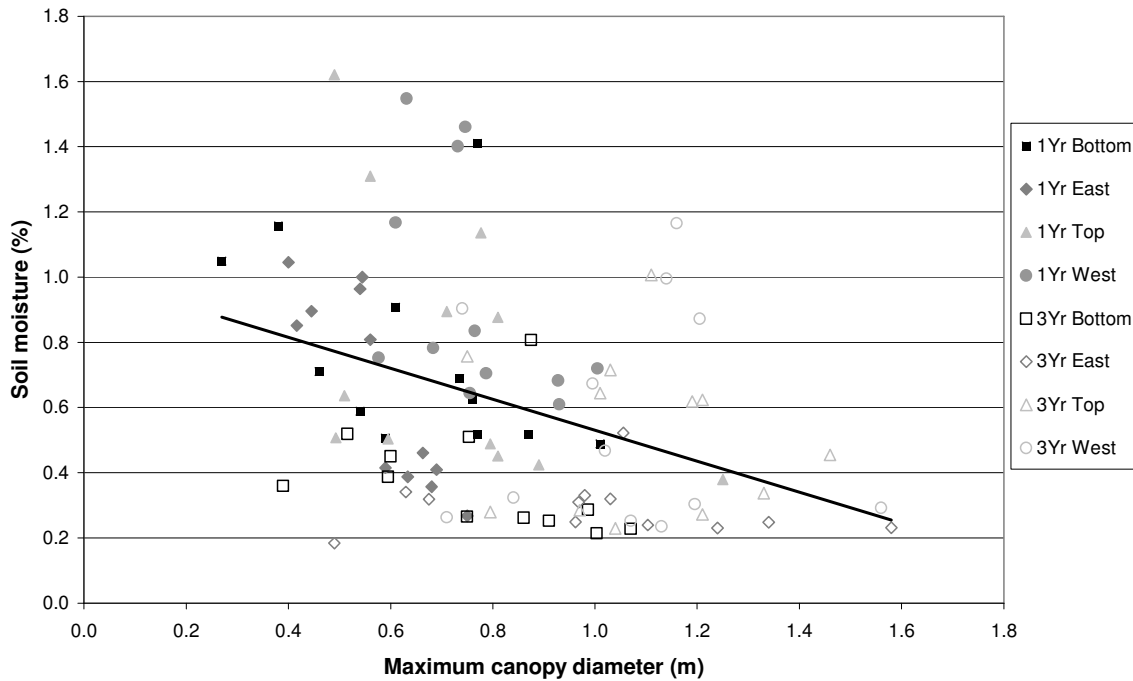


Figure 4.5.30 Soil moisture (%) as a function of maximum canopy diameter (m) of *H. kraussii* for trial one across two fire exclusion periods and four catenal positions. (The equation describing this function is $y = -0.4752x + 1.0051$ with an R^2 value of 0.1431 $P < 0.001$).

A simple linear regression was also conducted for maximum canopy diameter and soil moisture to examine the trend that exists for the dataset (Figure 4.5.30). An increase in soil moisture resulted in a decrease in maximum canopy diameter. A decrease in soil moisture was also associated with a decrease in variation and therefore a more consistent response. Grouping due to catenal position was not clear however separation based on fire exclusion period was more obvious (indicated by closed versus open points for one and three year fire exclusion periods respectively). This separation is accounted for by an increase in maximum canopy diameter and a decrease in soil moisture with an increase in exclusion period. Some separation based on catenal position is evident for sites with three year fire exclusion where top and west sites tended towards larger individuals compared

with bottom sites. Along this response of maximum canopy diameter to soil moisture, west facing sites had the greatest variability where individuals not only varied in size (diameter) but also soil moisture. This difference was not as pronounced for a one year fire exclusion period.

Soil moisture has been identified as an important determinant of *H. kraussii* density (Owen 1992). From these trials data it is not possible to investigate influences of soil moisture on density however growth of *H. kraussii* can be assessed through changes to maximum canopy diameter. The most important factors affecting growth are fire exclusion period, biomass removal (clipping), and catenal position accounting for approximately 60 % of the variation for maximum canopy diameter. Fire exclusion resulted in greater sizes of *H. kraussii* as did the removal of the surrounding biomass. Regular burning therefore has the capacity to reduce growth for this species but over lying this is an important influence of grazing where increased stocking rates increase growth. This is primarily due to a reduction in the surrounding biomass which reduces light competition and shading effects. Higher lying areas are also more prone to increased growth and therefore require greater management focus.

4.5.11. Biomass by vegetative category in response to fire exclusion period, catenal position, and clipping

Section 4.4.4.4 outlines methodology for the collection of above ground biomass for plots from trial one. Harvested biomass was separated into three vegetative categories comprised of grass, herbaceous, and woody material. This was conducted for clipped and unclipped plots, the four catenal positions, and two fire exclusion periods. Above ground biomass for unclipped and clipped plots is presented in Figure 4.5.31 and Figure 4.5.32 respectively. Note that the wild fire burnt all these plots originally and therefore unclipped biomass response is subsequent to this event. Limitations surround the lack of formal design to test for differences in response to the treatments and have been included to highlight possible trends in biomass response noted in the field.

Above ground biomass for unclipped plots with a one year fire exclusion period was dominated by grass. This grass biomass increased from bottom to west facing sites. An increase in fire exclusion resulted in a substantial decrease of grass biomass, more than

half for west facing sites. It is interesting to note that this response is different to that obtained using the disc pasture meter where grass dry matter peaked within a three year fire exclusion before dropping off again with increased fire exclusion (Table 4.1). This may be due to increased lignification of the culms affecting calibration, a measure of which was taken but not used to correct the equation (Appendix 7 and Appendix 8). Woody biomass for top and west facing sites with a three year fire exclusion greatly increased when compared with a one year exclusion period. The reverse was true of woody biomass for bottom sites. Generally, herbaceous biomass was consistently the least compared to grass and woody biomass across all catenal positions and fire exclusion periods. East sites with three year fire exclusion were the only exception to this trend.

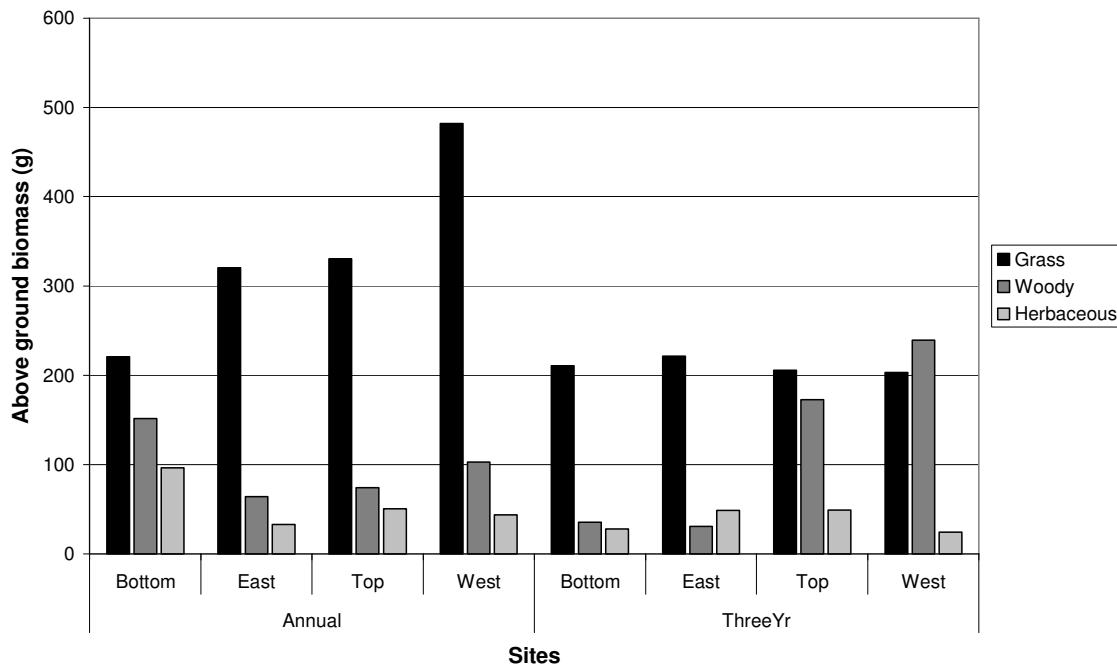


Figure 4.5.31 Above ground biomass (g) from unclipped control plots for different vegetation components in response to two fire exclusion periods and four catenal positions from trial one north of the Manzengwenya Offices, South Africa.

Clipping greatly altered this trend in biomass response for the three vegetative categories (Figure 4.5.32). Important to note is the difference in scale being almost ten times reduced. Grass biomass was greatest for a one year fire exclusion period and

decreased with increased exclusion and is consistent with unclipped plots. Bottom sites with a one year fire exclusion period had the greatest biomass and this decreased through to west facing sites. This is a reversal of the trend observed for unclipped plots.

The greatest difference lies with the biomass for woody and herbaceous species being greatly increased in comparison with grass biomass. This response may be a little biased due to timing of harvesting of the biomass. Had this been done at a later stage it is quiet likely that this trend would be more similar to that observed with unclipped plots. Never the less it is important to note the almost equal response in biomass for the three vegetative categories over a short period of time (approximately three months).

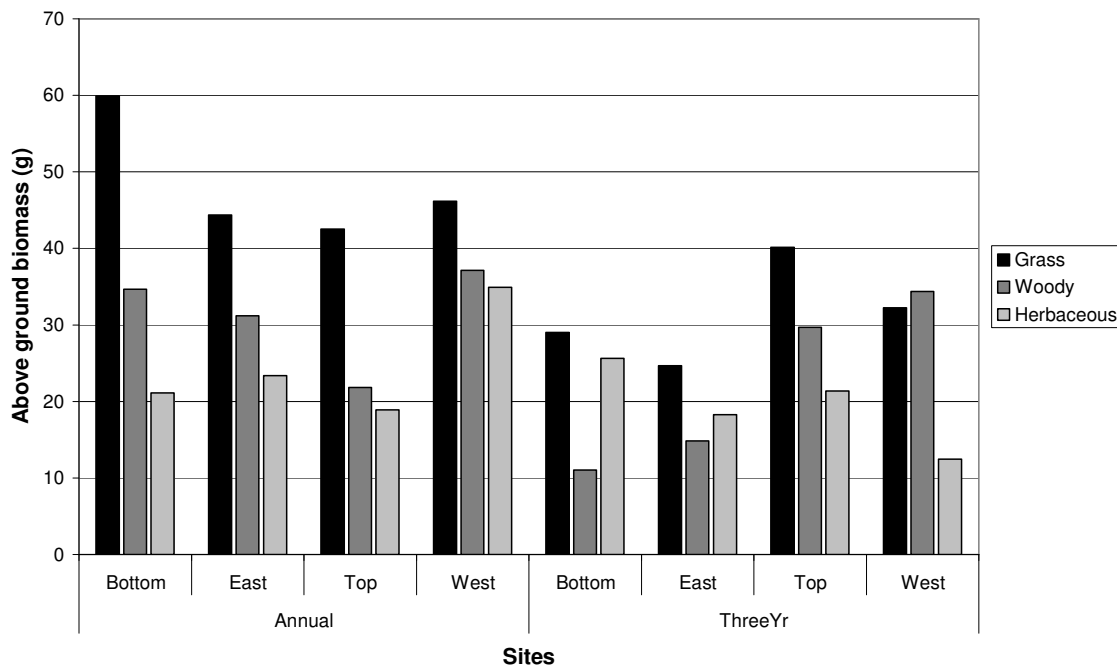


Figure 4.5.32 Above ground biomass (g) from clipped control plots for different vegetation components in response to two fire exclusion periods and four catenal positions from trial one north of the Manzengwenya Offices, South Africa.

A more useful expression of the above trends in biomass response is to express the response for clipped plots as a percentage of unclipped plots (Figure 4.5.32). This allows better understandings of the response of clipped plots in comparison to its potential. Thus a greater percentage for a particular vegetative category and treatment would indicate a quicker growth response for that time period.

Immediately obvious is the response of the herbaceous biomass where in one instance a site (bottom site with a three year fire exclusion period) had achieved greater than 90 % of its biomass in three months. This was also observed for east and west facing sites with a one year fire exclusion period. Grass biomass did not achieve more than 30 % of its unclipped biomass and as mentioned previously indicates a delay in growth response where woody and herbaceous species direct their reproductive outputs to above ground biomass faster when compared with grasses. Woody response for east facing sites was greater in comparison to the other catenal positions and within a short period of time was able to achieve 50 % of its potential.

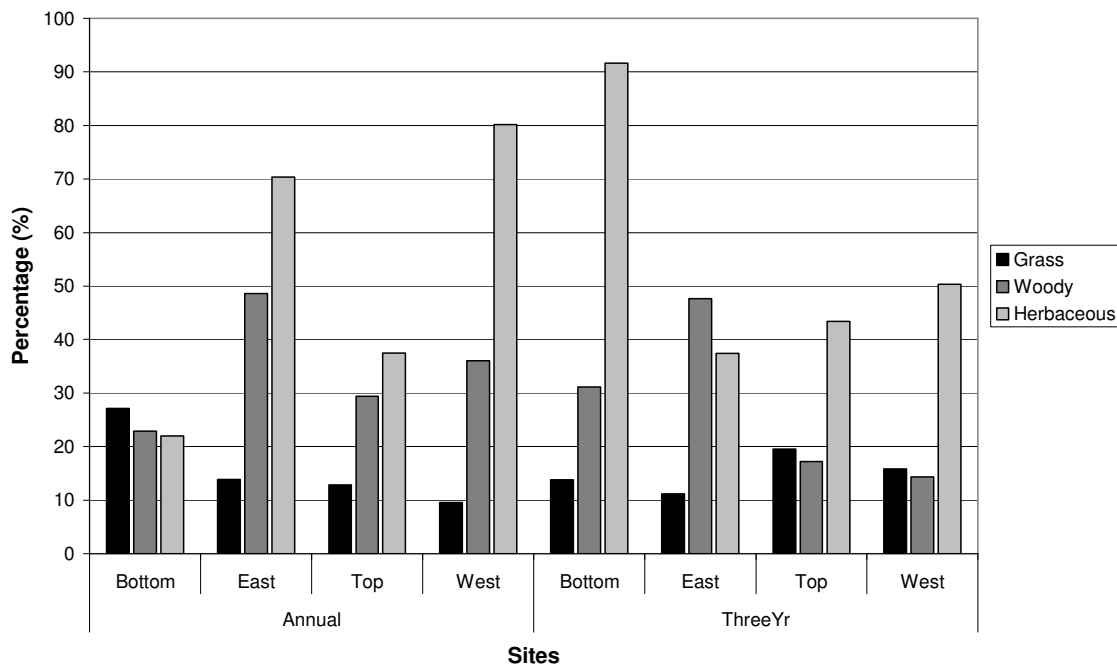


Figure 4.5.33 Above ground biomass expressed as a percentage of clipped versus unclipped plots for different vegetation components in response to two fire exclusion periods and four catenal positions from trial one north of the Manzungwenya Offices, South Africa.

From these data it is clear that an exclusion period of one year or regular burning greatly increases grass biomass when compared with three year fire exclusion. Clipping effectively leveled this skewed dominance of biomass to which herbaceous and woody

biomass responded the fastest. It is difficult to infer whether clipping promoted herbaceous productivity or due to the nature of defoliation which removed all biomass and timing of the investigation reveals differing life history strategies between the three vegetative categories. Had this investigation been repeated months later a different trend in biomass response may have become evident. A one year fire exclusion promoted herbaceous biomass increase when compared with a three year fire exclusion period. This may indicate certain responses to grazing following burning where stocking at levels which remove the majority of the grass biomass in a particular area may improve herbaceous biomass and possibly diversity. Herbaceous response to disturbance can be complex and variable (Morris & Fynn 2003) and furthermore without more formal methods of testing this can only be observed in terms of its trend.

The response of the woody species within annual burnt sites is alarming. From section 4.5.4 above and personal observations during harvesting of the biomass the majority of the woody biomass is comprised of *Diospyros villosum* and *D. lycioides*. These species are therefore very well adapted to survive regular burning and recover rapidly in terms of their above ground biomass. Woody species that are capable of attaining considerable height are however absent from this fire exclusion period initially but with further exclusion become more prevalent. These shorter woody species may therefore also facilitate woody establishment through the amelioration of the surrounding environment. Root/shoot competition and influences of a change in shading may also be affecting growth response (Montserrat 1997).

These data may indicate the importance of timing of burning. For short periods of fire exclusion only the short woody species are adapted to defoliation and contribute quickly to the biomass of the sward thereby competing effectively for light. As this exclusion period increases grass biomass decreases and different taller woody species begin to establish through the shorter species possible role as facilitators. Thus woody biomass increases. Catenal position exacerbates this where west facing sites have greater woody biomass and this is possibly due to differences in soil moisture where these sites would tend to be drier. *Helichrysum kraussii* has a role as a facilitator where increasing light conditions at the soil surface with an increase in size for this species may provide the release on germination and disturbance to facilitate taller woody species establishment

(refer to section 4.5.10). Thus there is almost a priming of the environment becoming increasingly conducive for encroachment. Burning however effectively reduces tall woody biomass and promotes grass biomass.

4.6. DISCUSSION

4.6.1. Density

It is possible by comparing the various woody species density for the three fire exclusion periods to establish a clear trend within both the different fire exclusions as well as catenal positions. Excluding fire from the coastal grasslands results in a marked decrease in total plant density with density decreasing with further exclusion in a diminishing fashion. Within fire exclusion periods, bottom sites were consistently denser and with density decreasing for higher lying east and west facing sites. Other underlying environmental variables may be responsible for this consistent difference within fire exclusion. A possible explanation could lie with increased soil moisture for bottom sites and/or aggregation of finer colloidal material gravitating down slope and thereby improving fertility.

Separating total density into the three vegetation categories Grass, Herbaceous, and Woody indicates differing responses within density to fire exclusion and catenal position. Grass density was greatest for bottom sites with one year fire exclusion. This trend is repeated within fire exclusion period where grass density is greatest for bottom sites. For all catenal positions grass density was greater than the herbaceous and woody densities. The only exception was for west facing sites with a one year fire exclusion period where woody density dominated the other two categories.

Examining density within each of the three vegetation categories allowed an understanding of the species level response in density to fire exclusion and catenal position. One year fire exclusion resulted in a greater number of grass species present where *T. triandra* dominated, particularly in east facing sites. This species was not present for increased fire exclusion. With the exception of *D. amplexans* (East), *Eragrostis racemosa* (West), and *Chloris gayana* (West) grass species density was greatest within bottom sites. Generally, east site density for grasses was reduced in

comparison with bottom and west sites. Species responding differently to this were generally not among the top six densest species. An increase in fire exclusion resulted in a change to this pattern with a reduction in the number of grass species present and a dramatic increase in bottom site grass density. West facing sites had consistently less grass density for the top four grass species. Further exclusion of fire continued with this trend where *U. agropyroides* was ranked most prevalent particularly for bottom sites.

Lobelia coronopifolia was ranked with the highest density for herbaceous species within sites with one year fire exclusion. East sites for this species had greater densities with a decrease through to west facing sites. There was considerable variability for each species within catenal position with no clear trend establishing. An increase in fire exclusion resulted in a greater number of herbaceous species sampled. Density was consistently greatest in bottom sites for all species with *Limeum viscosum* dominating this density. Further exclusion of fire continued this trend except *C. filiformis* was more prevalent.

Woody species density was dominated by *Diospyros villosum*, *S. cordatum*, and *D. lycioides* for sites with one year fire exclusion. *S. cordatum* increased in density for west facing sites whilst the other two woody species experienced greater densities for bottom sites. Excluding fire from the system for three years resulted in a greater number of woody species which conforms with the increase in herbaceous species. Interestingly, *Diospyros villosum* and *D. lycioides* remained dominant indicating both a fire adapted strategy and an ability to persist with changing fire regimes. *Helichrysum kraussii* increased in ranking with respect to density preferring bottom sites. This trend continued when fire was excluded further from the system with bottom sites remaining the dominant catenal position.

Woody species density in response to fire exclusion reveals that a number of woody species are able to establish effectively with regular burning. Withholding fire results in a greater number of taller woody species establishing and the fire adapted shorter woody species remain dominant. It is thought that competition is initially for light. Growth rates immediately following disturbance allows adequate sequestration of resources to remain dominant within the stand (Falster & Westoby 2005). As taller species begin to establish and dominate these resources these species continue at lower levels for this resource

adequately. Therefore, fire exclusion does not result in a complete species turnover for woody plants but does permit fire intolerant species to establish.

H. kraussii density in contrast with total density was greatly reduced for sites with a one year fire exclusion period. Establishment and proliferation is therefore greatly promoted through the exclusion of fire from the system. This reduction in density has been attributed to a susceptibility of the mature seeds to heat greater than 90°C and may be the factor influencing density for these sites (Owen 1992).

4.6.2. Height

The height and height class data clearly indicate a strong response to fire exclusion where increased exclusion of fire results in an increase in the number of taller woody plants and their height. This increase in height is variably affected by catenal position but generally bottom sites have fewer tall woody individuals whereas east and west facing sites have a greater number of tall woody plants compared. Woody plants were maintained effectively at small heights across catenal position. Removing fire resulted in a rapid increase in average height, particularly in west facing sites with this trend continuing with increased exclusion of fire. *Diospyros villosum*, *D. lycioides* and *D. cinerea* were present as short individuals for all fire exclusion periods and catenal positions indicated by reduced variations. *Helichrysum kraussii* was also present for all sites but increased in height once fire was excluded. *Strychnos spinosa* and *P. reclinata* increased greatly in height for sites with a six year fire exclusion period.

The number of short woody plants (less than 0.30m) decreased with increased fire exclusion however remained persistent as the most numerous height classes. These numerous shorter species are the reason for greater than expected woody densities in sites burnt regularly. Excluding fire resulted in a greater number of individuals for larger height classes with individuals represented for heights greater than eight meters with a six year fire exclusion.

Therefore, it would appear that for areas of coastal vegetation maintained as grassland and then withholding fire from the system results in a change in structure where the numerous woody plants present do not change in height or disappear from the system but

a number of new woody species capable of attaining greater heights establish. In other words woody establishment is not limited by fire but woody structure is.

4.6.3. Ordination, diversity, and veld condition

Ordination of mean point-to-plant distances for species within sites north of the Manzengwenya Offices has indicated a distinct separation between sites with a one year fire exclusion period and the others. Therefore fire exclusion period has accounted for explanation of 34 % of the variation in species composition and secondary separation between three and six year fire exclusion periods accounted for a further 24 %. The majority of the variation associated with species composition can be accounted for by fire exclusion period. Grouping of sites became more variable with increased fire exclusion with bottom sites becoming more similar in species composition and west facing sites becoming more different. *Helichrysum kraussii* increased in abundance for sites with a fire exclusion period of three years as did a number of other woody species. Interestingly, sites with a six year fire exclusion period had a greater number of herbaceous species with increased abundance for these sites. It is therefore possible through the ordination of sites in relation to their species composition to observe a successional trend with the exclusion of fire. Regular burning is associated with a few species with increased abundance but dominated by palatable grass species. Removing fire from the system for three years results in a change through to predominantly woody species with subsequent exclusion allowing succession through to sites with a greater abundance of herbaceous species.

The NMDS of sites has added to the understandings gained where it is clear that fire exclusion has resulted in a unique response of species with grouping a direct result of fire exclusion period. Therefore, sites within each fire exclusion period are more similar to one another than between fire exclusion period. Additional differences exist within fire exclusion periods pertaining to catenal position. The greatest similarity being between bottom sites and this similarity decreases for east and west facing sites. From the density (section 4.5.1) and height (section 4.5.4) data, bottom sites had the greatest density but the shortest woody individuals. The NMDS ordination based on species abundance indicates similarity between these bottom sites.

Diversity was greatest within sites with a six year fire exclusion period and decreased with an increase in fire exclusion. A decrease in fire exclusion resulted in greater evenness and therefore more of an equal sharing of abundance across the species present. On average diversity was greater for a three year fire exclusion period. Veld condition on the other hand decreased with an increase in fire exclusion period. Condition also varied with catenal position where west facing sites tended to be of a better condition compared with bottom sites. This trend is reversed for diversity where diversity tended to be greater for bottom sites. Therefore it would appear that management for improved biodiversity may be at the expense of veld condition but would need to be more rigorously and formally assessed as these are merely trends observed for the dataset.

4.6.4. *Helichrysum kraussii* trials

Helichrysum kraussii is a small woody perennial shrub that establishes readily on the higher-lying sand dune remnants of the Zululand coastal plain. Understanding of this species response to different management regimes for this region is limited due to complications with previous investigations (Owen 1992). However, a number of factors are recognised as affecting density and distribution of this species. Owen (1992) summarised these factors broadly as follows:

1. Topsoil disturbance – increased exposure of the soil surface promoted establishment resulting in greater densities,
2. Seedling shading – susceptibility to shading was observed in seedlings indicted by severe etiolation, and
3. Soil moisture (edaphic control) – an increase in soil moisture resulted in a decrease in density along a topographical gradient.

Helichrysum kraussii has been identified as a precursor to woodland shrub and forest (Conlong & Breen 1982). This shrub establishes readily where conditions permit and effectively out-compete grasses thereby reducing carrying capacity. Therefore, any information assisting management with the control of this species within its environment will be important for ensuring the continuation and proper functioning of the system.

From these trial data it was only possible to investigate the growth response of *H. kraussii* for a number of factors and a full investigation into measures for the control of this species were not conducted. In other words the study aimed at reproducing natural conditions using existing environmental factors. For an understanding of the differences in density due to catenal position and fire exclusion period refer to section 4.5.3 above.

These data agree with the classification of this species as a stress tolerant ruderal (Owen 1992). In terms of average growth response little seemed to affect *H. kraussii*. Historical burning regimes, burning, and catenal position had no effect on growth (maximum canopy diameter). Clipping of the plant biomass surrounding this species had variable affects where a reduction in competition from the surrounding biomass may result in an increase in growth. This has important implications when considering the factors most responsible for the reduction of biomass (e.g. fire but particularly grazing). *Helichrysum kraussii* is an unpalatable sclerophyllous shrub and therefore unaffected by animal grazing or browsing. Increasing grazing pressure may cause an increased ability for *H. kraussii* to out compete other plant species (mainly grasses) through the increased interception of light as a result of increased volumes (inferred from increased canopy diameters) and therefore increase reproductive output.

Burning had no effect on the growth response of *H. kraussii* but would never the less result in complete defoliation of all plant biomass. *Helichrysum kraussii* however coppices readily from rootstock buds that perennate at or below ground level (Owen 1992). Although burning and disturbance does not inhibit or alter growth response for this species it does have the capacity to change/impact the growth response of the surrounding vegetation thereby increasing or altering competition effects (Fynn *et al.* 2004). These have not been considered for these trials however these disturbance regimes need to be carefully considered so that *H. kraussii* is not given the competitive advantage. Grazing and disturbance should therefore aim to promote grass and herbaceous vigour as much as possible thereby increasing diversity, invasion resistance, and improve stability of production (Fynn *et al.* 2004; Tilman *et al.* 1997).



Plate 4.6.1 *Helichrysum kraussii* coppices readily following defoliation by fire (left). This regeneration is rapid with growth usually seen enveloping previous season's woody remnants (right).

Owen (1992) highlighted the importance of timing of burning where heat exposure of the seeds greatly affected viability. Seed viability was reduced at temperatures greater than 90°C and for increased soil moisture conditions. Therefore where these conditions are approximated it is likely that seed banks for this species will be reduced, impacting on this species ability to succeed into future generations. Each adult plant for this species has the capability to produce 20 000 seeds per annum, ripening and maturing between September and mid October (Plate 4.6.2). Burning before this period would place stress on adult plants in their reproductive phase but promote herbaceous vegetation (Owen 1992).



Plate 4.6.2 *Helichrysum kraussii* flower heads. Note that the yellow clusters are the flower heads and this colouration is due to the pale yellow bracts. Fluffy white ‘ball-like’ structures are galls and not fruits or seed heads.

From trial one (section 4.5.9.1 above), topography was found to have no significant effect on growth however increased soil moisture has been shown to effectively exclude *H. kraussii* (Owen 1992) and certainly where this inundation is frequent, differences are obvious (Plate 4.6.3). For higher lying sections of the dune cordon, differences in soil moisture and distribution of *H. kraussii* within the catena is not so obvious. Separation can therefore be made between higher lying areas and lower lying areas periodically inundated. The former proportions may require more focus in terms of research, planning, and management. This is particularly true for periods where the hygrophilous grasslands are inundated and therefore inaccessible to grazers excluding these sections as a resource.

Depending on stocking densities, a reduction in rainfall may require increased burning frequencies for higher lying sections to knock *H. kraussii* back within the grass sward and promote herbaceous regeneration. For areas receiving heavy and frequent grazing this is particularly important because the change in seasonal palatability may result in a shift from these areas to the lower sections as they become accessible (Porter

& Blackmore 1998). If this has been sufficient to remove the majority of the biomass, *H. kraussii* may be afforded an opportunity to dominate the above ground biomass and greatly increase reproduction output and facilitate woody establishment. Fire has the potential to shift these areas of frequent grazing (patches) from becoming too entrenched within the system (Archibald & Bond 2003). Therefore it would appear that an important balance exists between stocking density, burning regime, and soil moisture.

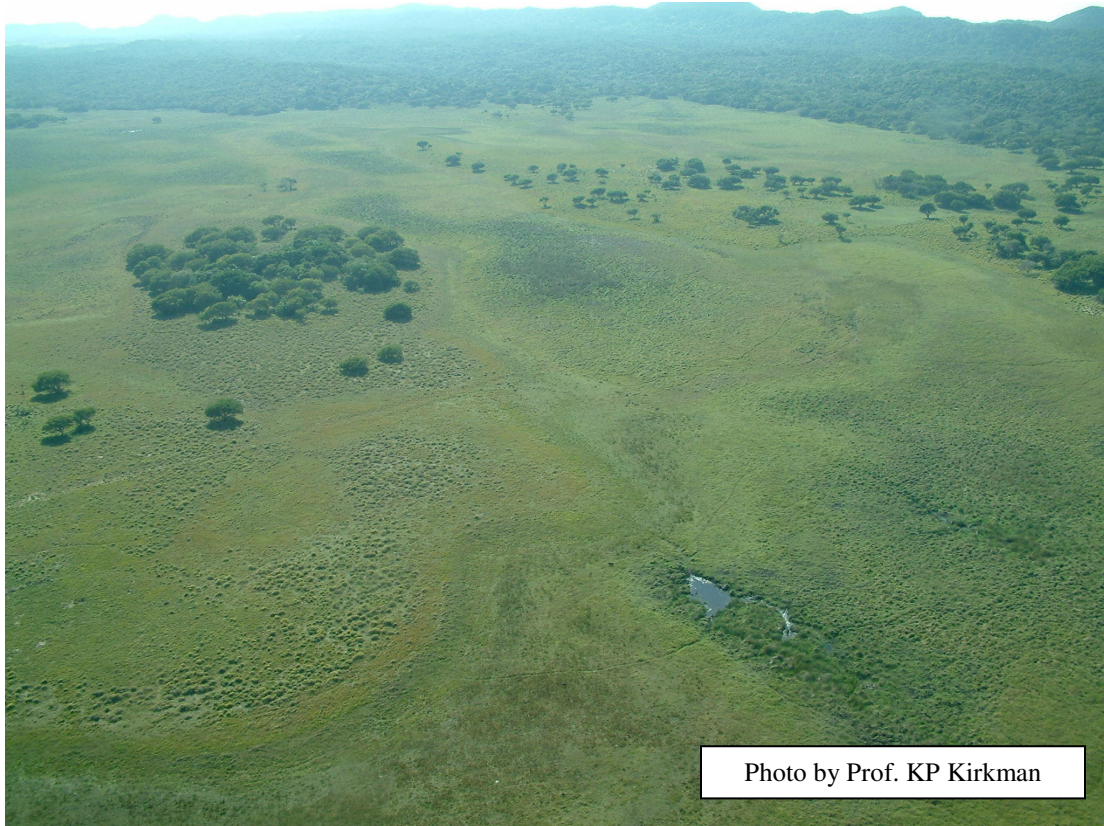


Photo by Prof. KP Kirkman

Plate 4.6.3 Aerial view of a section of the Eastern Shores of St Lucia. Note the visible difference between areas inundated (right) and those above this level (left). The ‘bobbled’ appearance to the sections left and above inundation is due to the presence of *Helichrysum kraussii*. Where water tables have permitted the higher lying sections have continued through to taller woody species.

It is also important to note that for all plots within the three trials none of the individual plants decreased or were excluded from the system and is therefore persistent under the conditions observed. *Helichrysum kraussii* was observed to effectively exclude

the establishment of grasses but allow woody species to grow underneath. Within the canopies of the larger plants there were commonly woody species present such as *D. cinerea* (Plate 4.6.4). These woody species would appear to then grow through to an open canopy shrubland and subsequently shade out the *H. kraussii* plants beneath.

An increase in soil moisture negatively affected size for *H. kraussii* and further highlights the susceptibility of the drier high lying areas where conditions promote larger individuals of this species. Very interestingly growth of this species results in an increase in light transmission through to the soil surface. Smaller plants effectively exclude light where the circumference of the plant is dense with the sclerophyllous leaves. However, as the plant increases in diameter the aerial volume occupied by that branches ending does not increase at the same rate as the branch elongation outwards and therefore the branches cannot maintain the same density at this increased circumference. Thus transmission of light to the soil surface increases with an increase in diameter and this may explain the presence of a number of taller woody species being able to establish beneath the canopies for this species. Thus *H. kraussii* is able to facilitate woody establishment where permitted to grow through to larger individuals. Note that this facilitation is predominantly for the taller woody species which are not adapted to regular defoliation.

Shorter woody species such as *Diospyros villosum* and *Diospyros lycioides* are not excluded from sites burnt regularly or where defoliation of the aerial biomass is severe. However, an increase in fire exclusion for the system results in a noticeable increase in the woody biomass for the taller species.



Plate 4.6.4 Areas regenerating following complete defoliation due to the clipping treatment for the trials and cool point source burning gave a good impression of the number of woody individuals that exists within the grass sward (top left and middle respectively). Often, woody species were found to have established within the canopies of *Helichrysum kraussii*. Note *Dichrostachys cinerea* and *Syzygium cordatum* growing from within the canopy of *Helichrysum kraussii* and indicates a form of facilitation (top right and bottom).

Unclipped and clipped plant biomass response following burning highlighted differences between fire exclusion period and catenal position. Broadly, fire exclusion resulted in a decrease in grass biomass and an increase for woody biomass. Initial biomass response within clipped plots was far greater for the grasses of one year fire exclusion and indicates vigour for grasses may improve with regular burning and defoliation. It is interesting to note that for unclipped plots grass biomass was greatest in west facing sites with one year fire exclusion and woody biomass was greatest for west facing sites with three year fire exclusion. This is an important response to note as west facing sites have a better veld condition and produce greater volumes of grass biomass but are quickly transformed by woody species. Fire effectively reverses this trend. Herbaceous biomass, when comparing clipped with unclipped biomass, attained a greater percentage biomass and indicates adaptation to defoliation by increasing growth compared to grasses and woody species. Therefore, a long term strategy needs to be developed for the survival of the higher lying sections of grasslands remaining and may require further investigation and trials.

5. Aerial photography

In order to evaluate the historical changes in vegetation proportions over time aerial photography covering three time intervals was chosen for two sites within the IWP. The sites were selected based on the following criteria:

1. The areas covered by the two sites needed to differ in terms of current and historical management practices.
2. Site variation such as topology, proximity to Lake St Lucia, and other environmental factors needed to be kept to a minimum for adequate comparisons in vegetation response.
3. The spatial extent of each site needed to include a minimum area so as to cover a cross-section of vegetation communities.

Based on the above criteria, two sites were located, one on the Eastern Shores of Lake St Lucia and another within the Tewate Wilderness Area (Figure 5.3.1). The site on the Eastern Shores historically had a greater population of people and cattle when compared to the northern parts of Maputaland and it has been established that this would have resulted in an important impact upon the vegetation (refer to Section 2.3). However, a number of pine plantations were located directly to the north and south of this site and resulted in the effective exclusion of fire. Conservation priorities also saw the exclusion of people, cattle and their associated agriculture practices. The site within the Tewate Wilderness Area however has had all influences from people excluded and been left without deliberate management interventions since the 1980s. As a result these two sites present two different areas from a management perspective and may be useful in highlighting effects of management of these coastal dune communities.

5.1. RESEARCH PURPOSE

The purpose of this research was to describe historical changes in vegetation structure over time (1937 to present) for the Maputaland region in response to changing fire regimes.

5.2. RESEARCH OBJECTIVES AND KEY QUESTIONS

1. Determine and describe historical changes in both the relative proportions and spatial differences of the grassland, bushveld/savanna, and dune forest over time (1937 to present) for selected sites on the Eastern Shores of Lake St Lucia and the adjacent Tewater Wilderness Area.
 - i. Have the establishment of pine plantations and the subsequent exclusion of anthropogenic disturbance, particularly fire, resulted in a change in the relative proportions of grassland and dune forest over time?

5.3. METHODOLOGY

Although site selection aimed to reduce variation in topography and environmental variables some differences have been identified and need to be considered for interpretation of the results. The study site on the Eastern Shores of Lake St Lucia is a narrow section between two pine plantations north and south and constricted by the coast (east) and Catalina Bay (west). In comparison, the study area for the Tewater Wilderness is a large expanse from coastline to the Lake edge. The major difference therefore lies with topography where on the Eastern Shores topography drops sharply westwards towards Lake St Lucia. However, this section is far greater within Tewater and undulates towards the Lake edge. As a result middle sections comprising hygrophilous grassland are contained within the middle of the Tewater site but form the western limit for the Eastern Shores. Additionally, the difference in time interval may have unexpected bearing on vegetation successions as these periods may have encompassed widely variable environmental conditions. However, having equal time intervals does not change this potential variation in conditions. Comparisons are however not limited but these differences need to be considered when comparing study sites.

5.3.1.1. Image rectification

In order to assess changes in the spatial distribution of the vegetation communities occurring within the sites identified above three time intervals (1937, 1975, and 2000)

were chosen and scanned aerial photography georectified using a Geographical Information System (GIS). Georeferencing raster (image) data allows it to be viewed, queried, and analyzed with other geographic data (ESRI 2005). Photographs were scanned in greyscale to create electronic images using a flatbed scanner with a resolution of 300 dots per square inch (dpi). Image scale was not recorded however, during the georectification process an approximate resolution (pixel size) of one meter for all photos was chosen to standardize the resolution of the images. Capturing, storing, and manipulating data through pixels is referred to as raster analysis. Once a number of images covering the time intervals and two sites had been identified, images were clipped and converted to the GIF file extension using 'The GIMP' image manipulation software (Kimball & Mattis 2002).

Before these images were georectified a co-ordinate system (map projection) was chosen. A co-ordinate system is an arbitrary designation for spatial data with the purpose of providing integrity with respect to a particular place or area on the earth's surface. Projection parameters include the projection, unit of measure, zone, and datum. A South African co-ordinate system (LO33) was chosen due to its ability to preserve both area and angular distance. The LO33 system is a meters-based system which uses a Cape Transverse Mercator projection, the Cape datum and longitude 33° East as the central meridian (ESRI 2005). Any additional data incorporated into the raster analysis therefore had to be reprojected into this co-ordinate system.

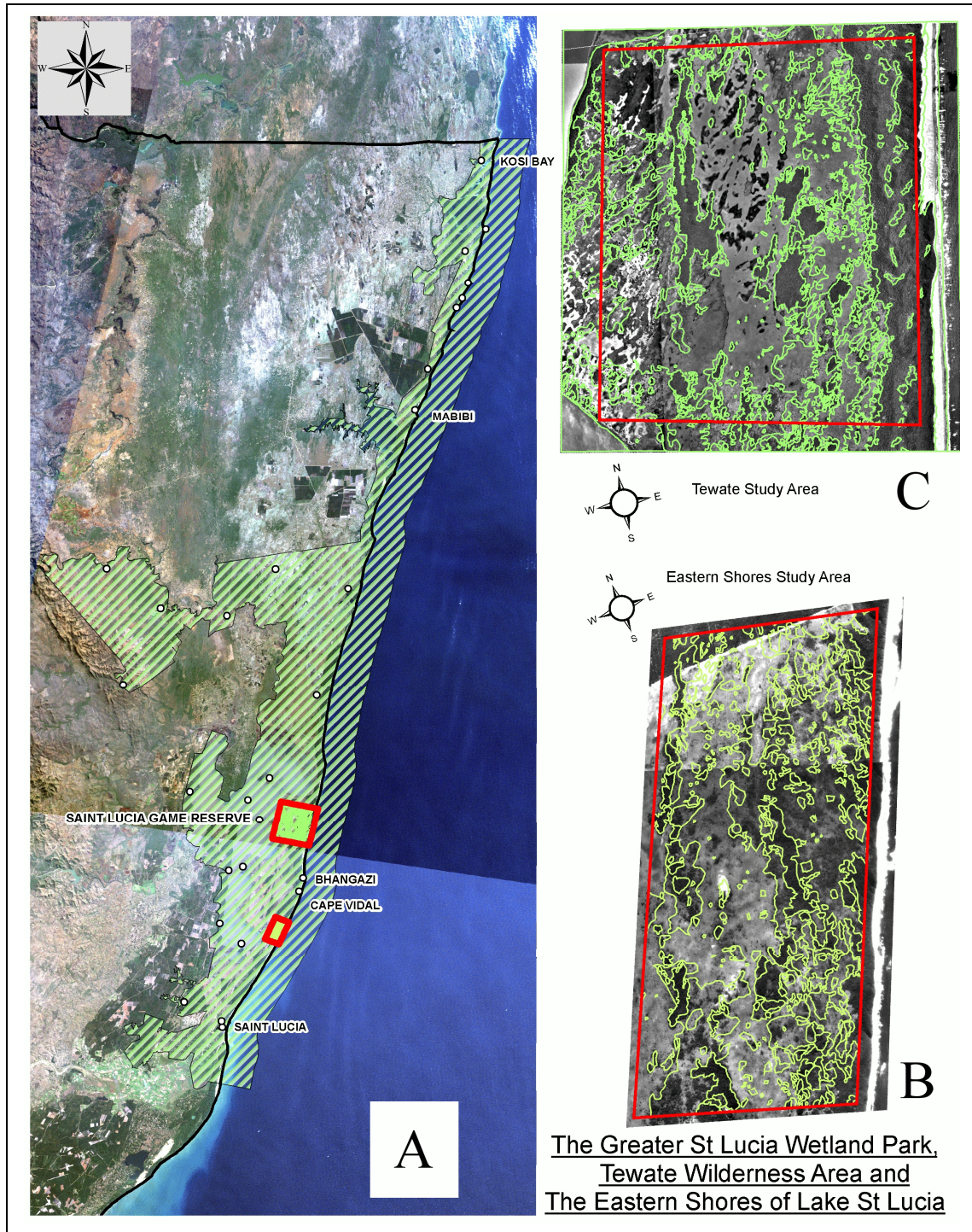


Figure 5.3.1 Map illustrating the proximity (A) of the two sites used in evaluating the change in proportions of vegetation over time (B & C).

Ideally, in order to accurately rectify the imagery, control points would need to be obtained from permanent, easily identifiable structures. Ground-truthing of these structures would then be conducted using a global positioning system (GPS) to provide co-ordinates for the structures visible within the aerial photo. Due to the inaccessibility and scale of evaluation, ground-truthing of ground points was not possible. For this reason, orthophotos (georectified imagery) from 1996 were used to identify control points to conduct georeferencing. Problems resulting from this procedure relate to the following:

1. Although the orthophotography adequately represents attributes of the image with respect to its location on the earth's surface, inherent error exists within each orthophoto. The magnitude of this error is not known and can be exacerbated during the georeferencing process.
2. A common set of control points for each site across all images does not exist and therefore the error between images is not constant.
3. The use of permanent structures was not always possible and therefore single, isolated mature trees were used as control points. This too results in inconsistencies depending on changes in volume and the angle of the sun (shadows) with exact point location.

Although this error affects accuracy and interpretation of the associated digitized areas, the effectiveness of the transformation was assessed using the residual mean square error (RMS) for each image. An RMS value indicates the accuracy of the derived transformation through the measurement of fit between the true locations and the transformed locations of the output control points (ESRI 2005). An acceptable RMS value of ten meters was chosen and images exceeding this figure were georeferenced again. A minimum of twenty control points was used in the georeferencing of each image. Effort was made in locating points along the periphery of each image to allow for greater precision in transformation. During this transformation process, images are orientated and re-scaled using the control points. However, lens curvature, focal distance, and other parameters affecting image quality were not removed from the image (orthorectification). This may result in further error during digitizing.

Once images were suitably georectified, images were tiled, merged and clipped to form a single layer. A second clipping was done to standardise layers for the different

sites and time intervals. These layers were then stored within a geodatabase. This allowed for the definition of a spatial extent, co-ordinate system, and automatic calculation of polygon areas for any layer added. The added advantage of using a geodatabase is the ability to incorporate a classification system for polygons across layers, available during 'heads-up' digitizing. The various vegetation types likely to be digitized were therefore defined and added to the geodatabase.

A scale of 1:4 000 was kept constant across images during digitizing. The following vegetation categories were defined and identified within each image, namely:

1. Cultivation – any form of disturbance resulting in a change in land use and structure of the vegetation
2. Dune forest – any woody vegetation greater than three square meters and with an overlapping canopy
3. Dwelling – any formal or informal structure designed to house people.
4. Fire break – any area maintained by burning or mowing so as to prevent the spread of fire into adjacent areas
5. Grassland – consisting all herbaceous, graminoids, dwarf woody, and hygrophilous species without the presence of tall, visible shrubs
6. Pine – homogenous, single species stand of *Pinus sp*
7. Sand – any exposed soil surface greater than five square meters
8. Scattered trees – consisting all interspersed short and tall shrub and woody species without overlapping canopies and with a volume less than three square meters. Each polygon was buffered by approximately two meters where savanna was concerned.

Once digitizing was completed, a spatial adjustment was conducted on the vector data using the raster layers as a template. In other words, the vector layers of 1937 and 2000 were spatially corrected to the raster layer of 1975. This greatly reduced the error due to a lack of orthorectification and increased the accuracy for comparison of the difference in areas over time. A third clipping of the sites was conducted, indicated by a red box in Figure 5.3.1 to exclude the Indian Ocean and Lake St Lucia as these areas were complicating georectification. These vector layers were then analyzed using a model within ArcMap 9.1 (ESRI 2005). This model is diagrammatically represented in Figure

5.3.2. The two vector layers for comparison (e.g. 1937 versus 1975) were converted to a single part layer, merged, and then areas that had changed or remained unchanged were extracted into a separate layer. All attributes were merged and gaps allowed with a cluster tolerance of zero. These separate layers were then reclassified and mapped to a constant scale to indicate areas of change and no change. The associated areas for each category was also calculated and either graphed or presented in tabular form.

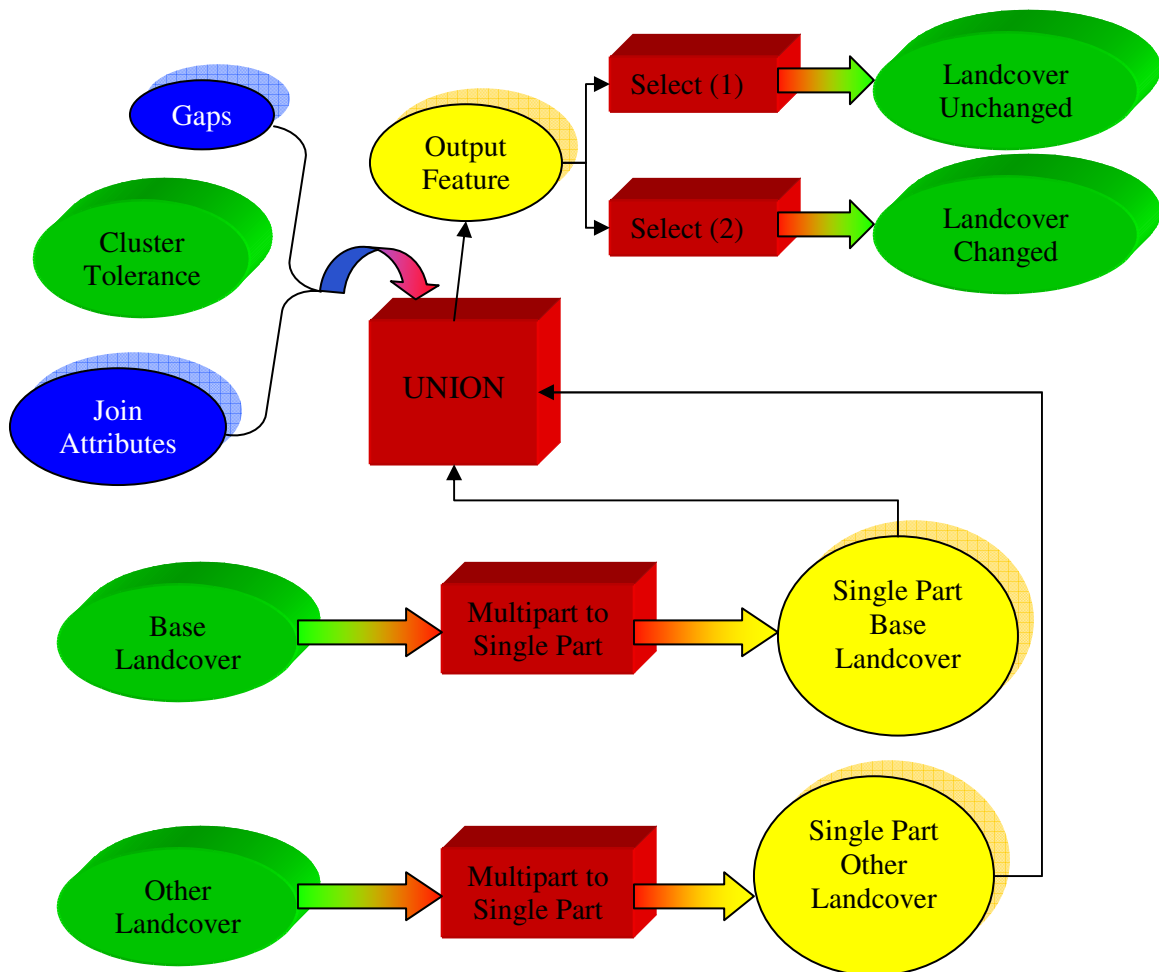


Figure 5.3.2 Diagrammatic representation of the steps involved in analysis of the vector layers using a GIS. Green polygons have parameters needed by the model for analysis (e.g. file location), items highlighted in blue are pre-selected parameters, and yellow polygons are interim steps due to processing (red polygons).

There are some important errors not mentioned which affect accuracy of the digitizing and can be summarised as follows:

1. Relief of an object will cause distortion due to a shift or displacement in the photographic position
2. During flight, horizontal tilting results in displacement within each image and therefore a non-orthogonal scale across the photograph.
3. As mentioned above, camera and lens distortions introduce additional distortion. Additionally, differences in age, temperature, humidity, spool tension, and effects introduced during storage and processing of the negatives can further complicate the georectification process (Wilton 2002).

Although methods exist for the correction of the above mentioned distortions (Wilton 2002), no such correction was conducted on the images used in this study due to logistical constraints in time, software, and expertise. It is therefore important to note that the digitizing for the evaluation of the change in vegetation proportions over time contains inaccuracy but is suitable enough to allow for an evaluation of trends over time.

5.4. RESULTS

5.4.1. *Historical changes in vegetation proportions over time*

Table 5.1 and Figure 5.4.1 refer to areas calculated from the digitisation and GIS for the vegetation categories of the Eastern Shores of Lake St Lucia whereas Table 5.4 and Figure 5.4.10 refer to that of the Tewate Wilderness Area. Important to note is the difference in area between the two sites (682.38 ha versus 2948.53 ha for the Eastern Shores and Tewate respectively) as visualised in Figure 5.3.1 above as well as small differences in area within sites due to small areas (slivers between polygons) not having been digitized. In order to maintain a consistency across sites imagery was chosen to cover a similar suite of topographical and environmental gradients. This similarity is represented by a change in topography from high-lying dunes in the east through to lower lying hygrophilous grasslands on the edges of Lake St Lucia. To cover this change in topography whilst maintaining consistency between sites required a far greater area for the Tewate Wilderness hence the difference in area.

Of primary importance is the change in area for vegetation categories Dune Forest, Grassland, and Scattered Trees. Although other categories do exist these constitute small proportions and are indicative of the exclusion of people both on the Eastern Shores and Tewate, and the establishment of pine plantations and associated infrastructure on the Eastern Shores. For ease of interpretation and consistency, colours used to denote a specific vegetation category have been kept identical across images.

5.4.1.1. The Eastern Shores of Lake St Lucia study site

A clear trend exists for the vegetation categories digitised for the site on the Eastern Shores (Table 5.1). Grassland and Scattered Trees decreased in extent from approximately 266 ha (39%) and 249 ha (36%) in 1937 to 61 ha (9%) and 80 ha (11%) in 2000 respectively, whereas Dune Forest increased from 111 ha (16%) in 1937 to 503 ha (73%) in 2000. This can be clearly seen in both Figure 5.4.1 and when comparing Figure 5.4.2 with Figure 5.4.3 and Figure 5.4.4. Dune Forest and Scattered Trees increased at the expense of grassland up to 1975, after which Scattered Trees declined at the expense of

Dune Forest. Scattered Trees increased initially by approximately 10 % but declined rapidly in extent between 1975 and 2000. Grassland made an extremely small recovery (2 %) following a drastic decrease.

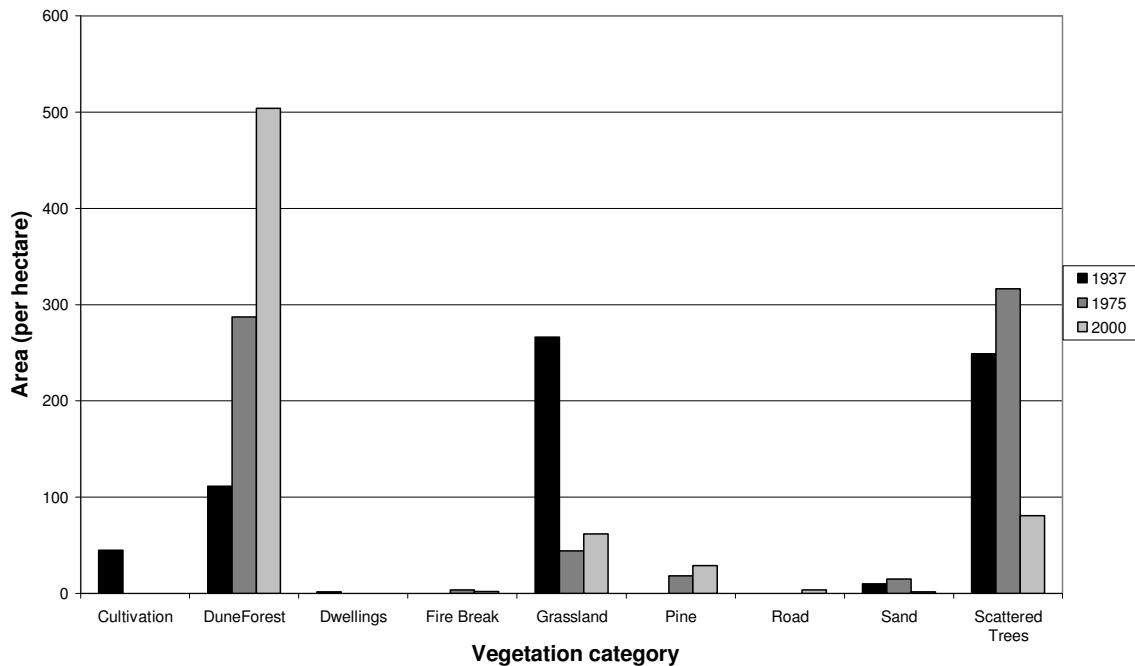


Figure 5.4.1 Differences in area (hectares) for various vegetation categories over three different time intervals on the Eastern Shores of Lake St Lucia, South Africa.

The comparison of vegetation on the Eastern Shores in 1937 (Figure 5.4.2) with that of 1975 (Figure 5.4.3) as well as 1975 with that of 2000 (Figure 5.4.4), highlights the above mentioned trends in vegetation change. These figures depict both the spatial extent and distribution of the various vegetation categories and how these proportions change with management over time. In 1937 (Figure 5.4.2) the Eastern Shores was populated (yellow polygons) by people who practiced extensive shifting agriculture (orange polygons), the impact of which was mainly on the lower lying areas adjacent to the coastal dune ridges. Grassland, including both the drier high-lying grasslands and the lower hygrophilous grasslands (red polygons) were maintained by regular burning in order to provide high quality forage for livestock (Hall 1984). This is a practice still followed in the Ozabeni grasslands close to Sodwana Bay and the grasslands between

Manzengwenya and Kosi Bay. Scattered Trees, comprising large portions of savanna and palm veld, comprised the next greatest area in extent and would require regular disturbance to maintain the open grassland/scattered trees (Sankaran *et al.* 2005). As a consequence of the regular burning, Dune Forests (green polygons) were limited in extent and distribution, being restricted to high-lying dune ridges and where high water table levels prevented intense fires burning through.

Table 5.1 Total area (ha) for the different vegetation categories at three time intervals for the site on the Eastern Shores of Lake St Lucia

	1937	1975	2000
Cultivation	44.74	0.00	0.00
Dune Forest	111.01	287.12	503.77
Dwellings	1.68	0.00	0.00
Fire Break	0.00	3.39	2.08
Grassland	266.30	44.10	61.80
Pine	0.00	18.04	28.76
Road	0.00	0.00	3.45
Sand	9.73	14.98	1.70
Scattered Trees	248.93	316.49	80.78
Total	682.38	684.12	682.34

By 1975 (Figure 5.4.3) the local population, along with their cattle and associated burning and agricultural practices, had been progressively relocated (complete removal in 1956) to make way for a combination of conservation and the establishment of pine plantations (pink polygons) primarily for pulp wood (Thompson 1991). Immediately evident in comparison to 1937 is the reduction in Grassland (red polygons) and expansion of both Scattered Trees (blue polygons) and Dune Forest (green polygons). By 2000 (Figure 5.4.4) the reduction in burning and the establishment of a second pine plantation immediately south of the study area was firmly entrenched. Dune Forest showed a further increase to become the dominant land cover for the study area. There has being little change in the extent of Grassland, however Scattered Trees has been largely transformed and drastically reduced when compared to previous extents.

The above presents a clear transition from a system maintained by disturbance (fire) and dominated by Grassland through to one of less severe disturbance and dominated by Scattered Trees, a precursor to Dune Forest. The establishment of this trend is important

when considering the implementation of management practices. An understanding however of those areas remaining constant over time versus those changing through to different vegetation categories would provide additional understanding behind this trend in vegetation succession and greatly assist management.

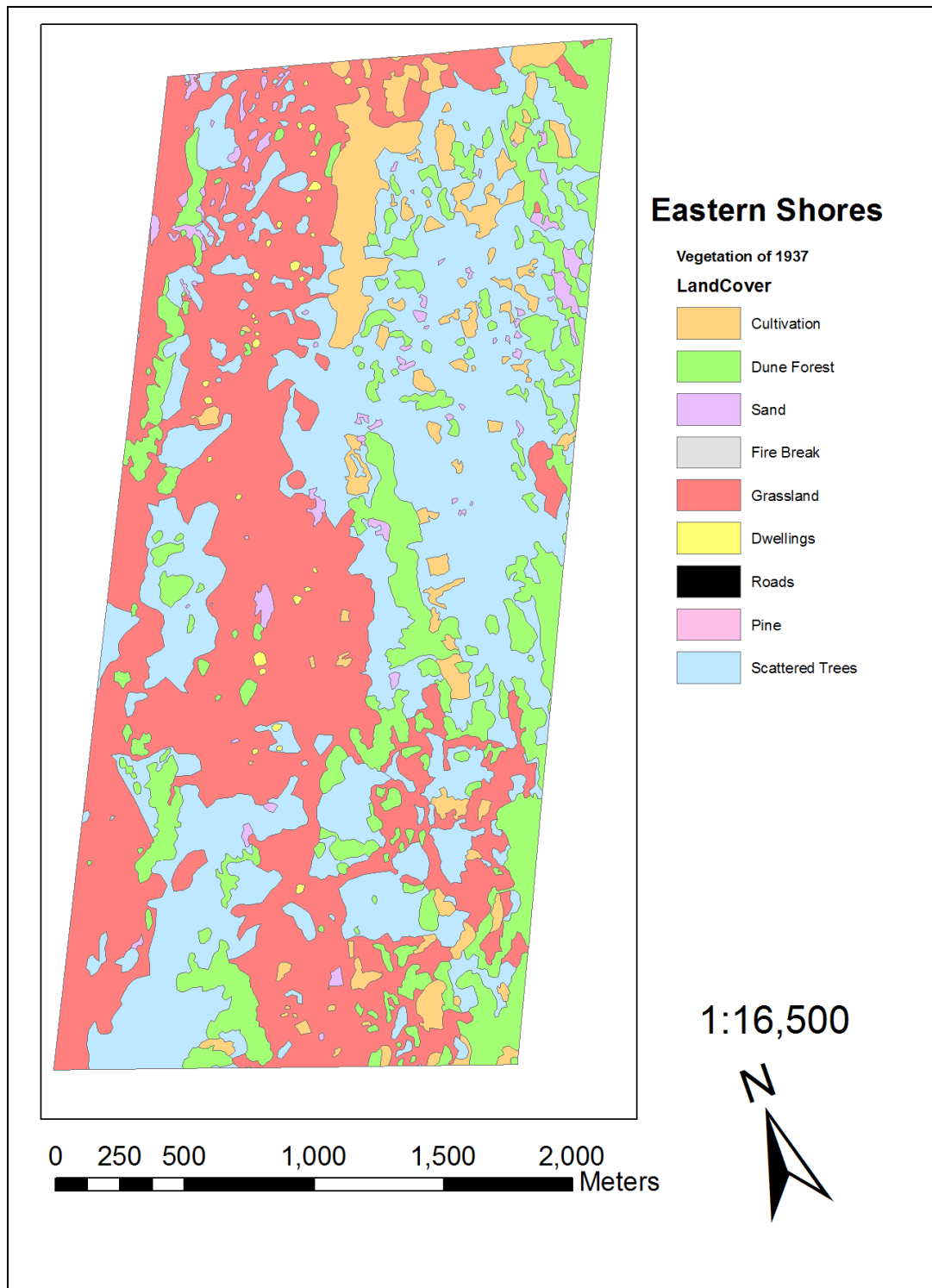


Figure 5.4.2 Site on the Eastern Shores of Lake St Lucia (1937) with different vegetation categories digitized.

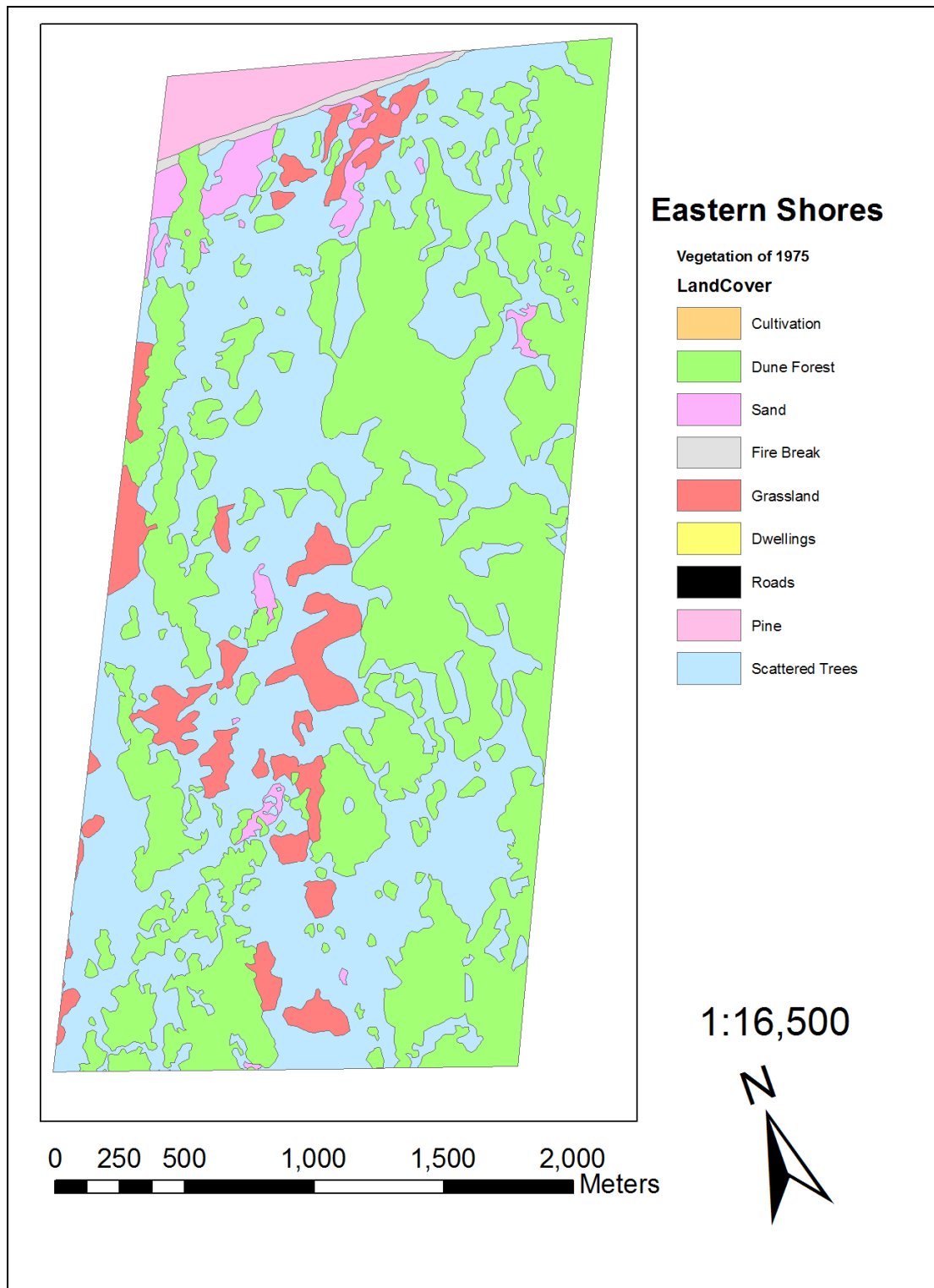


Figure 5.4.3 Site on the Eastern Shores of Lake St Lucia (1975) with different vegetation categories digitized.

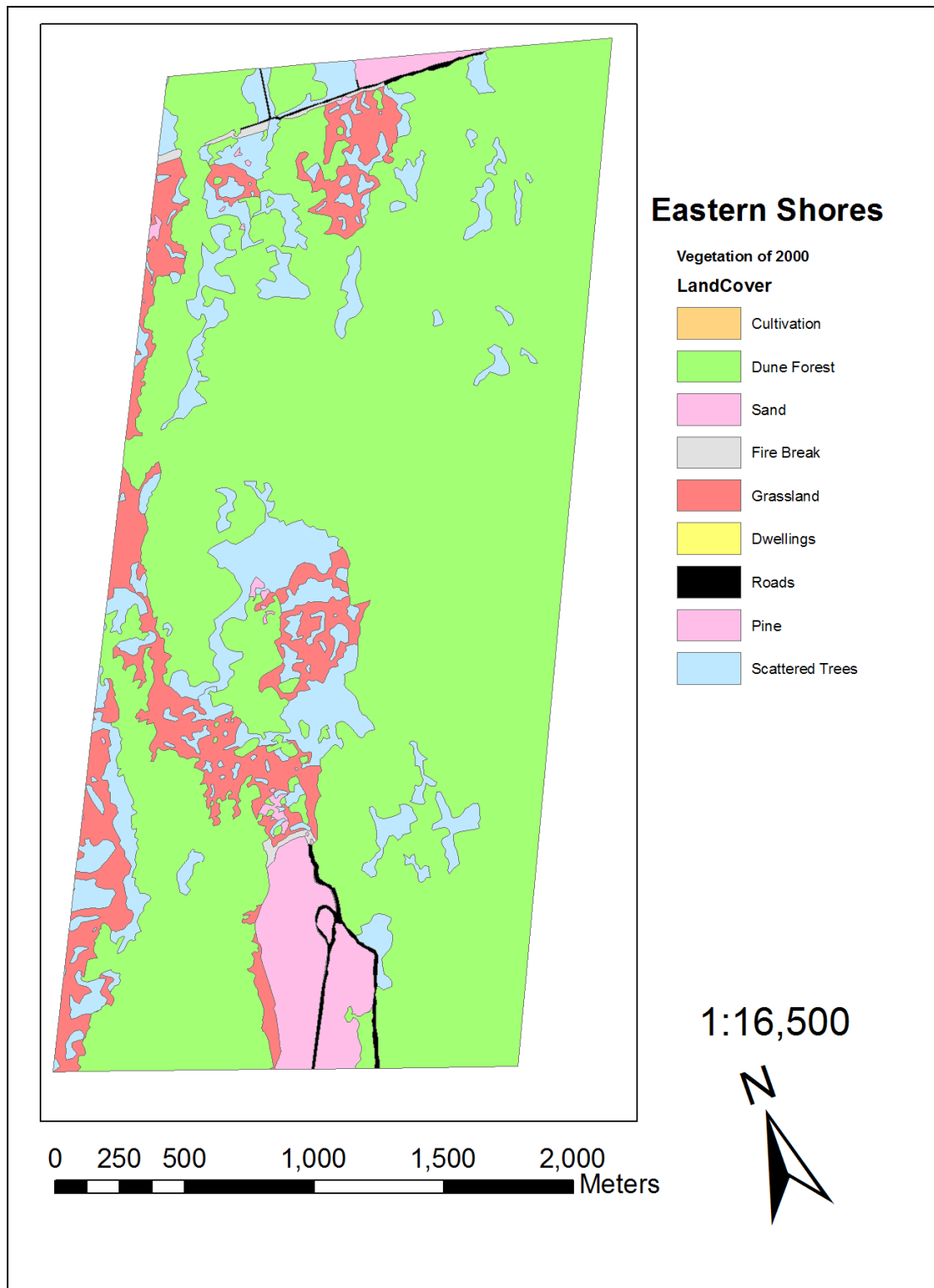


Figure 5.4.4 Site on the Eastern Shores of Lake St Lucia (2000) with different vegetation categories digitized.

5.4.2. Landcover without change over time for the Eastern Shores

The area of vegetation remaining constant between the time intervals studied and the relative change in this area (expressed as a percentage of previous extent) across intervals can be a useful indication of transformation. For example, from Figure 5.4.5 which summarises the percentage area per vegetation category remaining constant between the time intervals, it becomes evident that of the three dominant vegetation categories, Dune Forest has the greatest percentage area remaining constant. This percentage has increased during the second time period (nearly doubling) and indicates a continual expansion and entrenchment of Dune Forest within the system.

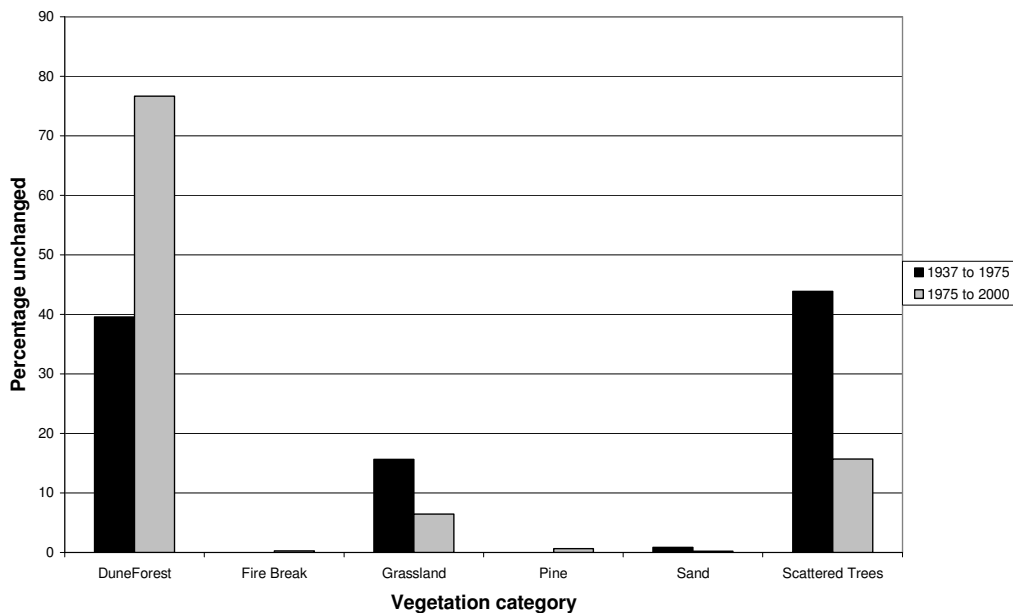


Figure 5.4.5 Total areas (expressed as a percentage) remaining constant (unchanged) for different vegetation categories and time intervals on the Eastern Shores, South Africa.

Grassland has an opposite trend where a small percentage remains unchanged between 1937 and 1975 and in the second time interval (compared with 1975) this percentage continues to decrease. Scattered Trees follows a similar trend to Grassland, where increases in area from 1937 to 1975 (Table 5.1) have resulted in a greater percentage unchanged but recruitment into a closed canopied dune forest between 1975 and 2000 resulted in an ultimate reduction in percentage extent left unchanged. This is

further depicted visually in spatial extent and distribution in Figure 5.4.6 and Figure 5.4.7.

Comparing these two figures reveals the drastic increase in Dune Forest remaining unchanged between 1975 and 2000. It is also interesting to note that this area increases more for the eastern part of the study area when compared with the western side. This study area covers the lower lying hygrophilous areas to the west near Lake St Lucia and the higher lying dune cordon to the east. This increase can be attributed to an inferred reduction in soil moisture for these higher lying sections to the east. Therefore, with the active exclusion of fire due to the establishment of pine plantations north and south of the study area, the areas remaining Grassland (Red) are confined to the lower lying sections in the west. These are more than likely only remaining as a result of periodic inundation precluding woody species from establishing. Scattered Trees are also greater in area unchanged for eastern sections where these have been transformed to predominantly Dune Forest by the second time period. Ultimately the extent of Grassland is considerably reduced becoming greatly fragmented by Scattered Trees which in turn proceed through to a closed canopy due to changes in the disturbance regime.

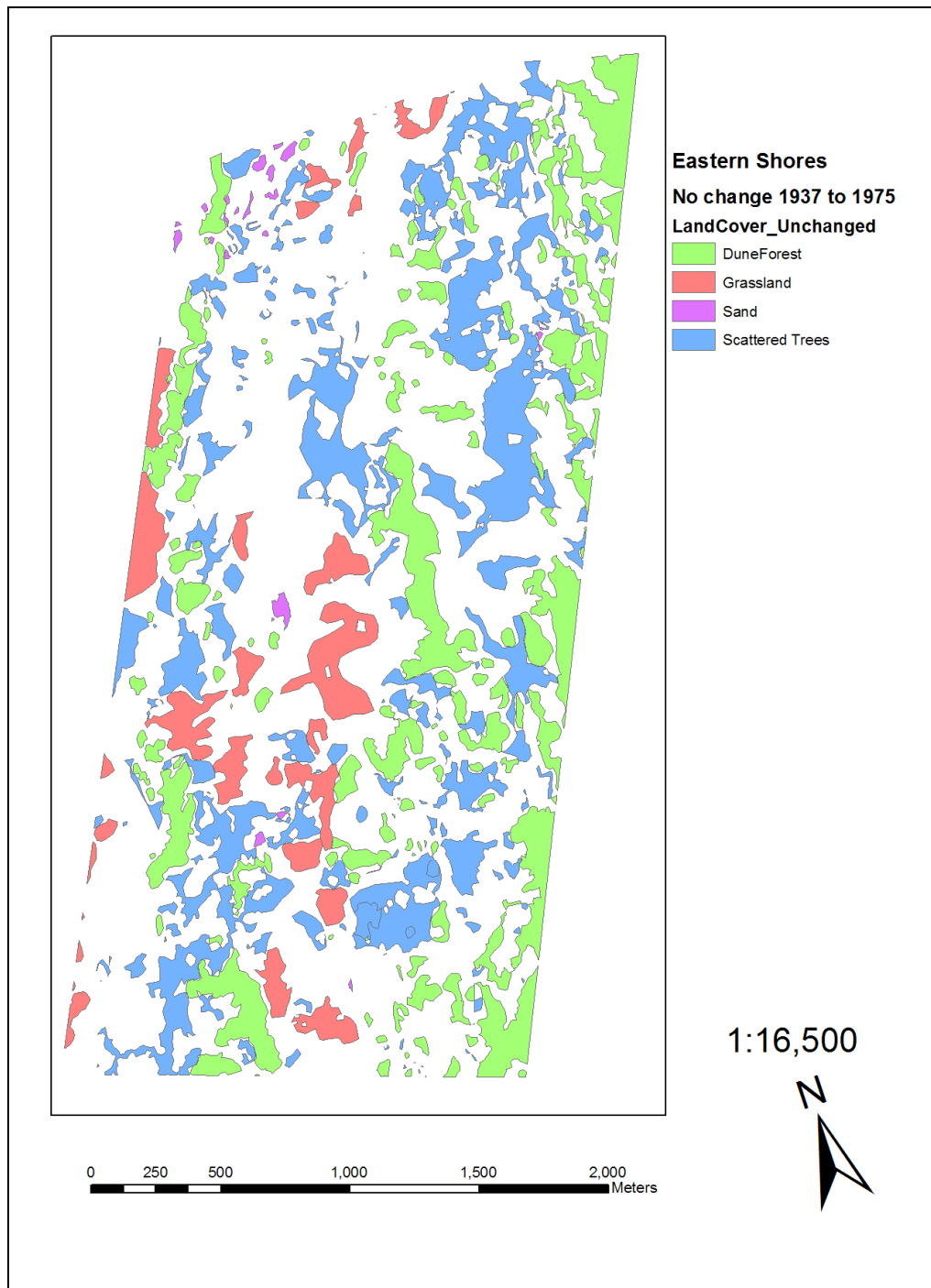


Figure 5.4.6 Vegetation categories remaining constant in extent from 1937 to 1975 for a study area on the Eastern Shores, South Africa.

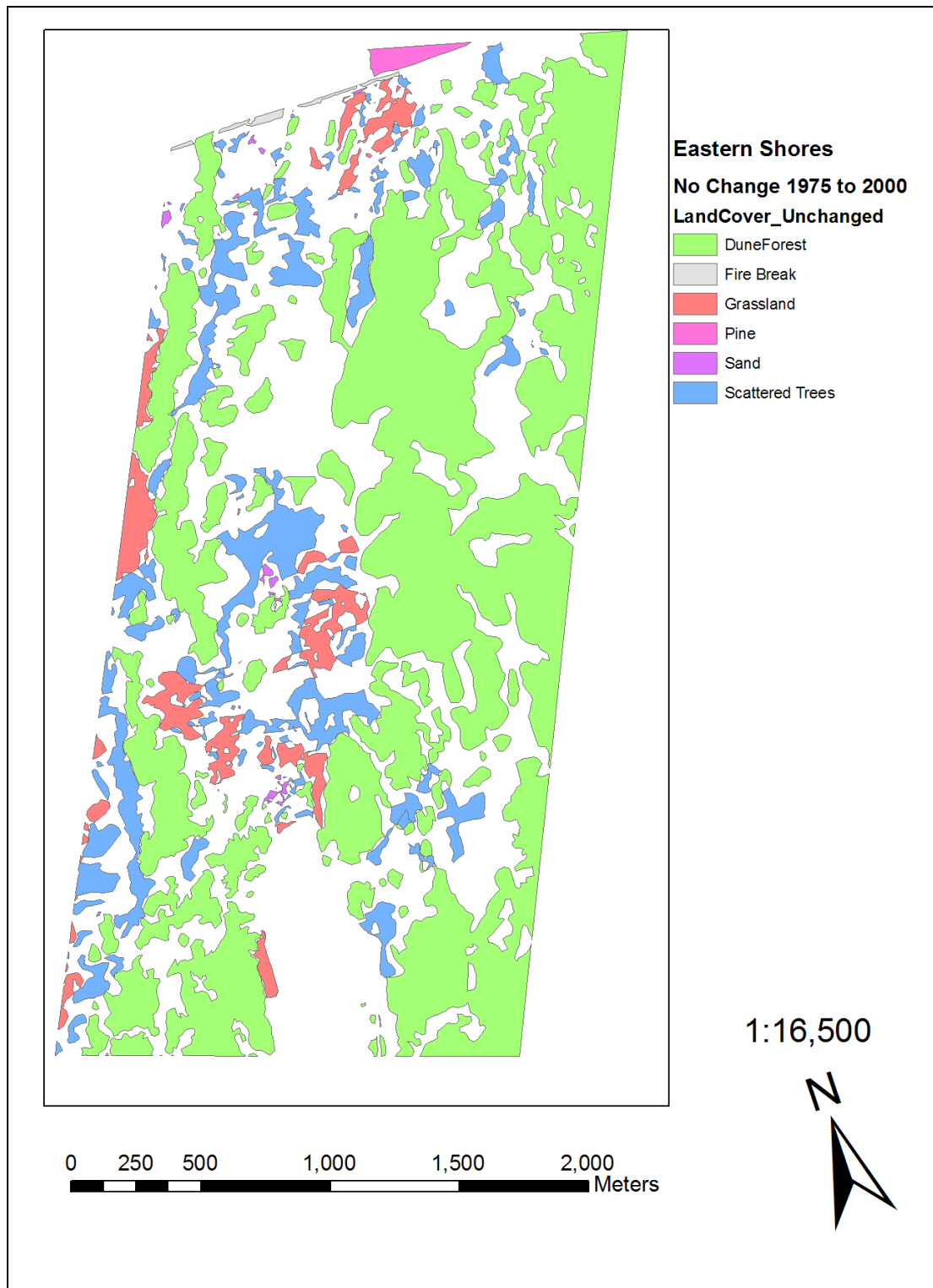


Figure 5.4.7 Vegetation categories remaining constant in extent from 1975 to 2000 for a study area on the Eastern Shores, South Africa.

5.4.2.1.Landcover change over time for the Eastern Shores

Although areas of vegetation remaining constant over time are a good indication of which particular vegetation category is persisting and increasing into the following period, it does not indicate to what category the areas changing are changing too. For this reason only areas changing over time were selected and were reclassified to express the original vegetation category plus the present category it has changed too (Table 5.2 and Table 5.3) and the associated areas. This enhances the understanding of each vegetation category and to which category the greatest change is occurring and therefore highlights broad successional trends in vegetation establishment.

Table 5.2 summarises this change according to the reclassified categories from 1937 to 1975 on the Eastern Shores of Lake St Lucia. Addressing the categories sequentially, Cultivation changed primarily through to Scattered Trees and Dune Forest, with a small proportion (4 ha) changing to Grassland. Some change did occur to Dune Forest with the greatest change occurring through to Scattered Trees (10 ha). However, the greatest change occurred to the Grassland where change was largely through to Dune Forest (34 ha). This is better depicted visually in Figure 5.4.8.

Table 5.2 Change in area for reclassified vegetation categories from 1937 to 1975 for the study area on the Eastern Shores, South Africa. Categories 1, 2, 3, 10, & 19 (bolded and italicized) were excluded from analysis and are a result of errors with digitizing

	Vegetation Category	Area (m ²)	Area (Ha ⁻¹)
1	<i>Dune Forest</i>	1.02	0.00
2	<i>Sand</i>	0.01	0.00
3	<i>Scattered Trees</i>	2.62	0.00
4	Cultivation to Dune Forest	153889.93	15.39
5	Cultivation to Fire Break	5138.73	0.51
6	Cultivation to Grassland	38127.45	3.81
7	Cultivation to Pine	8420.70	0.84
8	Cultivation to Sand	30513.93	3.05
9	Cultivation to Scattered Trees	211321.88	21.13
10	<i>Dune Forest</i>	7.76	0.00
11	Dune Forest to Grassland	635.87	0.06
12	Dune Forest to Pine	2453.73	0.25
13	Dune Forest to Sand	2163.75	0.22
14	Dune Forest to Scattered Trees	107741.77	10.77
15	Dwellings to Dune Forest	2798.56	0.28

	Vegetation Category	Area (m ²)	Area (Ha ⁻¹)
16	Dwellings to Grassland	229.31	0.02
17	Dwellings to Pine	777.00	0.08
18	Dwellings to Scattered Trees	12981.38	1.30
19	Grassland	0.30	0.00
20	Grassland to Dune Forest	338223.86	33.82
21	Grassland to Fire Break	22449.38	2.24
22	Grassland to Pine	133432.95	13.34
23	Grassland to Sand	77550.63	7.76

In comparison, changes in vegetation categories from 1975 to 2000 are very different. From Table 5.2 small changes have occurred within the Dune Forest and other categories (e.g. Fire Break, Pine, and Sand). Grassland has continued to be encroached by Scattered Trees although in a decreasing amount (10 ha). The greatest change has occurred however, for Scattered Trees, changing through to Dune Forest (205 ha). This is clearly depicted when comparing Figure 5.4.8 with Figure 5.4.9 indicated by a dominance in the shade of blue and a reduction in the diversity of colour from Figure 5.4.9 when compared to Figure 5.4.8.

It is important to note the absence of green shades from both figures where the presence of this colour would indicate Dune Forest changing through to a different category. This is certainly not the observed for either time period. Also, note the location of the shades representing the vegetation categories Grassland (shades of Red) and Scattered Trees (shades of blue). Between 1937 and 1975 the majority of the areas comprising Scattered Trees succeeded through to Dune Forest (Blue) and the lower lying sections of Grassland through to Scattered Trees (Red). However, between 1975 and 2000 the majority of the higher lying sections to the east were dominated by Dune Forest which remained unchanged. Change was therefore confined to the lower lying sections which were previously Grassland but encroached by Scattered Trees. This encroachment continued through to Dune Forest.

Table 5.3 Change in area for reclassified vegetation categories from 1975 to 2000 for the study area on the Eastern Shores, South Africa. Categories 1, 2, 9, 16, 23 & 28 (bolded and italicized) were excluded from analysis and are a result of errors with digitizing

	Vegetation Category	Area (m ²)	Area (Ha ⁻¹)
1	<i>Dune Forest</i>	<i>8.06</i>	<i>0.00</i>
2	<i>Dune Forest</i>	<i>21.62</i>	<i>0.00</i>
3	Dune Forest to Fire Break	217.19	0.02
4	Dune Forest to Grassland	12982.39	1.30
5	Dune Forest to Pine	4385.23	0.44
6	Dune Forest to Road	2977.54	0.30
7	Dune Forest to Sand	1062.26	0.11
8	Dune Forest to Scattered Trees	26799.58	2.68
9	<i>Fire Break</i>	<i>2.72</i>	<i>0.00</i>
10	Fire Break to Dune Forest	3599.29	0.36
11	Fire Break to Grassland	3283.60	0.33
12	Fire Break to Pine	5082.66	0.51
13	Fire Break to Road	6020.56	0.60
14	Fire Break to Sand	716.93	0.07
15	Fire Break to Scattered Trees	4067.22	0.41
16	<i>Grassland</i>	<i>142.05</i>	<i>0.01</i>
17	Grassland to Dune Forest	40752.23	4.08
18	Grassland to Fire Break	3737.31	0.37
19	Grassland to Pine	51278.72	5.13
20	Grassland to Road	3763.80	0.38
21	Grassland to Sand	256.14	0.03
22	Grassland to Scattered Trees	103173.39	10.32
23	<i>Pine</i>	<i>0.01</i>	<i>0.00</i>
24	Pine to Dune Forest	108730.65	10.87
25	Pine to Fire Break	1881.66	0.19
26	Pine to Road	2303.80	0.23
27	Pine to Scattered Trees	44686.34	4.47
28	<i>Sand</i>	<i>4.37</i>	<i>0.00</i>
29	Sand to Dune Forest	23424.54	2.34
30	Sand to Fire Break	83.01	0.01
31	Sand to Grassland	64340.92	6.43
32	Sand to Pine	1356.40	0.14
33	Sand to Scattered Trees	51503.71	5.15
34	<i>Scattered Trees</i>	<i>362.94</i>	<i>0.04</i>
35	Scattered Trees to Dune Forest	2054131.44	205.41
36	Scattered Trees to Fire Break	3797.52	0.38
37	Scattered Trees to Grassland	299273.36	29.93
38	Scattered Trees to Pine	202592.79	20.26
39	Scattered Trees to Road	19498.81	1.95
40	Scattered Trees to Sand	5940.50	0.59

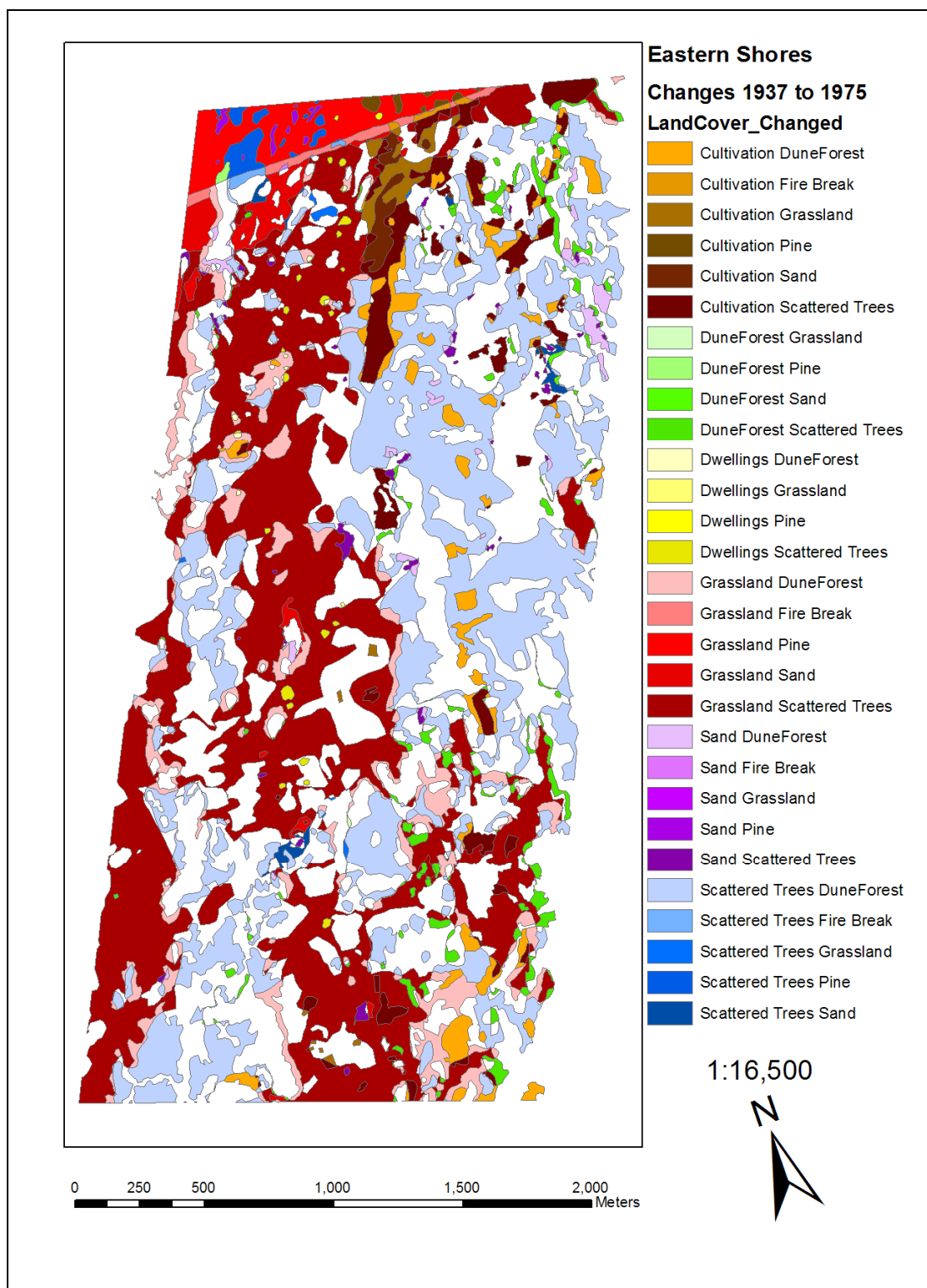


Figure 5.4.8 Reclassified vegetation categories changing in extent from 1937 to 1975 for a study area on the Eastern Shores, South Africa.

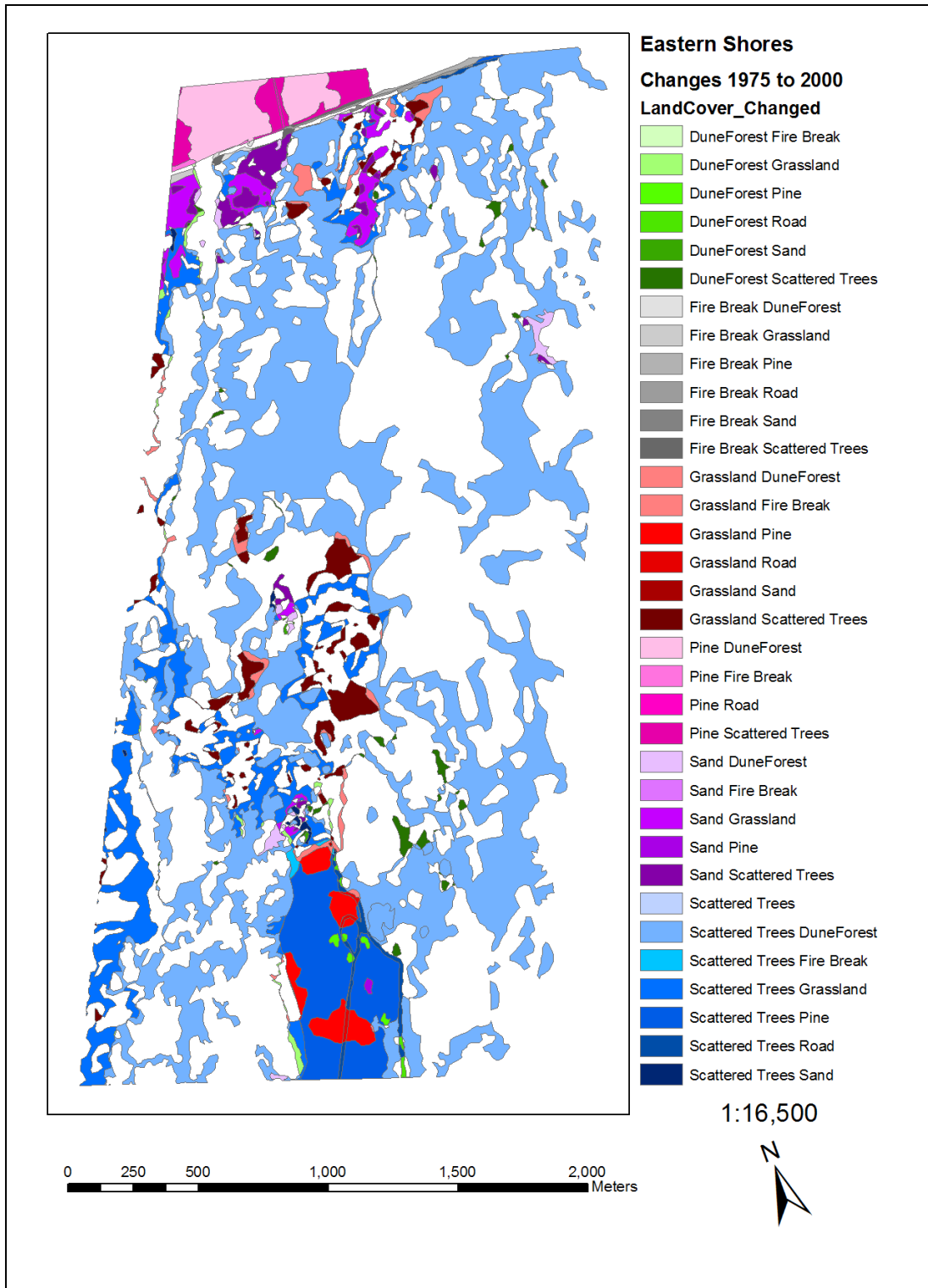


Figure 5.4.9 Reclassified vegetation categories changing in extent from 1975 to 2000 for a study area on the Eastern Shores, South Africa.

5.4.2.2. The Tewate Wilderness study area

As with the site on the Eastern Shores, a clear trend exists with the site on the Tewate Wilderness Area (Table 5.4) however, changes in areas for the different vegetation categories are more consistent (Figure 5.4.10). In contrast to the Eastern Shores, a greater percentage of the area within Tewate was under Cultivation in 1937 (59 ha versus 45 ha) however, a smaller area was apportioned to Dwellings and therefore (through inference) a smaller population was present (Refer to Figure 5.4.11). Between 1937 and 1975 the Tewate Wilderness Area was proclaimed (1956) with the main aim of preserving the environmental and biological diversity indicative of the region (Porter *et al.* 1999). Management intervention for this area was minimal with burning being allowed to continue naturally and not actively excluded often spreading from areas north or south depending on wind conditions and fire intensities. It is unclear how effective exclusion of human utilisation for this area was and whether grazing and cultivation continued past 1956. Certainly by comparing the three years, 1937, 1975, and 2000 (Figure 5.4.11, Figure 5.4.12, and Figure 5.4.13, respectively) it is possible to see sections of the Dune Forest having being disturbed and progressing to Scattered Trees. The cause for this is unknown but is similar to the pattern of cultivation observed for 1937 in the Dune Forest.

Table 5.4 Total area (per hectare) for the different vegetation categories and time intervals for the site within the Tewate Wilderness Area, South Africa

	1937	1975	2000
Cultivation	58.89	0.00	0.00
Dune Forest	732.12	865.02	981.04
Dwellings	0.74	0.00	0.00
Grassland	1615.73	1209.14	969.87
Sand	3.83	3.33	1.05
Scattered Trees	537.23	870.56	997.15
Total	2948.53	2948.05	2949.12

It is important to reiterate differences between the study area for the Eastern Shores and Tewate Wilderness Area. These relate to area covered where the latter is greater in extent. As a result a greater portion of the hygrophilous grassland has been incorporated in the analysis of change in areas. As a result the Tewate Wilderness study site can be

considered 'wetter' compared and more influenced by ground water tables. These differences need to be considered when compared sites.

Grassland was the dominant vegetation category in 1937, however this category decreased in extent from approximately 1615 ha (55%) to 970 ha (33%) in 2000. Dune Forest and Scattered Trees increased consistently from 732 ha (25%) and 537 ha (18%) in 1937 to 981 ha (33%) and 997 ha (33%) in 2000 respectively. The three dominant categories therefore were approximately equal in their extent in 2000. Compared with the Eastern Shores where Dune Forest increased to dominate 60 % of the vegetation these increases within Tewate are minimal. Also interesting to note is the difference in change to Scattered Trees and Grassland. For the Eastern Shores Scattered Trees increased and then decreased with a change through to Dune Forest and Grassland decreased drastically. Within the Tewate Wilderness Area this change was not as drastic or as large. Although Dune Forest increased as did Scattered Trees, Grassland decreased less abruptly. This difference still indicates the natural progression of these coastal grasslands through to a woody dominated vegetation type but in the presence of regular disturbance, largely by fire, this change is not as rapid and complete.

Figure 5.4.10 depicts this trend in vegetation change and comparing this with that observed for the Eastern Shores (Figure 5.4.1), establishes a similar trend where Grassland is decreasing in extent whilst Scattered Trees and Dune Forest is increasing. However, the magnitude and severity of change is considerably different within Tewate when compared with that seen on the Eastern Shores. Of importance is that the Grassland vegetation category has remained interlinked and not become fragmented. This relative change is best observed through comparing Figure 5.4.11 with Figure 5.4.12 and Figure 5.4.13. Note the similarity between the three years in comparison to the Eastern Shores.

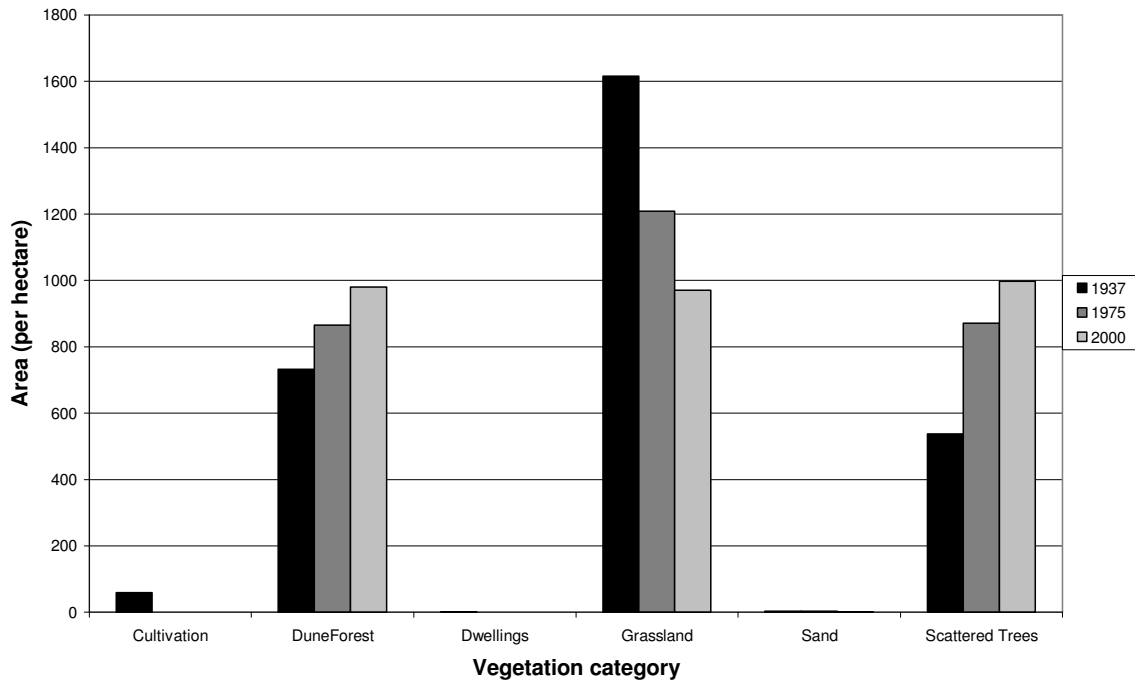


Figure 5.4.10 Differences in area (per hectare) for various vegetation categories over three different time intervals within the Tewate Wilderness Area.

As with the Eastern Shores (outlined in Section 5.4.1.1 above), local inhabitants would have increased disturbance and promoted the establishment of the dominant Grassland category through burning regimes to improve grazing and clearing land for their shifting agricultural practices, thus limiting the establishment and expansion of the Dune Forest. By 1956 all human habitation and disturbance would have been removed, however total exclusion of fire, as with the Eastern Shores due to the establishment of pine plantations, was not actively enforced. This area was therefore more than likely exposed to a greater fire frequency in comparison to that experienced on the Eastern Shores and with fires left unattended would inevitably result in greater areas burnt (Thompson 1996).

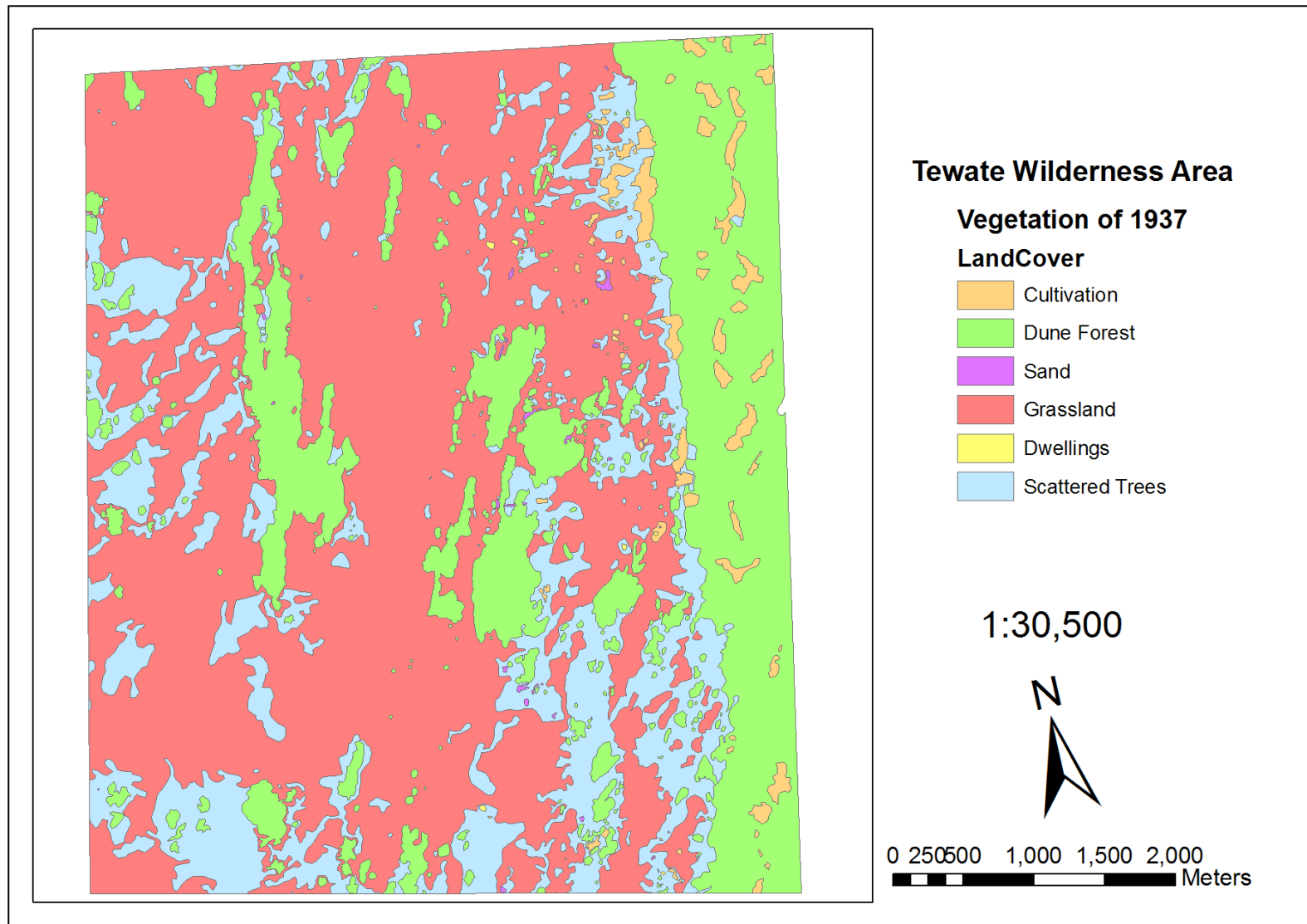


Figure 5.4.11 Site within the Tewate Wilderness Area (1937) with different vegetation categories digitized.

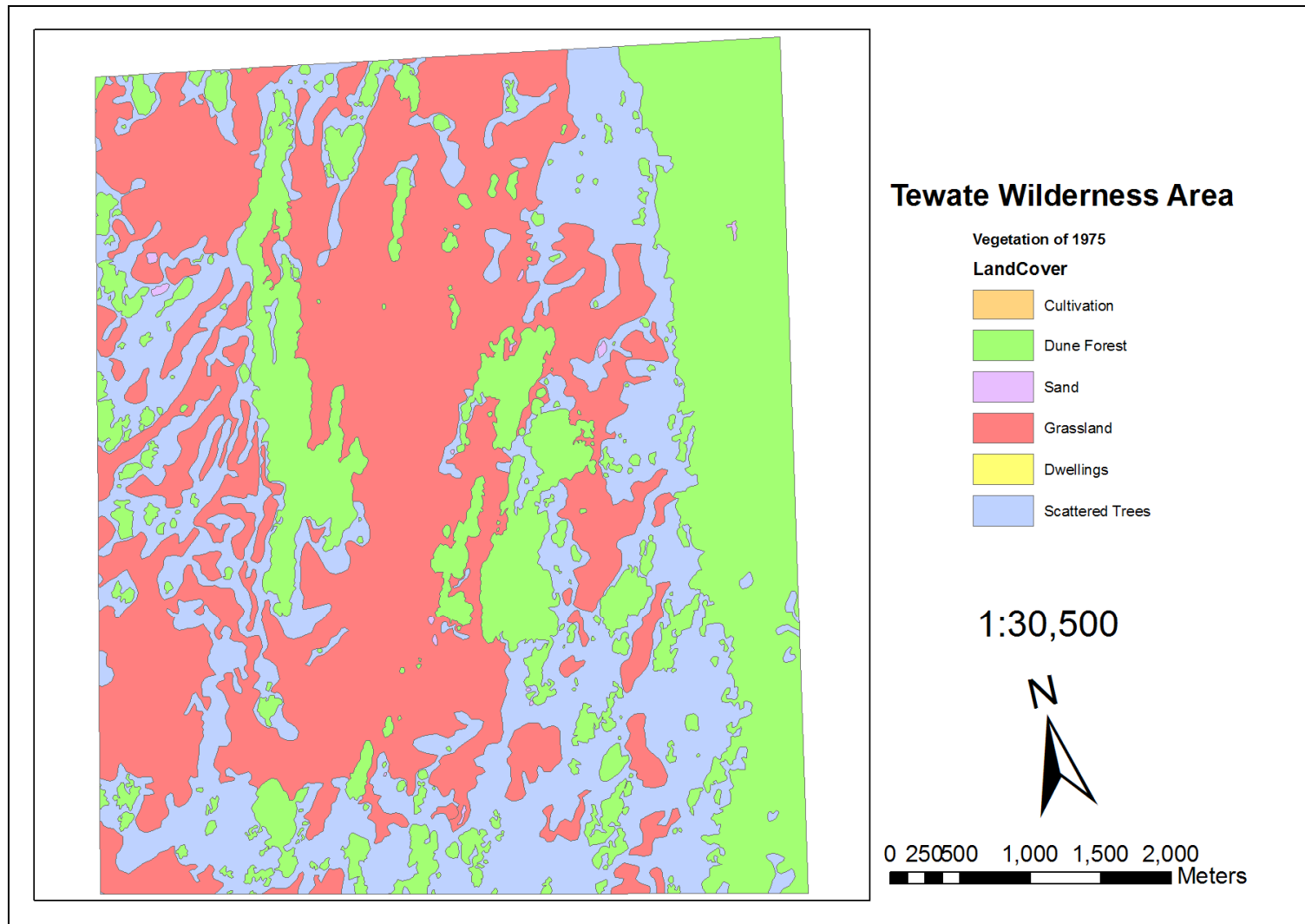


Figure 5.4.12 Site within the Tewate Wilderness Area (1975) with different vegetation categories digitized.

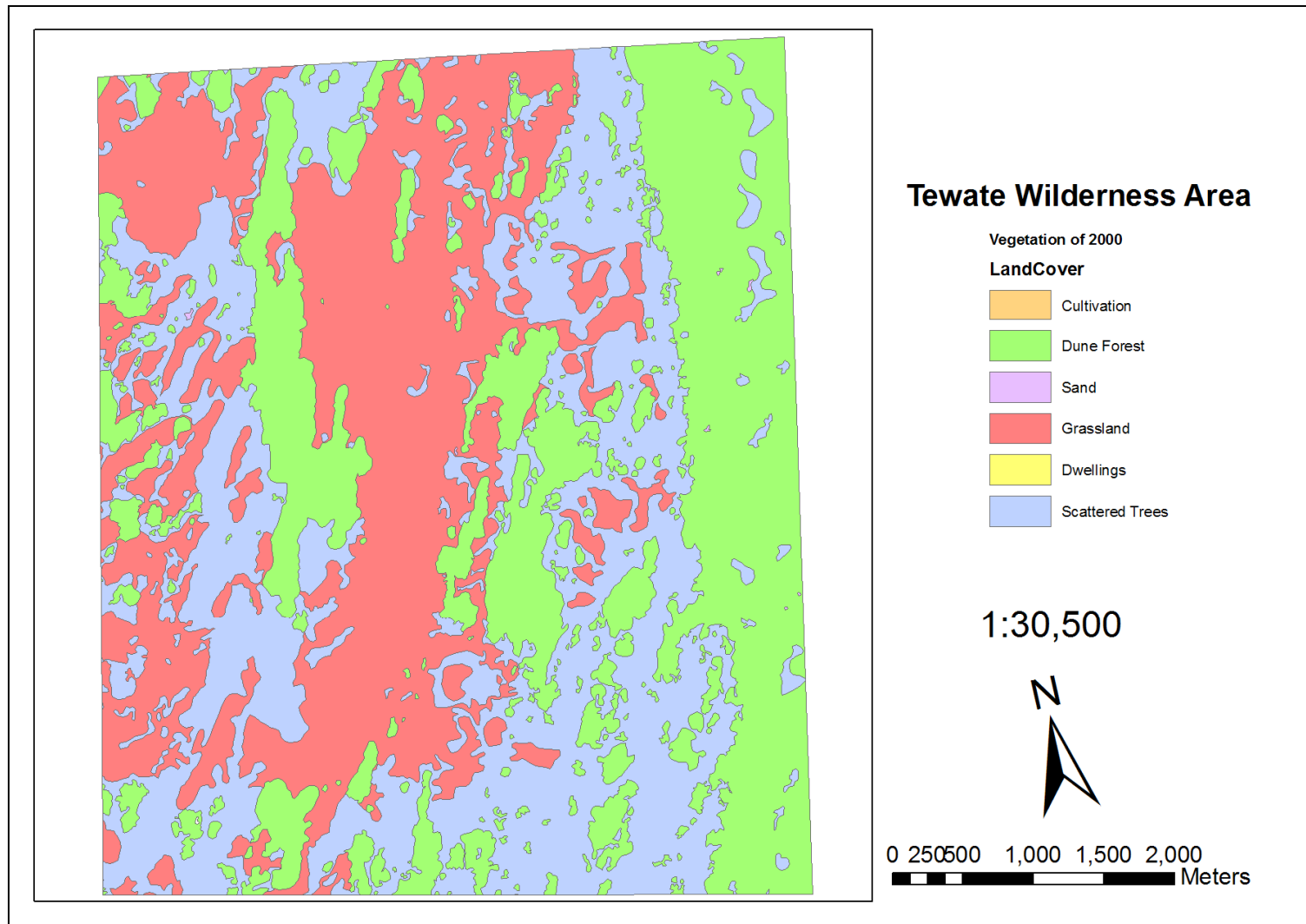


Figure 5.4.13 Site within the Tewate Wilderness Area (2000) with different vegetation categories digitized.

5.4.2.3. Landcover without change over time for the Tewate Wilderness Area

Extracting areas remaining unchanged between 1937 and 1975, and 1975 and 2000 reveals a very different pattern compared with the study area for the Eastern Shores. The percentage area per vegetation category remaining constant between time intervals is presented in Figure 5.4.14. Unlike the response for the Eastern Shores, Grassland has the greatest percentage area remaining for both time periods. This percentage was reduced for the time period 1975 to 2000. Here both Scattered Trees and Dune Forest increased at the expense of Grassland but at no point did the percentage area remaining unchanged increase above that for Grassland. Grassland therefore remained the least transformed vegetation category within the Tewate Wilderness Area.

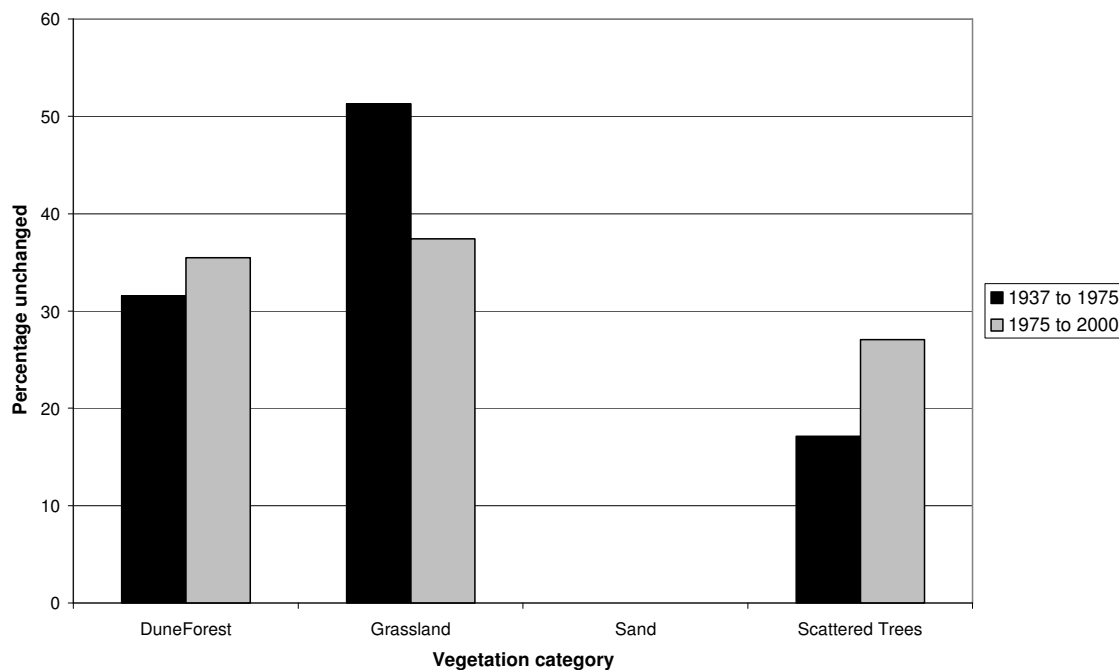


Figure 5.4.14 Total areas (expressed as a percentage) remaining constant (unchanged) for different vegetation categories and time intervals within the Tewate Wilderness Area, South Africa.

The areas remaining unchanged for the different vegetation categories and two time intervals have been extracted and presented in Figure 5.4.15 and Figure 5.4.16. Comparing these two figures highlights visually what has been established graphically in Figure 5.4.14. Across the study area for both time intervals the vegetation categories remain largely untransformed with Grassland occupying the greatest area. Examining the two time intervals closely reveals very little change in an east/west gradient. It is unclear the degree of similarity between the two study areas in terms of topography and other environmental factors such as proximity to ground water, however, there is certainly a gradient from lower lying hygrophilous grasslands in the west and higher lying dune ridges to the east. Quite contrary across this east/west gradient all three major vegetation categories remained largely unchanged with no clear difference in response being observed.

Scattered Trees has visibly increased for some of the southeast sections where previously fragmented Grassland has been effectively transformed. These sections are more comparable with the site on the Eastern Shores. Dune Forest however shows very little change. This apparent equilibrium is being maintained by presumably anthropogenic and 'natural' fire regimes and high water tables. Geographically these areas are not greatly separated (approximately 15km apart) and have been mapped to be similar in topography. The major difference between these two sites is scale where the Tewate site is larger and therefore covers more of the hygrophilous grassland. It is unlikely that mean annual precipitation would vary tremendously over this distance. What is not clear is the frequency of the use of fire particularly for the second time interval between 1975 and 2000.

On the Eastern Shores where fire was actively prevented, change in vegetation category was immediate and substantially noticeable. Although pine plantations were not established within the Tewate Wilderness area and fire not actively prevented, human habitation occurred after 1956. From the small difference between the two time periods it is possible to conclude that fire regimes continued as per usual. These management regimes promoted the persistence of Grassland for this area.

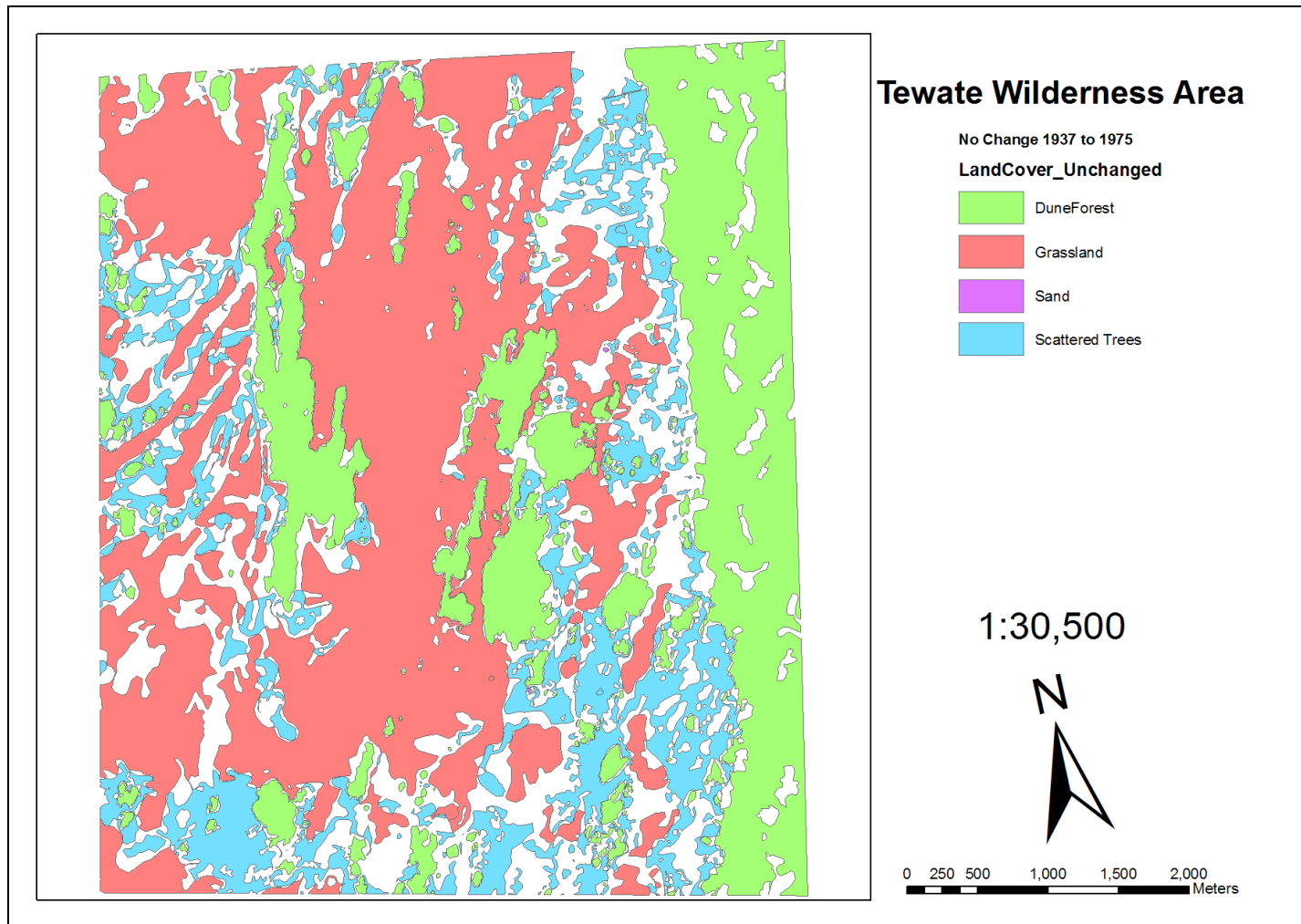


Figure 5.4.15 Vegetation categories remaining constant in extent from 1937 to 1975 for a study area within the Tewate Wilderness Area, South Africa.

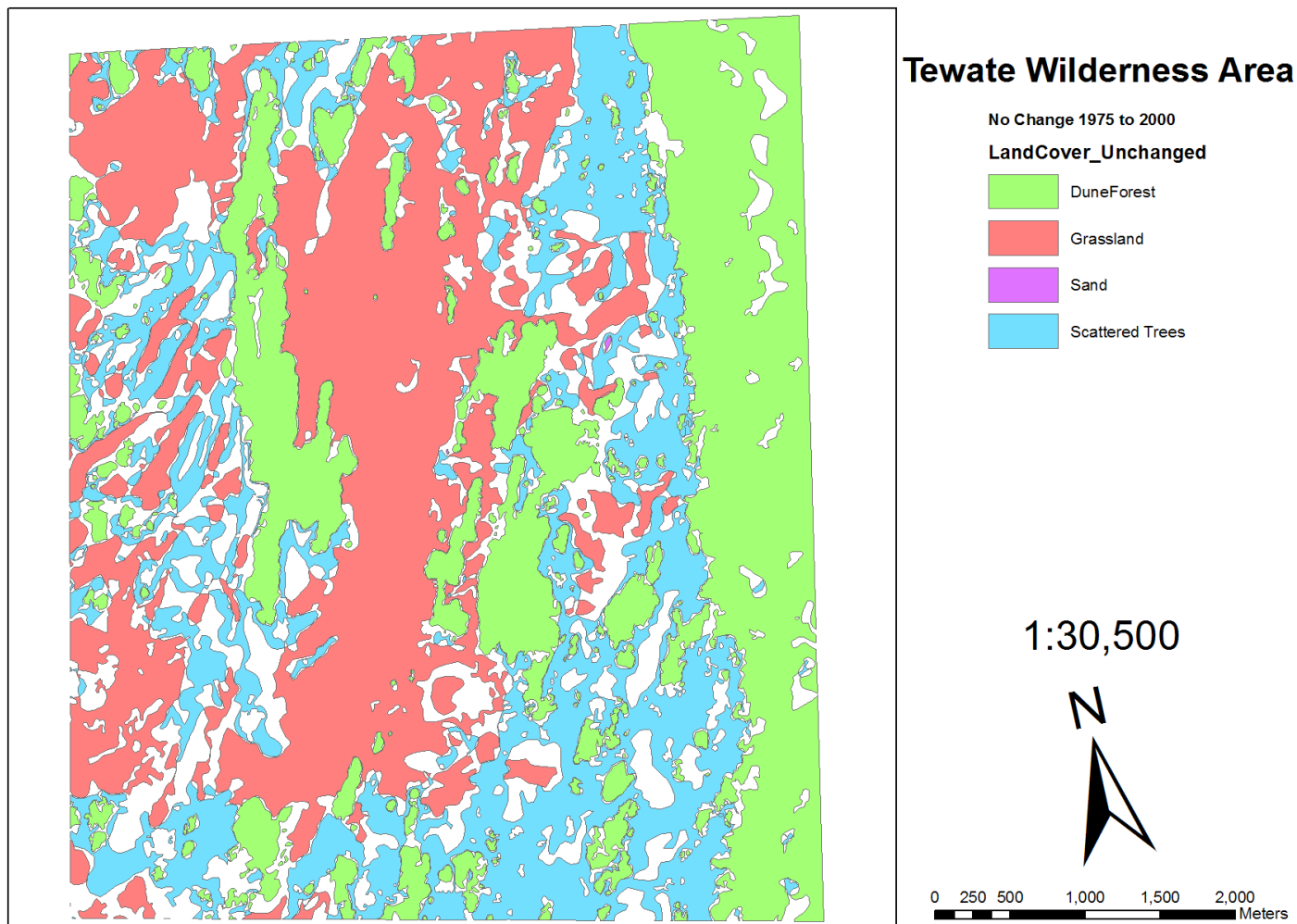


Figure 5.4.16 Vegetation categories remaining constant in extent from 1975 to 2000 for a study area within the Tewate Wilderness Area, South Africa.

5.4.2.4.Landcover change over time for the Tewate Wilderness Area

The areas for the vegetation categories changing over time have been extracted as for areas remaining unchanged in section 5.4.2.3 above. Original vegetation category as well as current category for that time period has been included to generate a unique name identifying the various areas for classification. This permits understandings surrounding the vegetation categories changing and direction of this change. Table 5.5 summarises the vegetation categories changing for the time period 1937 to 1975 for the Tewate Wilderness Area. These reclassified categories have been grouped according to the vegetation category for 1937. Referring to this table, the majority of Cultivation has changed through to Dune Forest (39.73 ha of the 41.03 ha) with smaller sections progressing to Grassland and Scattered Trees. Interestingly, Dune Forest has changed and this was predominately through to Scattered Trees (30.43 ha). Grassland underwent the largest transformation changing through to Scattered Trees (443.49 ha) and Dune Forest (37.23 ha). However this reduction in Grassland was not accompanied by sizeable increases in Dune Forest and therefore Grassland continued to dominate area. Scattered Trees changed to greater degree to Dune Forest (90.11 ha) however a large portion of this area progressed to Grassland (67.65 ha). This has been presented visually in Figure 5.4.17.

Therefore, between 1937 and 1975 the change to vegetation category was concerned largely with a change of Grassland to Scattered Trees, Scattered Trees to Dune Forest, and Scattered Trees to Grassland. Cultivation, previous Dwellings, and exposed areas of Sand reverted more readily through to Scattered Trees as opposed to Grassland. Disturbance would therefore appear to promote woody encroachment which is greater for high lying sections above the influence of the water table.

Table 5.5 Change in area for reclassified vegetation categories from 1937 to 1975 for the study area within the Tewater Wilderness Area, South Africa. Categories 1, 2, 3, & 21 (bolded and italicized) were excluded from analysis and are a result of errors with digitizing

	Vegetation Category	Area (m ²)	Area (Ha ⁻¹)
1	<i>Dune Forest</i>	5.46	0.00
2	<i>Grassland</i>	1.48	0.00
3	<i>Scattered to Trees</i>	9.23	0.00
4	<i>Beach Sand to Dune Forest</i>	4428.03	0.44
5	Cultivation to Dune Forest	397370.89	39.74
6	Cultivation to Grassland	9053.37	0.91
7	Cultivation to Sand	3811.31	0.38
8	Cultivation to Scattered Trees	178690.91	17.87
9	Dune Forest to Grassland	61438.53	6.14
10	Dune Forest to Sand	59.10	0.01
11	Dune Forest to Scattered Trees	304298.50	30.43
12	Dwellings to Dune Forest	7.76	0.00
13	Dwellings to Grassland	1367.96	0.14
14	Dwellings to Scattered Trees	6031.24	0.60
15	Grassland to Dune Forest	372275.67	37.23
16	Grassland to Sand	17049.09	1.70
17	Grassland to Scattered Trees	4434913.74	443.49
18	Sand to Dune Forest	6743.35	0.67
19	Sand to Grassland	4414.91	0.44
20	Sand to Scattered Trees	19232.00	1.92
21	<i>Scattered Trees</i>	5.52	0.00
22	Scattered Trees to Dune Forest	901147.16	90.11
23	Scattered Trees to Grassland	676492.54	67.65
24	Scattered Trees to Sand	8917.38	0.89

Table 5.6 summarises the vegetation categories changing for the second time period from 1975 to 2000. The trends for this time period are almost identical to that of the previous period. The greatest change to area has occurred for Grassland being transformed to Scattered Trees (328.65 ha). The next greatest change in area was for Scattered Trees to Dune Forest (145.67 ha) and Scattered Trees to Grassland (98.11 ha). The number of reclassified categories was reduced for this second time period due to the exclusion of people from this area and therefore previous areas cultivated for crops were no longer visible.

Therefore, for this second time period (1975 to 2000) changes to vegetation category did not differ greatly in their response when compared with the first time period. The second time period saw a smaller area of Grassland transformed and therefore, although Grassland diminished over time, the rate of this decrease in area was gradual as opposed to abrupt as was the case of Grassland for the Eastern Shores.

Table 5.6 Change in area for reclassified vegetation categories from 1975 to 2000 for the study area within the Tewate Wilderness Area, South Africa. Categories 1, 2, 6, & 12 (bolded and italicized) were excluded from analysis and are a result of errors with digitizing

	Vegetation Category	Area (m ²)	Area (Ha ⁻¹)
1	<i>Dune Forest</i>	5.52	0.00
2	<i>Dune Forest</i>	0.03	0.00
3	Dune Forest to Grassland	41356.29	4.14
4	Dune Forest to Sand	4136.62	0.41
5	Dune Forest to Scattered Trees	389344.76	38.93
6	<i>Grassland</i>	0.10	0.00
7	Grassland to Dune Forest	171917.66	17.19
8	Grassland to Scattered Trees	3286516.43	328.65
9	Sand to Dune Forest	3784.05	0.38
10	Sand to Grassland	5020.06	0.50
11	Sand to Scattered Trees	24055.90	2.41
12	<i>Scattered Trees</i>	6.43	0.00
13	Scattered Trees to Dune Forest	1456696.87	145.67
14	Scattered Trees to Grassland	981057.77	98.11
15	Scattered Trees to Sand	3395.24	0.34

Comparing the mapped vegetation change for the two time periods visualizes the above discussion of results (comparing Figure 5.4.17 with Figure 5.4.18). For the two figures the shades of red consistently dominate the palette and indicate a greater area of Grassland is being transformed. This is occurring to a greater extent for sections west of the dunes (in the east) but east of the hygrophilous grasslands (center). This eastern section (comprising about a third of the figure) is more comparable to the Eastern Shores which does not incorporate the hygrophilous grassland to the same extent due to positioning. Very little change has occurred to the Dune Forest and is noted by the reduction in green shading. In western parts, Scattered Trees has transformed largely to

Grassland (blue shades). This can be largely attributed to a change in topography where these areas are higher up the catena compared with central parts of this study site and the increased use of fire and grazing as these sections were the preferred place for dwellings. It is interesting to note that for the central sections which are largely hygrophilous grasslands regularly inundated, only small changes to the vegetation categories are observed. This is largely associated with a change from Grassland to Dune Forest (light red). These areas delineate the Dune Forest patches that have not changed within the hygrophilous grassland and can be attributed to growth for the Dune Forest as opposed to a response to management regimes. Therefore, a move away from the influence of the water table results in an increased susceptibility to woody encroachment.

This pattern of change is furthered for the second time period (1975 to 2000). The Grassland east of the lower lying hygrophilous grassland was particularly susceptible to Scattered Trees. This transformation is not as complete as was observed for the Eastern Shores but does indicate the tendency for these areas above the influence of the water table and adjacent Dune Forest to become encroached with woody species. The lower lying sections remained relatively unchanged. It is interesting to note the disturbance to the Dune Forest indicated by the green patches to the east. This is very similar to the patches of cultivation observed for the 1937 imagery.

From this particular study area that was not as obvious for the Eastern Shores is the influence of the water table on woody species establishment and expansion. Above this, woody encroachment is inevitable without management intervention. It would appear that fire effectively changes this trend and biases the vegetation towards a grassland state (Fire Climax Grassland).

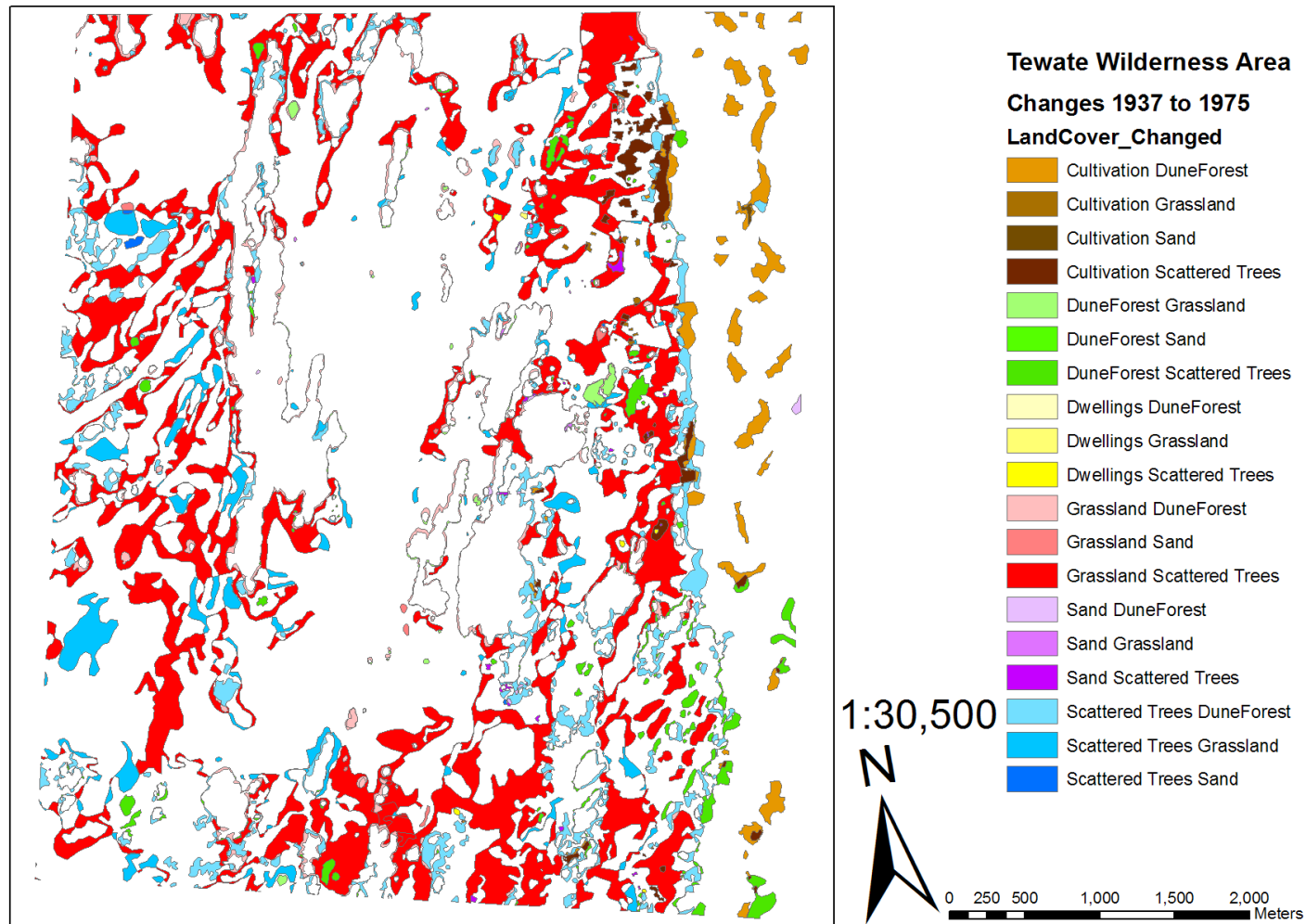


Figure 5.4.17 Reclassified vegetation categories changing in extent from 1937 to 1975 for a study area within the Tewate Wilderness Area, South Africa.

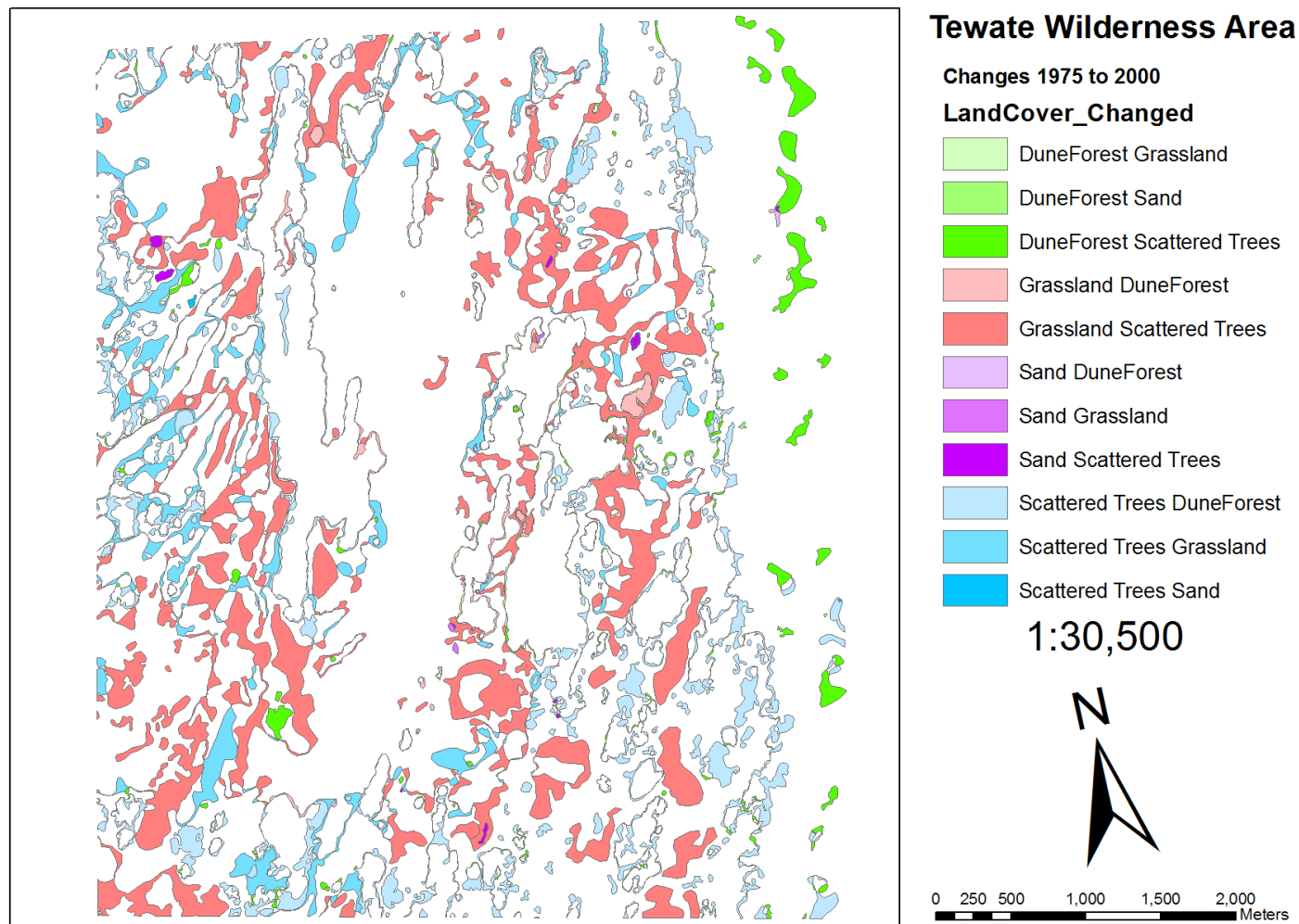


Figure 5.4.18 Reclassified vegetation categories changing in extent from 1975 to 2000 for a study area within the Tewate Wilderness Area, South Africa.

5.5. DISCUSSION

Historical disturbance regimes have been important determinants of the vegetation within the IWP. Differences in these disturbance regimes lie with an increase in severity from north to south where occupation of the Eastern Shores was greater and for longer periods of time (Hall 1984). As a direct result of this increased number of disturbance by cultivation and grazing was greater for these southern sections. Additionally, fire was used extensively to improve grazing and clear vegetation (Hall 1984). These were important factors contributing to the vegetation present during this period of occupation (pre 1956). The exclusion of the people from these areas along with their cattle and shifting agricultural practices, establishment of pine plantations and the subsequent exclusion of fire from these southern sections have resulted in drastic impacts on the vegetation dynamics experienced and a reversal of this pattern of occupation where northern areas would have absorbed the displacement of people. This is greatly exaggerated for the section examined on the Eastern Shores and can be attributed to the active exclusion of fire.

Despite the buffering effect of increased areas of hygrophilous grassland included for the Tewate site, it is still possible to derive useful comparisons between the Eastern Shores and Tewate study sites. For both of these areas which suffer different disturbance regimes, grassland was transformed by the establishment of scattered trees which ultimately succeeded through to closed canopied Dune Forest. This was particularly prevalent for west facing sites above the influence of the water table.

Therefore, the removal of fire from the coastal grasslands above the influence of the water table resulted in a rapid change through to a closed canopied forest. Where water tables are at or near the soil surface, woody establishment and encroachment is severely limited and allows the hygrophilous grassland to dominate. However, inundation does not necessarily preclude woody establishment and if periods of drought are sufficiently long, lower lying areas may be susceptible to woody encroachment albeit at a very different rate. Movement up the catena and away from the influence of the water table results in a rapid succession through to savanna type vegetation and Dune Forest due to the absence of fire or some other disturbance regime favouring the establishment of grassland.

6. Conclusions

From the various discussions for each of the associated sections it is possible to make a number of conclusions, inferences, and general observations requiring further investigation. These are derived from a number of clipping trials implemented within the IWP's coastal grasslands to investigate treatment effects on *H. kraussii*, an assessment of fire exclusion period and catenal position on vegetation response, and mapping the changes in vegetation categories for two study sites over time. Across these investigations is a common thread to conclusions pertaining particularly to woody species response. The two spatial and temporal scales covered during this study, permit understandings surrounding both the broad vegetation change, as well as a species level response underlying this change. Both scales reveal a strong directional change to a woody dominated state.

It is clear that these coastal edaphic grasslands are well adapted to regular burning. Changes to the burning regime have the single most consequential effect on vegetation for the IWP. Removing fire from this system results in a rapid succession (less than six years) through to a closed canopied dune scrub forest for areas above the influence of the water table. Regular burning however does not effectively exclude all woody species from the grass sward. In fact the opposite was true where woody density was far greater for sites burnt regularly and this density decreased with increasing fire exclusion. The three main woody species exhibiting this fire-adapted strategy were *Diospyros lycioides*, *Diospyros villosum*, and *S. cordatum*. Of these three species only *S. cordatum* increased in height with the exclusion of fire and is regularly observed as a tall mature tree favouring moist soils. The other two species persisted as short, dense individuals irrespective of fire exclusion period. The presence of these woody species within the grass sward has led to these coastal grasslands being referred to as edaphic or woody.

Excluding fire from the coastal grasslands resulted in a decrease in the number of species present, an increase in woody height, and a decrease in plant density. This change was not associated with a complete turnover of woody species where 'shorter' species were replaced with 'taller' species but rather woody composition was added to by a number of taller species and shorter fire adapted species persisted beneath the canopies of

the taller developing woody species. Diversity was therefore greater at intermediate levels of disturbance.

The grasses were negatively correlated with fire exclusion period where an increase in exclusion period resulted in a decrease in the number of grass species within the sward. *Themeda triandra* was rapidly lost from the system with an increase in fire exclusion. As a result veld condition also decreased with increased fire exclusion and therefore negatively affecting carrying capacity. The reverse was true for diversity which increased with increasing fire exclusion. This interplay between woody encroachment and reduction in grass vigour with increasing fire exclusion was exacerbated by topography where bottom sites 'resisted' woody encroachment but were poorer in condition. The higher lying areas however (particularly west facing sites) had better veld conditions, more palatable species, and better response (vigour) to defoliation but were far more likely to succeed through to scrub.

Ordination of species composition for these sites improved this understanding where fire exclusion (three year exclusion period) resulted in an initial increase in woody species and further exclusion (six years) resulted in an above average abundance of herbaceous species. *H. kraussii* was more abundant for sites with a three year fire exclusion period. Therefore sites with a reduction in fire exclusion period were characterised by an abundance of a few palatable grass species and a less than average abundance of herbaceous and woody species. Ordination by NMDS grouped sites according to fire exclusion period indicating greater similarity within fire exclusion period than between. Bottom sites had greater similarities between fire exclusion periods and this decreased with a change from east to west where west sites had the least similarity across fire exclusion periods.

Helichrysum kraussii is a stress tolerant ruderal species well adapted to survive regular defoliation. In terms of growth very little affected *H. kraussii*. Removing surrounding biomass was the only treatment that significantly affected this species ($P < 0.05$) where clipping tended to increase this species ability to attain greater sizes but this was not consistently the case across trials. Density, however decreased with a reduction in fire exclusion period and associated with this was a reduction in height. A reduction in soil moisture resulted in an increased ability for this species to attain size.

Therefore, the two main environmental factors affecting distribution of this species is firstly, soil moisture where inundation excludes establishment and secondly, where increased frequencies of fire decrease density and size of this species within the sward. This decrease in density has been attributed to seed susceptibility (reduced viability) to fire (temperatures greater than 90°C) whilst still maturing on the plant or exposed on the soil surface (Owen 1992).

Transmission of light through the canopy of *H. kraussii* revealed an unexpected change to this resource at the soil surface with an increase in maximum canopy diameter. At smaller sizes, light is effectively excluded but with an increase in canopy diameter this changes and the transmission of light through the plant increases. Therefore, it is hypothesized that facilitation by this species of other woody plants is a result of a change in the light resource at the soil surface. After a certain height light interception by the canopy decreases and allows sufficient light for the germination of these species which are protected and ameliorated by the canopy.

Plant biomass response to fire exclusion, catenal position, and clipping highlighted the improvement to the grass species' vigour when regularly defoliated and this decreased with increasing fire exclusion period. Woody biomass increased within west facing sites further highlighting the natural propensity and certain predicament for these catenal positions. Interestingly, for all sites the herbaceous species responded quicker in terms of directing resources to above ground biomass but are physiologically prevented from attaining dominance in terms of volume in the long term. These species may have an important role in providing cover following disturbance. Regular burning improved the grass species' ability to produce above ground biomass which indicates an improvement in vigour with these management regimes. Grass biomass however decreased with increasing fire exclusion which would reduce fire intensity and in turn affect the ability of fire to control woody encroachment.

An examination of the change in vegetation area over time revealed that the exclusion of disturbance from these coastal grasslands has tremendous bearing on the types of communities present. Historical disturbances by clearing for cultivation, grazing by livestock, and particularly burning greatly altered the balance between grasses and trees present for both study sites. The proximity of the water table to the soil surface and

degree of inundation effectively excluded woody vegetation from establishing. These areas remained dominated as hygrophilous grasslands during the period of study. Above these sections of inundation however, a completely different response was observed. Historical utilisation of these higher lying areas, where gradients were still fairly shallow, was intense, with fire being used extensively for clearing of land for cultivation and to improve forage quality for grazing. Additionally, Dune Forest was cleared for use as building material and to make way for cultivation. These historical disturbances greatly affected the distribution of Dune Forest within the landscape, restricting this vegetation type to steeper higher lying dune ridges. Grassland dominated as a result of this exclusion and was maintained through the judicious use of fire for these higher lying sections. The exclusion of fire from these coastal edaphic grasslands resulted in a complete transformation of these higher lying areas into a predominantly closed canopied forest. This transformation varied depending on proximity to higher lying areas and orientation within the catena where west facing sites showed the greatest degree of change. Lower lying sections tended towards scattered trees or a savanna-like vegetation type before ultimately succeeding through to Dune Forest. The degree of transformation to these grasslands is concerning for a number of reasons but the degree of severity does ultimately depend on the management objectives for the IWP as a whole.

These higher lying grasslands, particularly west facing sites, constitute the best condition veld when burnt regularly and at higher frequencies of defoliation are capable of producing greater biomass with improved vigour for the grass species. These sections of grassland therefore present veld capable of carrying a far greater number of animals compared with lower lying hygrophilous grasslands. With the exclusion of fire however these areas are quickly encroached upon by woody species which results in a decrease in palatable grasses and veld condition. Diversity however improves as fire intolerant woody species enter the system and subsequently allow a greater number of herbaceous species to establish. The loss of this resource to woody vegetation has a considerable effect on stocking rates for grazing ungulates. Not only will partial exclusion of fire reduce veld condition and as a result carrying capacity but stocking rates need to be set using the area of grassland available throughout the year. This limits this calculation to the higher lying sections above the influence of the water table which remain accessible

during periods of high rainfall. The various data from this study successfully details the rapid loss of grassland to woody encroachment if not burnt regularly.

Fire presents management of these areas with a very effective tool for the control of woody encroachment within these higher lying sections, the exclusion of which results in a clear succession through to Dune Forest. It is clear that these coastal grasslands are however, well adapted to regular defoliation and is now possible for sections of the Eastern Shores due to the complete clear-felling of pine plantations. It is important to reiterate the north/south difference that still exists in terms of fire regimes where within northern sections of the IWP fire regimes are still governed by rural people. These fires are frequent with these northern grasslands burning every year. This may direct efforts further south where fire has been excluded for longer periods of time.

Burning the grasslands above the influence of the water table every three years but no less than every four years will maintain diversity, veld condition, and a 'grassland' state. After a four year fire exclusion period, woody height has greatly increased and it is unlikely that regular intense fires would greatly affect establishment and persistence as Dune Forest. Note that the climax community for these areas is Dune Forest where up to a point fire is able to arrest succession. This indicates that a threshold exists for the use of fire and maintenance of grassland at around four years. Once this threshold has been crossed it is unlikely that merely fire as an intervention will change the successional trajectory through to Dune Forest. Bottom sites regularly inundated can be burnt less frequently with the focus being on higher lying east and west facing slopes.

6.1. RECOMMENDATIONS

The following recommendations have been made to facilitate future research of the IWP, assist management with decisions surrounding primarily the implementation of fire for the control of woody encroachment, and suggest measures for the control of *H. kraussii*. These recommendations assume that the grasslands within the IWP are to be maintained and promoted to allow improved veld condition and carrying capacity potential and are meant merely to facilitate discussion surrounding the management of these coastal dune communities. These recommendations are therefore not to be considered as ‘hard and fast rules’ providing a reliable and predictable outcome but may provide useful in conceptualizing a framework or starting point for management to adjust as data and feedback permits. While every effort has been made to encompass a broad set of vegetation types and environmental factors directing vegetation change, these are by no means comprehensive and recommendations are therefore limited in their general application however, some important recommendations can be derived.

6.1.1. Burning coastal grasslands

Burning recommendations have focused primarily on the existing edaphic grasslands situated above the influence of the water table and include vegetation communities where fire has been excluded for a period no longer than six years. Depending on the time since last burnt these grassland communities may be characterised by substantial woody biomass but will still be recognised as grassland due to reduced heights for this woody component. It is unclear what the effects of burning and likelihood of success in reverting succession through to grassland would be for areas where fire has been excluded for periods greater than six years. This will largely depend upon the height and density of the woody species present. The hygrophilous grasslands will also require burning however these regimes are not discussed.

Fire very clearly presents an effective management tool for the maintenance of coastal grasslands above the influence of the water table. For these areas fire should be implemented at least every three years but left for no longer than four years to avoid woody encroachment by ‘taller’ species. Where fire exclusion has continued for an

extended period, fire will need to be implemented regularly but allow resting to ensure adequate biomass is accumulated for an intense fire and conditions suitable to facilitate this (e.g. hot north-easterlies). Priority should be given to higher lying west facing sites and these areas burnt more regularly (bi-annually) to promote palatable grass production and vigour. Depending on previous season's rainfall and associated grass biomass accumulation this frequency may even be increased.

Burning season for management fires extends from April to October and objectives for the burn will need to be clarified before timing can be decided upon. Timing of burning has been considered for the control of *H. kraussii* in section 6.1.2 below. Type of burn implemented will depend again on objectives. Warm temperatures, low humidity, increased wind velocities with adequate dry fuel loads would tend towards hot fires suitable for the control of taller woody species. This research has highlighted that conducting such a burn regularly would ultimately result in a contraction of Dune Forest and expansion of grassland. Where the control of woody encroachment is required then this would be the correct fire regime to adopt. However, for areas where historical disturbance regimes have largely excluded Dune Forest from the system and remain as relic clumps (e.g. Ozabeni) these burning conditions and fire frequencies should be avoided to allow re-establishment and recovery of these patches into more continuous sections. For these areas a 'cooler' burn should be implemented with higher humidity, fuel moisture content, and reduced wind speeds or fire excluded completely where Dune Forest is desired.

For the reclamation of grassland reverting through to a woody dominated stand, it is recommended that initial burning regimes be frequent and hot. This should only be reduced once the system has responded by a decrease in taller woody species. Once these grasslands have been adequately secured by management then a different burning strategy can be implemented (e.g. point source burning) where areas burnt will largely be determined by conditions at the time of the burn. Perhaps a balance between these strategies exists but this will require monitoring to ensure sections of grassland are not left unburnt for extended periods of time (greater than four years) to prevent succession reverting to Dune Forest.

6.1.2. Controlling *Helichrysum kraussii*

Helichrysum kraussii can be classified as a stress tolerant ruderal species persisting once established and facilitates the establishment of woody species. The distribution of this species is restricted to areas above the influence of the water table and is quickly lost from the system beneath taller closed canopied woody species however *H. kraussii* is clearly a natural part of the system.

Growth of this species was found to be unaffected by historical burning regimes, fire, and different catenal positions. Removal of the surrounding biomass indicated that increased stocking rates may promote growth for this species but results varied. Density and an ability to attain size were however affected by burning and soil moisture. Plants of this species tended to be smaller and less dense for increased soil moisture and frequency of burning.

Although components of the data supporting the following recommendations have not been comprehensively tested and therefore require further investigation, a clear response to fire is nevertheless evident and indicates the usefulness of fire in controlling the proliferation of this species in the higher lying grasslands. Should these grasslands be required by management to remain as such, burning will need to be implemented frequently to prevent *H. kraussii* from dominating the grass sward and thus out competing the grass species and facilitating woody establishment. Timing of this burn is important as the seeds of this species are susceptible to temperatures above 90°C and therefore burning when these are maturing on the plant (August) or still on the soil surface ensures maximum effect. Once established however very little affects growth and therefore remains persistent.

6.1.3. Monitoring and future research

The following aims to highlight some future considerations and direct research efforts concerned with the conservation of coastal edaphic grasslands. Additionally, some of the conclusions from this research are limited to higher lying grasslands and need to be further investigated to encompass a greater diversity of habitats in future.

In terms of species response to management regimes researchers need to take cognizance of the short woody species within the grass sward particularly when considering woody density as a response variate. A change in woody species mix within the grass sward may be an important indicator for the crossing of a threshold between forest and edaphic grassland. It is recommended that an additional measure of density be included for comparison with the PCQ method.

A number of other investigations are proposed for future research and can be summarised as follows:

1. The difference and contribution of the higher lying grasslands to carrying capacity needs to be thoroughly investigated and should include a variety of topographies, including temporarily inundated sites for a number of locations within the IWP. These findings can then be incorporated into a GIS to assist with the prioritization of grasslands requiring more intensive management.
2. Other areas with known fire regimes need to be added to this assessment to further management's ability to maintain these coastal grasslands. These need to include woody vegetation that has established due to differing fire exclusions and investigate the impact of fire on these communities.
3. Changes to the transmission of light through the canopy of *H. kraussii* with an increase in size bears further investigation and should include an understanding of the types of woody species establishing beneath and a measure of soil moisture.
4. Bottom sites were considerably denser indicating differences within fire exclusion period which need further investigation. Soil fertility should be included for an investigation of this nature.
5. Time since last burnt could be used to create a successional trajectory from grassland to forest to evaluate species response to this exclusion over time and burning this vegetation for different fire exclusion periods will assist identification of the threshold between grassland and woody scrub.

The clipping trials have been abandoned however it is recommended that the fire exclusion periods north of the Manzengwenya Offices be continued for the three and one

year fire exclusion periods. Carefully designed long term trials should be established to continue investigations on *H. kraussii* response to management. These should aim to investigate seed mortality and changes to density.

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Appendices

Appendix 1 Latitude and longitude for all plots in the three burning and clipping trials, IWP, South Africa. Co-ordinates taken within the centre of each plot and are in decimal degrees, using the geographic co-ordinate system WGS'84.

Trial One

Flnt	Aspect	Plot	Latitude	Longitude
Annual	Bottom	1	S27.25426	E32.77241
		2	S27.25419	E32.77245
		3	S27.25410	E32.77245
		4	S27.25414	E32.77250
		5	S27.25395	E32.77248
		6	S27.25395	E32.77251
Annual	West	1	S27.25351	E32.77040
		2	S27.25352	E32.77042
		3	S27.25350	E32.77037
		4	S27.25345	E32.77040
		5	S27.25340	E32.77038
		6	S27.25334	E32.77039
Annual	Top	1	S27.25329	E32.77073
		2	S27.25325	E32.77070
		3	S27.25323	E32.77070
		4	S27.25317	E32.77068
		5	S27.25318	E32.77066
		6	S27.25315	E32.77074
Annual	East	1	S27.25351	E32.77100
		2	S27.25350	E32.77098
		3	S27.25343	E32.77106
		4	S27.25343	E32.77106
		5	S27.25334	E32.77104
		6	S27.25333	E32.77107

Flnt	Aspect	Plot	Latitude	Longitude
ThreeYr	West	1	S27.25525	E32.77024
		2	S27.25536	E32.77019
		3	S27.25540	E32.77017
		4	S27.25546	E32.77017
		5	S27.25551	E32.77020
		6	S27.25557	E32.77014
ThreeYr	Top	1	S27.25529	E32.77053
		2	S27.25532	E32.77057
		3	S27.25529	E32.77062
		4	S27.25536	E32.77061
		5	S27.25539	E32.77054
		6	S27.25543	E32.77047
ThreeYr	East	1	S27.25521	E32.77090
		2	S27.25524	E32.77090
		3	S27.25528	E32.77090
		4	S27.25530	E32.77090
		5	S27.25533	E32.77089
		6	S27.25536	E32.77088
ThreeYr	Bottom	1	S27.25534	E32.77121
		2	S27.25536	E32.77121
		3	S27.25538	E32.77121
		4	S27.25542	E32.77122
		5	S27.25545	E32.77126
		6	S27.25551	E32.77122

Trial Two

VegT	Block	Plot	Latitude	Longitude
ESP	1	a	S28.15356	E32.47478
		b	S28.15337	E32.47485
	2	a	S28.15311	E32.47490
		b	S28.15296	E32.47500
	3	a	S28.15262	E32.47504
		b	S28.15247	E32.47516
ESG	1	a	S28.15354	E32.47451
		b	S28.15335	E32.47449
	2	a	S28.15305	E32.47460
		b	S28.15283	E32.47460
	3	a	S28.15257	E32.47462
		b	S28.15242	E32.47474

Trial Three

Site	Plot	Latitude	Longitude
ESB	1	S28.15315	E32.47456
	2	S28.15313	E32.47429
	3	S28.15291	E32.47411
	4	S28.15268	E32.47416
	5	S28.15254	E32.47447
	6	S28.15254	E32.47473
ESX	1	S28.15305	E32.47458
	2	S28.15302	E32.47433
	3	S28.15289	E32.47430
	4	S28.15269	E32.47431
	5	S28.15271	E32.47444
	6	S28.15274	E32.47469

MBP Plots

Site	MBP 1	MBP 2	MBP 3	MBP 4	MBP 5	MBP 6	MBP 7	MBP 8	MBP 9
Latitude	S27.25317	S27.25316	S27.25390	S27.25598	S27.25628	S27.25608	S27.25778	S27.25782	S27.25776
Longitude	E32.77040	E32.77135	E32.77256	E32.77031	E32.77100	E32.77200	E32.76827	E32.76920	E32.77178

Appendix 2 Plant species list with acronyms, full botanical name and category into which each species was classified

Number	Acronym	Species	Category
1	Abrulae	<i>Abrus laevigatus</i>	Woody
2	Acalvil	<i>Acalypha villicaulis</i>	Herbaceous
3	Aloepar	<i>Aloe parvibracteata</i>	Woody
4	Annosen	<i>Annona senegalensis</i>	Woody
5	Apoddim	<i>Apodytes dimidiata</i>	Woody
6	Arisspp	<i>Aristida sp.</i>	Grass
7	Asclalb	<i>Asclepias albens</i>	Herbaceous
8	Aspaden	<i>Asparagus densifolius</i>	Herbaceous
9	Aspavir	<i>Asparagus virgatus</i>	Herbaceous
10	Athrphy	<i>Athrixia phyllioides</i>	Woody
11	Barlmey	<i>Barleria meyeriana</i>	Woody
12	Berkbip	<i>Berkheya bipinnatifida</i>	Herbaceous
13	Bracdis	<i>Brachylaena discolor</i>	Woody
14	Bridcat	<i>Bridelia cathartica</i>	Woody
15	Bridmic	<i>Bridelia micrantha</i>	Woody
16	Bulbcon	<i>Bulbostylis contexta</i>	Herbaceous
17	Cassfil	<i>Cassytha filiformis</i>	Herbaceous
18	Centgla	<i>Centella glabrata</i>	Herbaceous
19	Chaebur	<i>Chaetacanthus burchellii</i>	Herbaceous
20	Chilvir	<i>Chilianthus viridis</i>	Woody
21	Chlogay	<i>Chloris gayana</i>	Grass
22	Chroodo	<i>Chromolaena odorata</i>	Woody
23	Chrymon	<i>Chrysanthemoides monilifera</i>	Woody
24	Clerogla	<i>Clerodendrum glabrum</i>	Woody
25	Commafr	<i>Commelina africana</i>	Herbaceous
26	Crotdur	<i>Crotalaria dura</i>	Woody
27	Cymbplu	<i>Cymbopogon plurinodis</i>	Grass
28	Cymbval	<i>Cymbopogon validus</i>	Grass
29	Cypenat	<i>Cyperus natalensis</i>	Herbaceous
30	Dactaus	<i>Dactyloctenium australe</i>	Grass
31	Dalbobob	<i>Dalbergia obovata</i>	Woody
32	Dichcin	<i>Dichrostachys cinerea</i>	Woody
33	Digieri	<i>Digitaria eriantha</i>	Grass
34	Diheamp	<i>Diheteropogon amplexans</i>	Grass
35	Dihecon	<i>Diheteropogon contortus</i>	Grass
36	Dioslyc	<i>Diospyros lycioides</i>	Woody
37	Diosrot	<i>Diospyros rotundifolia</i>	Woody
38	Diosvil	<i>Diospyros villosa</i>	Woody
39	Dodovis	<i>Dodonaea viscosa</i>	Woody
40	Drypret	<i>Drypetes reticulata</i>	Woody
41	Eragrac	<i>Eragrostis racemosa</i>	Grass
42	Eragrup	<i>Eragrostis superba</i>	Grass
43	Eriocor	<i>Eriosema cordatum</i>	Woody
44	Erioluc	<i>Eriosema lucipetum</i>	Herbaceous
45	Eriosal	<i>Eriosema saligna</i>	Woody
46	Eriosqu	<i>Eriosema squarrosum</i>	Herbaceous
47	Euclnat	<i>Euclea natalensis</i>	Woody
48	Eugealb	<i>Eugenia albanensis</i>	Woody

Number	Acronym	Species	Category
49	Euphdum	<i>Euphorbia dumosa</i>	Woody
50	Gladdal	<i>Gladiolus dalenii</i>	Herbaceous
51	Gramber	<i>Grammatotheca bergiana</i>	Herbaceous
52	Grammber	<i>Grammatotheca bergiana</i>	Herbaceous
53	Gymnmar	<i>Gymnosporia markwardii</i>	Woody
54	Helicep	<i>Helichrysum cephaloideum</i>	Herbaceous
55	Helidec	<i>Helichrysum decorum</i>	Herbaceous
56	Helikra	<i>Helichrysum kraussii</i>	Woody
57	Helilon	<i>Helichrysum longifolium</i>	Herbaceous
58	Helispp	<i>Helichrysum sp.</i>	Herbaceous
59	Hermbodo	<i>Hermbstaedtia odorata</i>	Herbaceous
60	Hypadis	<i>Hyparrhenia dissoluta</i>	Grass
61	Hypohem	<i>Hypoxis hemerocallidea</i>	Herbaceous
62	Hypospp	<i>Hypoxis sp.</i>	Herbaceous
63	Impecyl	<i>Imperata cylindrica</i>	Grass
64	Isogova	<i>Isoglossa ovata</i>	Woody
65	Jasmmul	<i>Jasminum multipartitum</i>	Woody
66	Krauflo	<i>Kraussia floribunda</i>	Woody
67	Kyllalb	<i>Kyllinga alba</i>	Herbaceous
68	Landkir	<i>Landolphia kirkii</i>	Woody
69	Ledeova	<i>Ledebouria ovatifolia</i>	Herbaceous
70	Ledespp	<i>Ledebouria sp.</i>	Herbaceous
71	Limevis	<i>Limeum viscosum</i>	Herbaceous
72	Lobecor	<i>Lobelia coronopifolia</i>	Herbaceous
73	Melirep	<i>Melinis repens</i>	Grass
74	Mimucaf	<i>Mimusops cafra</i>	Woody
75	Mystaet	<i>Mystroxydon aethiopicus</i>	Woody
76	Ochnser	<i>Ochna serrulata</i>	Woody
77	Ostegra	<i>Osteospermum grandidentatum</i>	Woody
78	Oxygrob	<i>Oxygonum robustum</i>	Herbaceous
79	Ozorofo	<i>Ozoroa obovata</i>	Woody
80	Ozorpan	<i>Ozoroa paniculosa</i>	Woody
81	Panideu	<i>Panicum deustum</i>	Grass
82	Panimax	<i>Panicum maximum</i>	Grass
83	Paricap	<i>Parinari capensis</i>	Woody
84	Peropat	<i>Perotis patens</i>	Grass
85	Phoerec	<i>Phoenix reclinata</i>	Woody
86	Polyfru	<i>Polygala fruticosa</i>	Woody
87	Polypro	<i>Polygala producta</i>	Woody
88	Psyccap	<i>Psychotria capensis</i>	Woody
89	Psydluc	<i>Psydrax locuples</i>	Woody
90	Raphhir	<i>Raphionacme hirsuta</i>	Woody
91	Rhoidig	<i>Rhoicissus digitata</i>	Woody
92	Rhusden	<i>Rhus dentata</i>	Woody
93	Rhuspen	<i>Rhus pentheri</i>	Woody
94	Rhuspyr	<i>Rhus pyroides</i>	Woody
95	Rhusreh	<i>Rhus rehmanniana</i>	Woody
96	Rhynmin	<i>Rhynchosia minima</i>	Herbaceous
97	Rhynspp	<i>Rhynchosia sp.</i>	Woody
98	Rhyntot	<i>Rhynchosia totta</i>	Herbaceous
99	Sapiint	<i>Sapium integerrimum</i>	Woody

Number	Acronym	Species	Category
100	Scabcol	<i>Scabiosa columbaria</i>	Herbaceous
101	Sclebir	<i>Sclerocarya birrea</i>	Woody
102	Sebased	<i>Sebaea sedoides</i>	Herbaceous
103	Secafil	<i>Secamone filiformis</i>	Herbaceous
104	Senegla	<i>Senecio glaberrimus</i>	Herbaceous
105	Senelat	<i>Senecio latifolius</i>	Herbaceous
106	Setameg	<i>Setaria megaphylla</i>	Grass
107	Setasph	<i>Setaria sphacelata</i>	Grass
108	Smilanc	<i>Smilax anceps</i>	Herbaceous
109	Sphepru	<i>Sphedamnocarpus pruriens</i>	Woody
110	Stepaby	<i>Stephania abyssinica</i>	Herbaceous
111	Stryspi	<i>Strychnos spinosa</i>	Woody
112	Stylfru	<i>Stylosanthes fruticulosa</i>	Herbaceous
113	Synakir	<i>Synaptolepis kirkii</i>	Woody
114	Syzycor	<i>Syzygium cordatum</i>	Woody
115	Tecocap	<i>Tecomaria capensis</i>	Woody
116	Tephdif	<i>Tephrosia diffusa</i>	Herbaceous
117	Tephlat	<i>Tephrosia latifolia</i>	Woody
118	Tephsem	<i>Tephrosia semiglabra</i>	Herbaceous
119	Themtri	<i>Themeda triandra</i>	Grass
120	Thespal	<i>Thesium pallidum</i>	Herbaceous
121	Tracspi	<i>Trachypogon spicatus</i>	Grass
122	Urelagr	<i>Urelytrum agropyroides</i>	Grass
123	Urocmos	<i>Urochloa mosambicensis</i>	Grass
124	Urylagr	<i>Urelytrum agropyroides</i>	Grass
125	Veprlan	<i>Vepris lanceolata</i>	Woody
126	Vernnat	<i>Vernonia natalensis</i>	Woody
127	Vernoli	<i>Vernonia oligocephala</i>	Woody
128	Ximecaf	<i>Ximenia caffra</i>	Woody

Appendix 3 List of herbaceous species classified as having woody properties using the point-centred quarter method for which no height was recorded. Note the inclusion of a few potentially tall woody species (bolded) due to misclassification of their juvenile form

Number	Acronym	Species
1	Abrulae	<i>Abrus laevigatus</i>
2	Aloepar	<i>Aloe parvibracteata</i>
3	Athrphy	<i>Athrixia phyllicoides</i>
4	Barlmey	<i>Barleria meyeriana</i>
5	Chilvir	<i>Chilianthus viridis</i>
6	Chroodo	<i>Chromolaena odorata</i>
7	Chrymon	<i>Chrysanthemoides monilifera</i>
8	Crotdur	<i>Crotalaria dura</i>
9	Dichcin	<i>Dichrostachys cinerea</i>
10	Dioslyc	<i>Diospyros lycioides</i>
11	Diosvil	<i>Diospyros villosa</i>
12	Eriocor	<i>Eriosema cordatum</i>
13	Eriosal	<i>Eriosema saligna</i>
14	Eugealb	<i>Eugenia albanensis</i>
15	Euphdum	<i>Euphorbia dumosa</i>
16	Gymnmar	<i>Gymnosporia markwardii</i>
17	Isogova	<i>Isoglossa ovata</i>
18	Jasmmul	<i>Jasminum multipartitum</i>
19	Krauflo	<i>Kraussia floribunda</i>
20	Landkir	<i>Landolphia kirkii</i>
21	Ostegra	<i>Osteospermum grandidentatum</i>
22	Paricap	<i>Parinari capensis</i>
23	Polyfru	<i>Polygala fruticosa</i>
24	Polypro	<i>Polygala producta</i>
25	Raphhir	<i>Raphionacme hirsuta</i>
26	Rhoidig	<i>Rhoicissus digitata</i>
27	Sphepru	<i>Sphedamnocarpus pruriens</i>
28	Stryspi	<i>Strychnos spinosa</i>
29	Tephlat	<i>Tephrosia latifolia</i>
30	Veprlan	<i>Vepris lanceolata</i>
31	Vernnat	<i>Vernonia natalensis</i>
32	Vernoli	<i>Vernonia oligocephala</i>

Appendix 4 Density per species for sites north of the Manzengwenya Offices, South Africa. Species italicized and bolded were excluded from further analysis.

	MBP 1	MBP 2	MBP 3	MBP 4	MBP 5	MBP 6	MBP 7	MBP 8	MBP 9
<i>Abrulae</i>	5161	12140	1771	611	85	332	377	80	468
<i>Acalvil</i>	<i>0</i>	<i>0</i>	<i>0</i>	306	<i>0</i>	995	75	<i>0</i>	<i>0</i>
<i>Aloepar</i>	<i>0</i>	<i>0</i>	<i>0</i>	61	<i>0</i>	<i>0</i>	38	<i>0</i>	<i>0</i>
<i>Annosen</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	38	<i>0</i>	<i>0</i>
<i>Antiver</i>	<i>0</i>	<i>0</i>	<i>0</i>	61	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>
<i>Asclalb</i>	1720	<i>0</i>	1771	550	<i>0</i>	663	<i>0</i>	<i>0</i>	<i>0</i>
<i>Aspaden</i>	<i>0</i>	1917	<i>0</i>	122	85	1327	113	318	187
<i>Aspavir</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	332	75	159	562
<i>Athrphy</i>	27528	1917	885	1344	1108	2321	0	40	0
<i>Barlmey</i>	3441	<i>0</i>	3542	244	<i>0</i>	<i>0</i>	38	40	94
<i>Berkbip</i>	<i>0</i>	<i>0</i>	<i>0</i>	122	<i>0</i>	663	75	279	842
<i>Bracdis</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	113	80	<i>0</i>
<i>Bulbcon</i>	7742	5751	9740	183	597	1658	113	40	562
<i>Cassfil</i>	0	0	0	0	0	0	1434	1473	1591
<i>Centgla</i>	<i>0</i>	<i>0</i>	2656	183	171	<i>0</i>	75	<i>0</i>	<i>0</i>
<i>Chaebur</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	341	995	<i>0</i>	<i>0</i>	<i>0</i>
<i>Chilvir</i>	<i>0</i>	<i>0</i>	<i>0</i>	122	<i>0</i>	332	<i>0</i>	<i>0</i>	<i>0</i>
<i>Chlogay</i>	6022	<i>0</i>	885	<i>0</i>	256	<i>0</i>	<i>0</i>	<i>0</i>	187
<i>Chrymon</i>	5161	1917	1771	122	512	1990	755	478	2902
<i>Commafr</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	151	80	<i>0</i>
<i>Crotdur</i>	4301	<i>0</i>	<i>0</i>	<i>0</i>	85	<i>0</i>	75	<i>0</i>	<i>0</i>
<i>Cymbval</i>	10323	6389	15052	1039	1108	12270	981	716	2808
<i>Cypenat</i>	8602	2556	1771	0	256	1990	151	0	655
<i>Dalbobo</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	1327	<i>0</i>	119	<i>0</i>
<i>Dichcin</i>	21506	15335	2656	1772	1364	3316	189	80	94
<i>Digieri</i>	13764	7667	24792	1589	2217	10612	944	1035	1685
<i>Diheamp</i>	8602	19807	2656	550	1023	663	0	637	842
<i>Dihecon</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	717	<i>0</i>	<i>0</i>
<i>Dioslyc</i>	11183	20446	29219	1344	1876	10612	1170	1035	2902
<i>Diosvil</i>	17205	19168	28334	2444	3240	12934	1548	1512	3744
<i>Eragrac</i>	6882	5751	2656	0	171	0	0	0	0
<i>Eriocor</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	85	1327	151	40	<i>0</i>
<i>Erioluc</i>	3441	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	995	75	119	281
<i>Eriosal</i>	<i>0</i>	3834	<i>0</i>	183	597	663	<i>0</i>	<i>0</i>	<i>0</i>
<i>Eugealb</i>	18065	12140	8854	0	853	1658	226	358	1498
<i>Euphdum</i>	15484	4473	5313	855	938	2985	264	159	562
<i>Gladdal</i>	<i>0</i>	<i>0</i>	<i>0</i>	428	171	663	151	<i>0</i>	<i>0</i>
<i>Gramber</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	663	<i>0</i>	40	<i>0</i>
<i>Gymnmar</i>	0	15335	24792	550	426	1990	38	597	0
<i>Helidec</i>	<i>0</i>	<i>0</i>	<i>0</i>	183	<i>0</i>	332	<i>0</i>	<i>0</i>	<i>0</i>
<i>Helikra</i>	860	1917	3542	672	341	2985	340	239	374
<i>Helilon</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	995	151	119	655
<i>Hermbodo</i>	<i>0</i>	<i>0</i>	885	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>
<i>Hypadis</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	171	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>
<i>Hypohem</i>	0	4473	3542	306	426	1327	0	0	0
<i>Impecyl</i>	0	0	7969	428	341	0	0	0	0
<i>Isogova</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	332	38	40	<i>0</i>
<i>Jasmmul</i>	<i>0</i>	<i>0</i>	<i>0</i>	61	<i>0</i>	<i>0</i>	38	<i>0</i>	<i>0</i>
<i>Krauflo</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	332	38	40	<i>0</i>
<i>Landkir</i>	860	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	995	151	358	<i>0</i>
<i>Ledeova</i>	7742	4473	<i>0</i>	244	85	332	302	40	<i>0</i>
<i>Ledespp</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	226	80	<i>0</i>
<i>Limevis</i>	0	0	0	1161	2302	10281	0	0	0
<i>Lobecor</i>	9463	22363	15938	0	341	4975	0	1035	2434
<i>Melirep</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	189	80	<i>0</i>
<i>Mystaet</i>	<i>0</i>	<i>0</i>	<i>0</i>	61	<i>0</i>	<i>0</i>	<i>0</i>	80	<i>0</i>
<i>Ochnser</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	332	<i>0</i>	<i>0</i>	<i>0</i>
<i>Ostegra</i>	<i>0</i>	<i>0</i>	6198	122	85	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>

	MBP 1	MBP 2	MBP 3	MBP 4	MBP 5	MBP 6	MBP 7	MBP 8	MBP 9
Oxygrob	0	0	0	0	512	995	38	0	0
Panideu	0	0	0	0	0	1327	113	279	0
Panimax	0	0	0	0	0	0	189	80	0
Paricap	14624	15974	16823	1283	2473	10281	642	796	1778
Peropat	0	0	0	0	0	0	113	0	0
Phoerec	0	0	0	306	0	0	75	40	0
Polyfru	0	639	885	428	853	1658	38	0	0
Polypro	0	0	7083	61	0	0	0	0	0
Psydloc	0	0	0	0	0	663	38	0	0
Raphhir	6882	639	6198	122	512	0	38	0	0
Rhoidig	0	0	5313	0	0	332	113	80	0
Rhusden	0	0	0	0	0	0	0	318	0
Rhuspyr	0	0	0	0	0	0	38	0	0
Rhynmin	6882	5112	0	672	597	2653	38	0	0
Rhyntot	0	0	14167	0	0	332	38	0	0
Sapiint	0	0	0	0	0	0	75	0	0
Scabcol	0	3195	885	489	341	3648	38	159	1404
Secafil	0	0	0	0	0	0	189	80	0
Senelat	7742	12140	12396	611	1194	1658	151	438	842
Setasph	24947	7667	26563	1955	3666	11607	1170	756	2714
Smilanc	860	1278	1771	122	512	1327	75	119	842
Sphepru	0	0	0	0	0	0	113	80	0
Stepaby	2581	639	5313	855	853	2985	340	199	1030
Stryspi	5161	0	1771	306	0	1990	0	119	0
Stylfru	12043	6389	885	244	0	332	0	0	94
Synakir	0	0	0	0	85	0	340	0	0
Syzycor	36991	10862	15052	794	1194	1990	415	637	374
Tecocap	0	0	0	0	0	663	0	0	0
Tephdif	0	0	0	122	0	332	75	279	94
Tephlat	860	1917	34531	367	1023	6301	793	915	1778
Themtri	19786	23002	16823	0	0	0	0	0	0
Urylagr	7742	11501	21250	1711	2131	7959	491	1274	2902
Veprlan	0	0	0	122	0	0	113	0	0
Vernnat	11183	7667	10625	0	1364	995	151	119	842
Vernoli	0	0	0	0	0	1658	38	159	562
Ximecaf	0	0	0	244	0	0	0	80	0
Total	373346	298388	405524	28841	38964	161174	17702	18627	41183

Appendix 5 Dry matter (DM; gm), associated disc pasture meter (DPM) heights (Ht; cm) and degree of lignification (DegLig) used for calibrating the DPM for sites on the Eastern Shores of Lake St Lucia

Sample	Ht	DegLig	DM	Sample	Ht	DegLig	DM	Sample	Ht	DegLig	DM
1	15	2	95.16	26	12	2	84.84	51	17	3	111.52
2	25	3	159.75	27	7	2	54.35	52	14	1	101.94
3	19	2	98.12	28	15	2	123.44	53	32	3	253.41
4	36	3	291.58	29	12	1	118.36	54	13	1	80.74
5	18	2	110.10	30	12	2	115.16	55	16	3	102.28
6	10	1	80.94	31	15	1	125.86	56	12	2	85.01
7	11	1	87.18	32	21	3	130.26	57	7	2	75.96
8	15	2	113.98	33	12	1	86.52	58	18	2	140.43
9	24	2	183.30	34	10	2	78.63	59	13	1	119.23
10	12	1	113.86	35	11	1	78.77	60	11	3	71.61
11	21	2	170.82	36	12	3	134.71				
12	17	2	214.23	37	9	2	95.56				
13	11	1	99.23	38	8	1	80.16				
14	9	1	74.95	39	14	2	86.13				
15	8	1	61.50	40	9	1	72.46				
16	18	3	132.67	41	12	1	86.97				
17	14	1	106.01	42	12	1	119.11				
18	15	2	96.71	43	17	2	133.22				
19	24	2	158.29	44	9	2	63.78				
20	24	2	146.17	45	12	1	110.79				
21	16	1	131.52	46	10	1	121.23				
22	13	1	101.61	47	13	2	126.71				
23	18	2	136.40	48	24	2	251.46				
24	16	1	116.35	49	13	1	124.45				
25	19	2	134.76	50	6	1	119.39				

Appendix 6 Dry matter (DM; gm), associated disc pasture meter (DPM) heights (Ht; cm) and degree of lignification (DegLig) used for calibrating the DPM for sites north of the Manzengwenya Offices

Sample	Ht	DegLig	DM	Sample	Ht	DegLig	DM	Sample	Ht	DegLig	DM
1	18	1	120.24	26	11	1	78.46	51	7	0	54.45
2	16	2	122.43	27	9	0	64.07	52	12	0	67.92
3	6	0	48.64	28	11	1	78.80	53	12	0	87.04
4	11	1	62.71	29	9	1	62.26	54	20	1	110.09
5	8	1	52.01	30	9	1	55.66	55	10	0	68.39
6	13	1	62.41	31	13	1	84.01	56	14	1	89.20
7	10	1	75.73	32	9	0	52.44	57	10	1	89.06
8	14	1	86.60	33	14	2	73.55	58	8	0	56.83
9	9	1	58.18	34	19	2	115.14	59	9	0	61.59
10	11	2	72.57	35	11	0	64.09	60	5	0	60.23
11	8	1	61.14	36	16	1	84.41	61	18	1	126.62
12	10	1	76.56	37	13	1	67.12	62	5	0	52.99
13	8	1	51.54	38	7	1	49.15	63	8	1	58.55
14	15	2	69.73	39	7	1	45.13	64	10	1	99.26
15	10	1	75.15	40	11	1	61.86	65	8	1	57.41
16	11	2	75.06	41	10	0	56.70	66	11	1	83.49
17	17	1	71.07	42	14	2	70.57	67	9	1	61.69
18	10	1	80.02	43	12	1	89.28	68	12	0	58.06
19	11	0	57.81	44	8	1	81.25	69	9	0	40.39
20	13	2	91.78	45	9	0	77.78	70	8	0	51.21
21	8	1	52.81	46	12	1	61.02	71	9	1	77.26
22	17	2	108.92	47	13	1	77.83	72	16	1	79.16
23	7	0	52.67	48	6	0	41.93	73	8	1	60.92
24	12	1	87.11	49	14	1	103.45	74	12	0	85.58
25	8	1	54.59	50	12	0	78.29	75	11	1	62.88

Appendix 7 Grass sward height (Ht; cm) and an indication of lignification for each reading (DegLig) for sites on the Eastern Shores of Lake St Lucia

	ESP		ESG			ESP		ESG			ESP		ESG			ESP		ESG	
Sample	Ht	DegLig	Ht	DegLig	Sample	Ht	DegLig	Ht	DegLig	Sample	Ht	DegLig	Ht	DegLig	Sample	Ht	DegLig	Ht	DegLig
1	10	1	10	1	26	15	2	8	1	51	21	2	14	1	76	15	1	26	3
2	11	2	12	2	27	14	1	8	1	52	16	1	17	1	77	24	2	18	2
3	10	3	11	2	28	16	1	6	1	53	20	2	17	1	78	21	1	22	2
4	8	1	7	0	29	15	2	7	2	54	14	2	17	2	79	23	1	14	1
5	11	2	12	2	30	9	1	18	2	55	9	1	11	1	80	16	1	5	1
6	17	3	16	3	31	17	1	10	1	56	26	2	13	1	81	25	2	13	2
7	12	3	13	1	32	17	2	9	2	57	22	2	11	1	82	10	1	16	2
8	14	2	22	2	33	8	1	8	1	58	21	2	11	2	83	16	3	7	1
9	28	2	21	3	34	15	2	17	2	59	19	1	12	1	84	7	1	8	2
10	16	1	8	1	35	7	1	23	2	60	6	1	10	1	85	5	2	26	2
11	12	2	8	2	36	14	1	10	1	61	17	1	13	1	86	16	1	29	3
12	17	3	10	2	37	12	2	14	1	62	13	2	17	2	87	17	2	15	2
13	11	2	10	1	38	13	3	16	1	63	17	3	10	1	88	24	3	36	3
14	12	2	6	0	39	18	2	11	2	64	11	1	14	3	89	7	3	19	2
15	13	2	9	1	40	10	1	17	2	65	10	1	12	2	90	7	1	22	1
16	7	1	7	2	41	28	2	12	1	66	12	2	7	2	91	18	2	10	1
17	10	1	9	1	42	12	2	16	2	67	16	2	32	3	92	26	3	12	2
18	16	1	7	1	43	9	1	16	3	68	18	3	8	2	93	5	1	7	1
19	14	1	8	1	44	14	2	11	2	69	19	2	24	2	94	5	1	17	2
20	9	1	8	2	45	13	2	8	1	70	19	2	10	1	95	10	3	10	1
21	11	1	5	1	46	11	2	13	2	71	23	3	10	2	96	14	3	14	1
22	14	2	9	1	47	10	1	15	1	72	22	3	3	0	97	4	3	14	1
23	18	2	11	1	48	11	2	4	3	73	26	2	6	2	98	17	3	8	1
24	15	2	13	2	49	10	1	11	1	74	23	2	29	3	99	19	2	8	1
25	20	3	5	1	50	21	2	10	1	75	17	3	34	3	100	11	3	12	2

Appendix 8 Grass sward height (Ht; cm) and an indication of lignification for each reading (DegLig) for sites north of Manzengwenya Offices, South Africa

Sample	MBP 1		MBP 2		MBP 3		MBP 4		MBP 5		MBP 6		MBP 7		MBP 8		MBP 9	
	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig
1	12	1	12	2	11	2	25	3	29	3	23	3	21	3	11	3	9	3
2	8	1	12	1	16	1	28	3	10	2	17	2	14	3	8	3	12	3
3	8	1	13	1	11	1	27	3	17	3	28	3	14	3	11	3	6	2
4	8	1	12	0	13	1	32	3	23	3	32	3	35	3	8	3	12	3
5	16	2	11	1	11	1	19	3	19	3	29	2	25	3	24	3	11	3
6	13	1	9	1	11	1	25	3	20	3	22	2	14	3	18	3	11	3
7	5	1	13	1	10	1	27	3	29	3	29	3	17	3	34	3	14	3
8	17	2	15	2	15	1	21	3	13	2	24	3	43	3	17	3	12	3
9	10	1	12	1	15	1	24	3	33	3	24	3	11	3	19	3	10	3
10	8	1	5	0	9	1	26	3	33	3	13	2	14	3	8	3	11	2
11	9	1	11	2	7	2	31	3	24	3	23	3	26	3	19	3	7	3
12	10	1	14	2	11	2	21	3	20	2	21	3	23	3	16	3	11	3
13	6	1	19	1	10	1	25	3	15	3	20	3	18	3	11	3	31	3
14	7	1	12	2	15	2	27	3	18	2	15	3	21	3	11	3	12	3
15	8	1	11	1	10	1	30	3	13	1	27	3	33	3	18	3	9	3
16	7	2	15	2	8	0	16	3	28	3	17	2	10	3	10	3	11	3
17	7	1	12	0	12	2	18	3	32	3	20	3	31	3	16	3	17	3
18	15	2	17	1	14	1	27	3	35	3	12	2	32	3	16	3	12	3
19	4	1	8	0	13	0	16	3	19	3	15	2	23	3	6	3	5	1
20	9	1	6	1	4	0	20	3	10	2	10	2	17	3	11	3	20	3
21	7	1	10	1	12	1	24	3	33	3	32	3	33	3	12	3	8	3
22	5	2	12	2	9	1	27	3	23	3	35	3	35	3	10	3	8	1
23	8	1	8	1	11	1	28	3	22	3	31	3	29	3	19	3	19	3
24	8	1	21	2	11	1	23	3	20	3	33	3	31	3	12	3	11	3
25	8	2	20	2	12	1	21	3	20	3	26	3	15	3	13	3	9	3
26	8	1	9	1	9	1	8	3	19	3	33	3	19	3	14	3	11	3
27	9	2	8	1	8	0	36	3	27	3	37	3	19	3	17	3	16	3
28	7	0	16	2	10	1	13	3	14	3	32	3	10	3	21	3	17	3
29	7	1	12	1	12	1	24	3	23	3	23	3	27	3	19	3	19	3
30	12	2	8	1	15	1	24	3	22	3	30	3	21	3	14	3	20	3
31	8	1	15	2	9	1	28	3	28	3	23	3	17	3	11	3	14	3
32	5	1	9	1	11	1	32	3	21	3	21	3	14	3	11	3	8	2
33	7	1	2	1	8	0	39	3	25	3	29	3	16	3	32	3	16	3

Sample	MBP 1		MBP 2		MBP 3		MBP 4		MBP 5		MBP 6		MBP 7		MBP 8		MBP 9	
	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig
34	6	2	12	1	13	1	26	3	32	3	18	3	19	3	16	3	9	2
35	9	1	10	2	12	1	31	3	25	3	7	2	14	3	12	3	14	3
38	8	2	15	1	6	0	24	3	26	3	35	3	19	3	21	3	9	2
39	8	1	9	0	11	1	21	3	37	3	39	3	18	3	7	3	12	3
40	7	1	15	2	14	2	20	3	31	3	11	3	12	3	9	3	19	3
41	5	1	9	1	10	1	24	3	33	3	26	3	18	3	21	3	15	3
42	7	1	10	1	12	1	22	3	15	2	20	3	27	3	21	3	20	3
43	8	0	9	1	9	1	20	3	40	3	12	3	17	3	9	3	20	3
44	11	0	9	1	12	1	26	3	21	3	33	3	9	3	15	3	26	3
45	11	0	10	1	15	2	17	3	34	3	15	2	10	3	24	3	5	2
46	12	1	7	1	12	1	14	3	28	3	16	3	15	3	35	3	17	3
47	11	1	11	0	11	1	11	3	27	3	21	3	11	3	32	3	20	3
48	8	0	10	2	9	1	22	3	24	3	27	3	23	3	28	3	13	3
49	8	1	11	1	11	1	23	3	22	3	16	3	10	3	21	3	11	3
50	8	1	10	1	7	1	41	3	29	3	16	3	13	3	21	3	9	2
51	9	1	8	0	13	2	10	2	28	3	11	2	15	3	24	3	11	3
52	10	1	10	1	6	1	11	2	37	3	23	3	17	3	33	3	9	3
53	10	1	10	1	8	1	29	3	38	3	8	2	15	3	8	3	20	3
54	8	1	9	2	9	2	30	3	35	3	24	3	12	3	13	3	23	3
55	9	1	11	1	11	1	31	3	28	3	22	3	10	3	11	3	28	3
56	9	1	10	1	11	1	25	3	23	3	26	3	19	3	9	3	24	3
57	10	2	13	1	11	1	39	3	29	3	9	3	14	3	10	3	15	3
58	13	1	19	2	12	0	18	3	27	3	17	3	12	3	21	3	23	3
59	11	1	12	1	10	1	24	3	25	3	19	3	21	3	12	3	12	3
60	15	0	10	2	14	1	21	3	39	3	28	3	18	3	27	3	21	3
61	15	2	12	1	7	1	31	3	29	3	30	3	14	3	19	3	12	3
62	12	2	10	1	15	1	13	1	16	3	27	3	12	3	31	3	14	3
63	9	2	14	1	10	1	31	2	24	3	28	3	11	3	26	3	11	2
64	13	1	15	1	11	1	6	2	32	3	22	3	35	3	14	3	22	3
65	12	2	9	1	12	1	10	3	35	3	32	3	23	3	7	3	25	3
66	9	1	8	1	10	1	12	3	29	3	14	3	15	3	10	3	9	2
67	14	2	7	1	10	2	32	3	25	3	10	3	33	3	10	3	16	3
68	6	2	10	1	12	1	28	3	16	3	23	3	10	3	30	3	9	2
69	13	2	15	1	9	1	27	3	13	3	22	3	11	3	7	3	8	3
70	12	1	9	0	13	2	30	3	12	3	10	3	18	3	10	3	17	3
71	11	0	11	1	11	1	24	3	15	3	11	2	18	3	12	3	7	2
72	14	2	7	1	12	1	16	3	20	3	16	3	9	3	10	3	24	3

Sample	MBP 1		MBP 2		MBP 3		MBP 4		MBP 5		MBP 6		MBP 7		MBP 8		MBP 9	
	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig	Ht	DegLig
73	8	1	14	1	12	1	9	3	30	3	10	3	21	3	12	3	24	3
74	13	0	12	1	9	0	19	3	28	3	10	3	27	3	14	3	10	2
77	10	1	14	2	15	1	11	3	26	3	34	3	25	3	13	3	13	2
78	11		14	1	9	1	23	3	28	3	11	3	21	3	28	3	14	3
79	10	2	11	2	15	1	25	3	29	3	15	2	19	3	11	3	24	3
80	10	1	10	0	11	0	25	3	20	3	17	2	19	3	13	3	12	3
81	10	1	10	2	13	1	28	3	25	3	19	3	27	3	31	3	9	3
82	11	2	12	1	18	2	30	3	18	3	22	3	31	3	8	3	11	3
83	14	1	14	1	13	1	29	3	22	3	18	3	17	3	6	2	21	3
84	10	1	11	1	13	1	28	3	15	3	22	3	14	3	12	2	9	3
85	8	2	12	1	12	2	18	3	37	3	17	3	16	3	6	2	20	3
86	10	0	10	1	12	1	29	3	16	3	12	3	14	3	26	3	11	2
87	11	1	12	1	14	2	22	3	12	2	21	3	29	3	11	3	14	3
88	11	2	14	2	7	1	22	3	11	2	23	3	26	3	16	3	18	3
89	13	2	10	1	10	1	17	3	31	3	8	2	14	3	9	3	15	3
90	12	2	15	1	11	1	19	3	16	3	18	3	18	3	21	3	19	3
91	12	1	11	1	8	1	34	3	27	3	49	3	23	3	24	3	18	3
92	8	1	11	2	11	1	27	3	32	3	7	3	43	3	21	3	20	3
93	15	2	10	1	11	1	24	3	29	3	8	2	11	2	21	3	26	3
94	10	1	20	1	9	1	22	3	35	3	10	2	3	2	32	3	20	3
95	9	0	9	1	7	1	15	3	32	3	31	3	13	2	7	3	19	3
96	10	1	12	1	11	1	21	3	41	3	10	2	13	2	8	2	8	2
97	10	1	13	0	12	1	28	3	25	3	12	2	30	3	6	2	18	3
98	10	0	12	1	22	2	14	3	15	3	30	3	6	3	10	3	7	2
99	12	1	15	1	3	0	34	3	22	3	24	3	35	3	35	3	13	3
100	16	1	7	1	12	2	13	3	28	3	34	3	10	3	21	3	9	2

Appendix 9 Grass species abundance data from the PCQ method used for the calculation of a relative ecological index value (REIV) which is a product of the percentage abundance (%) and the ecological index value (EIV) for sites north of the Manzengwenya Offices, South Africa

Site	Sp Acronym	Species	Quad 1	Quad 2	Quad 3	Quad 4	Total	%	EIV	REIV
MBP 1 (W)	Chlogay	<i>Chloris gayana</i>	0	4	2	4	10	5.00	10	50.00
	Cymbval	<i>Cymbopogon validus</i>	4	3	6	4	17	8.50	7	59.50
	Digieri	<i>Digitaria eriantha</i>	7	10	4	10	31	15.50	10	155.00
	Diheamp	<i>Diheteropogon amplexans</i>	3	3	5	6	17	8.50	10	85.00
	Eragrac	<i>Eragrostis racemosa</i>	2	2	5	3	12	6.00	4	24.00
	Setasph	<i>Setaria sphacelata</i>	16	14	14	11	55	27.50	10	275.00
	Themtri	<i>Themeda triandra</i>	16	12	11	9	48	24.00	10	240.00
	Urylagr	<i>Urelytrum agropyroides</i>	2	2	3	3	10	5.00	7	35.00
MBP 2 (E)	Cymbval	<i>Cymbopogon validus</i>	3	0	2	5	10	5.00	7	35.00
	Digieri	<i>Digitaria eriantha</i>	5	1	3	4	13	6.50	10	65.00
	Diheamp	<i>Diheteropogon amplexans</i>	11	18	14	9	52	26.00	10	260.00
	Eragrac	<i>Eragrostis racemosa</i>	2	1	2	4	9	4.50	4	18.00
	Setasph	<i>Setaria sphacelata</i>	4	1	4	8	17	8.50	10	85.00
	Themtri	<i>Themeda triandra</i>	20	24	17	14	75	37.50	10	375.00
	Urylagr	<i>Urelytrum agropyroides</i>	5	5	8	6	24	12.00	7	84.00
MBP 3 (B)	Chlogay	<i>Chloris gayana</i>	0	1	0	0	1	0.50	10	5.00
	Cymbval	<i>Cymbopogon validus</i>	4	4	5	6	19	9.50	7	66.50
	Digieri	<i>Digitaria eriantha</i>	7	11	14	11	43	21.50	10	215.00
	Diheamp	<i>Diheteropogon amplexans</i>	1	2	2	1	6	3.00	10	30.00
	Eragrac	<i>Eragrostis racemosa</i>	3	0	0	1	4	2.00	4	8.00
	Impecyl	<i>Imperata cylindrica</i>	3	2	3	2	10	5.00	7	35.00
	Setasph	<i>Setaria sphacelata</i>	14	12	8	12	46	23.00	10	230.00
	Themtri	<i>Themeda triandra</i>	10	12	8	8	38	19.00	10	190.00
	Urylagr	<i>Urelytrum agropyroides</i>	8	6	10	9	33	16.50	7	115.50
MBP 4 (W)	Cymbval	<i>Cymbopogon validus</i>	8	6	4	7	25	12.50	7	87.50
	Digieri	<i>Digitaria eriantha</i>	8	13	11	9	41	20.50	10	205.00
	Diheamp	<i>Diheteropogon amplexans</i>	3	5	4	2	14	7.00	10	70.00
	Impecyl	<i>Imperata cylindrica</i>	2	1	3	3	9	4.50	7	31.50
	Setasph	<i>Setaria sphacelata</i>	14	15	16	14	59	29.50	10	295.00
	Urylagr	<i>Urelytrum agropyroides</i>	15	10	12	15	52	26.00	7	182.00
MBP 5 (E)	Chlogay	<i>Chloris gayana</i>	1	0	1	1	3	1.50	10	15.00
	Cymbval	<i>Cymbopogon validus</i>	6	2	6	3	17	8.50	7	59.50
	Digieri	<i>Digitaria eriantha</i>	7	13	6	9	35	17.50	10	175.00
	Diheamp	<i>Diheteropogon amplexans</i>	6	5	2	3	16	8.00	10	80.00
	Eragrac	<i>Eragrostis racemosa</i>	2	0	0	0	2	1.00	4	4.00
	Hypadis	<i>Hyparrhenia dissoluta</i>	1	1	0	0	2	1.00	7	7.00
	Impecyl	<i>Imperata cylindrica</i>	2	3	1	1	7	3.50	7	24.50
	Setasph	<i>Setaria sphacelata</i>	20	20	21	20	81	40.50	10	405.00
	Urylagr	<i>Urelytrum agropyroides</i>	5	6	13	13	37	18.50	7	129.50

Site	Sp Acronym	Species	Quad 1	Quad 2	Quad 3	Quad 4	Total	%	EIV	REIV
MBP 6 (B)	Cymbval	<i>Cymbopogon validus</i>	14	15	11	19	59	29.50	7	206.50
	Digieri	<i>Digitaria eriantha</i>	12	13	11	11	47	23.50	10	235.00
	Diheamp	<i>Diheteropogon amplexans</i>	1	0	1	0	2	1.00	10	10.00
	Panideu	<i>Panicum deustum</i>	0	1	2	1	4	2.00	10	20.00
	Setasph	<i>Setaria sphacelata</i>	17	12	9	12	50	25.00	10	250.00
	Urylagr	<i>Urelytrum agropyroides</i>	6	9	16	7	38	19.00	7	133.00
MBP 7 (W)	Cymbval	<i>Cymbopogon validus</i>	10	12	11	12	45	22.50	7	157.50
	Digieri	<i>Digitaria eriantha</i>	9	9	6	11	35	17.50	10	175.00
	Dihecon	<i>Diheteropogon contortus</i>	10	13	10	7	40	20.00	10	200.00
	Melirep	<i>Melinis repens</i>	1	1	3	1	6	3.00	4	12.00
	Panideu	<i>Panicum deustum</i>	2	1	0	0	3	1.50	10	15.00
	Panimax	<i>Panicum maximum</i>	2	1	1	1	5	2.50	10	25.00
	Peropat	<i>Perotis patens</i>	1	1	2	0	4	2.00	4	8.00
	Setasph	<i>Setaria sphacelata</i>	12	7	12	12	43	21.50	10	215.00
	Urylagr	<i>Urelytrum agropyroides</i>	3	5	5	6	19	9.50	7	66.50
	Cymbval	<i>Cymbopogon validus</i>	8	10	6	5	29	14.50	7	101.50
MBP 8 (E)	Digieri	<i>Digitaria eriantha</i>	9	6	9	14	38	19.00	10	190.00
	Diheamp	<i>Diheteropogon amplexans</i>	10	8	11	4	33	16.50	10	165.00
	Melirep	<i>Melinis repens</i>	0	0	1	1	2	1.00	4	4.00
	Panideu	<i>Panicum deustum</i>	3	2	4	0	9	4.50	10	45.00
	Panimax	<i>Panicum maximum</i>	0	2	0	0	2	1.00	10	10.00
	Setasph	<i>Setaria sphacelata</i>	9	9	6	7	31	15.50	10	155.00
	Urylagr	<i>Urelytrum agropyroides</i>	11	13	13	19	56	28.00	7	196.00
	Cymbval	<i>Cymbopogon validus</i>	12	12	9	11	44	22.00	7	154.00
MBP 9 (B)	Digieri	<i>Digitaria eriantha</i>	10	7	4	9	30	15.00	10	150.00
	Diheamp	<i>Diheteropogon amplexans</i>	4	4	3	5	16	8.00	10	80.00
	Setasph	<i>Setaria sphacelata</i>	7	13	15	8	43	21.50	10	215.00
	Urylagr	<i>Urelytrum agropyroides</i>	15	13	19	17	64	32.00	7	224.00

Appendix 10 Clipped biomass separated into its component categories (Grass, Woody, Herbaceous; gm) for selected plots from Trial One (A) and Trial Two & Three (B)

A					
Aspect	Fint	Clip	Grass	Woody	Herbaceous
Bottom	Annual	Clip	59.92	34.66	21.15
Bottom	Annual	Unclip	220.56	151.42	96.23
Bottom	ThreeYr	Clip	29.02	11.06	25.63
Bottom	ThreeYr	Unclip	210.74	35.51	27.97
East	Annual	Clip	44.34	31.19	23.38
East	Annual	Unclip	320.34	64.24	33.22
East	ThreeYr	Clip	24.66	14.83	18.26
East	ThreeYr	Unclip	221.34	31.13	48.8
Top	Annual	Clip	42.52	21.85	18.9
Top	Annual	Unclip	330.45	74.3	50.46
Top	ThreeYr	Clip	40.16	29.72	21.39
Top	ThreeYr	Unclip	205.99	172.84	49.25
West	Annual	Clip	46.12	37.12	34.88
West	Annual	Unclip	481.89	102.96	43.51
West	ThreeYr	Clip	32.21	34.35	12.46
West	ThreeYr	Unclip	203.11	239.18	24.73
B					
Type	Burn	Clip	Grass	Woody	Herbaceous
Grass	Burnt	Clip	31.45	28.33	0.00
Grass	Burnt	Unclip	241.31	33.26	17.99
Grass	Unburnt	Clip	34.25	24.97	15.51
Grass	Unburnt	Unclip	392.94	28.67	21.18
Pine	Burnt	Clip	237.26	17.33	0.00
Pine	Burnt	Unclip	427.45	47.58	0.00

Appendix 11 All possible subset selection of the model for the forward stepwise regression analysis. Adjusted R^2 , Mallows Cp statistic, and Degrees of Freedom (Df) are presented for the variables percentage soil moisture (Moisture), photosynthetically active radiation (PAR), intercepted at ground level (Ground), fire exclusion period (Fire Excl), biomass removal (Clip), catenal position (Aspect), and PAR intercepted within the upper canopy (Canopy).

Best subsets with 1 term								
Adjusted R^2	Cp	Df	Moisture	Ground	Fire Excl	Clip	Aspect	Canopy
25.82	21.96	2	-	-	0.026	-	-	-
24.06	22.77	2	-	0.031	-	-	-	-
18.16	25.47	2	-	-	-	0.056	-	-
16.34	26.3	2	-	-	-	-	-	0.067
1.2	33.23	2	0.295	-	-	-	-	-
<0.00	32.03	4	-	-	-	-	0.469	-
Best subsets with 2 terms								
Adjusted R^2	Cp	Df	Moisture	Ground	Fire Excl	Clip	Aspect	Canopy
47.36	12.38	3	-	-	0.011	0.022	-	-
33.45	18.29	3	-	0.13	0.108	-	-	-
30.67	18.94	5	-	-	0.026	-	0.315	-
26.51	20.43	5	-	0.037	-	-	0.37	-
26.35	21.31	3	-	-	0.112	-	-	0.313
23.77	21.42	5	0.046	-	-	-	0.125	-
20.91	22.45	5	-	-	-	0.058	0.368	-
20.56	23.77	3	0.791	-	0.056	-	-	-
Best subsets with 3 terms								
Adjusted R^2	Cp	Df	Moisture	Ground	Fire Excl	Clip	Aspect	Canopy
59.15	9.36	6	-	-	0.007	0.015	0.145	-
51.07	11.2	4	-	0.184	0.009	0.035	-	-
49.73	11.73	4	0.228	-	0.007	0.013	-	-
48	12.41	4	-	-	0.011	0.026	-	0.303
39.49	15.79	6	-	0.138	0.097	-	0.291	-
36.14	16.88	6	0.194	-	0.107	-	0.17	-
31.4	18.92	4	-	0.187	0.09	-	-	0.449
30.74	18.65	6	-	-	0.106	-	0.335	0.338
Best subsets with 4 terms								
Adjusted R^2	Cp	Df	Moisture	Ground	Fire Excl	Clip	Aspect	Canopy
71.51	6.39	7	-	0.046	0.002	0.007	0.05	-
64.23	8.53	7	-	-	0.005	0.011	0.1	0.154
62.73	7.41	5	0.052	0.044	0.002	0.005	-	-
54.65	11.35	7	0.931	-	0.023	0.051	0.296	-
51.19	11.56	5	0.209	-	0.006	0.014	-	0.269
46.62	13.2	5	-	0.424	0.013	0.059	-	0.992

38.17	16.2	7	-	0.172	0.078	-	0.295	0.398
36.88	16.58	7	0.464	0.318	0.169	-	0.272	-
Best subsets with 5 terms								
Adjusted R ²	Cp	Df	Moisture	Ground	Fire Excl	Clip	Aspect	Canopy
71.73	7.4	8	0.331	0.035	0.003	0.008	0.17	-
68.05	8.36	8	-	0.188	0.003	0.015	0.071	0.876
62.81	8.16	6	0.037	0.061	0.002	0.006	-	0.336
59.93	10.48	8	0.857	-	0.012	0.025	0.225	0.178
35.87	16.78	8	0.434	0.225	0.134	-	0.265	0.381
13.74	22.57	8	0.3	0.497	-	0.921	0.312	0.665
Best subsets with 6 terms								
Adjusted R ²	Cp	Df	Moisture	Ground	Fire Excl	Clip	Aspect	Canopy
69.42	9	9	0.282	0.104	0.006	0.017	0.249	0.549

Oil

Microwave Sample Preparation Note: XprOP-1
Category: Oils

Rev. Date: 6/04

Sample Type: Oil
Application Type: Acid Digestion
Vessel Type: 55 mL
Number of Vessels: 12
Reagents: Nitric Acid (70%)
Method Sample Type: Organic
Sample Weight: 0.5 gram

Step 1:

<u>Acid Type</u>	<u>Volume</u>
Nitric	10 mL

Heating Program: Ramp to Temperature Control

Stage	Max. Power	% Power	Ramp (min.)	Pressure (psi)	Temperature (°C)	Hold (min.)
(1)	1200 W	75	15:00	-	200	15:00

NOTE A: This procedure is a reference point for sample digestion using the CEM Microwave Sample Preparation System and may need to be modified or changed to obtain the required results on your sample.

NOTE B: Manual venting of CEM closed vessels should only be performed when wearing hand, eye and body protection and only when the vessel contents are at or below room temperature to avoid the potential for chemical burns. Always point the vent hole away from the operator and toward the back of a fume hood.

NOTE C: Power should be adjusted up or down with respect to the number of vessels. General guidelines are as follows: 8-12 vessels (50% power), 13-20 vessels (75% power), >20 vessels (100% power).

NOTE D: "Organic Method Sample Type" should be used for most sample types. Choose "Inorganic" for samples with more than 1 gram of solid material remaining at the bottom of the vessel at the end of the digest (ex. leach methods). Choose "Water" for samples that are largely aqueous prior to digestion.