IMPLICATIONS OF CHANGING LAND USE AND INTRODUCING EXTRALIMITAL GIRAFFE ON VEGETATION IN THE SUBTROPICAL THICKET, SOUTH AFRICA

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ABSTRACT

Land use change has increased in southern Africa as many livestock farms convert to game reserves, to restore degraded and overgrazed lands. This leads to a change in herbivore communities with potential positive and negative consequences for vegetation and landscape productivity. This study aimed to look at the effect of land use change and subsequent herbivore community changes, on thicket vegetation structure, composition, and landscape productivity. To attain the study objectives, data were collected from four game reserves and their adjacent livestock farms within the Eastern Cape province in South Africa. These sites were selected because they are within the Subtropical Thicket biome (similar vegetation) and were once used for livestock farming. At each study site, vegetation composition and structure were assessed using a unique bush clump sampling technique along fence line contrasts. Six plots were sampled at each site, three plots on the game reserve lands and three plots on the adjacent livestock farmlands during the dry (July/August 2020) and wet (January/February 2021) seasons. The Normalized Difference Vegetation Index (NDVI), in-situ leaf area index (LAI) and the fraction of intercepted photosynthetically active radiation (FIPAR), were used to assess vegetation productivity between the two land use types. Additionally, diet of an extralimital herbivore, giraffe (*Giraffa camelopardalis*), was assessed during contrasting seasons (dry and wet) to infer the role this species might have on these landscapes. The diet of giraffes was assessed through field observations, recording plant species that giraffes were feeding on. Floristic results showed that there were no differences in vegetation structure, species composition and richness between the two land types. There was no difference in the overall diversity of plant species on the game reserves than in the adjacent livestock farms. The primary productivity was greater on the game reserves compared to the livestock farms. Field observations of giraffe feeding showed that they fed predominantly on *Vachellia karroo* followed by *Searsia longispina*. Their diets did not differ between the two seasons. My study provides an insight into the effects of changing land use and this information can be used to infer the extent to which these changes might have on restoration of degraded landscape and how land use changes may be effective in restoring the degraded thicket vegetation caused by overgrazing and overstocking of domestic livestock.

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CHAPTER 1

GENERAL INTRODUCTION

Introduction

The Eastern Cape Subtropical Thicket biome has undergone severe degradation due to domestic livestock overgrazing and overstocking (Rutherford et al., 2014). Land degradation is defined by the United Nations Convention to Combat Desertification (UNCCD) as *"the reduction or loss of biological or economic productivity*" (Vogt et al., 2011, page 150). Degradation is exacerbated by the high levels of aridity in the Subtropical Thicket (Rutherford et al., 2014). In the years 2009/10, the Eastern Cape province experienced severe drought (Clarke et al., 2012) and this might have contributed to the current levels of degradation observed in these landscapes. This degradation resulted in the loss of vegetation structure and associated functioning in the Subtropical Thicket (Rutherford et al., 2014). As such, efficient restoration techniques are needed in the Subtropical Thicket biome to restore the lost ecosystem processes and, floral and faunal biodiversity (Gerber, 2006; Vlok et al., 2003). Within South Africa, there has been a shift in land use practices from livestock farming of goats (*Capra aegagrus hircus*) and sheep (*Ovis aries*) to game reserves with wild herbivores that range in size from common duiker (*Sylvicapra grimmia*) to African elephants (*Loxodonta africana*). The change in land use could bring about changes in vegetation structure and landscape productivity, owing to differences in browsing pressure and/or behaviour of domestic and wild herbivores (Stuart-Hill, 1992). The Eastern Cape Subtropical Thicket biome provides an ideal opportunity to explore the extent to which these changes might occur and understanding the implication of these changes in the restoration of the Subtropical Thicket biome is paramount and this is the motivation of this study.

Subtropical Thicket

The Subtropical Thicket biome is found within the south-eastern area of South Africa and is unique in its numerous crucial functional respects (Rutherford et al., 2014). As the biome does not support fire, it is unique within the African ecosystems as herbivores are the major reason for defoliation (Cowling et al., 2005). Other distinctive functional aspects of the Subtropical Thicket biome are the high biomass, which is around 80 000 kg ha^{-1}, litter production is similar to biomes of higher rainfall such as Temperate Forests, and the soil within the biome is carbon-rich compared to soils within other South African biomes (Rutherford et al., 2014). The uniqueness of the Subtropical Thicket biome is also shown by the numerous geological types it covers, including quartzite and shale, and not having one specific substrate type (Vlok et al., 2003). Climatic variables are unpredictable within the Subtropical Thicket biome, whereas the other seven South African biomes' climates are more predictable (Dlamini, 2011). The Subtropical Thicket biome has always supported a high density and diversity of indigenous wild herbivores of all sizes (Skead, 1989). High African elephant (hereafter elephant) numbers were often recorded by early travelers to the Eastern Cape (Stuart-Hill, 1992). This large herbivore presence is due to the nutrient-rich vegetation and proximity of several perennial rivers. Consequently, these large herbivores help to shape vegetation structure and maintain ecosystem properties (Stuart-Hill, 1992; Kerley et al., 1999). Plant species in the Subtropical Thicket have evolved with herbivory, some species creating specific defense mechanisms against herbivores (Haschick, 2002). However, the historical replacement of wild herbivores (e.g., kudu *Tragelaphus strepsiceros*, zebra *Equus quagga*, black rhinoceros, *Diceros bicornis* and elephant) with domestic livestock (e.g., goats, cattle (*Bos taurus*) and sheep) in the Subtropical Thicket changed the grazing pressure, making the biome extremely vulnerable to overgrazing and degradation, especially in the last 200 years (Rutherford et al., 2014). Kerley and Landman (2006) noted that the megaherbivores (≥ 1000 kg; Owen-Smith, 1988) that roamed the Subtropical Thicket area had a less detrimental effect on ecosystems than domestic livestock. The collapse of ecosystems and ecosystem services due to the extreme land degradation has threatened the biodiversity of areas within the Subtropical Thicket and caused the utilization of the land to be unsustainable (Kerley et al., 1995; 1999). Changes to the Subtropical Thicket due to degradation are noticeable and these include vegetation structural simplification, a decline of perennial plants and replacement of those plants by annuals, a decrease and loss of biomass, soil erosion, loss of soil nutrients and organic matter, and the preference of less palatable plants or non-native species (Hoffman and Cowling, 1990). Thus, restoration of the Subtropical Thicket is crucial and necessary with the current levels of thicket degradation, although many believe that it cannot recover from drastic disturbance events (Gerber, 2006). Thicket recovery is a long process that requires very long periods and its recovery is especially slow after a major disturbance event (Midgley and Cowling, 1993). Midgley and Cowling (1993) noted that Subtropical Thicket canopy species regenerate through root sprouts and not seedlings, and this would affect the rate and extent of recovery. Most research on herbivory in the Subtropical Thicket focuses on the effects of domestic herbivores (Gerber, 2006) and elephants, thus, extensive research is still needed on the effects of wild herbivores on the function and structure of the Subtropical Thicket vegetation.

The effects of domestic herbivores on landscapes

Degradation within the southern Africa region is linked to overgrazing and overstocking of domestic herbivores, such as goats, cattle, and sheep (Stuart-Hill, 1992). Goat feeding habits, as individuals and groups, differ from wild herbivore feeding habits in that goats are gregarious animals and will feed as groups on one individual plant, leading to intense and targeted localized impacts (Stuart-Hill, 1992). Goats also feed from the side of bush clumps whereas wild indigenous herbivores feed from the top of bush clumps, thus promoting the recruitment of vegetation (Stuart-Hill, 1992). When goats eat from the side of the bush clumps, it causes structural damage and allows a bush clump interior to become exposed and thus receive further damage from wind and water erosion (Stuart-Hill, 1992). The detrimental effects of livestock grazing are seen globally through the negative impact on biodiversity in many countries (Schieltz and Rubenstein, 2016). Domestic livestock overgrazing impacts not only biodiversity but also reduces biomass and density of animal and plant species, alters ecological succession, nutrient cycling, and affects landscape heterogeneity, leading to homogenization of landscapes (Kauffman and Pyke, 2001). An important factor in understanding the impact of domestic livestock on landscapes is the stocking rate or grazing intensity instead of simply looking at grazed versus ungrazed landscapes (Schieltz and Rubenstein, 2016). Proper management of livestock can have a positive impact on landscapes and ecosystem health (Reid et al., 2013). The intensive livestock farming within Savanna and Thicket type landscapes has led to a focus on the herbaceous vegetation growth for increased grazing and controlling woody plant cover (O'Connor, 1996; Weber et al., 1998; Schieltz and Rubenstein, 2016). The woody vegetation component has been overlooked in many studies and as a result, there has been poor management and understanding of the structural and species diversity of woody vegetation within Savanna and Thicket systems (Scogings, 1998).

The effects of wild herbivores on landscapes

Large wild herbivores (≥100 kg) are key ecosystem engineers in many landscapes (Ripple et al., 2015). Trampling and consumption of vegetation by herbivores maintain landscape heterogeneity by allowing many functional types to grow instead of a homogenous woody landscape (Ripple et al., 2015). Additionally, through this trampling, large herbivores like elephants make food resources accessible to other smaller herbivores like an impala (*Aepyceros melampus*) (Rutina et al., 2005) and reduce the intensity of fire (Lungren et al., 2018). Wild herbivores also play an important role in nutrient cycling through consumption and defecation, which returns nutrients to soils faster than the process of leaf loss and decay (McNaughton et al. 1988; Danell et al., 2006; Ripple et al., 2015). Furthermore, they disperse and distribute seeds and nutrients across long distances (Ripple et al., 2015). For example, elephants disperse seeds up to 65 km from their source (Bunney et al., 2017), while grazing by white rhino (*Ceratotherium simum*) maintains shorter grass swards favoured by smaller herbivores such as the blue wildebeest (*Connochaetes taurinus*) (Waldram et al., 2008). The increasing trends of introducing wild herbivores in areas where they had historically occurred and in areas outside their natural range are done to promote conservation and ecotourism within private and state-protected areas (Parker and Bernard, 2005; Truter 2020). Of these introduced wild herbivores, giraffes (*Giraffa camelorpadalis*) have been introduced into the Eastern Cape and they are not indigenous to the area (Jacobs, 2008). The native range of giraffes ranges from the Kalahari to Kruger National Park in South Africa (Deacon and Smith, 2017). Giraffes feed off deciduous species during the summer months in their native ranges (Parker and Bernard, 2005) and only a handful of studies have been conducted outside their native range, to provide insight into their diet and behaviour (Parker and Bernard, 2005; Paulse, 2018). Thus, more research on the diet of giraffes is needed and such information could be used to infer the role that giraffes might have in the Subtropical Thicket biome.

Remote sensing techniques

Using appropriate approaches to assess changes in vegetation structure and landscape productivity will help attain the study objectives, hence, the study adopted the use remote sensing and geographic information sensing (GIS) because these tools have been implemented in assessing land cover change in the past (Aburas et al., 2015). Normalized Difference Vegetation Index (NDVI) is one remote sensing indicator, effective in detecting Spatio-temporal changes in vegetation cover (Aburas et al., 2015). There are different remote sensing indices used in vegetation analysis and the most common is the NDVI. The NDVI characterizes canopy vigour or growth of vegetation. Leaf Area Index (LAI) is often compared to NDVI

(Xue and Su, 2017). The differences and changes in leaf greenness and canopy spectral characterize and interpret vegetation remote sensing information (Xue and Su, 2017). Normalized Difference Vegetation Index is an approximate estimate of vegetation health through the use of chlorophyll content within plants (Pettorelli et al., 2018). The NDVI is calculated by dividing average surface reflection by ranges of wavelengths in the visible ("red") and near-infrared regions of the electromagnetic spectrum (Carlson and Ripley, 1997). It can represent many characteristics of vegetation in an area such as leaf area index, vegetation condition, fractional vegetation cover, and biomass (Carlson and Ripley, 1997). Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) is used to monitor inter-annual and seasonal variability in photosynthetic activities of vegetation (Gobron et al., 2007), such as canopy photosynthesis, evapotranspiration rates, and carbon assimilation (Weiss et al., 2010). Photosynthetically Active Radiation (PAR) is the solar radiation that reaches the vegetation canopy within the 0.4 – 0.7 µm wavelength area (Gobron et al., 2007). The FAPAR is an effective tool for measuring energy balances and estimating carbon balance over a broad range of spatial and temporal scales (Gobron et al., 2007). The FAPAR is one of the widely used approaches for modeling gross primary productivity (GPP) proposed by Monteith (1972) (Rossini et al., 2012).

Leaf Area Index is defined as "the projected area of leaves over a unit of land" (Running, 2002). Leaf surfaces are an important border of mass exchange and energy, and key processes such as canopy interception, gross photosynthesis, and evapotranspiration are directly proportional to LAI (Running, 2002). The LAI is non-linearly related to surface reflectance, and therefore the estimation of LAI from remote sensing is scale-dependent (Terrascope, 2019).

The FAPAR and LAI are two biophysical components that work well together to aid in describing the earth's terrestrial vegetation (Fensholt et al., 2004). The LAI allows for to estimation of the green leaf area of vegetation, while FAPAR measures the fraction of sunlight that leaves absorb and therefore gives the vegetation canopy's energy absorption capacity (Myneni et al., 1995). The FAPAR is key to assessing vegetation productivity and LAI can provide suitable data for hydrological modeling (Fensholt et al., 2004). Another approach for assessing GPP of landscapes is a simplified version of Monteiths' (1972) light-use efficiency (LUE) model that makes use of FAPAR. This approach suggests that GPP can be recorded through indices that are directly related to chlorophyll content in vegetation, such as NDVI and LAI (Rossini et al., 2015; Harris and Dash, 2010). The studies that followed this approach (Gitelson et al., 2008; Harris and Dash, 2010) made use of the incident PAR value and thus used Fraction of Photosynthetically Radiation Intercepted by vegetation (FIPAR). Rossini et al (2012) highlighted that NDVI was a poor individual indicator of productivity but when used alongside LAI and FIPAR it provides greater accuracy on GPP.

This study aimed to assess changes brought about by changes in land use. The specific objectives were 1) to understand how changes in herbivore communities (domestic livestock to wild herbivores), associated with changes in browsing pressure and/or behaviour would affect vegetation structure, plant species composition, and landscape productivity, 2) to describe the diet of an extralimital giraffe in the Eastern Cape Subtropical Thicket biome, to infer the role this species might have on these landscapes. Specific objectives and predictions are explained in detail in their respective chapters. This thesis consists of six chapters. **Chapter one** is the general introduction, **chapter two** is the description of the study sites, **chapter three** describes all the methods used to collect data for specific chapters, these being **chapters four and five**, and the final chapter, **chapter six** is the concluding discussion, providing the overview of the study.

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CHAPTER 2

STUDY SITES

The study was conducted in four game reserves within the Eastern Cape Subtropical Thicket biome, that include Amakhala Game Reserve (Amakhala), Kariega Game Reserve (Kariega), Kwandwe Game Reserve (Kwandwe), and Pumba Game Reserve (Pumba). These reserves were chosen because they were adjacent to active domestic livestock farms (figure 2.1), which were used as experimental sites for the vegetation surveys. Each reserve is home to several megaherbivores (≥ 1000 kg, Owen-Smith 1988); African elephant (*Loxodonta africana*), black rhinoceros (*Diceros bicornis*), white rhinoceros (*Ceratotherium simum*), and giraffe (*Giraffa camelopardalis)*. Of these megaherbivores, giraffes and white rhino are extralimital species in the Eastern Cape. Extralimital species are species that do not historically occur in an area they have been introduced (Maciejewski and Kerley, 2014). Table 2.1 below summarizes the characteristics of each game reserve, and further details of each reserve are provided in the paragraphs below.

Table 2.1: Summary of the main characteristics of each game reserve chosen as a study site. Records of rhinoceros have been excluded from this table for security reasons.

Site name	**Site code**	**Closest town**	**No. of elephant**	**No. of rhino**	**No. of giraffe**	**Size (ha)**	**Thicket type (According to STEP map – figure 2.2)**
Amakhala	A	Paterson	25	-	30	8500	Albany coastal belt and Kowie thicket
Kariega (Harvestvale section)	KA	Kenton-on-sea	12	-	52	4600	Albany coastal belt and Kowie thicket
Kwandwe	KW	Makhanda	56	-	60	22 000	Great Fish Noorsveld
Pumba	P	Makhanda	20	-	95	6000	Kowie thicket

Table 2.2: Summary of the main characteristics of each livestock farm chosen as a study site.

Site name	**Neighbouring reserve**	**Livestock farmed**	**Size (ha)**	**Thicket type (According to STEP map – figure 2.2)**
Nanaga Farm	Amakhala	Cattle	1184	Albany coastal belt and Kowie thicket
Nightingale Farm	Kariega	Cattle, Boer goats	928	Albany coastal belt and Kowie thicket
Dell Farm	Kwandwe	Dorper sheep, Savanna goats, cattle	2500	Great Fish Noorsveld
Bowles Farm	Pumba	Cattle, goats, sheep	995	Kowie thicket

Table 2.3: List of herbivores present on each game reserve.

Species	**Common name**	**Amakhala**	**Kariega**	**Kwandwe**	**Pumba**
Aepyceros melampus	Impala	X	X	X	X
Alcelaphus buselaphus caama	Red hartebeest	X	X	X	
Antidorcas marsupialis	Springbok	X		X	
Ceratotherium simum	White rhinoceros	X	X	X	X
Connochaetes gnou	Black wildebeest	X	X		X
Connochaetes taurinus	Blue wildebeest		X	X	X
Damaliscus pygargus	Bontebok		X	X	
Damaliscus pygargus phillipsi	Blesbok	X	X	X	X
Diceros bicornis	Black rhinoceros		X	X	
Equus quagga burchellii	Burchell's zebra	X	X	X	X
Giraffa camelopardalis	Giraffe	X	X	X	X
Hippopotamus amphibius	Hippopotamus	X	X	X	X
Hippotragus niger	Sable			X	
Kobus ellipsiprymnus	Waterbuck	X	X	X	X
Loxodonta africana	Elephant	X	X	X	X
Oryx gazella	Gemsbok	X	X	X	X
Pedetes capensis	Springhare	X	X	X	
Phacochoerus africanus	Common warthog	X	X	X	X
Philantomba monticola	Blue duiker				X
Raphicerus melanotis	Grysbok		X		X
Redunca fulvorufula	Mountain reedbuck	X	X	X	X
Sylvicapra grimmia	Common duiker	X	X	X	X
Syncerus caffer	Cape buffalo	X	X	X	X
Taurotragus oryx	Eland	X	X	X	X
Tragelaphus angasii	Nyala	X	X	X	X
Tragelaphus scriptus	Bushbuck	X	X	X	X
Tragelaphus strepsiceros	Greater kudu	X	X	X	X

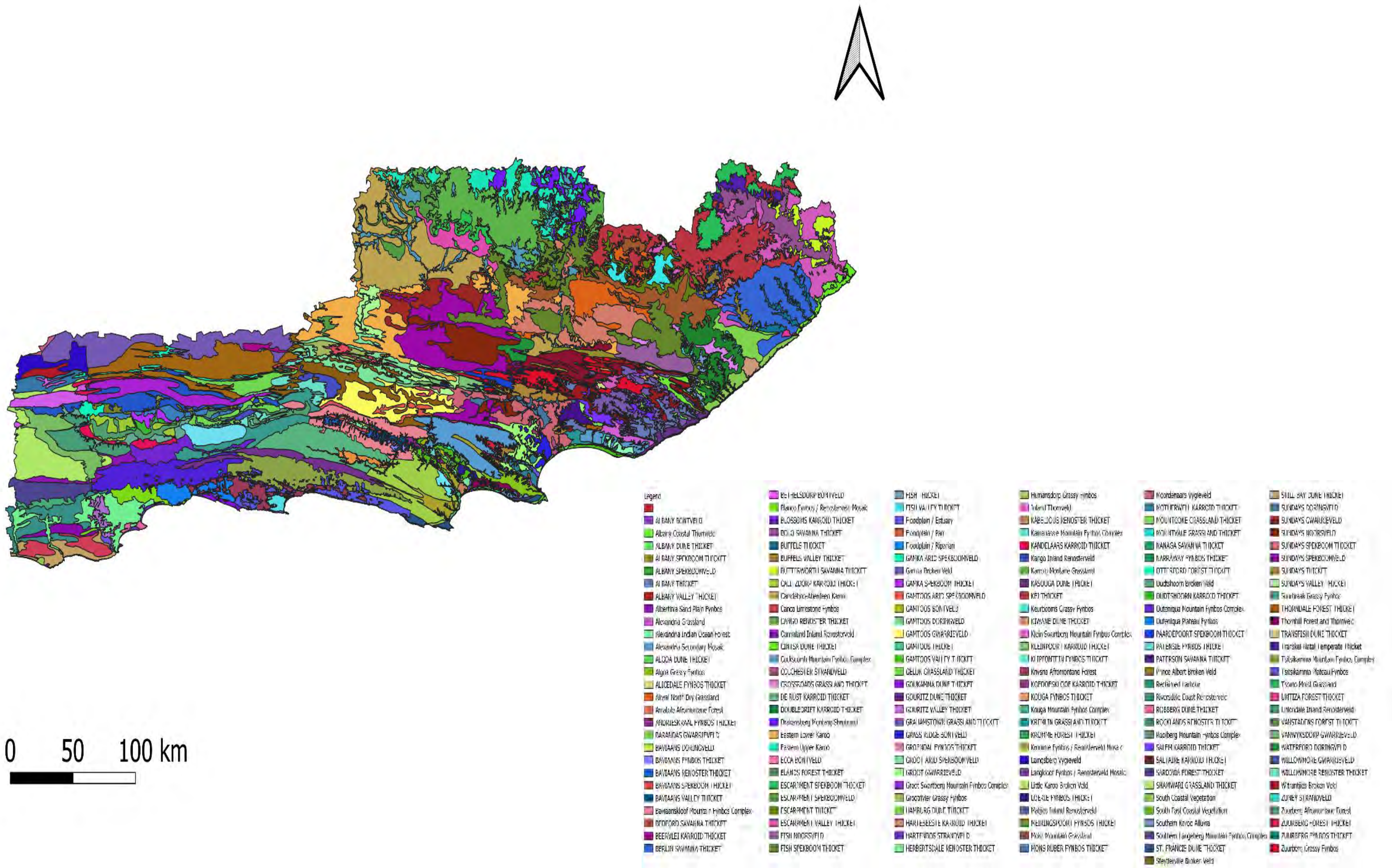

Figure 2.1: Subtropical Thicket Ecosystem Planning across the Eastern Cape province.

Amakhala Game Reserve and Nanaga Livestock Farm

Site description

Amakhala was founded in 1999 as a joint project for the conservation of six lodges (Amakhala Game Reserve, 2021). Historically, this land was used for cattle and sheep farming until the 1900s (Amakhala Game Reserve, 2021). After this period of livestock farming, the reserve turned to a conservation perspective and initiatives for conservation began in the late 1980s. These initiatives included clearing of man-made infrastructure and invasive vegetation, and reintroductions of small wildlife populations. The reserve owners wanted to restore the native flora and fauna of the area, thus reintroducing wild herbivores and carnivores in the hope of conserving the lands' natural heritage (Amakhala Game Reserve, 2021).

The reserve is in the Frontier and Addo country of the Eastern Cape, South Africa. It is located between Grahamstown (Makhanda) and Port Elizabeth (Gqeberha) (33°32'07", -26°05'12") on the N2 highway (figure 2.2). The reserve stretches 7500 hectares (ha) and as of 2017 consists of 11 properties that were once sheep and cattle farms. The reserve is separated into three sections – Main reserve, Carnarvondale, and Leeuwenbosch. The reserve is home to the big five (elephant; buffalo *Syncerus caffer*, black and white rhinoceros; lion *Panthera leo*, and leopard (*Panthera pardus*). Amakhala shares a border with the Nanaga trust farm on its southwestern fence line. The farm consists mainly of cattle, specifically for dairy products. The farm has been overgrazed by livestock and has been transformed into agricultural land. There are fences in place to limit the movement of cattle particularly close to the Amakhala fence line.

Figure 2.2: (A) The four study sites within the Eastern Cape, (B) Amakhala Game Reserve Main section and Nanaga Farm along N2 and surrounding towns (Google Earth Pro, 2021).

Climate

The area receives rainfall in spring of approximately 443 mm annually (Zengeni et al., 2016) and has an average maximum temperature of 26°C with temperatures reaching up to 40°C in the warm season between November and February. The minimum temperature at the coldest time of the year (between May and September) is 0°C. The average minimum temperature is 10°C.

Vegetation

The Subtropical Thicket biome dominates the reserve. The thicket in the reserve consists of the Albany Coastal belt and the Kowie thicket (figure 2.1). The Kowie thicket is predominantly found in the northern section of the reserve and the Albany Coastal belt is found within the southern sections of the reserve (figure 2.1). Within these thicket types, there are sub-thicket types found on the reserve, these are Albany Valley thicket, Geluk Grassland thicket, Paterson Savanna thicket, Salem Karroid thicket, Shamwari Grassland thicket, and Thorndale Forest thicket. The sub-thicket types found on the reserve according to the STEP vegetation map are highlighted in figure 2.3.

Across the reserve are large patches of *Vachellia karroo* (commonly known as ‘sweet thorn’) that are maintained and controlled by giraffes and elephants through browsing (O’Kane et al., 2011), particularly during wet season months. The areas of the intact thicket on the reserve are composed of a variety of woody species and these include *Euclea undulata*, *Schotia afra*, *Gymnosporia* species, *Azima tetracantha, Carissa haematocarpa, Searsia longispina,* and *Sideroxylon inerme,* and succulent shrubs like *Portulacaria afra* (Zengeni *et al*., 2016). There are also areas of the transformed thicket on the reserve where *P. afra* is no longer present and many other species have started growing. These species include grasses such as *Themeda triandra* and *Panicum maximum*, and some herbaceous species such as *Senecio linifolius, Crassula mesembryanthoides, Cyphia sylvatica,* and *Chrysocoma ciliata* (Zengeni *et al*., 2016).

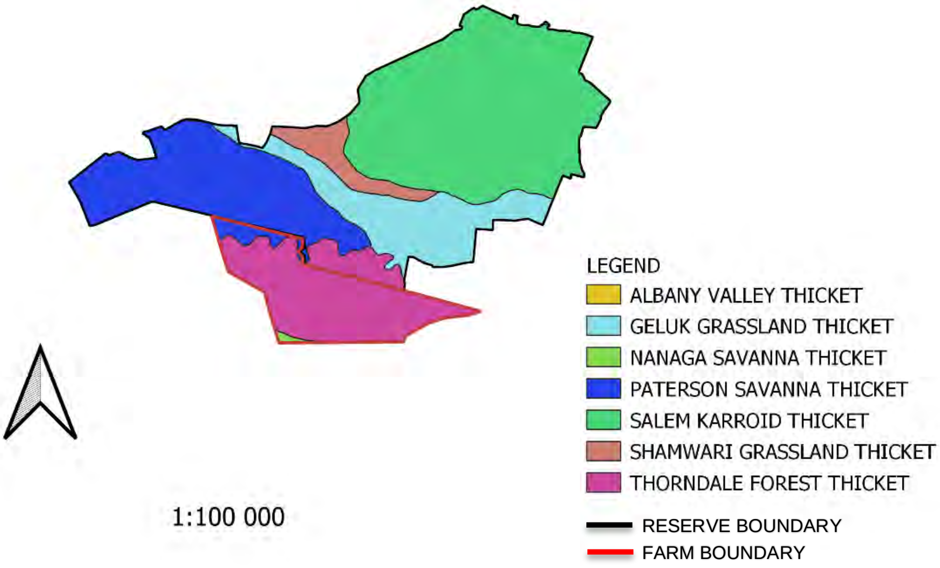

Figure 2.3: Amakhala Game Reserve and Nanaga Livestock Farm according to the STEP vegetation map.

Geology and topography

Amakhala includes many different landforms that make up the topography of the landscape. The reserve consists of cliffs, slopes, and valleys. The altitude ranges from ~180 meters above sea level (m.a.s.l) around the Bushman's river that runs through the reserve, to 400 m.a.s.l. (Nuttall-Smith, 2018). The reserve has undulating hills, changing in altitude throughout the reserve. Steep slopes occur along the Bushman's river that separates the higher plateau in the southern section of the reserve and the low flood plains in the northern section of the reserve (Nuttall-Smith, 2018). The sites that were chosen for this study are on a north-facing cliff both in the reserve and on the adjacent farm.

The Nanaga farmland topography is made up of similar landforms to the Amakhala reserve. The majority of the livestock farm is cliffs with steep slopes that create numerous valleys, spreading across the farmland. Many valleys that are found in the farmland are closer together than the valleys found on the reserve, with higher peaks found on either side of the valley slopes.

Reserve herbivore community

Amakhala is home to many herbivore species ranging in size from small (i.e., common duiker *Sylvicapra grimmia*) to megaherbivores (table 2.3). The megaherbivores present are elephants, white and black rhinoceros, hippopotamus (*Hippopotamus amphibious*), and giraffes. During the period of this study, there were 25 elephants, three hippopotamus, and 30 giraffes (rhinoceros' numbers could not be obtained due to the high sensitivity of this information, as poaching is still a major issue within South Africa). Elephants and black and white rhinoceros were reintroduced onto the reserve in 2003, while giraffes were the first megaherbivores introduced onto the reserve in 1999. Hippopotamus was only reintroduced onto the reserve in 2018.

Kwandwe Game Reserve and Dell Livestock Farm

Site description

Kwandwe is located (33°08'45", -26°31'37") in the Eastern Cape province, South Africa. It is spread across 22 000 hectares and is home to the big five. The reserve was founded in 1999. The land had previously been used for small stock and ostrich farming. The Great Fish River flows through the reserve for 30 km and is the main water source within the reserve (Parker, 2004). Kwandwe's southern fence borders on Dell farmland (33°11'36", -26°25'13"). The farm was purchased by its current owners in 1948. The farm spans 2500 hectares. Dorper sheep, savanna goats, and cattle are farmed on the land.

Figure 2.4: (A) The four study sites within the Eastern Cape, (B) Kwandwe Game Reserve and Dell Farm and surrounding towns (Google Earth Pro, 2021).

Climate

The area experiences a similar climate to its closest town, Grahamstown. Therefore, weather data were taken from the Grahamstown weather station. The area does not receive seasonal rainfall but has two clear rainfall peaks, September to November and January to April. The area receives an average of 500 mm annually. In the summer months (December to February), temperatures can reach up to 35°C, while during winter months, from June to August temperatures can drop below 5°C.

Vegetation

Kwandwe is situated in both the Subtropical Thicket and Nama-Karoo biomes. The Nama-Karoo biome is found in a small region of the southern section of the reserve and is characterised by Albany Broken Veld. Great Fish Noorsveld, Great Fish thicket, and Kowie thicket are all found within the reserve, with Great Fish Noorsveld dominating the landscape (figure 2.5). The Great Fish and the Kowie thicket only make up small areas of the reserve in the northern and southern regions, respectively. The reserve is home to a wide range of vegetation types from Succulent thicket, Riverine thicket, Short and Tall Euphorbia thicket, Karoo Shrubland, and Savanna Bush clumps (Parker, 2004). Areas of the reserve boasting Succulent thicket are characterized by succulent shrubs, lianas, and trees, mainly *Grewia robusta, Brachylaena ilicifolia, P. afra, Rhigozum obovatum,* and *Maytenus capitata* (Low and Rebelo, 1998). Succulent thicket replaces grasslands and savanna when megaherbivores are removed (Low and Rebelo, 1998). Due to the presence of browsers such as black rhino and kudu (*Tragelaphus strepsiceros*) within the Subtropical Thicket biome, the succulent thicket is controlled and does not replace grasslands and savannas (Parker, 2004). Tall Euphorbia thicket is mainly found on the northern hills of the reserve with species such as *Euphorbia tetragona, E. triangularis, S. afra, E. undulata,* and *Pappea capensis* characterizing this area (Low and Rebelo, 1998). While Short Euphorbia thicket is mainly characterized by Euphorbias less than one meter tall such as *Euphorbia bothae* (Parker, 2004). The Riverine thicket is found within the drainage lines of the reserve and around many water sources (Parker, 2004). This vegetation is mainly characterized by *Vachellia karroo* along with *Azima tetracantha* and *Lycium species* (Parker, 2004). There are large sections of *V. karroo* within the reserve that have not been controlled as they provide browse for giraffes and elephants within the reserve. These two animals potentially control the growth and spread of encroaching plant species (*V. karroo*). The Karoo Shrubland is mixed Nama-Karoo found on the reserve that includes some grasses and shrubs that are dependent on seasonal rainfall (Low and Rebelo, 1998). The Karoo shrubland and Nama-karoo include plant species such as *Pentzia incana, P. capensis, V. karroo,* and *Eriocephalus ericoides* (Parker, 2004). Many of the grass species found within the reserve fall into the Savanna Bush clump group, along with bush clumps mainly composed of *P. capensis, S. afra,* and *Carissa haematocarpa* (Parker, 2004).

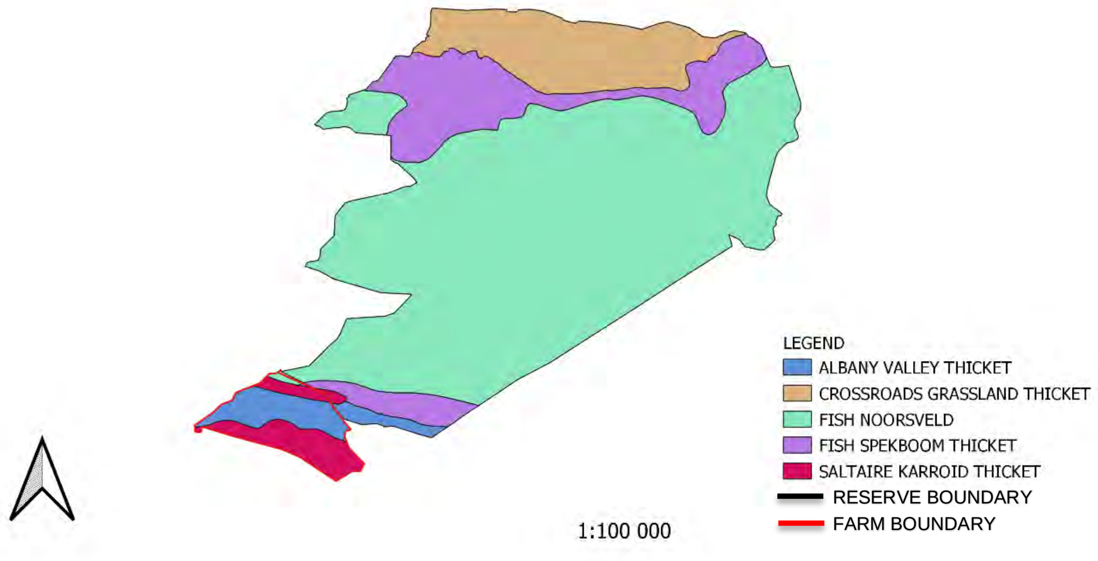

Figure 2.5: Kwandwe Game Reserve and Dell Livestock Farm according to the STEP vegetation map.

Geology and Topography

The reserve consists mainly of open plains and gentle slopes, but steep gorges and valleys are found in the southern region of the reserve (Nuttall-Smith, 2018). The highest point in Kwandwe reaches up to 580 m.a.s.l in the northeast of the reserve (Parker, 2004). The lowest point on the reserve is within the Great Fish River valley at 283 m.a.s.l (Parker, 2004). The Dell farmland consists of a similar topography to the southern part of the reserve, with gentle slopes surrounded by steeper gorges and valleys. The geology of the area is dominated by the Ecca Group shales that create sandy loam and deep lime-rich soils, along with the Cape supergroup lithosols and sandy clays, Ecca and Dywka Formations, and Beaufort group dolerites (Low and Rebelo, 1998).

Reserve herbivore community

Kwandwe is home to many herbivore species ranging in size from small (common duiker) to megaherbivores (table 2.3). The megaherbivores present are elephants, white and black rhinoceros, hippopotamus, and giraffes. There were 56 elephants, 15 hippopotamus, and 60 giraffes during the period of the study. Rhinoceros numbers could not be obtained due to the high sensitivity of this information, as poaching is still a major issue within South Africa. Elephants and hippopotamus were reintroduced onto the reserve in 2001.

Kariega Game Reserve and Nightingale Livestock Farm

Site description

Kariega was founded in 1990. Initially, the reserve covered an area of approximately 1900 ha when it was proclaimed. The land had previously been used for pineapple, maize, and chicory farming until 1990. In 2003, the western section of the reserve opened at 3000 ha. This section was previously used for farming cattle and sheep, and as small-scale pineapple and chicory farms until 2002. The Harvestvale section is the third section of the reserve and was incorporated into the reserve in 2014. The land was previously used to farm cattle and had small antelope from 2004 until 2014. This section is found along the Bushman's river and is where this study was conducted. Kariega is located between Kenton-on-sea and Grahamstown along the R343 (33°34'33", -26°36'13") (figure 2.6).

The eastern section of the reserve borders Sibuya Game Reserve. This section does not have elephant or lion populations. Only the western section of the reserve has lions and elephants. The Harvestvale section of Kariega borders onto Nightingale farm (33°38'16", -26°31'53"). This farm was an allotment given to the Garner family in 1820 and has remained in the family to the present day. The farm has mainly cattle, specifically beef farming, and Bonsmara and Boer goats. The farm had previously been used for Angora goat and sheep farming, as well as dairy farming, and chicory. Harvestvale was used as farmland on the Nightingale farm before it was incorporated into the reserve. Before the reserve was formed, the land was used for small-stock with some crop farming along the Kariega river floodplains (Parker, 2004).

Figure 2.6: (A) The four study sites within the Eastern Cape, (B) Kariega Game Reserve (sectioned) and Nightingale Farm and surrounding towns (Google Earth Pro, 2021).

Climate

Weather data were taken from the closest weather station to the reserve which is the Port Alfred weather station. Rainfall is limited to the spring season with the reserve receiving an average of 620 mm annually. Climate is largely influenced by the reserves' proximity to the coastline. The land/sea breezes and coastal fog increase rainfall in the area (Stone et al., 1998; Parker, 2004). Maximum temperatures reach 30°C during the summer months between November and April, while winter temperatures drop to 5°C between the winter months, May to August.

Vegetation

Kariega is dominated by the Subtropical Thicket. The Subtropical Thicket is characterized in the reserve by Coastal thicket, Valley thicket, Eastern Thorn Bushveld, Old Farmlands, and Secondary Acacia thicket (Parker, 2004). Coastal forest is mainly within the deeper valleys on the reserve along the West and East boundaries, composed of *Sideroxylon inerme, Mimusops caffra,* some *Strychnos species,* and *Cassine aethiopica* (Low and Rebelo, 1998). The Valley thicket is found on the slopes of many of the hills on the reserve and is composed of dense evergreen woody trees and shrubs (Parker, 2004). These trees and shrubs include *E. triangularis, E. tetragona, Cassine aethiopica,* and *Plumbago articulata* (Low and Rebelo, 1998). The northern region, and a few ridges within the southern section of the reserve, are dominated by Eastern Thorn Bushveld (Parker, 2004). The Eastern Thorn Bushveld is characterized by small *V. karroo* trees, *Searsia* species, *Diospyros dichrophylla, Eritrea rigida,* and *Scutia myrtina* (Low and Rebelo, 1998). Secondary Acacia thicket is found predominantly along sections of the river where there has been clearing of indigenous vegetation (Parker, 2004). *Vachellia karroo* is widely spread across the reserve and many of these plants have been poisoned or left as browse for giraffes and elephants. There are old farmlands on the floodplains of the Kariega river that are dominated by grass species such as *T. triandra, P. stapfianum,* and *Eragrostis curvula* (Parker, 2004). Invasive *Opuntia ficus-indica* (prickly pear) and *Acacia* *mearnsii* (black wattle) were introduced onto the reserve by previous farmers when the land was still used for agricultural purposes.

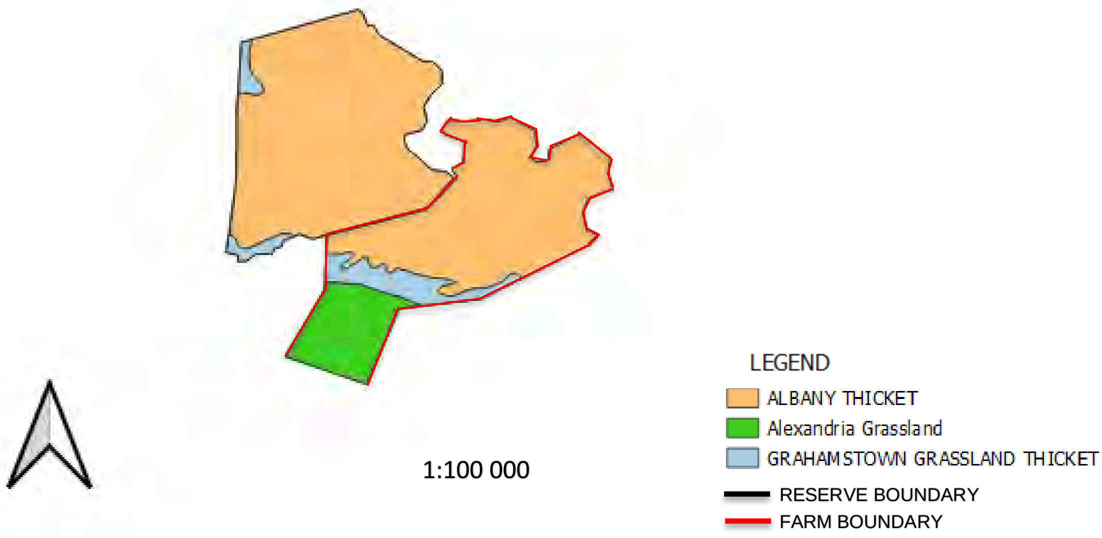

Figure 2.7: Kariega Game Reserve and Nightingale Livestock Farm according to the STEP vegetation map.

Geology and topography

The highest point of the reserve is 262 m.a.s.l in the north-western corner of the reserve, while the lowest point is 23 m.a.s.l at the base of the Kariega river valley (Parker, 2004). The northern and southern sections of the reserve differ in their topology. The northern section of the reserve is on a plateau that sits above the Kariega river valley, while the southern section of the reserve is mainly characterized by undulating hills and flat low-lying ground (Parker, 2004). The Nightingale farmland mainly consists of gentle sloping valleys and large cliff plateaus. Beaufort Group shale, solonetic soil, sandstone, and mudstone along with Cape Supergroup lithosols and sandy clays are the dominant geology of the area (Low and Rebelo, 1998).

Reserve herbivore community

Kariega is home to many herbivore species within the Harvestvale section (table 2.3), where data were collected. The herbivores in this area range from small species (duiker) to megaherbivores such as elephants, white and black rhinoceros, and giraffes. During the period of this study, there were 12 elephants and 52 giraffes (rhinoceros’ numbers could not be obtained due to the high sensitivity of this information, as poaching is still a major issue within South Africa) within the Harvestvale section. Elephants, giraffes, and rhinoceros were introduced onto the Harvestvale section of the reserve in 2014.

Pumba Game Reserve and Bowles Livestock Farm

Site description

Pumba was founded in 2004 for conservation and ecotourism after the landscape was dominated by small-stock farming until 2004. The reserve covers 6000 ha. Because of the shift to ecotourism, the reserve has reintroduced larger charismatic wildlife species back into the reserve. Pumba (33°23’05”, -26°24’44”) is located along the N2 between Grahamstown and Port Elizabeth (figure 2.8).

The eastern fence of Pumba borders Bowles farm. This farm consists a variety of livestock such as cattle for beef, goats, and sheep. The vegetation composition is the same as the reserve; however, the landscape has been overgrazed by cattle and goats.

Figure 2.8: (A) The four study sites within the Eastern Cape, (B) Pumba Private Game Reserve and Bowles Farm and surrounding towns (Google Earth Pro, 2021).

Climate

The area experiences a similar climate to its closest town, Grahamstown, which is 15 km away from the reserve. Temperatures for wet season (October to March) range between 23°C and 32°C. Dry season (April to September) temperatures do not vary much from wet season temperatures, with a range of 24°C to 32°C. Rainfall ranges from 60 mm to 160 mm during the year with the lowest precipitation during June and the highest precipitation during September.

Vegetation

The Fynbos, Savanna, and Thicket biomes dominate Pumba. The Savanna biome is confined to the central section of the reserve while the Fynbos vegetation covers the northern and southern sections of the reserve. The Fynbos vegetation in the reserve mainly consists of Suurburg Quartzite and Suurburg Shale Fynbos, and Zuurberg Grassy Fynbos (Nuttel-Smith, 2018). The Savanna vegetation mainly consists of Bisho Thornveld. The Subtropical Thicket biome is found in the valley systems of the reserve. Kowie Thicket is the main thicket vegetation found in the valleys. Grahamstown Grassland thicket is found within most of the flat grasslands of the reserve (figure 2.9). Within the reserve and bordering farmland, there are large sections of invasive *Eucalyptus globulus* (blue gum) trees. Both the reserve and farm have been clearing these invasives over the past few years. On the northern slopes of Pumba, they have actively been clearing invasive *Acacia saligna* (Port jackson). *Vachellia karroo* is also present on the reserve but in small patches as they are mainly targeted by giraffes for a browse.

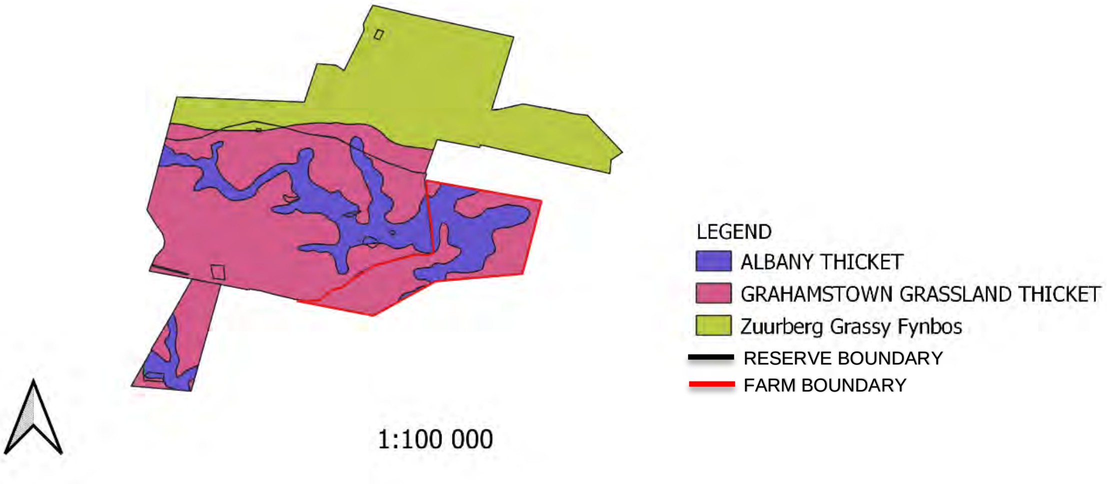

Figure 2.9: Pumba Game Reserve and Bowles Livestock Farm according to the STEP vegetation map.

Topography

The altitude of the reserve varies from 300 m.a.s.l. in the low-lying hills of the southern section, to 800 m.a.s.l. on the northern plateau. The area is comprised of many narrow valleys with high peaks on either side. The reserve boasts numerous gentle undulated hills and slopes. The farmland is mainly comprised of narrow valleys and has fewer open plateaus than the reserve. The reserves' primary geological formations include mudstone and sandstone from the Beaufort Group, the Cape supergroup, and the Dywka and Ecca formations (Low and Rebelo, 1998). Sandy-clay loams, sandstone, and shale are examples of substrata found in this area (Low and Rebelo, 1998).

Reserve herbivore community

Pumba is home to many herbivore species, ranging in size from duiker to elephant (table 2.3). The megaherbivores present are elephants, white and black rhinoceros, hippopotamus, and giraffes. During the period of this study, there were 20 elephants, 18 hippopotamus, and 95 giraffes (rhinoceros' numbers could not be obtained due to the high sensitivity of this information, as poaching is still a large-scale issue within South Africa) on the reserve. Elephants, giraffes, and black and white rhinoceros were introduced onto Pumba in 2005.

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CHAPTER 3

METHODS

Historical records

Historical records were obtained from four game reserves and livestock farms within the Eastern Cape province to gain insight as to when old farmlands were incorporated into the game reserves, and to understand the land use types of all incorporated farmlands and active farmlands. These records were also used to show when elephants (*Loxodonta africana*), black rhinoceros (*Diceros bicornis*), white rhinoceros (*Ceratotherium simum*), and giraffe (*Giraffa Camelopardalis*) were introduced into the reserves. Additionally, the study looked at these historical records to gain a better understanding of the vegetation of the landscape at certain points in time, the herbivore communities within the reserves and livestock farms, and the climate of the area to establish dry and wet seasons.

Sample sites

Data for this study were collected at four game reserves (Kwandwe, Amakhala, Pumba, and Kariega) that had indigenous and extralimital wild meso-herbivores (< 1000 kg) and megaherbivores (≥ 1000 kg). These reserves were paired with nearby livestock farms that had domestic herbivores but had no indigenous and extralimital megaherbivores. Each site was named after the respective game reserve where sampling occurred. Therefore, the site names were Amakhala, Kariega, Kwandwe, and Pumba. At each of these selected sites (the four game reserves and four livestock farms (figure 3.1)), the study used three standardized plots per site for vegetation surveys. The plots were 30 x 30 meters (m) in size, with 30 m buffers between the three plots (figure 3.2). This experimental design was to ensure that each plot was within one pixel of the remote sensing satellite imagery (30 x 30 m resolution). Google Earth Engine was used to select sites of the same landform and similar altitude for each game reserve and livestock farm plot to ensure these variables were controlled. The reserve sites and the farm sites were within the same landform. The code used to calculate landform is attached as appendix 3A. Landform, altitude, and thicket type (deduced from the STEP vegetation map) were all controlled variables for the livestock farms and game reserves.

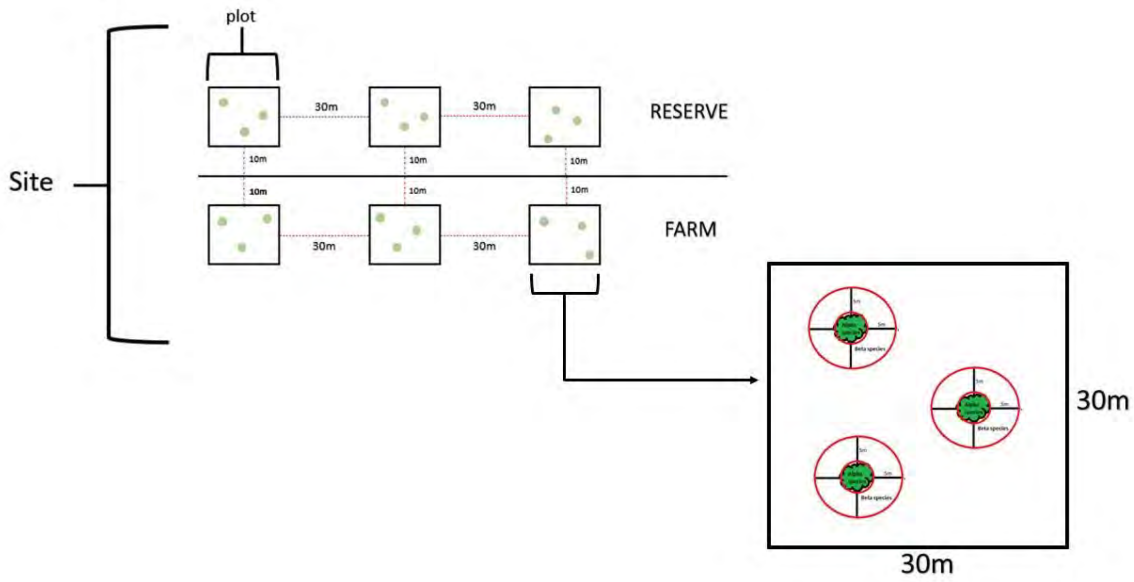

Figure 3.1: Systematic outline of each game reserve and livestock farmland site with the definition of plot, site, and bush clump.

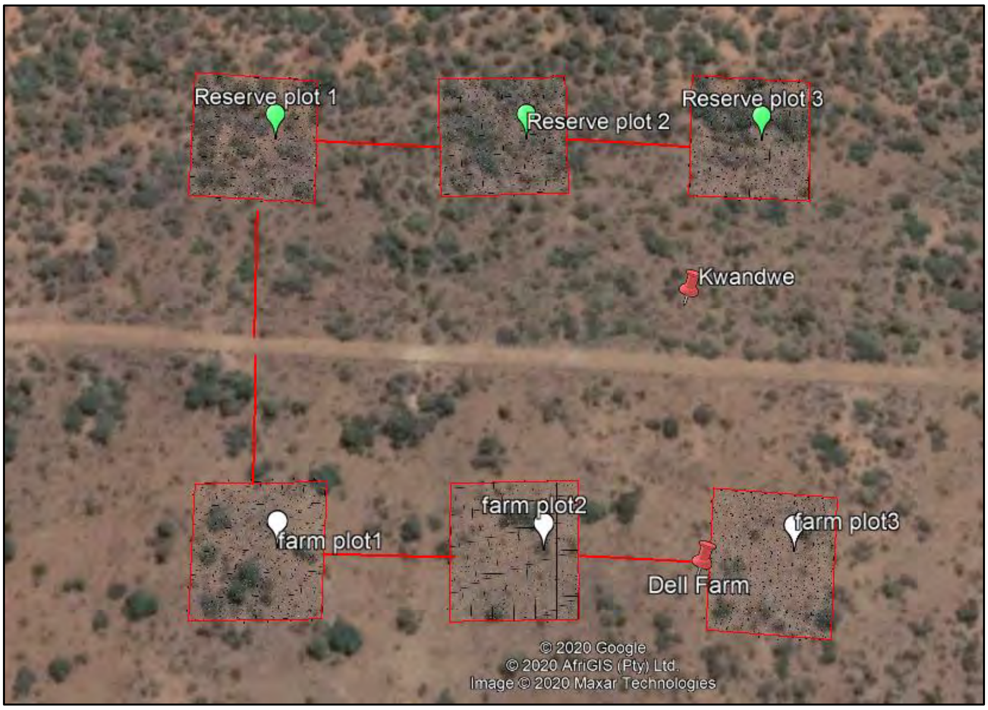

Figure 3.2: The setup for vegetation sampling surveys at Kwandwe Game Reserve and adjacent Dell farm.

Vegetation sampling

At each 30 x 30 m sample plot, three bush clumps were selected using a 30 x 30 m grid split into 900 1 x 1 m blocks. The grid was placed onto Google Earth as an image overlay within the 30 x 30 m plot. A random number generator was used on Microsoft Excel where a grid number was chosen between one and 900. If the grid number contained vegetation cover, this was selected as the sample bush clump. A bush clump was defined as a clump of more than one plant species present and on soil raised above the surrounding ground to ensure that all the plant species are originating from a similar origin. All species that were found within the bush clump were recorded. These are known as the Bush clump species (as seen in figure 3.3). A radius of five meters was delineated around the bush clump to assess the grasses and herbaceous species in the sample site. Plant species around the bush clump were assessed by measuring out four five-meter transects around the bush clump in each cardinal direction

(North, East, South, and West). The transects were five meters long unless interrupted by another bush clump. In that case, the transect was only measured from the sampling bush clump to the closest bush clump in the cardinal direction. Only plant species that were within a one-meter width of the transect were recorded (as seen in figure 3.2 and figure 3.3). These are known as the Matrix species. This allowed the study to define the bush clumps as part of a thicket mosaic or as part of a true degraded bush clump/remnant (Vlok et al., 2003). A ceptometer was used to measure the Leaf Area Index (LAI) and Fraction of Intercepted Photosynthetically Absorbed Radiation (FIPAR) of the bush clumps. Three readings were taken above the canopy and three readings were taken below the canopy at a north-facing position for every bush clump. The same sampling process was conducted in all the selected sites (the four game reserves and four livestock farms). The sampling process was conducted during the dry (July to August 2020) and wet seasons (January to February 2021). Six plots were sampled at each site, three on the game reserves and three on the livestock farmland. In total, 24 plots were sampled over the whole study, twelve plots on the game reserves and 12 plots on the livestock farmlands overall (see figure 3.2).

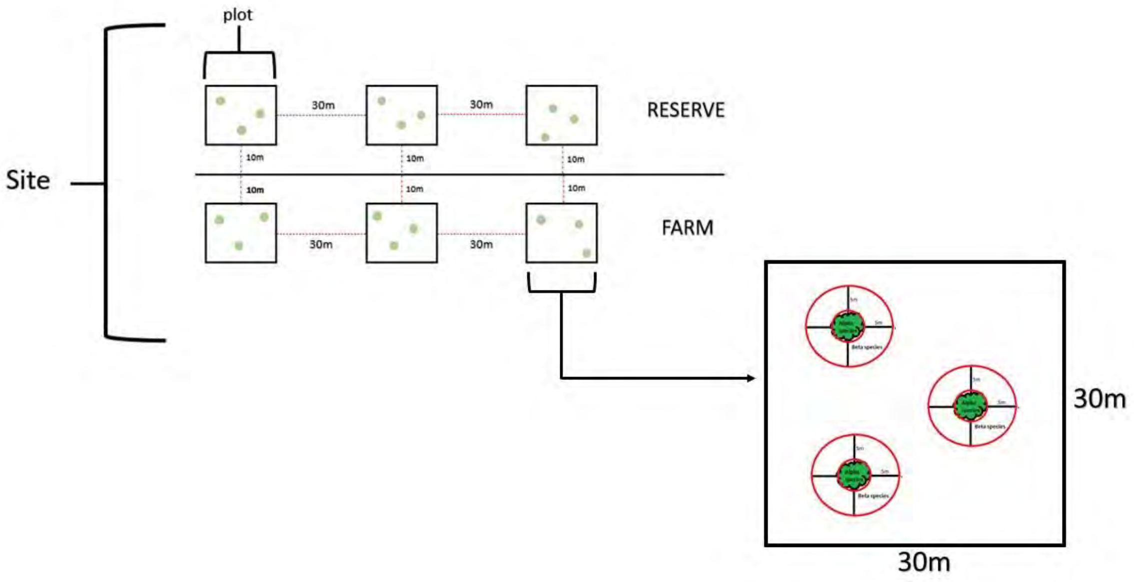

Figure 3.2: Systematic outline of each game reserve and livestock farm with the definition of plot, site, and bush clump.

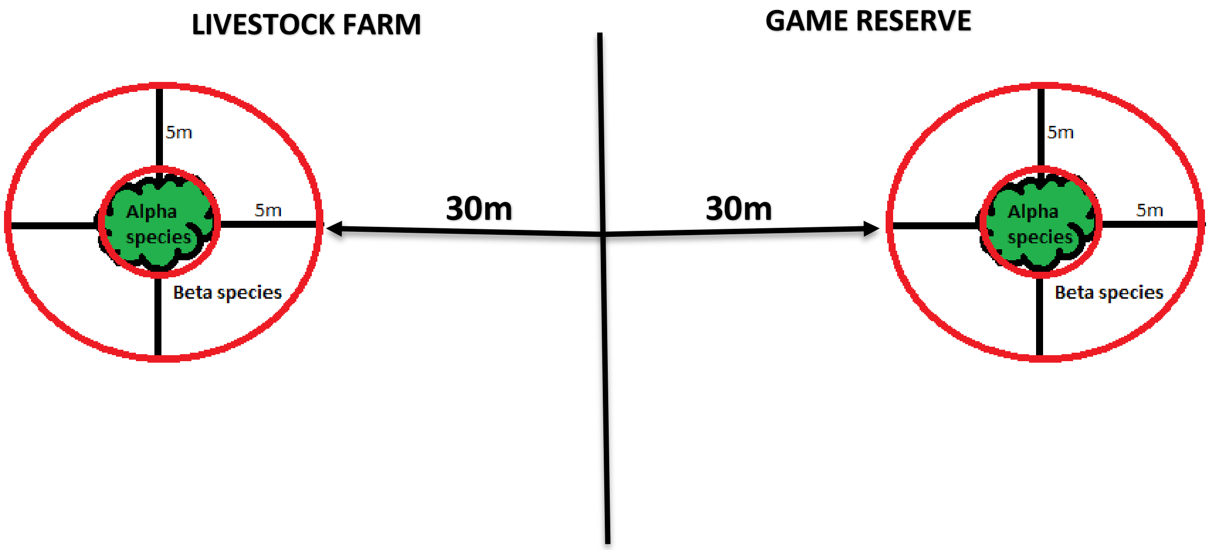

Figure 3.3: Systematic outline of sampling of the bush clump and matrix vegetation within the field.

Remote sensing

The Fraction of Intercepted Photosynthetically Active Radiation (FIPAR) is a proxy for Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) and is used in this study instead of FAPAR. Fraction of Intercepted Photosynthetically Active Radiation is used as the measurement to calculate above and below PAR and can be recorded in the field with the ceptometer (Ridao et al., 1998). Additionally, the study made use of remote sensing indices of Leaf Area Index (LAI), Normalized Difference Vegetation Index (NDVI), and FIPAR to deduce the landscape productivity between the two land use types (game reserves and livestock farms). I compared these indices between the livestock farms and game reserves. The NDVI was calculated from the game reserves starting year and for the year that in situ field sampling was done. Google Earth Engine was used to calculate these indices. The NDVI values were taken for each plot at every game reserve and livestock farm site. If the plot had several pixels, an average of those pixels was taken for the average NDVI of the plot. The NDVI values for the three plots on each game reserve and livestock farm were then averaged to get the NDVI for each game reserve and each livestock farm. The satellite imagery was taken from Landsat-7, with a resolution of 30 x 30 m. The code used to calculate NDVI in Google Earth Engine is attached as appendix 3B.

Statistical analyses

A two-way analysis of variance was used to compare the structural differences (height, breadth, and width of bush clumps) between the livestock farms and the game reserves, and between the wet and dry seasons. Data were tested for normality using the Shapiro-Wilk test and quantile-quantile (Q-Q) plots. A Tukey post hoc test was conducted on the bush clump width and breadth results to gain a further understanding of where the significant differences were seen between the two land types (livestock farms and game reserves) and across the two seasons (refer to Appendix 3D for R code).

Quantitative and qualitative analyses were used to compare plant species composition between the livestock farms and game reserves. I recorded plant species within bush clumps (Bush clump species) and plant species in transects (Matrix species) across sites in an Excel spreadsheet, showing the presence and absence of each plant species. A non-metric multidimensional scaling analysis (NMDS) was conducted on the bush clump and matrix species. This is a form of ordination that collapses information from several communities into a few so that it can be visualized and interpreted (Podani, 2005). A NMDS uses rank orders allowing this type of analysis to be used for a variety of data. The closer two species on an NDMS graph, the more likely they are to be found in the same land (Podani, 2005). The code used to run the NMDS can be found in appendix 3C. I used the Vegan package (Oksanen et al., 2013) for these analyses, and graphs were plotted using the ggplot2 package (Wickham et al., 2021) in Rstudio.

To assess species diversity across sites and to deduce if the bush clumps were true remnant degraded bush clumps and not thicket mosaics, Simpson's diversity index was used from the package "Vegan" in R. To get the unbiased Simpson's Index, the rarefy function was used. This code can be found in appendix 3E. The plant species diversity analysis between the livestock farms and game reserves was conducted for each season using the Simpson Index. The Simpson index was used as the sample size is relatively small and it allows for more unbiased estimate of population diversity than the Shannon-Weiner Index (Eberhardt, 1971; Smith and Grassle, 1977). However, there is criticism of the use of Simpson's Index to measure plant species diversity among populations, as it is extremely dependent on the most dominant species within a population therefore, not taking into account rare species found in a population (Williams, 1964; Sanders, 1968; Whittaker, 1972). Therefore, I used the proposed method by Hurlbert (1971) to improve on this limitation. The expected species diversity is the expected number of species seen when *n* individuals are taken at random from a given population (Hurlbert 1971; Smith and Grassle, 1977). Based on this expectation, *n* defines a separate diversity measure within a group of diversity measures, and therefore for a fixed *n*, each species' contribution to the diversity measure is the chance that it will exist in a random sample of individuals taken from the population (Hurlbert 1971; Smith and Grassle, 1977). The diversity measure will be sensitive to rare species within a population if n is large and will be dominated by the dominant species when n is small (Smith and Grassle, 1977). When $n = 2$, the species diversity measure is equal to the Simpson's Diversity which I used here to calculate the difference in plant species diversity between all the livestock farms and all the game reserves during the wet season.

To assess the differences in species diversity across the land use types, I used a two-way ANOVA with the diversity values calculated from the Simpson's diversity tests for each land use type. A two-way ANOVA was also conducted for each season and the interaction between land use type and season was also tested.

To gain a greater understanding of the plant species richness within the two land types, I looked at the raw data (Appendix 4B and 4C) and assessed the different functional groups (woody species, succulents, herbaceous species, and grasses) present on each land type. It is important to look at functional types and the cover in each land type as this can give us a view of the functionality of the ecosystems (Schmidt et al., 2019). To calculate the species richness, I recorded how many different types of woody species, succulent species, herbaceous species, and grass species were found on each livestock farm and richness game reserve. Once these were recorded, I used a two-way ANOVA to deduce the difference in species richness between the two land use types. I also used a two-way ANOVA to calculate the difference in species richness across the wet and dry seasons, as well as to test the interaction of these two factors. This was done for the overall species richness as well as each functional group species richness.

To assess the vegetation composition further and aid in understanding the structure of the landscape, I looked at the matrix species richness and diversity. Matrix species are the plant species recorded in the 5 m radius around the bush clumps. In analysing the matrix plant species, I can deduce whether bush clumps are true degraded/remnant bush clumps or if they are part of a thicket mosaic (Vlok et al., 2003). There is a lack of data to describe the main patterns of alpha, beta, and gamma diversity within the thicket, but Birch et al. (1999) indicate that bush clump diversity is higher within bush clumps than diversity outside clumps (matrix species). Birch et al. (1999) also describes that species diversity between bush clumps is low. Within the thicket, it is suggested that when a bush clump is true degraded/remnant, the bush clump species diversity and the matrix species diversity will be low (Vlok et al., 2003). However, if the area is a mosaic, the bush clump species diversity will be high and so will the matrix diversity (Vlok et al., 2003). The difference in diversity was conducted using Simpson's diversity index.

To assess landscape productivity, two-way ANOVAs were conducted for each game reserve and adjacent livestock farm to identify the differences in NDVI from the reserve starting year to 2021. These results were fitted onto graph models. ANOVAs were conducted on the NDVI values taken across the game reserves and the livestock farms from the game reserve starting year to 2021 as well as for the study sample time (July 2020 to February 2021) (refer to Appendix 3F for code).

Two-way ANOVAs were conducted on FIPAR values that were calculated using the above and below PAR values recorded from the ceptometer in the field. The FIPAR is a good proxy for FAPAR and was used as data to conduct FAPAR could not be accessed. Equation **(1)** was used to calculate FIPAR (Fensholt et al., 2004).

$$FIPAR = \frac{(above - below)PAR}{above\ PAR}$$

(1)

The ANOVAs were conducted in the same manner as the LAI. The FIPAR and LAI were compared between the seasons and land use types (refer to Appendix 3G).

For all my statistical analysis I used a confidence interval of 95 % and an alpha of 0.05 to assess statistical significance. Terms such as “moderate evidence” and “weak evidence” were used for p-values between 0.05 and 0.1. All my statistical analyses were performed in R using R studio unless otherwise stated.

Giraffe feeding observations

To assess the diet composition of giraffes in the Subtropical Thicket biome, I observed them opportunistically while they were feeding, across the four game reserves (Kwandwe, Amakhala, Pumba, and Kariega) during dry and wet seasons. These observations were done in the early mornings (6 am to 9 am) and late afternoons (3.30 pm to 5.30 pm) because that is when most animals are active (Chabwela et al, 2017). Observations were hour-long, per session (morning or afternoon), and during this time, I noted all the plants eaten by all the giraffes within a tower at five-minute intervals (see Parker 2004 for a similar technique). Plant species selected were easily identifiable because I was approximately within 10 m from the giraffes, in cases where I could not see the plant clearly, I used binoculars and the game guards within the reserves helped identify the plants. I conducted eight observations at each reserve, four observations during the dry season (July – August 2020) and four observations during the wet season (January – February 2021). Overall, 32 observations were conducted. Data collected from giraffe feeding observations were analysed by using each observation as a replicate and conducting a non-metric multidimensional scaling analysis (NMDS) and One-Way Analysis of Similarities (ANOSIM) in Primer-7 to assess if there were differences in plant species targeted by giraffes during the dry and wet seasons. The ANOSIM uses an R-value ranging between +1 to -1 to indicate similarities and dissimilarities between groups, thus, an R-value greater than zero indicates dissimilarities while an R value of zero indicate similarities between groups (Quinn and Keough, 2002).

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CHAPTER 4

DO CHANGES IN LAND USE AFFECT VEGETATION STRUCTURE, COMPOSITION, AND PRIMARY PRODUCTIVITY?

Introduction

Historically, the Subtropical Thicket biome was home to several indigenous wild herbivores, which played an important role in maintaining ecosystem structure and functioning (Skead 2007; Kerley and Landman, 2006). Over time, many of these wild herbivores were lost due to overhunting (Hall-Martin 1992; Skead 2007) and this resulted in changes in land use because many of the indigenous wild herbivores (e.g., elephants *Loxodonta africana* and black rhinoceros *Diceros bicornis*) were replaced by livestock such as goats (*Capra aegagrus hircus),* resulting in changes in browsing pressure and, vegetation structure and composition in the Subtropical Thicket biome. As such, many ecological processes in the biome were lost during the time of the 1820 settlers, when the land was converted to agricultural lands (Rutherford et al., 2014). During this time, sheep (*Ovis aries*), cattle (*Bos taurus*), and goats were all extensively farmed, leading to land degradation through overgrazing and erosion (Rutherford et al., 2014).

Recently, there has been an increasing trend of reincorporating old farmlands into game reserves in the Eastern Cape, particularly in the Subtropical Thicket biome. This has included reintroducing wild herbivores back onto these old farmlands (Moolman and Cowling, 1994). These game reserves have incorporated many old livestock farms to provide adequate space for the reintroduced wild herbivores, comprising both meso-herbivores (< 1000 kg) and megaherbivores (≥ 1000 kg; Owen-Smith, 1988). Given that wild herbivores play an important role in maintaining soil nutrients and vegetation structure (McNaughton et al., 1988; Caughley

1976), their reintroduction onto the Subtropical Thicket biome could aid in the restoration of the biome from the damaging effects of domestic herbivores on the thicket vegetation structure and composition and replacing lost ecosystem processes (Stuart-Hill, 1992; Lungren et al., 2018). The Subtropical Thicket biome is made up of many different thicket types (refer to chapter 2, figure 2.1) and the vegetation in this biome can be vulnerable to livestock browsing (Stuart-Hill 1992), thus, we need to better understand the potential consequences of changing land use from livestock farming to game reserves in order to mitigate the impacts of these changes on these landscapes.

In this chapter, I assessed changes in vegetation and productivity that might have occurred, following replacement of livestock farming by game reserves. Specifically, I measured vegetation structure (i.e., height, width, and breadth of bush clumps), quantified plant species composition (i.e., plant species richness, diversity and composition), and landscape productivity (i.e., NDVI, LAI and FIPAR) in the Subtropical Thicket biome during dry and wet seasons. I predicted that plants would be taller and intact during wet season on the game reserves, owing to the differences in the browsing behaviour of wild herbivores and domestic herbivores (Stuart-Hill 1992), and differences on the influence of season on vegetation. In addition, I predicted greater diversity of species across all functional types (woody plant species, succulents, herbaceous species, vine species and grasses) and greater species composition within bush clumps for the game reserves than livestock farms during the wet season; Lastly, I predicted that the game reserves would be more productive than the livestock farms, owing to the decrease in landscape fertility resulting from livestock browsing (Lechmere-Oertel, 2003).

Methods

The techniques and methods used to assess changes in vegetation structure and species composition, remote sensing, and statistical analyses have been described in detail in Chapter three.

Results

Vegetation structure – livestock farms versus game reserves

Height of bush clumps

There was weak evidence that season ($p = 0.072$) and land use type ($p = 0.067$) influenced the height of bush clumps. There was no evidence that the interaction between land type and season ($p = 0.310$) had an influence on bush clump height.

Width of bush clumps

There was no evidence ($p = 0.949$) that land use type influenced bush clump width. However, there was very strong evidence ($p = 0.001$) that season (wet and dry season) influenced bush clump width, showing that bush clumps on the livestock farms were wider during the wet season than during the dry season ($p = 0.002$). There was weak evidence ($p = 0.065$) that the interaction between season and land use type influenced the width of bush clumps.

Breadth of bush clumps

There was no evidence ($p = 0.768$) that land use type had an effect on bush clump breadth. However, there was moderate evidence ($p = 0.022$) that season (dry and wet season) had an effect on bush clump breadth, the breadth of bush clumps was wider during the wet season on the livestock farms than during the dry season ($p = 0.02$). There was weak evidence ($p = 0.097$) that the interaction between land use type and season had an effect on bush clump breadth.

The post hoc test for bush clump breadth showed that there was moderate evidence (p = 0.028) for the difference in bush clump breadth between the wet and dry seasons.

Plant species composition – livestock farms versus game reserves

Bush clump plant species richness

There was no evidence (p = 0.311) that land use type had an effect on species richness within the bush clumps. There was no evidence (p = 0.494) that season had an effect on species richness within the bush clumps. The interaction between season and land use type showed no evidence (p = 0.298) for an effect on species richness within the bush clumps.

At the functional type level within bush clumps, there was no evidence that land use type had an effect on woody plant species richness (p = 0.707), succulent species richness (p = 0.565), herbaceous species richness (p = 0.576), grass species richness (p = 0.615), and vine species richness (p = 0.201). Additionally, there was no evidence that season had an effect on woody plant species richness (p = 0.496), succulent species richness (p = 0.639), herbaceous species richness (p = 0.255), grass species richness (p = 1), and vine species richness (p = 0.402), found within the bush clumps. There was no evidence that the interaction between land use type and season had an effect on woody plant species richness (p = 0.311), succulent species richness (p = 0.883), herbaceous species richness (p = 0.407), grass species richness (p = 1), and vine species richness (p = 0.396), found within the bush clumps.

Bush clump plant species diversity

The average plant species diversity at the bush clump level for the game reserves during the dry season was slightly higher than the livestock farms during the same season (Simpsons index 0.965 and 0.956, respectively). The average plant species diversity at the bush clump level for game reserves during the wet season was 0.963, while it was 0.962 for livestock farms during the same season.

There was no evidence (p = 0.274) that land use type had an effect on plant species diversity within the bush clumps. There was also no evidence (p = 0.617) that season had an effect on plant species diversity within the bush clumps. There was no evidence (p = 0.466) that the interaction between land use type and season had an effect on plant species diversity within the bush clumps.

Bush clump plant species composition

Plant species composition varied between the livestock farms and game reserves during the dry season (figure 4.5). There were no overlaps between livestock farms and game reserves during the dry season, indicating a difference in plant species composition between the land use types, across all sites (figure 4.5). The NMD plot in figure 4.5A shows that plant species composition varied between the sites nested within the different land use types. In the wet seasons, the dissimilarity between the sites decreases as there is a more prominent overlap between the livestock farms and game reserves across sites (figure 4.5B). The NMD plot shows that there is still a difference between the plant species composition of the livestock farms and the game reserves during the wet season. Plant species composition varies between the sites nested within different land types (figure 4.5B).

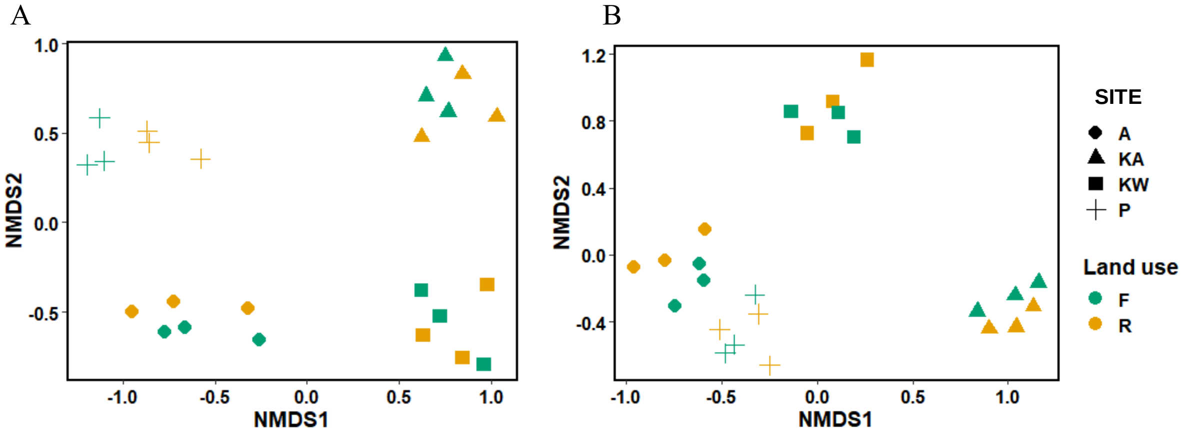
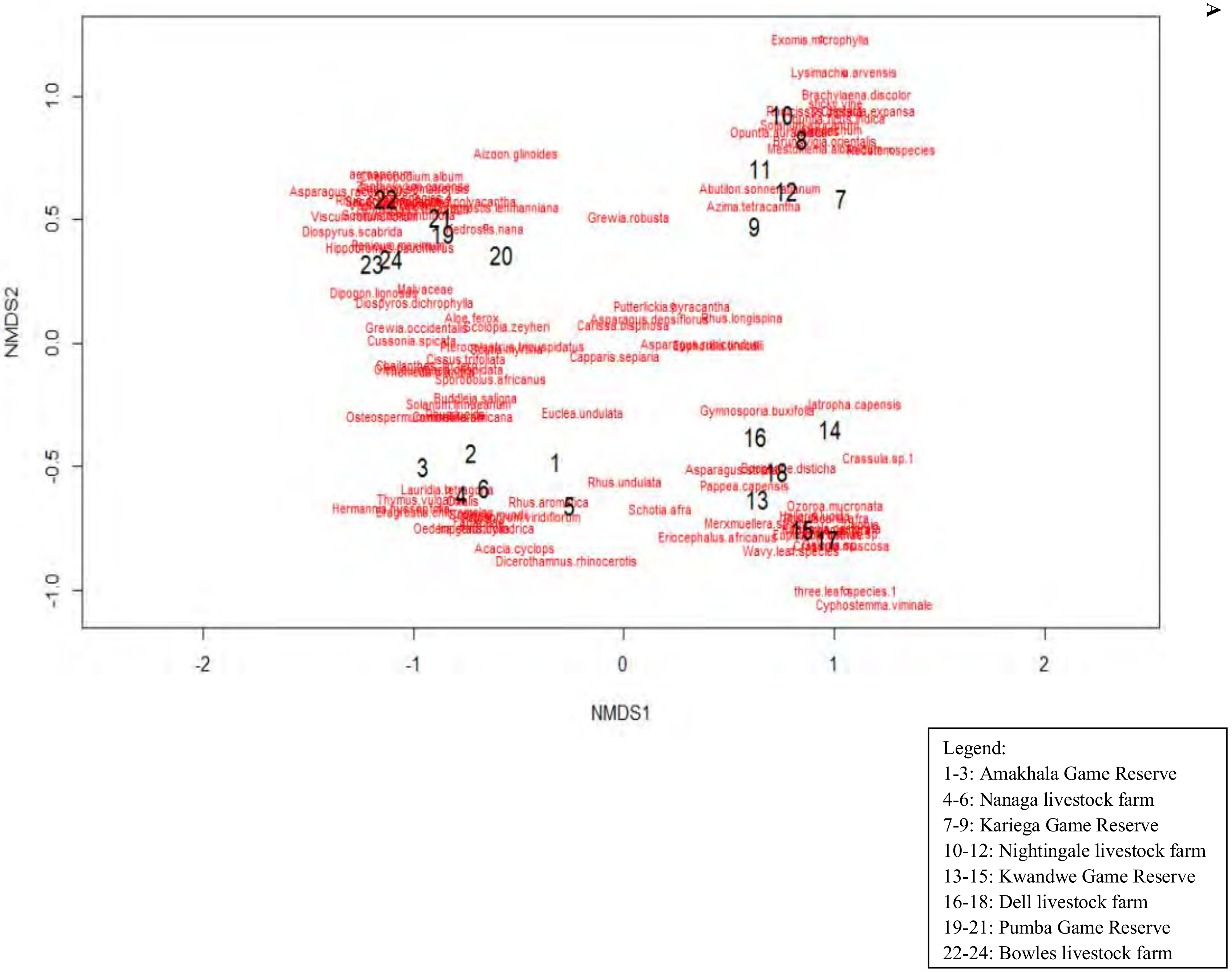


Figure 4.5: Non-metric Multidimensional Scaling ordination of bush clump vegetation species composition between livestock farms (F) and game reserves (R) during the dry season (A) and wet season (B).

The plant species clustered towards the middle of the ordination in figure 4.6A and 4.6B are the species that are found across all sites. During the dry season, the species that were found at all sites include *Asparagus densiflorus, A. rubicundus, Searsia longispina, Gymnosporia buxifolia, Euclea undulata, and Scutia myrtina* (figure 4.6A and Appendix 4A). During the wet season the species that were found on all sites include *A. densiflorus, Pterocelastrus tricuspidatus, E. undulata, S. myrtina, Azima tetracantha, Solanum linnaeanum, and Themeda triandra* (figure 4.6B and Appendix 4B).

A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0.5
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Exomis.microphylla
Lysimachia.arvensis
Brachylaena.discolor
Opuntia
Abutilon.sonneratianum
Azima.tetracantha
Aizoon.glinoides
Grewia.robusta
Asparagus
Visc
Diospyrus.scabrida
Hippobromus
Dipogon.lignosus
Malvaceae
Diospyros.dichrophylla
Aloe.ferox
Grewia.occidentalis
Scolopia.zeyheri
Cussonia.spicata
Cissus.trifoliata
Sporobolus.africanus
Buddleja.saligna
Osteospermum
Euclea.undulata
Putterlickia.pyracantha
Rhus.longispina
Carissa
Capparis.sepiaria
Gymnosporia.buxifolia
Jatropha.capensis
Crassula.sp.1
Rhus.undulata
Schotia.afra
Pappea.capensis
Merxmuellera
Eriocephalus.africanus
Wavy.leaf.species
Ozoroa.mucronata
three.leafed.species.1
Cyphostemma.viminale
Lauridia.tetragona
Thymus.vulgaris
Hermannia
Rhus.aromatica
Acacia.cyclops
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Legend:
1-3: Amakhala Game Reserve
4-6: Nanaga livestock farm
7-9: Kariega Game Reserve
10-12: Nightingale livestock farm
13-15: Kwandwe Game Reserve
16-18: Dell livestock farm
19-21: Pumba Game Reserve
22-24: Bowles livestock farm

B

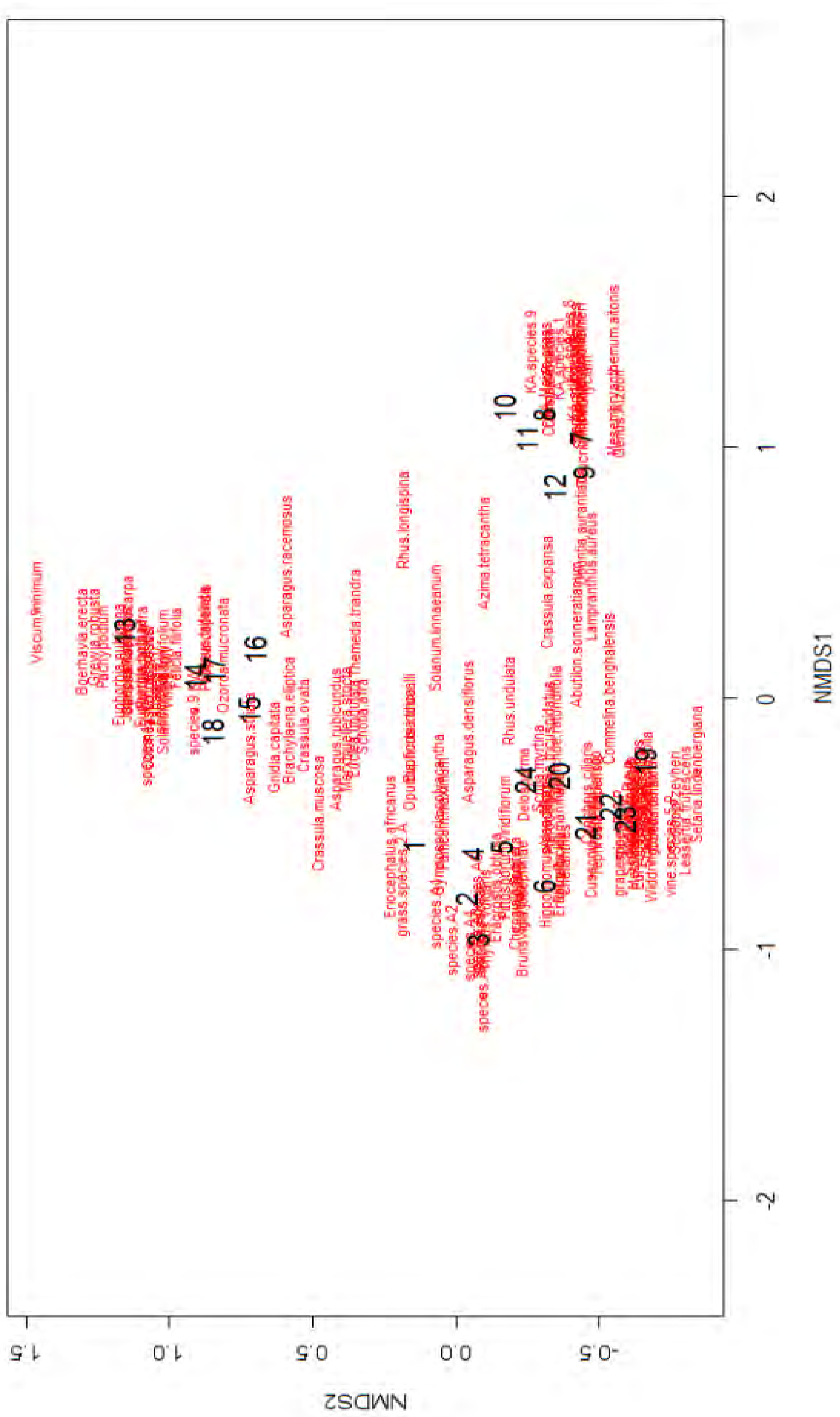


Figure 4.6: Non-metric Multidimensional Scaling ordination highlighting the specific bush clump plant species that are present on the game reserves and livestock farms during the dry season (A) and wet season (B).

Matrix plant species richness

There was moderate evidence (p = 0.019) that land use type had an effect on plant species richness within the matrix. There was no evidence (p = 0.937) that season had an effect on plant species richness within the matrix. The interaction between season and land use type showed no evidence (p = 0.929) for an effect on plant species richness within the matrix.

At the functional type level, there was moderate evidence that land use type had an effect on woody plant species richness (p = 0.011). There was little to no evidence that land use type had an effect on succulent species richness (p = 0.376), herbaceous species richness (p = 0.536), and grass species richness (p = 0.556), found within the matrix. There were no vine species found within the matrix. There was moderate evidence (p = 0.063) that season had an effect on succulent species within the matrix. There was no evidence that season had an effect on woody plant species richness (p = 0.937), herbaceous species richness (p = 0.536), and grass species richness (p = 0.845) found within the matrix. There was no evidence that the interaction between land use type and season had an effect on woody plant species richness (p = 0.929), succulent species richness (p = 0.751), herbaceous species richness (p = 0.770), and grass species richness (p = 0.460), found within the matrix.

Matrix plant species diversity

The average plant species diversity for game reserves during the dry season was 0.889, while it was 0.932 for the livestock farms during the same season. The average plant species diversity for game reserves during the wet season was 0.902, while it was 0.931 for the livestock farms during the same season.

There was moderate evidence (p = 0.012) that land use type had an effect on plant species diversity within the bush clumps. There was also no evidence (p = 0.680) that season had an effect on plant species diversity within the bush clumps. There was no evidence (p = 0.609) that the interaction between land use type and season had an effect on plant species diversity within the bush clumps.

Matrix plant species composition

Species composition differed between the livestock farms and game reserves (figure 4.7) during both the wet and dry seasons (table 4.6). The greatest difference in species composition was recorded between Kwandwe game reserve and Dell livestock farm, while the other reserves and livestock farms showed minor differences in species composition.

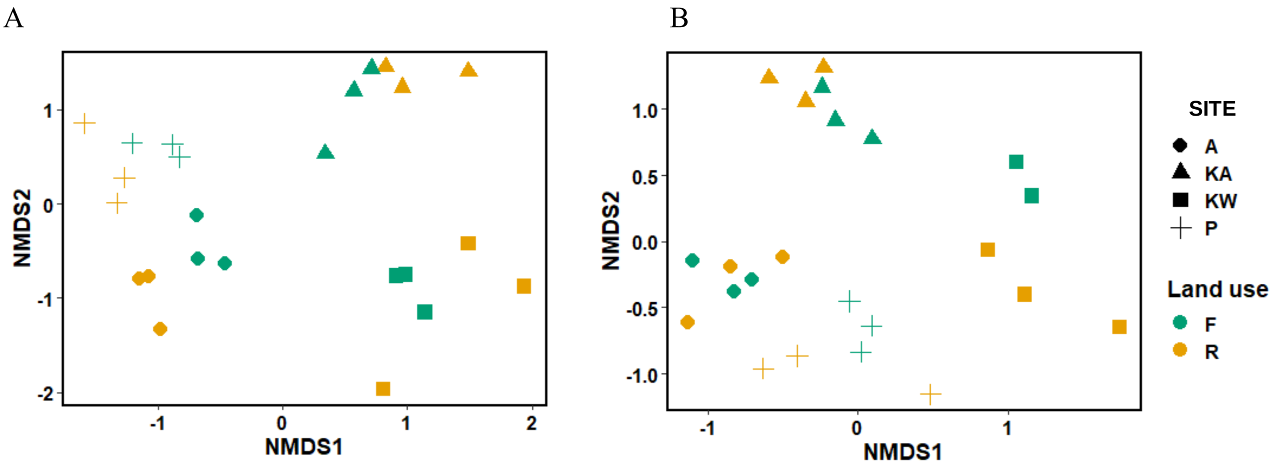
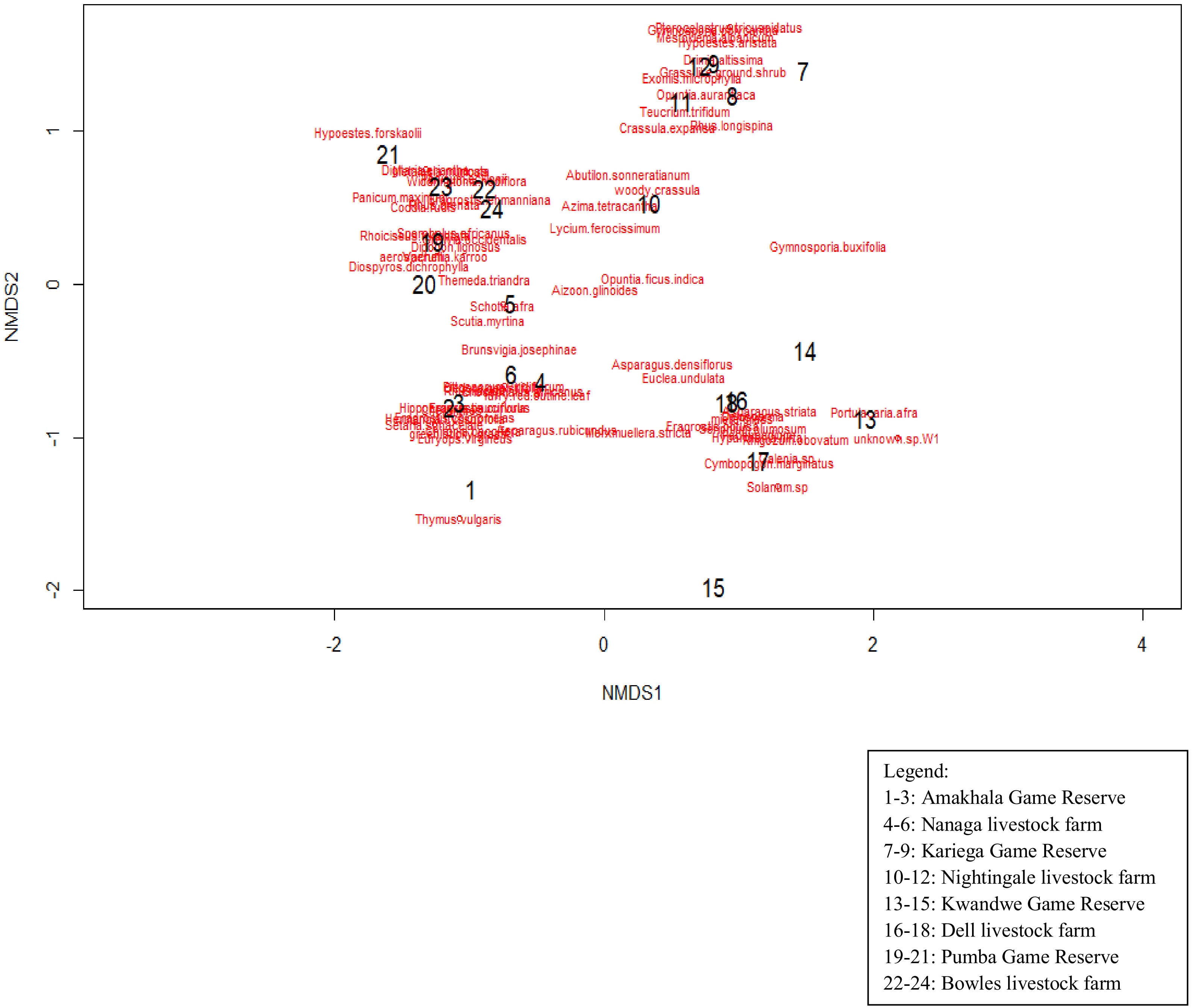


Figure 4.7: Non-metric Multidimensional Scaling ordination of matrix vegetation species composition between livestock farms (F) and game reserves (R) during the dry season (A) and wet season (B).

The plant species clustered towards the middle of the ordination in figure 4.8A are the matrix species that are found across all sites during the dry season. These species are *Opuntia ficus-*

indica and *Aizoon glinoides*. There is a clear difference between the sites nested within land types.

A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Grass.ground.shrub
Exomis.microphylla
Opuntia.aurantiaca
Teucrium.trifidum
Crassula.expansa
Rhus.longispina
Abutilon.sonneratianum
woody.crassula
Azima.tetracantha
Lycium.ferocissimum
Gymnosporia.buxifolia
Opuntia.ficus.indica
Aizoon.glinoides
Panicum.maximum
Rhoicissus
Sporobolus.africanus
Digitaria.eriantha
Diospyros.dichrophylla
Vachellia.karroo
Themeda.triandra
Schotia.afra
Scutia.myrtina
Brunsvigia.josephinae
Asparagus.densiflorus
Euclea.undulata
Asparagus.striata
Portulacaria.afra
Asparagus.rubicundus
Merxmuellera.stricta
Eragrostis
Euryops.virgineus
Setaria
Cymbopogon.marginatus
Solanum.sp
unknown.sp.W1
Thymus.vulgaris
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Legend:
1-3: Amakhala Game Reserve
4-6: Nanaga livestock farm
7-9: Kariega Game Reserve
10-12: Nightingale livestock farm
13-15: Kwandwe Game Reserve
16-18: Dell livestock farm
19-21: Pumba Game Reserve
22-24: Bowles livestock farm

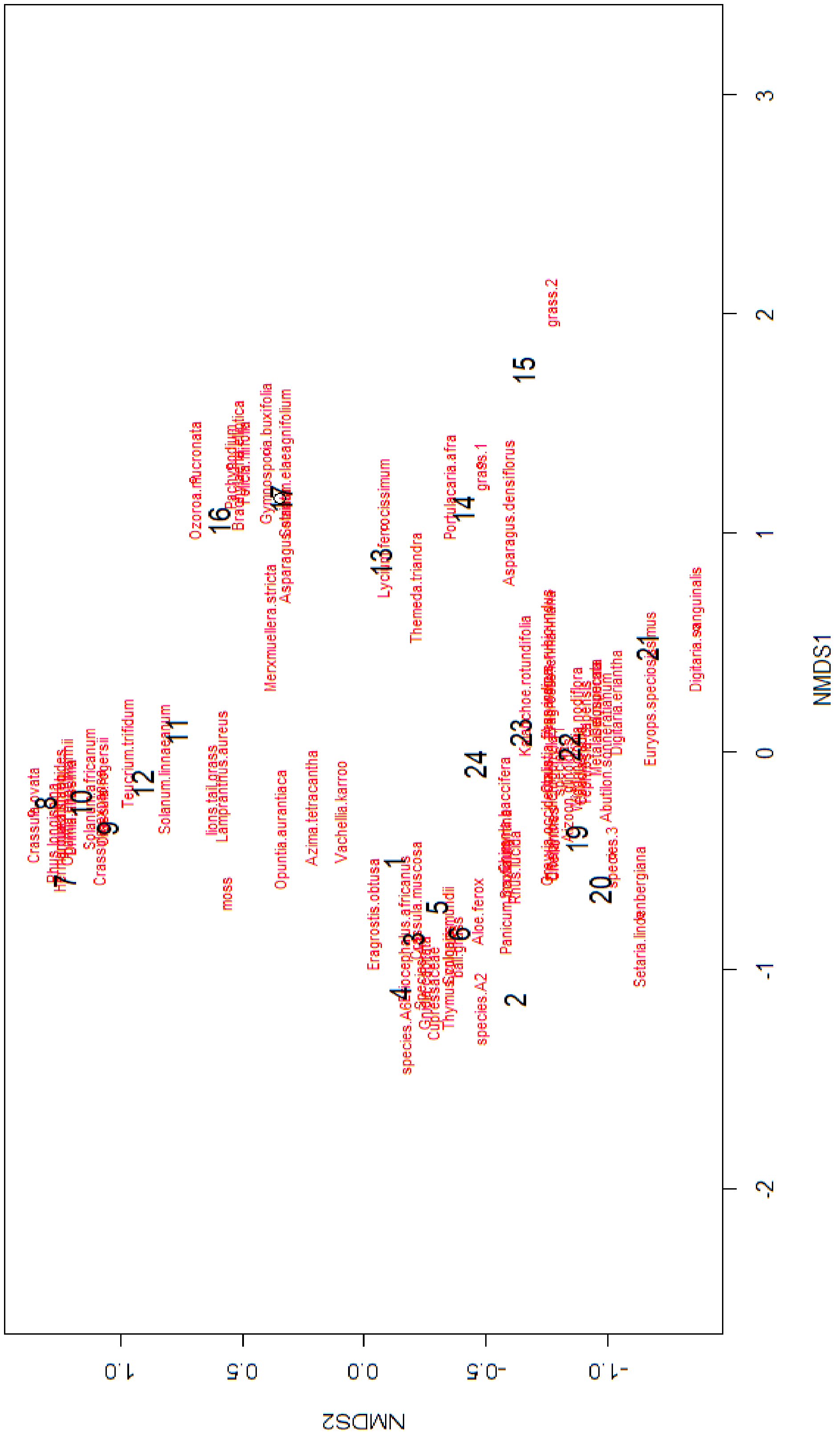

Figure 4.8: Non-metric Multidimensional Scaling ordination highlighting the specific matrix plant species that are present on the game reserves and livestock farms during the dry (A) and wet seasons (B).

Landscape productivity

There was no significant difference in NDVI across the years between the game reserves and the adjacent livestock farms (table 4.6) and between seasons (table 4.7). However, overall, there was always a slightly higher NDVI across the years on the game reserves for all sites (figure 4.13). While there were some overlaps between the NDVI on the game reserves and the livestock farms, overall NDVI was greater on the game reserves (figure 4.13).

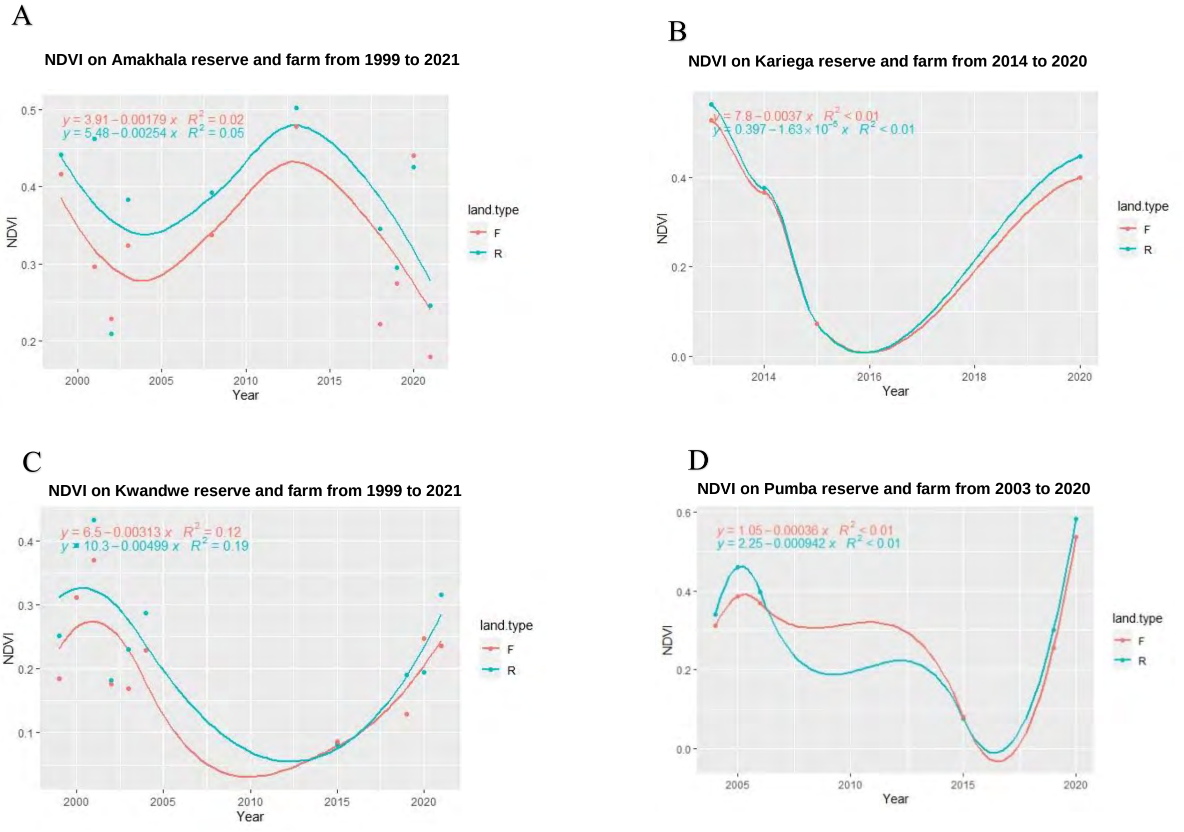

Figure 4.13: NDVI (from Landsat-7 imagery) comparison between livestock farms and game reserves across the years.

Table 4.6: Two-way analysis of variance results of Normalized Difference Vegetation Index across both land use types over the years from reserve start year to present day.

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	1	0.005	0.005	0.284	0.596
Land type	1	0.025	0.026	1.434	0.236
Year: Land type	1	0.001	0.002	0.084	0.772
Residuals	56	0.997	0.018		

Table 4.7: Two-way ANOVA results of NDVI across both land use types (livestock farms and game reserves) and both seasons (wet and dry) for the project duration (2020 to 2021).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Land type	1	0.0001	0.0001	0.005	0.945
Season	1	0.0014	0.0014	0.077	0.787
Land type: Season	1	0.0096	0.0096	0.531	0.480
Residuals	12	0.2167	0.0181		

Table 4.8: Two-way ANOVA results of Leaf Area Index across both land use types (livestock farms game reserves) and both dry (July/August 2020) and wet (January/February 2021) seasons.

	Df	Sum Sq	Mean Sq	F Value	Pr(>F)
Land type	1	1.911	1.911	6.531	0.025*
Season	1	0.345	0.345	1.179	0.299
Land type: Season	1	0.066	0.066	0.227	0.643
Residuals	12	3.512	0.293		

There was moderate evidence that land use type affected LAI (livestock farm and game reserve) (p-value = 0.025, table 4.8), this was due to the difference between Pumba and the adjacent livestock farm (pair-wise post-hoc p = 0.089). There was no evidence that season had an effect on LAI (p = 0.299, table 4.8). There was no evidence that the interaction between land use type and season had an effect on LAI (p = 0.643, table 4.8).

Table 4.9: Two-way analysis of variance results of Fraction of Intercepted Photosynthetically Absorbed Radiation across both land use types and both dry (July/August 2020) and wet seasons (January/February 2021).

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Land type	1	0.028	0.028	10.480	0.007**
Season	1	0.006	0.006	2.173	0.166
Land type: Season	1	0.001	0.001	0.512	0.488
Residuals	12	0.032	0.003		

There was strong evidence that land use type affected FIPAR (p = 0.007, refer to table 4.9), FIPAR was greater on the game reserve across both seasons. Like LAI, FIPAR had the greatest variability on the livestock farm during the dry season. However, there was no evidence that seasons had an effect on FIPAR (table 4.9). There was also no evidence that the interaction between land type and season affected productivity as expressed by FIPAR (p = 0.488, table 4.9).

Discussion

This study highlights possible changes in vegetation that may have occurred because of changing land use from livestock farming to game reserves and the potential influence this land use change might have on vegetation restoration.

Effect of land use change on bush clump size

Contrary to my predictions, bush clump size did not differ between the livestock farms and game reserves. This might suggest that bush clump sizes in the livestock farms and game reserves are changing at the same rate, thus land use change from livestock farming to game reserves in the Subtropical Thicket biome (at least in my study sites) have not had a significant effect on the size of bush clumps. Similarly, Hester et al. (2006) conducted a similar study in semi-arid subtropical savanna and found that livestock browsing had no impact on bush clump size. Contrary to the results of this study, Hoffman and Cowling (1990) found that bush clump size decreased with an increase in grazing pressure in their study, suggesting that land use change could affect vegetation structure but the results are context dependant. Fabricius et al. (2003) also found that when comparing communal grazing lands with an area in a private game reserve in the Great Fish area, bush clumps were larger on the game reserves. The small sample size within my study may explain why my results do not concur with my predictions and the results found by Hoffman and Cowling (1990) and Fabricius et al. (2003).

While the overall bush clump size did not differ between sites, there was a difference in the width and breadth of the bush clumps between the wet and dry seasons. This difference was on the livestock farm only and not between sites. This finding provides some evidence that season has an effect on bush clump size at least on the livestock farms in the Subtropical Thicket biome.

Effect of land use change on plant species richness, diversity, and composition

Rutherford and Powrie (2013) provided evidence that the greatest differences in species richness between livestock farms and game reserves are seen within the Thicket and Kalahari dune savanna biomes. My results on species richness fail to match these and many other findings on species richness changes in the Thicket biome. Species richness did not differ across land use types and seasons in this study. Contrary to my results, Higgins et al. (1999) found that within semi-arid landscapes the woody species component had a greater species richness on game reserves compared to livestock farms. Kerley et al. (1995) noted that degraded subtropical thicket due to overgrazing by domestic livestock lacked regeneration and therefore exhibited lower species richness. The observation by Kerley et al. (1995) and the slow growth rate of thicket plant species (Aucamp 1976) could explain the lack of differences in the two land use types in my study.

Plant species composition did not differ between the livestock farms and game reserves and this contradicts my predictions. The plant species composition within the bush clumps varied slightly during the dry season as there were no overlaps in species of the game reserves and livestock farms seen in the NMDS graphs. However, there was a decrease in dissimilarity during the wet season as there were more overlaps of species in the NMDS between the game reserves and livestock farms. Evans et al. (1997) analysed changes in vegetation across different land use types in the Thicket biome, also focusing on species composition. Their study highlights five different thicket communities found on the game reserves and commercial farms – short succulent thicket (SST) (*Euphorbia bothae, Rhigozum obovatum, Portulacaria afra)*, medium succulent thicket (MST) (*P. afra, E. undulata, Grewia robusta)* , mesic bush clump savanna (MBS) (*Scutia myrtina, Vachellia karroo, Digitaria eriantha, Helichrysum dregeanum)*, grasslands of mesic bush clump savanna (GMBS) (*V. karroo, Digitaria eriantha, Eragrostis obtusa, S. myrtina)*, and succulent bush clump savanna (SBS) *(P. afra, Euphorbia tetragona, Kalanchoe rotundifolia, Delosperma calycinum)*. Evans et al. (1997) identified SST, MST, MBS, and GMBS communities on the livestock farms and SST, MST, MBS, GMBS, and SBS on the game reserves. My results closely follow those found by Evans et al. (1997) where MST, MBS, and GMBS communities were found on all livestock farms sampled in my study, however SST was only found on Kwandwe game reserve and Dell farm. Succulent bush clump savanna was mainly found on Kwandwe game reserve and Pumba game reserve but one species present in SBS were found on all game reserves and livestock farms. All communities highlighted by Evans et al. (1997) were found on all the game reserves and livestock farms except SST which was only found on Kwandwe game reserve and Dell livestock farm.

The results show that there is no evidence to suggest that land use type had an effect on overall plant species diversity. However, when looking at the specific functional types, there were small differences in diversity between the game reserve lands and the livestock farmlands.

There was a higher diversity of woody plant species on the game reserves than the livestock farms across both the wet and dry seasons (Appendix 4A). Stuart-Hill (1992) attributes the high woody plant density within the thicket to the presence of elephants uprooting trees that allows for increased coppicing of woody species, as well as soil churning and trampling which increases seed germination with the aid of dung. Germination also increases in areas rich in rhino dung (La Cock, 1992).

The succulent diversity and herbaceous plant species diversity were also greater on the game reserves than on the livestock farms across both the wet and dry seasons. The succulent component is the first species to disappear when landscapes are under pressure from livestock grazing (Evans et al., 2010). The Eastern Cape Subtropical Thicket has a large number of endemic succulents and geophytes (Hoffman and Cowling, 1990; Kerley et al., 1995). The overgrazing of domestic herbivores on livestock farms lead to a loss in many of these endemic succulent species (Hoffman and Cowling, 1990).

There was a greater diversity of grasses on the game reserves than on the livestock farms across both the wet and dry seasons. This greater diversity of grasses found on the reserve sites compared to the adjacent livestock farms suggests that reserve sites are possibly not completely untransformed as highlighted by Vlok et al. (2003).

Vlok et al. (2003) broke down the thicket vegetation into structural types based on the relative cover of woody, succulent, and grass species. These types were solid type thicket – thicket that has an unbroken canopy, and mosaic type thicket – thicket with isolated bush clumps in a vegetation matrix of different composition, structure, and function. Vlok et al. (2003) suggested that when a bush clump is a true degraded/remnant bush clump, the bush clump species diversity and the matrix species diversity would be low. However, if the area is a mosaic, the bush clump species diversity will be high and so will the matrix diversity (Vlok et al., 2003). My results therefore, suggest that the bush clumps on these game reserve and livestock farms are not remnants of truly degraded bush clumps but are part of a bigger thicket mosaic. Following Vlok et al. (2003) findings, the matrix species recorded around bush clumps in this study suggests that all the game reserves and livestock farms sampled were thicket mosaics due to their high diversity of plant species. Vlok et al. (2003) suggest that thicket mosaics are unlikely to be caused by megaherbivores, even at a high population density, but rather megaherbivores have fragmented solid thicket within arid thicket types, causing a mosaic-like landscape.

Effect of land use change on landscape productivity

The NDVI did not differ between the livestock farms and game reserves and these findings contradicted my predictions. Although there were no significant differences, the NDVI over time on the game reserves were slightly higher. The NDVI results follow a trend of a decrease in NDVI from the reserve starting year to 2015, where the lowest NDVI values were observed, followed by an increase in NDVI from 2015 to 2021. The game reserves and livestock farms follow the same trend across all sites, with the livestock farms' NDVI always remaining lower than the game reserves NDVI values. The lower NDVI values seen in 2015 are potentially due to the severe drought recorded in the Eastern Cape in the years leading up to 2015. This is because lower NDVI values indicate higher water stress on vegetation (Thapa et al., 2019). Hyvarinen et al. (2019) suggest that rainfall is a primary driver of vegetation change and must be looked at alongside vegetation indices to assess primary productivity. During 2015, the Eastern Cape province received between 25 to 50 mm during the wet season (January 2015) and 50 to 100 mm during the dry season (August 2015) (South African Weather Service, 2022). These values during 2015 were the highest values recorded for the past three years and most likely caused the start of the increase in NDVI values from 2015 onwards. During 2017 and 2018, 50 to 100 mm of rain was recorded during the wet season (January) and 50 to 100 mm during the dry season (August) (South African Weather Service, 2022). This sudden increase in rainfall across both seasons would have increased the NDVI values across both the livestock farms and the game reserves.

As predicted, the LAI differed across the livestock farms and game reserves. LAI was substantially larger on the game reserves than on the livestock farms. The higher median LAI recorded on the game reserves than the livestock farm suggested LAI values are more similar and consistent through the game reserves. The higher LAI on the game reserves also suggests greater biomass on the game reserves as the denser thicket vegetation is more consistent seasonally due to the higher presence of evergreen woody trees (Parker, 2020) (Appendix 4.1 and 4.2).

As predicted, FIPAR was greater on the game reserves than the livestock farms. The FIPAR is useful in assessing vegetation health in a different way to NDVI but combined allow for a greater understanding of vegetation health (Ridao et al., 1998). These remote sensing indices were used as proxies for productivity.

The slightly higher NDVI on the reserves suggest that vegetation may be healthier and less stressed (Ridao et al., 1998). This is further supported by the higher FIPAR and LAI values recorded on the game reserves. This suggests greater biomass on the game reserves and therefore, greater productivity of the game reserves vegetation.

Hyvarinen et al. (2019) suggest that the rainfall events are the dominant influence over landscape productivity, providing insight to the changes in NDVI, LAI, and FIPAR across the game reserves and livestock farms. However, biotic and abiotic factors work together to shape vegetation within semi-arid environments, and therefore the impact of browsing and grazing on thicket vegetation should not be underestimated (Fynn and O’Connor, 2000; Hyvarinen, 2018).

Conclusion

My results suggest that land use change from livestock farming to game reserves have not had significant impacts on the bush clump size and plant species composition in the Subtropical Thicket biome. The results from this study show how land use change might have an impact on landscape productivity over time. To fully understand the impacts of land use change on the Subtropical Thicket biome, a more extensive long-term (>5 years) research project would be ideal so that one can look at the changes in structure and vegetation composition over several years. A more thorough study into the individual wild herbivore and further megaherbivore impacts on landscape structure over the long-term should be conducted to fully understand structural changes and therefore, the overall impact of megaherbivore introductions and/or reintroductions, and land use change from livestock farming to game reserves.

One of the main purposes of land use change from livestock farming to game reserves is to increase landscape productivity. This study shows using remotely sensed data with in-situ sampling, that land use change has had an impact on landscape productivity in the Subtropical Thicket biome. Research gaps do need to be filled and several adjustments can be made to provide more evidence into land use change, herbivory changes, and megaherbivore reintroduction impacts on landscape productivity, vegetation structure, and vegetation composition (refer to Chapter 6).

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CHAPTER 5

DIET OF THE EXTRALIMITAL GIRAFFE (*GIRAFFA CAMELOPARDALIS*) IN THE SUBTROPICAL THICKET

Introduction

There has been an increasing trend of introducing giraffes (*Giraffa camelopardalis*) into the Eastern Cape Subtropical Thicket, mainly in game reserves for ecotourism and aesthetic value (Parker and Bernard, 2005). Historically, giraffe populations are natively found in the Savanna biome of northern South Africa, with the Limpopo province supporting the largest population of giraffes in their native range (Theron, 2005; Marais, 2019). Giraffes are classified as browsers and almost exclusively browse from trees and shrubs, mainly on the leaves and shoots (Furstenburg and Van Hoven, 1994). Thus, Savanna biome is the most suitable habitat for giraffes due to the presence of large trees that provide browse material (Furstenburg and Van Hoven, 1994). Within their native range, giraffes feed predominantly on *Acacia nigrescens, A. welwitschii, Combretum imberbe,* and *Dichrostachys cinerea* during wet summer months, and *A. erubescens, Lonchocarpus capassa, A. xanthoploea, Maytenus heterophylla,* and *A. robusta* during the dry winter months (Furstenburg and Van Hoven, 1994). This seasonal change in diet occurs due to the lack of availability of leaf foliage of the preferred summer species during the winter months and changes in vegetation phenology (Du Toit et al., 1990; Marais, 2019).

Giraffes are extralimital species within the Eastern Cape province (Skead, 2007) and therefore, their diet and potential impact on the vegetation may differ to indigenous megaherbivores such as elephants (*Loxodonta africana*) and black rhinoceros (*Diceros bicornis*). Despite this prediction, little is known about the diet of giraffes outside their native range, particularly in the Eastern Cape, where giraffes are populating the landscapes of many game reserves. A handful of studies conducted in the Eastern Cape show that giraffes feed mainly on *Vachellia karroo, Euclea undulata, Boscia oleoides,* and several *Sersia* species, and their diet changes seasonally (Theron, 2005; Parker and Bernard, 2005). Giraffes tend to prefer the leaves of evergreen species during the dry season, while the wet season sees giraffes targeting leaves of deciduous shrubs and trees (Theron, 2005; Parker and Bernard, 2005). This seasonal variation in diet occurs both in giraffes' natural ranges and beyond those ranges, which includes the Thicket biome (Parker and Bernard, 2005). Past research highlights great quantities of *Acacia* species in the diet of giraffes, and this is likely due to an increase in the condensed tannin content found in *Acacias* (Furstenburg and Van Hoven, 1994; Parker and Bernard, 2005). Giraffes are ruminants; thus, they have an efficient digestive system (Hofmann, 1989). A large portion of giraffes' diets includes spinescent species such as *Senegalia* and *Vachellia* species. Spinescence has been shown to have little to no effect on giraffe feeding as their uniquely equipped tongue helps strip leaves off trees and branches (Sasaki et al., 2001). Understanding the diet of giraffes in the Subtropical Thicket biome will allow us to assess their potential impact as introduced species into the Eastern Cape as these species have not co-evolved with the vegetation present in the Subtropical Thicket biome. The management of extralimital species for biodiversity conservation and restoration is crucial to understanding the impact of introduced species (Castley et al., 2001).

In this chapter, I determined the diet composition of giraffes outside their natural range during the wet and dry seasons. Specifically, I wanted to assess which plant species would be selected the most by giraffes in the Eastern Cape Subtropical Thicket biome. Given that giraffes feed predominantly on *Vachellia* species in their natural range, I predicted that *Vachellia* species within the biome would be selected the most by giraffes. Additionally, I wanted to assess if the plant species selected by giraffes would differ between dry and wet seasons. The Eastern Cape Subtropical Thicket biome receives nonseasonal rainfall, and evergreen woody plants dominate the biome and there has been a severe drought in the past five years, thus, I predicted that there would be no differences in the plant species selected by giraffes between seasons.

Methods

The details of the technique used to observe giraffe feeding behaviours and data analyses can be found in Chapter three, giraffe feeding observations.

Results

Overall, giraffes fed on 24 plant species across the seasons (Tables 5.1 and 5.2). Of these 24 plant species, *V. karoo* was utilised the most, followed by *S. longispina* and *E. undulata*, respectively. During the wet season, giraffes fed on 11 different plant species only, across the four game reserves (Table 5.1). Of these 11 plant species, *V. karroo* was the most targeted plant species, making up 73.8% of the overall feeding observations, across the four game reserves (Table 5.1). *Azima tetracantha* (5.5%) was the second most targeted plant species followed by *B. oleoides* (4.1%).

Giraffes broaden their diet during the dry season by feeding on 22 different plant species across the four game reserves (Table 5.2). Of these 22 species, *V. karroo* was the most targeted species making up 22.2% of the overall feeding observations across the four game reserves (Table 5.2). *Searsia longispina* (20.5%) was the second most targeted plant species followed by *E. undulata* (11.7%). While this was the case, both the NMDS (figure 5.1) and ANOSIM ($R = 0.083$ and $p = 0.02$) conducted showed no clear differences in the plant species targeted by giraffes between seasons.

Table 5.1: Plant species targeted by giraffes during the wet season, across the four game reserves [Amakhala (A), Kariega (KA), Kwandwe (KW), Pumba (P)] in the Eastern Cape (January 2021 - February 2021).

FAMILY	**SPECIES**	**DIET (%)**				
		A	**KA**	**KW**	**P**	**OVERALL**
Woody shrubs		N = 35	N = 37	N = 36	N = 35	N = 145
Anacardiaceae	*Searsia angustifolia*	0.0%	2.7%	0.0%	0.0%	0.7%
Anacardiaceae	*Searsia longispina*	**8.6%**	0.0%	5.6%	0.0%	3.4%
Capparaceae	*Boscia oleoides*	0.0%	**13.5%**	5.6%	0.0%	**4.1%**
Celastraceae	*Gymnosporia polyacantha*	0.0%	0.0%	5.6%	**8.6%**	3.4%
Ebenaceae	*Euclea undulata*	5.7%	0.0%	0.0%	2.9%	2.1%
Fabaceae	*Schotia afra*	0.0%	0.0%	2.8%	2.9%	2.8%
Fabaceae	***Vachellia karroo***	**85.7%**	**70.3%**	**66.7%**	**77.1%**	**73.8%**
Rhamnaceae	*Scutia myrtina*	0.0%	0.0%	0.0%	5.7%	1.4%
Salvadoraceae	*Azima tetracantha*	0.0%	**13.5%**	2.8%	2.9%	**5.5%**
Sapindaceae	*Pappea capensis*	0.0%	0.0%	2.8%	0.0%	0.7%
Scrophulariaceae	*Buddleja saligna*	0.0%	0.0%	**8.3%**	0.0%	2.1%
TOTAL NUMBER OF SPECIES		**3**	**4**	**8**	**6**	**11**

Table 5.2: Plant species targeted by giraffes during the dry season, across the four game reserves [Amakhala (A), Kariega (KA), Kwandwe (KW), Pumba (P)] in the Eastern Cape (July 2020 – August 2020).

FAMILY	**SPECIES**	**DIET**	**(%)**			
		A	**KA**	**KW**	**P**	**OVERALL**
Woody shrubs		N = 57	N = 42	N = 48	N = 22	N = 171
Amaranthaceae	*Exomis microphylla*	0.0%	**26.2%**	0.0%	0.0%	5.8%
Anacardiaceae	*Searsia longispina*	**14.0%**	**16.7%**	**27.1%**	0.0%	**20.5%**
Anacardiaceae	*Searsia lucida*	**14.0%**	0.0%	0.0%	**9.1%**	6.4%
Apocynaceae	*Carissa haematocarpa*	0.0%	0.0%	8.3%	4.5%	3.5%
Asparagaceae	*Asparagus asparagoides*	0.0%	0.0%	0.0%	4.5%	0.6%
Bignoniaceae	*Rhigozum obovatum*	0.0%	2.4%	0.0%	0.0%	0.6%
Boraginaceae	*Ehretia rigida*	0.0%	0.0%	2.1%	0.0%	0.6%
Celastraceae	*Gymnosporia buxifolia*	1.8%	0.0%	0.0%	0.0%	0.6%
Celastraceae	*Gymnosporia polyacantha*	3.5%	4.8%	**22.9%**	**9.1%**	8.8%
Ebenaceae	*Diospyros dichrophylla*	0.0%	0.0%	0.0%	4.5%	0.6%
Ebenaceae	*Euclea undulata*	**21.1%**	4.8%	8.3%	**9.1%**	**11.7%**
Fabaceae	*Schotia afra*	7.0%	2.4%	0.0%	0.0%	2.9%
Fabaceae	***Vachellia karroo***	**22.8%**	**26.2%**	**8.3%**	**45.5%**	**22.2%**
Oleaceae	*Chionanthus virginicus*	1.8%	0.0%	0.0%	0.0%	0.6%
Rhamnaceae	*Scutia myrtina*	0.0%	4.8%	2.1%	0.0%	0.6%
Rubiaceae	*Coddia rudis*	0.0%	0.0%	0.0%	**9.1%**	1.2%
Salvadoraceae	*Azima tetracantha*	7.0%	4.8%	2.1%	0.0%	2.3%
Sapindaceae	*Pappea capensis*	1.8%	2.4%	**12.5%**	4.5%	7.0%
Scrophulariaceae	*Buddleja saligna*	1.8%	0.0%	0.0%	0.0%	0.6%
Solanaceae	*Lycium ferocissimum*	5.3%	4.8%	0.0%	0.0%	1.2%
Succulents						

Euphorbiaceae	*Euphorbia bothae*	0.0%	0.0%	2.1%	0.0%	0.6%
Portulacaceae	*Portulacaria afra*	0.0%	0.0%	4.2%	0.0%	1.2%
TOTAL NUMBER OF SPECIES		**12**	**11**	**11**	**9**	**22**

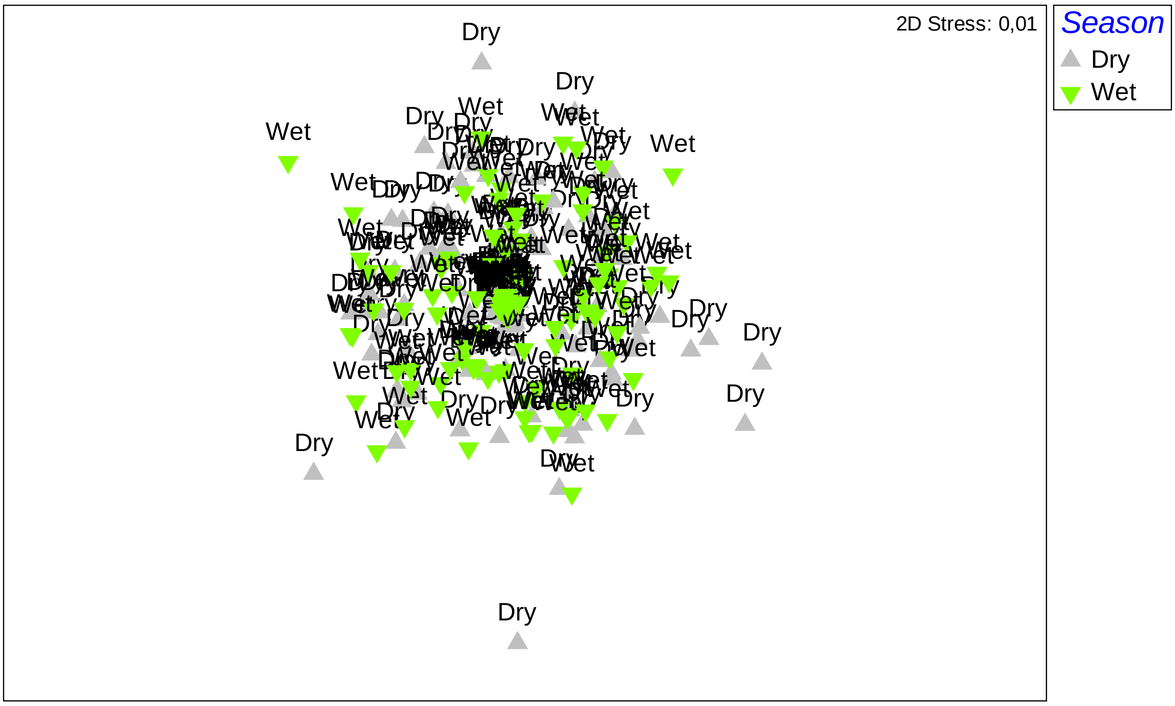

Figure 5.1: Non-metric Multidimensional Scaling ordination (NMDS) showing differences/similarities in plant species targeted by giraffes.

Discussion

While giraffes utilised a variety of plant species (n = 24) in the Subtropical Thicket biome, it is clear from my observations that they fed predominantly on *V. karroo*, *S. longispina* and *E. undulata*, with *V. karroo* being the most utilized plant species. These findings are in agreement with my prediction, that giraffes would utilise *Vachellia* species the most. Additionally, my results are in agreement with previous findings, which showed that giraffes tend to feed on *Vachellia* species in and outside their natural range (Furstenburg and Van Hoven, 1994; Theron, 2005; Parker and Bernard, 2005). The extensive use of *V. karoo* in the Subtropical Thicket biome could be explained by its widespread distribution within the biome (Khoza, 2021), which makes it easily accessible to giraffes and other browsers.

Plant species targeted by giraffes did not vary between seasons; however, the number of plant species targeted by giraffes during the dry season was twice the number of plant species targeted during the wet season. During both seasons, *V. karroo* was the most targeted species overall. My results followed the same trend found by Furstenburg and Van Hoven (1994) that giraffes' wet season diet comprised of fewer species than the dry season diet. Furstenburg and Van Hoven (1994) showed that the diet of giraffes in Kruger National Park composed of 32 plant species during the wet summer season, however, 83% of their diet was made up of only five plant species, and these include *A. nigrescens*, *A. tortilis*, *A. welwitschii*, *Combretum imberbe*, and *Dichrostachys conerea*. During the dry winter season, giraffes targeted several different plant species (*L. capassa*, *A. robusta*, *A. xanthophloea*, *A. erubescens*, *Maytenus heterophylla*, and *A. exuvailis*) as the leaf foliage of preferred plant species declined (Furstenburg and Van Hoven, 1994). A study conducted in the Free State province showed that the diet of giraffes comprised 28 plant species, with three plant species making up 74% of their diet (*V. karroo*, *Asparagus laricinus*, and *Ziziphus mucronata*) (Theron, 2005). In the Eastern Cape province, giraffes utilized 14 different plant species within the Thicket biome, with the most utilized plant species being *V. karroo* (25.7%), *S. longispina* (47.9%), and *E. undulata* (17.6%) (Parker and Bernard, 2005). *Vachellia karroo* was utilized more during the wet season than the dry season in the Free State and Eastern Cape (this study). Additionally, *S. longispina* was utilized more in the dry winter months than the wet summer months in the Eastern Cape (Parker et al., 2003; Parker and Bernard, 2005). The results obtained by Parker and Bernard

(2003; 2005) in the Eastern Cape are consistent with the observations of the current study, which also show that *V. karroo* was targeted more by giraffes during the wet season (73.8%) compared to the dry season (22.2%). Similarly, *S. longispina* was utilized in the greatest quantities by giraffes during the dry season (20.5%). During the period of this study, it was observed that *E. undulata* was an important plant species for giraffes during the dry season, comprising 11.7% of their visually observed diet and this observation is consistent with the results obtained by Parker and Bernard (2003; 2005). With *V. karroo* being one of the most targeted plant species by giraffes in this study, during both the dry and wet seasons, it is important to understand the impact that giraffes might have on this species and the role of this species on the landscape. While *V. karroo* is native in the Thicket biome it has the potential to grow and expand across the landscape, threatening the establishment of herbaceous plants (Khoza, 2021), thus, the browsing of *V. karroo* by giraffes could be controlling the spread of encroaching *V. karroo* on these landscapes.

While giraffes may help control the spread of *V. karroo* on these landscapes, this might have negative consequences on other plant species and animals that are dependent on the *V. karroo* (Bond and Loffel 2001). In semi-arid environments like the Subtropical Thicket biome, there is a lot of competition between megaherbivores for feed. The introduction of giraffes places further pressure on food availability in the thicket vegetation as giraffes compete with elephants and black rhinoceros, and many other browsers (Marais, 2019).

The larger numbers of species targeted during the dry season could be explained by the changes in the production of plant defence chemicals and therefore changes in palatability of certain species (Zweifel-Schielly et al., 2012; Marais, 2019). With game reserves being fenced off in South Africa, herbivores cannot travel long distances in search of more palatable plants and therefore, have to utilize what is available (Furstenburg and Van Hoven, 1994). Giraffes require up to 48 kg of vegetation per day (Bothma and Du Toit, 2010), fences restricting the movement of giraffes' limit chances of them meeting their food daily intake requirements, and as such, giraffes become less selective in non-optimal conditions (Parker and Bernard, 2005). This requires giraffes to include secondary plant species within their diets (Parker and Bernard, 2005; Marais, 2019).

The results from this study were compared with three other studies on giraffe diets in the Thicket. Throughout all these studies, the species that were all recorded as being a part of giraffe diets were *S. longispina, V. karroo, S. afra,* and *S. myrtina*. In all studies, giraffe diets comprised mainly of woody shrubs and trees and a high percentage of *V, karroo.* This suggests that giraffes can control *V. karroo* encroachment and therefore, aid in restoring thicket vegetation by allowing other plant species to thrive and not compete with *V. karroo*. *Euphorbia bothae, L. ferocissimum, C. virginicus, A. asparagoides,* and *S. angustifolia* were all standout plant species in this study as they were only recorded as part of a giraffes' diet in this study and not the other three studies conducted.

The introduction of giraffes has mainly been based on the increased appeal for ecotourism. The results of this study suggest that introducing giraffes into the Subtropical Thicket may potentially have a positive impact in controlling encroaching *V. karroo*. However, there is a high presence of elephants in the Subtropical Thicket biome, a species that is indigenous to the area, and a species able to control *V. karroo*. There is therefore no immediate need to introduce giraffes into the Subtropical Thicket biome. Giraffes do not play a specific role in bringing back a specific ecosystem process that is not already filled through the reintroduction of indigenous megaherbivores. Moreover, the results from this study suggest that giraffe introductions have not caused detrimental effects on the Subtropical Thicket biome

Conclusion

This study has provided some insight into the diet of giraffes and their utilization of the Subtropical Thicket biome. There is no clear difference in plant species selected by giraffes between the wet and dry seasons; however, there is a difference in the number of species selected during the seasons. This seasonal change in the number of plant species targeted is due to the growth of the plant species and the presence of palatable leaves, favouring species such as *E. undulata* and *S. longispina* during the dry seasons and *B. oleoides* and *A. tetracantha* during the wet season. *Vachellia karroo* was targeted across both seasons as it is an evergreen plant and makes up the largest component of plant species utilized by giraffes. Further long-term (>5 years) research needs to be conducted in order to assess the influence of giraffes in the Subtropical Thicket biome and the impact giraffes might have on the indigenous plant species.

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CHAPTER 6

CONCLUSION

This study provides some insight into the influence that land use change from livestock farming to game reserves might have on vegetation and landscape productivity. The data collected on vegetation structure, composition, and remote sensing show some evidence that the game reserves, which were once livestock farms, differ to some extent from active livestock farms and I, therefore, hypothesise that changes in land use, and subsequently herbivore communities, might have a positive effect on the restoration of these landscapes that were heavily grazed by domestic livestock. The increased productivity and biomass of the game reserves suggest that productivity can be restored on game reserves with a different grazing pressure from indigenous wild herbivores. This is a positive and important step in restoring the thicket vegetation and potentially regaining ecosystem processes and productivity. My results provide additional information about the role of an extralimital giraffe in the Subtropical Thicket biome. I showed that giraffes, as an extralimital species in the Subtropical Thicket biome may cause negative and positive impacts on the vegetation but more research is needed to ascertain the impact of giraffes. I hypothesise that giraffes may play an important role in the Subtropical Thicket by potentially controlling the encroaching *V. karroo*. Overall, land use change, with the subsequent herbivore community and grazing changes, could be an effective technique for restoring the Thicket from once degraded and overgrazed lands.

Management implications

For land use change to be effective as a restoration technique in the Subtropical Thicket biome, sustainable management of herbivores needs to be implemented. Due to the high levels of aridity in the Subtropical Thicket biome (Rutherford et al., 2014), food available to herbivores can be limited, particularly for megaherbivores such as elephants who require at least 200 kgs of feed a day (Rowan and Faith, 2019). Therefore, populations must be controlled to keep the vegetation and landscape in a restorative state rather than leaving overpopulated megaherbivores to destroy and degrade the landscape further. Elephants are often destructive of vegetation in search of food, for simple play between young ones, or destructive bulls in musth (Owen-Smith, 1988). Populations need to be controlled for elephant and can be done through the female contraceptives (Porcine zona pellucida vaccine) that has proven successful in many cases in South Africa (Garai et al., 2018). Rhino populations are already being closely monitored due to the ongoing poaching issues within southern Africa and therefore, species numbers are being controlled. Currently, the drought within the Eastern Cape has placed strain even on controlled herbivore populations, causing further degradation to vegetation. This may lead management to provide artificial feed, such as alfalfa, for megaherbivores.

If giraffe populations are to be introduced into a game reserve in the Subtropical Thicket biome, there also needs to be population control. Although giraffes are not as destructive of vegetation as elephants, they can still have detrimental effects on specific species. Trade-offs need to be discussed in the management of these game reserves, between aesthetic appeal for tourism and the protection of specific plant species in the Subtropical Thicket biome.

Research gaps and further research opportunities

The use of fence line contrasts in the Subtropical Thicket has been criticized previously as the comparison between intact thicket and severely transformed thicket proposes a disadvantage (Schmidt et al., 2019). The disadvantage is that the contrasts are often conducted between two or three points and not along an entire transformation gradient (Lechmere-Oertel et al., 2008; Sigwela et al., 2009; Schmidt et al., 2019). Thus, this approach limits the ability to understand and predict the whole transformation process and therefore one cannot identify all indicators of change to aid landowners of threshold changes in ecosystem functioning (Landman and Kerley, 2014). Therefore, there is a need to conduct more sampling along the fence lines of game reserves bordering active livestock farms to get a better understanding of any changes that occur here in the long term. This was one of the implications within this study as sample size was small to show true changes in vegetation structure, richness, diversity, and composition.

Further research can be conducted to further assess the potential of land use change in the Subtropical Thicket biome through greater analysis into remote sensing indices and satellite imagery with higher resolution (using imagery with a higher resolution than 30 m, such as Planet imagery) to understand the landscape at a species level with remote sensing. There is potential to further analyse the faecal matter of giraffes to get a better understanding of the species they are targeting as feed. To better understand the concept of land use change, a long-term study will need to be conducted to analyse vegetation structural changes and assess the effects the ongoing drought continues to have on the Subtropical Thicket biome. There is a need to look more closely at soils on the game reserves and the livestock farms to assess the herbivore impact on carbon stocks, along with further remote sensing indices. This will allow for further understanding of megaherbivores on more ecosystem processes besides productivity and biomass.

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APPENDIX 3A – Google Earth Engine python code for landform structure

```
var dataset = ee.Image('CSP/ERGo/1_0/Global/SRTM_landforms');
var landforms = dataset.select('constant');
var landformsVis = {
  min: 11.0,
  max: 42.0,
  palette: [
    '141414', '383838', '808080', 'EBEB8F', 'F7D311', 'AA0000', 'D89382',
    'DDC9C9', 'DCCDCE', '1C6330', '68AA63', 'B5C98E', 'E1F0E5', 'a975ba',
    '6f198c'
  ],
};
Map.setCenter(26.086724,-33.572808, 11);
Map.addLayer(landforms, landformsVis, 'Landforms');



// create legend
var legend = ui.Panel({
  style: {
    position:'bottom-right',
    padding: '8px 15px'}
});

// create legend title
var legendTitle = ui.Label({
  value: 'Legend',
  style: {
    fontWeight: 'bold',
    fontSize: '18px',
    margin: '0 0 4px 0',
    padding: '0'
```

```
  }
});

//create legend title
legend.add(legendTitle);

// Creates and styles 1 row of the legend.
var makeRow = function(color, name) {

   // Create the label that is actually the colored box.
   var colorBox = ui.Label({
    style: {
      backgroundColor: '#' + color,
      // Use padding to give the box height and width.
      padding: '8px',
      margin: '0 0 4px 0'
    }
   });

   // Create the label filled with the description text.
   var description = ui.Label({
    value: name,
    style: {margin: '0 0 4px 6px'}
   });

   // return the panel
   return ui.Panel({
    widgets: [colorBox, description],
    layout: ui.Panel.Layout.Flow('horizontal')
   });
};

//Palette with colours
var palette=[ '141414', '383838', '808080', 'EBEB8F', 'F7D311', 'AA0000', 'D89382',
```

```
  'DDC9C9', 'DCCDCE', '1C6330', '68AA63', 'B5C98E', 'E1F0E5', 'a975ba',
  '6f198c']

// create names
var names=['peak/ridge(warm)','peak/ridge','peak/ridge(cold)','mountain/divide','cliff','upper
slope (warm)',
'upper slope','upper slope (cool)','upper slope (flat)','lower slope (warm)','lower slope','lower
slope (cool)',
'lower slope (flat)','valley','valley (narrow)']

// Add color and and names
for (var i = 0; i < 15; i++) {
  legend.add(makeRow(palette[i], names[i]));
  }

// add legend to map
Map.add(legend);
```

APPENDIX 3B – Google Earth Engine python code to calculate Normalised Difference Vegetation Index (NDVI)

```
var dataset = ee.ImageCollection('LANDSAT/LE07/C01/T1_8DAY_NDVI')
                  .filterDate('2020-08-01', '2020-08-31');
var colorized = dataset.select('NDVI');
var colorizedVis = {
  min: 0.0,
  max: 1.0,
  palette: [
    'FFFFFF', 'CE7E45', 'DF923D', 'F1B555', 'FCD163', '99B718', '74A901',
    '66A000', '529400', '3E8601', '207401', '056201', '004C00', '023B01',
    '012E01', '011D01', '011301'
  ],
};
Map.setCenter(26.16, -33.52);
Map.addLayer(colorized, colorizedVis, 'Colorized');
```

APPENDIX 3C – R code for NMD ordinations in R studio

```
install.packages("vegan")
library(vegan)

read.csv("species present bush clumps - dry season coded 0and1.csv",header=TRUE)
species<-read.csv("species present bush clumps - dry season coded 0and1.csv",header=TRUE)



#make community matrix - extract columns with species information
veg = species[,3:ncol(species)]

#turn veg data frame into a matrix
m_veg = as.matrix(veg)

set.seed(141)
nmds = metaMDS(m_veg, distance = "bray")
nmds

plot(nmds)



ordiplot(nmds,type="n")
orditorp(nmds,display="species",col="red",air=0.01)
orditorp(nmds,display="sites",cex=1.25,air=0.01)
```

APPENDIX 3D – Structural measurements (height, width, breadth) ANOVA R code

```
read.csv("ANOVA bush clump measurements.csv")
bush clump<-read.csv("ANOVA bush clump measurements.csv")

# normality tests of height, width, breadth

height<-bush clump$Height
shapiro.test(height)
qqnorm(height)
qqline(height)

width<-bush clump$Width
qqnorm(width)
qqline(width)

breadth<-bush clump$Breadth
qqnorm(breadth)
qqline(breadth)

# Factorial ANOVA looking at thicket type and land type
#Height
aov(Height~Land.type*Thicket.type,data=bush clump)
HeightANOVA<-aov(Height~Land.type*Thicket.type,data=bush clump)
anova(HeightANOVA) #ANOVA table
boxplot(Height~Land.type*Thicket.type,data=bush clump)
boxplot(Height~Land.type,data=bush clump)
boxplot(Height~Thicket.type, data=bush clump)

#Width
aov(Width~Land.type*Thicket.type,data=bush clump)
WidthANOVA<-aov(Width~Land.type*Thicket.type,data=bush clump)
```

```
anova(WidthANOVA) #ANOVA table
boxplot(Width~Land.type*Thicket.type,data=bush clump)
boxplot(Width~Land.type,data=bush clump)
boxplot(Width~Thicket.type, data=bush clump)

#breadth
aov(Breadth~Land.type*Thicket.type,data=bush clump)
BreadthANOVA<-aov(Breadth~Land.type*Thicket.type,data=bush clump)
anova(BreadthANOVA) #ANOVA table
boxplot(Breadth~Land.type*Thicket.type,data=bush clump)
boxplot(Breadth~Land.type,data=bush clump)
boxplot(Breadth~Thicket.type, data=bush clump)

# Factorial ANOVA looking at season and land type
#Height
aov(Height~Land.type*Season,data=bush clump)
HeightANOVA<-aov(Height~Land.type*Season,data=bush clump)
anova(HeightANOVA) #ANOVA table
boxplot(Height~Land.type*Season,data=bush clump)
boxplot(Height~Land.type,data=bush clump)
boxplot(Height~Season, data=bush clump)

#Width
aov(Width~Land.type*Season,data=bush clump)
WidthANOVA<-aov(Width~Land.type*Season,data=bush clump)
anova(WidthANOVA) #ANOVA table
boxplot(Width~Land.type*Season,data=bush clump)
boxplot(Width~Land.type,data=bush clump)
boxplot(Width~Season, data=bush clump)

#breadth
aov(Breadth~Land.type*Season,data=bush clump)
BreadthANOVA<-aov(Breadth~Land.type*Season,data=bush clump)
anova(BreadthANOVA) #ANOVA table
```

```
boxplot(Breadth~Land.type*Season,data=bush clump)
boxplot(Breadth~Land.type,data=bush clump)
boxplot(Breadth~Season, data=bush clump)



aov(Height~Land.type,data=bush clump)
anovaLH<-aov(lm(Height ~ Land.type,data=bush clump))
summary(anovaLH)
boxplot(Height ~ Land.type,data=bush clump)

aov(Width~Land.type,data=bush clump)
anovaLW<-aov(lm(Width ~ Land.type,data=bush clump))
summary(anovaLW)

aov(Breadth~Land.type,data=bush clump)
anovaLB<-aov(lm(Breadth ~ Land.type,data=bush clump))
summary(anovaLB)

# Seasonal effect

aov(Height~Land.type*Season,data=bush clump)
anovaLHS<-aov(lm(Height ~ Land.type*Season,data=bush clump))
summary(anovaLHS)
boxplot(Height ~ Land.type*Season,data=bush clump)
TukeyHSD(anovaLHS)

aov(Width~Land.type*Season,data=bush clump)
anovaLWS<-aov(lm(Width ~ Land.type*Season,data=bush clump))
summary(anovaLWS)
boxplot(Width ~ Land.type*Season,data=bush clump)
TukeyHSD(anovaLWS)

aov(Breadth~Land.type*Season,data=bush clump)
```

```
anovaLBS<-aov(lm(Breadth ~ Land.type*Season,data=bush clump))
summary(anovaLBS)
boxplot(Breadth ~ Land.type*Season,data=bush clump)
TukeyHSD(anovaLBS)
```

APPENDIX 3E – R code for Simpson’s Index in R studio

```
library(vegan)
## beta diversity dry season diversity

read.csv("BETA SPECIES CODED 1and0 - DRY SEASON - Sheet1.csv")
beta.dry<-read.csv("BETA SPECIES CODED 1and0 - DRY SEASON - Sheet1.csv")
data(beta.dry)
diversity(beta.dry)
H <- diversity(beta.dry)

diversity(beta.dry, "simpson")
simp <- diversity(beta.dry, "simpson")

invsimp <- diversity(beta.dry, "inv")
## Unbiased Simpson (Hurlbert 1971, eq. 5) with rarefy:
rarefy(beta.dry, 2) - 1
unbias.simp <- rarefy(beta.dry, 2) - 1
## Fisher alpha
alpha <- fisher.alpha(beta.dry)
## Plot all
pairs(cbind(H, simp, invsimp, unbias.simp, alpha), pch="+", col="blue")
## Species richness (S) and Pielou's evenness (J):
S <- specnumber(beta.dry) ## rowSums(BCI > 0) does the same...
J <- H/log(S)
```

APPENDIX 3F – NDVI ANOVA R code

```
## NDVI per land type
read.csv("NDVI VALUES R - ALL RESERVES.csv",sep=",")
ALL_NDVI<-read.csv("NDVI VALUES R - ALL RESERVES.csv",sep=",")

# Year and Land.type
ANOVA<-aov(lm(NDVI ~ Year*Land.type, data=ALL_NDVI))
aov(lm(NDVI ~ Year*Land.type, data=ALL_NDVI))
summary(ANOVA)
boxplot(NDVI ~ Year*Land.type, data=ALL_NDVI)
#TUKEY HSD post hoc test
TukeyHSD(ANOVA)
```

APPENDIX 3G – FIPAR and LAI ANOVA R code

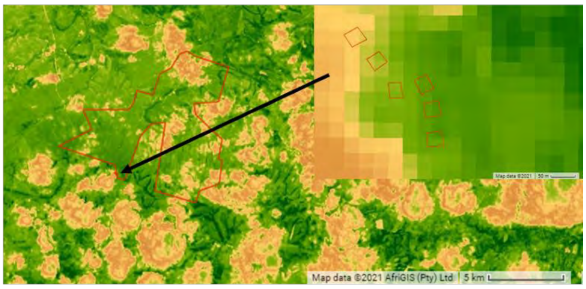
```
read.csv("LAI DATA - LAI.csv",sep=",")
LAI<-read.csv("LAI DATA - LAI.csv",sep=",")

install.packages("ggplot2")
library(ggplot2)
library(tidyverse)
library(ggpubr)
library(stats)
library(ggpmisc)

shapiro.test(LAI$LAI)

ANOVA2<-aov(LAI~Land.type*Season, data=LAI)
aov(LAI~Land.type*Season, data=LAI)
summary(ANOVA2)
boxplot(LAI~Land.type*Season, data=LAI)
TukeyHSD(ANOVA2)
plot(TukeyHSD(ANOVA2))

read.csv("FIPAR R - Sheet1.csv",sep=",")
FIPAR<-read.csv("FIPAR R - Sheet1.csv",sep=",")

shapiro.test(FIPAR$FIPAR)

ANOVA1<-aov(FIPAR~Land.type*Season, data=FIPAR)
aov(FIPAR~Land.type*Season, data=FIPAR)
summary(ANOVA1)
boxplot(FIPAR~Land.type*Season, data=FIPAR)
TukeyHSD(ANOVA1)
plot(TukeyHSD(ANOVA1))
```

APENDIX 4A – NDVI maps for all reserves from starting year to present day

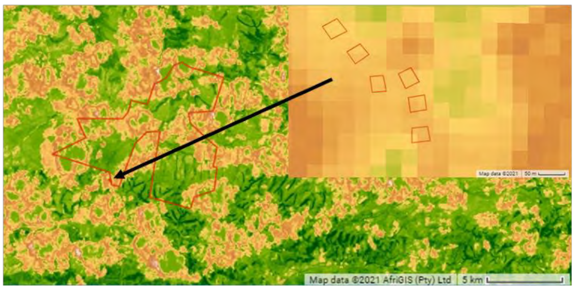
Amakhala Game Reserve:

Amakhala 1999 - Starting year; Giraffe introductions

Amakhala 2001

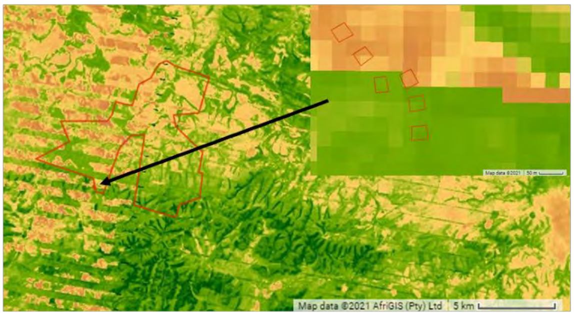


Amakhala 2002

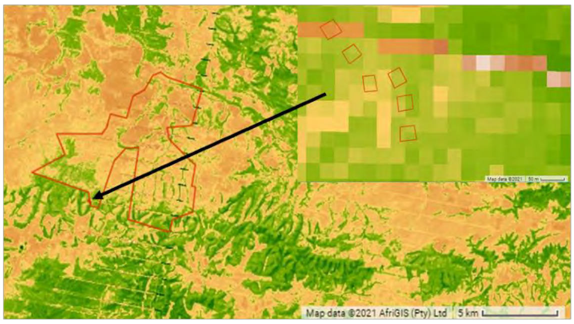


Amakhala 2003 – Elephant and rhino introductions

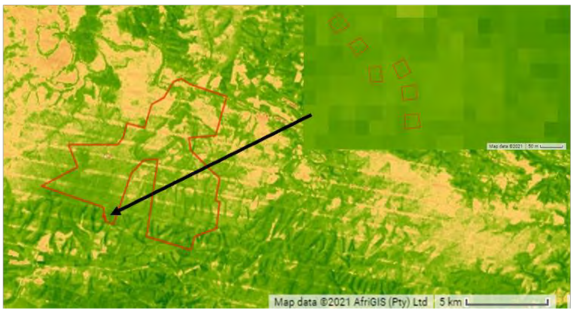
Amakhala 2018



Amakhala 2019



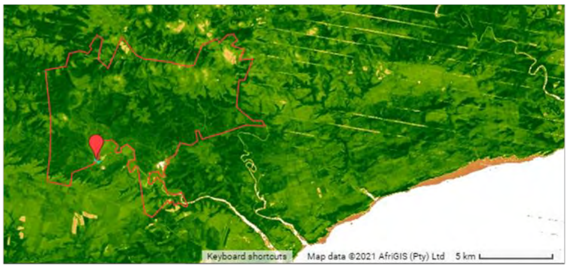
Amakhala August 2020 – Dry season



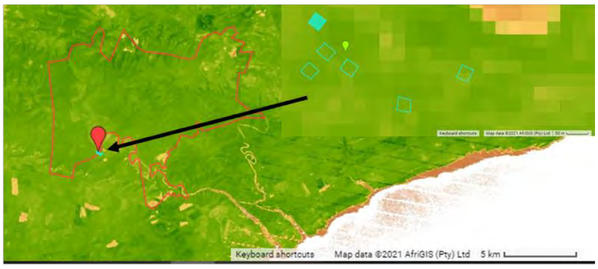
Amakhala August 2021 – Wet season

Kariega Game Reserve:

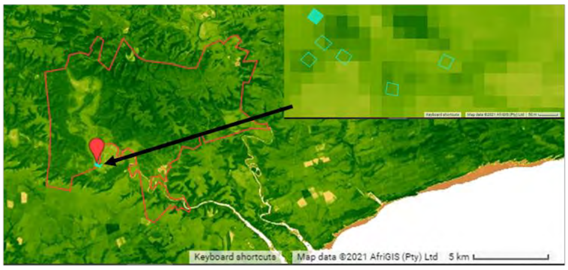
Kariega 2013 – Year before Harvestvale was incorporated



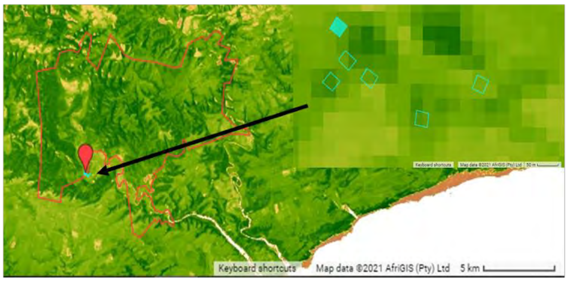
Kariega 2014 – Harvestvale incorporated into reserve; elephants and rhino introduced



Kariega August 2020 – dry season

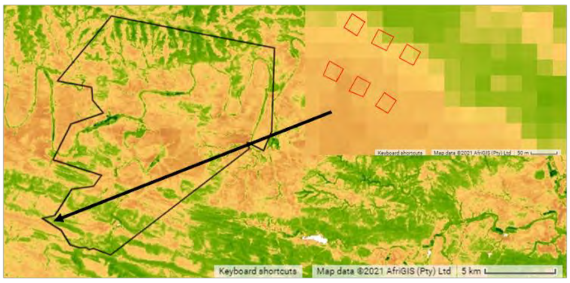


Kariega January 2021 – wet season

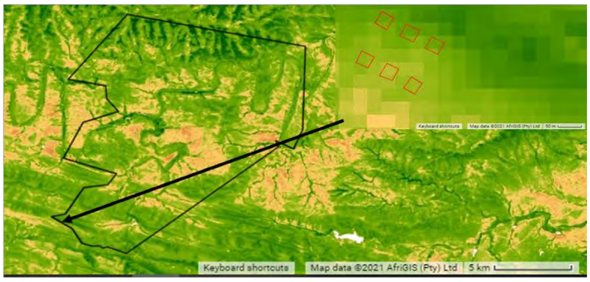


Kwandwe Game Reserve:

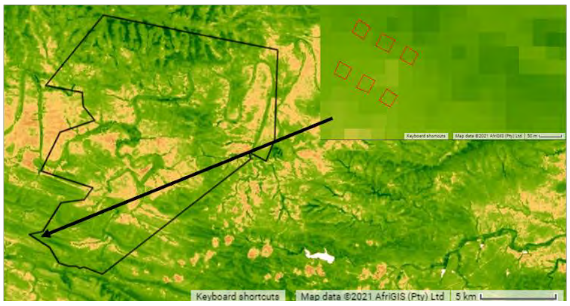
Kwandwe 1999 – starting year



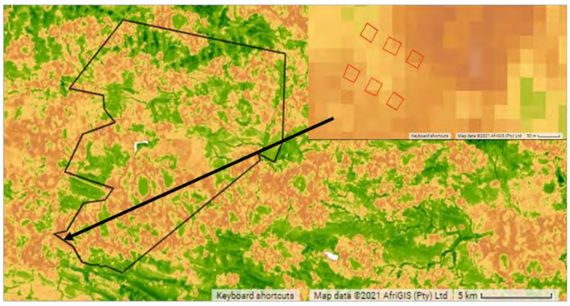
Kwandwe 2000 – Rhinos introduced



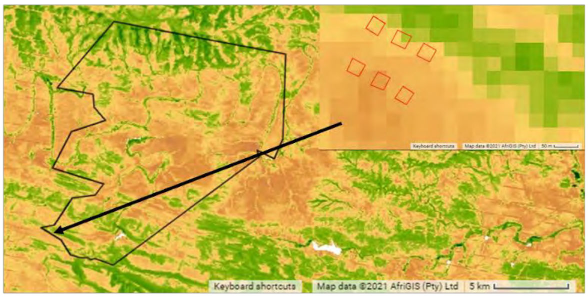
Kwandwe 2001 – Elephants introduced



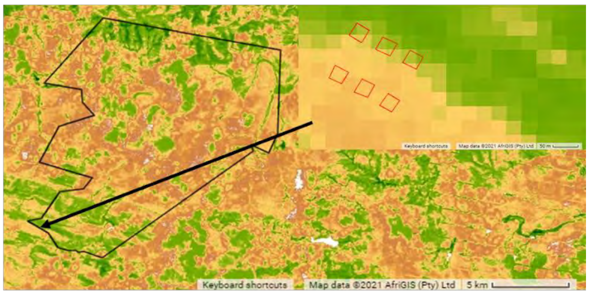
Kwandwe 2002 – Elephants introduced



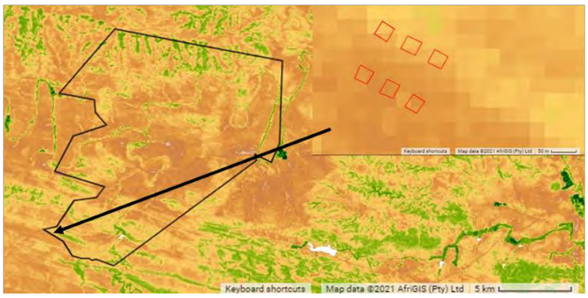
Kwandwe 2003 – Giraffes introduced



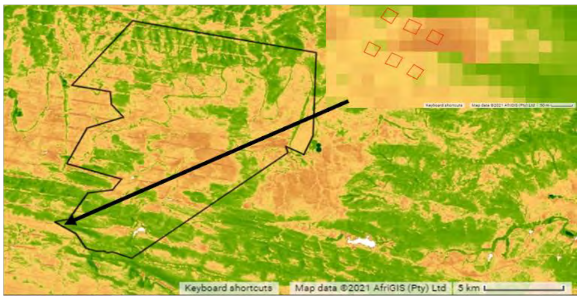
Kwandwe 2004



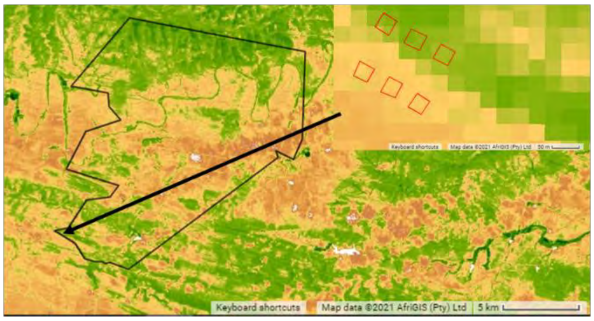
Kwandwe 2019



Kwandwe July 2020 – Dry season

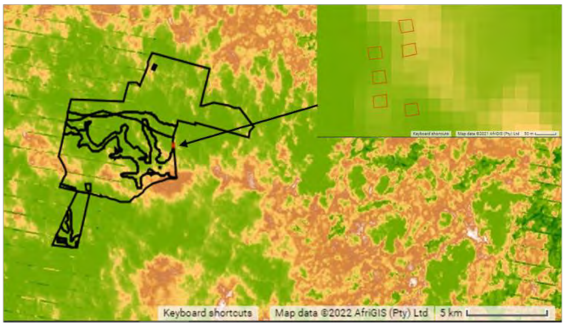


Kwandwe February 2021– Wet season

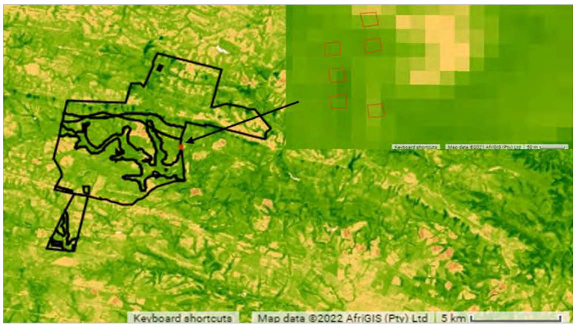


Pumba Game Reserve:

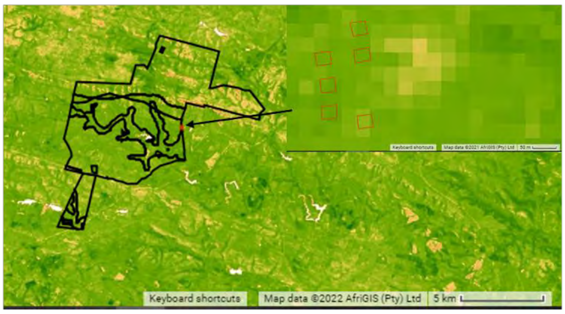
Pumba 2004 – reserve starting year



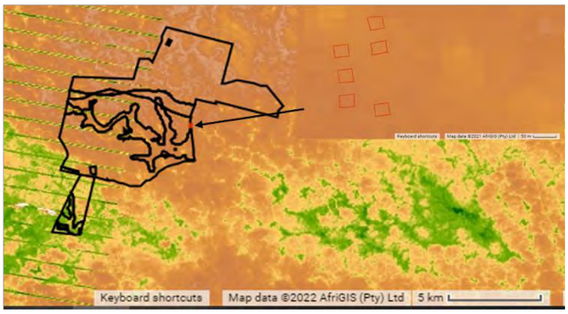
Pumba 2005 – elephants, rhino, and giraffe introduced



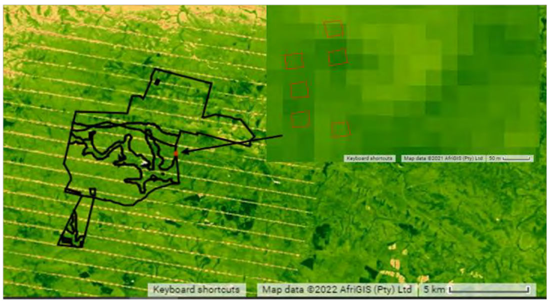
Pumba 2006



Pumba 2015

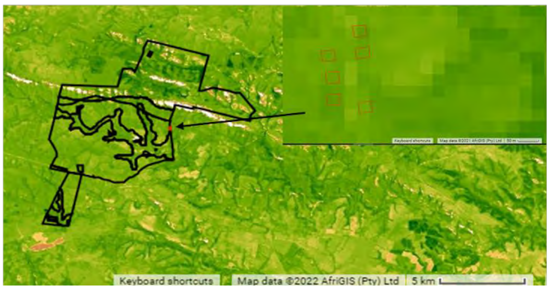


Pumba 2020



Pumba January 2021 – wet season sampling

Pumba May 2021 – dry season sampling



APPENDIX 4B – Plant species present on each sample site (AR – Amakhala Reserve, NF – Nanaga farm, KAR- Kariega Reserve, NIF – Nightingale Farm, KWR – Kwandwe Reserve, DF – Dell Farm, PR – Pumba Reserve, BF – Bowles Farm) categorized into functional groups across the wet season.

FAMILY	SPECIES	AR	NF	KAR	NIF	KWR	DF	PR	BF
	Woody species								
Aizoaceae	*Aizoon glinoides*							X	X
Aizoaceae	*Genus Aizoon*			X					
Aizoaceae	*Lampranthus aureus*		X	X	X			X	X
Anacardiaceae	*Ozoroa mucronata*	X			X	X	X		
Anacardiaceae	*Searsia longispina*		X	X	X	X	X		
Anacardiaceae	*Searsia lucida*	X	X					X	X
Anacardiaceae	*Searsia undulata*	X	X	X	X				
Anacardiaceae	*Schinus terebinthifolia*							X	X
Apocynaceae	*Carissa bispinosa*							X	X
Apocynaceae	*Carissa haematocarpa*					X	X		
Araliaceae	*Cussonia spicata*		X					X	X
Asparagaceae	*Asparagus densiflorus*	X	X			X	X	X	X
Asparagaceae	*Asparagus racemosus*			X	X	X	X		
Asparagaceae	*Asparagus rubicundus*	X				X	X	X	X
Asparagaceae	*Asparagus setaceus*				X				
Asparagaceae	*Asparagus striata*	X	X			X	X		
Asteraceae	*Artemisia cana*					X			
Asteraceae	*Brachylaena elliptica*					X	X	X	X
Asteraceae	*Eriocephalus africanus*	X	X				X		
Asteraceae	*Euryops speciosissimus*							X	X
Asteraceae	*Felicia filifolia*						X		
Asteraceae	*Metalasia muricata*							X	X
Asteraceae	*Osteospermum moniliferum*								X
Ceasalpiniaceae	*Schotia afra*					X	X	X	
Celastraceae	*Gymnosporia buxifolia*					X	X		
Celastraceae	*Gymnosporia polyacantha*	X				X	X	X	X
Celastraceae	*Pterocelastrus tricuspidatus*	X	X	X	X			X	X
Cupressaceae	*Cupressaceae*	X	X						
Cupressaceae	*Widdringtonia nodiflora*								X

Ebenaceae	*Diospyros dichrophylla*	X	X						X
Ebenaceae	*Diospyros whyteana*							X	X
Ebenaceae	*Euclea undulata*	X	X		X	X	X	X	X
Fabaceae	*Lessertia frutescens*							X	X
Fabaceae	*Tephrosia capensis*								X
Fabaceae	*Vachellia karroo*		X	X				X	X
Geraniaceae	*Geranium*							X	
Lamiaceae	*Teucrium trifidum*				X				
Loganiaceae	*Buddleja saligna*	X							
Malvaceae	*Abutilon sonneratianum*	X			X				X
Malvaceae	*Hermannia althaeoides*			X	X				
Mimosaceae	*Acacia cyclops*		X						
Ochnaceae	*Ochna serrulata*				X				
Pittosporaceae	*Pittosporum viridiflorum*	X	X	X					
Polygalaceae	*Polygala myrtifolia*							X	X
Rhamnaceae	*Scutia myrtina*	X	X	X	X	X	X	X	X
Rosaceae	*Cotoneaster pannosus*					X			
Rubiaceae	*Coddia rudis*							X	X
Salicaceae	*Scolopia mundii*		X						
Salicaceae	*Scolopia zeyheri*							X	X
Salvadoraceae	*Azima tetracantha*			X	X	X	X	X	X
Sapindaceae	*Hippobromus pauciflorus*	X						X	X
Sapindaceae	*Pappea capensis*				X	X	X		
Solanaceae	*Lycium ferocissimum*						X		
Solanaceae	*Solanum africanum*			X	X				
Solanaceae	*Solanum elaeagnifolium*					X	X		
Solanaceae	*Solanum linnaeanum*			X	X	X	X	X	X
Thymelaeaceae	*Gnidia capitata*		X			X	X		
Tiliaceae	*Grewia occidentalis*	X	X			X	X	X	X
Tiliaceae	*Grewia robusta*					X	X		
	TOTAL	18	19	13	17	22	23	27	30
	Succulents								
Aizoaceae	*Delosperma*					X		X	
Aizoaceae	*Mesembryanthemum aitonis*			X					
Apocynaceae	*Pachypodium*					X	X		
Asphodelaceae	*Aloe ferox*		X				X	X	X

Crassulaceae	*Cotyledon orbiculata*					X			
Crassulaceae	*Crassula brian*					X			
Crassulaceae	*Crassula expansa*			X	X				
Crassulaceae	*Crassula imperialis*					X			
Crassulaceae	*Crassula muscosa*	X	X			X			
Crassulaceae	*Crassula ovata*					X	X	X	
Crassulaceae	*Crassula perforata*					X	X		
Crassulaceae	*Crassula rogersii*				X				
Crassulaceae	*Crassula tetragona*					X			
Crassulaceae	*Kalanchoe rotundifolia*				X		X	X	X
Euphorbiaceae	*Euphorbia bothae*					X	X		
Euphorbiaceae	*Euphorbia nubigena*					X			
Euphorbiaceae	*Euphorbia tirucalli*					X	X	X	X
Euphorbiaceae	*Jatropha capensis*					X	X		
Portulacaceae	*Portulacaria afra*					X	X		
Santalaceae	*Viscum minimum*					X			
Santalaceae	*Viscum rotundifolium*								X
Urticaceae	*Obetia tenax*							X	X
Vitaceae	*Cyphostemma cirhossum*					X			
Vitaceae	*Cyphostemma quinatum*					X			
	TOTAL	1	*2*	2	3	17	9	6	5
	Hebaceous species								
Asteraceae	*Cirsium vulgare*								X
Asteraceae	*Haplocarpha scaposa*								X
Asteraceae	*Pseudognaphalium luteoalbum*					X	X		
Asteraceae	*Senecio deltoideus*							X	X
Commelinaceae	*Commelina benghalensis*							X	X
Commelinaceae	*Callisia fragrans*						X		
Fabaceae	*Dipogon lignosus*					X			
Fabaceae	*Fabaceae*					X	X		
Gentianaceae	*Chironia baccifera*	X	X					X	X
Hyacinthaceae	*Drimia altissima*			X	X				
Lamiaceae	*Thymus vulgaris*	X	X						
Nyctaginaceae	*Boerhavia erecta*					X			
Oleaceae	*Jasminum multipartitum*					X	X		
Pteridaceae	*Cheilanthes (lip fern)*	X	X					X	X

	TOTAL	3	*3*	1	1	5	4	4	6
	Grasses								
Poaceae	*Cenchrus ciliaris*							X	
Poaceae	*Digitaria sanguinalis*							X	
Poaceae	*Eragrostis lehmanniana*	X						X	X
Poaceae	*Eragrostis obtusa*	X	X					X	
Poaceae	*Merxmuellera stricta*	X			X		X		
Poaceae	*Panicum ecklonii*								X
Poaceae	*Panicum maximum*	X	X			X	X	X	X
Poaceae	*Themeda triandra*	X		X	X	X	X		X
	TOTAL	5	2	1	2	2	3	5	4
	Vines								
Asteraceae	*Senecio deltoideus*							X	X
Cucurbitaceae	*Ibervillea lindheimeri*			X	X				
Smilacaceae	*Smilax aspera*					X			
Solanaceae	*Salpichroa origanifolia*							X	
Vitaceae	*Cissus trifoliata*						X		
	TOTAL	0	*0*	1	1	1	1	2	1
	Unidentifiable								
Unidentified	*grape vine? P*							X	
Unidentified	*grass 4 KW*						X		
Unidentified	*grass species 2 A*	X							
Unidentified	*KA egg shape vine*			X	X				
Unidentified	*KA grass species 2*				X				
Unidentified	*KA ground shrub*			X	X				
Unidentified	*KA Maize grass*				X				
Unidentified	*KA species 1*			X	X				
Unidentified	*KA species 10*				X				
Unidentified	*KA species 12*				X				
Unidentified	*KA species 2*			X					
Unidentified	*KA species 4*			X					
Unidentified	*KA species 5*			X					
Unidentified	*KA species 7*			X					
Unidentified	*KA species 8*			X					
Unidentified	*KA species 9*				X				
Unidentified	*KA sticky vine*			X	X				

Unidentified	*lycium?*			X	X				
Unidentified	*Searsia? P*							X	X
Unidentified	*species 10 P*							X	X
Unidentified	*species 11 KW*						X		
Unidentified	*species 11 P*							X	X
Unidentified	*species 12 KW*						X		
Unidentified	*species 14 P*								X
Unidentified	*species 19 P*								X
Unidentified	*species 2 KW*					X			
Unidentified	*species 2 P*							X	
Unidentified	*species 21 P*								X
Unidentified	*species 3 P*							X	
Unidentified	*species 5 P*							X	X
Unidentified	*species 6 KW*					X			
Unidentified	*species 6 P*							X	
Unidentified	*species 7 KW*					X			
Unidentified	*species 8 KW*					X			
Unidentified	*species 9 KW*					X			
Unidentified	*species A1*	X							
Unidentified	*species A2*	X							
Unidentified	*species A3*	X	X						
Unidentified	*species A4*	X							
Unidentified	*Species A5*		X						
Unidentified	*species A6*		X						
Unidentified	*species A7*	X							
Unidentified	*species A8*	X							
Unidentified	*vine 3 KW*						X		
Unidentified	*vine species 3 P*							X	X
Unidentified	*vine species 5 P*								X
Unidentified	*wild bulb A*		X						
	TOTAL	7	*4*	10	10	5	4	9	9

APPENDIX 4C – Plant species present on each sample site (AR – Amakhala Reserve, NF – Nanaga farm, KAR- Kariega Reserve, NIF – Nightingale Farm, KWR – Kwandwe Reserve, DF – Dell Farm, PR – Pumba Reserve, BF – Bowles Farm) categorized into functional groups across the dry season.

FAMILY	SPECIES	AR	NF	KAR	NIF	KWR	DF	PR	BF
	Woody species								
Acanthaceae	*Hypoestes aristata*	X			X				
Acanthaceae	*Hypoestes forskaolii*							X	
Aizoaceae	*Aizoon glinoides*				X			X	X
Aizoaceae	*Lampranthus sp.*			X					
Aizoaceae	*Mestoklema albanicum*			X	X				
Amaranthaceae	*Chenopodium album*							X	
Amaranthaceae	*Exomis microphylla*				X				
Anacardiaceae	*Searsia aromatica*	X							
Anacardiaceae	*Searsia crenata*							X	X
Anacardiaceae	*Searsia longispina*	X	X	X	X	X	X	X	
Anacardiaceae	*Searsia lucida*	X	X					X	X
Anacardiaceae	*Searsia undulata*	X	X		X	X	X		
Anacardiaceae	*Ozoroa mucronata*					X			
Anacardiaceae	*Schinus terebinthifolia*							X	X
Apocynaceae	*Carissa bispinosa*					X	X	X	
Apocynaceae	*Carissa haematocarpa*						X		
Araliaceae	*Cussonia spicata*	X	X				X	X	X
Asparagaceae	*Asparagus asparagoides*				X				
Asparagaceae	*Asparagus racemosus*								X
Asparagaceae	*Asparagus rubicundus*	X	X	X	X	X	X	X	
Asparagaceae	*Asparagus striata*	X	X		X	X	X		
Asparagaceae	*Asparagus setaceus*					X			
Asparagaceae	*Asparagus asteroides*	X							
Asparagaceae	*Asparagus densiflorus*	X		X	X	X	X	X	X
Asteraceae	*Brachylaena ilicifolia*					X		X	
Asteraceae	*Eriocephalus africanus*		X			X	X		
Asteraceae	*Dicerothamnus rhinocerotis*		X						
Asteraceae	*Euryops speciosissimus*							X	X
Asteraceae	*Euryops virgineus*	X	X						

Asteraceae	*Metalasia muricata*							X	X
Asteraceae	*Oedera genistifolia*	X	X						
Asteraceae	*Brachylaena discolor*			X	X				
Bigoniaceae	*Rhigozum obavatum*					X	X		
Capparaceae	*Capparis sepiaria*						X	X	
Ceasalpiniaceae	*Schotia afra*	X	X			X	X		
Celastraceae	*Gymnosporia buxifolia*	X	X	X	X	X	X		
Celastraceae	*Gymnosporia capitata*					X			
Celastraceae	*Gymnosporia polyacantha*							X	
Celastraceae	*Lauridia tetragona*	X							
Celastraceae	*Mystroxylon aethiopicum*	X							
Celastraceae	*Putterlickia pyracantha*	X							
Celastraceae	*Pterocelastrus tricuspidatus*	X	X	X	X			X	X
Ebenaceae	*Diospyros dichrophylla*	X	X					X	X
Ebenaceae	*Diospyros whyteana*							X	
Ebenaceae	*Diospyrus scabrida*								X
Ebenaceae	*Euclea natalensis*							X	
Ebenaceae	*Euclea undulata*	X	X	X		X	X	X	X
Fabaceae	*Vachellia karroo*							X	X
Fabaceae	*Lessertia frutescens*							X	
Gentianaceae	*Chironia baccifera*	X	X						
Loganiaceae	*Buddleja saligna*	X	X					X	
Malvaceae	*Abutilon sonneratianum*			X	X	X		X	
Malvaceae	*Hermannia althaeoides*			X	X				
Malvaceae	*Hermannia hyssopfolia*	X							
Mimosaceae	*Acacia cyclops*		X						
Oleceae	*Olea europaea*	X							X
Pittosporaceae	*Pittosporum viridiflorum*	X	X						
Plumbaginaceae	*Plumbago auriculata*							X	
Polygalaceae	*Polygala myrtifolia*							X	X
Pteridaceae	*Cheilanthes (lip fern)*	X	X					X	X
Rhamnaceae	*Scutia myrtina*	X	X	X	X	X		X	X
Rubiaceae	*Coddia rudis*							X	X
Rutaceae	*Zanthoxylum capense*							X	
Salicaceae	*Scolopia mundii*	X	X						
Salicaceae	*Scolopia zeyheri*					X			X

Salvadoraceae	*Azima tetracantha*			X	X	X	X	X	
Sapindaceae	*Pappea capensis*	X				X	X	X	
Sapindaceae	*Hippobromus pauciflorus*	X						X	X
Solanaceae	*Lycium ferocissimum*			X	X				
Stilbaceae	*Halleria lucida*						X		
Tiliaceae	*Grewia occidentalis*	X	X					X	X
Tiliaceae	*Grewia robusta*				X		X	X	
Vitaceae	*Rhoicissus digitata*			X	X				
Vitaceae	*Rhoicissus tridentata*							X	X
	TOTAL	31	23	15	20	20	18	37	23
	Succulents								
Aizoaceae	*Galenia sp.*					X	X		
Aizoaceae	*Genus Delosperma*							X	X
Aizoaceae	*Mesembryanthemum aitonis*			X					
Apocynaceae	*Pachypodium lealii*					X	X		
Asphodelaceae	*Aloe ferox*		X			X	X	X	X
Asteraceae	*Osteospermum moniliferum*	X	X						X
Crassulaceae	*Crassula expansa*			X	X				
Crassulaceae	*Crassula muscosa*					X	X		
Crassulaceae	*Crassula ovata*					X			
Crassulaceae	*Crassula perforata*					X	X		
Crassulaceae	*Crassula rogersii*					X			
Crassulaceae	*Crassula sp 1*					X			
Crassulaceae	*Kalanchoe rotundifolia*							X	
Euphorbiaceae	*Euphorbia bothae*					X	X		
Euphorbiaceae	*Euphorbia nubigena*					X			
Euphorbiaceae	*Euphorbia tirucalli*				X	X	X		
Euphorbiaceae	*Jatropha capensis*			X	X	X			
Portulacaceae	*Portulacaria afra*					X	X		
	TOTAL	1	*2*	3	3	13	8	3	3
	Hebaceous species								
Amaryllidaceae	*Boophone disticha*					X	X		
Asteraceae	*Erigeron sumatrensis*							X	X
Commelinaceae	*Commelina africana*	X	X					X	
Commelinaceae	*Commelina benghalensis*							X	X
Fabaceae	*Dipogon lignosus*	X							X

Fabaceae	*Fabaceae*	X	X						
Lamiaceae	*Thymus vulgaris*	X							
Lamiaceae	*Plectranthus madagascariensis*								
Malvaceae	*Genus Malvaceae*							X	
Oleaceae	*Jasminum multipartitum*					X	X		
Oxalidaceae	*Oxalis*	X							
Primulaceae	*Lysimachia arvensis*			X					
	TOTAL	5	*2*	1	0	2	2	4	3
	Grasses								
Poaceae	*Eragrostis chloromelas*	X	X						
Poaceae	*Eragrostis curvula*	X				X	X		
Poaceae	*Eragrostis lehmanniana*	X			X			X	X
Poaceae	*Digitaria eriantha*							X	
Poaceae	*Imperata cylindrica*	X	X						
Poaceae	*Merxmuellera stricta*	X					X		
Poaceae	*Panicum maximum*	X						X	X
Poaceae	*Sporobolus africanus*		X					X	
Poaceae	*Themeda triandra*	X	X					X	X
Poaceae	*Hyparrhenia hirta*						X		
	TOTAL	7	4	0	1	1	3	5	3
	Vines								
Vitaceae	*Cissus trifoliata*	X						X	
Apocynaceae	*Cynanchum*			X	X				
Campanulaceae	*Cyphia*					X			
Vitaceae	*Cyphostemma viminale*						X		
Cucurbitaceae	*Kedrostis nana*							X	
Asteraceae	*Senecio angulatus*							X	X
Asteraceae	*Senecio deltoideus*							X	
Commelinaceae	*Tradescantia zebrina*							X	
	TOTAL	1	*0*	1	1	1	1	5	1
	Unidentifiable								
Unidentified	aerosperum							X	X
Unidentified	green sticky grass	X							
Unidentified	Maize like grass			X					
Unidentified	Redstem species			X					
Unidentified	sticky vine			X	X				

Unidentified	three leaf species 1					X			
Unidentified	vine 3							X	
Unidentified	vine species 4							X	
Unidentified	Wavy leaf species					X			
	TOTAL	1	0	3	1	2	0	3	1