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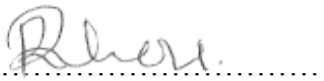
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In partial fulfillment of the Master of Science Degree requirements

University of the Witwatersrand, Johannesburg

Declaration

I declare that, "*The long term changes of woody vegetation patches inside and outside of exclosures in Kruger National Park"* is my own work, that it has not been submitted before for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged as complete references.

Signature 

Date 17 July 2013

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Abstract

Continuous grass and discontinuous trees and shrubs (woody vegetation) characterize savanna landscape. However, burning, consumption and destruction of trees by fire and elephants may further reduce woody vegetation i.e. may lead fragmentation of woody patches. In Kruger National Park (KNP), fire and browsers, specifically elephants (*Loxodonta Africana*), influence the growth of woody vegetation. Therefore, the interaction between fire and the increase in elephant density in KNP over time have led to reserve managers expressing concern about the increasing influence of fire, and elephants on woody vegetation. The main aim of this study was to determine the relative difference in the composition (size and number), complexity (shape) and configuration (connectivity) of woody vegetation patches in and out of two exclosures (Makhohlola and Nwashitshumbe), and to evaluate the changes in woody vegetation patches between basaltic and granitic soils over a period of time (1971 – 2010). Landscape metrics were used to quantify the spatial woody vegetation patterns of the landscape in KNP using aerial photographs. The results indicate that all of our data have no linear relationship with time ($p > 0.05$), except for edge density ($P = 0.0073$). Despite no linear trend, there were significant directional changes in the landscape metrics over time, which indicates that these systems are very fluid with substantial turnover of woody species over short time periods. Variability in the trend of other metrics may be due to the recruitment events and the loss of large trees during the period. There was no difference in the composition, complexity and configuration between the inside of the exclosure and the outside for both Makhohlola and Nwashitshumbe ($p > 0.05$), indicating that the processes driving woody patch formation are similar inside and outside the exclosures. Although there was no significance difference in other metrics for basalt (Makhohlola) and granite (Nwashitshumbe), however edge density (ED) and area weighted mean patch fractal

dimension (AWMPFD) were significant ($p < 0.05$). The results for AWMPFD and ED indicated that Makhohlola is much more fragmented than Nwashitshumbe (Table 4). Although, basalt region (Makhohlola) is situated on rich soils associated with high plant growth. However, high plant growth is associated with high fuel load resulting in high fire intensity. High numbers of herbivores and high fire frequency on the basaltic region may further influence woody vegetation patches on the basalt region. Although the findings were on a small scale due to limited resources and photo availability, however, it is important to consider these findings as they provide an insight into the dynamics of woody vegetation patches in Kruger National Park.

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thank my mother, though she was far away but the principles of life she taught me, sustained me during this journey when things were tough. Finally yet importantly I really want to thank God for taking me this far.

Glory be to God

Dedication

I dedicate this thesis to my mother, who has been there for me from my young age until now. She taught me how to persevere, to be patient, to work hard, to be determined in everything I do and above all to be disciplined towards my goals.

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Chapter 1.0 Introduction

1.1 The background of the research

Sub-Sahara savannas are characterised by continuous grass cover and a discontinuous layer of trees and shrubs (van Langeveld *et al*. 2003). The occurrence of grass and trees/shrubs depends primarily on factors such as rainfall, physical soil characteristics and the position of the landscape (Scholes and Archer 1997). Although the mean annual rainfall, type of species and soil type (availability of nutrients) in savanna can limit the growth of woody vegetation, other factors such as fire and herbivores such as elephants, giraffe and black rhinoceros may further reduce the growth of woody vegetation (Bucini and Hanan 2007, Van Wilgen 2009; Trollope *et al.* 1998). Fire and browsers, specifically elephants (*Loxodonta africana*), influences the growth and persistence of woody vegetation patches due to severe burning, consumption and knocking down trees (Bucinni and Hanan 2007; Baxter and Getz 2005; White and Jentsch 1991). Therefore, temporal and spatial variations of woody vegetation patches in the savanna landscape can be attributed to fire and herbivores (Trollope *et al*. 1998; Kutsch *et al*. 2008; van Langeveld *et al* 2003). Intense elephant browsing and burning influence the ecological dynamics of savanna ecosystems (Staver *et al*. 2009), and can lead to changes in woody vegetation patches (Ben-Shahar 1996).

In Kruger National Park (KNP), long-term studies have shown that changes in woody vegetation patches are due to fire and increase in elephant population density (Trollope *et al*. 1998; Eckhardt *et al*. 2000; van Wilgen *et al.* 2004). The long-term analysis of changes of woody vegetation cover in KNP between 1940 and 1998 has indicated an increase of trees/shrub by 12% on the park's granite soil but decrease by 64% in basalt soils (Eckhardt *et al.* 2000). Overall, there was a decrease in large trees on both granite and basalt during the

1940 to 1998 period (Trollope *et al.* 1998; Eckhardt *et al.* 2000). The current management regime in KNP allows maintenance of biodiversity in all natural facets and fluxes, but the main concern is the loss of large trees due to frequent fires and the increase in the elephant density (Eckhardt *et al.* 2000; Debuse *et al.* 2007; Schmiegelow and Monkkonen 2002; Rutledge 2003; Bucinni and Hanan 2007; van Wilgen *et al* 2004). Therefore, conservation management can be more efficient by understanding the dynamics of woody patches, since woody vegetation patches are critical for the survival of animal species (Knight 1987).

1.2 Rationale

The influence of fire and elephants may lead to decline of woody vegetation, and resulting in fragmentation of woody patches (Bond and van Wilgen 1996). Fragmentation is the breaking down of large woody vegetation patches into smaller patches (Rutledge 2003). Fragmentation of woody vegetation patches reduces patch shape, connectivity and size of patches, and causes an increase in the number of patches (Debuse *et al*. 2007; McGarigal and Mark 1995; Bender *et al.* 1998). Reduced patch size due to fragmentation can lead to limited availability of food resources, loss of habitat and reduced connectivity; and eventually this may result in the decline of the species depending on these patches as their habitat e.g. birds (Baxter and Getz 2005). Fragmentation of woody vegetation can lead to an increase in grass biomass, thus more resources for grazers, and more fuel load, which makes fire more intense causing more damaging to trees (van Langevelde *et al.* 2003).

Reduction in trees/shrubs in savannah may have a negative impact on the forage quality. Grasses that grows under tree canopies are characterised by favourable more leaf/stem ratio, higher protein and lower fibre concentrations than grasses from the open field (Ludwig *et al*. 2008). In Tarangire National Park, the loss woody vegetation found to have an influence on the forage quality hence the survival of herbivores such as wildebeest (Ludwig

et al. 2008). In addition, fragmentation of woody vegetation patches may lead to reduction in patch area and isolation of patches. Isolation of woody vegetation patches can cause disruption of species social structures such as mating patterns (Rutledge 2003). Isolation of woody vegetation patches can be more influential on populations of smaller, less vagile species such as insects e.g. ants, because their dispersal distances is very low therefore changes landscape structure can exert a strong influence on the population structure of ants (Debuse *et al*. 2007). The changes in woody vegetation patch structure often alter habitat suitability for animal species, especially for birds, suitable nesting area can be disrupted/destroyed (Rutledge 2003). Apart from fragmentation of woody vegetation patches, the loss of large trees may lead to bush encroachment (van Langeveld *et al*. 2003).

Monitoring of woody vegetation patches is therefore important to understand the dynamics of both animal and plant species. In addition, an understanding of how woody vegetation patches change and the extent of these changes, helps to evaluate the influence of changes in woody vegetation patches on ecological processes (Apan *et al*. 2002). Monitoring of landscape structure over time will provide information on how woody vegetation structure is changing and the information can help to implement correct measures against woody vegetation fragmentation (Gillson and Duffin 2007). This information may also help when adjusting Thresholds of Potential Concern (TPCs) and reviewing the South African National Parks (SANParks) policy on the management of elephants and fire. Therefore, it is fundamental for conservation managers to understand the relationship between factors that cause changes in spatial patterns and ecological dynamics for effective maintenance of biodiversity (Rutledge 2003; Bucini *et al*. 2009).

In KNP, utilisation of woody vegetation especially by elephants by means of debarking and push over, can compromise large trees such that trees, which are usually immune to fire and make them more susceptible fire damage (van Wilgen et al. 2008).

Therefore, as the pressure on woody vegetation, structure continues to increase due to high elephant population density and use of fire, the spatial pattern of woody vegetation patches in KNP remains one of the major areas to be explored. However, few studies have been done on assessment of woody vegetation patches in KNP, using landscape metrics (Simpson *et al.* 1994; Asner *et al.* 2009). In addition, there is little information on how woody vegetation patches have been changing in KNP over time. Therefore, quantitative assessment of the spatial structure of woody vegetation may help ecologists to understand possible challenges threatening the ecosystem (Southworth *et al.* 2002; Riitters *et al.* 2000; Griffiths and Mather 2000), and may help for efficient resource utilisation and conservation management (Apan *et al.* 2002).

Remote sensing and geographic information systems (GIS) are the most effective tools to map and monitor land cover at regional or local scale (Skidmore *et al.* 1997). However, the present study focuses on integration of remote sensing techniques in assessing spatial changes of woody patches inside and outside of the two exclosures, Nwashitshumbe and Makhohlola. Makhohlola is located in the southern area of KNP, on basaltic soils. Nwashitshumbe is situated in the northern area of KNP and is underlaid by granitic soils. Exclosures excludes herbivores from the access the inside of the exclosures, thereby isolating the effects of fire from herbivores, allowing for the assessment of the effects of fire (inside the exclosure) and the effects of fire and herbivores (outside the exclosure) on woody vegetation. Therefore, exclosures are useful to determine the effects of fire separately from the effects of herbivory on tree structure and spatial pattern. Makhohlola and Nwashitsumbe provide an opportunity to assess changes of woody vegetation on basaltic and granitic soils (Venter *et al.* 2003). The results of this research will help to inform the management choices for KNP and many other reserves.

The main aim of this study was to assess the changes of spatial patterns of woody vegetation patches in Kruger National Park over time (1971–2010). The objectives of this study were:

To determine the changes in configuration, complexity and composition of woody vegetation patches inside and outside the exclosures using landscape metrics; and

To evaluate the changes of woody vegetation of patches in basaltic (Makhohlola) and granitic (Nwashitshumbe) soils.

The change in the spatial pattern of woody vegetation patches was determined using size or number of patches (composition), shape (complexity) and connectivity (configuration) of these patches (Apan *et al.* 2002). In this study, landscape metrics are used to measure and quantify the spatial woody vegetation patterns of the landscape in KNP. A number of landscape metrics were used including the number of patches (NUMP), edge density (ED), area weighted mean patch fractal density (AWMPFD), mean patch size (MPS), mean nearest neighbour (MNN) and mean shape index (MSI), to quantify the spatial landscape structure for inside and outside of the exclosures (Botequilha Leitao and Ahern 2001). The landscape metrics were derived from aerial photographs (1971, 1977, 1987, 2004 and 2008 for Nwashitsumbe; 1984, 1997, 2003, and 2010 for Makhohlola) using Patch Analyst 4. Woody vegetation patches were measured according to the landscape metrics and the differences within years, between the inside and outside, and between the exclosures (Makhohlola and Nwashitshumbe) were determined.

Chapter 2.0 Literature Review

General Introduction

Several factors influence the fragmentation of woody patches, including fire, elephants, rainfall, and type of species and type of soil (availability of nutrients). In this study, the main factors under consideration are fire and elephants although other factors are being taken into account. Landscape metrics were used to measures the influence of fire and elephants on the landscape structure i.e. to determine the degree to which woody vegetation patches are fragmented.

2.1 Landscape Structure

Savanna is characterised by discontinuous tree cover in a continuous grass under storey (Scholes and Archer 1997). The occurrence of trees in savanna can improve grass production through hydraulic lift, reduced evapotranspiration an increased nutrient availability (Scholes and Archer 1997; Ludwig *et al.* 2004a). Woody vegetation patches in the savanna often increase species diversity by creating low-light microhabitats suitable for colonization by shade-tolerant species such as under storey herbs and grasses (Belsky 1994). In addition, woody plants increase spatial heterogeneity and faunal diversity by providing forage for browsers and shade for small animals during the day. Changes in the distribution and pattern of woody patches would therefore have an influence on herbivore food quality and availability. Increase in woody vegetation patches improves productivity of savanna, as they can improve fertility, structure of soils below tree crowns and improved water relations of shaded plants, thereby creating a good environment for shade tolerant species (Belsky 1994). Therefore, woody vegetation increases the spatial heterogeneity in the savanna landscape structure.

Landscape structure can be defined as a heterogeneous area, which comprises different patches (McGarigal and Marks 1995). In other words, it refers to the physical distribution, configuration and interaction of patches within a landscape. Landscape structure determines how the patches interact with other patches on the landscape and controls the movement of materials, energy and animal species in and out of the landscape (McGarigal and Marks 1995). Various components of landscape structure include the physical and biological ecosystems that interact in different ways (Forman and Gordon 1986; Apan *et al.* 2002). Patches are distinctive elements of the landscape structure (Apan *et al*. 2002; Urban *et al*. 1987). Therefore, changes in the landscape structure can be measured by the dynamics of patches over time (Debuse *et al.* 2007). However, changes in landscape structure can be determined by the size or number of patches (composition), shape (complexity) and connectivity (configuration) of these patches (Apan *et al*. 2002).

Composition of the landscape indicates the variety (size) and abundance (number of patches) of patches occupying the landscape (McGarigal and Marks 1995). Landscape composition indicates the extent to which the landscape has been fragmented (Rutledge 2003). Many ecological processes in a landscape structure are determined by landscape composition (McGarigal and Marks 1995). Compositional structure of woody vegetation influences the abundance of species that depend on woody vegetation (McGarigal and Marks 1995; Senft *et al.* 1987).

Complexity refers to the irregularity and the shape of patches (Moser *et al*. 2002). The complexity of patches can be described as simple (regular) and complex (irregular) (McGarigal and Marks 1995). Irregular patches have interior to edge ratio than regular patches (Apan *et al.* 2002). Population density of particular species that can survive in a patch may be influenced by the size of the patch (Lavers and Haines-Young 1993). The shape of a patch determines the movement of animals and the distribution of plants in a landscape

(Forman and Gordon 1986). Complexity of woody patches helps to evaluate the ecological processes of the ecosystem (Moser *et al.* 2002).

Configuration of the landscape can be described as the physical distribution of woody patches and the relationship of these patches within a landscape (McGarigal and Marks 1995). Landscape configuration measures the degree of clumping of patches relative to the focal patch, indicating the degree of connectivity between patches and the ultimate distribution of patches across the landscape (McGarigal and Marks 1994; Rutledge 2003). The interaction between complexity and the configuration of patches influence processes in the ecosystem such as resource utilisation, and dispersal and specie richness for both animals and plants (McGarigal and Marks 1995; Apan *et al*. 2002).

This study focuses on the spatial relationship and changes of woody vegetation patches at a fine temporal and spatial scale (micro-scale). The spatial scale of an image involves grain and extent. Grain can be defined as the resolution of the data or area represented by each data unit to be assessed (Turner *et al.* 1989). Fine-grain images would have information organized in 1ha units whilst coarser-grain data are organized in 10ha units (Turner *et al.* 1989). Extent represents the size of the study area (Turner *et al.* 1989).

2.2 Landscape Metrics

Landscape metrics act as quantitative tools that are used to interpret spatial patterns of the landscape (Herold and Menz 2001, Blaschke and Petch 1999). Landscape metrics can be used to describe the composition, configuration and complexity of the landscape and can be useful to attain ecological landscape structure knowledge into planning and for supporting decision making (Pixova and Sklenicka 2006; McGarigal and Marks 1995). Therefore, landscape metrics are used to measure the changes in the landscape structure, biodiversity and disintegration of habitat (Dunn *et al*. 1991).

In this study, landscape metrics were used to describe the changes in composition, configuration and complexity of woody vegetation patches. Woody vegetation patch is contiguous/ closed-canopy area covered by trees. Woody vegetation patches improves productivity of savanna, as they can improve fertility, structure of soils below tree crowns and improved water relations of shaded plants, thereby creating a good environment for shade tolerant species (Belsky 1994). Therefore, woody vegetation patches increases the spatial heterogeneity in the savanna community. Landscape metrics were used to quantify the spatial relationship among woody vegetation patches (McGarigal and Marks 1995). Two groups of landscape metrics were used and these are non-spatial and spatial. Non-spatial landscape metrics quantify the composition structure of the landscape and spatial metrics were used to quantify patch attributes and landscape fragmentation (Rutledge 2003).

2.3 Fragmentation of woody vegetation

Kruger National Park is characterised by continuous grass cover and a discontinuous layer of wood vegetation (van Langeveld *et al.* 2003). Fragmentation of woody vegetation patches is a very complex process and it changes with time (Rutledge 2003), but in some areas bush encroachment has been reported due to the loss of large trees leads (van Langeveld *et al* 2003). Woody vegetation fragmentation influences the size, shape and degree of connectivity of woody vegetation patches (Turner 1998; Rutledge 2003). Shape, size and connectivity of woody patches determine the number of species that can be supported by the landscape (Debinski and Holt 2000). Fragmentation reduces patches into smaller units leading to a possible reduction in species density that can be sustained by these patches e.g. birds (Bender et al. 1998). Reduced patch size can lead to limited food resources, fragmentation of habitat and disruption of socially structure of birds (Baxter and Getz 2005; Bender *et al.* 1998). The change in woody vegetation patches therefore will influence the amount of resources available to animals because fragmentation changes the flow of

propagules and nutrients (Rutledge 2003*).* Isolation of woody vegetation patches can be more influential on populations of smaller, less vagile species such as insects e.g. ants, because their dispersal distances is very low (Debuse et al. 2007).

Seed production, germination rate and the survival of trees may be affected by fragmentation of woody vegetation patches (Rutledge 2003). Fragmentation of woody vegetation patches reduces patch size, increasing the distance between plant species causing reduction in reproductive success, and making species vulnerable to disturbances reducing chances for germination and survival (Rutledge 2003). Fragmentation of woody vegetation patches may lead to changes of the micro-habitat conditions of the landscape (Belsky and Canham 1994), due to decreased woody vegetation cover. The decrease in woody vegetation cover may lead to the increased change of abiotic conditions that favours shade tolerant species (Rutledge 2003; Belsky and Canham 1994). The change in abiotic conditions leads to a change in the woody composition, as shade tolerant species are restricted (Rutledge 2003; Ludwig et al. 2008), because seed production, germination and seed survival is affected. Shade tolerant species can improve the savanna community structure. It is therefore important to understand the factors that influence the fragmentation of woody vegetation patches for sound management of the park (Bucini *et al*. 2009).

2.4 Factors affecting woody vegetation fragmentation

2.4.1 Elephants

Elephants (*Loxodonta africana*) are one of the major herbivores that reduce woody plant survival through knocking down, feeding and debarking of trees, leading to the regional extinction of certain species thereby compromising management efforts by conservation workers (de Beer *et al*. 2006; Chira and Kinyamario 2009). High utilization of vegetation by elephants has a major influence on tree density due to their destructive foraging behaviour

and also their observed effects such as knocking down and debarking adult trees (Owen-Smith 1988; Holdo 2003). The influence of elephants on woody vegetation tends to vary with population density of the elephants. In addition, high elephant densities may induce a decline of some plant species as they cannot recover even if the elephant population density decreases leading to extinction of some woody vegetation species. High elephant densities may result in the total destruction of species and habitats, thereby reducing the diversity of species that rely on those habitats (Cumming *et al.* 1997; Lombard *et al.* 2001; Botes *et al.* 2006).

Elephants are mixed feeders; they feed on both grass and trees. Elephants feed on grass during the rainy season and consume leaves and branches in the dry season. When browsing elephants eat branch tips, barks, fruits, bulb or roots of trees, sometimes they just uproot trees without feeding on them, and this can lead to death and loss of woody vegetation (Holdo 2003; Owen-Smith 1988). General feeding impacts of elephants include braking of branches and trunks and stripping of bark causing severe damage to woody plants, thus reducing their competitiveness (Holdo 2003; Lombard *et al*. 2003; O'Connor *et al*. 2007). Utilisation of woody vegetation by elephants can also result in changes in the tree/grass balance (Holdo 2003; Frost *et al.* 1986).

The influence of elephants is increased by confinement, which can increase local elephant population density due to limited dispersal (White and Goodman 2009; Guldemond and van Aarde 2008). In a confined area, the seasonal movement of elephants is restricted by fences and this may result in prolonged and increased feeding impacts within the boundaries (White and Goodman 2009; Guldemond and van Aarde 2008). Although elephants and giraffe act as primary drivers of woodland changes, the effects of fire (Holdo 2007) can increase the influence of especially elephants on woody vegetation. The effects of the

combination of elephants and fire on woody vegetation also depend on the intensity of grazing by herbivores (Staver *et al*. 2004).

2.4.2 Fire

Fire is known to be one of the major influences that affect a savanna ecosystem (Eckhardt *et al*. 2000; Hoffmann *et al*. 2009). Fire affects woody vegetation biomass, composition and structure (Sims *et al.* 2009). The main influence of fire on woody vegetation is burning and reduces canopy cover (Bailey 1988). Burning of trees in savanna further reduces canopy cover, affecting recruitment of young trees into higher size classes (Bond *et al.* 2005). Fire shapes the savanna woody structure and heterogeneity (Bond *et al*. 2005; Eckhardt *et al*. 2000; Hoffmann *et al*. 2009). The influence of fire on trees depends upon the height of the tree and fire intensity. Fire is responsible for influencing trees that are short (less than three metres in height) and have thin bark and trees taller than about three metres in height can be considered to have escaped the fire trap (Bond and van Wilgen 1996).

The influence of fire depends upon fire intensity, frequency and season. Variations in fire intensity are due to different rainfall amounts, soil fertility, herbivory, season and weather conditions at which the fire is set (van Wilgen *et al.* 2004). The intensity of fire increases when there is high rainfall and low grazing intensity through allowing accumulation of high fuel loads (Leuthold 1996; Gignoux *et al*. 1997). Heavy grazing by other herbivores can contribute to less frequent and less intense fires due to reduced grass fuel loads. High grazing rates reduces grass fuel load thereby resulting in an increase in woody vegetation (bush encroachment) due to less frequent and intense fires, and less competition from grass (Archibald *et al.* 2005; Manier and Hobbs 2006). Less frequent fires give rise to the thickening of woody plants and this allows young plants to quickly escape the fire zone (Scholes and Archer 1997). However, short burning intervals restrict re-sprouts from reaching a fire-resistant size (Hoffmann *et al*. 2009), and frequency of fire influences the

possibility of young trees escaping the fire zone and becoming adult trees (Bucini and Hanan 2007).

The intensity of fire may vary, thus the influence of fire on the vegetation may be different from time to time (van Wilgen *et al*. 2004). Several fire management regimes have been employed in KNP for the past several decades. Burning blocks were established between 1957 and 1980 and burning was done after three years in each block. During 1981 and 1991 burning was done depending on the fuel load, rainfall and post fire age of the plants (van Wilgen *et al*. 2004). Natural fire policy was adopted between 1992 and 2001 and natural fire policy allowed lightning-ignited fires to burn and human lit fires were suppressed (van Wilgen 2009). From 2002 wildfires and point ignition fire are allowed where fire is necessary (van Wilgen 2009).

The effects of fire alone are minimal but when combined with reduced reproduction and a lack of recruitment into mature stages, the effects of fire may lead to the reduction in tree density (Hoffmann 1999). The combination of fire and browsing has more influence on survival of mature trees (Bond and van Wilgen 1996), and decreases the recruitment rate of trees causing an overall decline in the number of trees (Barnes 2001). Browsing by elephants (and other mega herbivores) keeps trees short and in the "fire trap" for longer, so prevents recruitment of trees into adult size classes (Holdo 2003). In addition, damage to the bark of large trees by elephants can make even large trees (which are usually considered immune to fire) susceptible to fire, and can even kill them (Holdo 2003; Barnes 2001).

2.4.3. Soil type, Rainfall and Landscape

Several factors influence the survival of trees, including rainfall, landscape structure, water distribution and soil type (Sankaran *et al*, 2005). Soil type and climatic conditions often affect recruitment of trees after disturbances from herbivory and fire (Ihwagi *et al.* 2010). The

influence of browsing and fire on woody vegetation depends on seasons, whereby in dry season, much of the browsing and fire influences are experienced. Seasons usually influence debarking, with low rates of debarking being recorded in wet months especially between November and December where alternative food and water sources are available (Ihwagi *et al.* 2010). Debarking of plants by elephants correlates with the level of nutrients in the tree bark (Ihwagi *et al,* 2010). Environmental factors such as drought, low rainfall, floods, high temperatures and disease can increase the influence of fire and elephants on woody vegetation. Trees that are subject to damage, disease or insects may suffer increased mortality when exposed to factors such as fire and herbivory (Franklin *et al*. 1987).

Nutrients and moisture content are associated with the soil type. Granite-derived soils have less nutrient content than loamy soils derived from basalt. In granite-derived soils, moisture percolates through the soil particles more easily than in the loamy and basalt-derived soils. Soil type is the most important factor that affects the interactive influence of fire and elephants on the survival of trees (Trollope *et al*. 1998). Some soils promote the shrub-like trees, which are not stable woodlands, and some soils promote the growth of large trees (Lewis 1991). In addition, soil resources determine the growth rate of resprouting trees and influences the time needed for a plant to reach a fire resistant size (Hoffmann *et al*. 2009). The amounts of moisture content and nutrients in the soil influence the growth rates of trees and determine the competitive interaction between trees and grasses in savanna (Staver *et al.* 2009). A high soil nutrient pool favors high growth rates and plants can quickly grow into mature trees. In addition, high soil nutrient can lead to an increase in grass biomass, yielding to fuel load, thus more intense and frequent fires hence more damage to trees, and this may result in an reduced in woody vegetation (van Langevelde *et al.* 2003).

Drainage patterns are one of the dominant factors that influences tree height, woody canopy cover and the influence of drainage patterns are controlled primarily by rainfall, and

species composition (Opdam *et al.* 1995). Drainage patterns are related to elevation, soil type and drainage (landscape structure). Landscape structure and rainfall gradients do appear to be the principal environmental controls on vegetation composition and structure (Opdam *et al*. 1995). Plant species diversity and composition also vary with changes in the parameters of landscape structure (Hernandez-Stefanoni 2008). The influence of landscape structure on plant species diversity is related to distance between sources and sites for colonisation as well as seed type and dispersal agents (Ingrid *et al.* 2000). The landscape patterns may control the ecological processes that shape plant species diversity and composition of the forest (Galanes and Thomlinson 2009). Landscape variation may result in significant spatial variations in plant community structure (Archer *et al*. 1988).

2.4.4 Woody plant species

The response of plant species to the effects of elephants and fire can be difficult to interpret due to other influences such as drought, diseases, other herbivores (like the rhinoceros) and trampling (Gillson and Lindsay 2003; Skarpe *et al*. 2004; Wiseman *et al.* 2004). The response of plants to browsing and fire depend on plant type, tolerance, intensity and frequency of defoliation due to fire, plant developmental stage at the time of the impacts, plant parts affected, stem diameter, time between fire intervals, growth rate of the plant and environmental factors before and after the impacts **(**Bergström 1992). Higher growth rates in plants reduce the susceptibility of plants to the fire trap thereby enhancing the ability of plants to recruit into the adult stage (Hoffmann *et al*. 2009). The survival of plants after being exposed to browsing and fire effects also depends upon the landscape features (O'Connor *et al*. 2007). Landscape features such as riparian areas, rocky features, ridges and ridge tops can influence the survival of woody species by acting as spatial refuges for plants (Abrams and McCay 1996).

The survival of woody plants depends upon the ability of those plants to coppice after felling or after disturbances. The extent to which trees are knocked down by elephants depends upon the strength of the trunk and the depth and strength of the root system (O'Connor *et al*. 2007). In addition, the degree of the effects of debarking depends upon the extent to which the bark has been stripped. Ring barking may result in the death of the plant if the phloem is damaged. However, the effects of bark stripping on multi-stemmed plant species due to elephants is very low even if bark stripping increases the chances of insect and fungal infection, rot and fire (Kerley *et al*. 2008).

Some plant species contain toxins in their bark and these may reduce levels of bark stripping (Kerley *et al*. 2008). Individual trees depend upon certain strategies for their survival (Gignoux *et al*. 1997). There are two main strategies that enable trees to withstand the influence of fire and these are rebuild and resprout versus stay and restrict (Menaut and Cesar 1979). Plants that survive from below-ground structures (starch stored in the roots) quickly rebuild above-ground structures and young plants survive by resprouting each year (Menaut and Cesar 1979; Staver *et al.* 2009). Young shoots will be successfully recruited into mature trees if the below ground structures are strong enough to produce a fire-resistant perennial trunk and high growth rate (Menaut and Cesar 1979).

Root reserves are important for sustaining resprouting especially before the plant has developed sufficient leaf area to sustain its growth (Hoffmann *et al*. 2009). Adult savanna trees also survive from fires through adaptation such as thick bark and high resprouting ability (Gignoux *et al*. 1997). Plants with thicker bark incur lower rates of top-killing than those with thin bark and trees with long bare trunks and thick bark tend to escape defoliation by fire (Hoffmann *et al*. 2009). Due to the suppressing effects of fire on the growth of trees, more trees can grow into mature trees in years without fire than in years with fire (Staver *et al*. 2009).

Normally the ability to resprout and regrow is taxon-specific. Persistence of plant species after utilization by elephants depends on the relative capacity of the plant species to restrict and compensate for the damage inflicted. For example, the growth rate and persistence of *Dichrostachys cinerea* is believed to be stimulated by utilization by elephants (Levick and Rogers 2008). On the other hand *Dalbergia melanoxylon* and *Albizia harveyi* appeared not to be affected whilst *Horsfieldia coriacea* and *Colophospermum mopane* are affected but can persist, and *Combretum imberbe, Combretum hereroense* and *Lannea schweinfurthii* appeared to be more affected by browsing (Levick and Rogers 2008).

Chapter 3.0 Materials and Methods

3.1 Site

Kruger National Park (1 948 528 ha) is located in the north-eastern part of South Africa (24.0110° S, 31.4850° E) and has a mean annual rainfall of about 350mm in the north and 750mm in the south. Similarly, rainfall ranges from 300 – 500mm in the east and 500 – 700mm in the west (van Wilgen *et al.* 2000). Average temperatures in KNP range from a minimum temperature of 9^0C during the night to maximum temperature above 32^0C during the day. The park is characterised by different soil types in which the west part is underlain by granitic soils and the eastern is predominantly basaltic soils (Venter *et al.* 2003). KNP consist of gabbro intrusions that are scattered throughout the park (Colgan *et al*. 2012). The gabbro intrusions weather into clay rich soils, which are rich in nutrients (Colgan *et al*. 2012). Six perennial rivers, Olifants, Limpopo, Crocodile, Luvhuvhu, Letaba and Sabie run from west to east supplying the park with rainfall water (Ekhardt *et al*. 2000).

Vegetation in Kruger National Park is about 20 – 30% tree cover although the distribution varies with the soil type (Eckhardt *et al*. 2000). Kruger National Park contains several plants species and these include about 400 tree and 220 grass species (Eckhardt *et al*. 2000). Marula (*Sclerocarya birrea*) and red bushwillow (*Combretum apiculatum*) dominate the south-western region. The south-eastern region is largely occupied by grass and trees mostly marula *(Sclerocarya birrea)* and leadwood (*Combretum imberbe*) (Eckhardt *et al*. 2000). The north-western granitic region is characterised by less grass cover and largely mopane (*Colophospermum mopane*) and the northern eastern region is dominated by mopane trees (Eckhardt *et al*. 2000). There are 148 species of mammals in KNP (Eckhardt *et al*. 2000) and large mammals are mainly elephants (*Loxodonta africana)*, white rhinoceros (*Ceratotherium simum*), and hippopotamus (*Hippopotamus amphibius*).

The study will involve the use of two long-term exclosures in KNP, Makhohlola (3.6 ha) and Nwashitshumbe (230 ha). Makhohlola was constructed in 1974 and Nwashitshumbe was constructed in 1967 (Trollope *et al*. 1998). The two exclosures provide an opportunity to assess the effects of fire (inside the exclosure) by keeping out animals and the effects of fire and herbivores (outside the exclosure) on woody vegetation separately. Inside of the exclosure is characterised by an increase in both grass and tree due to less disturbances, yielding to fuel load, thus more fire intensity (Levick and Rogers 2008). The two exclosures are situated on different geologic formations (granite and basalt) characterised by same rainfall patterns. The granitic and basaltic soils allow the assessment of the difference in woody vegetation patches between these two geologic locations. Although the two exclosures (Makhohlola and Nwashitshumbe) are situated on different soil types, receive same rainfall and consist of different vegetation, during the comparison all the differences between the two exclosures were considered.

Makhohlola is situated on basaltic soil and is characterized by rainfall of about 450mm per year, and Nwashitsumbe is underlaid by granitic soils with rainfall of about 425mm per year. Species of *Acacia* and big marula (*Sclerocarya birrea*) dominate Makhohlola region and Nwashitshumbe region is largely characterised by *Colophospermum mopane* (Colgan *et al*. 2012). Two other study sites outside the exclosures were identified and used for comparison. These study sites (inside and outside of the exclosure) had the same soil type, rainfall, landscape or catena. The plots inside and outside the exclosures give an opportunity to study the effects of fire (inside the exclosure) and the effects of fire and elephants (outside the exclosure) on woody vegetation structure. The figure below shows the location of the two exclosures in KNP.

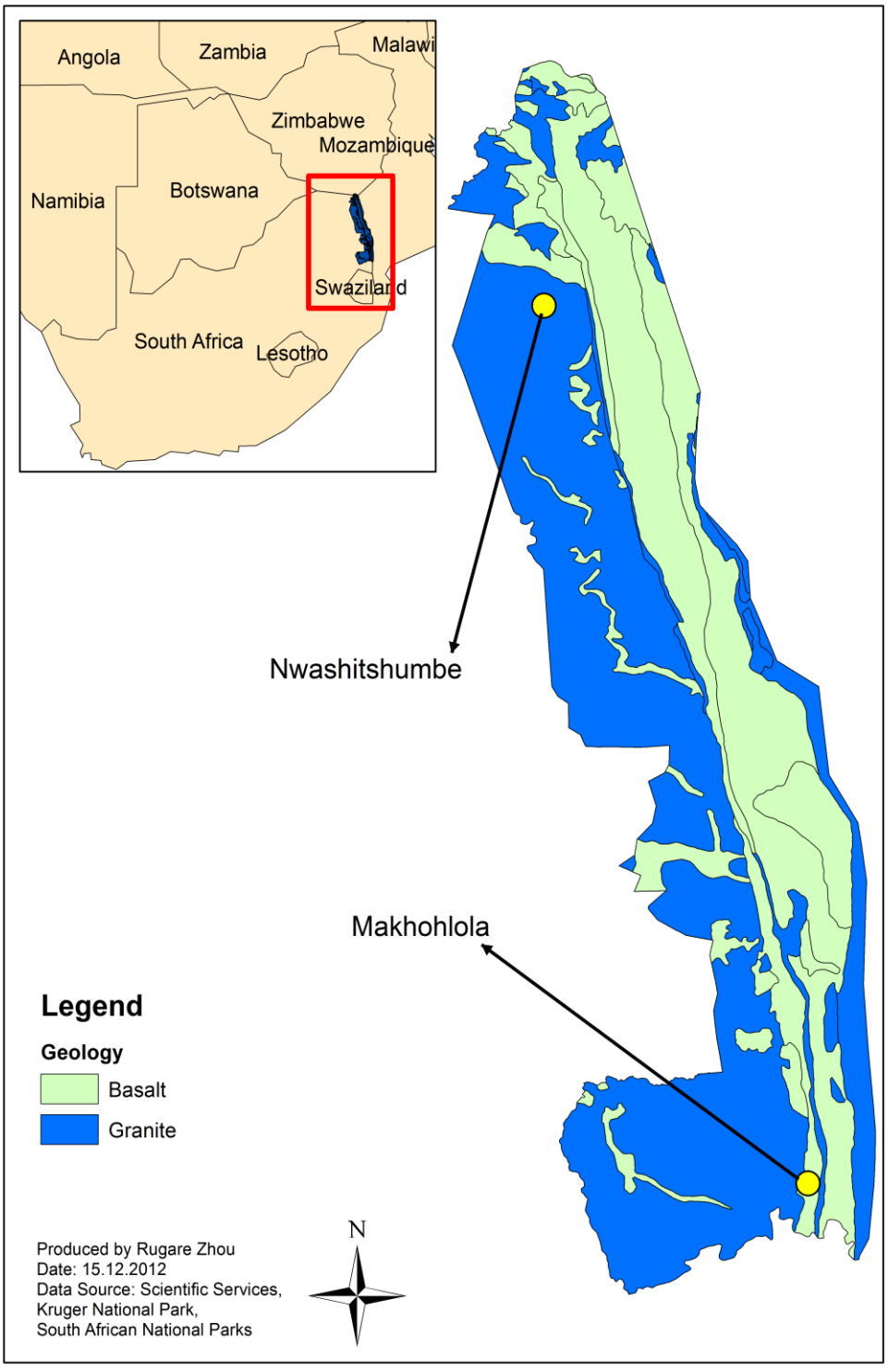


Figure 1: Study area, Kruger National Park (1 948 528 ha), showing the location of Makhohlola (3.6 ha) and Nwashitshumbe (230 ha) exclosures. Makhohlola (basalt) is situated in the Southern part and Nwashitshumbe (granite) located in the northern part of Kruger National Park (two sites have similar rainfall).

3.2 Materials and Software Used

3.2.1 Aerial photographs

The aerial photographs were obtained from National Geo-spatial Information in South Africa. Nine aerial photographs were obtained (1971, 1977, 1987, 2004 and 2008) for Nwashitshumbe and (1984, 1997, 2003, and 2010) for Makhohlola, were used to assess changes of woody vegetation patches cover time. Aerial photographs were obtained from same sites from 1971 – 2010 for both Makhohlola and Nwashitshumbe. Geographical information systems (GIS) technology was used to analyse and interpret aerial photographs (McGarigal and Marks 1995). Most of the aerial photographs were taken during the dry season (Table 1).

Table 1: List of aerial photographs that were used in this study

Area	Year	Date
Nwashitshumbe	1971	17/08/1971
	1977	29/07/1977
	1887	17/06/1987
	2004	24/07/2004
	2008	29/11/2008
Makhohlola	1984	29/07/1984
	1997	14/08/1997
	2003	17/08/2003
	2010	31/08/2010

3.2.2 Image processing

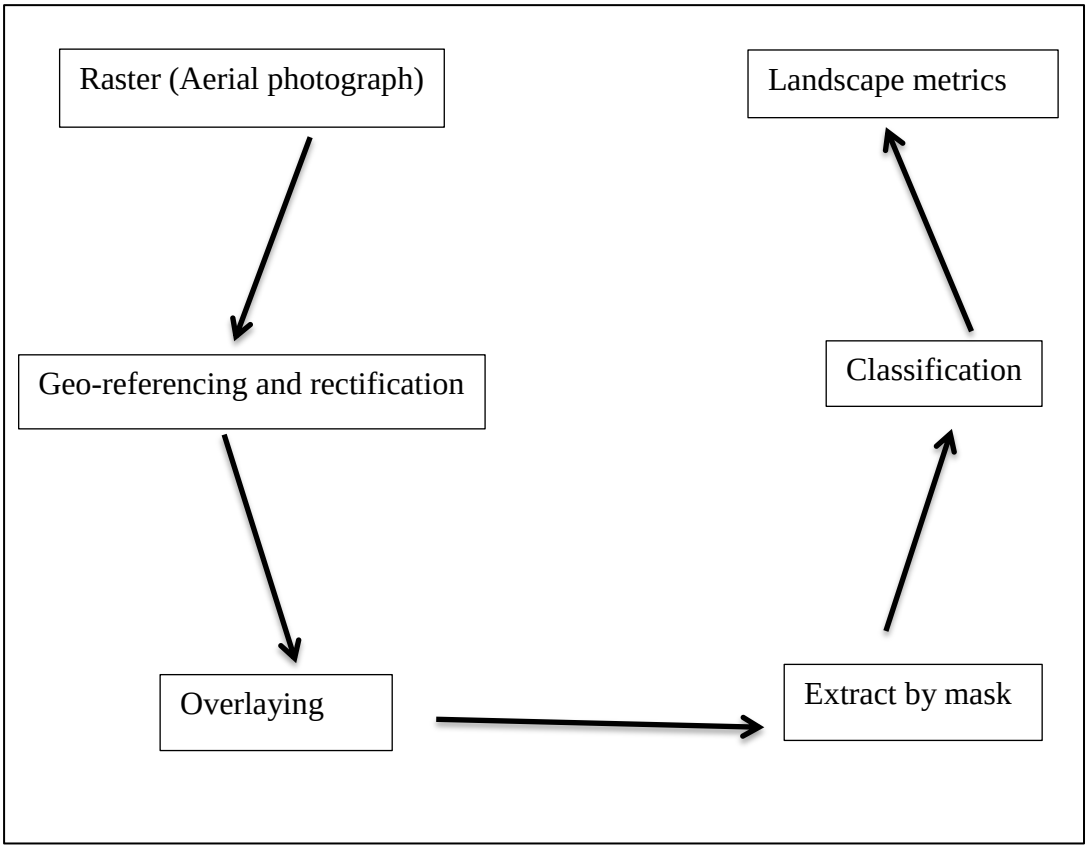


Figure 2: Flow chart showing all steps involved in processing aerial photographs

The ESRI ArcMap 9.3.1 was used to process the aerial photographs. The aerial photographs were referenced using the UTM reference system. Geo-rectification was carried out using the nearest neighbour resampling algorithm and the root-mean- square (RMS) error of less than 0.5 pixels. The RMS was kept as low as possible (less than 0.5) to increase accuracy of the transformation. The nearest neighbour resampling, is one of the fastest re-sampling techniques and does not alter the raster dataset. The rectified photographs (2008 and 2010) served as the basis to rectify other aerial photographs (1971, 1977, 1984, 1987, 1997, 2003 and 2004). Ground Control Points were used to match the coordinates of the reference image to that of the raster using ArcMap 9.3.1. Overlapping was done to verify that the images were correctly geo-referenced.

Polygons were used to mask and extract fixed areas in and out of the exclosures for analysis. The extracted areas were randomly selected from the 1971 (for Nwashitshumbe) and 1984 (for Makhohlola) aerial photographs and polygons of 2.23 ha in size for both the inside and outside of Makhohlola and Nwashitshumbe were extracted. The extracted areas were limited to 2.23 ha because Makhohlola exclosure is small (3.6 ha). In addition, the differences in extent (size) of study area affect the range of values of landscape metrics (Meentemeyer and Box 1987). Since, the extent of the study area influences the landscape metrics values, in this study the size of the study area for both inside and outside of the exclosures was maintained at 2.23 ha and across years. The technique of this research is to assess long-term changes of woody vegetation patches on fixed areas.

The extracted areas were classified into two patch types or classes (covered and bare). Unsupervised classification was used to group objects based on the observable features or spectral reflectance characteristics. Unsupervised classification organises data into specified classes (or clusters) and each class contains objects with the same features or spectrally homogenous. Two categories (classes) were obtained, the covered category represented the woody vegetation patches and bare category represented non-woody vegetation patches such as grass, bare ground and others (Fig. 2). Classification helps to identify vegetation distribution. The classified areas were then run on Patch Analyst 4 (Fragstats 2.0) to compute the landscape metric statistics (Elkie *et al.* 1999). The spatial analysis of this study was done on a small-scale (micro-scale). All the aerial photographs were scanned at a resolution of 300 dot per inch (d.p.i.) except for the 2010 image one pixel is equivalent to 0.5 of 1m.

The figure below shows a reclassified and resampled area for Nwashitshumbe inside.

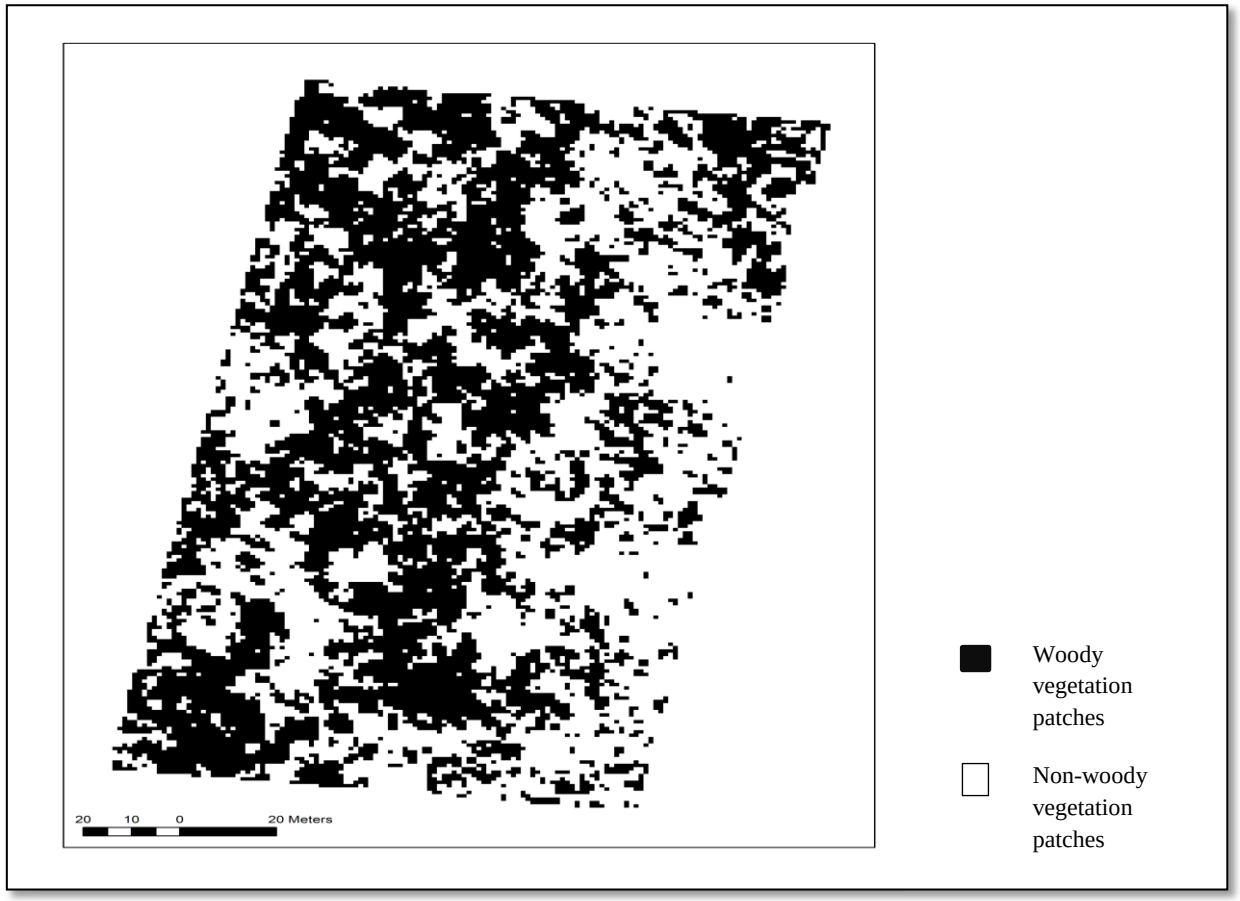


Figure 3: Nwashitshumbe inside, reclassified study area taken in 2004 (total area of 2.23ha, and a resolution of 300 dot per inch)

3.2.2 Patch Analyst 4

Patch analyst 4 is a modified version of FRAGSTATS 2 and consists of analysis and modelling functions (McGarigal and Marks 1995). Patch analyst 4 software was chosen because it can work on both vector and raster data. Patch Analyst 4 is an extension to ArcGIS and was used to compute landscape metrics, namely number of patches, mean patch size, mean shape index, edge density, area weighted mean patch fractal dimension, and mean nearest neighbour (Elkie *et al*. 1999). Landscape metrics were chosen based on their suitability to quantify the spatial structure of woody vegetation (Rutledge 2003; McGarigal and Marks 1995). This study focuses on the measurement of woody vegetation. Patch analysis allows the data to be analysed in three ways i.e. landscape, classes and patches.

Six metrics were considered and these are shown in Table 1 below. Number of patches (NUMP) is one of the landscape metrics that was used to describe the configuration of the woody vegetation patches. Mean patch size (MPS) indicates the average area of each patch in the landscape (McGarigal and Marks 1995).

MPS =

$$\left(\frac{\sum_{i=1}^{m}[ai]}{m}\right)$$

Where a_i = the patch size and m = the total number for *i*th landscape (Tang *et al.* 2005). Area weighted mean patch fractal dimension (AWMPFD) and mean shape index (MSI) measures the irregularity of patches (Hargis *et al*. 1998).

AWMPFD =

$$\sum_{i=1}^{m}\left[\frac{2\ln(0.25pi)}{\ln(ai)}\left(\frac{ai}{A}\right)\right]$$

where m = is the total number for *i*th landscape, p*i* = perimeter, a*i* = area (of each woody vegetation patch) and A*i* = the total area for one landscape class (Tang *et al*. 2005). Mean shape index (MSI) measures the average irregularity of all patches in a class or landscape (McGarigal and Marks 1995).

MSI =

$$\left[\frac{\sum_i^m \frac{pi}{2\sqrt{\pi.ai}}}{m}\right]$$

where P*i* = perimeter, m = the total number for ith landscape and A*i* = area of the *i*th landscape (respectively). Mean nearest neighbour (MNN) measures the distance between neighbouring patches of the same type.

MNN =

$$\left[\frac{\sum_{i=1}^m hi}{m}\right]$$

where h*i* = the distance from each patch to its nearest neighbour, m = the total number for ith landscape (Tang *et al* 2005). MNN measures the configuration of patches in the same class for example woody vegetation class (McGarigal and Marks 1995). MNN cannot be meaningful if the distribution of the patches is complex (McGarigal and Mark, 1995). Edge density (ED) represents the configuration of the landscape (McGarigal and Marks 1995), but it is not spatially explicit.

ED =

$$\frac{Pi}{Ai}$$

where P*i* = perimeter and A*i* = area of the *i*th landscape (respectively). The definitions of landscape metrics used in this study are in the table below.

Table 2: Landscape metrics used to quantify the woody vegetation patches and their definitions

Landscape Metrics	Definitions
NUMP	Total number of patches in each class
MPS	Average patch size for the class in hectares.
ED	Sum of length of all edge segments for the class, divided by the total landscape area.
MSI	Average complexity patch shape for a class
MNN	Average edge to edge distance from a patch to the nearest patch of the same type
AWMPFD	The average complexity and fragmentation of a patch by a perimeter-area proportion

NUMP: Number of Patches; MPS: Mean Patch Size; ED: Edge Density; MSI: Mean Shape Index; MNN: Mean Nearest Neighbour; AWMPFD: Area Weighted Mean Patch Fractal Dimension (Forman 1995; Griffth *et al.* 2000; Riitters *et al.* 1995; and Southworth *et al.* 2002)

The landscape metrics were used to quantify the composition (NUMP and MPS), shape (ED and MSI) and configuration (MNN and AWMPFD) of woody vegetation patches. There are several landscape metrics that can be used to measure the spatial composition;

complexity and configuration of the woody vegetation patches (McGarigal and Marks 1995) (Table 2). Since landscape variability is difficult to summarise using a single metric, two metrics were used to measure each landscape aspect (composition, complexity and configuration).

Table 3: Landscape features measured and landscape metrics used to quantify each landscape feature.

Landscape Feature	Symbol	Measures
Composition	NUMP MPS	The number and the features associated with each patch type
Shape	AWMPFD MSI	Complexity and the fragmentation of the landscape
Configuration	MNN ED	Aggregation and clumpy of the patches in the landscape

3.2.3 Data Analysis

The Fragstats data outputs from Patch Analyst 4 were then export to SAS Enterprise Guide 4.2 and Microsoft excel 2010 for further analysis. Statistical analysis was done to determine the variations of woody patches between the outside and inside of the exclosures, and between the Makhohlola (basalt) and Nwashitshumbe (granite). A generalized linear model (GLM) was fitted to determine the differences between the inside and the outside of the exclosure, and the changes of woody vegetation patches between the basaltic and granitic

regions. SAS Enterprise Guide 4.2 was used to fit the data into GLM. Three factors including enclosed (whether the site has been enclosed or not), site (granite and basalt) and year were considered in models. The three and two way interactions of these factors were dropped since they appeared not important (not significant). The interactions were obtained by crossing the quantitative variables when analysing using SAS Enterprise Guide 4.2. Therefore, effects of year, enclosed and site were considered, as main factors in the model, and the composition, complexity and configuration of woody vegetation patches were the response variables. To determine whether the omission of the interactions will bring about some significance in the model, the parameter estimates were used to determine the extent to which each of the factors (year, enclosed and site), influences each landscape metric and the differences within each factor. Nine aerial photographs were determined from different years for both Makhohlola and Nwashitshumbe, with Makhohlola having four and Nwashitshumbe five years.

Chapter 4.0 Results

4.1 Overall changes in woody vegetation

There was an increase in number of patches for both Makhohlola and Nwashitshumbe, 48.4% and 80.4% respectively (Table 4). Mean patch size decreased with about 54.5% for Nwashitshumbe and 16.7% for Makhohlola (Table 4). Mean shape index for Nwashitshumbe increased by 9.9% whilst there was no change for Makhohlola. There was no change in area weighted mean patch fractal dimension for Nwashitshumbe, and increased by 8.4% for Makhohlola (Table 4). Mean nearest neighbour decreased by 8.3% for Nwashitshumbe and 16.2% for Makhohlola. There was an increase in edge density increased by 26% for Nwashitshumbe and 31.1% for Makhohlola (Table 4).

There was an 88.5% and 66.7% increase in number of patches (NUMP) and a decrease in the mean patch size (MPS) (300% and 42.9%) for Nwashitshumbe inside and outside respectively between 1971 and 2008 (Table 5). Area weighted mean patch fractal dimension (AWMPFD) and mean shape index (MSI) for Nwashitshumbe inside decreased by 0.8% and 5.7% (respectively) and increased by 0.7% and 26.3 % (respectively) for Nwashitshumbe outside (Table 5). Mean nearest neighbour (MNN) decreased by 3.4% and 12.8%, and edge density (ED) increased by 1.6% and 52.6% for both Nwashitshumbe inside and outside respectively (Table 5).

Number of patches (NUMP) for Makhohlola inside increased by 100% whilst the mean patch size decreased by 66.7 % from 1984 to 2010 (Table 5). There was a decrease in number of patches (-6.7%) and an increase of 25% in mean patch size for Makhohlola outside (Table 5). Area weighted mean patch fractal dimension (AWMPFD) for both Makhohlola inside and outside (7.4% and 9.4% respectively), and there was a decrease in MSI for Makhohlola inside by 12.8% and an increase of 12.2% for Makhohlola outside (Table 5).

There was a decrease in MNN by 13% and 19.2%, and an increase in ED by 22.9% and 38.3% for Makhohlola inside and outside respectively (Table 5).

4.2 The trend of woody vegetation changes

4.2.1. Compositional trend

The general linear model was used to assess the relationship between the composition (number of patches and mean patch size) and time. The results suggest that there was no specific linear trend concerning how number of patches vary with time ($t = 1.53$, $p = 0.147$; Fig. 4a, Table 6). Likewise, mean patch size does not follow a linear trend ($t = 0.99$, $p = 0.339$; Fig. 4b, Table 6). The results suggest that number of patches and mean patch size appeared to vary randomly with time. In addition, time has the least contribution to the influence on both number of patches (estimate = 0.47; Table 6) and mean patch size (estimate = -0.001; Table 6). The results suggest, that time has no influence on the abundance and size of woody patches. Time is not an important variable in determining the change in woody patches composition (number of patches and patch size).

4.2.2 Complexity trend

The relationship between the complexity (area weighted mean patch fractal dimension and mean shape index) of woody vegetation patches was determined using the generalised linear model. There was no linear relationship between area weighted mean patch fractal dimension (AWMPFD) and time ($t = 1.14$, $p = 0.275$; Fig. 4c, Table 6). The results for mean shape index (MSI) shows that there was no linear relationship between mean patch size and time ($t = 0.99$, $p = 0.339$; Fig. 4d, Table 6). The parameter estimates of time for both area weighted mean fractal dimension (estimates = 0.001; Table 6) and mean patch index (estimate = 0.003; Table 6) indicated that, time has the least effects complexity of woody

vegetation. The results indicated the shape or complexity of woody vegetation patches does not depend upon time.

4.2.3 Configuration

To consider whether the configuration of woody patches depends on time, a general linear model with additive main effects of time was fitted. The mean nearest neighbour (MNN) appeared not to be following a linear trend over time ($t = 0.99$, $p = 0.339$; Fig. 4e, Table 6). The results indicated that time does not influence mean nearest neighbour of woody patches in Kruger National Park. Furthermore, the estimate for mean nearest neighbour (estimate = -0.034; Table 6) shows that time has minimum influence on mean nearest neighbour. Edge density seems to be highly influenced by time, thus the results showed that edge density followed a specific linear trend ($p = 0.007$; Fig. 4f, Table 6). The results suggest that edge density increases with time, edge density appeared to be higher in the 2000s than in the early 1970s (Fig. 4f). The interpretation suggests that the proportion of each class were becoming more even, proposing an increase in disintegration of woody vegetation patches, leading to increase in edge density.

4.3 The difference between the inside and outside of the exclosure, and basaltic and granitic region

4.3.1 Composition

Generalised linear models were fitted to determine the difference in woody vegetation composition between the inside and the outside of the exclosure, and between the basaltic and the granitic region. The inside of both Makhohlola and Nwashitshumbe exclosures are characterised by a higher number of patches than on the outside (difference = 9.44, standard error (SE) = 7.66; Fig.7a, Table 6), which is associated with a greater degree of fragmentation, although, the difference was not significant ($p = 0.238$; Table, 3). Comparing

the two exclosures, Makhohlola appeared to be more fragmented than Nwashitshumbe because Makhohlola has a higher number of patches than Nwashitshumbe (difference = 2.40, SE = 8.19; Fig. 5a, Table 6). Despite Makhohlola appearing to be more fragmented than Nwashitshumbe, the difference was not significant (p = 0.774; Table 6). In addition, although the differences are not important, but the factor enclosed (estimate = 9.44; Table 6) appeared to be contributing more variation to number of patches than site (estimate = 2.40; Table 6). Broadly, the model in cooperating additive effects of the factors time, enclosed and site exhibited a poor fit (p = 0.248), thus all the factors included in the model, had no influence on number of patches.

Mean patch size for the inside of the exclosures appeared to be slightly less than that for the outside (difference = 0.01, SE = 0.02; Fig. 5a, Table 6), and this suggests that the inside is more fragmented than the outside. However, the overall difference between the mean patch size for the inside and the outside appeared not to be significant (p = 0.339; Table 6). The results suggest that Makhohlola was characterised by higher mean patch size than Nwashitshumbe. Makhohlola has larger woody vegetation patches than Nwashitshumbe, although the difference appeared not significant (p = 0.850; Table 6). The effects of whether the site is enclosed or not on mean patch size appeared to be higher (estimate = 0.02; Table 6) than that of site (estimate = 0.003; Table 6). However, the results of the model suggested that factors included in the model were not significant (p = 0.569; Table 6).

4.3.2 Complexity

The generalised linear model results indicated that the outside of the exclosure was dominated by higher area weighted mean patch fractal dimension (AWMPFD) than the inside (difference = 0.06, SE = 0.03; Fig. 5b, Table 6). These results suggest that the outside consists of patches that are more irregular and the inside is characterised by simple patches, a factor indicating that the inside was more fragmented than the outside. However, the

evidence was weak (p = 0.093; Table 6). Of the two sites Makhohlola consists of less area weighted mean patch fractal dimension, and Makhohlola appeared to be more fragmented than Nwashitshumbe (difference = 0.08, SE = 0.03; Fig. 5b, Table 6). The results shows that area weighted mean patch fractal dimension for Makhohlola and Nwashitshumbe are different (p = 0.033; Table 6). There is evidence that the basaltic region has less area weighted mean patch fractal dimension than granite. The results suggest that Makhohlola has simple shaped woody vegetation patches and Nwashitshumbe has patches that are more irregular. Furthermore, the results suggested that site (estimate = 0.078; Table 6) has higher influence on the area weighted mean patch fractal dimension than enclosed (estimate = 0.05; Table 6). Therefore, the variations in area weighted mean patch fractal dimension were due to different sites.

The inside of both Makhohlola and Nwashitsumbe has lower mean shape index (MSI) than the outside of both exclosures. Low mean shape index is associated with simple patches indicating that the inside was more fragmented than the outside (difference = 0.14, SE = 0.08; Fig. 5b, Table 6). However, the difference appeared not to be significant (p = 0.106; Table 6). Makhohlola is characterised by low mean shape values, which shows that simple patches dominate Makhohlola whereas Nwashitshumbe has patches that are more irregular. These results suggest that Makhohlola is more fragmented than Nwashitshumbe (difference = 0.11, SE = 0.08; Fig. 5b, Table 6). Even though there was a difference in the mean shape index between Makhohlola and Nwashitshumbe, the difference seems not to be important (p = 0.233; Table 6). The influence of whether the site is enclosed or not, on mean shape index seems to be higher (estimate = 0.14; Table 6) than that of the site (estimate = 0.11; Table 6).

4.3.3 Configuration

The generalised linear model results suggest that Makhohlola and Nwashitshumbe inside has a higher mean nearest neighbour, which means the patches inside

the exclosures are further apart than outside (difference = 0.91, SE = 0.85; Fig.7c, Table 6). The results suggest that both Makhohlola and Nwashitshumbe inside are more fragmented than the outside, but difference seem not to be significant (p = 0.303; Table 6). Makhohlola seems to have a higher mean nearest neighbour value than Nwashitshumbe, suggesting that the patches in Makhohlola are more fragmented than in the outside (difference = 1.43, SE = 0.91; Fig. 5c, Table 6), however the differences are not significant (p = 0.138; Table 6). In addition, site appeared to have much more influence on mean nearest neighbour (estimate = 1.43; Table 6) than whether the site is enclosed or not (estimate = 0.91; Table 6).

The results for edge density suggest that the outside of the exclosures seems to have high edge densities (difference = 54.24, SE =104.13; Fig.4c, Table 6). However, the linear model suggest that there is no major difference (p = 0.611; Table 6). When comparing Makhohlola and Nwashitshumbe, Makhohlola appeared to be characterised by lower edge density than Nwashitshumbe (difference = 244.63, SE =111.36; Fig. 5c, Table 6). The results suggest that Makhohlola is less fragmented than Nwashitshumbe (p = 0.045; Table 6). The model indicated that some of the factors that were included in the model were important (P = 0.033: Table 6), the results showed that time and site influences edge density of each landscape.

Table 4: Overall changes of woody vegetation patches during 1971 - 2008 for Nwashitshumbe and from 1984 - 2010 for Makhohlola

	Nwashitshumbe	Makhohlola
Number of patches	80.4	48.4
Mean patch size	-54.5	-16.7
Mean shape index	9.9	0
Area weighted mean patch fractal dimension	0	8.4
Mean nearest neighbour	-8.3	-16.2
Edge density	26	31.1

Table 5: Overall changes of woody vegetation patches for Nwashitshumbe inside, Nwashitshumbe outside, Makhohlola inside and Makhohlola outside

	Nwashitshumbe Inside	Nwashitshumbe Outside	Makhohlola Inside	Makhohlola Outside
Number of patches	88.5%	66.7%	100%	-6.7%
Mean patches	-300%	-42.9%	-66.7%	25%
Area weighted mean patch fractal dimension	-0.8%	0.7%	7.4%	9.4%
Mean shape index	-5.7%	26.3%	-12.8%	12.2%
Mean nearest neighbour	-3.4%	-12.8%	-13%	-19.2%
Edge density	1.6%	52.6%	22.9%	38.3%

Table 6: The generalised linear model output for all factors that have been included in the model. Three factors were included in the model are time (year), enclosed (whether the area is enclosed or not) and site (basalt or granite).

Landscape metrics	Factors	Estimate	Standard Error	t-test	p-value
Number of patches (NUMP)	Year	0.47	0.30	1.53	0.1474
	Not enclosed	-9.44	7.66	-1.23	0.2381
	Site (basalt)	2.40	8.19	0.29	0.7743
Mean patch size (MPS)	Year	-0.001	0.001	-1.04	0.3152
	Not enclosed	0.02	0.02	0.99	0.3391
	Site (basalt)	0.003	0.02	0.19	0.8502
Area weighted mean patch fractal dimension (AWMPFD)	Year	0.001	0.001	1.14	0.2754
	Not enclosed	0.05	0.03	1.80	0.0931
	Site (basalt)	-0.078	0.03	-2.36	0.0331
Mean shape index (MSI)	Year	0.003	0.003	0.99	0.3394
	Not enclosed	0.14	0.08	1.73	0.1056
	Site (basalt)	-0.11	0.08	-1.25	0.2331
Mean nearest neighbour (MNN)	Year	-0.03	0.03	-1.01	0.3275
	Not enclosed	-0.91	0.85	-1.07	0.3033
	Site (basalt)	1.43	0.91	1.57	0.1377
Edge density (ED)	Year	12.99	4.14	3.14	0.0073
	Not enclosed	54.24	104.14	0.52	0.6106
	Site (basalt)	-244.63	111.36	-2.20	0.0454

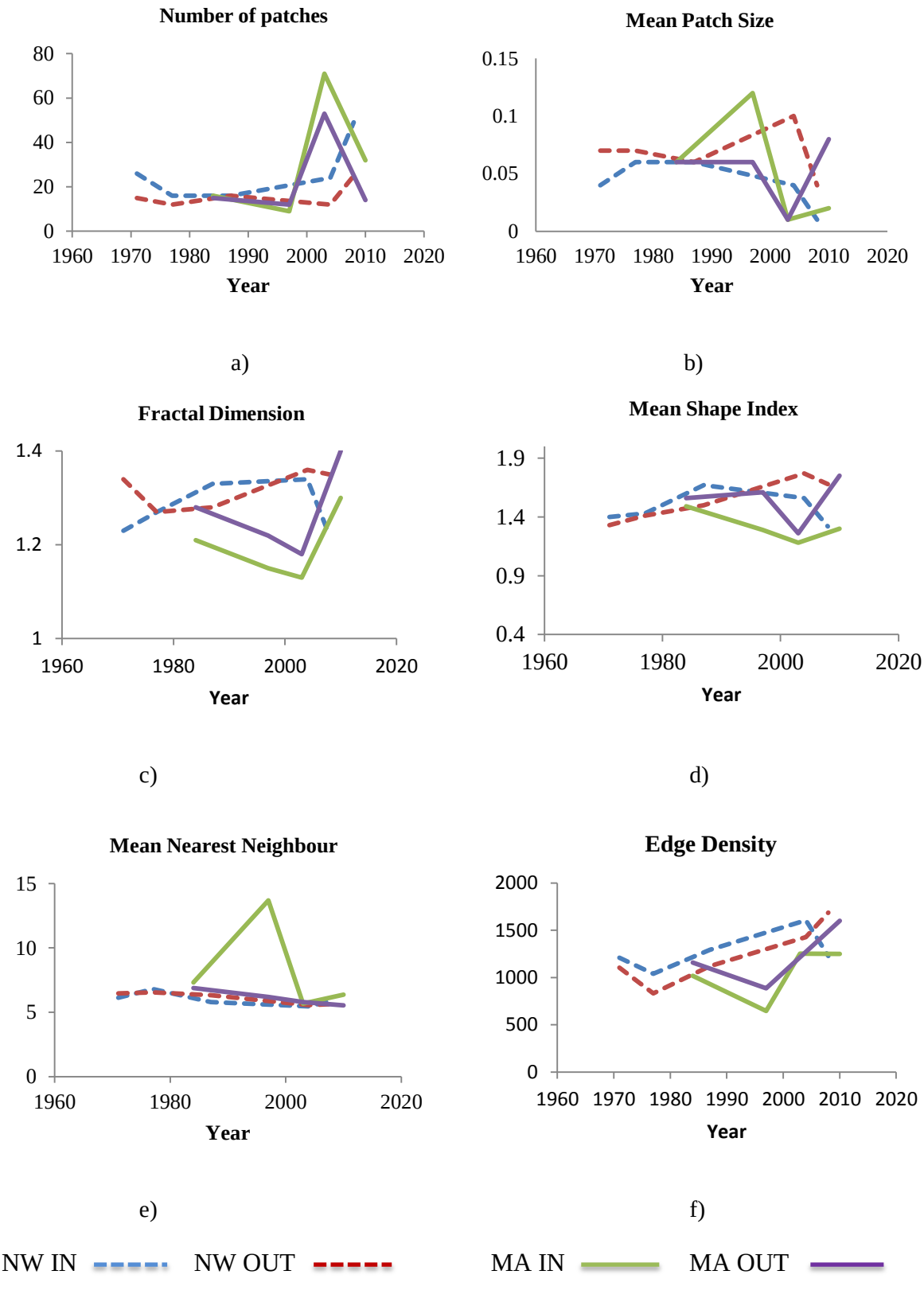
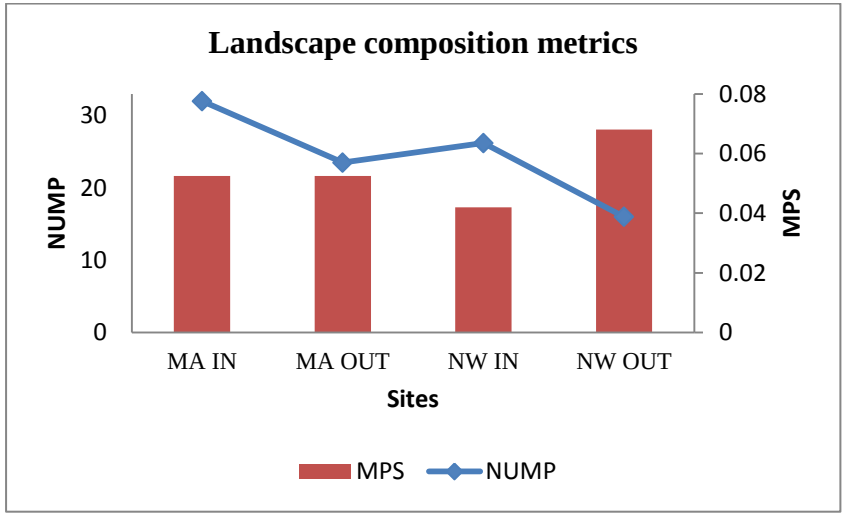
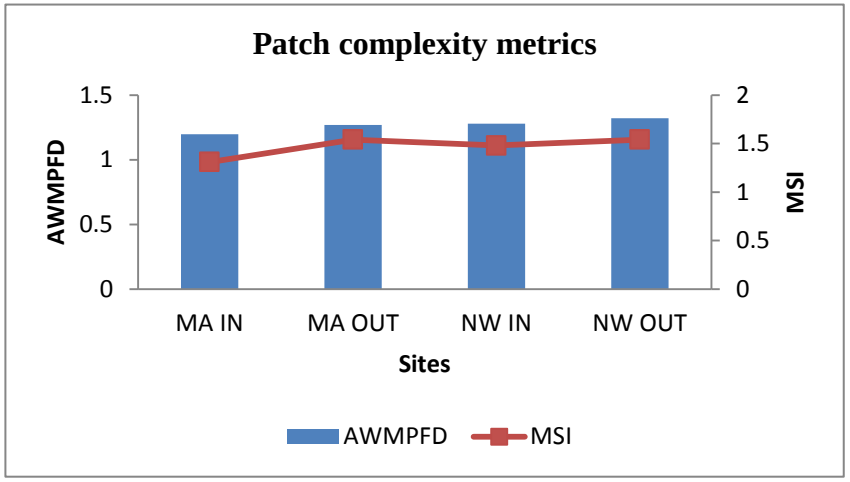


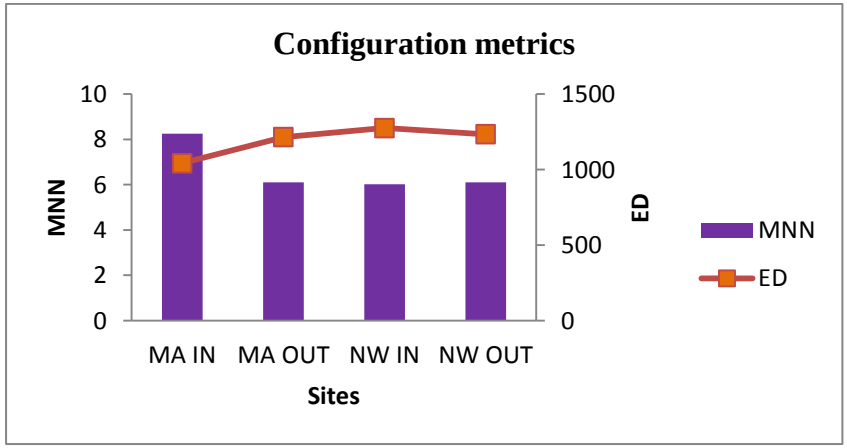
Figure 4 a, b, c, d, e, and f: Landscape metrics pattern for Nwashitshumbe and Makhohlola. Each landscape metric has its own graph. NW IN - Nwashitshumbe inside, NW OUT - Nwashitshumbe outside, MA IN - Makhohlola inside and MA OUT - Makhohlola outside.



a)



b)



c)

Figure 5: The mean values for landscape metrics, which represents the difference in composition, complexity and configuration between the inside and outside of the exclosures, between the basalt (Makhohlola) and granite (Nwashitshumbe) regions. NUMP - Number of patches, MPS – Mean patch size, AWMPFD – Area weighted mean patch fractal dimension, MSI - Mean shape index, ED – Edge density and MNN – Mean nearest neighbour.

Chapter 5.0 Discussion

The results of all our data indicate no linear trend over time, and no clear change from a more wooded to a less wooded state. Despite no linear trend, there were significant directional changes in the landscape metrics over time (edge density $p < 0.05$) (Table 6), indicating that these systems are very fluid with substantial turnover of woody species over short time periods. Although there were, some differences in the average values of certain metrics such as number of patches, for inside and outside exclosures, however, these were not significant ($p > 0.05$) (Table 6) indicating that the processes driving woody patch formation are similar. If herbivores were the main drivers of these changes, we would have expected larger changes outside the exclosures than inside, but we found similar degrees of change inside and outside the exclosures. There was no significance difference in the number of patches, mean patch size, mean shape index, and mean nearest neighbour between Makhohlola (basaltic) and Nwashitshumbe (granitic) region. However, area weighted mean patch fractal dimension (AWMPFD) and edge density, indicated that there was a significant difference between the Makhohlola (basaltic) and Nwashitshumbe (granitic) region ($p < 0.05$) (Table 6). According to AWMPFD and edge density the results suggested that, Makhohlola (basaltic) is more fragmented than Nwashitshumbe (granitic).

5.1 The trend of woody patches

The results of all other landscape metrics indicate no linear trend over time, except edge density ($p < 0.05$), which shows positive relationship with time (Figure 4f, Table 6). The other metrics indicate no clear change from a more wooded to a less wooded state ($p > 0.05$). There is much variability over time, but no clear trend in any of the fragmentation statistics tested. Variability in the trend of other metrics may be due to the recruitment events and bush encroachment. However, the increase in edge density indicates an increase in the sum of

length of woody patches, symbolizing more fragmentation of woody vegetation patches with time (Rutledge 2003). Based on the edge density, the results suggest there was an increase in the disintegration of woody patches, suggesting an increase in fragmentation of woody vegetation patches; however, even though other landscape metrics were not significant. Eckhardt *et al*. (2000) reported that there was a decrease in tall woody vegetation in Kruger National Park with time (between 1940 and 1998). The decrease in woody vegetation leads to increase in total edge density/edge density of woody patches (the border between patches of two different classes) (Rutledge 2003). The decrease in woody vegetation can be attributed to the increase in the number of elephants and fire frequency (Eckhardt *et al*. 2000). High elephant densities may result in the total destruction of woody vegetation and habitats, increasing the total amount of edge; thereby reducing the diversity of species that rely on those habitats (Cumming *et al.* 1997; Lombard *et al*. 2001; Botes *et al.* 2006, Rutledge 2003). Large herbivores, especially elephants (e.g., through debarking) influence the post-fire survival of trees and the ability of trees to out-compete grasses, thereby affecting the abundance and dominance of woody vegetation (Van Wilgen 2009). Hence, the association of fire and herbivory strongly affect the dynamics of woody plants especially in African savanna (Staver *et al*. 2009). In addition, repeated burning may lead to a high mortality rate of mature trees, causing fragmentation of woody vegetation patches as some of the trees may fail to recruit or may not be replaced (Hoffmann *et al.* 2009).

5. 2 Inside and outside of the exclosures

There was no difference in composition, complexity and configuration of woody vegetation between inside and outside of the exclosures (Table 6). The results show that the difference of woody vegetation patches between the inside and the outside of both Makhohlola and Nwashitshumbe was not significant ($p > 0.05$) indicating that the processes driving woody patch formation are similar. Other studies also found out that there were no

differences in bush densities inside and outside of the exclosures (Trollope *et al.* 1998). The rates of change of the woody vegetation patches are determined by the pattern and intensity of the influence (Bucini *et al*. 2009). Usually, the patch type that is more fragmented is more resistant to the propagation of disturbance such as fire than a contiguous/less-fragmented patch (McGarigal and Marks 2005). Outside the exclosures, there is much disturbance from browsers, grazers, fire and inside there is higher fuel load, which results in more intense fires. The results suggest the effects of browsers, grazers and fire outside the exclosure are almost the same to the effect of fire inside the exclosure. The analysis of the exclosures shows that neither fire, elephants nor the interaction of fire and elephants has any significant influence on the woody vegetation patches inside and outside of the exclosures.

5.3 Granitic and basaltic region

The results for number of patches, mean patch size, mean shape index and mean nearest neighbour were not significant, however, the results for area weighted mean patch fractal dimension (AWMPFD) and edge density, shows that there were differences in woody vegetation patches between the basaltic (Makhohlola) and granitic (Nwashitshumbe) regions. There were some differences in the average values of certain metrics (in particular number of patches, mean patch size and mean shape index) for basalt (Makhohlola) and granite (Nwashitshumbe) but these were not significant. The basaltic region appeared to be more fragmented than the granitic region ($p < 0.05$ for edge density and AWMPFD; Table 6). The results show that edge density for the basalt (Makhohlola) was higher than that of Nwashitshumbe (26% and 31.1% respectively) (Table 4). Area weighted mean patch fractal dimension increased by 8.4% for basalt and there was no change for granite region. Other studies show that there was a decrease in woody vegetation on the basalt by 64% and an increase on the granitic region by 12% (Eckhardt *et al*. 2000). Edge density and AWMPFD indicates that granite is less fragmented than basalt. Reduced woody vegetation

fragmentation on granite might be due to increase in woody cover and bush encroachment, The loss of large trees may lead bush encroachment and this is characterised by reduced fragmentation and increase in complexity of the woody patches. Granite soils is characterised by bigger woody vegetation patches (less no change in AWMPFD) than basalt soils because granite soils have higher water availability than basalt soils (Colgan *et al*. 2012). There is a higher percolation rate of rainfall in granitic soils than in basaltic soils, therefore in the granitic region there is more water/moisture available to woody vegetation in granite soils than basalt soils (van Langevelde *et al.* 2003). In addition, granite soils allow trees to access underground water more easily and this enhances the ability to outcompete grass (Scholes and Archer 1997). Moisture content and nutrients influence the growth rate of trees and determine the competitive interaction between trees and grasses in savanna (Staver *et al*. 2009). Granite soils have lower nutrient status, but the availability of moisture overrides low nutrient content (Colgan *et al*. 2012), resulting in large woody vegetation patches.

Intense fires are associated with high rainfall savanna regions, which are characterised by high water availability and fuel load production (Gignoux *et al*. 1997). The decrease in the woody vegetation patches in the basalt region has been attributed to frequent burning and higher fire intensity (Eckhardt *et al*. 2000). The basalt region is characterised by a quick recovery of vegetation from any fire and elephant disturbances leading to high biomass accumulation rate due to high grass production (Colgan *et al*. 2012). Quick recovery of vegetation can yield to high fire intensity and frequent fires, which in turn control grass to tree coexistence in the basalt region. The decrease of woody vegetation patches on the basalt region was mostly due to prescribed burning (van Wilgen *et al.* 2004). Short burning intervals restrict resprouts from reaching a fire-resistant size, maintaining trees in an unproductive stage (Hoffmann *et al*. 2009). The decline in woody vegetation in basalt region can be associated with fire frequency and intensity (Bucinni *et al*. 2009; Govender *et al*. 2006) and

reduced frequency or intensity of fires may lead to greater woody vegetation recovery (Bond *et al.* 2005; Metzger *et al.* 2005).

The overall change in edge density and area weighted mean patch fractal dimension of woody vegetation patches can be attributed to the influence of regular, frequent fires and increasing number of elephants on the basalt region (Eckhardt *et al*. 2000). In addition, the basalt region is characterised by palatable grass (Eckhardt *et al*. 2000), which attracts herbivores especially grazers. Over-grazing in the basalt region leads to excessive run off of rainfall and evaporation of moisture causing less moisture available to trees (Eckhardt *et al*. 2000). Grass can quickly recover from any disturbance due to high nutrients and there will be much competition between grass and trees (Eckhardt *et al*. 2000). Granitic region is characterised by low nutrients and less grass accumulation but largely wooded (Trollope 1993) This indicates that, reduced competition between woody plants and grass leads to increased woody cover recruitment (Bond *et al.* 2005; Metzger *et al.* 2005).

Chapter 6.0 Conclusions

Despite no linear trend, there were significant directional changes in the landscape metrics over time, which indicates that these systems are very dynamic. Variability in the trend of other metrics may be due to the recruitment events and as well as loss trees during the period. There was no difference in composition, complexity and configuration of woody vegetation between inside and outside of the exclosures, indicating that the processes driving woody patch formation are similar inside and outside the exclosures. Although there was no significance difference in other metrics for basalt (Makhohlola) and granite (Nwashitshumbe), however edge density and AWMPFD were significant. The results suggested that basalt region is more fragmented than the granitic region. Conservation managers have set Threshold of Potential Concern (TPCs), that a change of 80% woody vegetation requires corrective measures to be taken into account (Gillson and Duffin 2007). However, the findings suggested an increase in fragmentation of woody patches and a difference in basalt and granite region, which also requires conservation managers to look closely and revise their management policies towards woody vegetation patches. Although the findings were on a small scale due to limited resources and photo availability, it is important to incorporate these finding as they provide an important insight into what is happening on woody vegetation patches in Kruger National Park. Small scale findings should be noted since they can lead to large influence if the impacts are not addressed (Levick and Rogers 2008). In addition, the increase in the disintegration of woody patches may result in the change of habitat suitability and may lead to habitat loss for habitat specialist species such as birds. Change in habitat suitability may further influence the survival of such species. Since one of the major goals for conservation managers is to maintain species diversity of both animal and plant species (Coleman *et al*. 1996). Therefore, on-going monitoring system

of woody vegetation patches, may provide more information on the trends in woody vegetation changes throughout KNP. Continuous monitoring of woody vegetation will also provide more information on factors contributing to fragmentation of woody vegetation patches and the possible impacts on the animal species. However, corrective measures can be put in place to avoid loss of biodiversity due to increase in woody vegetation fragmentation. Above all it is fundamental for conservation managers to understand the relationship between factors and woody vegetation in order to prioritise concern for areas that are at greater risk. Overall, the understanding of changes of woody vegetation patterns and processes help conservation managers to effectively maintain biodiversity.

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