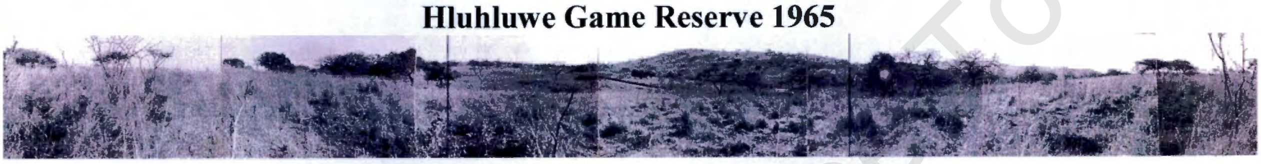
# Living in a changing world: An integrated approach to documenting and understanding medium to long-term vegetation changes in three contrasting land use systems in a mesic savanna, Northern Zululand, South Africa

**Hluhluwe Game Reserve 1965**



**Hluhluwe Game Reserve 1997**



By

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Submitted in fulfilment of the requirements of a Master of Science Degree

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## Abstract

There is an increasing amount of evidence suggesting that the balance between trees and grasses in savannas and grasslands has been disrupted in the recent past. Numerous studies from around the world have reported an increasing woody component at the expense of the grass layer. The causes most frequently cited for this shift are linked to changing land use practices. This study was therefore set up to investigate the effects of three contrasting land use systems on long-term vegetation dynamics in a mesic savanna. I aimed to determine if land use practices alone could account for the changes in vegetation cover evident at the study sites between 1937 and 2004. An alternative explanation for the changes could be linked to a global driver such as changing climate or increasing atmospheric $CO_2$ concentrations.

The rate and extent of vegetation changes were measured and recorded in areas that have remained under communal, commercial and conservation tenure for approximately the past century. Changes in vegetation were determined for a 25 $km^2$ area in each area using repeat panchromatic aerial photography from 1937, 1960 and 2004. Images were mosaicked and georeferenced then overlaid and manually classified. A comparison between manual classifications and machine-generated classifications using eCognition software was also undertaken. Past land use practices for the three study areas were reconstructed using a combination of archive materials and oral histories. The managers, land users or landowners from areas under communal, commercial and conservation tenure were extensively interviewed to determine their perceptions of the changes, consequences of the changes and reactions to the changes in vegetation.

The results showed that significant increases in woody cover occurred during the 67-year period at all three sites. The communal study site showed the least increase in tree cover. However, the overall increase in tree cover at the communal site, from 6.2 to 25.7 % (fourfold increase), is still a highly significant change. The greatest increase in tree cover was evident at the commercial study site where tree cover increased seventeen fold. Total tree cover increased

from 2.7 to 50.8 % during the 67-year period. The increase in tree cover at the conservation study site was also highly significant. Tree cover increased by ~360 %, from 14.7 % in 1937 to 58.5 % in 2004. These vegetation changes correspond to major losses of grassy habitats in each area. The biodiversity losses associated with these changes are largely unknown but are likely to be substantial.

Past land use practices and histories in each area were also shown to be significantly different with major differences in human densities, stocking rates, herbivore feeding types and burning practices. Long-term rainfall records did not show any significant changes in the quantity or seasonality of rainfall. The results suggest that past land use practices did have some impact on the type of and extent of bush encroachment. The study found that although the land users were aware of and concerned about the changes in woody cover in each area, they were not doing much to combat these changes. The perceived importance of the different causes of woody increase was also found to be substantially different amongst the different land users.

The findings suggest that land use practices alone cannot explain the widespread occurrence of bush encroachment in the area. This could suggest that a global driver is contributing to the increasing tree component.

## Acknowledgements

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# Contents

# Chapter 1. General Introduction

*The savanna biome*

A savanna can be defined as a vegetation type co-dominated by woody plants and grasses (Scholes 1997). The aboveground structure is generally two layered with discontinuous woody crown cover overlying a generally continuous grassy layer. An intermediate layer of shrubs or small trees is sometimes also present (Scholes 1997). The mechanisms of co-existence of the woody and grassy layers are subject to wide debate. It is thought that a complex web of factors including water, herbivory, fire, soil texture and nutrients influence the balance between grass and trees (Cole 1986; Skarpe 1992; Scholes and Walker 1993; Frost 1996; Higgins *et al.* 2000). The objective of this study is not aimed at determining the ecophysiological mechanisms of tree-grass co-existence and will not be discussed further. For a detailed summary of the proposed mechanisms of co-existence, Scholes and Archer (1997), Higgins *et al.* (2000) and Sankaran *et al.* (2004, 2005) are recommended.

Savanna forms one of the world's major biomes. Estimates of the global extent of savannas vary. Grasslands and savannas are estimated to occupy more than 40 % of the global terrestrial landscape (Chapin *et al.* 2001). Scholes and Hall (1996) estimate that savannas occupy 12 % of the global land surface. Ramankutty and Foley (1999) estimated that savanna covers 33 million $km^2$ of a total of 150 million $km^2$. This equates to about 22 % of the Earth's land surface. Savanna is the dominant vegetation type in Africa (Scholes 1997) and covers 54 % of Southern Africa (Rutherford 1997). In Southern African savannas, the main functional distinction lies between the broad and fine leaved savannas (Huntley and Walker 1982; Scholes 1990). The major underlying ecological difference is related to soil fertility and moisture with fine-leaved savanna usually occurring on nutrient rich soils in lower rainfall areas and broadleaved savanna usually occurring on nutrient poor soils in wetter areas (Scholes 1997).

*The dynamic nature of tree-grass co-existence*

Understanding the evolutionary history of savannas remains a major scientific challenge (Beerling and Osborne 2006). One of the main hypotheses suggests that atmospheric $CO_2$ fell below some critical threshold during the Miocene, causing the efficiency of $C_3$ plants to drop below that of their $C_4$ counterparts (Ehleringer *et al.* 1991, 1997; Cerling *et al.* 1997). Studies have shown that $C_4$ grasslands rapidly expanded during the late Miocene, ~8 Ma (Cerling *et al.* 1997; Keeleyand Rundel 2005). Keeley and Rundel (2005) propose that the late Miocene climate changes created a fire climate capable of replacing $C_3$ woodland with $C_4$ grassland. $C_3$ woodland tree species then evolved mechanisms (such as the ability to resprout from belowground starch reserves) to survive in a frequently burnt environment. These adaptations would have allowed the $C_3$ tree species to colonize $C_4$ grasslands at a later date resulting in the savanna biome as we know it. There have undoubtedly been major changes in the composition and structure of these systems through time and at a number of scales. Work done by Gillson (2004) in an East African savanna using palaeoecological techniques (analysis of fossil pollen and stable carbon isotopes) showed that long-term tree densities varied at finer scales (micro and local). In contrast to this, tree densities at the landscape scale ($10^2$ $km^2$) were found to be remarkably stable at the temporal scale of hundreds to thousands of years.

Tree densities in savannas are influenced by many factors, including climate, soil type, rainfall variability, nutrient availability, plant interactions and disturbance by fire and herbivores (Skarpe 1992; Augustine and Mcnaughton 2004; Bucini and Hanan 2007). These are all known to vary, both spatially and temporally, often manifesting in a patchwork of plant community types with varying degrees of woody densities at a number of different scales (e.g. Gillson 2004; Wiegand *et al.* 2006). Thus, savannas are typically ecosystems at disequilibrium (Wu and Loucks 1995; Wu and David 2002) with the respective proportions of trees and grasses fluctuating widely in space and time.

*An increasing tree component*

Despite the dynamic nature of savanna ecosystems there appears to have been a noticeable trend in many parts of the world of a rapid proliferation of the woody component, usually at the expense of grasses. This phenomenon is usually termed woody plant proliferation, bush encroachment or shrub encroachment in the literature. Encroaching woody species may be trees or shrubs, collectively referred to as bush in the South African literature (Hudak 1999). Recent trends towards increased bush encroachment in savannas and grasslands have been documented in North America (Archer *et al.* 1988; Archer 1995, Asner *et al.* 2003), South America (Adamoli *et al.* 1990; Silva *et al.* 2001; Cabral *et al.* 2003), Australia (Burrows *et al.* 1990; Fensham *et al.* 2003; Fensham *et al.* 2005; Brook and Bowman 2006), India (Singh and Joshi 1979), Europe (Laiolo *et al.* 2004; Bokdam and Gleichman 2000; Barbaro *et al.* 2001) and Africa (Skarpe 1990; Le Roux, 1996; Hoffman and O'Connor 1999; Higgins *et al.* 1999; Oba *et al.* 2000; Roques *et al.* 2001; Moleele *et al.* 2002; Kraaij and Ward 2006; Wiegand *et al.* 2006; Ward *et al.* 2007). In South Africa alone it has been estimated that 13 million hectares of savanna have been subject to thorn bush encroachment (Trollope *et al.* 1989). The extent of this is likely to have significantly increased in the 18 years since this study. Furthermore this estimate does not include the proliferation of broadleaved woody species. Grossman and Gandar (1989) estimated that more than 28 million hectares of a total of 43 million hectares of savanna vegetation in South Africa to be threatened or already impacted by severe bush encroachment to such an extent that it rendered the veld economically useless. In their national review of land degradation, Hoffman *et al.* (1999) reported that bush encroachment was threatening large parts of the country and was most severe in the Northern Province, Eastern Cape, Northern Cape and North West provinces of South Africa. Despite the widespread occurrence of this phenomenon, there is no consensus on the dynamics and causes of encroachment (Archer 1995).

The pattern, and relative abundance, of herbaceous and woody life forms in savannas result from interactions between climatic variables (e.g. rainfall amount and seasonality), topo-edaphic properties (e.g. texture depth, fertility and run-off) and disturbance regimes (e.g. grazing, browsing and fire) (Walker 1987; Scholes and Archer 1997; Asner *et al.* 2003; Bucini and Hanan 2007). During the past century the balance between plant life forms has shifted to favour trees and shrubs in both arid to semi-arid areas (e.g. Archer 1994, 2002; Wiegand *et al.* 2005; Kraaij and Ward 2006; Franco and Morgan 2007) and more mesic areas (e.g. Bowman *et al.* 2001; Lett and Knapp 2005; Brook and Bowman 2006).

There are, however, important differences in the type of encroachment occurring in arid and semi-arid areas as opposed to more mesic and wet areas. In Southern Africa the drier areas are usually subject to increases by a few dominant fine leaved species. This type of bush encroachment seldom leads to a complete exclusion of the grassy layer due to shading, as the canopy generally remains open. However, if these areas remain under high grazing pressure, overgrazing can lead to the complete removal of the grassy layer and further invasion of woody species (e.g. Wiegand *et al.* 2005; Kraaij and Ward 2006).

In the more mesic areas two very different types of bush encroachment are evident. The first type of woody proliferation is similar to the process in arid areas, whereby savanna trees and shrubs increase in density in grassy areas. This type of encroachment has been well documented in Hluhluwe iMfolozi Park, South Africa (Watson and Macdonald 1983). The second type refers to thicket or forest expansion, whereby previously open grassy areas become covered by thicket or forest (e.g. Cabral *et al.* 2003; Brook and Bowman 2006). This process usually results in the complete exclusion of the grassy layer and would be more aptly referred to as a biome shift.

The literature to date does not clearly distinguish between the types of woody plant proliferation and both are usually lumped together as bush encroachment or shrub invasion. Differences in the ecological consequences of the two processes would be profound. I therefore propose that the semantics of the process usually called bush encroachment or shrub encroachment be revised according to Figure 1.1.

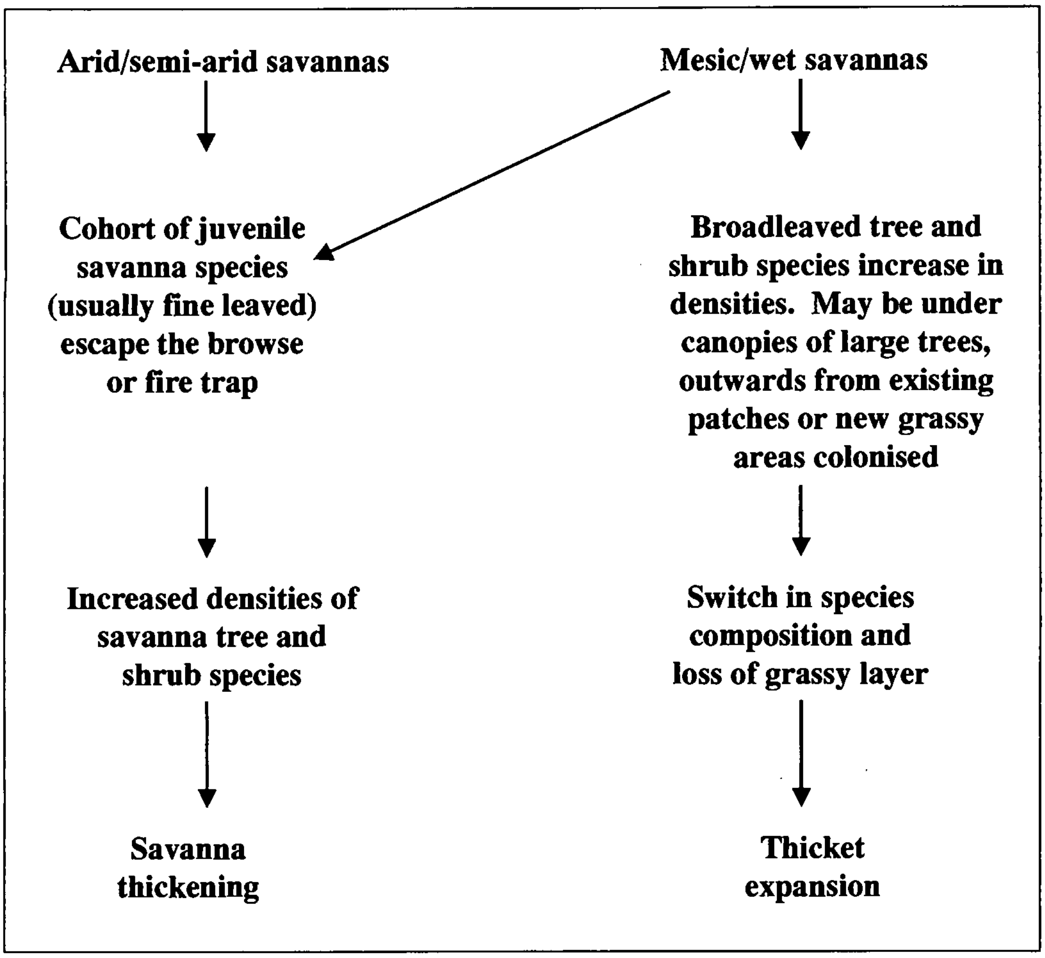


Figure 1.1. Schematic diagram showing the different types of woody plant proliferation that can occur in the different savanna types and the proposed names for the different processes.

*Causes of an increasing tree component: the usual suspects*

Assessing the relative importance of the agents causing vegetation change is challenging, but necessary if models predicting woody plant dynamics under various land management and environmental conditions are to be improved (Fensham *et al.* 2005). Livestock grazing has been evoked as the primary cause of desertification globally (Mabutt 1984). The most widespread form of rangeland degradation is encroachment by generally unpalatable trees and shrubs at the expense of palatable grasses over a time span of several decades (Hudak 1999). In the Southern African region, heavy grazing by domestic livestock is considered the main cause for vegetation degradation (Ringrose *et al.* 1990) and many studies have suggested that heavy grazing reduces the productivity of semiarid rangelands by increasing bush encroachment (e.g. Roques *et al.* 2001; Moleele *et al.* 2002; Angassa 2005). Altered burning practices (Trollope 1982; Higgins *et al.* 2000; Bowman *et al.* 2001; Briggs *et al.* 2005; Banfai and Bowman 2005; Brook and

Bowman 2006) and exclusion from fire and grazing (Gleason 1913 cited in Briggs *et al.* 2005; Silva *et al.* 2001; Russell-Smith *et al.* 2004; Condon and Putz 2007) have also been used to explain the changes.

Together with land use practices, global drivers may be providing additional impetus for directional shifts between grass and woody plant domination. Possible global drivers include changing climate and rainfall (Condon 1986; Archer 1989; Schlesinger *et al.* 1990; Fensham *et al.* 2005), atmospheric nitrogen deposition (Brown and Archer 1999; Kochy and Wilson 2001) and elevated atmospheric $CO_2$ concentration (Johnson *et al.* 1993; Polley *et al.* 1994; Polley 1997; Polley *et al.* 1997; Bond and Midgley 2000; Hoffman *et al.* 2000; Bond *et al.* 2003).

Increased atmospheric $CO_2$ concentrations were initially thought to be advantageous for $C_3$ plants. With increased atmospheric $CO_2$, stomatal conductance would be decreased resulting in lower water loss through transpiration (Polley *et al.* 1994). More water would then be available for the woody $C_3$ plants with deeper roots according to the Walter hypothesis (Walter 1971). Archer *et al.* (1995) claimed that the $C_3$ vs. $C_4$ argument was flawed, as $C_4$ grasses are also responsive to increased $CO_2$. Bond and Midgley (2000) suggested that increased atmospheric $CO_2$ levels would benefit woody plants with carbon rich skeletons more than herbaceous plants with carbon poor skeletons. With an increased supply of carbon, woody plants would therefore be able to grow much faster. This would allow them to escape out of the browse or fire trap at a faster rate, leading to increased woody densities (Bond and van Wilgen 1996). The fire trap in this case refers to the height at which a tree sapling is able to survive a fire without being top-killed (Skowno *et al.* 2004). The importance of global drivers such as increased atmospheric $CO_2$ concentrations has been contentious with Archer *et al.* (1995) and Fensham *et al.* (2005) arguing that land use change could predominantly account for woody plant thickening.

### *African savannas: Contrasting land use practices and tenure*

Bush encroachment has repeatedly been cited as one of the major causes of land degradation in South Africa (Grossman and Gandar 1989; Hoffman *et al.* 1999; Hoffman 2000). However the magnitude and dynamics of savanna thickening and thicket expansion are still poorly understood. Areas that are under communal land tenure are often perceived to be the most degraded. This study therefore set out to explore the phenomenon under the three main land tenure systems in South Africa. Variants of these three broad forms of land use, namely subsistence farming, commercial livestock farming and wildlife conservation are widely practiced in the savanna regions of Africa (Grossman and Gandar 1989). These contrasting land use practices can change the structure and functioning of savanna ecosystems and hence the type and quantity of ecosystem services provided (Higgins *et al.* 1999). A predictive knowledge of the relationships between land use practices, the composition, structure and function of vegetation, and the supply of ecosystem services is thus required (Higgins *et al.* 1999). Studies on the social, environmental, conservation and economic value of these forms of land use have failed to achieve consensus on the optimal management system for African savanna ecosystems (Higgins *et al.* 1999). This may be because many land use studies concentrate on the effects of a single aspect of a management system such as bush clearing (e.g. Scholes 1987), fuel wood harvesting (e.g. Shackleton 1993), or grazing (e.g. Skarpe 1986, 1990). Consequently, they do not account for the interactive effects of the management activities that constitute a land use option (Higgins *et al.* 1999). In South Africa, savannas are typically under radically different tenure. However, the ecological impacts of these different tenure systems are not well quantified.

Woody plant proliferation in grasslands and savannas has long been a concern of land managers because it adversely affects herbaceous productivity and livestock handling, thus threatening the sustainability of subsistence and commercial livestock production systems (Fisher 1977; Rappole *et al.* 1986). Woody plant proliferation is also of major concern for conservation managers as it has major biodiversity impacts. This is especially important for South African conservation managers whose chief mandate is to conserve and protect biodiversity.

*Aims of this study*

Although bush encroachment has been acknowledged as a global management issue, neither the rates of change nor the geographical extent of the phenomenon have been systematically quantified (Asner *et al.* 2003). This holds true for arid, semiarid and mesic savannas and grasslands. An investigation of the literature has shown that tree cover has significantly increased in savanna and grassland areas around the globe in the last century. Despite the widespread occurrence of woody plant proliferation we still do not have a fundamental understanding of the underlying mechanisms driving the process. Furthermore, as stressed by Asner *et al.* (2003), the rates of change and extent of woody plant proliferation need quantification. Savanna thickening and thicket expansion have been attributed to a number of drivers, which generally can be divided into two broad categories. Changing tree densities have been linked to drivers related to either land management or changing global patterns. To date the proposed drivers of bush encroachment have generally been studied in isolation. We need to investigate whether land use change can account for the changes in vegetation that have been documented in savannas and grasslands worldwide. A confounding issue has been that land use practices have often changed concurrently with global patterns of change. For example, increasing human population densities and the associated increases in natural resource use for many communal areas in South Africa has occurred simultaneously with increasing atmospheric $CO_2$ levels. There is therefore a need to tease out changes caused by land management from changes linked to climate, nitrogen deposition or increased atmospheric $CO_2$ concentrations.

A potential way of achieving this would be to determine how general the pattern of woody plant proliferation is. The process therefore needs to be studied at the landscape scale across areas that are known to have remained under radically different land management for an extensive period of time. Past management practices can then be reconstructed and correlated to the observed changes in woody cover. This would provide a clearer indication of whether past management practices were responsible for driving the changes in tree cover. If tree cover was found to have increased across the boundaries separating areas under different land use practices it would suggest that some overriding global driver such as changing climate and rainfall, nitrogen deposition or increased atmospheric $CO_2$ concentrations (e.g. Condon 1986; Schlesinger *et al.* 1990; Kochy and Wilson 2001; Hoffman *et al.* 2000; Bond *et al.* 2003) were responsible for the changes. The possibility of changing rainfall as a regional driver (of changes in tree densities) can be eliminated by analysing long-term rainfall records for the region.

The political backdrop of South Africa provides an ideal opportunity for studying the effects of different management practices on tree cover. The three main land use practices (communal, commercial and conservation) can often be found within close proximity of each other. Furthermore these areas have often remained under these contrasting tenures for extensive periods of time. This provides a valuable opportunity to study the long-term effects of contrasting land use practices on vegetation dynamics in a landscape sharing similar climate and soils.

The questions addressed in this study are:

1) What is the magnitude of savanna thickening and thicket expansion in the broader Hluhluwe area?
2) How has the magnitude and rate of savanna thickening and thicket expansion varied over time in three contrasting land use systems (communal, commercial and conservation)?
3) How have the potential drivers of change differed in the three land use systems?
4) How do the land users in the three systems perceive:
    a) The magnitude of change in woody cover?

b) The potential causes of change?

c) The consequences of the changes?

d) Potential responses and costs of responses to change?

5) Can the effects of past land use practices be teased apart from the effects of global drivers to explain the changes in tree cover evident in the area?

*Thesis outline*

This study was undertaken in the broader Hluhluwe area of the Hlabisa district in Northern Zululand, South Africa. Three study sites covering communal, commercial and conservation land use practices were located within close proximity (~15 km) of each other. In Chapter 1, the general background and aims of the study are provided. Chapter 2 provides a detailed description of the study sites. In Chapter 3, the historical background of the region was explored using archival data and oral histories. Historical stocking rates and other land management data were also obtained for each study site and their potential influence on the vegetation investigated. In Chapter 4, remote sensing techniques using repeat black and white aerial photography were used to measure and quantify the rates of vegetation changes at the landscape scale at the three study sites for the 67-year period between 1937 and 2004 using two methods of vegetation classification. In Chapter 5, the results from extensive interviews with the landusers and managers from each of the three contrasting areas are presented. Semi-structured interviews were undertaken in order to determine land users perceptions on the magnitude of vegetation change, the impacts of these changes and the perceived causes. The perceived consequences of, and responses to, the vegetation changes were also determined for the different landusers. An attempt at costing the potential methods used for combating the changes in woody cover was also undertaken. Chapter 6 provides an extensive discussion and synthesis of the findings from this study.

## Chapter 2. Study sites

The study sites are located in what was previously the Hlabisa Magisterial District, Northern Zululand, KwaZulu-Natal, South Africa (Fig. 2.1 A). The previous districts of KwaZulu-Natal have recently undergone a major transformation. According to the new demarcation process the study sites now fall into the Umkhanyakude District (Fig. 2.1 B), which is comprised of five local municipalities. For the purposes of this study I will refer to the Hlabisa district as it was prior to the new demarcation process in 2003. This is justified in that all of the archive data that I have collected is relevant for the Hlabisa district as it was prior to 2003.

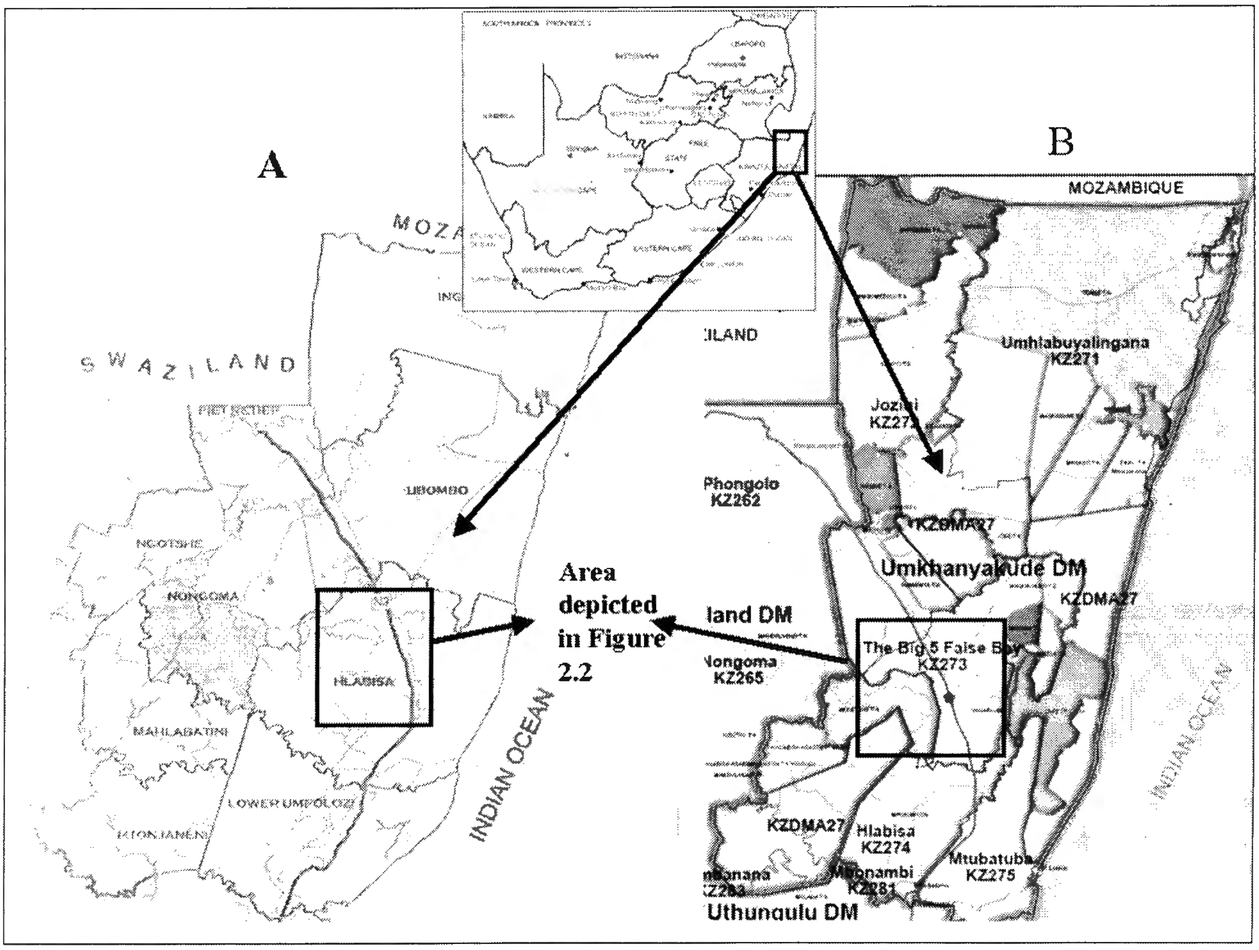


Figure 2.1. The magisterial districts of Northern KwaZulu-Natal showing the location of the Hlabisa District as it was prior to 2003 (A). The new demarcations of the districts showing the new Umkhanyakude District and the component municipalities (B). The area indicated in each image is shown in greater detail in Figure 2.2.

The Hlabisa district is made up of three land use systems. Approximately one third of the district (1218 km$^2$) falls within nature reserves, these include the Hluhluwe iMfolozi Park (HiP) and the Greater St. Lucia Wetlands Park. Approximately 1424 km$^2$ falls under communal land tenure while the remaining ~1627 km$^2$ is made up of commercial farms. The three land use systems are often juxtaposed and can usually be found within close proximity of each other. The locations and extent of the study sites in this study were adapted according to the objectives of the different chapters. The study that explores the history and past management of the area using archive data (Chapter 3) covers the entire Hlabisa district. The history of the district is discussed in greater detail in Chapter 3. Chapter 4 documents changes in vegetation under contrasting land use practices by analysing 25 $km^2$ areas under each land use practice. The three study sites that are analysed in Chapter 4 can be found between the Hluhluwe Game Reserve in the west and Hluhluwe town in the east (Fig. 2.2). The sites are located adjacent to each other along a 20 km east west gradient. The coordinates of the top left (NW) corner of each site are as follows:

Conservation site 28.041963 S 32.041963 E

Communal site 28.031300 S 32.143899 E

Commercial site 28.015662 S 32.210004 E

The sites are in close proximity and can be treated as a homogenous area in terms of climate, geology and vegetation type. The study area covered in the chapter on the perceptions and implications of bush encroachment for land users (Chapter 5) is described in detail in Chapter 5.

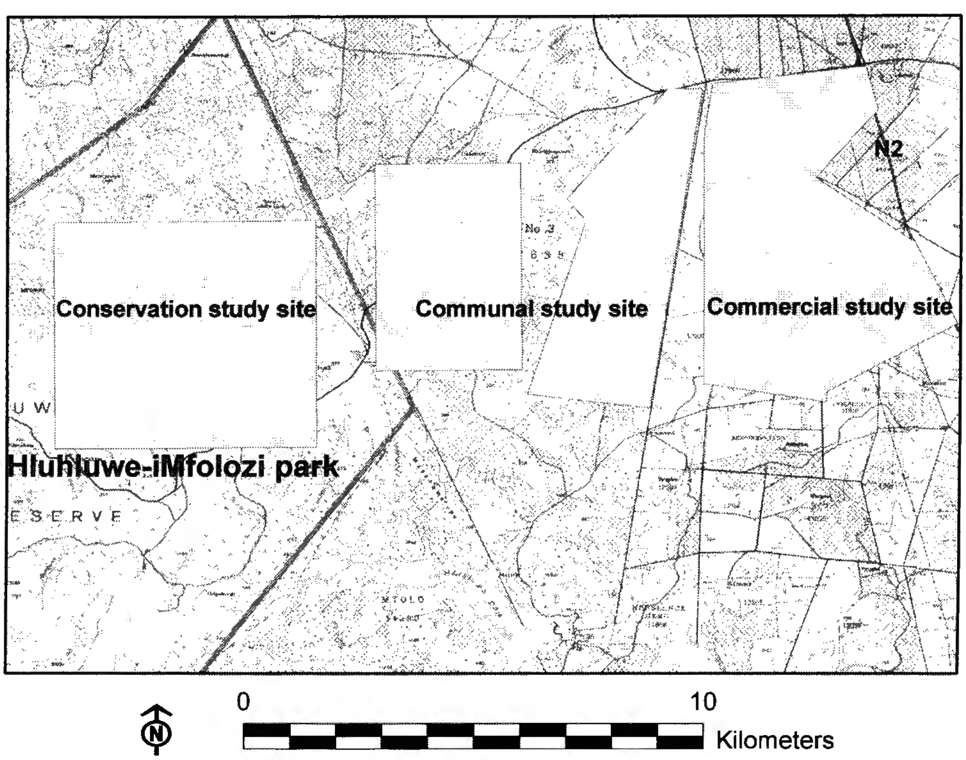


Figure 2.2. Locations of the three 25 $km^2$ study sites in areas under contrasting land use practices.

*Climate*

The climate of the area is coastally modified with mean annual precipitation (MAP) ranging from 990 mm at Godeni in the west of the Hluhluwe Game Reserve to 700 mm in Hluhluwe town which is ~25 km east of Godeni. The altitude at Godeni is ca. 450 meters above sea level (masl) while Hluhluwe town is at 100 masl. Balfour and Howison (2001) showed a significant positive relationship between rainfall and altitude in the area (Fig. 2.3, rainfall = (altitude) + 522.6 ($r^2 = 0.80$)). According to this equation we would expect MAP in Hluhluwe town to equal 622 mm which is fairly close to the long term average of 700 mm measured between 1934 and 1979. The altitude difference between study sites is less pronounced ranging from *ca.* 300 masl at the conservation site in Hluhluwe Game Reserve to *ca.* 150 masl at the commercial sites. This would equate to a maximum difference of 150 mm of rainfall between sites according to Balfour and Howison's (2001) equation.

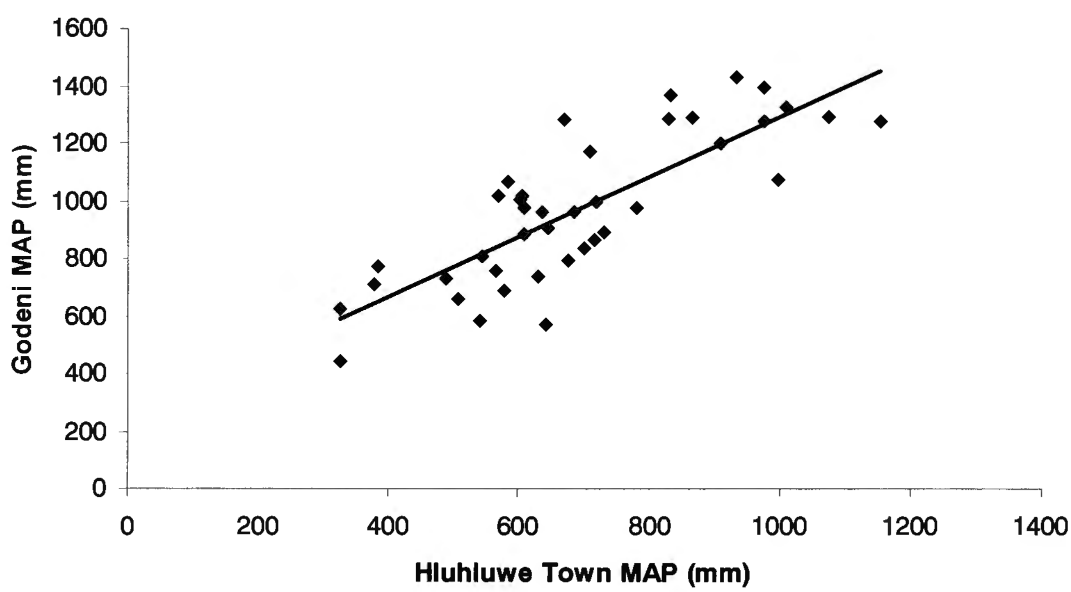


Figure 2.3. Mean annual precipitation plotted for Hluhluwe town and Hluhluwe Reserve (Godeni) for the period 1934 - 1979. The equation of the relationship is given as $y = 1.0452x + 249.27$, $r^2 = 0.66$.

Rainfall records for the area suggest that medium term periodic fluctuations above or below average annual rainfall occur, resulting in wet and dry phases of between 4 and 10 years (Tyson 1975; Balfour and Howison 2001). Rainfall patterns will be explored in more detail in Chapter 3. The temperatures in the region are moderate to hot with a mean minimum winter temperature of 13 °C and a mean summer maximum temperature of 35 °C (Greyling and Huntley 1984). Frost seldom occurs due to the mild winter temperatures and low altitudes at the study sites. Thunderstorms are a common feature of the summer rainfall season with lightning strikes occurring at densities of *ca.* five to six ground flashes per square kilometre per year (Anon 1994).

*Geology and topography*

The topography of the area is comprised of rolling hills and valleys dominated by an eastward sloping monocline. Undulating lowlands rise into steeper uplands in the west of Hluhluwe Reserve. Altitude spans a range of 540 m (Balfour and Howison 2001). There is a slight altitudinal gradient moving from the conservation study site in the west (ranges between 100 and 400 masl) to the commercial study site in the east (ranges between 100 and 250 masl). Despite these slight differences in topography, King (1970) noted that the geology of the Hluhluwe Game Reserve could serve as an introduction to the local geology of most parts of the Natal Coastal Belt.

The rock units generally dip eastwards at about 10 degrees causing the oldest formations to be exposed in the west of Hluhluwe Reserve (King 1970). The youngest formations (Stormberg Basalts) are found along the eastern boundary (King 1970) which is where the study sites are located. The geology of the area is diverse with 7 main geological formations. Shales and sandstones belonging to the Beaufort Series mainly underlie the eastern part of Hluhluwe Reserve (Whateley and Porter 1983). Basaltic lavas of the Stormberg Series cap the eastern hills of the reserve. Sedimentary rocks made up of Cave Sandstone generally underlie these caps. Upon weathering the lavas yield a rich black soil, which is widespread in the eastern part of the reserve (King 1970). A number of dolerite dykes can be found in the eastern parts of the reserve. The different geologies are characterized by intense fracturing and faulting which occurred during the break up of the Gondwanaland super-continent. Limited recent deposits along the major rivers usually result in young soils and alluvia in these areas (King 1970). The geology of the area usually results in clay rich soils derived from shales, mudstones and dolerite outcrops while the erosion of sandstones usually results in lighter sandy soils. Due to the close proximity of the sites to each other the geologies can be assumed to be fairly similar at each study site.

*Vegetation types*

Acocks (1953) defined two major veld types in the Hluhluwe iMfolozi Park. These were Zululand Thornveld (type 6) and the Lowveld Tropical Bush Savanna (type 10). These were later changed to three broad vegetation types for the area (Acocks 1975). These included grasslands and forested hilltops, which are usually found at higher altitudes (above 450 masl). These hilltop forests have also been referred to as scarp forest and are often dominated by species such as *Harpephyllum caffrum* and *Celtis africana.* Riverine forest usually dissects the park along its watercourses. The dominants in these forests include *Ficus sycamorous* and *Schotia brachypetala.* The remainder of the park is a mixture of fine leaved Acacia savannas and broadleaved woodland. The Acacia savanna ranges from open to closed canopy patches. The main fine leaved species in Hluhluwe Game Reserve include *Acacia karroo, Acacia nilotica* and *Dichrostachys cinerea.* Previously open grassy areas in Hluhluwe Game Reserve have repeatedly been reported to have undergone major thickening and encroachment (Ward 1962, Pratt *et al.* 1966 in Berry and Macdonald 1983; Whateley and Porter 1983; Watson and Macdonald 1983; Balfour and Howison 2001). The broad leaved woodlands and thickets are often located on the lower lying clay soils and support little understorey vegetation (Balfour and Howison 2001). The dominant woodland and thicket species in the park include *Euclea divinorum, Spirostachys africana* and *Gymnosporia senegalensis.* The dominant grass species in the area is the highly flammable andropogonoid, *Themeda triandra* Forske. The vegetation communities of Hluhluwe iMfolozi Park have been described in considerable detail by Whateley and Porter (1983). The close proximity of the three study sites ensured that the vegetation communities at all three sites were similar in their composition. The results from a number of ground truthing transects taken at all three sites confirmed this assumption. Many of the forest, woodland and thicket communities in the area have been invaded by *Chromolaena odorata,* an alien invasive shrub from South America.

*Historical background of the study sites*

*A) Communal*

The communal study site falls into an area that was part of the previous KwaZulu homeland. Under the apartheid laws of the previous South African government, homelands were set aside for black settlement. However, the land which was provided in these homelands, was granted on limited and precarious permits subject to administrative discretion (Adams *et al.* 1999). People living in these areas were placed under the jurisdiction of tribal authorities. During the apartheid era the traditional authorities played a central role in the administration of land. These traditional authorities usually had land administration rights as well as judicial and executive powers (Ntesebeza 1999). Thus, people living in these communal areas did not own the land but had to be granted permission to live there by the local Induna (traditional authority). The Induna also controlled the allocation of land for cultivation. Livestock in these communal areas are usually not restricted by fences and are therefore free to move and feed throughout the area. Human population densities have expanded rapidly in the communal areas of Hlabisa since the early 1900s. The majority of households in the communal area are not electrified and therefore rely on firewood for cooking and heating. The historical land use and management practices in the communal areas of Hlabisa are discussed in detail in Chapter 3.

*B) Commercial*

The majority of the commercial farms in the area were cattle farms up until relatively recently. This is summed up in the following statement by one of the elderly farmers in the area. *"This region used to be South Africa's best cattle producing country in the past up until about 1994, now there are just a few cattle left"*. During the 1960s some of the farmers in the area started converting to game farms. The conversion to game farming accelerated in the late 1970s when farmers were offered game from the Natal Parks Board for the price it took to capture them. The Natal Parks Board was instrumental in encouraging people to commence game farming. It was thought that if more private farms were turned into game farms it would help with the conservation of wildlife as the Natal Parks Board was unable to acquire new land for reserves.

The commercial study site is made up of two privately owned farms. The northern section (roughly half) of the study site covers the private game reserve of Ubizane which was one of the first privately owned game farms in the area. It was established as a private reserve in 1969 and used predominantly for private hunting until the 1990s. During this period the farm was heavily stocked with a range of wildlife species. Stocking rates were reduced after 2002 and have been maintained at these lower rates since then. Before 1969, the farm was part of a much larger farm, which was under cattle ranching. It was subsequently subdivided and separated into smaller farms.

HH Ranch, a privately owned cattle farm, covers the southern section of the study site. HH Ranch formed part of a 3600 ha farm that was under cattle farming until 2001. The farm then changed ownership and is in the process of switching to game farming. The farm has therefore been under heavy cattle grazing for almost a century. The previous owner (pre 2001) maintained a herd of 1200 cattle on 3600 ha. Thus, stocking rates were above the recommended stocking rate for the area, which is 4 ha/LSU (1 large stocking unit = 1 cow).

*C) Conservation*

Hluhluwe-iMfolozi Park (HiP) is made up of three main parts, Hluhluwe Game Reserve in the north, iMfolozi Game Reserve in the south and an area of land called the corridor connecting the two. Hluhluwe Game Reserve was originally proposed in 1885 as a protected conservation area and was officially demarcated in 1897 (Henkel 1937). The reserve was established with the objective of preserving and maintaining the indigenous species of game (Henkel 1937). Many species of large game were heavily exploited by hunters in the region during the late $19^{th}$ century and therefore needed protection. All of the local inhabitants living in the reserve were removed after demarcation.

The Hluhluwe Game Reserve has remained as a protected area since its proclamation in 1897. Management of the reserve has varied through time with a number of different policies implemented at various stages of the reserves history. The mission statement of current management is to conserve and protect biodiversity. The changes that have occurred in the vegetation of the reserve over the past 70 years have been of major concern for management. Research and management strategies in the park have often focussed on this phenomenon. A number of studies have documented significant changes in the woody component of the reserve with substantial increases in tree densities reported for large parts of Hluhluwe Game Reserve, in particular the northeastern section of the reserve (Pratt *et al.* 1966; Downing 1980; Whateley and Porter 1983; Watson and Macdonald 1983; Wills and Whateley 1983; King 1987; Watson 1995; Skowno *et al.* 1999; Skowno and Bond 2003). Bush encroachment has continued in the reserve despite ongoing efforts to control the spread of trees and shrubs since the 1960s.

*Conclusion*

The three study sites differed only in terms of land use for approximately the last century. Vegetation types, climate, topography and the underlying geologies are consistent across study sites. Thus, the underlying biotic and abiotic templates of the study sites cannot be used to explain differences in the patterns and rates of vegetation change if they immerge in later chapters of this study.

# Chapter 3. Historical account of past management and land use practices in the communal, commercial and conservation areas of Hlabisa

*Introduction*

The phenomenon usually referred to as woody plant proliferation, shrub encroachment or bush encroachment has been widely documented and discussed in the literature (Chapter 1). A number of agents have been proposed as important causal factors. These usually include one or more of the following:

1) Overstocking and associated overgrazing (e.g. Huntley 1982; Van Vegten 1983; Trollope 1984; Trollope and Tainton 1986; Skarpe 1990; Perkins and Thomas 1993; Graetz 1994; Ringrose *et al.* 1996; Brown and Archer 1999; Van Auken 2000; Roques *et al.* 2001; Sharpe and Bowman 2004; Van Langevelde *et al.* 2003; Fensham *et al.* 2005)
2) Altered burning practices (e.g. Trollope 1982; Higgins *et al.* 2000; Bowman *et al.* 2001; Banfai and Bowman 2005; Briggs *et al.* 2005; Brook and Bowman 2006)
3) Exclusion from fire and grazing (e.g. Gleason 1913 cited in Briggs *et al.* 2005; Silva *et al.* 2001; Russell-Smith *et al.* 2004; Condon and Putz 2007; Muller *et al.* 2007)
4) Changing climate and rainfall (e.g. Condon 1986; Archer 1989; Schlesinger *et al.* 1990; Fensham *et al.* 2005)
5) Nitrogen deposition (e.g. Brown and Archer 1999; Kochy and Wilson 2001)
6) Elevated $CO_2$ (Archer *et al.* 1995; Hoffman *et al.* 2000; Bond and Midgley 2000; Bond *et al.* 2003)

From the above list, it is clear that changes linked to land use practices are most frequently invoked as the leading cause of bush encroachment. In order to gain a better understanding of the potential drivers causing the changes in vegetation at the study sites we need an understanding of the historical context of the study area. This will be done by first providing the historical background of Zululand in general then for the Hlabisa magisterial district into which the study sites fall. Then in order to understand what might have driven the changes in vegetation under investigation in this study I will provide the historical stocking rates and other land management data where possible. Comparisons can then be made between past management and land use practices at the three study sites. Due to the nature of the three different land use systems, I expect to find radical differences in past land use practices and management in the communal, commercial and conservation areas of Hlabisa.

*Limitations of the data*

The historical account of the Hlabisa district is complicated by the fact that, in the 1960s under the apartheid government, Hlabisa was divided along arbitrary boundaries into Hlabisa, South Africa and Hlabisa, Kwazulu (one of the proposed independent homelands set aside for black settlement). Multiple searches through archival material and historical accounts failed to deliver a map that delineated the exact boundaries of the division of Hlabisa. The most accurate map I could locate (Fig. 3.1) shows the division of Hlabisa into its respective parts. This splitting of the Hlabisa district has made it difficult to reconstruct stocking rates and densities for the district through time as South African agricultural censuses only included areas officially deemed to be within South Africa. Thus, after the formation of KwaZulu as a proposed self-governing territory in the late 1960s, some areas previously enumerated in the South African censuses were no longer included in the Hlabisa district. Records from KwaZulu itself are scattered and hard to find. I did, however, manage to locate stocking data for the period 1981-1986. Following the first democratic elections in South Africa in 1994, the Hlabisa district was once again amalgamated into one district with the incorporation of KwaZulu back into South Africa. Thus, archival data after 1994 incorporates the entire Hlabisa district.

A further problem I encountered while attempting to reconstruct the historical background of the study sites was that for certain land management practices, such as burning and livestock production, few records exist. Both the commercial and communal landusers have never kept records of their burning practices and stocking rates. For the conservation study site there are records of burning (since 1955) and stocking rates (limited records since 1929). Landusers from the different land use systems were therefore interviewed in order to reconstruct the oral histories of each area. Caution should be taken when using census data as the methodologies and accuracy tends to vary through time. Despite these difficulties, the data presented below reflect the general trends and broad changes in land use/management at the study sites. The data presented in this chapter are a compilation of data sets that I researched and gathered from official government censuses and from government, Ezemvelo KZN Wildlife and library archives.

Archaeological evidence suggests that Early Iron Age people occupied the Natal coast and valley lowlands from A.D. 290 (Hall and Vogel 1978; Feely 1980). Zululand has thus been continuously settled by both Early and Late Iron Age peoples for more than 1700 years (Feely 1980). The extent to which these people influenced the vegetation on a landscape scale still remains a highly contentious issue amongst archaeologists although some authors (e.g. Feely 1978) suggest that even Early Iron Age settlers would have had profound influences on the vegetation through clearing for cultivation and iron smelting.

Written records of Northern Zululand are relatively recent when compared to the rest of the country. The first mention of white settlers as far north as the Umfolozi River was in 1840 when Mpande was recognised as King of the Zulus after Dingane's defeat by a combined Zulu and Boer force. Subsequent to Mpande's defeat, all the land between the Tugela and the Black Umfolozi rivers was ceded to the Republic of Natal, then under Boer command (Brookes 1967). However, the Republic of Natal was soon taken over by the British although white settlers never settled upon the land previously ceded to the Boers. Up until 1873 the land north of the Tugela River remained largely unsettled by white settlers, bar a few missionary stations and was under the control of the reigning Zulu king, Cetshwayo (Brookes 1967). In 1879, following the British defeat of the Zulus in the Zulu war, Britain split Zululand into thirteen districts and placed each district under a chief of their choice. This decision led to much discontent and unrest among the various chiefs and tribes. Due to the ongoing unrest and tension in Zululand subsequent to 1879, Britain decided to annex Zululand in 1887 (Brookes 1967). The Imperial Government ruled Zululand as a British Crown Colony from 1887 to 1897 (Brookes and Hurwitz 1957). During this period the Hluhluwe and iMfolozi Game Reserves were first proposed in 1885, with the aim of protecting large game, which were being heavily exploited by hunters throughout Zululand.

Henkel (1937) reported that in 1897 when the boundaries of the game reserves were demarcated there were a number of native kraals both inside and surrounding the Hluhluwe Game Reserve. The presence of old cattle kraals and grain pits suggested that cultivation had taken place and cattle had been kept in the area for some time. In 1897 Zululand was annexed to the Colony of Natal, which had enjoyed 'responsible' government for the previous four years (Brookes and Hurwitz 1957). At this stage a commission of two, one representing the Imperial and one the Colonial Government, was set up to delimit what they termed 'Native Reserves' in Zululand (Brookes and Hurwitz 1957). In 1899 there were *ca.* 210000 indigenous people in Zululand with 77000 people living on the coastal belt, 85000 on the middle belt and 48000 on the upper belt corresponding to densities of 6; 8 and 13.5 people per km$^2$ (Brookes and Hurwitz

1957). The area of interest to this study, mainly the Hlabisa district, falls mostly within the coastal belt, with the Western edge falling within the middle belt. The commission demarcated reserves totalling 15742 $km^2$ in Zululand, providing an average of 6.9 ha per person or 34.4 ha per family (of five) of arable and grazing land (Brookes and Hurwitz 1957). Up until this point Zululand was largely devoid of white settlers, although much of the land not allocated to reserves was soon to become available for sale to white settlers (Brookes and Hurwitz 1957).

The initial 'native reserves' (scheduled by the commission started in 1897) were demarcated in their present form by the Zululand Lands' Delimitation Commission of 1902-04. These Reserves (hereafter referred to as communal areas) were officially recognised as such with the passing of the Native Land Act of 1913 (Brookes and Hurwitz 1957). In Zululand, no additional land was added to the original communal areas until 1936 despite the rapid increase of human populations in these areas. Even after the passing of the Native Trust and Land Bill of 1936, which aimed at addressing the above problem, the only area in Zululand to receive more land was in the district of Eshowe (Brookes and Hurwitz 1957). Thus, in the magisterial district of Hlabisa the boundaries between state owned communal land, conservation areas and privately owned commercial farms appear to have remained constant from 1897 until the formation of KwaZulu as a proposed self-governing territory during the late 1970s when the magisterial district of Hlabisa was split into Hlabisa (Kwazulu) and Hlabisa (Natal, i.e. South Africa).

Throughout this period the local AmaZulu inhabitants would have been removed from areas allocated to white farmers and placed in the communal areas set aside for them. It can be assumed that the original Reserves would have been set up in areas that were most densely populated by AmaZulu people. The KwaZulu communal area falling within the Hlabisa district can be seen to surround the iMfolozi and Hluhluwe Game Reserves, (see Fig. 3.1) with a corridor of Crown land between the two game parks. The corridor of land between the Game Reserves, although managed for wildlife since the 1950s, was only officially handed over to the Natal Parks Board in 1982. The area adjacent to the Hluhluwe iMfolozi Park was settled in earnest by European farmers from 1914 (MacDonald 1979). The boundaries between communal, commercial and conservation areas in the Hlabisa District remained unchanged until 1994, when the previously divided Hlabisa District was once again amalgamated into one magisterial district after the dismantling of the apartheid state of Kwazulu.

During the late 1800s an outbreak of Rinderpest decimated both domestic and wild animal populations in large parts of Southern Africa, including Zululand. This was followed by an outbreak of Nagana (*Trypanosomiasis*) in the early 20th century. Accordingly from the 1920s onwards a variety of strategies were used in attempts to eradicate Nagana from the area. All of the strategies were aimed at eradicating the tsetse fly – the host vector for *Trypanosomiasis*.

During this period Nagana became a major problem for the recently established stock farmers in the area, the conservation managers and communal farmers, all of whom suffered major animal losses. Measures to control the disease are thought to have had significant effects on the reserve.

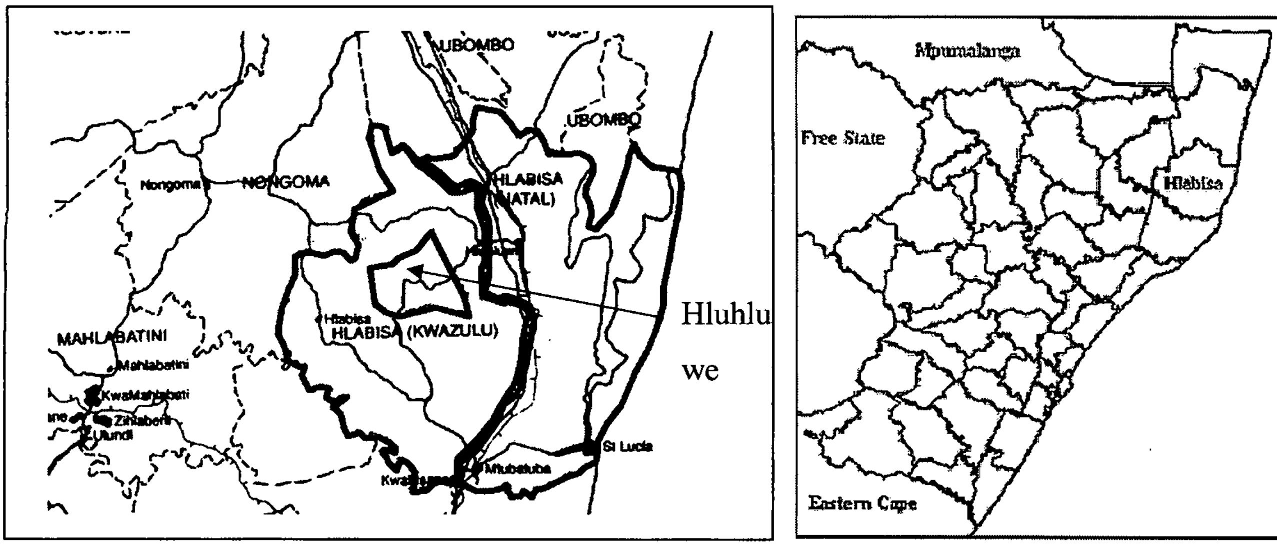


Figure 3.1. Map showing the Hlabisa district in Northern KwaZulu-Natal. The image on the left depicts the division of the district into Hlabisa KwaZulu and Hlabisa Natal. Note should be taken that the Hluhluwe Game Reserve remained in the Hlabisa Natal district despite being completely surrounded by Hlabisa KwaZulu. The image on the right depicts the district as it was prior to the formation of the KwaZulu homeland.

Major game eradication campaigns were undertaken in buffer zones around the game reserves from 1916. Extensive campaigns were undertaken in the periods from 1929-1930, which included the corridor, and later in 1942-1950 in the area that included iMfolozi (Mentis 1970). During these campaigns over 96 000 wild animals were destroyed with only black and white rhino spared. Hluhluwe Game Reserve was left untouched during this period. Another effort aimed at trapping tsetse fly using Harris flytraps (Mentis 1970). A major campaign was also undertaken to clear the woody vegetation on which the tsetse flies depended. Thus all woody plants were initially cleared in buffer zones around the reserves and subsequently on a limited scale in the thicket within the Hluhluwe Game Reserve. None of the above efforts were successful in completely eradicating Nagana from the area and new strategies had to be employed (Macdonald 1979). *Trypanosomiasis* was finally eradicated from the region by aerial spraying with DDT and BHC between 1947 and 1952 (Brookes and Macdonald 1983).

*Human population through time*

The first mention of human population numbers in Hlabisa was in 1899 when densities in the entire area were estimated at approximately 6 people per $km^2$. This figure was composed of isiZulu-speaking people only as there were no white settlers in Hlabisa at this stage. By 1911 the density of isiZulu-speaking people in the communal areas had increased to *ca.* 19/km$^2$, while there were only 60 white settlers living in the district. By 1980 the population density in the communal areas had risen to *ca.* 91.4 people/km$^2$ while the density of people living on commercial farms was *ca.* 4.4 people/km$^2$. By 2001 the human population density in Hlabisa had increased to *ca.* 151 people/km$^2$ in the communal areas and to *ca.* 5.6 people/km$^2$ on commercial farms. Throughout this period one can assume the population density inside the Hluhluwe and iMfolozi reserves to have remained consistently low. The total number of people living in Hlabisa (Fig. 3.2) can be seen to have increased from 14 923 in 1911 corresponding to an average density of 3.9 people/km$^2$ to 218 445 in 2001 corresponding to an average density of 56.7 people/km$^2$. However the average densities mentioned above are very skewed as most of the people living in the district are found in the communal areas which comprises approximately one third of the district, while the majority of land in the district has very low human densities.

The number of people living in communal areas in Hlabisa can be seen to have increased rapidly in the 20$^{th}$ century (Fig. 3.3). In 1911 there were under 15 000 (19 people/km$^2$) increasing to *ca.* 215 000 (151/km$^2$) in 2001 (Fig. 3.3). The slight decrease in population density in 1970 corresponds to the formation of KwaZulu when records are likely to be slightly inaccurate. The number of people living on commercial farms (Fig. 3.4) has remained consistently low relative to the communal areas. The entire white population in Hlabisa comprised only 60 people in 1911, gradually increasing to its maximum of just less than 4000 in 1991 after which the total white commercial population decreased again to reach *ca.* 2500 in 2001. This somewhat surprising decrease in population numbers most likely corresponds with the move towards fewer bigger farms evident in the area today. The number of people living in areas under commercial tenure would actually have been substantially higher as the census data does not include black people living on white owned farms. However if these numbers were taken into account they would not significantly increase the overall human densities in the commercial areas as the majority of farmers would not have had high numbers of labourers living on their farms. Furthermore, the impact that these labourers would have had on the vegetation would be mostly limited to the areas surrounding their homesteads on the farms.

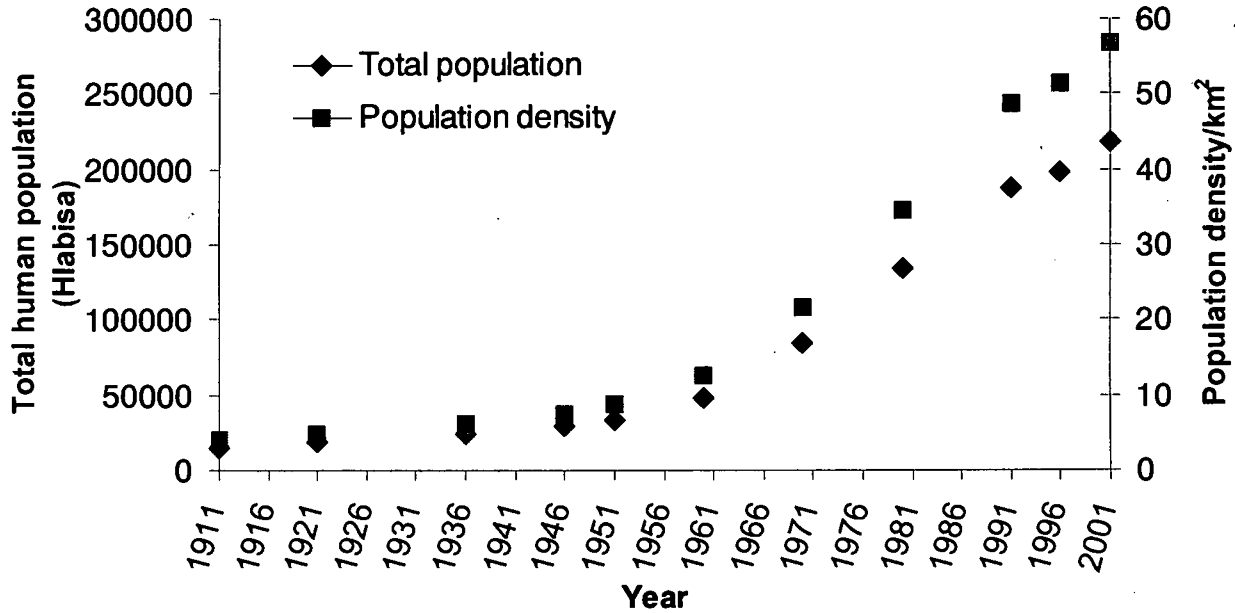


Figure 3.2. Total population and average population density for the Hlabisa district (1911 – 2001) plotted from census data.

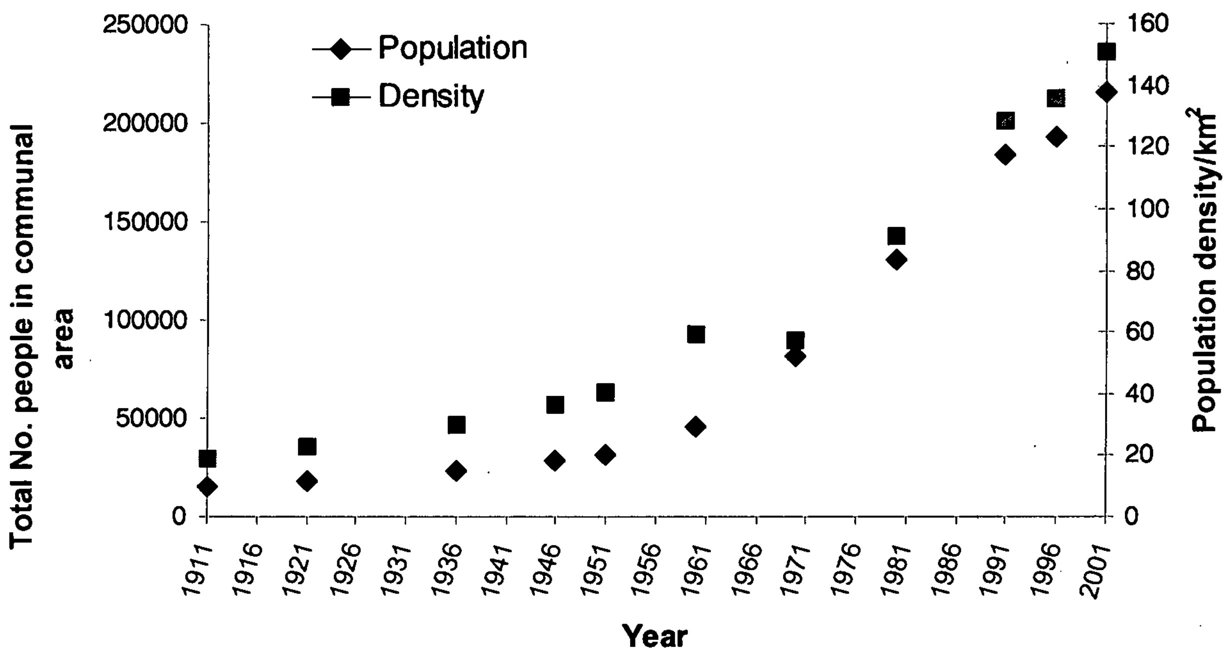


Figure 3.3 Total population and population density of people living in the communal areas of Hlabisa (1911-2001) plotted from census data.

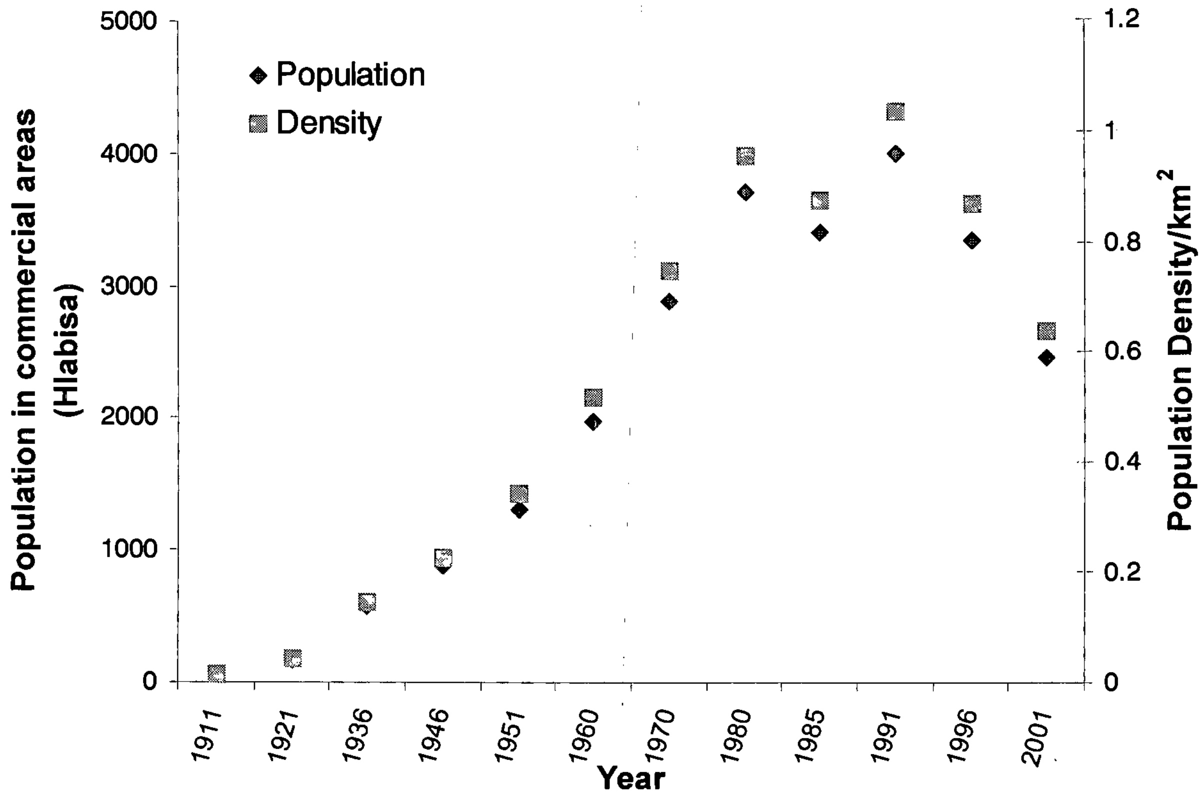


Figure 3.4. Total white population and density in Hlabisa, roughly corresponding to the number of people living in the commercial farming areas (1911-2001) plotted from census data. The plotted data is substantially lower than actual total number of people as they do not include black people living on the farms.

*Stocking Rates*

*Stocking rates in the communal areas*

All animal stocking rates in this chapter have been converted to Large Stock Units (LSUs) where 1 LSU = one 450 kg cow (Meissner *et al.* 1983). According to this conversion rate an adult goat or sheep is approximately 0.17 LSU. These conversions were performed in order to allow direct comparisons between land use systems. Historical records indicate that the Rinderpest outbreak in 1898 killed around 80 % of all cattle in Zululand (Macdonald 1979). It can therefore be assumed that cattle numbers owned by communal farmers in 1927 had gradually increased to the numbers indicated in Figure 3.5 (around 47 000). The extent of the communal areas in the Hlabisa district has remained fairly constant since the "Native Reserves" were set up in the early 1900s at around 1424 km$^2$. Thus, we can be fairly confident in the stocking densities shown in Figure 3.5, which showed a steady increase up until the late 1940s after which the density rapidly decreased. This decrease corresponds to the Nagana outbreaks in the area during the late 1940s and early 1950s. Following the eradication of Nagana during the so-called Nagana campaign during the 1950s, stocking densities steadily increased again and remained high until the early 1980s. The mid 1980s corresponded to another crash in cattle numbers possibly as a result of the severe drought followed by intense flooding during Cyclone Demoina in 1984. By the 1990s cattle numbers had recovered to earlier levels although since 1995 they have plummeted to densities similar to those following the Nagana outbreak during the late 1940s (42655 LSU or 30 LSU/km$^2$).

Goat numbers in Hlabisa (Fig. 3.6) show a fairly similar trend to cattle numbers with an initial increase from 1927 (3922 LSU) to the late 1930s. Goat numbers then decreased until 1950 after which they steadily increased reaching relatively high levels in the late 1950s and 1960s. No data was available until the mid 1980s. Goat numbers in the 1980s were initially higher than in the 1960s but then declined, and continued to do so for the next decade.

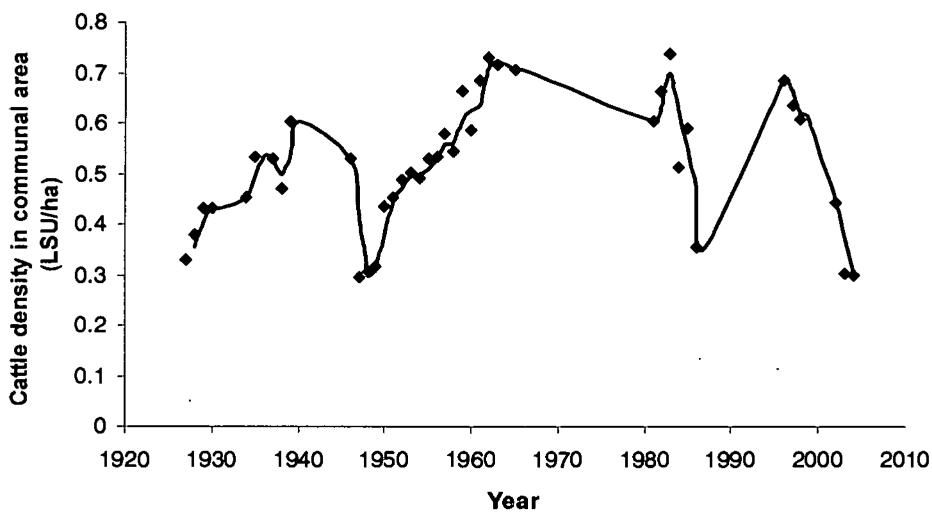


Figure 3.5. Total cattle density (LSU/ha) in the communal areas of Hlabisa (1927 – 2004 census data), the trendline shows the two yearly moving average.

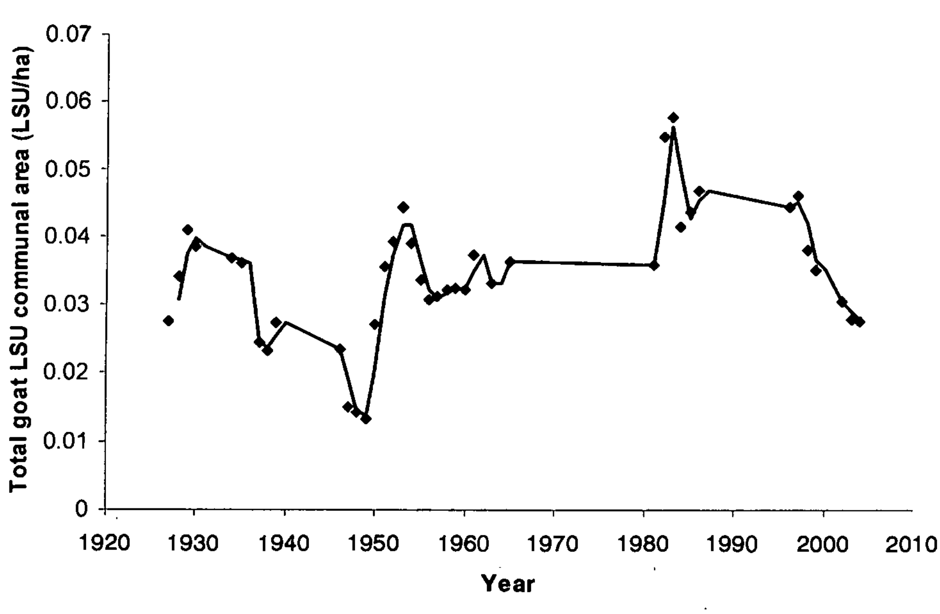


Figure 3.6. Total goat densities in the communal areas of Hlabisa (1927 – 2004 census data), the trendline shows the two yearly moving average.

*Stocking rates in the commercial areas*

Prior to 1911 there were unlikely to have been many cattle and goats in the commercial areas of Hlabisa as there were very few people in the area. The period from 1927 to the late 1950s, except for a decline in the years following the Second World War (1945 – 1950), showed a steady increase in cattle numbers and densities on commercial farms in Hlabisa (Fig. 3.7 and 3.8). The densities shown in Figure 3.8 reflect total cattle numbers for the district divided by all commercial land in the district, thus they are not true densities as many other farming activities such as cultivation of crops and sugarcane would have been taking place on some of the farms. The agricultural censuses do not provide the areas of land specifically under cattle farming. Thus, the true densities would be much higher than those shown here. However the plotted density is still useful as it shows the overall trend of cattle densities for commercial farms in the Hlabisa district through time. This trend shows a decrease in cattle numbers from the mid 1960s through the early 1980s after which there was a slight increase in the 1990s before numbers dropped to their lowest total yet in 2004 (3661 cattle).

Goats have never been farmed on a large scale in the commercial areas of the Hlabisa district, with the census data showing that most of the goats found on the commercial farms actually belonged to the farm labourers living on the farms. Figure 3.9 shows the number of goats on commercial farms to have increased during the late 1920s and early 1930s. However since the 1930s goat numbers and densities have never been considerable on the commercial farms in the Hlabisa district. The cattle to goat ratios (Fig. 3.10) for the commercial and communal areas show that there was a consistently lower ratio of cattle to goats in the commercial area. The commercial areas were therefore predominantly utilized by grazers while the communal areas were utilised by both grazers and browsers for the period between 1927 and 2004.

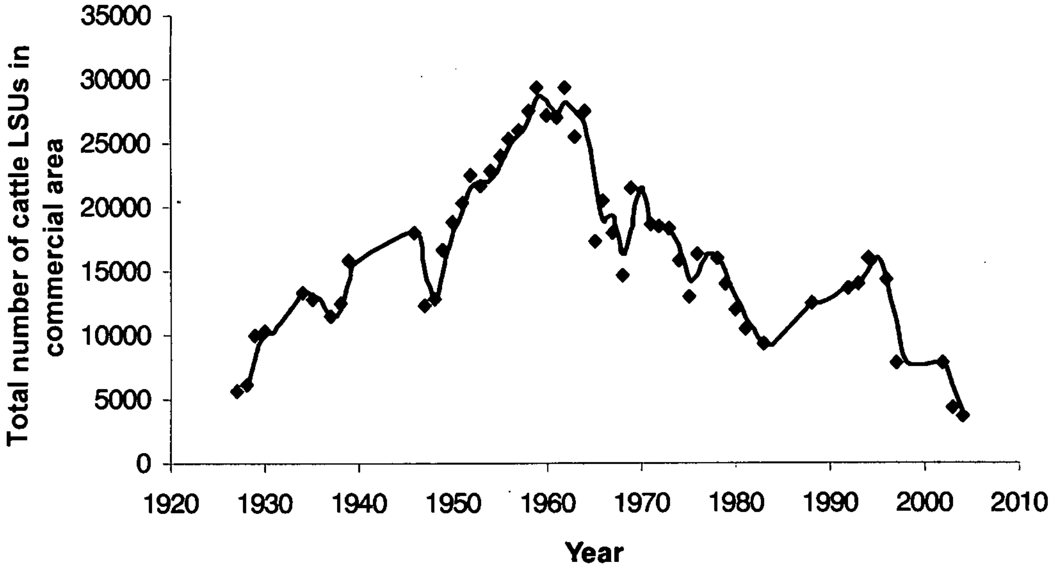


Figure 3.7. Total cattle LSUs in the commercial areas of Hlabisa (1927-2004 census data), trendline shows the two yearly moving average.

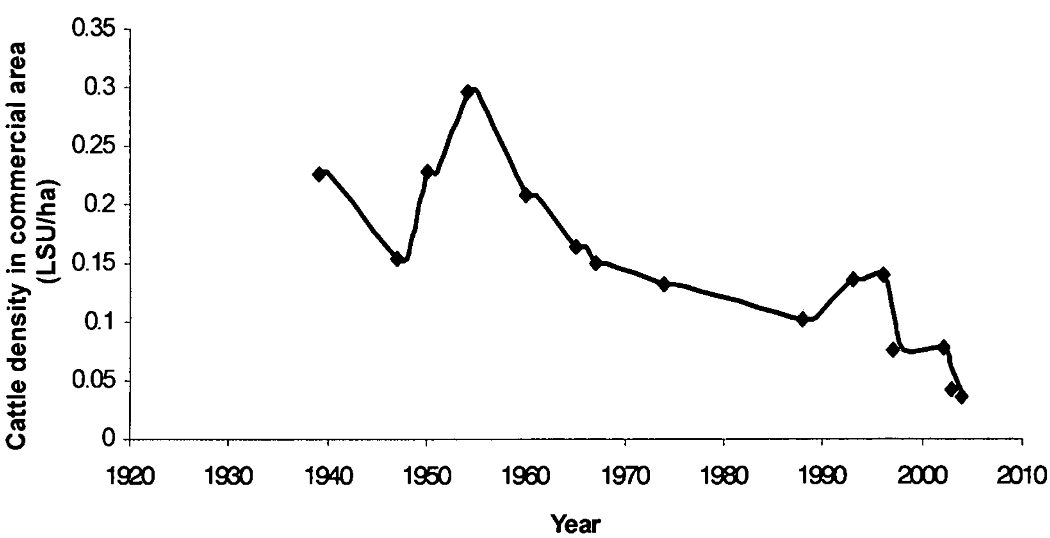


Figure 3.8. Total cattle densities for the commercial areas of Hlabisa (1939 – 2004 census data). I was unable to find data on total area under commercial tenure prior to 1939. The trendline shows the two yearly moving average.

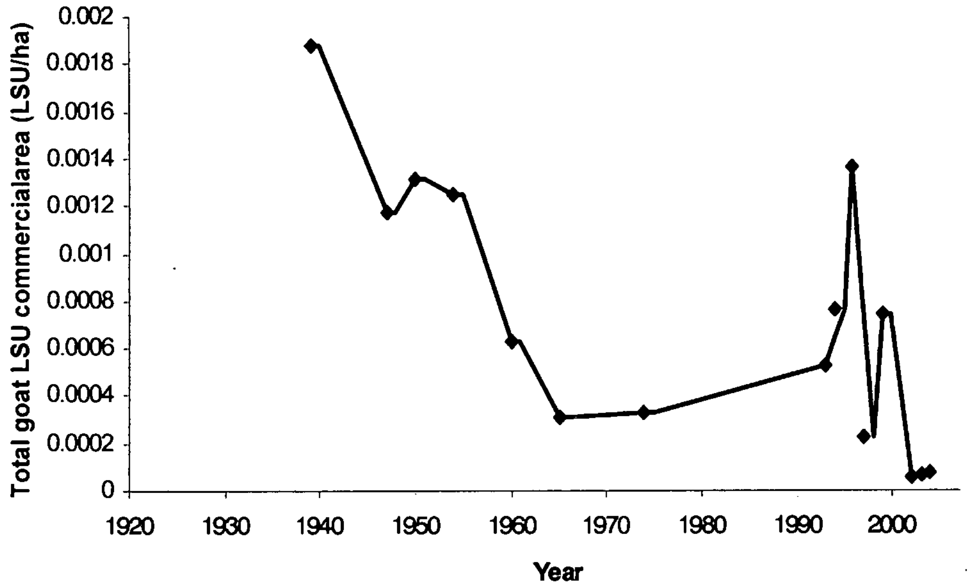


Figure 3.9. Total goat densities for the commercial areas of Hlabisa (1939-2004 census data).

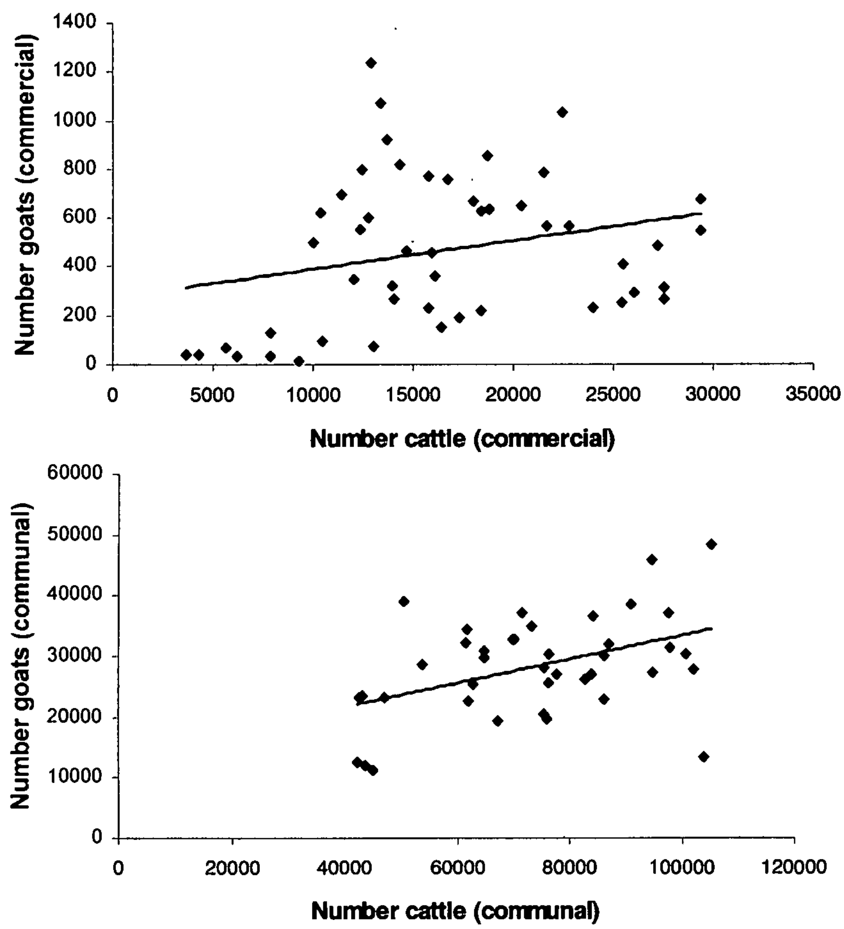


Figure 3.10. Cattle to goat ratios for the commercial area (top) and communal area (bottom). Data plotted from census data for the period 1927 -2004. Note the different scales.

*Stocking rates in the conservation area*

An outbreak of rinderpest in 1896 is known to have reduced game populations throughout Zululand and animal numbers did not begin to recover until 1905 (Brooks and Macdonald 1983). There were also a number of Nagana outbreaks in the area between 1914 and 1952. These outbreaks would have had major impacts on animal numbers in the park especially the iMfolozi Game Reserve and the corridor section where almost all of the animals were destroyed during the Nagana campaign. Brookes and Macdonald (1983) produced an ecological case history for HiP. In their paper they provided stocking rates for the reserve from 1929 till 1982. Their data have been updated with more recent stocking data for the park now covering the period from 1929 till 2003.

The stocking rates for Hluhluwe Game Reserve were converted into LSUs (Meissner *et al.* 1983). Total LSUs for Hluhluwe Game Reserve are plotted (Fig. 3.11) then total herbivore densities were calculated and plotted as LSU per ha (Fig. 3.12). A clear trend is evident showing a steady increase in herbivore densities. Herbivore densities in the park increased until the late 1960s then rapidly decreased during the early 1970s. Numbers had recovered slightly by the late 1970s after which they decreased substantially during the early 1980s. Numbers and densities of herbivores in Hluhluwe then gradually increased during the 1980s and 1990s. Herbivore densities have remained at these relatively high densities till present

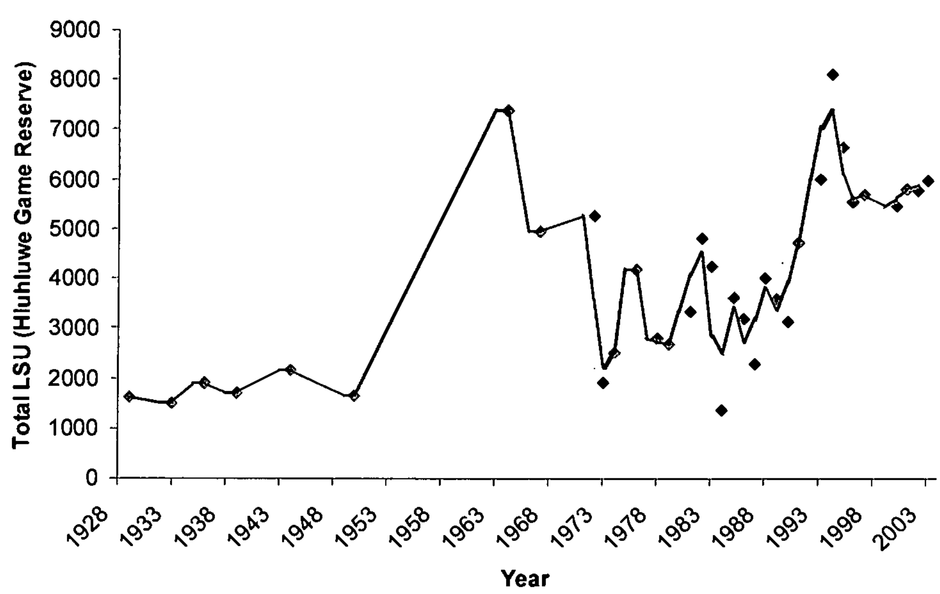


Figure 3.11. Total large stocking units (LSU) for Hluhluwe Game Reserve (1928 –2003, Park census data). Numbers of all counted herbivore species were converted into LSU, combined then plotted.

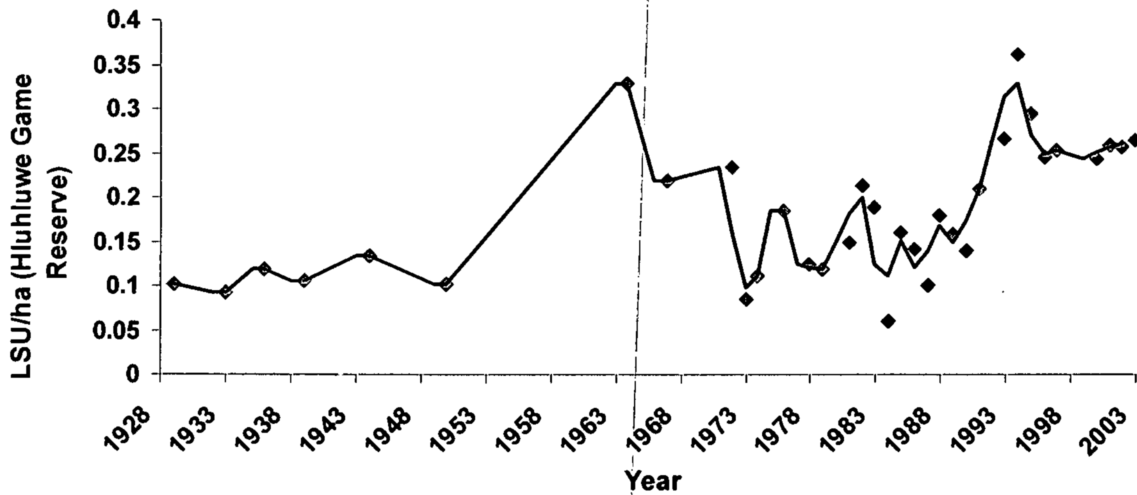


Figure 3.12. Animal densities LSU/ha for the Hluhluwe Game Reserve (Park census data, 1929 to 2004).

The main herbivore species in Hluhluwe Game Reserve were divided into functional feeding types (grazers, browsers and mixed feeders) then converted into LSUs (in order to determine what impacts the different feeding types would have had on the vegetation of the park through time. Buffalo, white rhino, waterbuck, warthog, wildebeest and zebra were included in the grazer feeding type. Giraffe, kudu, nyala and black rhino were included in the browser feeding type. Impala and elephant were included in the mixed feeder feeding type. The proportions of each feeding type remained fairly constant until the 1990s after which the numbers of grazers in Hluhluwe can be seen to decrease alongside a substantial increase in browser and mixed feeder types (Fig. 3.13). The densities of the three feeding types (Fig. 3.14) have been plotted to allow comparisons between the commercial and communal areas.

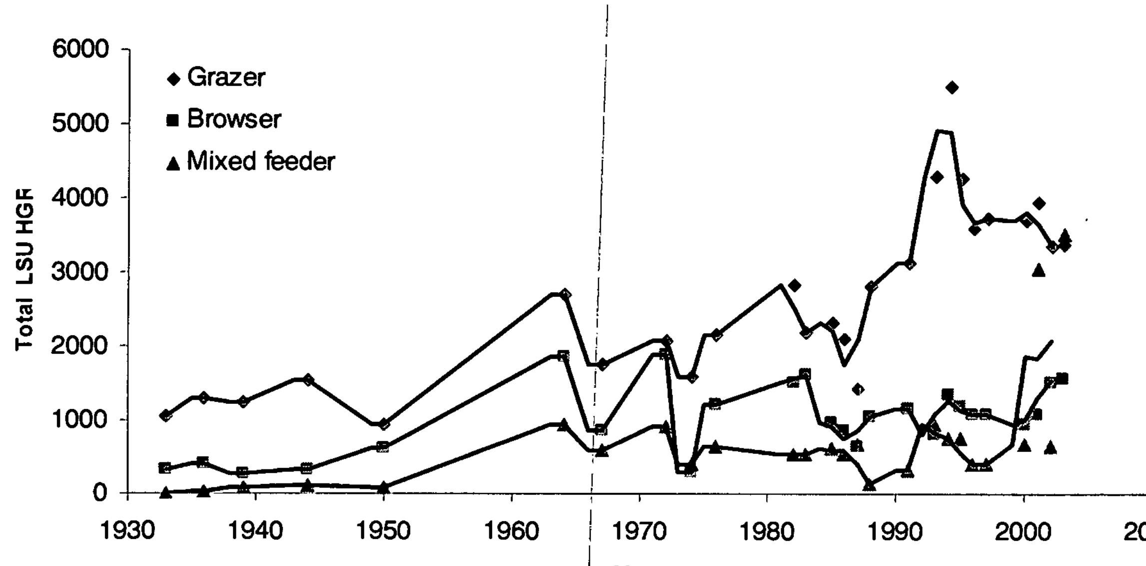


Figure 3.13. Herbivore LSUs divided into feeding types for Hluhluwe Game Reserve (HGR) through time. Total biomass of grazers, browsers and mixed feeders are plotted (1933-2003).

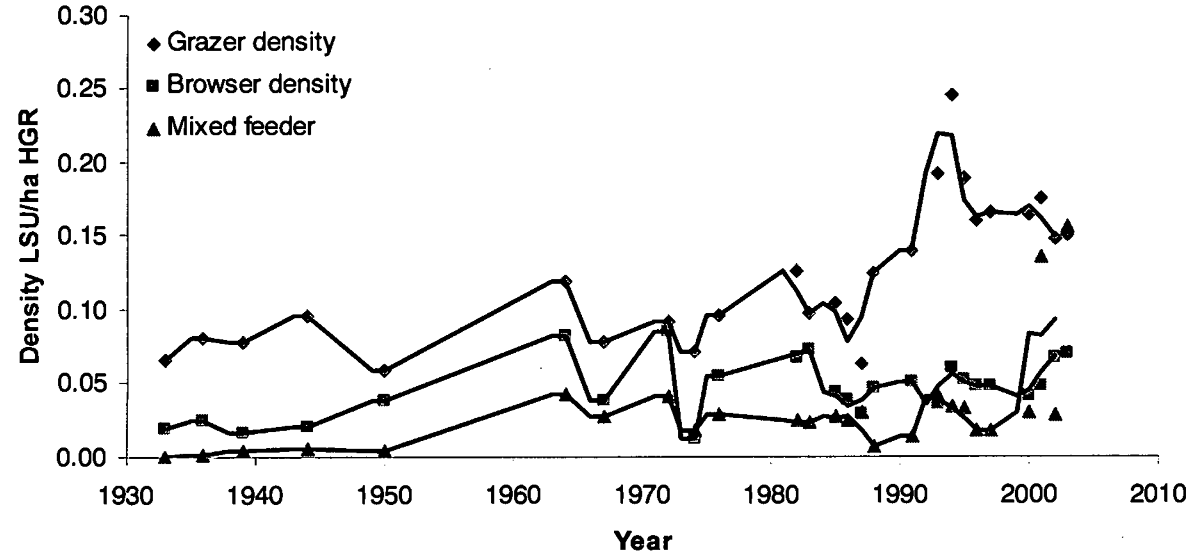


Figure 3.14 Total densities of the functional feeding types for Hluhluwe Game Reserve (1933-2003).

*Rainfall*

The longest rainfall data set available for the Hlabisa district is from the Hluhluwe Game Reserve, where monthly rainfall has been recorded since 1933. In the eastern parts of South Africa rain falls predominantly over the summer season thus rainfall has been calculated by season rather than on an annual basis. This enables the separation of summer and winter rainfall in order to determine if there have been any changes in rainfall seasonality over time. Mean annual rainfall (MAR) for the 70-year period from 1933/34 to 2003/04 (Fig. 3.15) shows a slight but not statistically significant decrease. Although wetter and drier periods are evident in the record. The decade 1934 to 1944 was an above-average wet period. The following decade until 1954 was a below-average dry period. The next ten years were once again above-average. The period from 1964 till 1974 had below-average rainfall again. The following decade ending in 1984 started off with above-average rainfall. However rainfall decreased towards the end of the ten-year cycle and the area experienced one of the worst recorded droughts with 1982 and 1983 both having less than 600 mm of rainfall. The highest rainfall on record followed this drought in 1984 with over 1600 mm falling mostly over a short time period when Cyclone Demoina resulted in devastating floods in Zululand.

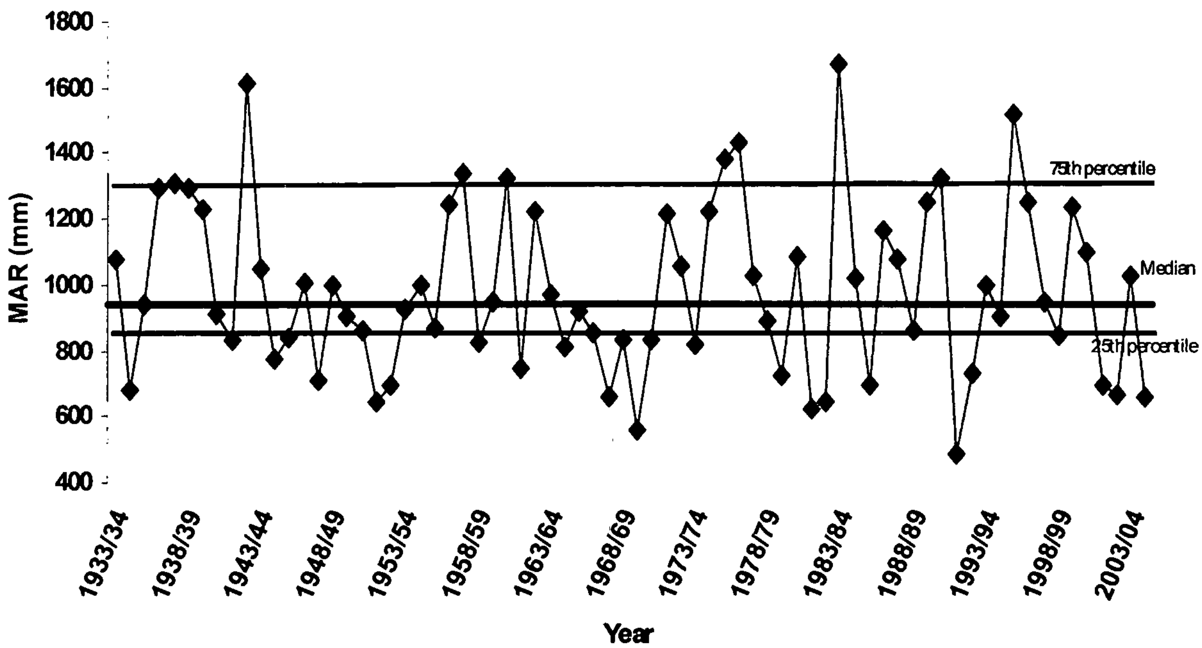


Figure 3.15. Mean annual rainfall (1933-2004) for Hluhluwe Game Reserve. Median, 25th and 75th percentiles are indicated. Years are split to include the rainfall season for each year not from January to December.

The general trend of decade-long wet and dry cycles evident for the previous five decades appears to deteriorate after 1984 with rainfall fluctuating above and below the median rainfall over the next two decades. The drought of 1992/3 was the most severe drought on record for the area while the period 2001 to 2004 was another below-average rainfall period. In order to determine if there has been a shift in the seasonality of rainfall over time I have plotted summer rainfall and winter rainfall separately (Fig. 3.16). There is no strong trend evident that suggests a decrease or shift in seasonal rainfall. The coefficient of variation (CV) for annual rainfall calculated as the SD/mean rainfall for the area was 0.26 (Table 3.1). Table 3.1 also shows that the winter CV (0.54) was much higher than the summer CV (0.28).

Table 3.1. Standard deviation, mean, median, 25th and 75th percentiles and coefficient of variation for rainfall (1933-2004) measured in the Hluhluwe Game Reserve.

| | summer(oct-march) | winter(april-sept) | Total rainfall |
|---|---|---|---|
| **Mean** | 740.6 | 243.3 | 983.9 |
| **Standard deviation** | 207.0 | 131.9 | 259.7 |
| **Median** | 707.0 | 214.4 | 944.0 |
| **Coefficient of variation (SD/mean)** | 0.28 | 0.54 | 0.26 |
| **25th Percentile** | 576.9 | 148.3 | 815.7 |
| **75th percentile** | 853.5 | 297.4 | 1220.4 |

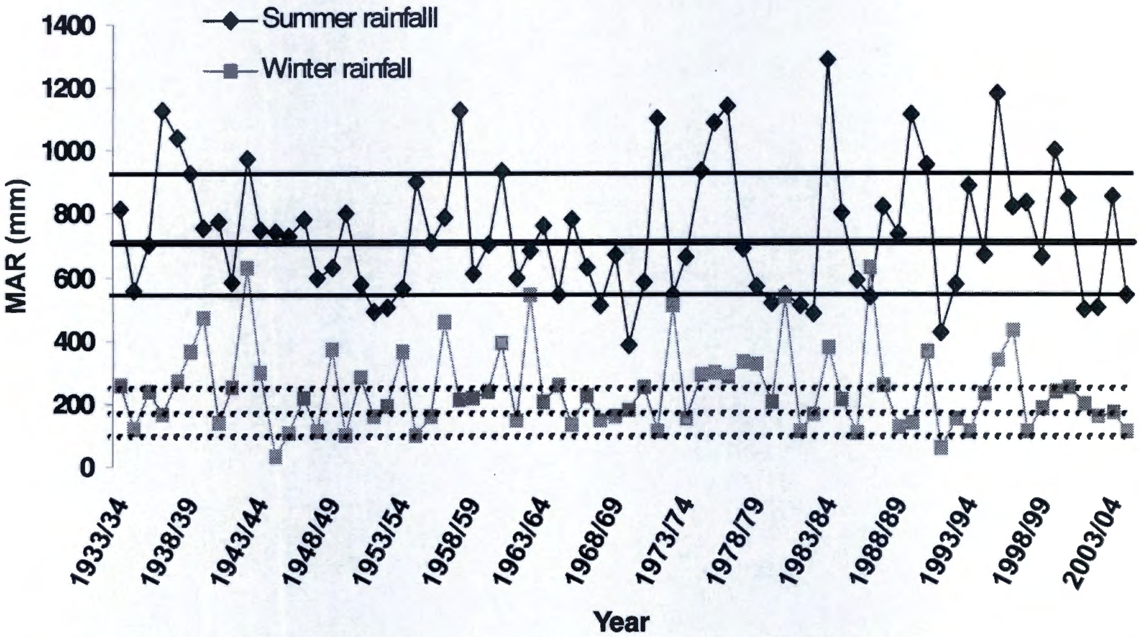


Figure 3.16. Rainfall measured at Godeni in the Hluhluwe Game Reserve. Summer rainfall (October – March) and winter rainfall (April – September) are shown with median, 25th and 75th percentiles for the period 1933 – 2004.

*Burning practices in HiP*

Henkel (1937) postulated that annual or periodic fires, ignited by man, swept through the Zululand area since the time of first occupation by Bantu settlers. From 1897 to 1911 it is unlikely that the fire regime in the Hluhluwe and iMfolozi Reserves changed much from that which had been occurring prior to proclamation (Berry and MacDonald 1979). Aitken and Gale (1921) who travelled through the area just east of the reserves in July 1920 reported that "*Scarcely a night during winter but that a grass fire is seen somewhere on the veld, and as the country is not divided into farms, a single fire may rage for three days before it dies out*". From 1920 onwards the only recorded accounts of burning practices in the area are for the conservation areas, which will be discussed in more detail below.

*Fire Regime 1920 to 1955*

Between 1911 and 1932 the Game Conservator and his staff carried out a primitive burning policy whereby the rangers patrolled the reserves and set fire wherever and whenever it seemed necessary, with some fires even being recorded in May (Vincent 1970). In 1929 the first anti-Nagana campaign was started which resulted in the placing of Harris flytraps throughout the area for the following ten years. As these traps were wooden, fire was excluded from the area for that period in order to prevent the traps from being burnt (Berry and MacDonald 1979). Aerial photography taken during the dry season of 1937 indicates a large number of fires in the area (Berry and MacDonald 1979). However these fires were usually small in extent. The records for the 1940s indicate that the iMfolozi Game Reserve and Corridor would have been burnt extensively during the dry season to improve visibility and to attract game animals during the anti-Nagana game eradication campaign (Vincent 1970). During this period the Hluhluwe Game Reserve only has records of burning the barrier clearings along the northern and eastern boundaries on an annual basis to suppress bush growth (Berry and MacDonald 1979). In 1950, the policy of indiscriminate burning was halted with very few accidental fires recorded for the following few years (Ward 1957 cited in Berry and MacDonald 1979). In 1955 the first firebreak system along the boundaries of HGR and a directive controlling all burning within the reserves was initiated (Ward 1957 cited in Berry and MacDonald 1979).

*Fire Regime 1955 to 2004*

From 1955 to present, fires in HiP have been documented and plotted in a GIS database. This has allowed useful analyses to be performed to determine whether there has been a change in the number of fires, size of area burnt, average size of fires and seasonality of burns. Balfour and Howison (2001) analysed the fire regime in HiP for the period 1956 to 1996. They found a strong relationship between rainfall, fire return interval, and total area burnt. They also found that management policy had a strong effect on fire attributes for the park. I have repeated some of the analyses including data for the period 1997 to 2004. The total proportion burnt and total number of fires for the entire complex (HiP) are plotted in Figure 3.17. Fire frequencies are shown in Figure 3.18 while the seasonality of burns is plotted in Figure 3.19.

For HiP the total proportion of the park that burnt (Fig. 3.17) increased through the 1950s, 1960s and 1970s. During the early 1980s relatively low proportions of the park burnt. However in the late 1980s and very early 1990s the total proportion of the park that burnt increased significantly. This decreased again in the early 1990s before rising again in the late 1990s and remaining relatively high in the early 2000s. There was a general increase in the total number of fires in HiP through time (Fig. 3.17). The average size of fires closely corresponds to the number of fires in HiP. Fires were generally small until the mid 1980s; this was followed by a period of widespread fires during the late 1980s. 1955 and 1987 were 2 exceptions when large proportions of the park were burnt in a few very big fires. Since the early 1990s fires in the park appear to have remained relatively small with lesser proportions of the park being burnt as a result of many smaller fires.

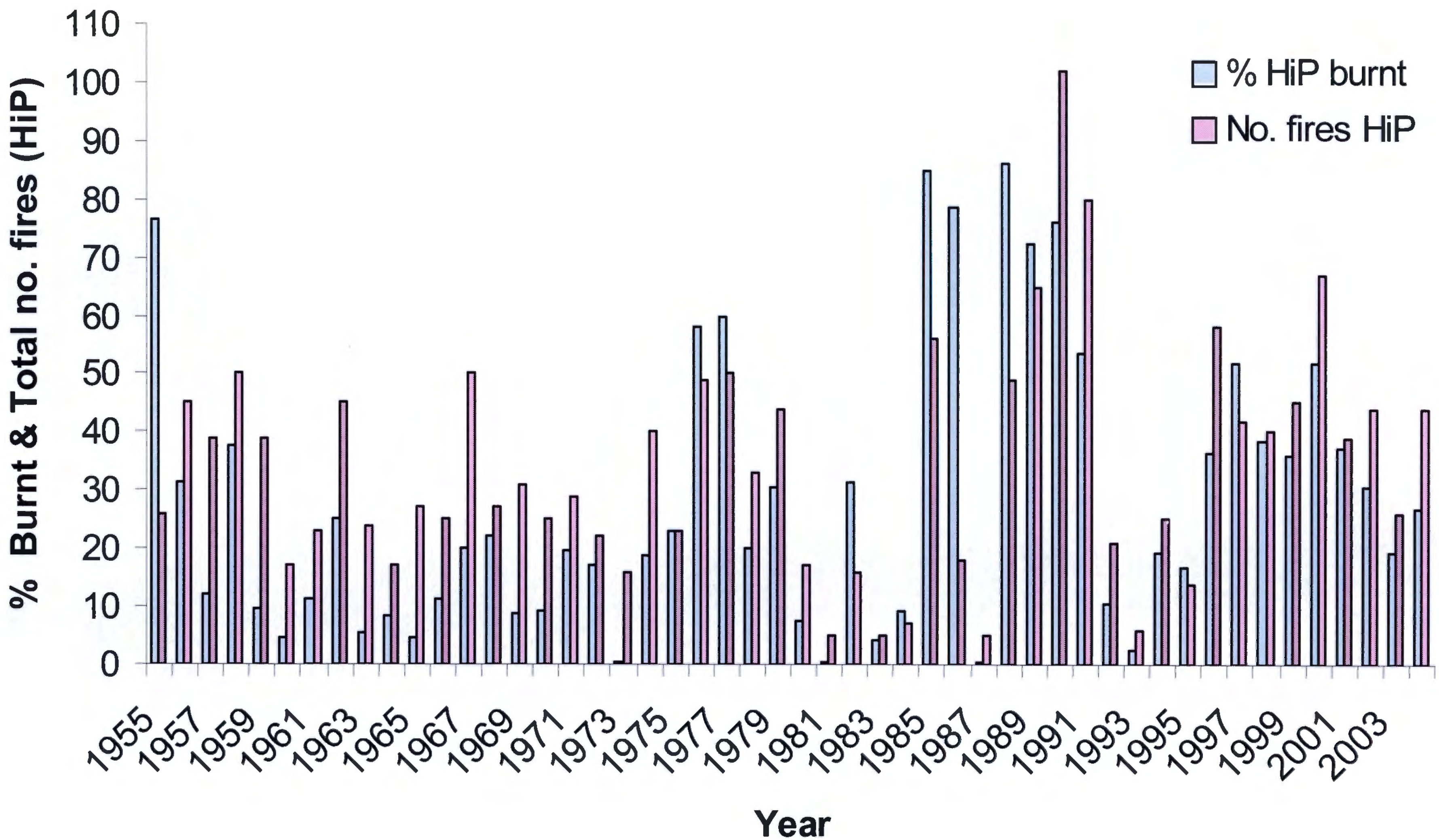


Figure 3.17. Total percentage burnt ( %) and total number of fires for the (HiP) complex on an annual basis (1955 –2004).

Table 3.2. Correlation matrix showing $r^2$ values of fire correlates for the different sections of HiP. H = Hluhluwe, C = Corridor, I = iMfolozi, HiP = Hluhluwe iMfolozi Park, TF = Total Fire, AF = Average Fire Size, AB = Area Burnt, PYR = Previous Years Rainfall, R = Rainfall. Levels of significance are as follows: ***P<0.001, **P<0.01, *P<0.05, ns not significant. Data are for the period 1955 to 2004 (n = 50). Rainfall totals were given according to season (e.g. April 2003 – March 2004), not according to year.

| | HTF | HAF | HAB | CTF | CAF | CAB | ITF | IAF | IAB | HIPTF | HIPAF | HIPAB | PYR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HAF | **-0.34*** | | | | | | | | | | | | |
| HAB | **0.314*** | **0.62***** | | | | | | | | | | | |
| CTF | 0.2 ns | -0.00 ns | **0.31*** | | | | | | | | | | |
| CAF | **0.36*** | 0.036 ns | 0.26 ns | -0.16 ns | | | | | | | | | |
| CAB | **0.43**** | 0.19 ns | **0.66***** | **0.43**** | **0.59***** | | | | | | | | |
| ITF | **0.47**** | -0.02 ns | **0.49***** | **0.62***** | 0.20 ns | **0.63***** | | | | | | | |
| IAF | 0.18 ns | 0.13 ns | 0.13 ns | -0.09 ns | **0.64***** | **0.35*** | -0.07 ns | | | | | | |
| IAB | **0.54***** | 0.27 ns | **0.68***** | **0.32*** | **0.56***** | **0.74***** | **0.59***** | **0.60***** | | | | | |
| HIPTF | **0.73***** | -0.15 ns | **0.48***** | **0.72***** | 0.2 ns | **0.64***** | **0.91***** | 0.02 ns | **0.63***** | | | | |
| HIPAF | -0.01 ns | **0.78***** | **0.65***** | -0.02 ns | **0.50***** | **0.54***** | 0.07 ns | **0.64***** | **0.66***** | 0.02 ns | | | |
| HIPAB | **0.51***** | **0.34*** | **0.81***** | **0.39**** | **0.57***** | **0.89***** | **0.64***** | **0.49***** | **0.95***** | **0.67***** | **0.69***** | | |
| PYR | **0.57***** | -0.05 ns | **0.36*** | 0.06 ns | 0.22 ns | **0.44**** | 0.28 ns | 0.12 ns | **0.42**** | **0.40**** | 0.18 ns | **0.45**** | |
| R | -0.12 ns | 0.15 ns | 0.03 ns | -0.07 ns | 0.00 ns | -0.05 ns | 0.12 ns | -0.04 ns | 0.06 ns | -0.01 ns | 0.08 ns | 0.02 ns | -0.26 ns |

Strong correlations were found between the number of fires, area burnt and average size of fires in Hluhluwe, the corridor and iMfolozi and for HiP (Table 3.2). These correlations are not surprising as they are all closely related. Of more interest are the correlations between the fire attributes and rainfall for the park. There were no correlations between the corresponding year's rainfall and fire attributes. However, a number of correlations were found between the previous year's rainfall (Measured by season i.e., April to March) and fire attributes (Table 3.2). A strong correlation was found between the total number of fires in Hluhluwe and total fires in HiP and the previous year's rainfall. Significant correlations were also found between the total area burnt in Hluhluwe, Corridor, iMfolozi and HiP and the previous year's rainfall.

Fire frequencies for HiP have been plotted (Fig. 3.18) showing that the Hluhluwe and Corridor sections have a short (1-3 year) fire return period while the fire return period for most parts of iMfolozi is much longer (between 3 and 10 years).

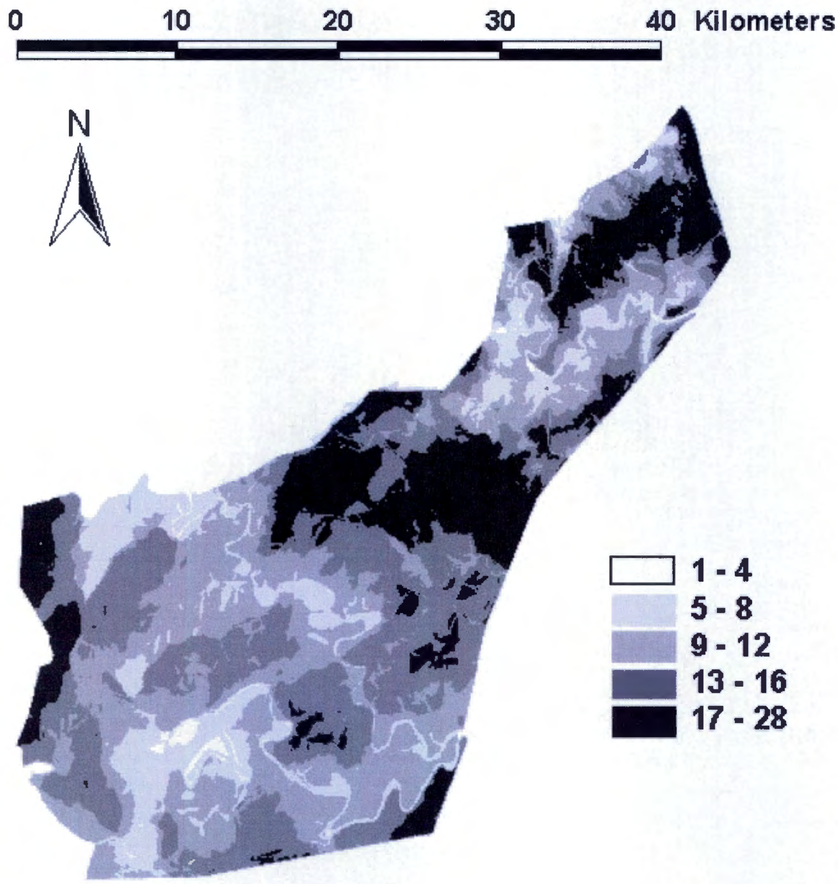


Figure 3.18. Fire frequencies in HiP for the period 1955-2004. The legend indicates the total number of burns in the 49-year period. The short fire return interval evident in the north eastern section of the reserve corresponds to the conservation study site. The fire frequency map was generated in ArcGIS by overlying all fires from 1955 to 2004 and then calculating fire frequencies.

The seasonality of fires in HiP (Fig. 3.19) has shown some clear changes through time with a higher proportion of summer, autumn and spring burns until the late 1970s. This was followed by a period of predominantly winter burns, which corresponds, to the increased area and average size of fires during the 1980s. Since the early 1990s fires in Hluhluwe have mostly occurred in spring and winter with very few fires in summer and autumn.

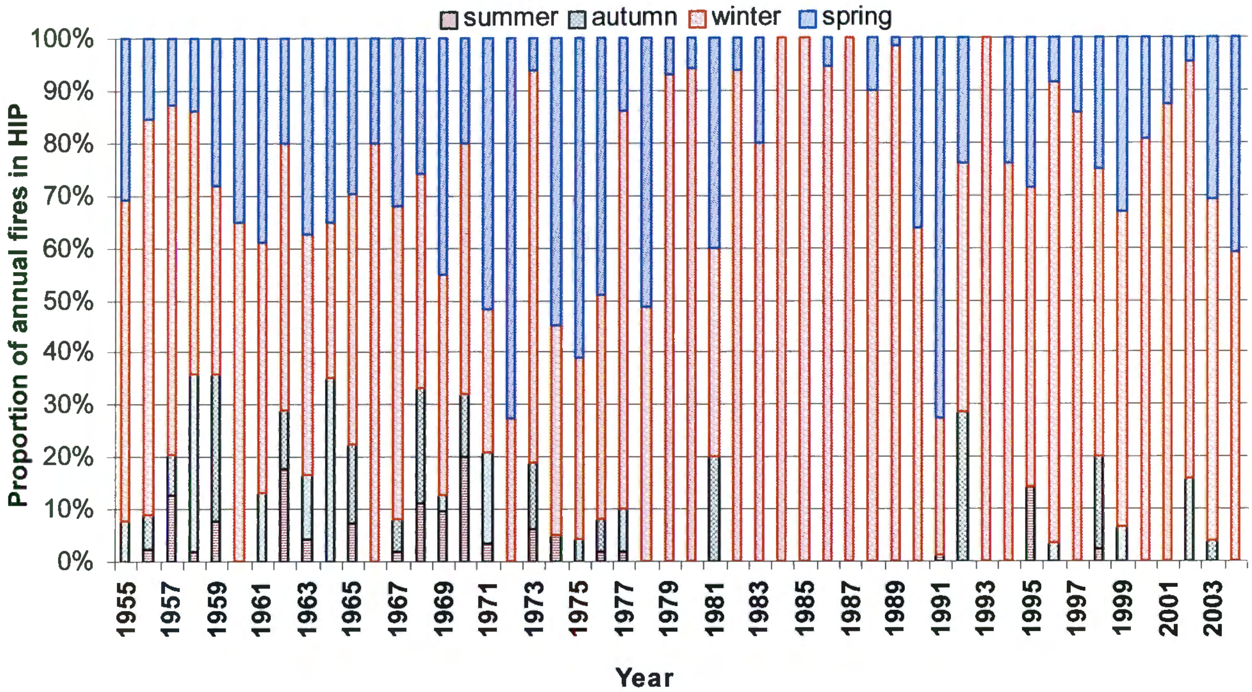


Figure 3.19. Seasonal annual proportions of fires for (from top to bottom) Hluhluwe, Corridor, iMfolozi and HiP (1955 –2004).

*Discussion*

This historical account of Hlabisa and the changes in land use practice and management evident from the results presented above have begun to provide the basis for a better understanding of the major changes that might have affected ecosystem processes at the landscape scale. The historical backgrounds of the three study sites prior to colonization are much the same. The area was thought to be widely used by Iron Age farmers (Feely 1978). The impacts that these early settlers would have had on the vegetation are still widely debated with some arguing for large impacts following clearing of land for the planting of crops and iron smelting. However the focus of this study was on vegetation changes in the last century and on differences in past land use practices and management of the three study sites. Up until the late 19$^{th}$ century, the area was widely settled by AmaZulu peasant farmers. One exception was the area between the White and Black iMfolozi Rivers, which was a traditional royal hunting ground for Zulu royalty and was not settled by AmaZulu farmers. This area now falls within the boundaries of the iMfolozi Game Reserve. All three of the study sites have a similar density of streams running through them and are of similar distance to the Hluhluwe River so that the distribution of water would have had a similar effect on settlement.

The status quo was significantly disrupted in the late 19$^{th}$ century with the arrival of Europeans in the area. Although Britain annexed Zululand in 1887 the effects of British rule would not have affected the AmaZulu farmers settled in the area until 1897 when the Hluhluwe and iMfolozi Game Reserves were proclaimed. This is supported by Henkel's (1937) report, which showed that in 1897 when the boundaries of the game reserves were demarcated there were a number of Zulu kraals both inside and surrounding the Hluhluwe Game Reserve. In 1897 Zululand was annexed to the Colony of Natal and three years later Zululand was divided into the so-called 'native reserves' for AmaZulu settlement and areas for European settlement. Thus it was during this period in the early 20$^{th}$ century that the history of the three areas under investigation in this study diverged. At this point the communal areas surrounding the Hluhluwe Reserve were officially declared while the area to the east of this was allocated to European settlement. This area was further subdivided into farming units and settled by white farmers in the early 1900s. The boundaries between the areas under different tenures have remained much the same since then. The period from the early 1900s till present is therefore of the most interest to us as this is when land use practices in each area diverged.

The most striking difference between study sites since the early 1900s has been the change in human population densities in each area. In the Hluhluwe iMfolozi Park human numbers have remained essentially negligible since the removal of people from the park subsequent to proclamation. In the commercial areas human densities have remained below 1 person/km$^2$ since first settlement. Thus, direct human impacts on the vegetation in the commercial areas will have remained consistently low, excluding land cleared for crops. In the communal areas there has been a significant increase in human densities from about 20 people/km$^2$ in 1911 to more than 150 people/km$^2$ in 2001. The majority of people living in these areas still rely on firewood for cooking and heating and other woody materials are extensively used for building and fencing. Many people's livelihoods further depend on natural resources in the area (e.g. natural medicines, wood for carving curios). These high human densities would undoubtedly have had substantial direct impacts on the vegetation of the area. Thus as human numbers increased in the communal areas their impacts on the environment would have increased proportionally.

Animal densities in the area would have been fairly similar across the landscape up until the end of the 19$^{th}$ century. The first noticeable changes in the conservation area would have been after the proclamation of the Hluhluwe and iMfolozi Reserves. At this stage animal numbers in the reserves would have been fairly low. The reserves were set up to protect game species whose numbers were dwindling throughout the area. The widespread occurrence of Nagana over the next 50 years would have kept numbers low especially in iMfolozi and the corridor where wild animals were purposefully destroyed in an attempt to control Nagana. The eradication of Nagana during the 1950s would then have allowed animal numbers to recover and start increasing. It wasn't until the 1960s that herbivore numbers reached densities that had the potential to influence the vegetation on a large-scale (0.2 – 0.3 LSU/ha, Fig. 3.12). Animal densities in the park dropped off steeply during the late 1970s due to management intervention and population control. Herbivore densities were perceived to be too high and thus a decision to control densities through culling was made at this time (Brooks and Macdonald 1983). Herbivores appear to have been maintained at fairly consistent densities until the mid 1980s. The densities of all feeding types decreased in the mid 1980s most likely as a result of the extreme drought followed by heavy flooding in the early 1980s. The densities of all feeding types had recovered by the early 1990s. An interesting phenomenon is evident since then whereby grazer densities have shown a steady decrease while browser numbers have shown a moderate increase and mixed feeder densities have increased rapidly. The question being addressed is whether these changes in stocking densities are likely to have driven changes in vegetation patterns evident in the park.

The available data suggests that during the 1960s and early1970s numbers were potentially high enough to cause overgrazing in the conservation area. The fire records for that period show that both the area burnt and the average size of fires (Fig. 3.17) during this period were lower than the period from the late 1970s to present. However, this period also coincides with a dry rainfall cycle (Fig. 3.15). The combination of low rainfall and high animal numbers would undoubtedly have affected the fire regime. The extensive drought during the late 1960s combined with high animal numbers would have affected the vegetation. The collapse in animal numbers following the drought of the late 1960s combined with good rainfall after the drought could have led to a major recruitment event for woody species. However, Brooks and Macdonald (1983) and results from the following chapter show that bush encroachment was already underway during this period. A similar recruitment event for woody species would have occurred after the drought of the early 1980s, which was followed by Cyclone Demoina. However herbivore numbers prior to the drought were being regulated by culling with more animals culled during dry years then wet years (Brooks and Macdonald 1983).

Herbivore numbers have since been allowed to increase and fluctuate according to natural processes. Buffalo are an exception as a number of animals infected with bovine tuberculosis are culled annually. A steady increase in woody plant densities has accompanied this increase in animal numbers in large parts of the Hluhluwe Reserve. The changes to the densities of the different herbivore feeding types in the last 15 to 20 years is most likely to correspond to increased woody cover in the reserve. The loss of pasture would explain the decreased grazer numbers while increased browse availability would explain the increase in browser and mixed feeder densities.

The stocking densities in the communal areas show a very different picture. Cattle numbers have been consistently high since the mid 1920s. The current government recommended stocking rate for the area is 4-5 ha/LSU or 0.25 LSU/ha. Thus stocking rates in the communal areas have been maintained at levels exceeding the recommended stocking rate since *ca.* 1927 (0.3-0.8 LSU/ha, see Fig. 3.5). This is consistent with South African communal areas in general, which are stocked at about 1.8 times the recommended stocking rates (Hoffman and Ashwell 2001). The records show that cattle numbers increased steadily until the mid 1940s. With the eradication of Nagana in the area numbers steadily increased reaching levels exceeding 0.8 LSU/ha by 1960. Records are lacking for the 18-year period between 1965 and 1983. However numbers during the early 1980s were still at levels between 0.6 and 0.7 LSU/ha. Thus, one can assume numbers remained fairly stable during this period. Communal cattle numbers decreased significantly after the drought of 1982-1983. Numbers appeared to recover by the mid 1990s but have since dropped to densities similar to 1926 (0.3 LSU/ha). The recent figures are possibly an underestimate as cattle numbers are counted when taken for dipping at government dipping tanks. However, after 1995 the government policy, which previously provided dip for communal farmers, collapsed and has only recently being reinstated. This would have led to some uncertainty in stock numbers as some communal farmers may no longer have taken their cattle to the dipping tanks, thus these animals would not have been included in the counts. Despite the uncertainty in numbers after 1995 it is clear from the data that cattle numbers in the communal areas have remained consistently high (0.3-0.7 LSU/ha) throughout the period of woody plant thickening. The general perception taken from the interviews with elders in the area is in strong agreement with the above data. The majority of the interviewees claimed that cattle numbers were retained at high levels for as long as they could remember.

Goat numbers in the communal area show a similar trend to cattle numbers. Goat numbers have remained consistently high through till the late 1990s after which they declined to levels similar to 1926. Thus the communal areas have had high grazer and browser stocking rates throughout the period of interest.

Commercial stocking rates show a very different pattern to both the communal and conservation areas. Cattle numbers increased steadily from 1925, peaking in the mid 1950s. Cattle numbers then remained high for the next ten years and decreased steadily over the following 40 years reaching the lowest levels yet in 2005. The steady decrease in cattle numbers can partially be explained by the switch to game farming in the area, which started in the late 1970s. This trend rapidly increased in the 1980s and 1990s with very few cattle farmers left in the area at present. Game stocking densities in the commercial areas were usually not available. However interviews with the landowners suggest that most of these farms have maintained low stocking densities of game species. Furthermore it would usually take a while for game species to reach high densities. The cattle densities provided in the results were substantially underestimated as they were calculated by dividing total commercial cattle numbers in Hlabisa by total area of the district not under conservation or communal tenure. Thus all areas owned by commercial farmers were included yet not all of the farmers in the district were farming cattle. Despite being significantly underestimated cattle densities were still above the recommended rate during the 1950s and 1960s. This suggests that the cattle densities were significantly higher than the recommended rates for an extensive period. Goat numbers in the commercial areas were found to be negligible. This switch in animal assemblages would have had significant impacts on the vegetation as browsers were essentially removed from vast areas leaving only grazers behind. Trollope (1983) showed that the removal of browsers (goats) from Eastern Cape Thornveld led to increased densities of *Acacia karroo* compared to areas utilised by both grazers (cattle) and browsers (goats).

The communal area has maintained high densities of both grazers and browsers for at least the past 80 years. The commercial area underwent a period of high grazer stocking rates lasting from around 1950 to 1980. For the period 1980 to present, cattle densities decreased on many commercial farms and browsers and mixed feeders were often reintroduced. For the conservation area total herbivore densities have been maintained at relatively low levels until the mid 1990s after which total herbivore densities have reached levels higher than 0.25 LSU/ha (Fig. 3.17). The main differences between Hluhluwe Game Reserve and the other two sites is that Hluhluwe has maintained the full compliment of feeding types since 1897; the commercial area has maintained mainly grazers while the communal areas have maintained grazers and browsers.

The above results show that there have been clear differences in historical stocking rates between the areas under contrasting land use practices for *ca.* the last century. Furthermore, each area has had completely different animal assemblages on them for this period. These differences and the resulting implications for the vegetation in each area would be considerable.

The long-term patterns in rainfall for the area show that there has not been a significant change in rainfall for the period 1934 to 2004. The results also show that there has not been a significant shift in seasonality of rainfall. Thus it is unlikely that differences in rainfall can be used to explain the changes in vegetation evident at each study site.

The fire records for HiP are fairly extensive going right back to 1955. Unfortunately this only covers the park and no records exist for the communal and commercial areas. One potential record we could potentially utilise for these areas is Landsat imagery, which goes back to 1978. Oral histories from the landusers in these areas suggest radically different histories for the commercial areas and communal areas. Early Portuguese travellers passing through the area referred to Zululand as "terra do fogo " (land of the fire) due to the widespread fires that used to rage throughout the Zululand area. Thus, prior to the diversion in land use at the study sites it is likely that widespread fires would often have covered the entire area. The commercial cattle farmers who settled in the area were said to have kept extremely high stocking rates, which would have excluded fire. The soil conservation committee, which was set up in the area, also advised farmers not to burn while permission had to be provided to the farmers before burning commenced. Thus fire was effectively excluded from most of the commercial cattle farms for a major part of the 20th century. On many farms, fire was only reintroduced as a management tool after the switch to game farming. However by this time substantial areas had been converted to broadleaved thicket or become heavily encroached by fine leaved woody species such as from the genus *Acacia*. Thus the intensity of fire was significantly reduced in many areas, while in encroached areas fire would often be completely excluded due to the loss of the grass layer.

In the communal areas a very different picture emerges from the oral histories. Fire has always being used as a tool to remove moribund grass and promote new growth, for tick control and for clearing areas for cultivation. It was claimed that prior to roughly the 1950s, fire was used in a controlled and systematic way. The interviewees suggested that fire is no longer managed and carefully controlled as it used to be in the past. This is due to a number of reasons including declining respect of traditional authorities in the area. Thus fire is said to be more frequent and uncontrolled at present. This has led to a much more heterogeneous fire regime in the communal areas with fires now occurring throughout the year leading to a range of intensities and sizes. However unlike the commercial farming areas, fire has continued to be used extensively throughout the last century.

An important finding from the fire data for HiP was that fire frequency and total area burnt were both significantly correlated to the previous year's rainfall for the Hluhluwe Reserve and Corridor section yet not for iMfolozi. This suggests that rainfall was the most important factor affecting the fire regime for the past 50 years in the park. Thus, despite different management objectives during this period, rainfall was an important factor affecting the outcome. This is in strong agreement with Balfour and Howison (2001) for HiP and Govender *et al.* (2006) for the Kruger National Park. Although management has manipulated fire in HiP to some extent the records show that fire has continued to frequently burn large parts of the reserve, especially the mesic areas in the north since 1955 (fire return interval of <2 years). The season of burn is most likely to have the biggest ecological effect on the vegetation. HiP management have maintained a policy of cool burning for an extensive period. Thus fires are usually started in early winter before the vegetation becomes too dry or in spring after some greening has occurred subsequent to the first spring rains. These cool, low intensity fires would have a lesser effect on the woody vegetation. Cool fires would result in a lower escape height (Bond and van Wilgen 1996) for the savanna tree species and would result in less damage to coppicing resprouters. These cumulative effects could partially explain the increased densities of trees and shrubs in HiP.

*Conclusion*

In summary it is evident that past land use practices and management at each of the study sites has been fundamentally different over the last century. Significant differences were evident in human densities, animal stocking rates and burning practices. These differences in land management took place over a similar biotic and abiotic template and in close geographic proximity. Furthermore, no long-term trends in rainfall amount or seasonality are evident from the records. The implications of these differences in past land use management and practices on the vegetation would be expected to be radically different for each of the study sites. Past management practices will be aligned and correlated to the changes documented in the vegetation at each study site in a later chapter.

# Chapter 4. Changes in woody plant cover under three contrasting land use systems, 1937-2004

*Introduction*

In Chapter 3, it was shown that the most frequently cited causes of bush encroachment are linked to overstocking, overgrazing and changes to burning practices. Due to the widespread occurrence of woody thickening in savannas around the world we need to readdress this problem and ask if it realistic to attribute the widespread increases in woody cover to management practices alone. To do this we need to examine the process at a much larger scale than most studies have attempted to date. This would allow the changes caused by land management to be teased out from the changes linked to $C0_2$, climate or atmospheric nitrogen deposition. The process also needs to be compared across a gradient of differing land use practices with radically different management histories.

South Africa's historical backdrop has provided a valuable opportunity for such a study. Much of the rural South African landscape forms a mosaic of areas under contrasting land use practices often with communal, commercial and conservation areas lying adjacent to one another. Furthermore, many of these areas have retained their boundaries and have remained under these different tenure systems for the past century or longer as shown in Chapter 3. This set-up provides an opportunity to determine the effects of contrasting land use practices on vegetation dynamics through time in landscapes sharing a similar climate and soils.

Aerial photography has long been recognised as a valuable tool for examining vegetation change (e.g. Carmel and Kadmon 1998; Kadmon and Harari-Kremer 1999; O'Connor and Crow 1999; Bowman *et al.* 2001; Pickard 2002; Fensham *et al.* 2003; Laliberte *et al.* 2004; Brook and Bowman 2006). Furthermore a time-series analysis is an important method for determining the medium-term (100 years) dynamics of vegetation at the landscape scale (Bowman *et al.* 2001). Often, an analysis of aerial photography is the only tool that can be used at these temporal and spatial scales since it predates satellite imagery by over 50 years for many areas. In addition, most long-term vegetation monitoring efforts are restricted to relatively small areas due to logistical constraints. The use of aerial photography has enjoyed an upsurge in use throughout the world, as it is often widely available and increased access to geographical information systems (GIS) provide a number of useful analytical tools (Bowman *et al.* 2001).

In Southern Africa a number of studies have analysed vegetation change using temporal sequences of aerial photography (e.g. Van Vegten 1983; Watson and Macdonald 1983; O'Connor and Crow 1999; Roques *et al.* 2001). These studies were all based on visual interpretation of vegetation types using prints of the aerial photographs. These labour intensive methods usually limit the spatial extent of vegetation databases (Woien 1995 in Carmel and Kadmon 1998). Furthermore, manual interpretation of aerial photography is usually assumed to be 100 % correct which is not necessarily the case (Biging *et al.* 1991, Congalton and Green 1993). A limited number of studies in Southern Africa have used textural analysis of aerial photography to determine changes in vegetation. However, these methods also have their limitations (Hudak and Wessman 1998, 2001).

In this study, I used an approach similar to Bowman *et al.* (2001) and Brook and Bowman (2001) to determine the medium-term dynamics of the vegetation. I performed manual onscreen classifications of plant cover on digital imagery using a point sampling method. In this way I was able to analyse a temporal sequence of panchromatic aerial photography from three time periods: 1937, 1960 and 2004. This allowed us to determine transitions in vegetation types between years and thereby calculate rates of change in vegetation cover. I addressed the following questions:

1) How has woody plant cover changed at the landscape scale (25 $km^2$) for the 67-year period between 1937 and 2004 in three adjacent areas that have remained under contrasting land use practices (communal, commercial and conservation) for most of the $20^{th}$ century?
2) Are the rates and extent of change in woody cover different for different land use practices?
3) How sensitive are estimates of woody cover to different methods of vegetation classification? I contrasted manual onscreen classification vs. a fractal net evolution approach (FNEA) using eCognition (Definiens 2003).
4) Can the FNEA embedded in eCognition be scaled up to the regional scale (100's to 1000's of $km^2$)?

If changes in land use practices account for the changes in woody cover then I would expect negligible change in the communal areas due to high levels of natural resource utilisation, frequent fires and the continued presence of browsers (goats). I would expect higher levels of woody thickening in the commercial areas due to high stocking rates of predominantly grazers and due to the exclusion of fire in the past. In the conservation area I would expect the least change in woody cover as stocking rates have been maintained at relatively low levels, all three functional feeding types have been retained and management has attempted to actively prevent and combat woody thickening with frequent burning and total clearing. If all three land use systems show increases in woody cover one would suspect additional effects of some widespread overriding global driver such as increased atmospheric $CO_2$ or climate change.

*Methods*

*Photo preparation*

All aerial photography (Table 4.1) was acquired from the Chief Directorate: Surveys and Mapping, Mowbray, Cape Town. The flight plans for each photo job were used to determine the photograph numbers needed from each job. Hard copies of the required photography were then acquired. All photographs were scanned at 1200 dpi (dots per inch) in 8 bits using a Hewlett-Packard flatbed scanner and saved as TIFF images. The 2004 imagery was geo-referenced using rectified Landsat imagery, 1:50 000 topographical maps and a digital elevation model (DEM). These images were then mosaicked to form one image covering the study area. The 1960 photography was then geo-referenced using the 2004 photography as the base, then mosaicked. Lastly the 1960 photography was used to geo-reference the 1937 photography, which was then also mosaicked. This methodology ensured that the relative accuracy between years was good, while the absolute accuracy was kept between 20 – 30 meters. All images were geo-referenced and projected into the Transverse Mercator Lo 31, Wgs 84 projection. All geo-referencing and mosaicking was performed using Erdas Imagine v 9.0.

Prior to analysis the 1937 imagery was resampled to a resolution of 1 m using the nearest neighbour method in ArcMap v 9.1 thereby ensuring that the resolution of all imagery was equal and, therefore, directly comparable. Nearest neighbour resampling was used, as it does not alter original pixel values (Lillesand and Keifer 2000). All images were convoluted using a 3x3 edge-enhancing kernel in Erdas Imagine v. 8.7. Radiometric normalization was performed on all imagery using the histogram equalisation option in Erdas Imagine v. 8.7.

Table 4.1 Details of the aerial photography used in the analyses.

| Date Flown | Job Number | Scale | Resolution | Total No. Photos |
|---|---|---|---|---|
| 09/09/1937 | 117_37 | 1:20 000 | 0.7m | 54 |
| 26/06/1960 | 442 | 1:40 000 | 1m | 33 |
| 16/09/2004 | 1089 | 1:50 000 | 1m | 18 |

*Change analyses*

*Manual classification*

Each of the photo mosaics from the three different dates was then clipped to the extent of the three 25 $km^2$ study sites from the communal, commercial and conservation areas. For the 1937 imagery covering the communal study site it was necessary to use two different areas, as there was a gap in the photography running through the middle of the communal area. A 30x30 m lattice was then created and saved as a shapefile with X and Y co-ordinates for each point using Hawths Analysis Tools for ArcGIS. For each 25 $km^2$ study site the lattice consisted of approximately 28 000 points. The lattice was then overlaid over the aerial photography from the three different dates using Arcview v. 3.3. Each point on the lattice was then manually classified for plant cover for each of the three dates. Due to the nature of this study and the relatively low resolution (1 m) of the photography only two classes (tree and grass) were used for the manual classifications of the conservation site. Three classes (tree, grass and cultivation) were used for the communal and commercial areas. Thus at every point of the lattice, the vegetation was classified as either tree, grass or cultivation for each of the three time sequences (Fig. 4.1).

Two observers using two desktop computers performed manual classifications of one image at a time. The image and lattice was displayed on one computer while a MS Excel spreadsheet was used on the other computer to record the classifications. In this way a total of over 250 000 points were classified (28 000 x 3 time sequences x 3 study sites). Each point of the lattice was labelled according to the classification and superimposed over the relevant image and checked for errors (Fig. 4.2). All errors were recorded and corrected then overlain over the image again and checked for errors a second time.

After correcting misclassifications for the second time, the total numbers of points classified in each class were calculated for each of the three years. Transitions between the different classes were calculated for each time series and converted into probabilities. These probabilities were then used to calculate Markov chain models (Keilson 1979) in order to determine whether the changes in vegetation were occurring at a constant rate.

The manual classifications were then converted into 30x30 m grids using Arcview v. 3.3. These grids were used to map the extent of each of the classes for each of the three years. I was then able to subtract one classification from another using the raster calculator in ArcMap v. 9.1 (e.g. 1960 – 1937) to map the transitions that occurred during that period. These calculations were performed for all three-transition periods (1960 – 1937, 2004 – 1960 and 2004 – 1937) for each of the study sites. The resulting maps provide a visual representation of the transitions that occurred during the period of interest.

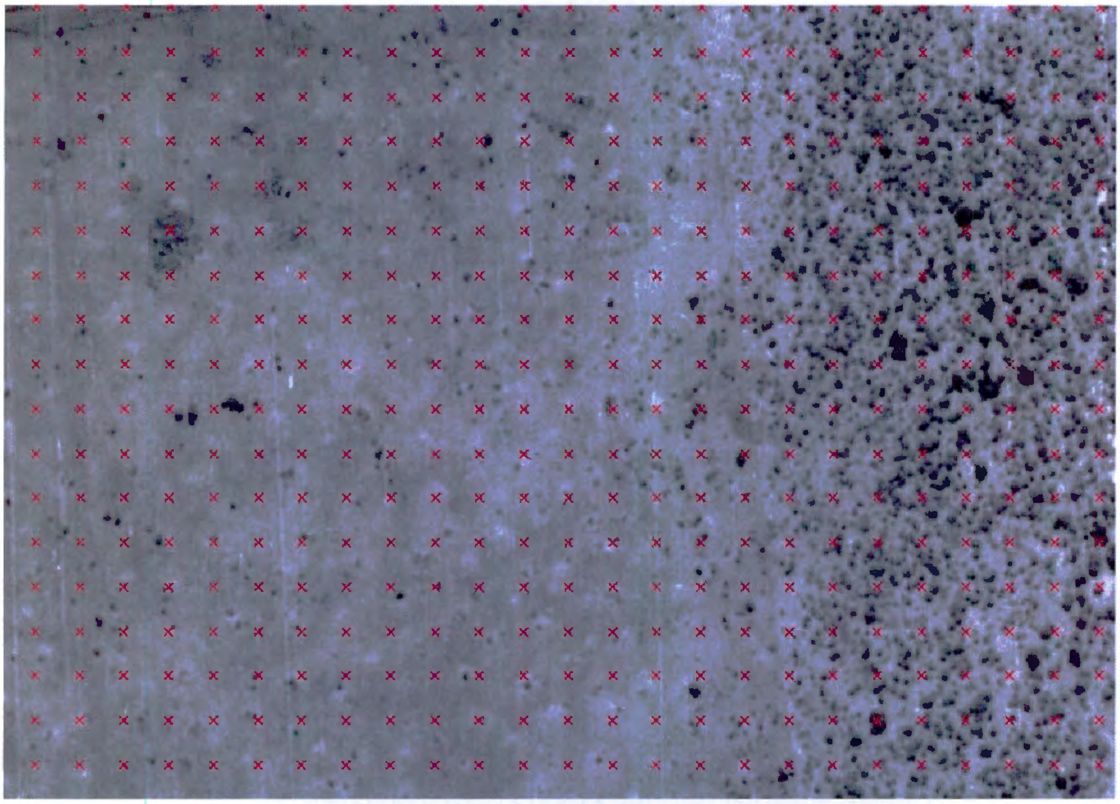

Figure 4.1. The 30x30 m lattice overlain over a portion of the 1960 imagery covering the commercial site. The vegetation at each point of the lattice was classified either as tree, grass or cultivation.

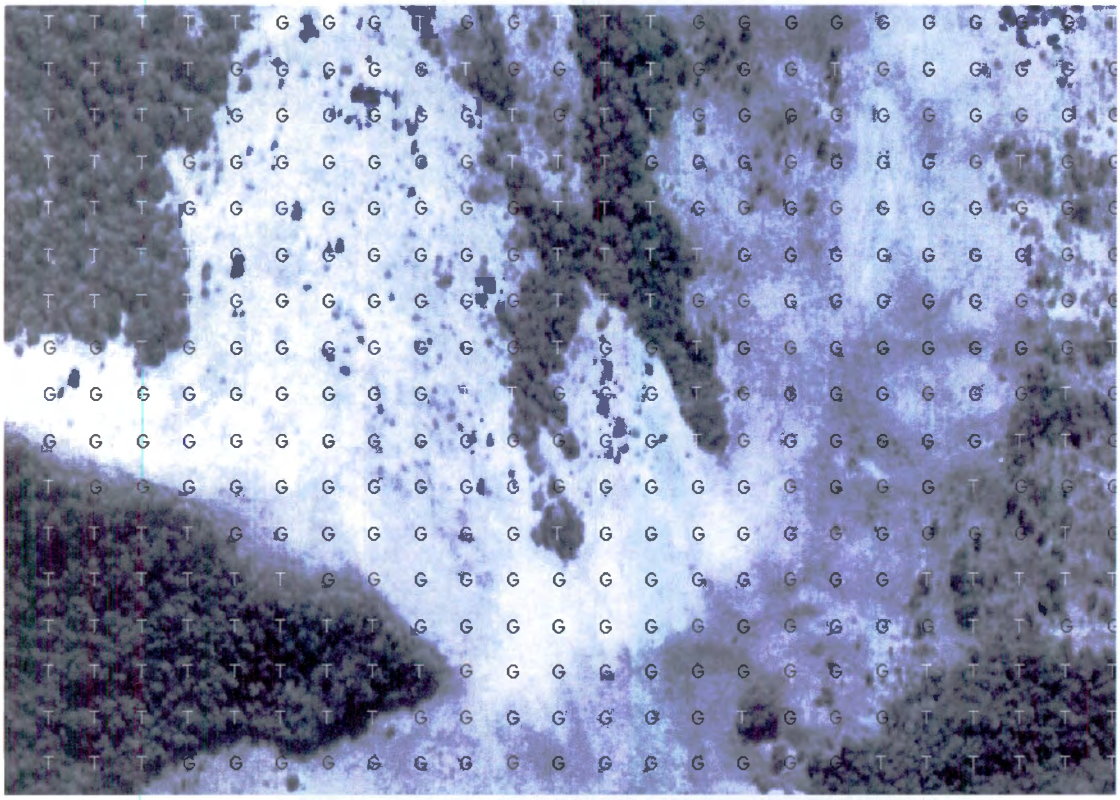

Figure 4.2. Each point of the lattice assigned into the class G (grass) or T (tree) or C (cultivation). These classifications were then manually checked for errors, corrected then rechecked and corrected again.

*Ground truthing*

A number of ground truthing transects were carried out during September and October 2005. Twenty (2 x100 m) transects were walked in areas ranging from open grassland to closed forest at each of the three study sites, totalling 60 transects. For each transect all woody species were identified, the number of stems counted, diameter at breast height (dbh), total height and percent open canopy were measured along the 2x100 m transects. GPS positions were recorded at the start and end of each transect then plotted onto the 2004 aerial photography. This allowed for direct comparisons between the manual and eCognition classifications and actual ground cover. For the conservation study site a vegetation mapping exercise was undertaken in 2006 by extensively driving through the area and manually mapping the vegetation on aerial photography. This vegetation map was also used as a benchmark against which to compare the 2004 classifications.

*Statistical analyses*

Chi-squared analyses were performed comparing total woody cover between all the time intervals at the three study sites (e.g. between 1937 and 1960). The expected values were taken as the original values (e.g.1937) while the observed values were taken as the values from the new count (e.g. 1960).

*Object orientated analysis using eCognition*

The fractal net evolution approach (FNEA), an object-orientated multiscale image analysis method embedded in the software eCognition (Baatz and Schaepe 2000; Definiens 2003) was also used to classify the imagery. As explained by Laliberte *et al.* (2004), the first step is a segmentation of the image based on three parameters: scale, colour (spectral information), and shape (smoothness and compactness), where the colour and shape parameters can be weighted between 0 and 1. Within the shape setting smoothness, and compactness can also be weighted between 0 and 1. Scale in this case is a unitless parameter, which is related to the resolution of the imagery.

The segmentation parameters used in this study (Table 4.2) were similar to those used by Laliberte *et al.* (2004). A number of alternative parameters were tried but they returned unfavourable results. The segmentation used in eCognition is a bottom-up region merging technique, whereby in level 1 the smallest object contains only one pixel (Laliberte *et al.* 2004).

Thus, in subsequent levels, smaller image objects are merged into larger ones according to the chosen scale, colour and shape parameters. These objects define the growth in heterogeneity between adjacent image objects. This process stops when the smallest growth exceeds the threshold defined by the scale parameter (Laliberte *et al.* 2004). This procedure produces highly homogenous segments in a selectable resolution and of a comparable size. Classification is then performed using the created objects rather than single pixels (Laliberte *et al.* 2004).

Table 4.2. Segmentation parameters used for the eCognition analyses. Each parameter is explained in detail in Laliberte *et al.* (2004).

| Segmentation Level | Scale | Colour | Shape | Shape Settings | |
|---|---|---|---|---|---|
| | | | | Smoothness | Compactness |
| Level 1 | 3 | 0.8 | 0.2 | 0.8 | 0.2 |
| Level 2 | 250 | 0.8 | 0.2 | 0.7 | 0.3 |

The classifications of the image objects were performed using membership functions that are based on fuzzy logic theory combined with user-defined rules. The membership functions range from 0 to 1 for each object's feature values with regard to the object's assigned class (Laliberte *et al.* 2004). Spectral, shape and statistical characteristics as well as relationships between linked levels of the image objects can be used in the rule base to combine objects into meaningful classes (Laliberte *et al.* 2004; Benz *et al.* 2004).

The imagery was segmented at the fine scale to capture individual trees and at a coarse scale to define broader landscape elements such as patches of forest. Woody elements were classified on the fine scale by defining three membership functions:

1) Mean brightness value;
2) Mean difference to neighbours;
3) Mean difference to super object.

Details of how these influence the classification can be found in Laliberte *et al.* (2004). All three of the membership functions generated equal weight in the analyses and were combined using a logic "and" function, which equals the minimum fulfilment of the single statements. The membership functions were adjusted until the classifications were deemed satisfactory by the author. This was achieved by comparing the most recent (2004) classification to the photography, vegetation maps and ground truthing data. Thus if the classification correctly and accurately classified the different classes evident in the most recent high resolution photograph it was deemed to be satisfactory.

eCognition was used to classify the imagery covering the conservation study site from 1937, 1960 and 2004. The same spatially and radiometrically enhanced images that were used for the manual classifications were used for the eCognition analyses.

Final classifications were then analysed in a similar manner to the manual classifications whereby the total number of 1x1 m pixels assigned to woody and non-woody classes were calculated for each of the three time sequences. Thus total woody and non-woody cover was calculated as a percentage and as total area. Transitions were also calculated for each time period and used to create a Markov model to test for constant rates of change. The classifications were imported into ArcMap v. 9.1, and reclassified with unique values. After this the raster calculator was used to map the transitions in cover type. Finally, to determine whether elevation and drainage lines were influencing the changes, the contours and rivers were overlain on top of the classification using ArcMap v. 9.1.

*Results*

*Manual classifications*

*1) Communal study site*

Results from the manual classification of the communal study site (Table 4.3) show a substantial increase in tree cover for both the 23-year period between 1937 and 1960 and the 44-year period between 1960 and 2004. Overall tree cover increased by 19.5 % in the 67-year period (from 6.2 % in 1937 to 25.7 % in 2004), equating to more than a threefold increase in total tree cover. A significant increase in cultivation (13 %) occurred between 1937 and 1960, but this decreased by more than half again (6.5 %) in 2004 (Fig. 4.3).

Table 4.3. Total number and area of each cover class calculated from the manual classifications of the communal study site.

| | **1937** | | **1960** | | **2004** | |
|---|---|---|---|---|---|---|
| | **Number** | **Hectares** | **Number** | **Hectares** | **Number** | **Hectares** |
| **Grass** | 26023 | 2342.1 | 20298 | 1826.8 | 18813 | 1693.2 |
| **Tree** | 1717 | 154.5 | 3814 | 343.3 | 7128 | 641.5 |
| **Cultivation** | 0 | 0 | 3628 | 326.5 | 1799 | 161.9 |
| **Total** | 27740 | 2496.6 | 27740 | 2496.6 | 27740 | 2496.6 |

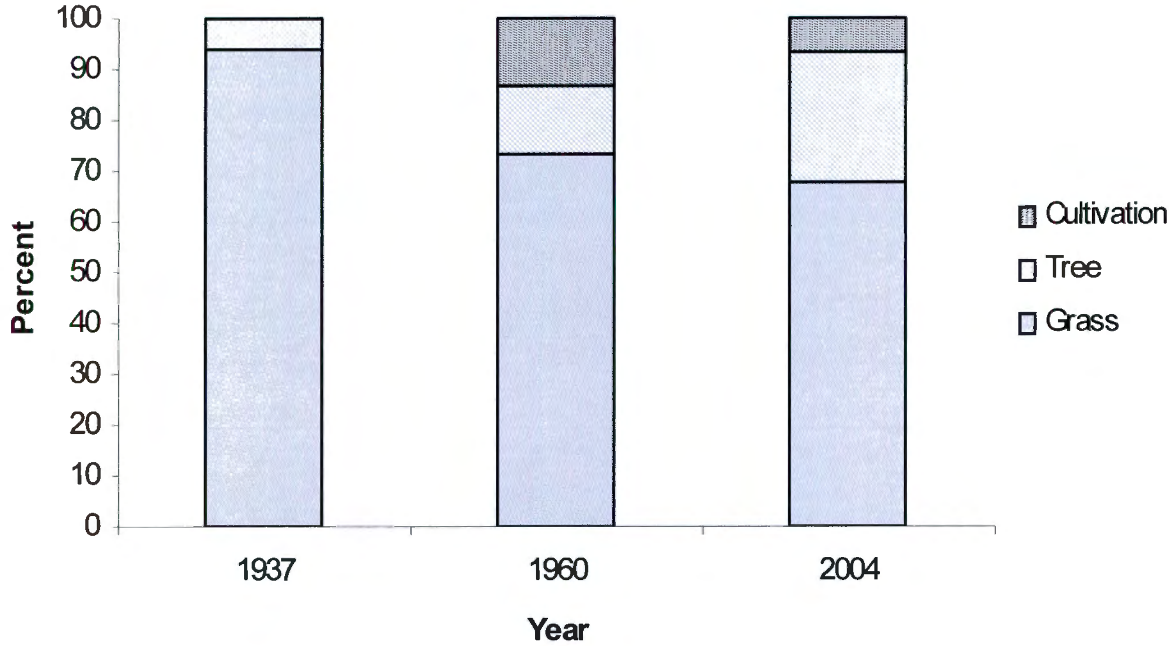


Figure 4.3. Total percentages of the three cover types for the three dates that were analysed for aerial photographs in the communal areas. Percentages are given as the total number of each class classified at each point of the lattice.

The Markov model (Table 4.4) for the communal area shows that the actual proportions of the cover classes found at the communal study site in 2004 differ substantially from the modelled values. The model predicted only 13 % tree cover in 2004 with the actual value being double that at 26 %. This suggests that the rates of change through time are not constant, with an amplified rate of increase in tree cover occurring subsequent to 1960.

Table 4.4. Markov model for the communal study site showing the probabilities of transitions between 1937 and 1960, modelled proportions of each class for two 23-year iterations (1983 and 2006) and the actual values for each class. G = grass, T = tree and C = cultivation.

| | From (1937) | | | | Modelled values | | | | Actual values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | G | T | C | | 1937 | 1960 | 1983 | 2006 | 1937 | 1960 | 2004 |
| G | 0.75 | 0.46 | 0 | G | 0.94 | 0.73 | 0.61 | 0.53 | 0.94 | 0.73 | 0.68 |
| T | 0.12 | 0.41 | 0 | T | 0.06 | 0.14 | 0.14 | 0.13 | 0.06 | 0.14 | 0.26 |
| To C | 0.13 | 0.13 | 1 | C | 0 | 0.13 | 0.24 | 0.34 | 0 | 0.13 | 0.06 |
| (1960) Total | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Results from the Chi-squared analyses (Table 4.5) showed that the changes in woody cover were highly significant for all periods (1937-1960; 1960-2004 and 1937-2004).

Table 4.5. Results from the Chi-squared analyses of change in woody cover for the three time intervals.

| | 1960 | | | 2004 | | |
|---|---|---|---|---|---|---|
| | $CHI^2$ | df | p | $CHI^2$ | df | p |
| **Communal 1937** | 3820.6 | 2 | $p < 0.001$ | 19050 | 2 | $p < 0.001$ |
| **Communal 1960** | | | | 3910.3 | 2 | $p < 0.001$ |

The increase in woody cover through time was usually quite unequivocal and was normally apparent from merely observing the aerial photography. The increase in woody cover, cultivation and anthropogenic influence at the communal study site can be clearly seen in Figures 4.4 to 4.6.

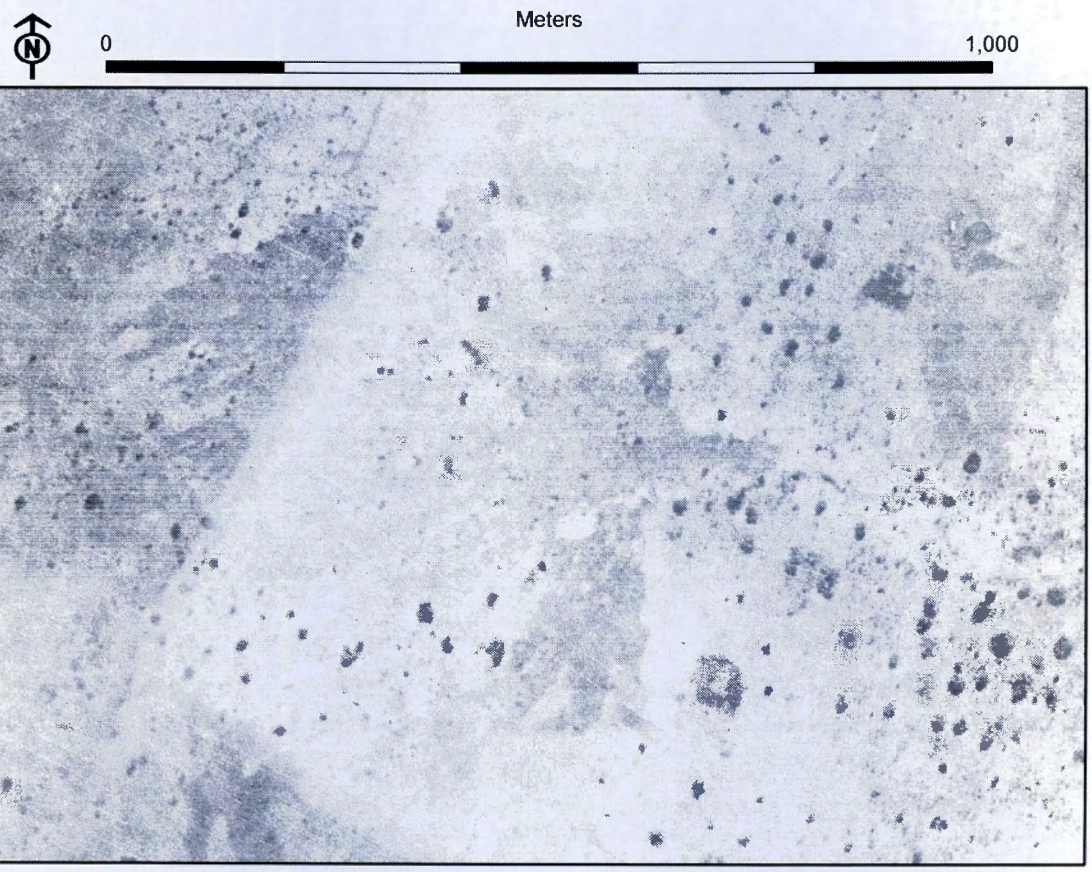


Figure 4.4. A portion of the 1937 image covering the communal study site. The image covers approximately 5 % of the communal study site (130 ha).

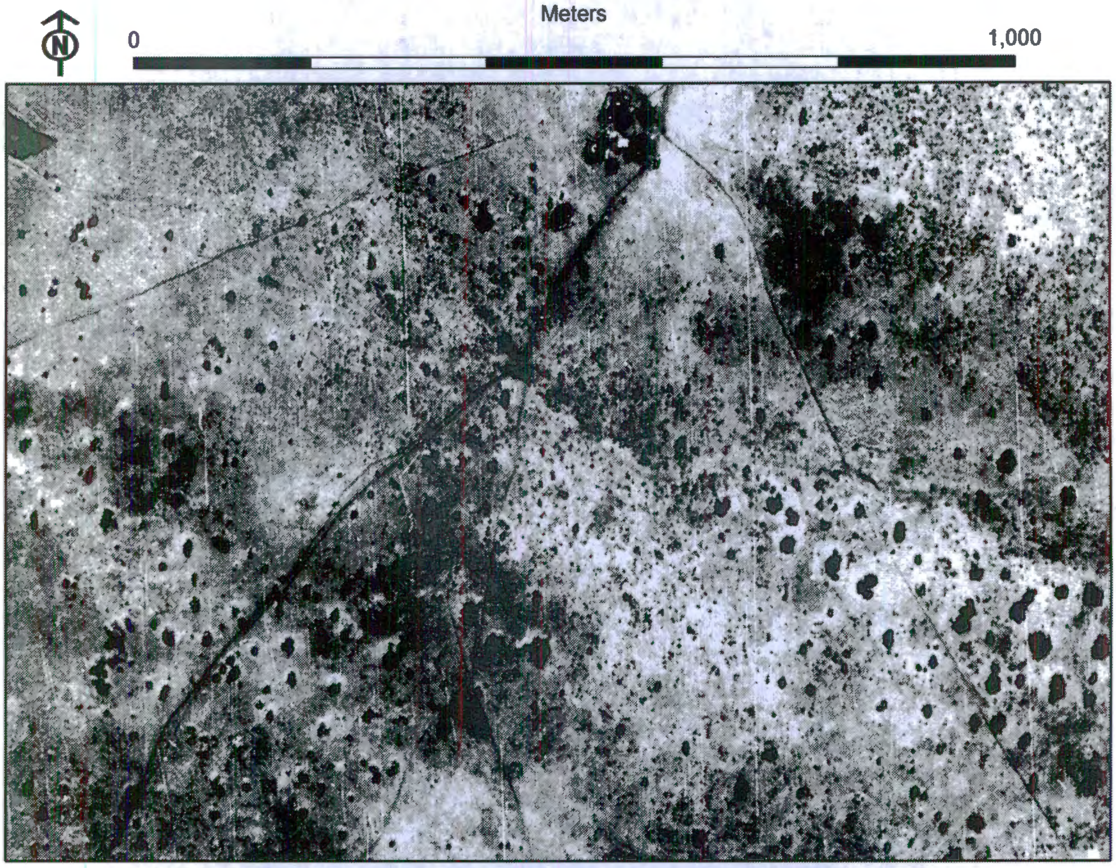


Figure 4.5.The same area as shown in Figure 4.4 as it appears in the 1960 photography.


Figure 4.6. The same area as shown in Figures 4.4 and 4.5 as it appears in the 2004 aerial photography.

The significant increases in tree and cultivation cover for the period 1937-1960 are clearly evident in Figure 4.7. A further increase in tree cover and decrease in cultivation is clear from Figure 4.8. The mapped transitions between 1937 and 2004 show that tree cover mostly increased from central points (clumps) and did not increase randomly across the study site. It is also evident that substantial areas that were covered by woody vegetation in 1960 have shifted back to grassy cover in 2004. Two factors could explain this, the first being spatial error in the geo-referencing of the images, or clearing of the woody cover for utilisation. Another important observation (Fig. 4.9) shows that most of the area that was under cultivation in 1960 had shifted back to grass cover and not woody cover by 2004. It is also clear that areas used for cultivation are constantly shifting with most of the area under cultivation in 1960 no longer under cultivation in 2004. Instead new areas were located, cleared and cultivated by 2004 (Fig. 4.8).

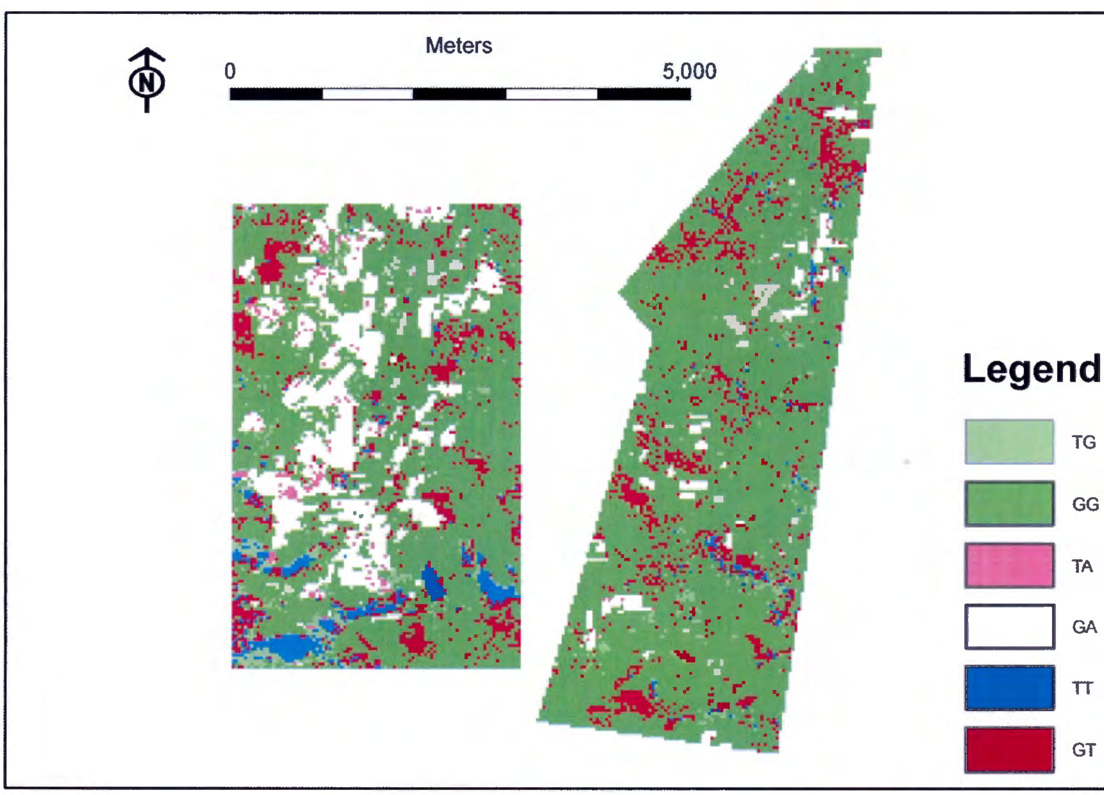


Figure 4.7. Transitions between the vegetation classes for the period 1937 - 1960. The first letter in the legend denotes the class in 1937, while the second letter denotes the class that that pixel falls into in 1960, where T = Tree, G = Grass and A = Arable lands.

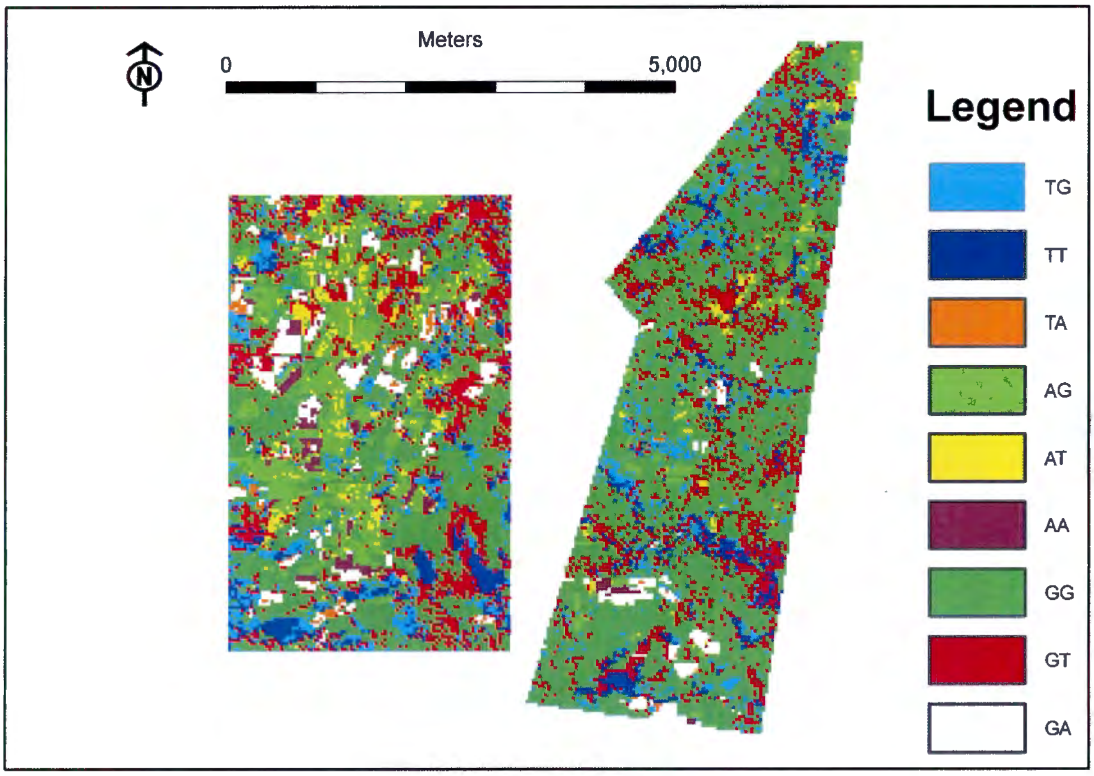


Figure 4.8. Transitions between the vegetation classes for the period 1960 – 2004, explanation of legend as per Figure 4.7.

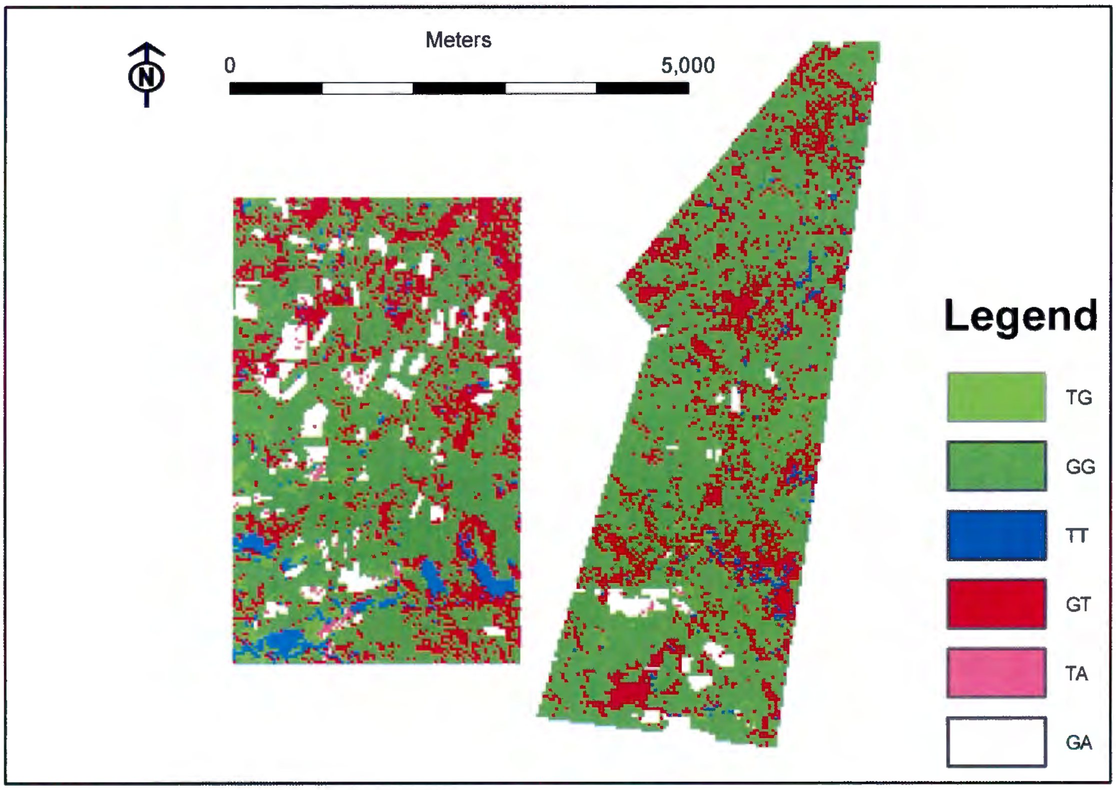


Figure 4.9. Transitions between the vegetation classes for the period 1937 – 2004, legend as per Figure 4.7.

*2) Commercial study site*

The commercial study site showed the greatest increase in tree cover of the three tenure systems, from 2.7 to 50.8 % (Fig. 4.10). This is a seventeen-fold increase in tree cover in less than 70 years. The total area under cultivation increased only slightly between 1937 and 1960 and remained fairly stable at around 3 % for the period 1960 – 2004.

Table 4.6. Total number and area for each class calculated from the manual classifications of the commercial study site

| | 1937 | | 1960 | | 2004 | |
|---|---|---|---|---|---|---|
| | **Number** | **Hectares** | **Number** | **Hectares** | **Number** | **Hectares** |
| **Grass** | 26668 | 2400 | 22923 | 2063 | 12692 | 1142 |
| **Tree** | 763 | 69 | 4095 | 369 | 14154 | 1274 |
| **Cultivation** | 442 | 40 | 855 | 77 | 1027 | 92 |
| **Total** | 27873 | 2509 | 27873 | 2509 | 27873 | 2509 |

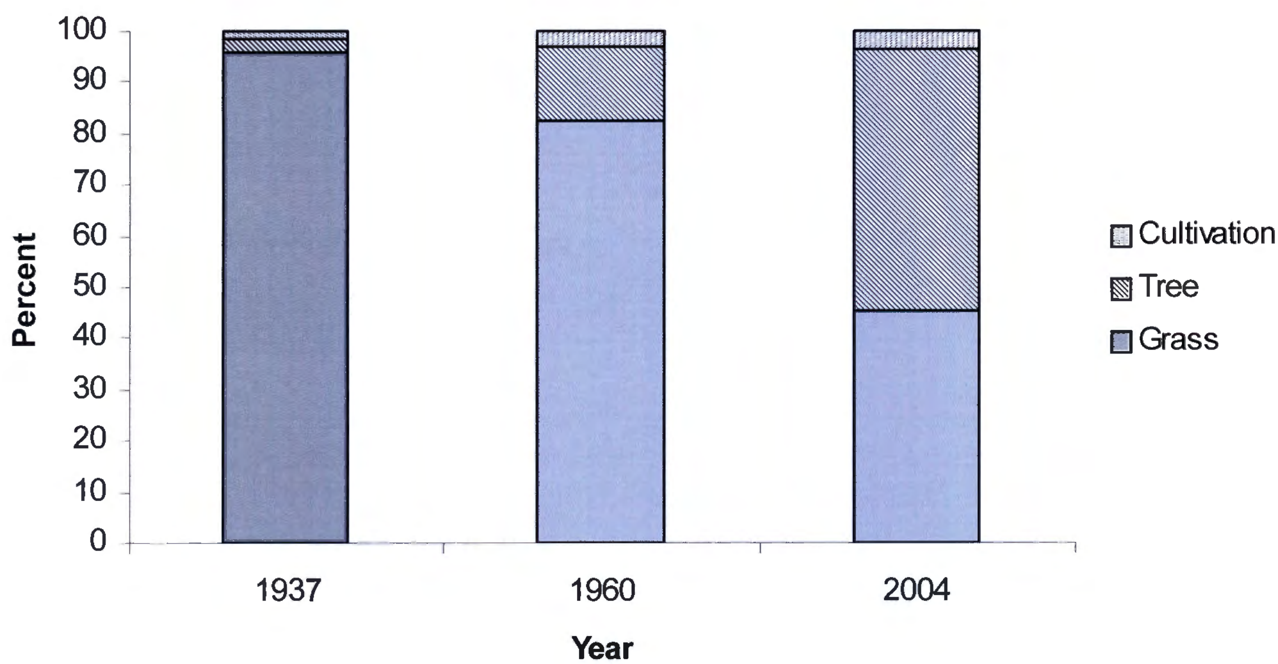


Figure 4.10. Total percentages of the three cover types for the three dates that were analysed at the commercial study site. Percentages are given as the total number of each class classified at each point of the lattice

A Markov model (Table 4.7) was calculated using the probabilities of the transitions between 1937 and 1960. The model was then used to model the expected proportions of each class until present. The actual values for tree cover in 2004 show that the model has significantly underestimated tree cover. Thus the rates of change in tree cover in the commercial area are not constant with much higher rates of change occurring in the period 1960 –2004 than expected from the transitions calculated for the period 1937-1960. This accelerated rate of woody plant proliferation can be clearly seen in Figure 4.10. Chi-squared analyses (Table 4.8) showed that the changes in woody cover were highly significant for all comparisons.

Table 4.7. Markov model showing probabilities of transitions between 1937 and 1960, the modelled values for two 23-year iterations, and the actual values are shown for the commercial study site.

| | | From (1937) | | | | Modelled values | | | | Actual values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | G | T | C | | 1937 | 1960 | 1983 | 2006 | 1937 | 1960 | 2004 |
| | G | 0.83 | 0.52 | 0.57 | G | 0.96 | 0.82 | 0.78 | 0.76 | 0.96 | 0.82 | 0.46 |
| | T | 0.14 | 0.48 | 0.07 | T | 0.03 | 0.15 | 0.19 | 0.2 | 0.03 | 0.15 | 0.51 |
| To | C | 0.03 | 0 | 0.36 | C | 0.02 | 0.03 | 0.04 | 0.04 | 0.02 | 0.03 | 0.04 |
| | Total | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Table 4.8. Results from the Chi-squared analyses of change in woody cover at the commercial study site for the three time periods.

| | 1960 | | | 2004 | | |
|---|---|---|---|---|---|---|
| | $CHI^2$ | df | p | $CHI^2$ | df | p |
| Commercial 1937 | 15463 | 2 | $p < 0.001$ | 243117 | 2 | $p < 0.001$ |
| Commercial 1960 | | | | 29310 | 2 | $p < 0.001$ |

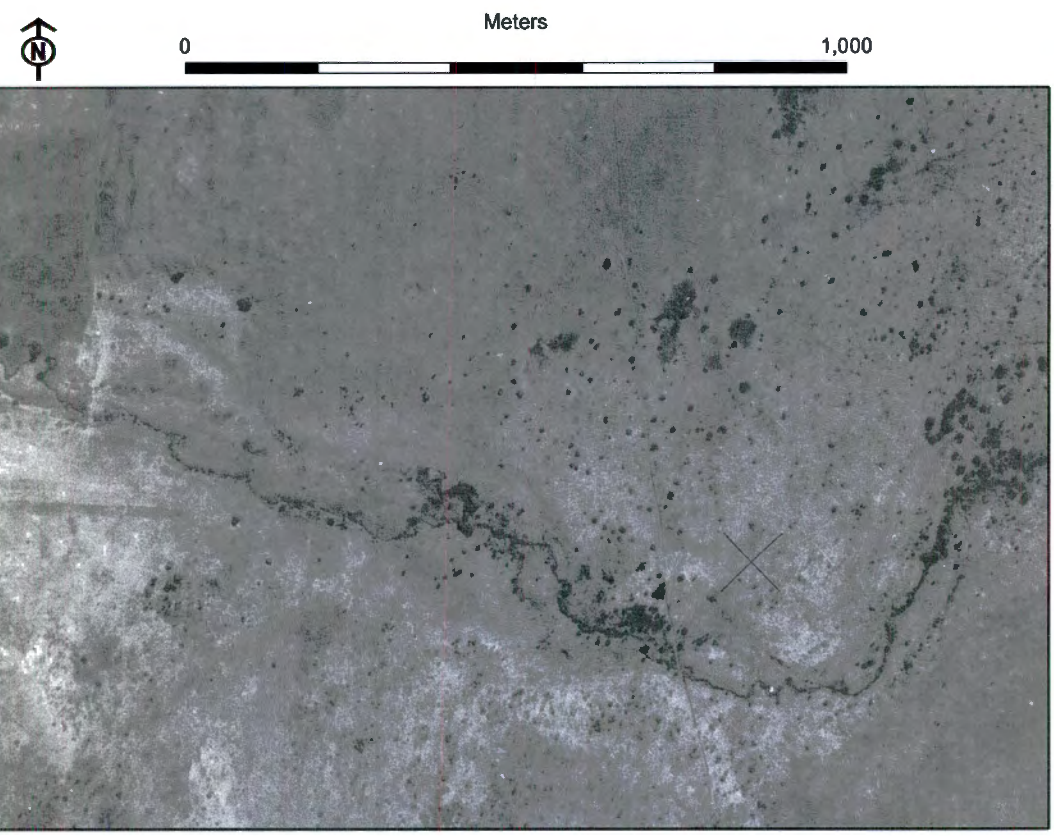


Figure 4.11. Aerial photography taken in 1937 covering part (*ca.* 180 ha) of the commercial study site.

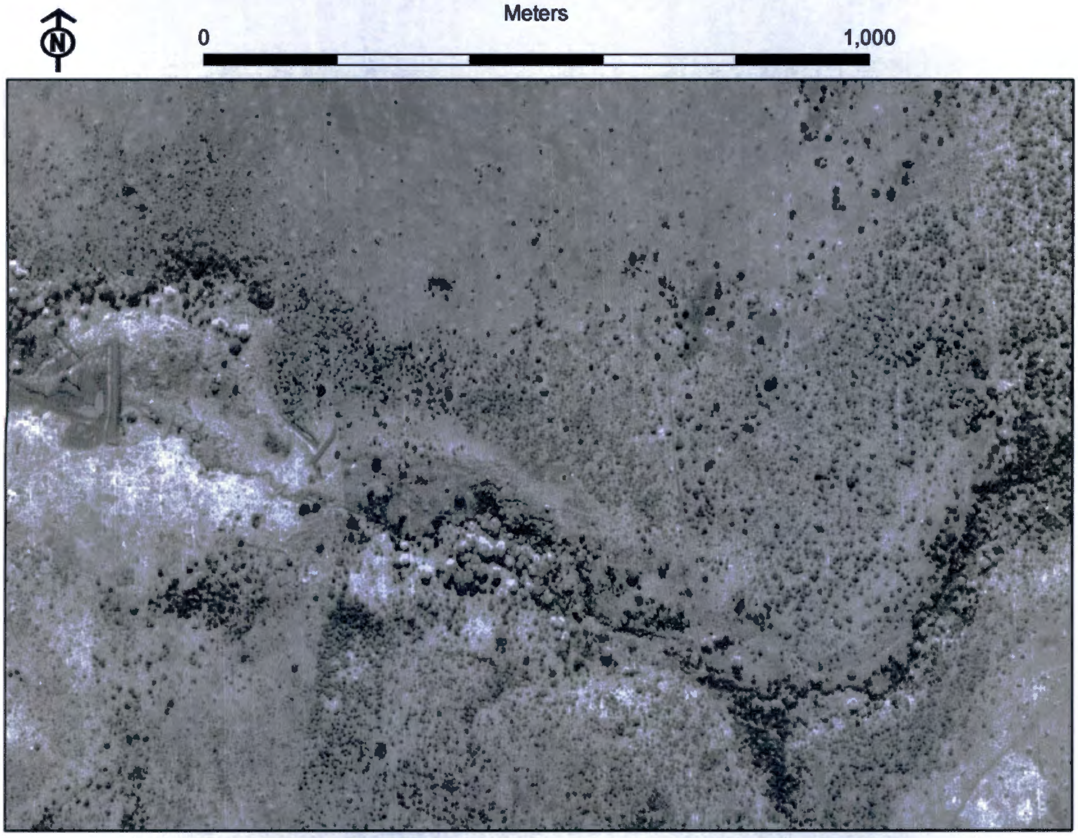


Figure 4.12. Aerial photography from 1960 showing the same area as per Figure 4.11.

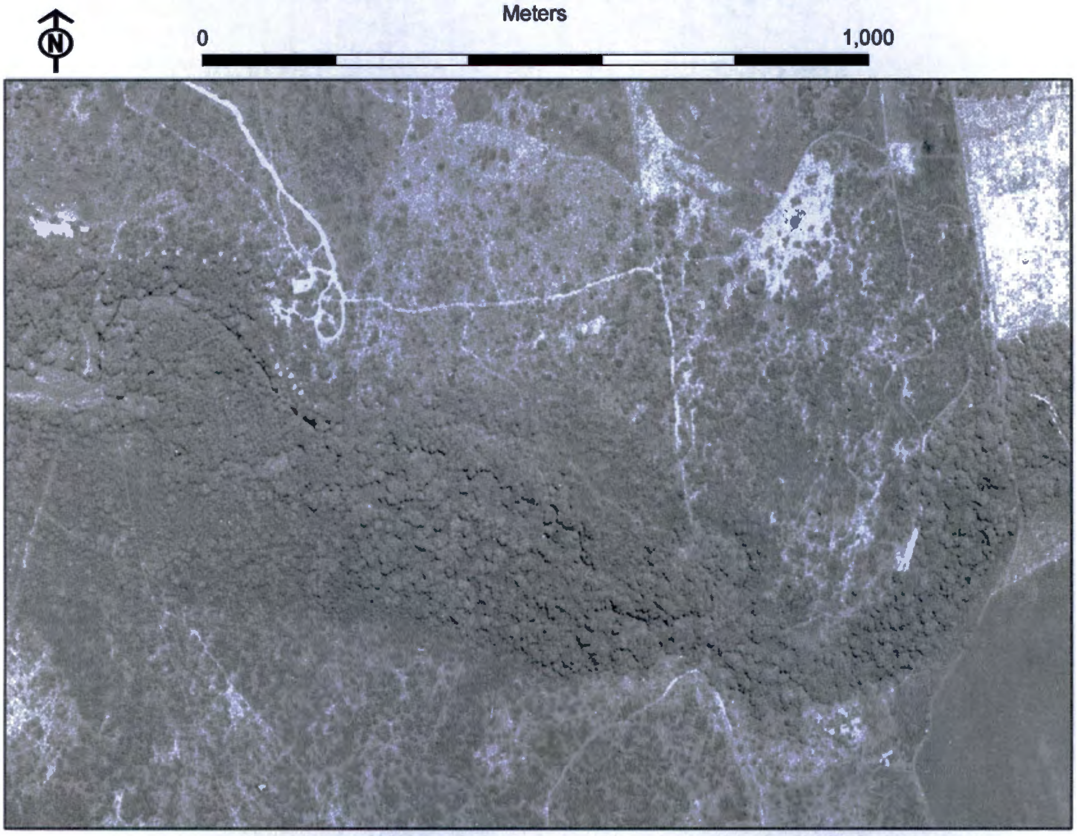


Figure 4.13. Aerial photography taken in 2004 showing the same area as per Figures 4.11 and 4.12.

The widespread increase in woody cover at the commercial study site can be clearly seen in the aerial photography sequence (Fig. 4.11 to 4.13), which documents the change from open grassland in 1937 to closed thicket in 2004.

The change maps (Fig. 4.14 to 4.16) for the commercial study site shows a moderate increase in tree cover for the period 1937-1960 (Fig. 4.14). It also shows that much of the area under cultivation in 1937 remained under cultivation in 1960 while a number of new areas had shifted to cultivation by 1960. Most of the areas classified as being comprised of woody vegetation in 1937 remained so in 1960. The mapped transitions for the period 1960-2004 (Fig. 4.15) show a considerable increase in tree cover by 2004. Most of the areas covered by trees in 1960 remained so in 2004. The map showing the total change between 1937 and 2004 (Fig. 4.16) shows the increase in tree cover to be highly clumped with woody areas expanding through time. Thus the results show a complete shift in biome type, changing from open grassland in 1937 to closed thicket in 2004 for most of the commercial area. Some areas still have some grass cover but are likely to shift rapidly to thicket at the current rate of spread.

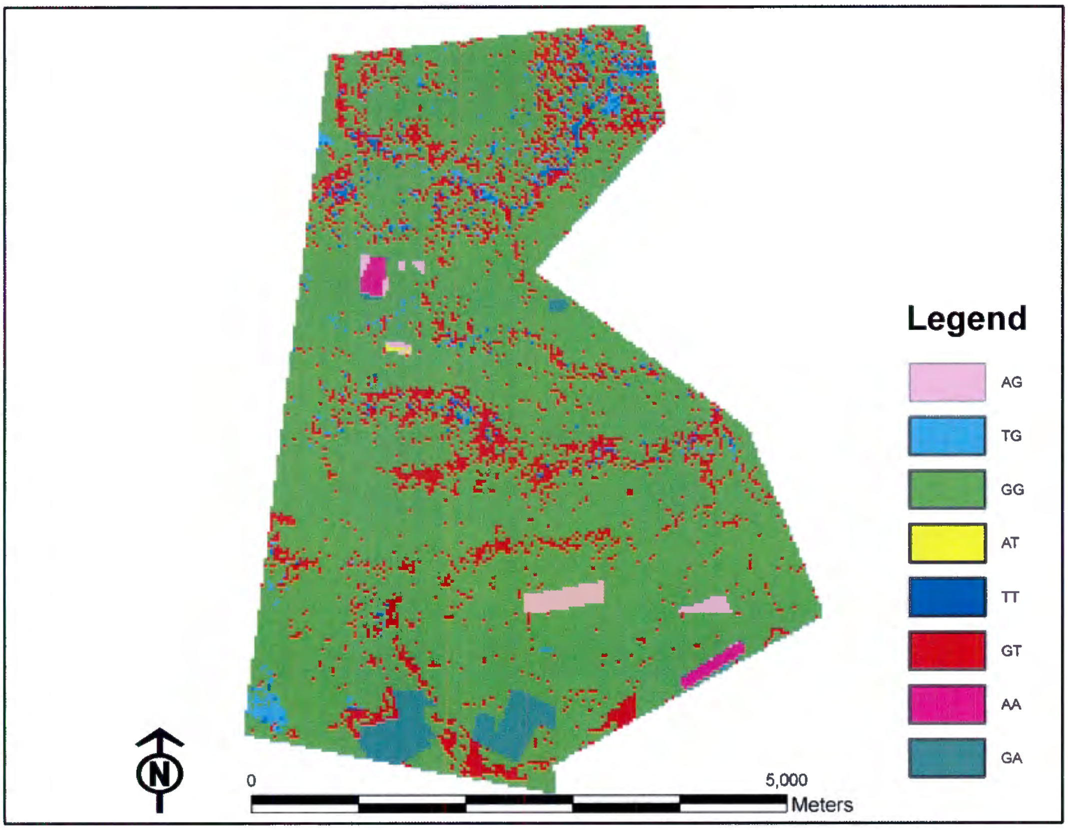


Figure 4.14. Transitions at the commercial study site for the period 1937 - 1960. The first letter in the legend denotes the class in 1937, while the second letter denotes the class that that cell falls into in 1960, where T = Tree, G = Grass and A = Arable lands

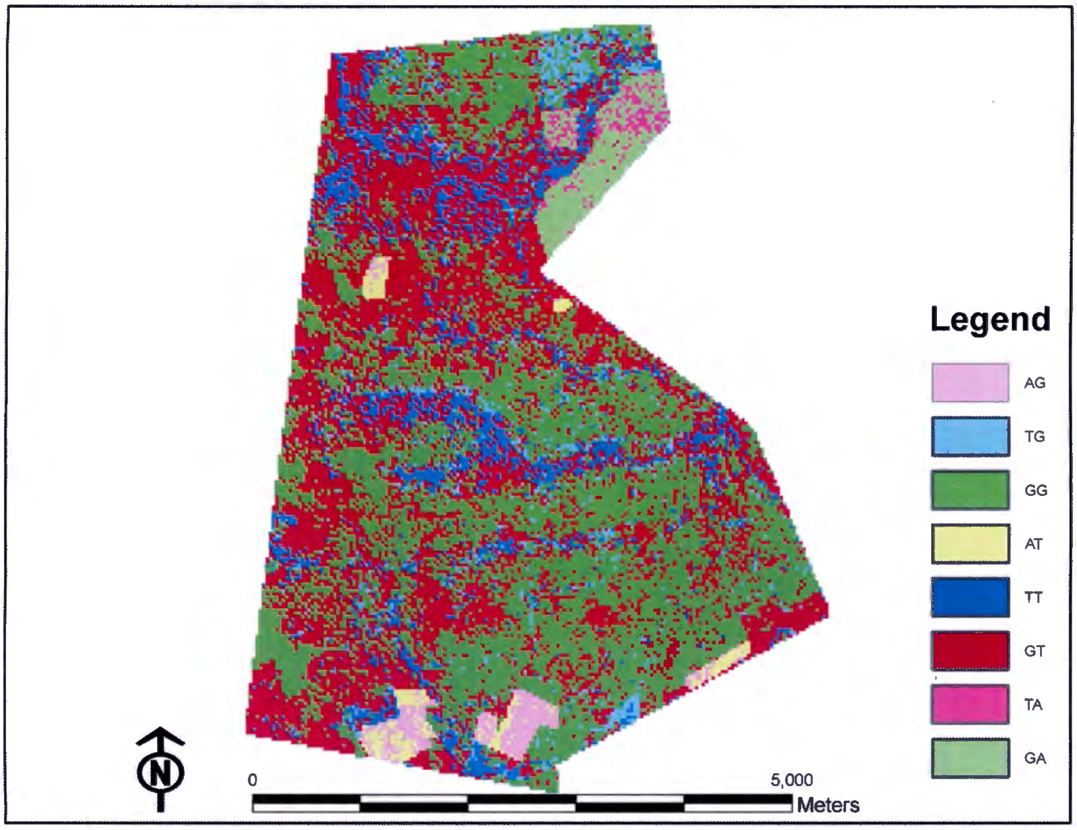


Figure 4.15. Transitions between classes at the commercial study site for the period 1960-2004, legend as per Figure 4.14.

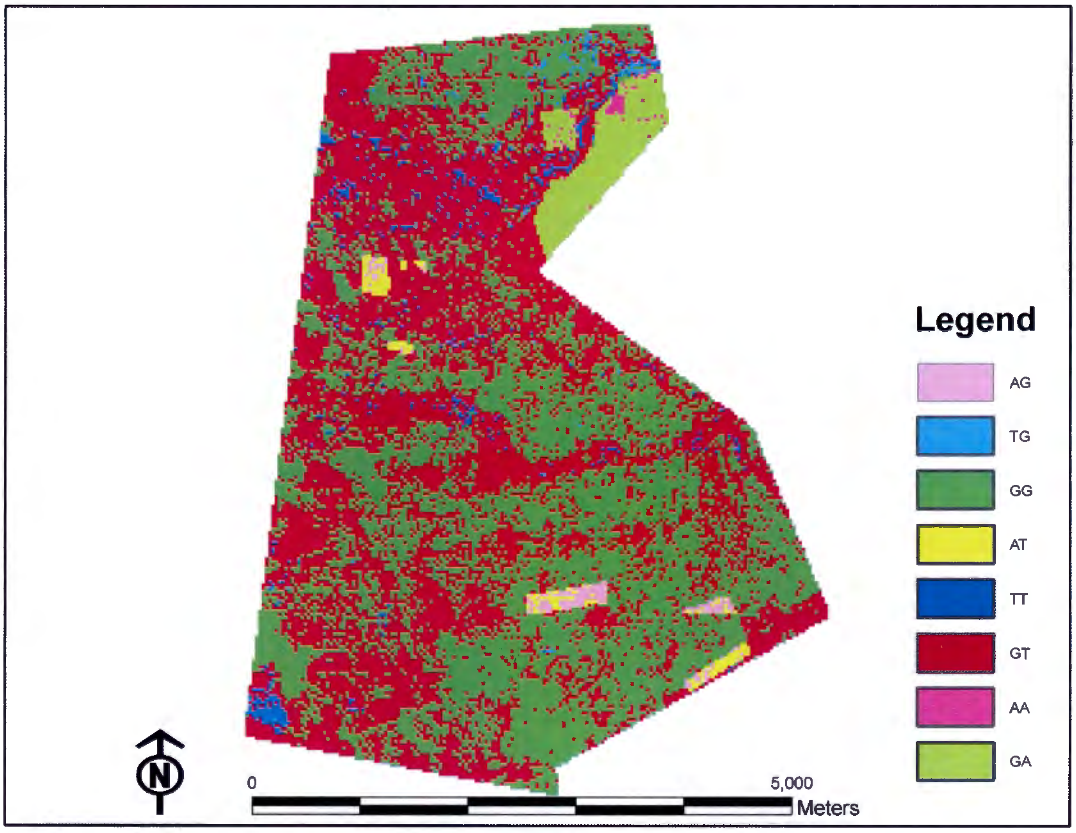


Figure 4.16. Transitions between classes at the commercial study site for the 67-year period 1937-2004. Legend as per Figures 4.14 and 4.15.

*3) Conservation study site*

The conservation study site showed a considerable increase in tree cover during the 67-year period. Tree cover increased from nearly 15 % in 1937 to over 58 % in 2004 (Table 4.9). This equates to nearly a threefold increase in tree cover at the direct expense of grass (Fig. 4.17), as there has been no cultivation in the park since people were removed in the early 1900s.

Table 4.9. Total number, percent and area for each class calculated from the manual classifications of the conservation study site.

| | 1937 | | 1960 | | 2004 | |
|---|---|---|---|---|---|---|
| | Number | Hectares | Number | Hectares | Number | Hectares |
| **Grass** | 23793 | 2141 | 16019 | 1442 | 11567 | 1041 |
| **Tree** | 4096 | 369 | 11870 | 1068 | 16322 | 1469 |
| **Total** | 27889 | 2510 | 27889 | 2510 | 27889 | 2510 |

The Markov model (Table 4.10) created using the probabilities of the transitions between 1937 and 1960 shows that the modelled proportions of cover for the conservation area are almost identical to the actual values for 2004. This suggests that the rates of change in the conservation area have occurred at a constant rate. This differs from both the communal and commercial areas which both showed accelerated increases in tree cover subsequent to 1960.

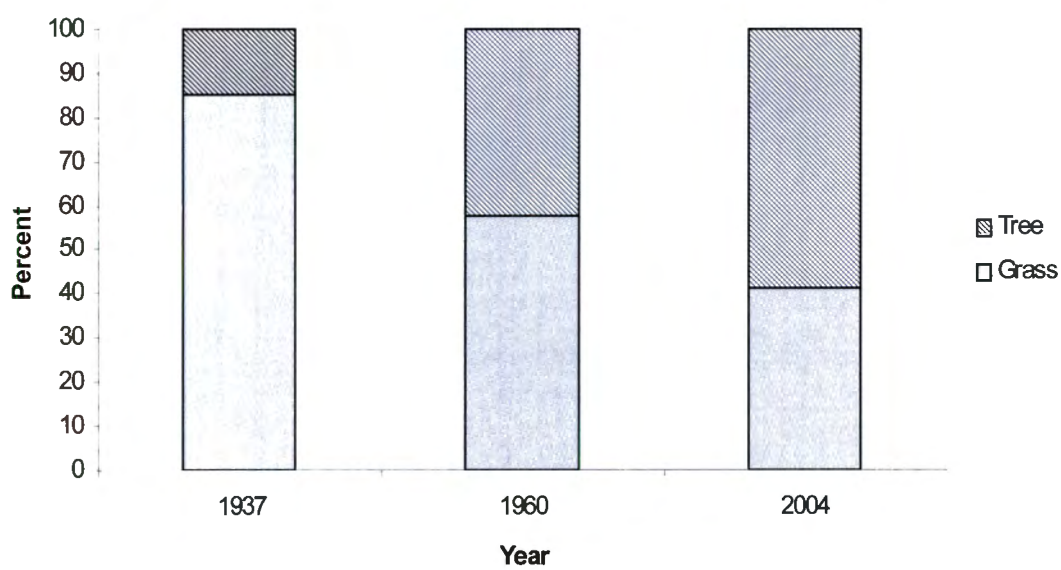


Figure 4.17. Total percentages of the two cover types for the three dates that were analysed at the conservation study site.

Table 4.10. Markov model showing probabilities of transitions between 1937 and 1960, the modelled values for two 23-year iterations, and the actual values are shown for the conservation study site.

| | | From (1937) | | | Modelled values | | | | Actual values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | G | T | | 1937 | 1960 | 1983 | 2006 | 1937 | 1960 | 2004 |
| | G | 0.64 | 0.2 | G | 0.85 | 0.57 | 0.45 | 0.4 | 0.85 | 0.57 | 0.41 |
| To | T | 0.36 | 0.8 | T | 0.15 | 0.43 | 0.55 | 0.6 | 0.15 | 0.43 | 0.59 |
| | Total | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Chi-squared analyses (Table 4.11) showed significant differences in total tree cover between the three time periods. Tree cover increased significantly for all three periods. The series of aerial photography images (Figures 4.18 to 4.20) taken from the three years clearly shows the significant increase in tree cover through time.

Table 4.11. Results from the Chi-squared analyses of change in woody cover at the conservation study site for the three time periods.

| | 1960 | | | 2004 | | |
|---|---|---|---|---|---|---|
| | $CHI^2$ | df | p | $CHI^2$ | df | p |
| **Conservation 1937** | 17295 | 1 | $p < 0.001$ | 42775 | 1 | $p < 0.001$ |
| **Conservation 1960** | | | | 2907 | 1 | $p < 0.001$ |

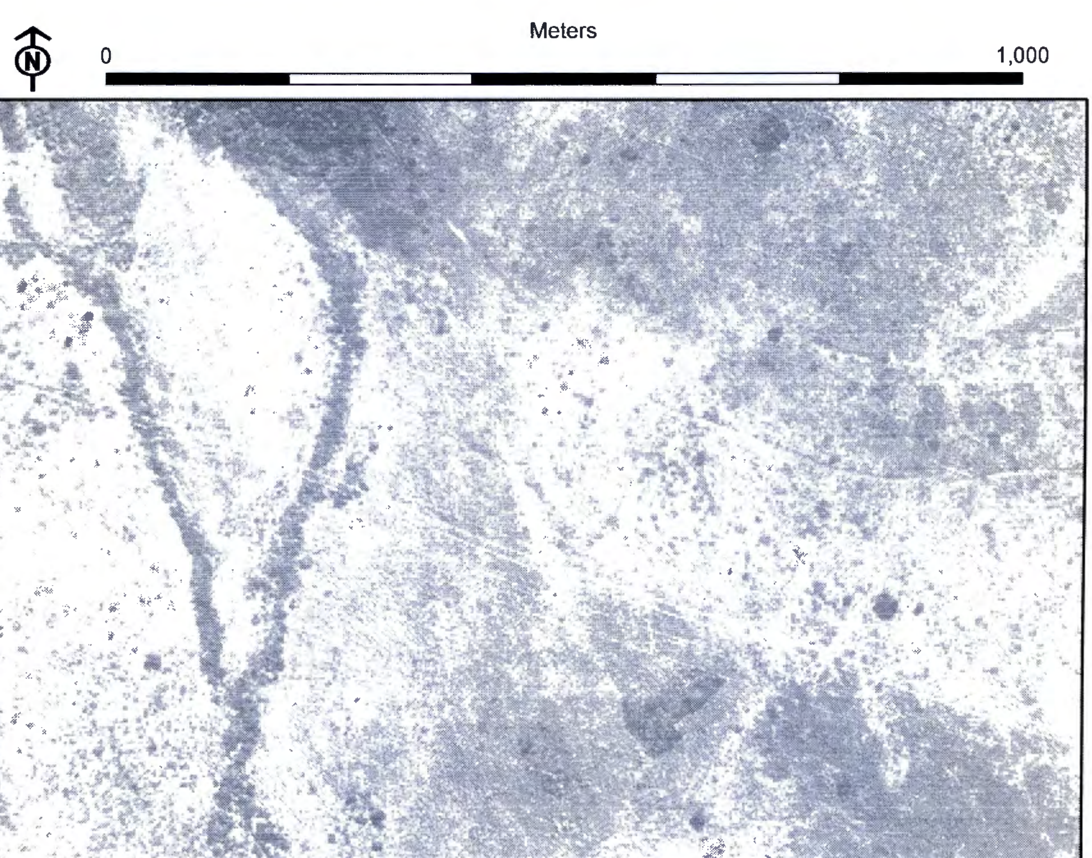


Figure 4.18. Aerial photography taken in1937 covering part of the conservation study site.


Figure 4.19. Aerial photography from 1960 showing the same area as per Figure 4.18.

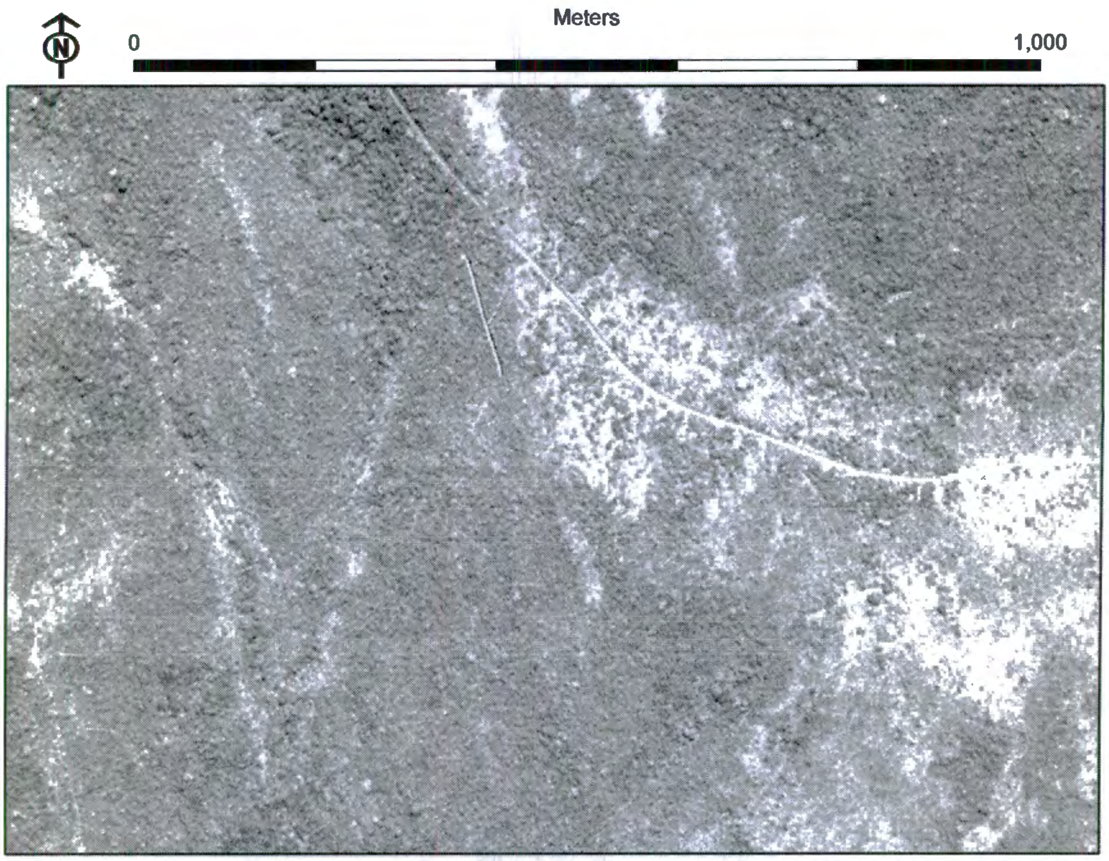


Figure 4.20. Aerial photography taken in 2004, covering the same area depicted in Figures 4.18 and 4.19.

The map showing the transitions between 1937 and 1960 (Fig. 4.21) shows a substantial increase in tree cover for the 23-year period. It also shows that the areas that were under tree cover in 1937 have mostly remained as trees in 1960. The map showing the transitions between 1960 and 2004 (Fig. 4.22) shows a further significant increase in tree cover. Once again the majority of pixels classified as tree in 1960 remained as tree in 2004. There is a however a noticeable number of transitions from tree back to grass in the southern half of the study site. This is most likely, in part, due to clearing efforts undertaken by the reserve management since the 1960s. The overall pattern evident from the mapped transitions between 1937 and 2004 (Fig. 4.23) again shows a predominantly clumped increase in tree cover as opposed to a randomly distributed increase in tree cover. It also clearly shows the biome shift from predominantly open grassland in 1937 to a closed canopy thicket or forest biome for large parts of the conservation study site.

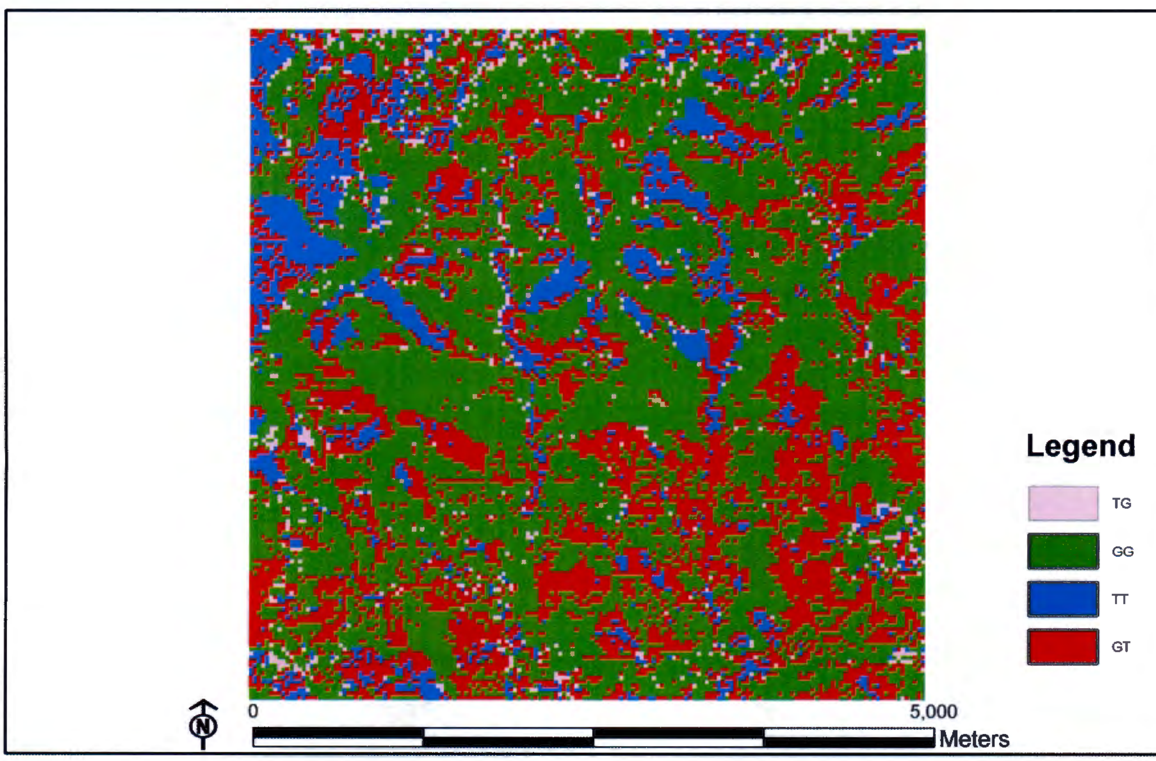


Figure 4.21. Transitions at the conservation study site for the period 1937 - 1960. The first letter in the legend denotes the class in 1937, while the second letter denotes the class that that cell falls into in 1960, where T = Tree and G = Grass.

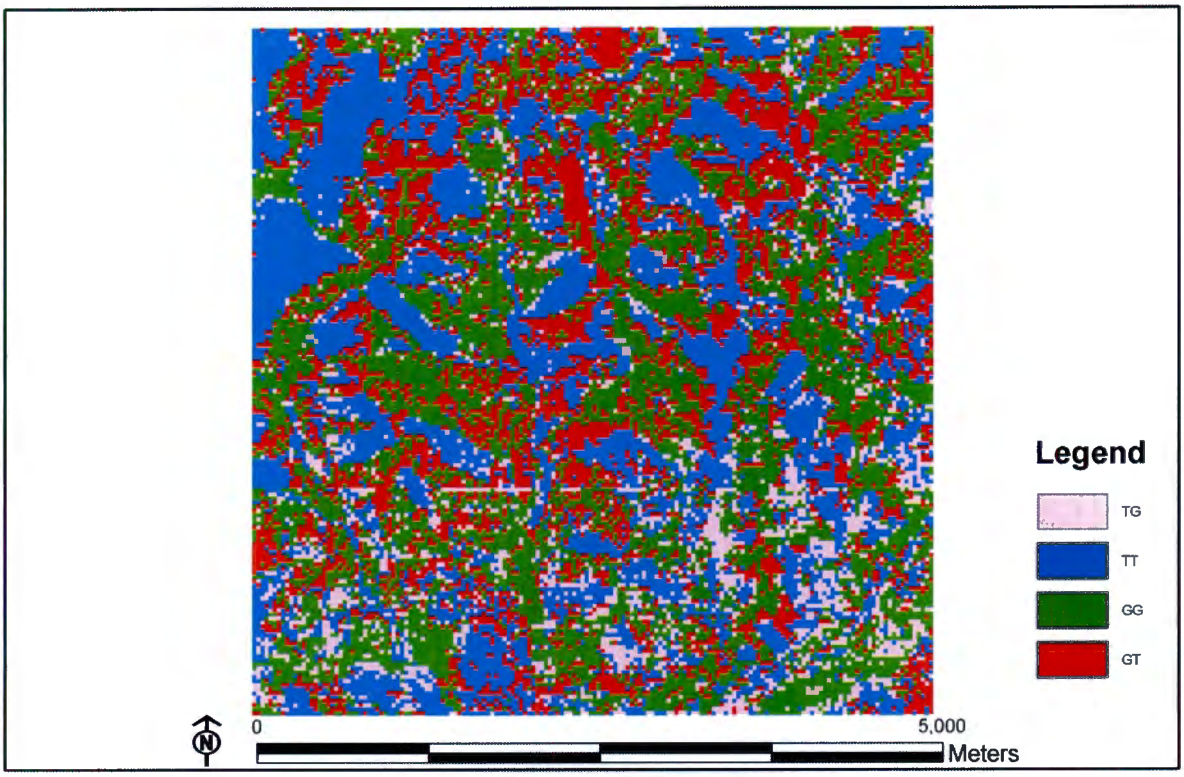


Figure 4.22. Transitions between classes at the conservation site for the period 1960-2004, legend as per Figure 4.21.

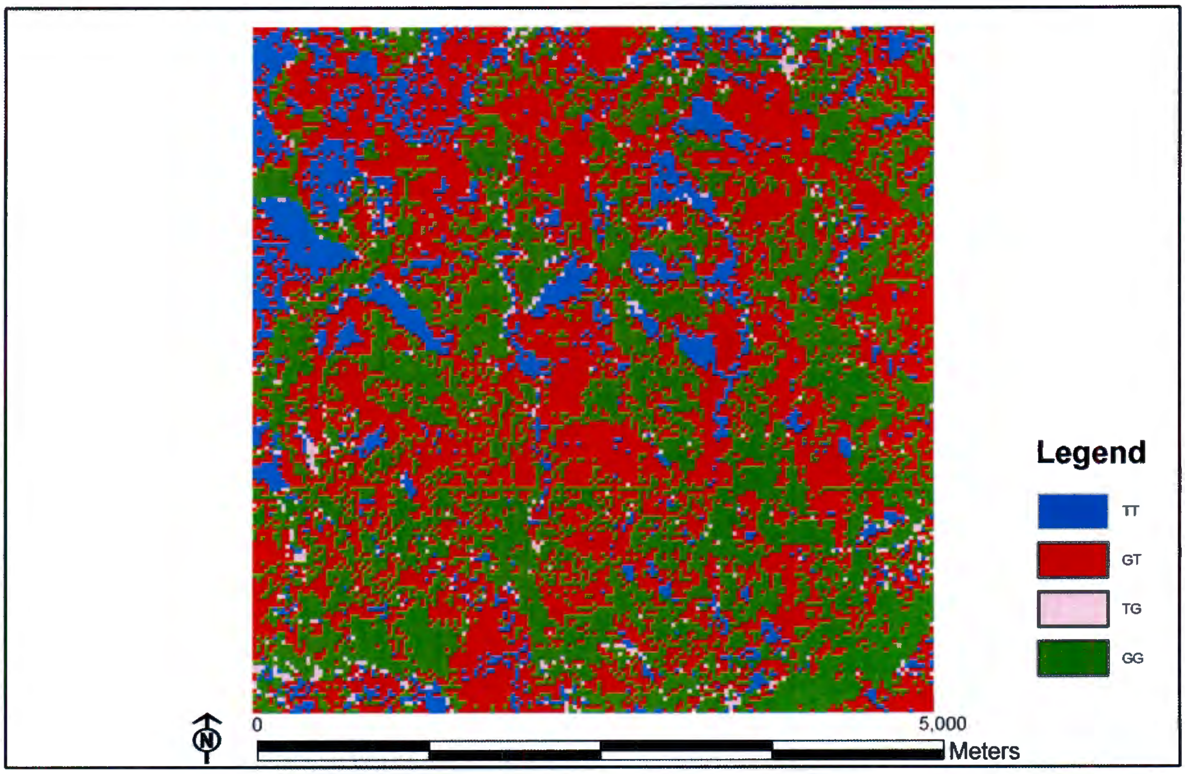


Figure 4.23. Transitions between classes for the 67-year period 1937-2004 at the conservation study site, legend as per Figures 4.21 and 4.22.

*eCognition Classifications*

The eCognition classifications (Table 4.12) for the conservation study site also showed a highly significant increase in tree cover during the 67-year period. However total tree cover was consistently lower than measured in the manual classifications. Total tree cover increased from ~9 % in 1937 to ~31 % in 2004 (Fig. 4.24). This equates to a two and a half fold increase in tree cover compared to the threefold increase reported by the manual classification.

Table 4.12. Total number, percent and area for each class calculated from the eCognition classifications of the conservation study site.

| | 1937 | | 1960 | | 2004 | |
|---|---|---|---|---|---|---|
| | **Number** | **Hectares** | **Number** | **Hectares** | **Number** | **Hectares** |
| **Grass** | 22905394 | 2291 | 19673386 | 1967 | 17227991 | 1723 |
| **Tree** | 2289930 | 229 | 5521938 | 552 | 7967333 | 797 |
| **Total** | 25195324 | 2520 | 25195324 | 2520 | 25195324 | 2520 |

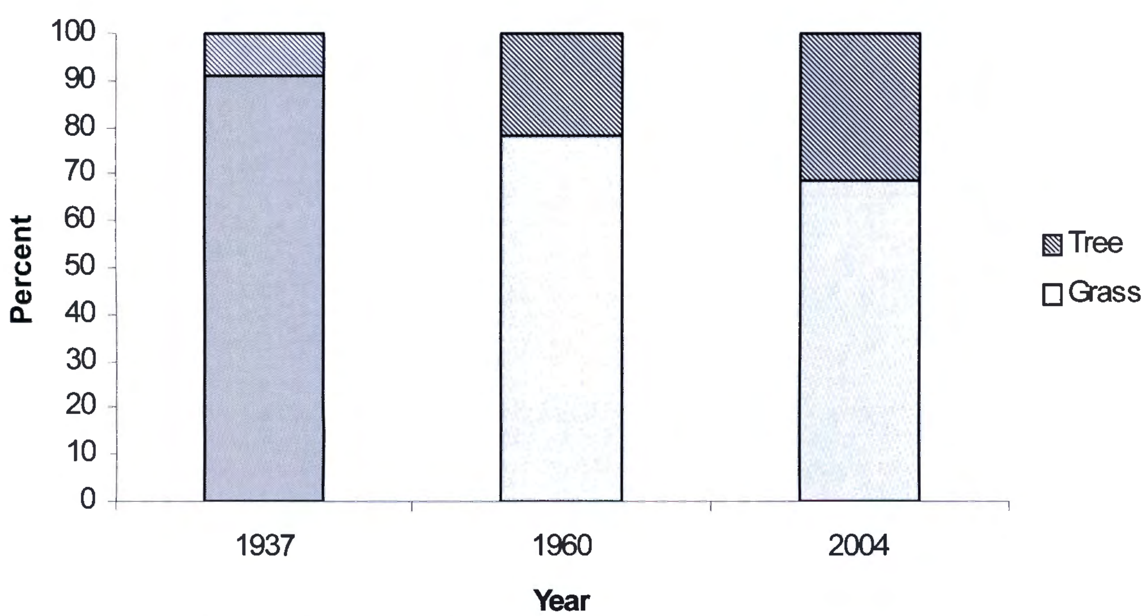


Figure 4.24. Total tree and grass cover for 1937, 1960 and 2004 as determined by the eCognition classifications.

The calculated probabilities of transitions between 1937 and 1960 were used to create a Markov model (Table 4.13). The model showed that the recorded rates of change were almost identical to the modelled values (Fig. 4.25).

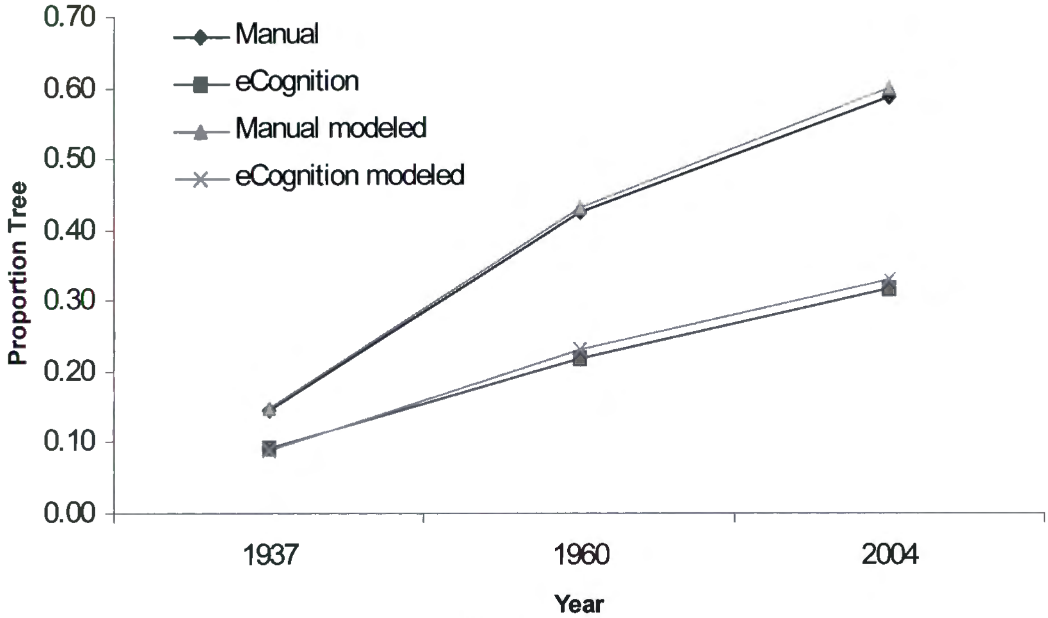

Figure 4.25. Proportion tree cover for the three years as calculated by the manual and eCognition classifications. The values predicted from the Markov models for each classification have been included.

Table 4.13. Markov model showing the modelled and actual proportions of tree cover using the probabilities calculated using the eCognition classification.

| | | From (1937) | | | Modelled values | | | | Actual values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | G | T | | 1937 | 1960 | 1983 | 2006 | 1937 | 1960 | 2004 |
| | G | 0.8 | 0.56 | G | 0.91 | 0.77 | 0.7 | 0.67 | 0.91 | 0.78 | 0.68 |
| To | T | 0.2 | 0.44 | T | 0.09 | 0.23 | 0.3 | 0.33 | 0.09 | 0.22 | 0.32 |
| | Total | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

The changes in tree cover between the three classifications were all highly significant when compared using the Chi-squared test (Table 4.14).

Table 4.14. Chi-squared analyses comparing total tree cover between the three classifications.

| | 1960 | | | 2004 | | |
|---|---|---|---|---|---|---|
| | $CHI^2$ | df | p | $CHI^2$ | df | p |
| **Conservation 1937** | 5017702 | 1 | p < 0.001 | 1548322 | 1 | p < 0.001 |
| **Conservation 1960** | | | | 1386907 | 1 | p < 0.001 |

*Comparisons between manual and eCognition classifications*

The results show that there are clear differences between the two methods of classification. The manual classifications consistently estimated higher tree cover than eCognition (Fig. 4.25). Thus, either the manual method is overestimating tree cover or eCognition is underestimating tree cover.

Examples of both methods of classification are shown in Figures 4.26 and 4.27. The effect of converting the point sampling method shown in Figure 4.26 into a spatially explicit map, whereby each point is converted into a 30x30 m cell shown in Figure 4.27 appears to exaggerate the extent of tree cover. The eCognition classification shown in Figure 4.27 is based on 1x1 m pixels and thus is able to classify smaller trees and shrubs.

In an attempt to make the methods more comparable, the eCognition classifications were aggregated into 30x30 m meter pixels using the majority rule, whereby if more than half the pixels in the new cell were classified as tree the new cell was classified as tree. Aggregations were performed using ArcMap v. 9.1. These aggregated classifications were then compared to the original classifications. The new aggregated classifications remained fairly similar to the original eCognition classifications. A possible explanation for this was that the majority of the aggregated 30x30 m cells consisted of a high proportion of grass pixels with less than 3 % of aggregated 30x30m cells containing between 90 and 100 % pixels originally classified as tree, while over 56 % of the 30x30m cells contained between 70 and 100 % grass pixels in the original eCognition classifications.

Differences in the scales of mapping are evident (Fig. 4.30) with the manual classification showing a more generalised pattern than the eCognition classification. The general pattern of change is however fairly similar between the two images (Fig. 4.28). The biggest difference between the two is that eCognition picks up the small areas of grass between patches of trees or thicket, while these areas are generally included as tree in the manual classification. This would partially explain the discrepancies that were found between the two methods.

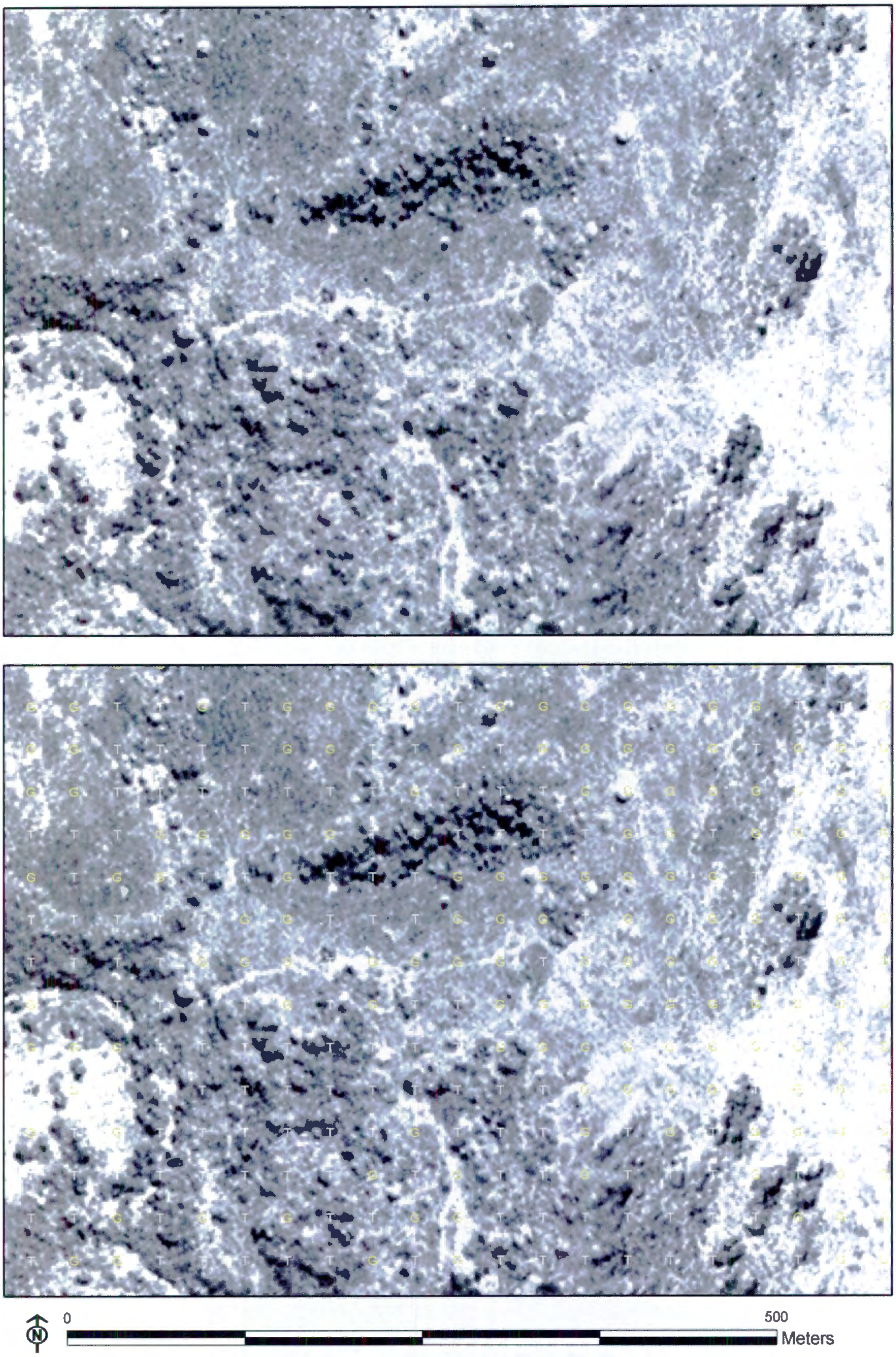


Figure 4.26. 2004 aerial photography covering part of the conservation study site (top), the same area with the manual classifications at every point of the overlaid 30x30m lattice (bottom), G = grass and T = tree.

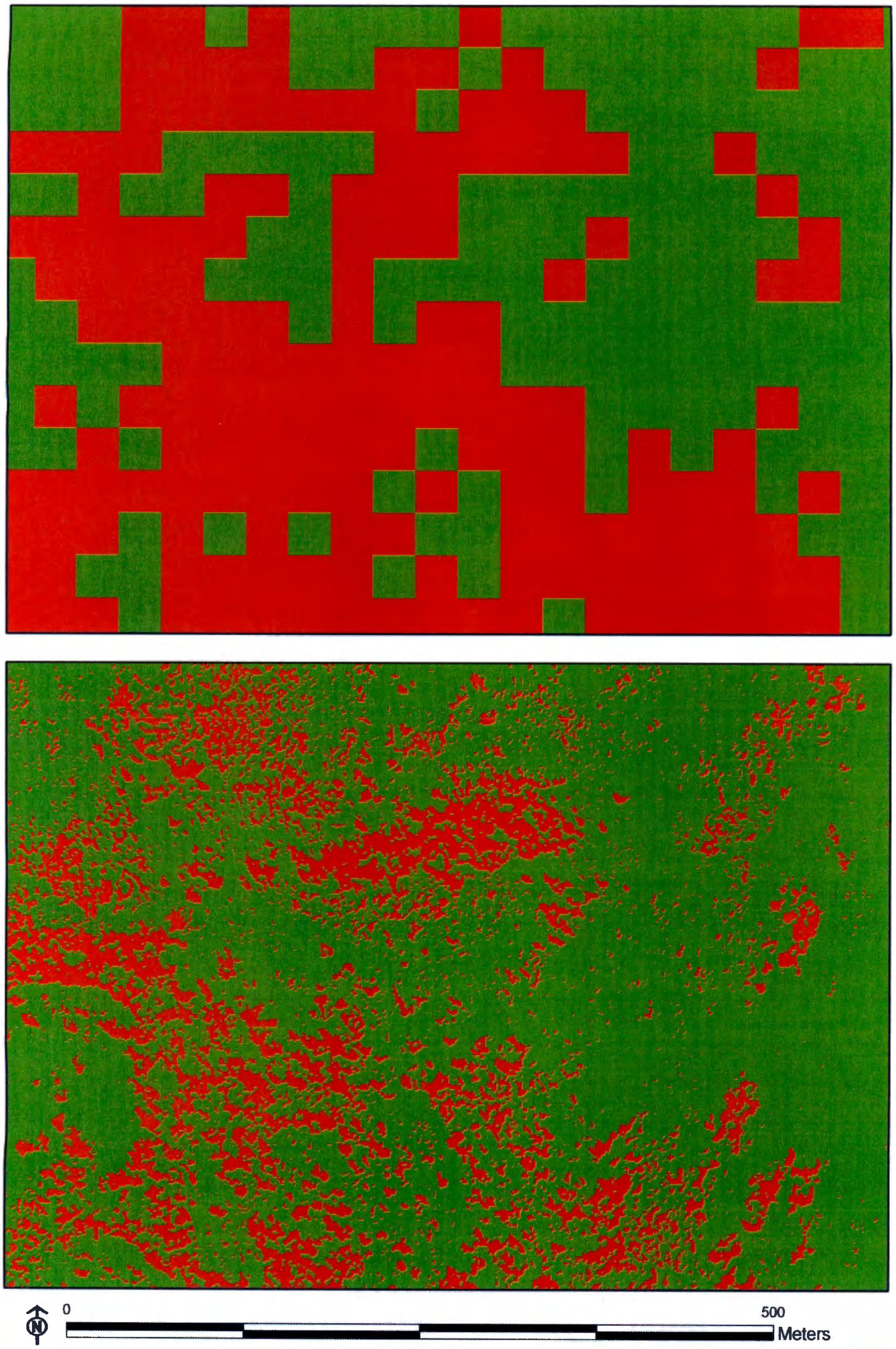


Figure 4.27. The same area as depicted in Figure 4.26 with the manual classification converted into a 30x30 m grid (top). The same area classified with eCognition (bottom). In both images red areas are classified as tree cover while green areas are classified as grass cover.

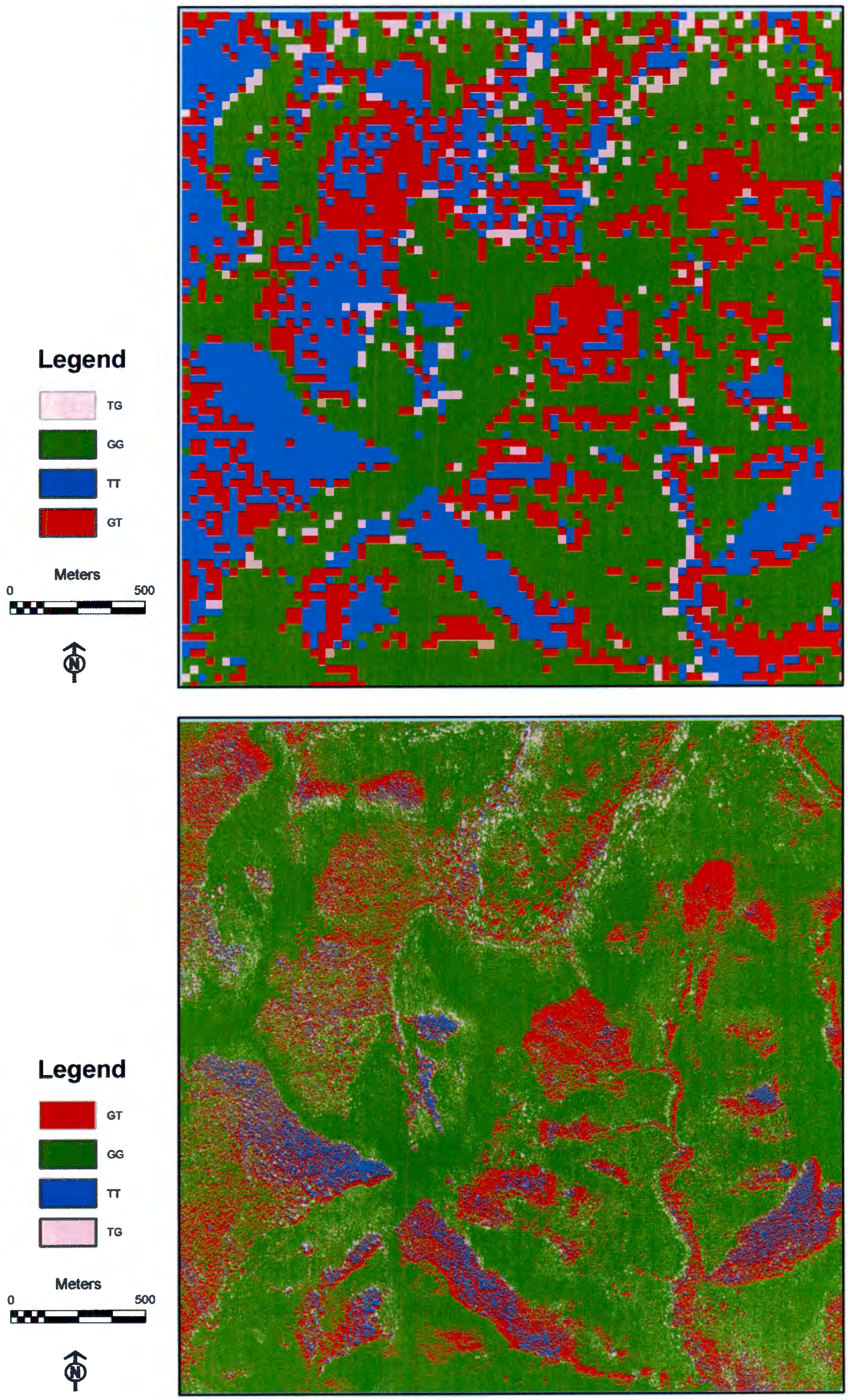


Figure 4.28. A comparison showing the manually classified mapped transitions between 1937 and 1960 for a portion of the conservation site (top) and the transitions for the same area as calculated using eCognition (bottom).

*Spatial patterns of change*

The objective of this study was not aimed at determining the spatial patterns of vegetation change. However in order to determine whether there were any broadly visible patterns, the drainage lines and contours were overlain over the map showing the total change between 2004 and 1937 at the conservation site (Fig. 4.26). A general pattern does appear to be evident with woody expansion appearing to be greatest along the drainage lines and steep slopes.

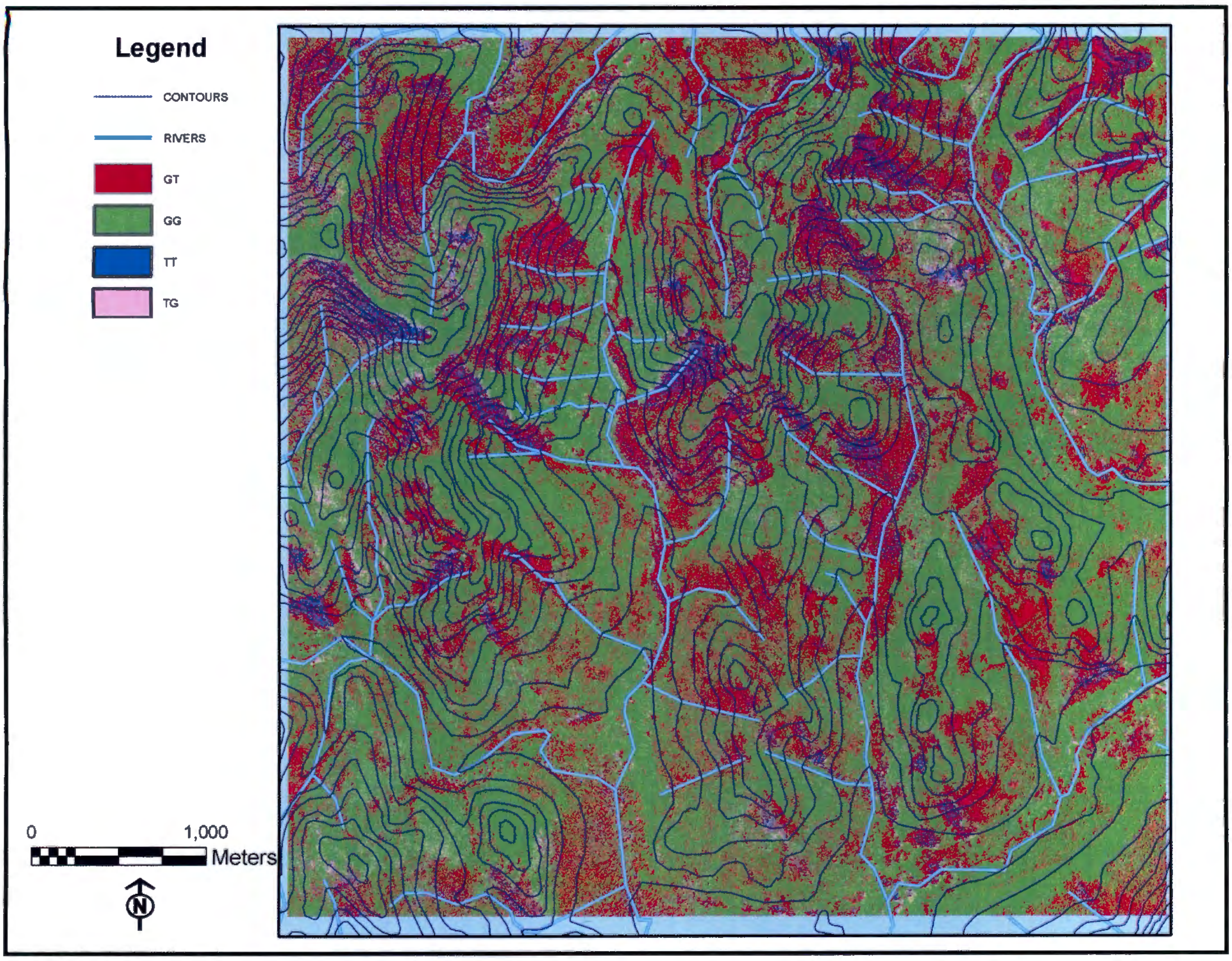


Figure 4.29. The transitions in vegetation classes between 2004-1937 at the conservation study site calculated from the eCognition classifications. Drainage lines and contours overlaid.

*Discussion*

*The use of repeat panchromatic aerial photography*

A number of problems arise when comparing temporal sequences of aerial photography. These include variations in scale, camera lenses, film type and distortion associated with irregularities of the flight path of the aircraft (Carmel and Kadmon 1998; Kadmon and Harari-Kremer 1999;

Fensham and Fairfax 2003a; Brook and Bowman 2006). Differences in the time of day that the photographs were taken can lead to further problems with shadows, especially in mountainous or undulating areas. Differences in the season can lead to differences in the reflectance of vegetation, especially for deciduous vegetation types.

The main advantage of image processing and GIS technologies is the spatial rectification of digitised aerial photography. This allows for some of the abovementioned weaknesses to be overcome as it allows chronological sequences of aerial photographs to be precisely overlaid to detect patterns of vegetation change (Johnson 1994; Bowman *et al.* 2001; Brook and Bowman 2006). Digital versions of aerial photographs can be machine classified to delimit different vegetation types in the same way that satellite images are processed. However, this type of classification is usually not effective because black and white aerial photography is limited to a single band, the grey-scale, and because the intensity of illumination changes both within and between frames (Hudak and Wessman 1998; Carmel and Kadmon 1998; Kadmon and Harari-Kremer 1999; Bowman *et al.* 2001). The major source of this uneven illumination in remotely sensed images is the topographic effect (Teillet *et al.* 1982; Carmel and Kadmon 1998). These and other problems associated with shadowing and seasonality of photography are especially relevant for this type of classification whereby only the spectral values of pixels are used to classify the image.

In light of the above constraints the manual onscreen classification approach using spatially rectified digitised imagery as used by Bowman *et al.* (2001) and Brook and Bowman (2006) was adopted as the appropriate method for this study. However, other automated approaches have been recently developed to overcome some of the aforementioned problems. Laliberte *et al.* (2004) showed that object-orientated image analysis using repeat aerial photography could successfully be used to accurately map shrub encroachment in New Mexico. One of the objectives of my study was to determine the potential of using object-orientated analysis to determine vegetation changes at a larger scale (landscape to regional scale). Classifications using the FNEA embedded in the software eCognition (Definiens 2003) were therefore performed for part of the area covered by the manual classifications. The results of the two classifications were then compared and will be further discussed below.

*Patterns of change*

This study demonstrated the widespread proliferation of woody plants at the study sites. Although differences were found between areas under different land use practices the one overriding pattern clear from the study is an unquestionable increase in woody cover regardless of land use practices and radically different land use histories. Limitations associated with processing and classifying aerial photography restricted the size of the study sites. However the spatial extent of our analyses (total of 75 $km^2$ or 7500 ha) was still far greater than most studies of this nature to date (e.g. Augustin *et al.* 2001 analysed an area of 25 ha; Bowman *et al.* (2001) analysed 30 $km^2$; while Brook and Macdonald (2006) analysed five sites ranging in size from 150 ha to 300 ha). Our study sites were chosen to be large enough to cover a landscape and to represent the general patterns of change at each study site.

The communal study site showed the least increase in tree cover. However the overall increase in tree cover from *ca.* 6 to 25 % is still a highly significant change. This equals a fourfold increase in tree cover since 1937. If these figures are converted into percentages of the total 2500 ha study site it equates to a 487 ha increase in tree cover. The Markov model created for the communal area showed that the changes in vegetation cover did not occur at a constant rate. The rate of woody increase was found to increase between 1960 and 2004. This would suggest that the rate of woody plant increase is accelerating at the communal study site. Another pattern evident at the communal study site was that cultivation peaked in the 1960s with less cultivation evident at present than during that period. This finding is consistent with the documented widespread collapse of subsistence farming in many rural areas of Sub Saharan Africa (Bundy 1979; Mckenzie 1994; Bryceson 2002).

The mapped transitions show a number of interesting patterns in the process of vegetation change at the communal study site. It is evident that areas used for cultivation are not kept constant through time but tend to change over time. The general pattern evident from the analyses is that woody cover has increased in many parts of the study site. However the increase in woody cover usually radiates outwards from a central point. Thus most of the increase is in the form of bush clumps or thicket expansion rather than randomly dispersed isolated trees. It is often perceived by farmers and scientists that bush encroachment occurs on abandoned fields. The mapped transitions show that this was not the case at the study sites. Most fields that were previously used for cultivation in the communal areas were found to be covered by grass and not trees in subsequent classifications.

The greatest increase in tree cover was evident at the commercial study site where tree cover increased by an astounding 1781 %. Total tree cover increased from *ca.* 2 to 50 % during the 67-year period. In terms of area this equates to a 1200 ha loss in grass cover or potential grazing. Commercial landowners have therefore lost nearly half of their grazing land to trees since 1937. Cultivation in the commercial area was not of major importance with total area under cultivation never increasing above 4 % of the total area. The Markov model for the commercial site showed a similar pattern to the communal site whereby the rate of woody increase was not constant but was found to accelerate rapidly between 1960 and 2004. The major pattern evident from the mapped transitions shows a clear nucleated or clumped increase in tree cover. Large areas that were open grassland in 1937 can be seen to have completely shifted to a closed canopy community which often results in the loss of the grass layer. This pattern can be clearly seen in the sequence of aerial photography shown in the results section (Figures 4.11 to 4.13).

The increase in tree cover at the conservation study site was also highly significant. Tree cover increased by ~300 % over the period from *ca.* 14 % in 1937 to 58 % in 2004. Closed woody vegetation has increased to become the dominant plant cover having gone from a minor proportion to more than half the total area (1100 ha) at present. The conservation area showed two main differences to the other study sites. The first difference was evident from the Markov model, which showed that the rate of woody increase was constant for the 67-year period. This is in direct contrast to the other two sites which both showed accelerated rates of woody increase subsequent to 1960. The other major difference was that the conservation study site showed significantly higher levels of tree cover in the initial 1937 photography. The communal and commercial study sites had initial values of ~6 % and ~3 % respectively compared to the initial value of ~15 % tree cover at the conservation study site. The slight gradient in altitude and associated rainfall (Balfour and Howison 2001) along the transect could be used to partially explain these initial differences in tree cover. Thus the slightly higher topography in Hluhluwe Game Reserve would have allowed higher initial forest cover. The differences could also indicate that the conservation site is at a more advanced stage of the widespread phenomenon of woody plant proliferation in the area. Alternatively the differences could be as a result of different land use and management practices prior to 1937. The pattern evident from the mapped transitions at the conservation site also showed a highly clumped or nucleated nature. The increase in tree cover was therefore mainly in the form of thicket expansion from existing patches of thicket or forest.

The clumped nature of woody cover increase as opposed to randomly distributed increases in tree cover evident at all three sites is of major ecological importance. The two spatial processes would have radically different consequences from an ecological perspective. An increase in randomly distributed trees throughout the landscape would still allow herbivores to access areas surrounding the trees and would let in enough light for grass to continue growing beneath them. However, when tree cover increases from a central point and radiates outwards to form clumps of thicket or forest it would have a very different ecological effect. Herbivores, especially grazers, would no longer be able to access areas under the trees. Furthermore, grazers would be likely to avoid densely wooded areas from fear of predation (Brown *et al.* 1999). As the patches of thicket grew in size they would progressively exclude the grass layer beneath them by shading and would eventually completely exclude grazers.

These changes in plant communities, reflecting a complete biome shift from savanna to scrub forest, would also have major biodiversity impacts. The high levels of faunal and floral biodiversity associated with grassy biomes would give way to a few dominant species associated with thickets. The mean plant species richness calculated from fifteen 2x100 m transects surveyed in thicket patches at the three study sites was found to be ~12, while total plant species richness from all transects (3000 $m^2$) was 35. Uys *et al.* (2004) who measured species diversity in twenty-seven, 100 $m^2$ quadrats (2700 $m^2$) in mesic South African grassland recorded 141 species. Although the transects surveyed in this study were probably not as meticulously surveyed as those of Uys *et al.* (2004) this comparison provides an estimate of how much biodiversity might be lost with conversion of grassland to thicket. A further indication of potential biodiversity loss is provided by Uys (2006), who recorded a total of 158 forb species from five savanna sites (total area of 1500 $m^2$) in the Hluhluwe Game Reserve. Skowno and Bond (2003) found that specific bird assemblages in Hluhluwe-iMfolozi Park were associated with vegetation types ranging from open grassland to broadleaf thicket. Their findings suggest that a biome shift from grassland or woodland to thicket would result in significant losses to bird diversity. Gottschalk *et al.* (2007) also found distinct bird communities are associated with short grasslands in the Serengeti. The loss of these areas to woody vegetation would therefore result in the loss of the associated bird community. Although a few studies have addressed the subject, the ecological impacts and effects on the biodiversity associated with this biome shift are not well understood. Studies are therefore urgently needed to address this problem.

The transitional patterns between cover types also show that the process of change is not completely unidirectional with a number of areas having changed from tree back to grass between classifications. Although spatial error in the geo-referencing of the images might explain some of these transitions it is not surprising that areas can shift in either direction between analyses despite the increasing trend in tree cover. The dynamic nature of natural systems, especially savannas, has recently been realised as more pronounced than previously thought (e.g. Behnke *et al.* 1993; Gillson and Hoffman 2007).

*Manual vs. Machine generated classifications*

This study was partly undertaken as a preliminary investigation into the feasibility of documenting vegetation changes at large regional scales. This would clearly not be possible using the manual methods we have adopted in the study. The approach was to use the manual classifications as a benchmark against which machine generated classifications using object-orientated analysis could be compared. Object-orientated analysis was chosen as the most appropriate methodology in light of the problems associated with pixel based maximum likelihood or supervised classifications of black and white aerial photography (e.g. Carmel and Kadmon 1998).

The most striking difference between the two methods was that the manual classifications consistently showed a higher degree of tree cover than the eCognition classifications. An important outcome however, was that the trends in eCognition classifications were consistent with the manual ones. Thus both showed close to a threefold increase in tree cover during the 67-year period. Furthermore the modelled rates of change for the conservation area, using Markov models showed the rates of change to be constant through time using both methods. These findings suggest that the manual method is consistently overestimating tree cover or that the object-orientated method is consistently underestimating tree cover. To tackle this question we closely compared classifications from the two methods. These comparisons showed that the main differences between the two methods arose in areas covered by thicket as opposed to forest or wooded grasslands. The manual method appeared to overestimate woody cover in these areas as it often missed grassy patches between thicket patches. eCognition on the other hand pulled out these areas and classified them as grass. This brings the chosen scale of the manual classification into question with the 30x30 m point sampling method not being fine enough to pick up the small patches of grass within thicket areas. eCognition which uses 1x1 m pixels as its base was able to differentiate these smaller areas. Furthermore, my attempt to upscale from point sampling into a spatial representation of an area assumes the entire 30x30 m area ($90m^2$) to be covered by the vegetation type found at the point of classification. The two methods of classification are not directly comparable as they are based on fundamentally different principles. Despite this the large degree of error between the two methods is of major concern. The actual degree of vegetation change is most likely to be somewhere between the results recorded from the two methods. Adjusting and fine-tuning the membership functions in eCognition could possibly improve the object-orientated analyses. Furthermore the scale of the point sampling technique used in the manual classifications could be made smaller (e.g. 20x20 m). Alternatively the methodology used by Bowman *et al.* (2001) could be adopted whereby each point was classified according to the surrounding vegetation and not only the vegetation found at each point of the lattice as was done in this study. Such changes could potentially provide a more accurate manual classification.

The findings from this study suggest that the fractal net evolution approach (FNEA) embedded in eCognition has good potential to scale up the analyses to the regional scale. The potential under-classification of tree cover by eCognition could be addressed by adjusting the membership functions. Thereafter, object-orientated analysis using eCognition could successfully be used to accurately document patterns in vegetation change at a larger scale providing sufficient computational capacity was available. Each method has therefore been shown to have its own pros and cons. The choice of which to use would therefore depend on the purpose of the classification and the required accuracy. For example the grass clumps classified within the woody matrix by eCognition would be too small to support a grassland fauna. The manual classification would therefore give a better representation of thicket for conservation managers concerned with protecting biodiversity. However these clumps of grass could potentially be used for grazing in the communal and commercial area so the eCognition classification would be suitable. The required accuracy of the classification therefore depends on the needs of the user. This issue of scale is a well-established phenomenon. The Nobel laureate, Ilya Prigogine, provides an example of this from his work on complex systems where he posits that the length of the English coastline depends on the scale at which it is measured (Scmaltz 2006).

*Conclusion*

This study has conclusively shown that tree cover has significantly increased in three areas that have remained under radically different land use practices for approximately the past century. It is the first study of its kind to compare the effects of different land use systems on the process of bush encroachment. The phenomenon of woody plant proliferation has usually been attributed to past management practices. The results from this study suggest that more than just land use practices have driven the significant increases in tree cover evident at the three study sites over the 67-year period between 1937 and 2004. The results also suggest that we are witnessing a major biome shift for large parts of the study sites. The consequences of such changes at the regional scale would have major ecological and biodiversity impacts and therefore need to be addressed. A potential explanation for the increased tree cover evident at all of the study sites could be related to increased atmospheric $CO_2$ levels. The accelerated rate of increasing tree cover subsequent to 1960 evident at the communal and commercial study sites is consistent with this argument.

# Chapter 5. Perceptions of bush encroachment by communal, commercial and conservation land users in the Hlabisa district KwaZulu-Natal, South Africa

*Introduction*

Chapter 4 clearly illustrated the large-scale changes in woody cover that have occurred under the three rural land use systems (communal, commercial and conservation) under investigation. The findings showed that woody plant cover in the form of both trees and shrubs has increased at all three sites. Although the occurrence of bush encroachment or woody plant increase has been widely documented around the world (e.g. Adamoli *et al.* 1990; Archer 1995; Silva *et al.* 2001; Asner *et al.* 2003; Fensham *et al.* 2003; 2005), little attention has been paid to what implications these changes have had on the land users themselves. There is therefore a need to determine how landusers perceive the magnitude, causes and consequences of the changes in vegetation cover. Furthermore an understanding of how landusers have generally responded to the changes is crucial as the results from the previous chapter suggest significant changes have occurred in all three areas. The ecological and biodiversity implications of the documented changes are likely to be considerable. If the landusers themselves are not concerned with these changes these areas are likely to continue changing at an unchecked pace. Due to the widespread extent of woody thickening the continued unlimited spread of woody vegetation types should become an issue of concern. The study therefore aimed to determine what the changes in vegetation denote to the land users and how the landusers are responding to the changes. The most appropriate way to achieve this was to consult the landusers themselves.

Indigenous knowledge has increasingly become recognised as an important and valuable source of information for scientists. Researchers have recently begun to stress the immense body of indigenous knowledge on environmental processes (Bollig and Schulte 1999). Sillitoe (1998) reiterated this in an extensive review on the importance of local knowledge especially with regard to development. He acknowledged that there is a shift in emphasis occurring in the development world from a focus on the 'top down' imposition of interventions to a so called "grassroots' participatory perspective. This should not be restricted to the development community but should also be applied to the scientific world. Ecologists should therefore draw on local knowledge in order to gain a better understanding of the processes leading to large scale changes in vegetation cover as has happened in many parts of Africa and other parts of the world over the last century. Scientists often tend to perceive indigenous land users as uneducated and therefore ignorant. The origins of scientific knowledge (usually by experimentation and validation) are often different to those of indigenous knowledge which is often inherently passed from generation to generation. With modernisation rapidly taking place in many parts of the world and the associated changes to traditions and cultures, valuable indigenous knowledge is being lost. The study area has changed significantly in the last century with accelerated change since 1950. In the first half of the 20$^{th}$ century the local inhabitants still widely practiced Zulu customs and traditions. The generation that was born and raised in this period therefore still retains much of the traditional knowledge passed down to them through many previous generations. However, once that generation is gone, so too will large component of the traditional knowledge be lost from the area.

People's perceptions are normally influenced by their own observations and experiences. How they interpret these may also be influenced by their education and peers. There are fundamental differences in the backgrounds of the different landusers. The majority of elders in the communal area are unlikely to have undertaken any official schooling and many are illiterate. Their ecological knowledge and understanding of the area derives predominantly from traditional knowledge. The majority of landusers in the commercial areas would have completed school and many are likely to have obtained a higher degree or diploma in agriculture or wildlife management. A number of the commercial landusers are also likely to come from families that have been farming for many generations. Thus the ecological understanding of the commercial landusers is likely to be derived from a combination of official learning and traditional knowledge. The conservation landusers would also have received official schooling and the majority of them would have attended an institution of higher learning and obtained a degree or diploma in the life sciences. These differences are likely to have influenced the landusers perceptions of the changes and causes of the changes.

The value of combining remote sensing techniques with ethnographically based research has become increasingly recognised (e.g. Sussman *et al.* 1994; Dahlberg 2000; Jiang 2003; Semwal *et al.* 2004). Fox *et al.* (2004) have also compiled an extensive list of case studies showing the value of combining household surveys with GIS data. These studies all successfully combined information gained from indigenous people living at the study sites with remote sensing in order to understand landscape scale changes on the ground. Important benefits can be gained from such an interdisciplinary approach. For example, information gained from the land users can be compared to, and used in conjunction with, historical aerial photography. Furthermore, older aerial photography can be used to validate the information gained from the land users living at the study sites. Thus, both local knowledge and aerial photography are extremely valuable for studies of this nature where landscape-scale land cover changes are being investigated.

In this chapter I record the different land users' perceptions of the changes documented in Chapter 4 using semi-structured interviews and oral histories. Thus I aimed to document and compare the perceptions of change within different land user communities Perceptions of the pre-1960 and current landscape condition or state and causes and impacts of the perceived changes were determined. I also documented whether anything had been done in the past or at present in response to these changes. I attempted to cost currently utilised and other potential methods of combating changes in woody plant cover. Furthermore I wished to determine which knowledge gained from the land users would contribute to our understanding of the causal factors driving the observed changes.

*Study site*

The extent of and history of the study sites have been described in detail in Chapter 2. A detailed map of the study sites is shown in Figure 5.1. In this study the three study areas mostly overlap with those shown in Chapter 4. However, the areas covered when interviewing the different landowners/land users covered a significantly larger area than those analysed in the previous chapter because of the differing sizes of properties under the different tenures. The extent of the communal area covered during the interviews included the area east of the Hluhluwe Reserve, north of the Hluhluwe River and West of the N2 (Fig. 5.1). The commercial area covered during the interviews included farms to the north, south and west of Hluhluwe town, with most of the properties falling between the towns of Hluhluwe and Mkuze adjacent to the N2 National Road. The conservation area covered in this chapter included the entire Hluhluwe-iMfolozi Park.

*Methodology*

*Semi-structured interviews*

The use of semi-structured interviews (Corbetta 2003) was chosen as the most appropriate method of gathering the required information from the land users. The nature of the study sites and location of the different land users excluded methods such as posting questionnaires to the interviewees as done by Fensham and Fairfax (2003) who constructed an extensive land management history for central Queensland, Australia, using mostly landholder questionnaires. This method would not have been appropriate in our study due to the relatively small size and location of each group of land users. Furthermore, all of the respondents were located by word of mouth and postal questionnaires would normally not have been possible, particularly in the communal areas where the respondents had to be located in person. In the commercial and conservation areas the respondents were usually contacted in advance by telephone. Upon agreement to undertake an interview a meeting was set up at a subsequent date. The use of semi-structured interviews allowed for a highly flexible process which enabled any particular topic or issue of interest that arose in any particular interview to be explored at length. The interviews were for the most part conducted on a one to one basis with the land users.

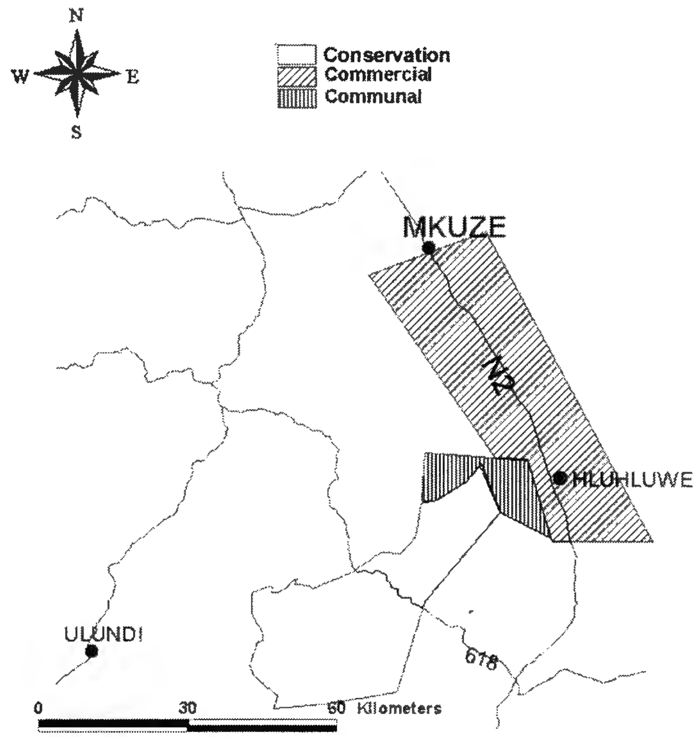


Figure 5.1. Map of the Hluhluwe area in Northern KwaZulu-Natal South Africa, showing areas under the three contrasting land use practices in which interviews were conducted with the land users/landowners.

The decision to use semi-structured interviews as opposed to formal interviews (e.g. Corbetta 2003), group discussions (e.g. Barbour and Kitzinger 1999) or Participatory Rural Appraisal (PRA) methods (e.g. Chambers 1994a; 1994b; 1994c) was decided upon after consultation with several social scientists familiar with these approaches and subsequent to a great deal of investigation into the pro's and con's of the different options. The use of semi-structured interviews was decided upon for a number of reasons. Firstly, it allowed the interviews to be relatively informal thereby avoiding intimidating the respondents. This was especially true for the elders in the communal area who were occasionally initially suspicious of our intentions. Secondly, it allowed each interview to be pursued in any direction without the constraints of a formal structure or order. Thirdly, the *a priori* intention was to form a narrative with the results rather than trying to statistically analyse the data. After performing the interviews I feel that the chosen method of using semi structured interviews was indeed the most appropriate method for this study and yielded very satisfactory results.

*Questionnaire design*

A list of important themes for discussion was drawn up before conducting the interviews (Appendix A). These themes were then used to steer the semi-structured interviews. The same questionnaire was used in interviews with all three groups of land users. There was one specific section, which was only relevant to the communal land users as it related to natural resource utilization. The questionnaire was used more as a guideline to steer the interviews and was never issued to the interviewees but was rather used by the author to ensure all the intended questions were asked during each interview. When a new theme or idea arose during the interviews it was pursued if it was deemed appropriate. To ensure anonymity in the reporting process each interviewee has been given a unique letter (e.g. Communal land user A). A controlled list, which relates the unique number to the name of the interviewee, has been filed securely.

*Communal land user interviews*

Prior to conducting fieldwork in the communal area the various Induna's or tribal authorities in charge of the area under investigation (see isiZulu traditional leadership explained in Chapter 2) were contacted. The objectives and motivation for this study were then explained to the Induna in each area. Permission was then requested to conduct interviews with the elders living in areas under their jurisdiction. Once permission was granted from the appropriate Induna we enquired after elders living in the nearby vicinity. We started by interviewing these elders then asked of them the localities of other elders living in the area. This method worked very well and in this way we managed to locate and interview the majority of elders living in the communal areas under investigation in this study.

Upon locating an elderly man or women we informed them that we had been granted permission from the appropriate Induna and then explained the objectives of the study to them and asked if they would be willing to participate in an interview. On occasion an elder was not satisfied with the motives for the study and was therefore reluctant to participate in an interview. Upon agreement we would commence with a semi-structured interview. The interviews were conducted with the help of a translator, who was able to translate the questions into isiZulu and the responses back into English. The author who has a working knowledge of isiZulu was also able to understand the majority of what was being said. This ensured that certain subtleties and expressions were not being lost during the translating process or as the translator saw fit.

Thirty-five elders in the communal areas to the east and north of the Hluhluwe Game reserve were interviewed (see Fig. 5.1). They ranged in age from approximately 50 to 102 years although many of the elders living in this rural area didn't know their exact age and therefore supplied estimates. The majority of the interviews were performed on a one to one basis, this being the favoured method as it allowed people to express their own opinions and memories without being interrupted or corrected by others. When performing group interviews there often tend to be one or two really outspoken people who often dominate the proceedings thereby drowning out the less outspoken or quieter people present. Furthermore, men often tend to dominate the interviews often not allowing women to contribute to the discussions (e.g. Corbetta 2003). In instances where group interviews were unavoidable we tried to allow everyone present to add his or her input and recorded everyone's answers to the questions being asked.

*Commercial land user interviews*

Commercial farmers in the area were located through the help of the regional conservation officers from the area and from various staff working in the Hluhluwe Game Reserve. I targeted mostly farmers who had been in the area for a relatively long time. However, this was often not possible due to the nature of the farming industry in the area where many of the farms have been converted into large private game reserves (see Chapter 2). Where possible I tracked down retired farmers, veterinary officers, and extension officers from the area and conducted interviews with them. A number of farmers and private game reserve owners or managers who are still farming in the area were also interviewed.

Semi-structured interviews were conducted on a one to one basis with interviews usually taking approximately two hours to complete. These interviews were conducted in English using the same list of questions and topics used in the communal interviews to steer the interviews. However any topics of particular interest raised by the interviewees were also pursued. Two current cattle farmers, two retired cattle farmers, one retired veterinary officer, two private game reserve owners, four private game reserve managers, one retired extension officer, one current extension officer and one elderly farm employee, all from the Hluhluwe area, were interviewed given a total of 14 commercial land users. The interviewees ranged from approximately 40 to 87 years in age.

*Conservation land user interviews*

The Hluhluwe iMfolozi Park (HiP) is one of the major reserves in KwaZulu-Natal province, run by Ezemvelo KZN Wildlife (see Chapter 2 for history). The park is made up of three main sections, the iMfolozi Game Reserve, the Hluhluwe Game Reserve with a corridor section between joining the complex into one large reserve. The complex is divided into five sections each with a section ranger allocated to it. Both the iMfolozi and Hluhluwe Reserves have a conservator in charge of managing the respective reserves.

Semi-structured interviews were conducted with all five of the section rangers and with the conservator of each reserve. An elderly technical assistant employed by the research branch of the reserve who has been employed by the reserve since he was a young man was also interviewed giving a total of 8 interviews. The interviews were conducted as per the communal and commercial land users. The same list of themes and questions was used to direct the interviews, while any themes or topics of particular interest to the interviewees were followed up in detail. Interviews were conducted in English with each interview taking approximately two to three hours to complete.

*Breakdown of interviews into themes*

Upon completion of the interviews the data were broken down into a number of major themes (Appendix B). The approach taken by Showers (2005) and Dahlberg (1996) to document environmental changes as perceived by the local land users was adopted. Thus, the major themes were then used to form a narrative to describe the changes as perceived by the land users at each study site. A qualitative approach was usually adopted. However, where possible, quantitative measurements have been provided to show how general or specific various perceptions were amongst the interviewees.

*Results and discussion*

*1) Communal land users*

Figure 5.2 provides a summary of the landscape states through time as perceived by the communal landusers. The diagram also provides the perceived causes of and responses to the changes. Each section is dealt with in detail below.

*Perceptions of the pre-1960 landscape compared to its present state*

There was a distinct divide in the communal land users' perceptions as to what the area looked like prior to 1960 (Fig. 5.2). The minority (29 %) of the 35 interviewees recall the area being much more forested in the past. However, when asked how general this was it was usually found that they were referring to a specific vicinity, normally surrounding their homesteads, or to a particular forest nearby which had decreased in size. Most of the interviewees who perceived the area to be more forested in the past were from a particular area in the vicinity of the Hluhluwe Dam and in the Pindasweni area north of the Hluhluwe Game Reserve. The following quote is the answer provided by an interviewee when asked what the area looked like when he was young: "*It used to be a forest, people have chopped it out*" (Communal land user B).

The majority (71 %) of interviewees however, recall the area being much more open in the past. They almost all spoke of the area being open grassland with big trees scattered throughout the landscape (e.g. "*The area was all tall grass with very few trees when I was young*" (Communal land user C)). There was also a strong perception that there never used to be as many shrubs in the area as indicated by the following quote: "*There used to be lots of big trees, these are gone now and there are only shrubs left*" (Communal land user E). There was almost complete agreement that there are very few big trees and many more shrubs now compared to when the interviewees were young (e.g. "*This area used to be open grassland, in 1940 there were no bushes here, and it looked more like an open woodland*" (Communal land user G)).

There was general agreement that the number of shrubs in the area had significantly increased. The most mentioned shrub species (see Appendix C) thought to have increased in densities were *Acacia karroo, Acacia nilotica, Dichrostachys cinerea, Maytenus senegalensis* and *Maytenus heterophylla*. The alien invasive shrub, *Chromolaena odorata,* was also perceived to have increased in densities and extent in large parts of the communal areas. There was also a perception that the shrubs and coppicing plants did not grow up into big trees anymore. Some also perceived a change in grass species to have occurred, e.g. "*There used to be isiQunga (thatching grass) [Hyperrhenia spp.] all over this area, now it has changed to Unsiki [Sporobolus spp.]*" (Communal land user C). In contrast to the predominant perception of the area being bushier now, one of the respondents perceived there to be less bush now than there was in the past (e.g. "*There is less bush now than in the past because people are using more trees and shrubs now*" (Communal land user H)).

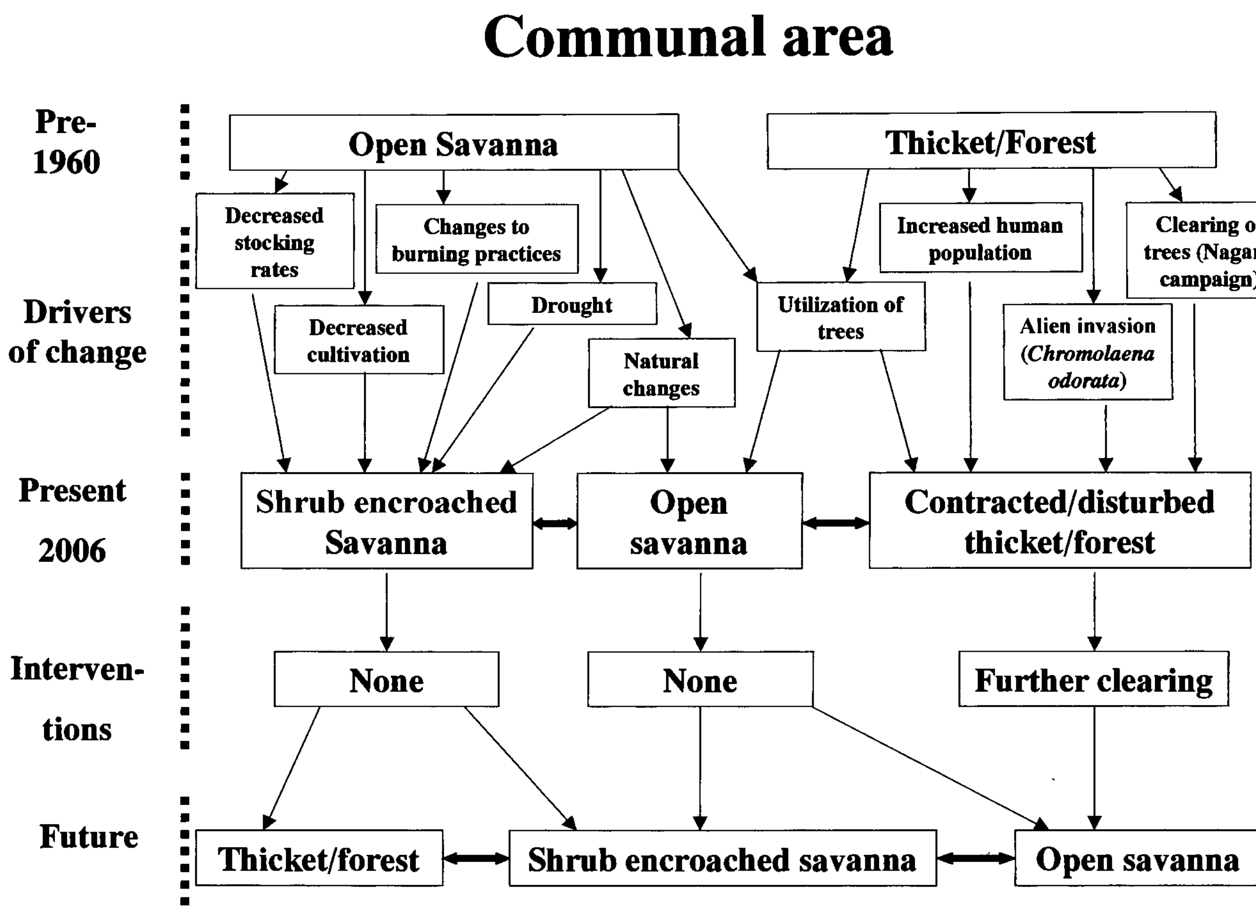


Figure 5.2. Diagram showing the perceived changes and drivers of these changes in the communal area over *ca.* the last century. Likely interventions in response to the changes and possible future outcomes resulting from these interventions are also shown.

*Perceptions of changes on contrasting land use types in the area*

The communal land users felt that relative to the communal areas, both the commercial and conservation areas had undergone greater changes with substantial increases in tree and shrub densities and cover since 1960. Many of the communal land users commented on the increase in the number of big trees in the commercial and conservation areas compared to the communal areas where big trees had decreased.

The following extract (from Interviewee I) supports this view and points to the potential drivers of this change:

Question: *"Have you noticed any changes in bush/tree densities in the park* [Hluhluwe] *and on the farms next to the communal area?"*

Answer: *"Yes, there is definitely more bush in these areas compared to what there used to be. In Ubizane* [a neighbouring private game reserve] *they used to burn to keep cattle, it was more open as they used to burn, but now there is more bush."*

Question: *"Why do you think there is more bush now in the park and on the farms next door?"*

Answer: "*They now have a fence at Ubizane. While in the park people were moved out. That is why there are more trees in the park. People were forced into the communal areas where there used to be more trees. So where people are living trees are removed. And inside the park people were removed so the tree numbers have increased. That is why there are fewer trees outside the park.*"

Question: "*So you think there are fewer trees in the communal areas now?*"

Answer: "*There are less* [trees] *now because people are forced closer together, but inside the park, big areas are left to nature causing an increase in the number of trees.*"

*Perceived causes of the observed changes in vegetation cover in the communal areas*

*1) Rainfall*

Many of the respondents (72 %) claimed that rainfall had changed since they were young, with much less rain now than there used to be with more frequent drought events and shorter growing seasons than there used to be. Some of the interviewees claimed that this was the reason why there were no longer any bigger trees left and so many shrubs. Some of the interviewees claimed that there was only enough rain to maintain the shrubs but not enough to allow the trees to grow into large mature adults. Perceived evidence for changes in rainfall included the drying up of springs, streams and rivers. It was also claimed that people often no longer grow crops in the area, as there is not enough rain anymore for their crops to survive. Changes in rainfall amount and increased drought were also blamed for the reduction in cattle numbers in the area. However, analyses of long-term rainfall records for the area did not show any significant differences in annual or seasonal rainfall over the *ca.* the last 60 years (see Chapter 3).

*2) Fire*

Almost all of the elders who were interviewed (86 %) stated that there have been major changes in the way in which fire is utilised and managed in the communal areas. In the past all of the burning in the communal areas was controlled by the Induna or Inkosi in charge of the area. Once permission was granted people would burn firebreaks around their homesteads with the help of neighbours. They would also burn areas they wished to cultivate and old cultivated lands. Fire was also used in areas where the grass had become moribund to ensure new growth for their livestock and to control ticks when they became a problem. Before burning people had to advise the Induna of their intentions and gather as many people as possible to help with the burn. The season of burning was also said to be important and people would usually burn in the dry season when grass was dry enough. People would always make sure conditions were suitable before burning commenced thereby preventing runaway fires.

Many of the elders indicated that there is no longer a controlled system for burning as there was in the past. This was thought to result from people having lost respect for the tribal authorities as they are now inclined to burn without advising anyone. It was also believed that more accidental or arson fires are started now compared to in the past, whether from people throwing cigarette butts in the grass or purposefully starting fires. Thus, it became evident there have been major changes to the fire regime in the communal areas. In the past areas were carefully monitored and grass would only be burnt when deemed necessary and safe to do so. Nowadays the consensus was that nearly all of the communal area burns on an annual basis, anytime of the year. Fires are no longer controlled or organised and people just burn when and where they please. (e.g. *"We used to burn firebreaks around the houses and we used to burn the pastures, but we would only burn half at a time, we used to burn in a controlled fashion. Now things are different, people just burn anywhere, anytime. An area would normally be burnt every 1-2 years when the grass became old, but we used to burn in the morning and we made sure it wasn't too hot or windy. We used to burn in late summer or autumn because we didn't want the grass to be too dry, as then the fire would just run away. Now there is no system anymore, people just burn anytime now, they just throw their cigarettes away and start fires"* (Communal land user K).

These changes in burning practices would have major impacts on the vegetation and prevent the recruitment of shrubs and juveniles into trees (Bond and van Wilgen 1996). It would also help explain the high occurrence of multi-stemmed short shrubs in the area as they would continuously coppice after being top-killed by frequent fires. Furthermore, the increased grass biomass resulting from lower cattle stocking rates (see below) would result in higher fuel availability for burning. This would allow more frequent and more intense fires than in the past when cattle numbers were much higher. The above explanations would partially explain why the communal areas are much more open than the surrounding conservation and commercial farms.

*3) Changes to cultivation practices*

Most of the interviewees (79 %) claimed that there is much less cultivation happening in the area at present compared to the past. There are currently very few communal land users still growing crops for their own subsistence. There has also been a major shift towards growing cash crops such as sugarcane by the few communal farmers still growing crops. It was also thought that people no longer plough as the importance of growing their own food has declined, access to labour and equipment is more difficult and rainfall patterns are perceived to have changed. Some of the perceived reasons for the decline in cultivation are given in the following quotes: (e.g. *"It is very different now, people plough less now and are lazy. People used to have big areas and plough them, now they only use a small portion of their lands."* (Communal land user C). *"People are lazy now, they don't want to plough, and even if they want to plough they are short of equipment such as oxen and tractors to plough. And there is more drought in summer now compared to the past"* (Communal land user H). *"There is less cultivation now as tractors are too expensive"* (Communal land user A). *"Drought has caused people to stop ploughing. There is less rain now"* (Communal land user L). *"Long ago we used to plough big areas and harvest a lot of food. Now you don't get as much food from your fields. That is why people don't plough anymore, [pointing to a hut], that room used to be filled with mielies every year, now there are none"* (Communal land user N). *"We used to be able to plough with cattle, now it is more difficult as tractors are too expensive"* (Communal land user J)).

The collapse of cultivation or deagrarianization over the last century has been well documented for sub-Saharan Africa (Bundy 1979; Mckenzie 1994; Bryceson 2002). At the more localised scale, incorporating the study site, Lenta (1978; 1981) has documented in detail the collapse of agriculture in the former homeland of KwaZulu in which the communal sites were situated (see Chapter 2). For example an unpublished KwaZulu Department of Agriculture and Forestry Annual Report showed that, in 1965, 80.5 % of all arable land was under cultivation, 73 % in 1972 and 67 % in 1978/79 (Lenta 1981). Bundy (1979) found that the loss of stock during the Rinderpest and other plagues meant that people were no longer able to cultivate, as they had no animals with which to do so. Lenta's (1981) study found that the lack of capital, shortage of labour and poor quality of land made cultivation unprofitable or impossible and that these were the key reasons for the collapse of cultivation in Kwazulu. Some of the reasons given for the collapse in cultivation are therefore in agreement with the literature. However, other reasons given by the interviewees (e.g. people are too lazy, less rain, and the high costs associated with ploughing with tractors) are in contrast to the above literature. Other contributing factors are likely to include changes to the traditions and cultures in the area alongside increased access to and ease of purchasing food.

Thus many of the areas that were previously under cultivation are no longer used and many claimed that these were the areas that have had major increases in shrub densities. In the past a cultivated area was used to grow crops for about three years then left dormant for a few years before being cleared, burnt and replanted. Thus cultivated areas were rotated to allow the soil to rest. The old cultivated fields were also thought to be more fertile than the surrounding areas due to cattle being allowed to graze on these areas after harvesting was completed. Thus these abandoned fertile fields would be perfect recruitment sites for trees and shrubs. The perception that previously cultivated areas have become heavily encroached with shrubs is evident in the following quote: *"It was grassland and woodland in the past with very few areas covered in thick shrubs. Now it is very different. There are many bushes, especially small shrubs because people don't plough anymore"* (Communal land user L).

*4) Increased human population and changes in cultural traditions*

The numbers of people and homesteads in the communal areas have increased significantly over the past 70 years (see Chapter 3). Furthermore people's lifestyles have changed in these areas. People now use cement, bricks and corrugated iron to build while many people now also have electricity. *"Now people use cement and wire to build houses and fences"* (Communal land user N). *"I preferred it the way it was long ago, now we have to buy cement and bricks to build, we just used to use poles and trees to build our houses"* (Communal land user I). People in these areas are no longer self-sufficient but rely on purchasing their food, beverages and fuel. *"We used to grow peanuts, mielies* [corn], *beans, sorghum and sweet potatoes. None of this sugarcane was here. When our mielies were dry, we used to dig a hole to store them in; they wouldn't rot in these holes. There were no shops; there was just one in Hluhluwe and one in Bushlands, which were very far away. We only used to buy sugar, if we wanted oil we would use peanuts to make oil, we used to have big cast iron pots to cook in and we never had small pots or stoves"* (Communal land user M). Children also usually attend school now and are therefore no longer able to assist with animal husbandry, firewood collection and crop cultivation.

A further explanation for the observed changes in the area was said to be changing traditions alongside a shift towards a western culture. Increased human densities in the area were often blamed for the lack of big trees in the area. These were said to have all been harvested for building materials and fence posts in the past. It was thought that there simply were not enough trees to supply everyone with enough materials. Other changes to traditional lifestyles have previously been mentioned. These included changes to burning practices and the fact that less importance is now being placed on owning cattle. Some of the elders believed that the observed increases in woody plant densities was due to the fact that people are now using modern materials such as cement and bricks for building houses and fences. Furthermore electrification of some homesteads means that less people are currently using wood for cooking and heating thereby leading to an increase in woody plants. It was also said that many people no longer utilise traditional medicines and many species are therefore no longer being harvested for medicinal purposes.

*5) Ecological or natural changes*

Many of the interviewees suggested that almost all of the shrub and tree species growing in the area are able to resprout after fire or chopping. Thus it was thought that the more frequently plants were burnt or harvested the more they would resprout which would lead to higher stem densities of these species with more frequent fire. Root suckering was also mentioned, leading to higher densities of shrubs such as *Dichrostachys cinerea* and *Maytenus senegalensis* in the area. Some of the communal elders believed that the changes were all part of a natural process and changed naturally regardless of human influences. Others said that they did not know why the changes had occurred.

*6) Changes in livestock stocking rates*

In the communal areas all of the interviewees (100 %) used to own more cattle, goats and donkeys in the past. Some of the perceived reasons for the lower numbers of cattle at present include increased drought frequencies, more frequent outbreaks of livestock diseases and livestock theft. Many of the elderly communal land users also believed that major cultural changes had occurred in the area since they were young with much less importance now placed on owning cattle. Furthermore, the prices of livestock are thought to be much higher now than they were in the past, making it very difficult to purchase cattle now.

In the past when people owned more cattle they used to be more concerned with maintaining open areas to ensure sufficient grazing for their cattle. The lower cattle numbers at present were thought to increase the amount of available annual grass biomass due to lower consumption. This increase in grass biomass would have direct links with the fire regime as mentioned above. The interviews also revealed that most homesteads in the area used to own many more goats than they do at present. It was thought that these goats would have fed on the bushes and shrubs in the area and would thereby have helped to control tree and shrub densities.

*Do the changes matter? Perceived implications of changes for the land users*

*1) Positive*

Although the majority of interviewees thought of the changes as problematic, most of them also acknowledged that the increases in woody cover also provided some advantages. Some of the advantages gained from increased woody densities included higher woody resource availability for building materials, fencing, firewood and curios. Some perceived there to be more fruit and berries available now with increased tree and shrub densities while others stated that more plants have become available for harvesting natural medicine. Another common perception was that the increased shrub numbers or densities provided increased browse for their goats.

*2) Negative*

Nearly two thirds (64 %) of the communal interviewees also perceived the changes to have a number of negative consequences. It was thought that areas that have become more shrubby or bushy have become difficult to pass through which makes it much more difficult to take care of their livestock. People were also often reluctant to live in areas surrounded by dense bush due to the dangers this exposed them to. Some of the mentioned threats included attacks from wild animals such as leopard, which are fairly common in the area especially in the areas bordering on the Hluhluwe Reserve. Another perceived hazard resulting from living in thick bush was the threat of thieves and criminals who could hide in the bush surrounding the homesteads.

Many of the elders associated changes in woody cover with changes in rainfall. These elders claimed that long ago before bush densities increased there was more rain. Thus they wished that the landscape looked like it did long ago as times were perceived to be good then. The high densities of shrubs in the area were also perceived to make it much more difficult to clear a new area for cultivation. It was claimed that in the past one could merely burn an area before ploughing. However, now one would have to invest a lot of time and effort into clearing an area before being able to plough. Another major perceived negative consequence of the vegetation changes in the area was that significantly less grass was now available for people's livestock, particularly cattle, as a result of the increased densities of shrubs. Many of the communal land users perceived the increased shrub densities to be a problem but wanted more big trees which could then be used for the construction of houses and fences.

*3) Neutral*

Some (29 %) of the elders who were interviewed did not mind the increase in woody plant densities as they claimed it had not affected their lives in any way. Others (7 %) did not have a problem with the increase in trees and shrubs and thought that they would be better off if there were even more shrubs and trees in the area.

*Past and present interventions*

In the communal areas there was general agreement that nothing had been done in the past in order to combat the changes that had occurred in woody cover in the area. There was also no intention of combating the changes in the future. This attitude is hardly surprising, as many of the people living in the area perceived the changes to have a number of associated advantages. These included increased resources such as firewood and building materials. Those who thought of the changes as disadvantageous did not have the capacity to combat the changes. Some of the elders did indicate that they would like the discipline and respect that was imparted to the traditional authorities in the past to be reinstated. Thus, if the importance of cattle ownership, cultivation and traditional burning practices were realised again it was perceived that it would lead to a healthier and more open landscape, as was the case in the past.

*Costs and implications of combating changes*

There were no efforts underway to combat the vegetation changes in the communal areas, therefore no direct costs were mentioned. The major indirect cost that was mentioned was the lack of big trees in the area now, compared to the past. Therefore trees are no longer available for use in the construction of buildings and fences. This has forced people to use modern materials for building, which have to be bought at relatively high prices compared to the average household's income. The general perception was that the shrubs were not intensely utilised though some were utilized for firewood and natural medicines. Another indirect cost that was mentioned was that new areas intended for cultivation had to be cleared of the shrubs growing there, whereas in the past, these areas only had to be burnt before ploughing.

*Commercial land users*

Figure 5.3 provides a summary of the landscape states through time as perceived by the commercial land users. The diagram also provides the perceived causes of and responses to the changes.

*Perceptions of the landscape pre-1960 compared to present state*

Unlike the communal land users, there was unanimous (100 %) agreement amongst the 14 commercial land users that the area used to be much more open (Fig. 3) in the past (e.g. *"I remember when I was a kid I could ride a horse all over our property without having to worry about bush or duck [for bush]. My father talks of riding from the Hluhluwe River to the Mkuze River without having to duck for bush. The only place where bush was found was in the river valleys. The rest of the area was open grassland with a few scattered big trees, such as Acacias [e. g. Acacia karroo, Acacia nilotica], Marulas [Sclerocarya birrea] and Schotias [Schotia brachypetala]"* (Commercial land user J). Another interviewee (Commercial land user G) suggested that *"I remember the area being very open, the whole area was a beautiful open grassland with a few scattered big trees".* All the interviewees who grew up in the area were in agreement that the landscape used to be much more open in the past when vast areas were still covered by grassland.

Most of the commercial land users who hadn't grown up in the area also perceived the area to be bushier now than it was in the past. This view was normally gained from speaking to other people in the area. There appeared to be a gradient in the perceived severity of encroachment with the farmers further north less affected than the ones in the south, closer to Hluhluwe. The main species thought to have significantly increased included *Acacia karroo, Acacia nilotica, Dichrostachys cinerea, Euclea spp., Maytenus senegalensis* and *Maytenus heterophylla*. In the commercial areas *Chromolaena odorata* was also often mentioned as a major problem having invaded large parts of the commercial farms in the area.

*Land users' perceptions of changes on contrasting land use types in the area*

All (100 %) of the commercial farmers perceived the communal areas to be much more open than their own land and many indicated that they wished their land looked like the communal areas which have much less of a bush encroachment problem today. However, many of the commercial land users did indicate that the communal areas had also experienced an increase in shrubs and a decrease in bigger trees. There was general agreement that the conservation areas had experienced equal increases in woody cover to the commercial areas. A few of the commercial land users perceived the communal areas to be fairly degraded with undesirable grass species. A few of the commercial farmers thought that the communal areas had shown some increases in woody cover, however these changes were not perceived to be as severe as for the commercial and conservation areas.

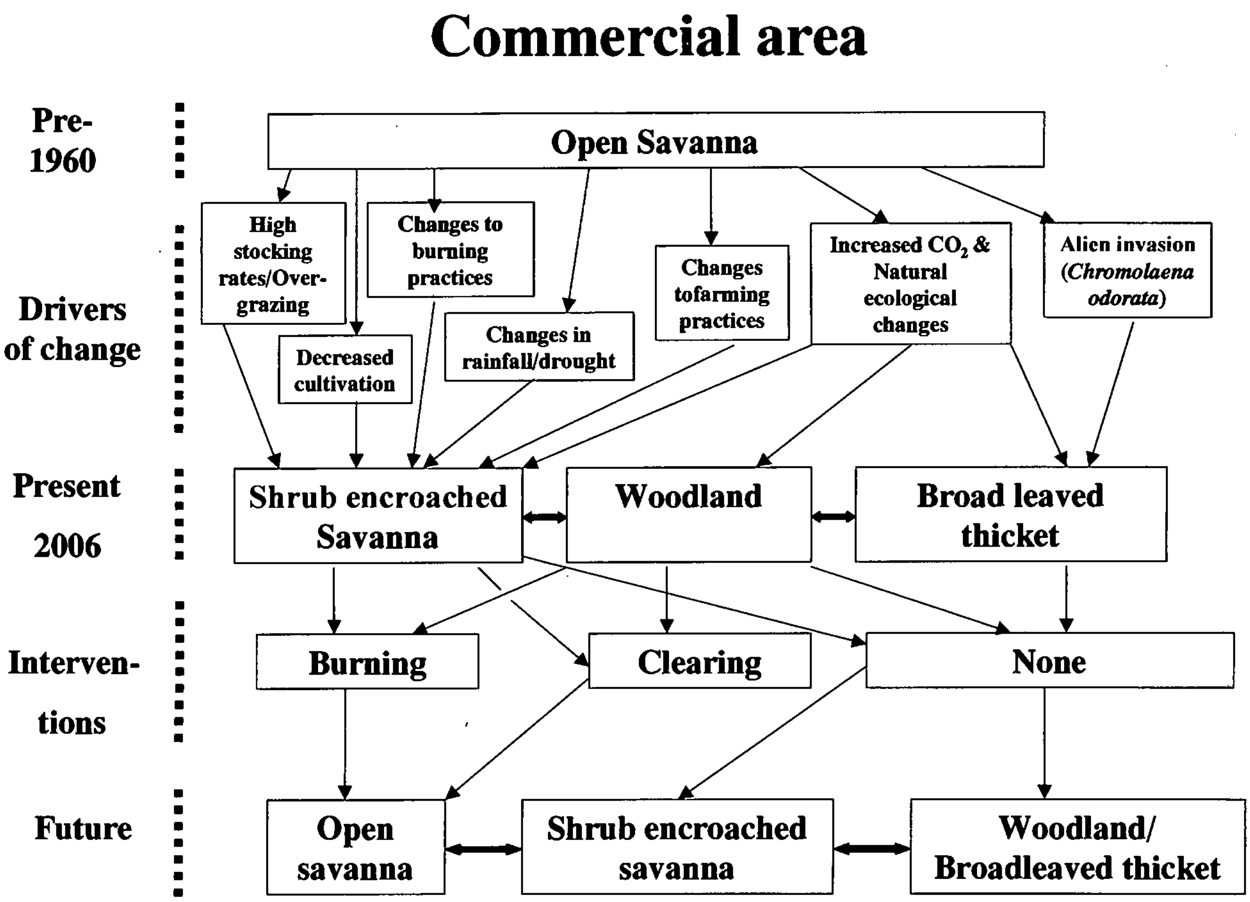


Figure 5.3. Perceived changes in woody plant cover and drivers of these changes for the commercial study site. Changes cover the past 70 – 80 years. All interventions and the likely responses to these interventions are also shown.

*Major land use changes evident in each area*

Major changes in land use have occurred in the area, with a substantial switch from cattle farming to game farming. According to the commercial interviewees this change first started in the late 1970s with more and more farmers switching to game farming right up until the present. From a total of 14 farmers interviewed only two were still farming cattle in the area, which was predominantly under cattle farming prior to 1960. The number of cattle on commercial farms in the Hlabisa district declined from 87,000 in 1980 to 4,000 animals in 2004 (Commercial land user B). The average size of commercial farms in the area has also increased over time. In the past there used to be many small farms in the area. These have mostly been bought up now by a few big landowners and added to adjoining properties to form large private game ranches such as Thanda which is over 5000 Ha in size. A reduction in the number of people living on the farms in the area would have accompanied the shift to larger game farms. This is due to the less labour intensive nature of game farming in comparison to cattle farming.

The interviews with the commercial land users in the area also revealed that in the past many of the farmers in the area were undertaking a limited amount of cultivation on their land. A number of farmers in the area had tried farming cotton and sisal in the past. There is currently no cotton or sisal farming in the area. Only one of the farmers in the area was still cultivating pineapples on a small portion of his land at the time of the interviews.

*Perceived causes of the observed changes in vegetation cover*

*1) Stocking Rates*

The main factor driving bush encroachment in the commercial areas was believed to be overgrazing resulting from high stocking rates in the past. This was frequently quoted as the main cause of the bush encroachment problem evident in the area today (e.g. *"The farms that are heavily encroached now are the ones that used to be heavily overstocked. These farmers would let their cattle graze their grass to the ground"* (Commercial land user G).

From the interviews it became clear that during the 1960s farming units in the area were made far too small. Once the northern Zululand area opened up to farming in the early 1900s (see chapter 2), it was split into numerous small units by the government. This was thought to have forced the farmers to overgraze these small units as they strived to make a living. Three hundred head of cattle was considered an economic unit at that time and indeed, in those days it was enough for a farmer to make a modest living. However, for a herd that size you would need at least 1200-1500 ha, but most farmers only had 800 ha. Thus, farms were almost half the necessary size for a herd of 300. Consequently farmers tried to keep herds of 300 on their farms, which were simply too small and therefore resulted in overgrazing. Accordingly, many farmers were said to have turned to cattle speculating as they then could at least get rid of their cattle during drought years. These speculators would normally buy a herd of oxen, fatten them up and then sell them. However, these speculators were still reluctant to burn their farms, as grass was the source of their livelihoods. Thus although many farmers were made aware of the importance of burning, they simply could not afford to burn their grass as their farms were too small.

*2) Fire*

Fire frequency and intensities are clearly associated with stocking rates as explained above. Overstocking normally resulted in overgrazing, which in turn results in low grass biomass or complete removal of the grass layer during drought years. This would effectively have excluded fire from the system. Without fire frequently impacting the woody plant seedlings or coppices, they would have managed to grow up and reach maturity. These past 'escape events' would have resulted in the higher densities of woody plants now evident in the area. As explained above, farmers in the past were trying to make a living off government allocated plots, which were far too small. Thus the farmers could not afford to burn their land as all available grass was of value to them.

Fire exclusion in the past was thought to be a major cause of the current encroachment problems. The fragmentation of the area was also perceived to have led to bush encroachment in the area as explained by the following quote: *"Fencing and boundaries have also led to problems. Before fires would sweep through vast areas, now fires are restricted to small areas at a time"* (Commercial land user H). Fragmentation of the landscape has lead to controlled or restricted fires thereby preventing them from reaching the high intensities and extents that they would have in the past. These large intense fires in the past were thought to have played a major role in keeping many trees and shrubs from reaching maturity and would have been likely to have killed many adult trees.

*3) Rainfall*

Many (38 %) of the commercial land users who were interviewed perceived rainfall to have changed over the past century. The general perception was that there is less rainfall now and droughts are much more frequent then they used to be. This was thought to be a possible explanation for the changes in woody cover, as fire would be excluded more frequently with the lower grass fuel loads resulting from lower rainfall. Some thought that trees are able to recruit en masse after flood events, especially if these flood events followed drought events. It was thought that these recruitment events in the past were responsible for the major increases in bush densities evident in the area at present. The following quotes taken from three different interviewees from the area summarize this perception. *"I believe that after the floods of Demoina in 1984, trees have increased dramatically"* (Commercial land user D). *"Heavy rains with lack of burning and low grazing pressure have lead to increased tree densities"* (Commercial land user C). *"Once the grass had recovered sufficiently after the drought of 1933,* *I returned with my cattle and noticed that there were thousands of tree seedlings especially in the areas where the cattle used to trample and where they defecated. These were the places where the Acacias first started encroaching. These trees all grew bigger and bigger and that was the start of the problem"* (Commercial land user G).

*4) Changes in farming practices*

A few (8 %) of the commercial land users felt that the widespread switch to game farming in the area had resulted in increased tree and shrub densities as cattle would have trampled and eaten seedlings in the past (e. g.: *"I believe that cattle prevent bush encroachment by trampling and eating seedlings, thereby keeping trees out. If I was still farming cattle I don't believe I would have as much bush as I now do"* (Commercial land user D. Another cause of the observed changes in woody cover was believed to be the abandonment of cultivated fields on many farms. In the past many of the farmers in the area (39 %) cultivated various crops such as cotton and sisal on their land. Due to changing markets and many failed harvests most of the farmers no longer grow crops in the area. Furthermore the majority of farms in the area have been transformed into private game ranches.

Many of the areas that were previously under cultivation were also fertilised. It was thought that these areas had become heavily encroached by woody species as a result of the added fertilisers combined with high rainfall in the summer months (e.g. *"Planting of crops leaving fertilizer behind, in summer with lots of water around this gives the trees a kick start leading to encroachment"* (Commercial land user I).

*5) Increased $CO_2$ and changing climate*

Increased atmospheric $CO_2$ and climate change was thought to be the cause of increased tree densities by some (23 %) of the commercial land users (e.g. *"However there must be more than just land use changes causing increase in woody plants. It could be changes in climate and $CO_2$"* (Commercial land user A). *"Maybe climate change is also responsible, there are no longer long rain events like there used to be. We now have more intense, quick thunderstorms, so I think the pattern of rainfall has changed"* (Commercial land user H). *"I think climate has something to do with it"* (Commercial land user E). Although some of the commercial land users thought climate change played a role in explaining the observed changes in woody cover none of them explained the mechanisms by which this would occur.

*6) Ecological or natural changes*

Changes to the natural herbivore assemblages that should be found in the area were thought to play a role in driving the vegetation changes. During the early 1900s the majority of natural herbivores were hunted down and eradicated from the area. These areas were subsequently fenced off and put under intense cattle ranching. This would have excluded most of the natural herbivores left in the area, which would undoubtedly have had major impacts on the vegetation. It was also said that with the switch to game ranching in the area many land owners had specific objectives and therefore stocked their properties accordingly. Therefore, many game ranch owners would still have lacked mega-herbivores on their properties after switching to game. The lack of mega-herbivores and stocking of specific species was thought to have led to increased bush densities in the area (e.g. *"We need to reintroduce mega-herbivores in the area to help combat bush encroachment"* (Commercial land user C)).

*Do the changes matter? Perceived implications of changes for the land users*

*1) Positive*

The main advantage resulting from increased woody cover in the commercial area was thought to be a major increase in available browse material for browsers such as Nyala and Kudu on the farms which had switched to game farming. The increased browse availability was thought to have resulted in higher browser numbers in the area. Some of the commercial land users perceived the changes to have led to increased biodiversity and heterogeneity as they now had a range of habitats on their land ranging from grassland to closed forest while previously they only had grassland species.

*2) Negative*

The most frequently mentioned negative consequence resulting from the vegetation changes in the area was thought to be the loss of grazing land that had occurred with increased bush densities. This was perceived to be a much bigger problem for the few cattle farmers still found in the area as their livelihoods depended on grass production. On the whole the game ranch owners did not appear to be too concerned with the loss of some grass as their stocking densities were generally much lower than those of the cattle farmers.

Some of the interviewees thought that a major loss of grassland species and associated biodiversity had occurred with the changes in vegetation. Furthermore, fire was said to be excluded from areas that have switched from open grassland or woodland to closed thicket or forest. The following quotes taken from the interviews focus on some of the above-mentioned perceptions. *"There are no hyena, waterbuck, eland, reedbuck, giraffe or white rhinos here anymore so we have lost a lot of species and biodiversity"* (Commercial land user F). *"There has been a massive increase in Nyala numbers while things like reedbuck and wildebeest have decreased"* (Commercial land user H). *"I do see bush encroachment as a problem which is getting worse. We have lost a hell of a lot of grazing land in this area. Trees are so dense now nothing grows underneath them. The changes I have seen since the 1930s have been massive"* (Commercial land user G). *"As a game ranch we suffer from poor visibility. We can't burn most areas as there is no grass in the thicket areas. Many areas haven't been burnt in so long that there is hardly any biomass so that even if we could burn it would be so mild that the fire would hardly achieve anything"* (Conservation land user H).

*Past and present interventions*

Although the majority (92 %) of the commercial land users acknowledged that they have had a problem with bush encroachment, many of them had not actually done anything in order to address the problem. Some of the farmers are now using fire as a tool to combat bush encroachment. They are now able to do this by allowing their grass biomass to accumulate which was not possible in the past as a result of high stocking rates. Now after two to three years, when sufficient grass biomass has accumulated, a fire is ignited late in the dry season on a hot day with low humidity in order to achieve an intense burn. A few of the commercial land users thought that in this way many of the trees and shrubs could be killed thereby preventing further encroachment. Many of the commercial land users were aware that most savanna tree species are resprouters and therefore need to be burnt every few years in order to prevent them from growing into mature plants and becoming a problem. However, many of the farmers were still reluctant to burn as they were more concerned with having enough grass for their animals during the dry season and times of drought.

Most of the farmers had not attempted manual or mechanical clearing as they claimed that it was far too expensive (e.g. *"It is too expensive to mechanically clear, therefore fire is the only tool I have to combat bush encroachment"* (Commercial land user D)). *"Chemicals are too expensive for most farmers"* (Commercial land user M)). A number of the commercial land users had experimented with chemical and mechanical clearing in the past, however very few were doing this on a regular or permanent basis. The following answer was given in response to being asked whether anything was been done to combat encroachment: *"No, it is too expensive for farmers to use mechanical or chemical methods to combat encroachment. One of the factors nowadays is that there is no longer a cheap workforce on most farms. Labour is more expensive now and new labour laws have changed the way in which farmers utilize labourers, many areas also have shortages of labour due to HIV/AIDS in KZN"* (Commercial land user M).

Most of the farmers were more concerned with clearing *Chromolaena odorata* with many of them having invested large sums of money into clearing efforts (e. g. "Chromolaena odorata *was found over most of my property [in the past]. 65 % of it has been eradicated with over R4 million spent on clearing* Chromolaena" (Commercial land use C)). Some of the commercial land users had allowed people from the communal areas to harvest woody plants on their land. However not much success was reported from this as people mostly collected dead wood for firewood.

One of the farmers in the area was combating bush encroachment by leasing his land to pineapple farmers who require virgin soil to grow pineapples. In this way new land would be cleared on which to plant pineapples. These areas would then be used for a few years before a new area would have to be cleared for the next crop. Mature savanna trees would be left behind when a new area was cleared. Furthermore, the owner put a clause into his lease stating that that the leasee would have to maintain the land clear of trees and aliens for a year after they have harvested their pineapples. In this way the area would be returned to an open savanna within a few years after the final harvest.

Many of the game ranch owners or managers claimed that some clearing efforts were performed on a regular basis. However, this was usually only done along the road verges and around the lodges in order to improve game viewing for their guests. Another interesting finding was that the threat of and uncertainty of land claims in the area has made farmers reluctant to invest money in their farms. (e.g. *"The threat of and uncertainty of land claims in this area has made farmers reluctant to spend money on their farms, in case they end up losing the land. Thus they are reluctant to spend money on clearing bush"* (Commercial land user M)).

*Costs/implications of changes*

During the interviews with the commercial land users I attempted to determine the direct costs of clearing areas that had become encroached. One of the farmers estimated that for heavily encroached land it would cost approximately R1000/ha. This did not include a follow up clearing effort. It was said that you would have to follow up the initial clearing at least twice in the first year, and then once every year for approximately the next ten years. Another farmer claimed an estimated cost of R300/ha if you owned your own machinery, and about R600/ha if contractors were used. This estimate was for shrubby areas and would be much higher in heavily encroached areas. The estimated cost of clearing *Chromolaena odorata* was also approximated at around R350/ha. This figure included the chopping down of the plants and herbicide application. One of the farmers estimated that without machinery a team of approximately ten labourers would be necessary for *Chromolaena* clearing and chemical application and a second year follow up would be needed to pull out the new plants. Thus it can be seen that clearing of *Chromolaena* is an expensive exercise but was deemed necessary. One of the commercial landowners estimated that he had lost approximately 30 % of the total area of his farm to encroachment and of this area approximately 95 % was due to *Chromolaena*.

Another of the commercial land users from the area provided the expenditure he had invested in clearing alien plant species on his farm. The high costs of chemicals/herbicides and labour become evident as the farmer had spent a total of R23 000 on chemicals and R48 500 on labour and transport over three months. Thus he spent nearly R24 000 per month on alien clearing alone. From estimates given by other farmers the cost of clearing bush would be fairly similar to clearing aliens. This one example of expenditure spent on clearing alien plant species provides a clear indication of the high costs involved in alien and woody plant clearing.

A cattle farmer in the area estimated that he was losing R675 per hectare to bush encroachment, after taking the size of his farm (7340 ha) and estimated area lost to encroachment he estimated that he should increase his total farm turnover by R1.35 million per annum.

One of the ways in which farmers attempted to control encroaching species in the past was by spraying with 2.4.5.T herbicide solution diluted with diesel. This was not perceived to be very expensive. However, more recently developed chemicals are perceived to be extremely expensive. It was generally thought that the use of heavy machinery in clearing encroached areas normally led to worse encroachment problems subsequent to clearing, rather than solving the problem. Many of the farmers thought that in heavily encroached areas, they would have to mechanically clear and then allow the grass layer to recover after which they would have to burn on a regular basis to avoid further bush encroachment problems. This would obviously require substantial inputs over a long time period, which was often thought to be beyond the means available to them. Some thought that the answer to the bush encroachment problem would be a systematic approach. Landowners should tackle say 10 % of their farms per year with a sound management plan using fire as the key management tool. Some of the commercial landusers were aware that the indirect costs such as the loss of biodiversity and poor game viewing for tourists was already costing them significantly.

*Conservation land users*

*Perceptions of the pre-1960 landscape compared to present state*

Figure 5.4 provides a summary of the landscape states through time as perceived by the conservation land users. The diagram also provides the perceived causes of and responses to the changes. Each phase in the diagram is dealt with in detail below. In the conservation area there were some differences in the perceived state of the reserve in the past. In the Hluhluwe section of the reserve there was unanimous agreement that the area used to be much more open in the past with vast sections of the Hluhluwe Reserve once covered by open grasslands (e. g. *"From speaking to people before me and from what I've seen, the vegetation definitely has changed. We have lost our grasslands. In a short time period things have changed drastically"* (Conservation land user C)). Despite many areas having thickened up it was emphasised that there were some areas already under forest in the Hluhluwe section in the past with these same areas still under forest today. The Corridor section was also perceived to be much more open in the past than it is now (e. g. *" In the corridor section I have noticed significant thickening especially of Acacias"* (Conservation land user E)).

In the iMfolozi section there were several different perceptions as to how the area looked in the past. Some (25 %) interviewees replied that they thought the area had not changed, others (25 %) thought specific areas had become woodier while the majority (50 %) thought that the whole section in general had become woodier than it was in the past. This is summed up in the following quote: *"In this section some areas come to mind. The short grazing lawn areas that are often surrounded by Acacia gerradii, have thickened up with Brachlaena, Dichrostachys and Croton spp. There hasn't been significant thickening in all areas. There are certain areas that have thickened while some not at all [thickened up]"* (Conservation land user E). The general perception of the iMfolozi reserve was that it had not changed as much as Hluhluwe had. There were some small areas that were thought to have thickened up, but in general the iMfolozi section was not considered to have much of an encroachment problem. The following quote provides an indication of the general opinion of the situation in iMfolozi: *"Most of the areas that have thickened don't seem to be invading into bigger areas, so the problem seems to be fairly marginal"* (Conservation land user E).

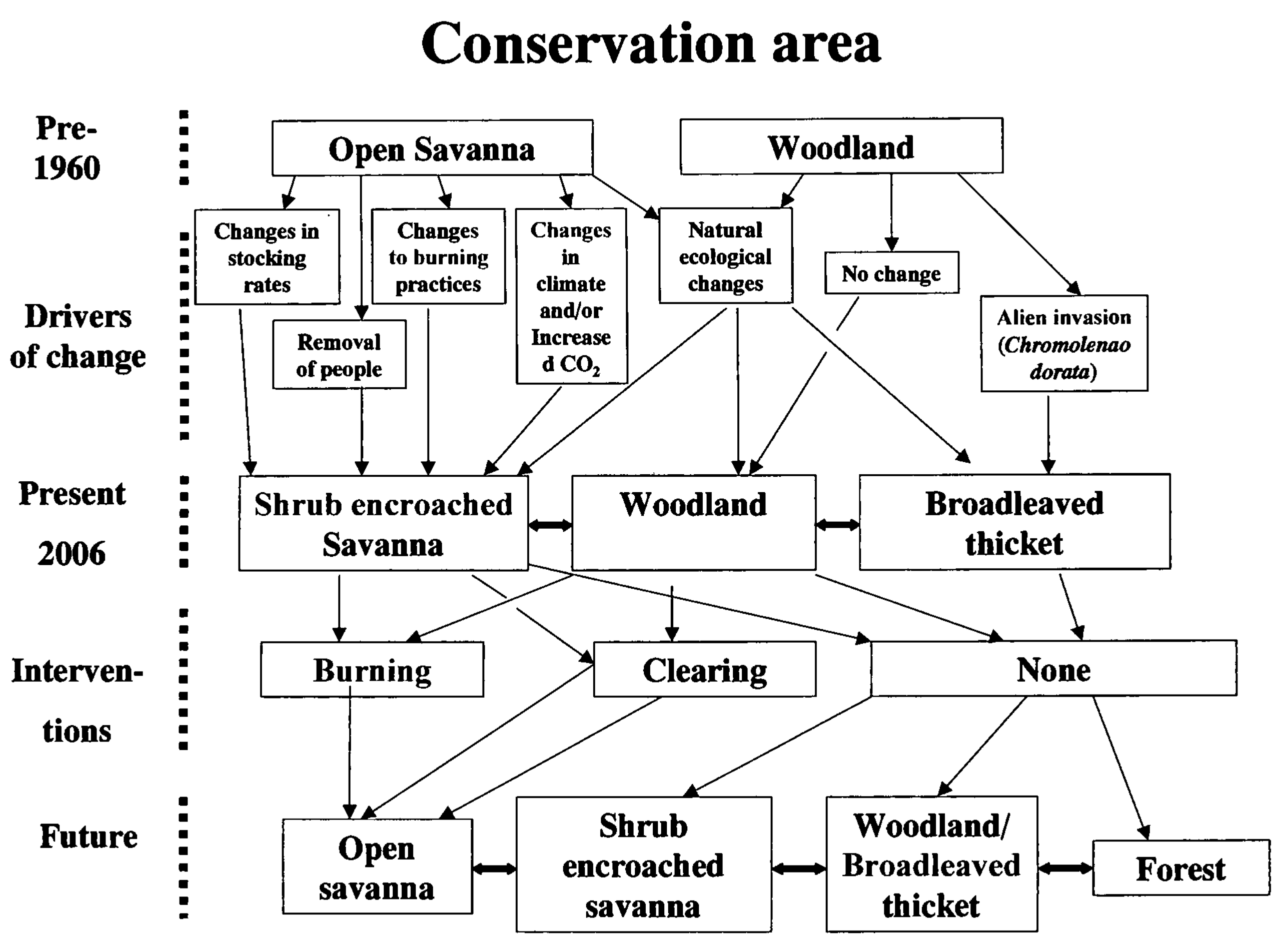


Figure 5.4. Perceived changes in woody plant cover and drivers of these changes for the conservation study site. Changes cover the past 70 – 80 years. All interventions and the likely responses to these interventions as well as all possible transitions between states are indicated for present and future states.

The corridor section of the reserve was perceived to be less encroached now then it was even in the recent past. The dominant perception (75 %) being that it is now in a better state than in the past with vast areas having been returned to open grassland. However the remaining 25 % thought that the corridor was heavily encroached in areas with species such as *Acacia karroo* and *Dichrostachys cinerea*. The Hluhluwe section of the reserve was thought to have significantly thickened up with woody species by all the interviewees. Large sections were thought to have shifted from open grassland to thicket, other areas have become heavily infested with shrubby species and many encroached areas have experienced secondary thickening with the invasion of *Chromolaena odorata* into these areas.

Thus, despite some clearing efforts in the past, the majority of the Hluhluwe Reserve was perceived to be heavily encroached with *Acacia karroo, Euclea spp.* and other broadleaved woody species. The following quotes sum up the situation in Hluhluwe: *"There have been massive changes in the vegetation of Hluhluwe"* (Conservation land user C). *"There has been a major* Chromolaena odorata *infestation and lots of bush encroachment into grassland areas.*

*This leads to further problems with* Chromolaena odorata *further invading these encroached areas. In summary I think there is a lot of bush encroachment in the area"* (Conservation land user D)).

*Land users' perceptions of changes on contrasting land use types in the area*

Some of the conservation land users perceived the adjacent communal area next to the Hluhluwe Reserve to be in a better condition than the park with much less bush encroachment than inside the park (e. g. *"They have much more open grassland. Some areas are overgrazed. There aren't as many trees outside as they chop them for use, but most of the hills are still nice and open, so they do have a problem [with bush encroachment] but not as big as our problem inside the reserve"* (Conservation land user A). *"There are beautiful areas outside. There are some areas where the trees have escaped the firetrap. I wish we could take these areas and put them inside the park. They have rolling grasslands with mature savanna trees. There doesn't seem to have been overgrazing, maybe due to low stock numbers"* (Conservation land user D).

However there were areas in the communal lands that were perceived to be degraded. The following was said about the area to the east of the corridor section: *"In the east the whole [communal] area is seriously devastated. There are loads of people with very little firewood left. The area is completely overgrazed and there are no woody plants left and the open grassy areas are especially overgrazed. Saplings and shrubs are kept low by goats while Aristida spp. and other poor grass species dominate. People are generally hostile and we experience loads of poaching from this area. The majority of people living there were forcefully removed from the Tugela area during the faction fighting and placed here, resulting in a very displaced and unhappy community. There are no trees or encroachment in the area as the people have removed all trees. There is one section near the fence that has become encroached due to overgrazing"* (Conservation land user A).

Interviewees from the reserve, however, were aware of the patchiness of bush encroachment and its response to different land use practices. They commented on the condition of the vegetation in areas to the west of the corridor section (e.g.*" On the west is a very different story. Things are very different. The area is under traditional farming, with people having been there for a long time, so there is a traditional community unlike the displaced people on the east. There are still a lot of undesirable grass species such as Aristida. However, there are still woody plants left in the area, with plenty of big Schotia, Acacia and Marula trees. The densities of people living in this area are much lower then in the east" (Conservation land user A).* The following is the perception of another interviewee, referring to the communal areas in general: *"There are areas that have been heavily overgrazed with thick stands of Acacia karroo,* *Dichrostachys cinerea, Maytenus senegalensis and Maytenus heterophylla and high cattle numbers"* (Conservation land user B). The majority of the conservation land users correlated bush encroachment and overgrazing with high human population numbers. Thus areas with fewer people were perceived to be in a better condition than areas with high human densities.

The conservation land users generally perceived most of the commercial areas to be heavily encroached by woody species as shown by the following quote: *"Especially the cattle ranches used to be open grasslands, but today are completely bushy, so there seems to have been a major shift from grassland to thick bush. Today the whole [commercial] area is pretty much covered in bush"* (Conservation land user C). Certain areas were thought to more heavily encroached than others, especially old cultivated lands (e.g. *"The most noticeable [encroached] areas are along old cotton lands"* (Conservation land user E)).

*Land use changes evident in the conservation area*

Hluhluwe and iMfolozi Game Reserves have been under consistent management over the past 70 years or so. In 1989 the Corridor Game Reserve was officialy proclaimed and consolidated with the Hluhluwe and Imfolozi Reserve. The parks have, however, been through a number of different management strategies, ranging from a no burning policy to frequent burning policy, different culling policies, and a number of clearing programmes. The initial objective of the reserve was to protect and conserve rhinoceros and other game species. The initial intention has since changed with the primary objective now aimed at maintaining biodiversity. The biggest changes to have occurred in the conservation area during the past century were probably the exclusion of people and the fencing of the reserve subsequent to proclamation.

*Perceived causes of the observed changes in vegetation cover*

*1) Fire*

Fire was thought to play a major role in driving the vegetation changes that have occurred in the park over the last century. The parks fire policy has varied considerably over the last century ranging from a no burn policy during the Nagana campaign (1940s - 1950s), to a so-called 'natural fire regime' whereby only natural fires were allowed to burn while anthropogenic fires were extinguished. This was followed by a cool burn policy, which was mainly aimed at getting rid of moribund grass material and to promote new growth. The current policy aims at achieving a heterogeneous landscape. Therefore different fire intensities are considered necessary by current management. Fires were thought to have had a major influence on the vegetation of the park. The fire exclusion policy in the past was thought to have allowed plants to grow into mature size classes, while cool management burns would not have top killed coppices and juveniles and therefore would have allowed them to reach maturity resulting in higher woody plant densities in the park. Fire frequency and intensity was perceived to be very important in controlling vegetation. It was claimed that in the corridor section large intense fires have been used to reverse the bush encroachment problem with an area previously encroached by *Acacia karroo* having been returned to open grassland. Most of the conservation land users were aware of the potential use of high intensity burns, which could be used as a management tool to combat bush encroachment.

*2) Stocking Rates*

Past herbivore stocking rates in the Hluhluwe-Imfolozi Game Reserve were thought to have influenced woody cover in the park. During certain periods in the past (e.g. during the 1950s and 1960s, see figure 3.11) stocking rates were perceived to be too high leading to overgrazing and consequently excluding fire. During other periods in the parks history, stocking rates were perceived to be too low (see chapter 2). This was thought to be especially true for browsers, which were thought to play an important role in controlling woody plants. For example some thought that high black rhinoceros densities would be able to control woody plant proliferation by maintaining a high browsing pressure. It was also thought that grasslands would not be able to be maintained with low herbivore numbers as shown by the following quote: *"There were possibly not enough animals to maintain the grasslands"* (Conservation land user C). A problem that became evident after the interviews was that nobody actually knows what the correct stocking densities should be. Some were of the opinion that current numbers are too high while others thought they were too low. Despite this uncertainty, stocking densities were perceived to play an important role in controlling the vegetation of the park as explained above.

*3) Rainfall/Changing Climate*

Changes to rainfall and climate were frequently mentioned as a potential driver of bush encroachment. This perception becomes evident from the following quotes: *"The $CO_2$ argument seems plausible. Plants are now able to survive for longer periods due to increased reserves, whether this is reversible it is hard to say"* (Conservation land user B). *"Climate change is also* *likely to be playing a role*" (Conservation land user C). *"There has been a change in weather patterns and possibly increased $CO_2$"* (Conservation land user C).

*4) Anthropogenic influences*

*"The rate of change is being influenced by external factors. I don't think it can be attributed to management only. Fences also cause an island situation. Thus animals may be forced to stay in the same area maybe leading to overgrazing. The problem is much greater than management practices alone. It's not just within our parameters, but seems to be a global problem"* (Conservation land user C). This quote taken from an interview with a conservation land user suggests how humans and anthropogenic influences have altered the dynamics of the landscape. The removal of people from the system was thought to have radically influenced woody plant cover. People would have been harvesting woody resources for a whole range of uses but once they were removed from the park they were no longer able to utilize these woody species. This was thought to have led to substantial increases in tree and shrub densities as shown by the following quote: *"All sorts of other factors especially the longer-term history need to be considered. For example the old style of building beehive huts would have utilized lots of saplings and Acacia bark for binding plus firewood harvesting and kraal building would also have impacted the woody species growing in the area. Thus the removal of people probably had massive impacts on tree clearing"* (Conservation land user G). Furthermore large-scale animal culling and tree clearing operations during the Nagana campaign (see Chapter 2) in many areas would have had long lasting effects on the vegetation of the park many of which would still be evident today.

*5) Ecological or natural changes*

Many of the changes in woody vegetation evident in the park were ascribed to natural causes by some of the interviewees. It was thought that the changes evident in the area were all just part of a natural long-term ecological cycle. The following quote reveals this perception *"Whether this [bush thickening] is actually a problem, I can not say. One of the problems is that we don't actually know what the longer term cycles are, thus the changes we are seeing could be part of a secondary process"* (Conservation land user G). It became evident that the park management required a better understanding of the long term ecological dynamics of the area as shown by the following quote: *"I think it is critical that we get a better understanding of how it all [vegetation changes] fits into the longer term cycle. Normally research is aimed at the short term, we desperately need a longer term understanding"* (Conservation land user G).

*Do the changes matter? Perceived implications of changes for the land users*

*1) Positive*

The main advantage gained from the increases in woody cover in the conservation area was thought to be the significantly increased browse availability for browsers such as black rhino, nyala, kudu, giraffe and mixed feeders such as impala. One of the interviewees perceived the changes to have lead to increased biodiversity as habitats in the park now ranged from open grassland to closed forest. Furthermore thicket and forest species would have benefited from the changes.

*2) Negative*

The most frequently mentioned negative outcome resulting from the changes that had occurred in the conservation area was thought to be the loss of grassland habitat and the associated biodiversity. This problem is especially relevant in the conservation area as the principal undertaking of park management is to conserve biodiversity. Some of these perceptions are shown in the following quotes. *"The changes are beneficial to some species but detrimental to others. Thus, all in all for management the changes are not beneficial"* (Conservation land user C). *"We are striving for biodiversity conservation. Thus, if a lot of areas are moving to the same state of encroachment it would lead to huge losses in biodiversity"* (Conservation land user B). *[Bush encroachment has lead to] taking out of habitat, loss of grassland species and biodiversity"* (Conservation land user D).

Another commonly mentioned negative impact of woody plant proliferation in the area was that encroached areas frequently became further invaded by *Chromolaena odorata*. The presence of woody plants seems to be a prerequisite for *Chromolaena odorata* to invade into an area, as one never observes the species invading open grassy areas. Bush encroachment was also perceived to negatively impact the conservation areas by affecting the visibility. Tourists who visit the reserve want to be able to see animals. With thicker bush densities the visibility of animals becomes obscured. This might stop tourists from visiting the park again as they might choose to rather visit a more open reserve on subsequent holidays.

*Past and present interventions*

In the conservation area some bush/tree clearing efforts have been attempted in the past. However no current efforts were reported to be underway. At present fire is the only tool being used to combat bush encroachment. Management attempts to achieve this by using hot fires to setback trees and shrubs and prevent them from recruiting into mature size classes and becoming a problem. No clearing is being done in the conservation area at present, although management would like to initiate clearing programs in the future to combat the perceived bush encroachment problem in the park.

A number of the interviewees from the conservation area, particularly the iMfolozi section, did not perceive bush encroachment as a problem. Accordingly there was nothing in the management plan addressed at combating bush encroachment in these areas. For example: *"My general perception of Umfolozi from having been here for quite a while is that things haven't really changed that much. There have been some changes in some areas but the overall balance is much the same. The previous manager might have been reacting to short-term changes in some areas by clearing. For example, in the corridor there used to be tall dense acacias, which are gone now. It wasn't a specific goal to get rid of them; it was more by chance"* (Conservation land user G). The Hluhluwe Game Reserve was acknowledged to have a problem with the realisation that future efforts would have to be initiated in order to achieve the goal of conserving biodiversity.

*Costs/implications of changes*

The biggest loss resulting from the vegetation changes in the conservation area was perceived to be the loss of biodiversity that has accompanied bush encroachment in parts of the park, especially the Hluhluwe Reserve. Although the loss of biodiversity was not really an instant monetary loss, in the long term it was perceived as a significant irreplaceable loss. The following quote is taken from one of the interviews with a conservation land user: *"There are changes in species composition and biodiversity. Streams may dry up as trees are using more water. In the end it is very costly"* (Conservation land user C).

Smuts (1980) estimated that bush encroachment in the park caused the overall grazer capacity to decline from 7.2 ha.LSU$^{-1}$ to an average of 10 to 15 ha.LSU$^{-1}$. Many of the current conservation landusers were in agreement with this and thought that the loss of grazing land to bush encroachment was a major problem, which would be extremely difficult to cost. Another major potential cost of bush encroachment was thought to be the loss of revenue from tourists who might not return to the park as a result of poor visibility resulting from dense bush in some areas. The following quote taken from one of the interviews highlights this problem: *"Tourists may complain about bush. I have heard complaints from tourists about the road between Memorial Gate and Hilltop. Tourists have complained that they couldn't see anything, was just wall-to-wall bush and alien plants, compared to what it was like in the past. They say they had seen significant changes and weren't aware of management efforts to combat the problem"* (Conservation land user C).

The following responses were given by a few of the interviewees when asked if anything was being spent on combating the bush encroachment problem in the park. *"We never spent money in the past. We let people from the communal areas come in and chop trees for firewood"* (Conservation land user C). *"Recently nothing is being spent on clearing bush. This might change. I would like to get funding and start spending on clearing. The short term goal is to clear an area, while the longer term goal would be to get it back to a grassland state"* (Conservation land user C).

The majority of conservation land users claimed that it would be extremely expensive to manually or mechanically combat the bush problem in the park. Money for clearing is not provided in the annual budget for the park. Thus although some of the conservation landusers would like to spend money on clearing it simply is not an option as they cannot afford to. The most recent records of clearing in Hluhluwe were from the early 1990s. At that time the cost of clearing was approximately R500 to clear and spray a single hectare. Current estimates for clearing heavily encroached areas in the reserve were thought to range from R1000 to R1500 per hectare.

*Conclusions*

The inputs and contributions provided by the interviewees during this study were substantial and have provided a better understanding of the implications of the landscape wide vegetation changes at the grassroots level. Comparing what the landscape changes have meant for land users under contrasting land use practices and how land use practices have affected landscape scale vegetation patterns has proven to be a novel approach in attempting to understand the phenomenon of woody plant proliferation or bush encroachment.

The results from this study have shown that there are clear differences in the perceived causes and implications of the large-scale vegetation changes that have occurred under all three land use practices in the area. The perceived extent of the changes in vegetation under each land use system closely matched the results from Chapter 4. There were major differences in the perceived importance of the different causal factors driving the observed changes evident in each area. The communal landusers thought that rainfall and increased drought frequencies were the leading causes for the changes while changes to burning and farming practices were also perceived to be a major driver of the changes. The commercial land users perceived the high livestock stocking rates in the past to be the most important cause of bush encroachment in the commercial areas. The exclusion of fire in the past was thought to be closely linked to high stocking rates and also a major cause of bush encroachment. The conservation land users on the most part thought that the burning practices and stocking rates in the past were influential in driving the vegetation changes in the Hluhluwe iMfolozi Park.

The changes that have occurred in each area have had different implications for the land users. The communal landusers predominantly thought of the changes as advantageous to most people living in the area. However there were some negative implications resulting from the changes. The commercial landusers mostly perceived the increased bush densities in the area to have negative implications. However there has been a progressive move towards game ranching in the commercial areas making the impacts of bush encroachment less serious than before as stocking rates are much lower than they were under cattle ranching and many of the species being stocked on the game farms are able to utilise the increased browse. The cattle farmers still remaining in the area appeared to be most concerned with the changes as their livelihoods were threatened by the loss of grazing land and it was claimed that bush encroachment was already significantly costing them. The estimated loss in capital as a result of bush encroachment provided by one of the cattle farmers was thought to be very high (R675/ha). However, if one looks at these numbers critically it is clear that it is an overestimate as the recommended stocking rate for the area is one large stocking unit (LSU where 1 LSU = ~1 cow) per four Ha. Thus one cow would need four hectares and if it took three years to reach maturity and was then sold for R3000, then each hectare is only earning the farmer R250 per annum. Thus he has clearly overestimated the cost of encroached land. Nonetheless even R250 income lost per hectare is a substantial loss.

The conservation land users were also highly concerned with the large-scale conversion of grassland habitat to thicket and shrub. The major concern was that biodiversity was being lost with the progression towards a closed canopy woody plant community. Already many grassland species such as Reedbuck, Wildebeest and Waterbuck numbers have declined or their numbers have dwindled to levels of concern (Brookes and Macdonald, 1983). However some of the conservation landusers were less concerned with the changes especially in the drier southern parts of the reserve.

The communal land users by and large had no intentions of combating the changes in woody cover that have occurred in the area over the last century as the increased woody densities were mostly perceived as beneficial. Some of the commercial farmers were trying to combat the increased woody densities with the use of intense fires. However, most of the commercial land users were more concerned with alien clearing, as they felt more threatened by alien species such as *Chromolaena odorata* than by increasing indigenous species. Many claimed that they would like to clear encroached areas but simply could not afford the high outlay required to do this effectively. In the conservation areas limited clearing efforts have been done in the past. However at present, despite the huge concerns over losing biodiversity alongside the biome shifts that are occurring in parts of the park, no clearing efforts are under way. Management is however attempting to use fire to control bush encroachment in parts of the park. A few of the conservation interviewees did also express intentions to combat the problem through clearing in the future. The high costs involved in clearing was said to be the major setback preventing a major clearing program in the reserve, however if funding became available such a program would be set up in the future.

In summary it is clear that the land users are all aware of the large-scale changes that have occurred under all three-land use types in the area. There do however appear to be large discrepancies between the different land users with regard to the causes of the changes. Despite the evident large-scale changes, no real efforts have being made to combat the changes. This is not surprising in the communal areas where people are generally living below the poverty line. Even if the changes were seen as a problem they would not be able to afford to invest money or effort into combating bush encroachment. In the commercial and conservation areas it is somewhat surprising that so little has been done about combating the changes despite many of the land users being seriously concerned about the implications of bush encroachment in the area.

# Chapter 6. Synthesis and conclusions

This study set out to compare the magnitude and rate of savanna thickening and thicket expansion in the Hluhluwe area under three contrasting land use systems. The template against which these changes occurred was then examined in detail by reconstructing past land use practices in the different land use systems. The general hypothesis to date has been that management and changing land use practices account for savanna or grassland thickening and thicket expansion. We have measured the extent and rates of change in woody cover in areas that have remained under radically different land use practices in the long-term. These documented changes were then correlated with past management practices to test this hypothesis.

*Climate*

Long-term rainfall records show that there has not been a significant reduction in rainfall at the study sites. Nor were any major changes evident in the seasonality of rainfall, with no significant decrease or increase evident in summer or winter rainfall for the period between 1933 and 2004. The biotic and abiotic template of the study sites were considered uniform due to their close proximity. Although there was a slight rainfall gradient between sites, this was not thought to have played a role in the changes. There were significant changes in vegetation cover at all three sites despite the rainfall gradient. Furthermore, rainfall data showed that the rainfall gradient remained consistent through time.

*Land use history in the broader Hluhluwe area*

*Communal areas*

Woody thickening was least pronounced in the areas under communal tenure. However, the increases in woody cover that did occur were still highly significant. The changes that occurred at the communal study site (25 $km^2$) between 1937 and 1960 equated to a 121 % increase in woody cover. In spatially explicit terms, this equates to a ~ 2 $km^2$ increase in tree cover or if measured as a rate, 8.2 ha grass cover lost per annum. During the same period human densities doubled from ~30 to 60 people/$km^2$. Cattle densities remained high during this period (between 0.3 and 0.6 LSU/ha). Cattle numbers did, however, plummet during the late 1940s and early 1950s (from 0.6 to <0.3 LSU/ha). By 1960 numbers had recovered to levels similar to 1937 (~0.5 LSU/ha). Goat densities followed a similar pattern during this period. Goat numbers decreased during the 1940s, then increased during the 1950s levelling out at around 0.04 LSU/ha during the 1960s (one goat = 0.17 LSU; 0.04LSU/ha = 0.25 goats /ha).

Interviews with elders from the area suggested that during this period, traditional burning practices were maintained. Fire was used in a controlled manor to burn specific areas for particular reasons, which included the removal of moribund grass, tick control and clearing of land for cultivation. A significant increase in cultivation (13.1 % or 327 ha) is also evident during this period.

The period between 1960 and 2004 witnessed a further 88 % increase in tree cover in the communal area. This equates to 3 $km^2$ of increased tree cover or ~7ha/annum. Human densities also increased significantly during this period from 60 people/$km^2$ in 1960 to ~150 people/$km^2$ in 2001. Cattle densities remained at relatively high levels (~0.6 LSU/ha) until the drought of the early 1980s which significantly depleted cattle numbers. Cattle numbers recovered by the late 1990s then dropped off again to reach current levels (0.3 LSU/ha). Goat densities remained relatively constant during most of this period (between 0.03 and 0.05 LSU/ha), with a slight decrease in numbers since the late 1990s.

The majority of elders claimed that there have been major changes to burning practices during this period. Traditional controlled burning practices were replaced by an ad hoc system whereby fires were no longer controlled and were started randomly both spatially and seasonally. The analyses of vegetation change show that the total area under cultivation in the communal areas decreased substantially after 1960. This is in agreement with the well-documented collapse in cultivation in the rural areas of Southern Africa during the past century (e.g. Bundy 1979; Mckenzie 1994; Bryceson 2002).

In summary, during the past 70 years the communal area has undergone major increases in human population densities. Cattle densities have generally remained consistently high and goat densities have remained remarkably stable. A substantial increase in cultivation was evident during the 1960s then significantly decreased again by 2004. Burning practices were said to have changed from less frequent controlled fires to more frequent uncontrolled burns. Set against this backdrop, woody densities have increased significantly at a relatively constant rate at the 25$km^2$ study site (7- 8 ha converted to tree cover per annum).

*Commercial areas*

The increase in woody plant cover was the most pronounced at the commercial study site. Between 1937 and 1960, tree cover increased by 436 %, in spatial terms this equals 3 $km^2$ or if calculated as a rate, 13 ha/annum was converted to tree cover. In the commercial farming areas, human densities have remained consistently low throughout the study period. Cattle numbers in the Hlabisa district increased steadily from the mid 1920s until the mid 1950s reaching nearly 30 000 head in total. The calculation of cattle densities was compromised by the limited data on farm sizes. However, when the total number of cattle was divided by total area under commercial farming it provided stocking densities of around 0.3 LSU/ ha during the peak in the 50s and 60s. Actual cattle stocking densities were likely to be much higher as the total area under cattle farming was likely to be much lower than the total area under commercial farming since parts of the commercial farming areas are also used for cultivation of sugarcane, pineapples and other crops. Goats were never farmed on a large scale on the commercial farms. The few goats found in the commercial farming areas probably belonged to the farm labourers living on the farms. Interviews with the commercial landowners/users revealed that during this period fires were very infrequent and often completely excluded.

During the period from 1960 to 2004 woody cover increased by a further 246 % (total of 9 $km^2$ or 21 ha/annum). Cattle numbers initially remained high until the mid 1960s (0.3 LSU/ha) then steadily decreased to current levels (<5000 in Hlabisa district or <0.05 LSU/ha). The widespread switch to game farming in the area further confounded herbivore-stocking densities in the commercial farming areas. The switch was purported to have started in the late 1970s then steadily gained momentum in the 1980s and 1990s. The majority of commercial farming areas in Hlabisa are now privately owned game farms. The commercial farming area analysed in this study consisted of two properties. One of the properties (northern half) switched to game farming in the late 1970s while the other (southern half) remained under cattle farming until 2001. An examination of changes that occurred at the commercial study site (Chapter 4, Figures 4.14 to 4.16) showed that woody cover increased to a more or less similar extent on both properties. Parts of the game farm in the north could be interpreted to have undergone slightly more thickening than the cattle farm in the south. The commercial land users maintained that during this period fire became recognised as a necessary ecological process. Thus, farmers started burning more extensively and more frequently. Many of the commercial landusers also began using fire as a management tool to combat woody thickening in the recent past.

In summary, the commercial farming areas have therefore undergone major changes in the past 70 years. Prior to the 1980s, the area was used predominantly for cattle farming. Cattle stocking densities increased rapidly during the first half of the century, peaking in the 1950s and 1960s. During this intensive cattle farming period, browsers were virtually absent on many of the cattle farms. The high stocking rates during this period would often have resulted in the exclusion of fire. Furthermore, many of the landowners often actively excluded fire during this period. Many of the farmers in the area have converted to game farming during the past twenty to thirty years. This has generally resulted in lower grazer densities and the reintroduction of browsers and mixed feeders to the system.

*Conservation areas*

The percentage increase in tree cover between 1937 and 1960 at the conservation study site (25 $km^2$) was over 190 % (total area of 6.9 $km^2$ or 30 ha/annum). In the conservation area (HiP) human densities have been negligible since the demarcation of the reserve and subsequent removal of local inhabitants. Stocking rates in the park remained low during the period between 1928 and 1950. A partial explanation for these low animal numbers would have been the prevalence of Nagana (*Trypanosomiasis*) in the area, which was finally eradicated in the 1950s. Subsequent to 1950 the densities of all three feeding types increased steadily reaching total densities of ~0.25 LSU/ ha in the mid 1960s.

Burning policies in the park varied during this period. During the 1930s and early 1940s, efforts to exclude fire from the reserve were attempted in order to protect wooden tsetse fly traps placed throughout the park. However, Berry and MacDonald (1979) used aerial photography to show that a large number of small fires were still evident in Hluhluwe Game Reserve during the dry season of 1937. Fire records are lacking for Hluhluwe Game Reserve for the 1940s and early 1950s. Fire records from 1955 to 1960 show that the majority of the northern and eastern sections of Hluhluwe Game Reserve burnt at least once during those five years, while some areas even burnt on an annual basis. This suggests that during the period up until 1960, parts of the reserve, especially the more mesic northern section of the park, burnt frequently despite efforts by management to exclude fire.

During the period between 1960 and 2004 the total percentage of woody cover increased by a further 38 % (4 $km^2$ or 9 ha/annum). Stocking densities in HiP were perceived to be too high during the late 1960s. Management intervened and undertook major culling campaigns, thereby significantly reducing stocking densities. Low stocking rates were maintained throughout the 1970s and 1980s. Animal densities were left to increase after 1990, eventually reaching current levels, which are the highest on record (>0.3 LSU/ha). Prior to 1990, the proportions of the different feeding types (grazers, browsers and mixed feeders) remained relatively consistent. The proportions of the different feeding types have since changed with a decrease in grazer densities and a substantial increase in browser and mixed feeder densities.

Fire records show that despite different management policies, fire continued to frequently burn large parts of the park for the period between 1955 and 2004. The previous year's rainfall was found to be significantly correlated to the total number of fires and total area burnt during the following dry season (Table 3.2). Due to the risks involved with burning late in the dry season, management has tended to burn in early winter or in spring after the first rains.

In summary, the records show that the conservation area has retained the full complement of feeding types at relatively low densities for most of the period between 1937 and 2004. The fire return interval has remained short (1-2 yrs) for most of this period, especially in the north-eastern parts of Hluhluwe Game Reserve. Fire seasonality did vary somewhat, but the majority of controlled burns were started in early winter or in spring.

*Evidence of differing land use practices*

The records show that the historical land use practices at the three study sites have been fundamentally different since the early 1900s. Prior to 1900, the wider area would have been used relatively homogeneously by the indigenous AmaZulu people living in the area.

Since the proclamation of HiP and the demarcation of the communal and commercial boundaries in the early 1900s, each of the areas has been utilised by a fundamentally different suite of feeding types. Cattle and goat densities in the communal area have remained consistently high, with a few exceptions when animal numbers plummeted due to disease or drought. The communal area has therefore retained high densities of both grazing and browsing feeding types throughout the period study period. The commercial farming areas were utilised predominantly by grazers until the early 1980s. Stocking densities remained high and browsers were practically absent on most farms. The reintroduction of indigenous game species to areas previously under cattle farming over the last thirty years does not appear to have impacted on the vegetation. The analysis of vegetation change at the commercial study site shows a uniform increase in tree densities despite the differences in farming types found at the study site. This is shown by the analyses in chapter 4 (Fig. 4.16) which suggest that the switch to game farming in the late 1970s on the northern half of the study site did not lead to significant differences in current vegetation when compared to the area that remained under cattle farming in the south. In contrast with the communal and commercial farming areas, the conservation area has retained all three functional feeding types since proclamation. Herbivore densities in Hluhluwe Game Reserve remained consistently low, especially during the first half of the 20$^{th}$ century. The analyses of vegetation change (Figs 4.18 to 4.23) in the conservation area shows that it was during this period of low stocking densities (1937 – 1960) that the biggest increase in woody cover occurred.

Burning practices during the study period also varied in the three areas. Fire records from HiP suggest that the north-eastern part of Hluhluwe Game Reserve (area in which the study site falls) burnt frequently throughout the study period. Low herbivore densities in a high rainfall area would result in the rapid accumulation of grass biomass. These large fuel loads would result in a relatively short fire return interval (1-2 yrs) as during the dry winter season, this fuel becomes extremely dry and flammable. Fires would often have entered Hluhluwe Game Reserve from surrounding communal areas. Furthermore, lightning strikes which are fairly common in the area, (Chapter 2) would often have started fires. During this period, the work force in the park was also likely to be deficient and would not have been efficient at controlling fires.

Fire records are lacking for the communal areas, however interviews with the landusers suggested that fire was used in a controlled manner for most of the study period. The elders were acutely aware of the ecological importance of burning. They therefore never completely excluded fire from the communal areas. High cattle densities were likely to have reduced fuel loads in the communal area resulting in less frequent fires. Increased human densities and the associated increase in cultivation would have resulted in more fragmentation in the communal areas. A highly fragmented landscape would result in smaller fires. In the communal areas fires have therefore remained frequent but the average size of fires is likely to have decreased through time.

In the commercial farming area, fires were purposefully excluded for the majority of the study period. Furthermore, high stocking rates would have resulted in lower fuel loads which would have resulted in fewer runaway fires or ignitions from lightning strikes.

The fire return period has therefore remained relatively short in the conservation area. Fires were largely excluded from the commercial farming areas area for most of the study period. In the communal areas, the fire regime has ranged from controlled and infrequent to a more uncontrolled and frequent.

*Conclusions*

Highly significant increases in woody cover have occurred at all three sites despite the unambiguous differences in past land use and management practices over approximately the last 100 years. This suggests that changing land use practices cannot be used to completely explain the widespread increases in woody cover evident at the landscape scale in the Hluhluwe area.

Since 1911, human population densities have increased by 650 % in the communal area. The increase in human densities in the communal areas would have resulted in a concomitant increase in the utilization of woody natural resources (e.g. firewood, fencing and building materials). In the conservation area management has attempted to actively combat bush encroachment through clearing and burning for nearly forty years. Browsers, mixed feeders and fire have been returned to many of the commercial farms for nearly thirty years.

Despite all of these factors and significant differences in past land use practices, woody plant cover has continued to increase at a rapid rate at all three sites. This study did find that there were differences in the rates of thickening under the contrasting land use systems. The rate of thickening in the communal areas has not been as rapid as in the commercial and conservation areas. Therefore, land use practices do have a limited influence on the rate of savanna thickening yet not enough to completely prevent the process from occurring. The significant increases in woody cover in all three land use systems could suggest that the changes are being driven by a global driver. Changing rainfall has been suggested as a potential widespread driver of the changes. The analyses of long-term rainfall patterns at the study site exclude this hypothesis.

Despite the documented widespread occurrence of savanna thickening and thicket expansion in the wider Hluhluwe area, very little is being done about it. This could suggest that a more widespread approach beyond the individual owner needs to implemented. An example can be taken from the Working for Water Program in South Africa, which has a Chromolaena clearing program, which is often associated with bush encroachment. Is a similar program needed to address bush encroachment in the country? However the problem remains as to who would fund such a program? How to effectively control or combat bush encroachment appears to remain unknown. Many of the methods (e.g. fire, fire and browsing and light or heavy grazing) employed by landowners to date have been ineffective at combating savanna thickening in the area. New innovative methods of clearing are therefore needed in order to successfully tackle the problem.

Previous studies (Johnson *et al.* 1993; Polley *et al.* 1994; Polley 1997; Polley *et al.* 1997; Bond and Midgley 2000; Hoffman *et al.* 2000; Bond *et al.* 2003) have shown that increasing atmospheric $CO_2$ concentrations significantly increased the growth rates of woody plants. However, studies that examine the competitive interactions between $C_3$ woody and $C_4$ grassy species at elevated concentrations are still needed. Globally increasing atmospheric $CO_2$ concentrations, together with changing climate and anthropogenic influences on savanna ecosystems, are all likely to be acting simultaneously, resulting in the significant changes in tree cover that have been documented at the study sites. A more extensive analysis at the regional scale is now needed to test the pervasiveness of the phenomenon of savanna thickening and thicket expansion.

If the changes in woody cover are been driven by a global driver it would suggest that the methods of combating the changes would also have to change. Thus, methods that were effective 30-50 years ago may not work today. Much of current conservation thinking and planning is focused on 'natural processes' which could be problematic in this case. Perhaps a more proactive attitude needs to be adopted by landowners. Should we be managing with a specific objective or outcome in mind, such as maintaining grass and the associated biodiversity? The question remains as to what we should be doing about the changes in woody cover at local, national and global levels. This study has shown that, to date, not much is being done at the local and national levels in South Africa.

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# Appendices

## Appendix A

Questionnaire used for semi-structured interviews

*Part 1: Land users' perceptions of bush encroachment*

1) *Perceptions and quantification of changes*

- Have you noticed a change in tree/shrub densities in this area since you were young?
- Can you explain these change if any?
- Any particular species or areas?
- When did you first notice these changes?
- Has it been a gradual or sudden process?
- Any particular periods of sudden change?
- Have you noticed changes in other areas besides where you live?
- If so where?
- Are these changes different to those around your home/village/farm?

2) *Causes*

- What do you think the main causes for the observed changes are?
- Why is it happening now and not in previous generations, e.g. your grandparents' time?
- Why is it worse in some areas than others?
- Why are there differences in areas under different land use practices?

3) *Implications*

- Do you see the changes in woody plant densities as a problem?
- Explain why?
- Have the above-mentioned changes affected your livelihoods in any way?
- If so how?
- Have you benefited at all from changes in tree/shrub densities?

- If you could choose what you wanted the surrounding areas to look like what would you choose?
- Why?

*Part 2: Land use history*

1) Human densities

- Have you noticed an increase in the number of people/homesteads in your area?
- Has it been a gradual or sudden increase/decrease?
- Any particular periods of rapid increase/decrease?
- Have people come from elsewhere, or has it been an expansion of local population?

2) Land *use and livelihoods*

- Any differences in numbers of livestock between now and long ago?
- What do you think has caused these differences?
- Any differences in extent/amount/type of cultivation compared to past?
- What do you think has caused these differences?
- How often does this area/farm burn?
- How do these fires normally start?
- If fires are started purposefully, why do you burn these areas?
- How were these areas burnt in the past?

*(Communal land users only)*

- What kind of wood is used for firewood and where do you get it?
- Is it harder/easier to find firewood now than it was in the past?
- Is this because of more people in the area or because there are more or fewer trees now than in the past?
- What other woody resources are utilised from the surrounding area (fence poles, building materials etc)?
- Are these becoming harder or easier to find than in the past?
- Are trees/shrubs ever cleared or chopped down for other reasons?
- If yes, how much? Which trees? How often? And for what reasons?

Part 3) Costing of bush encroachment

- Any efforts to combat the changes both past and present?
- Any records or estimates of the costs, both direct and indirect, of these efforts?
- Any future intentions of combating changes?

**Appendix B**

Major themes for each land use type

1. History of the area
2. Background of interviewees (summary)
3. Perceptions of the landscape before 1960
4. Perceptions of current landscape condition/state
5. Land users' perceptions of changes on other land use types in the area
6. Livelihood changes evident in each area
7. Causes of changes
8. Implications/Consequences of changes on land users
    - Positive
    - Negative
    - Neutral
9. Has/Is anything been done about the changes?
10. Costs/implications of combating changes

## Appendix C

A list of the most common species mentioned during interviews with the different land users. Growth forms and isiZulu names are provided.

| Species | Growth Form | Zulu name |
|---|---|---|
| *Acacia karroo* | shrub or tree | umuNga |
| *Acacia nilotica* | tree | umNqawe |
| *Acacia borleeae* | tree | iSanqawe |
| *Acacia nigrescens* | tree | umKhaya |
| *Sclerocarya birrea* | tree | umGanu |
| *Maytenus senegalensis* | shrub or tree | isiHlangu |
| *Maytenus heterophylla* | shrub or tree | uSala |
| *Schotia brachypetalla* | tree | uVovovo |
| *Diospyros dichrophylla* | shrub or tree | umNqandane |
| *Dichrostachys cinerea* | shrub or tree | uGagane |
| *Euclea divinorum* | shrub or tree | umHlangula |
| *Euclea racemosa* | shrub or tree | iChithamuzi |
| *Euclea natalensis* | tree | iDungamuzi |
| *Rhus pentheri* | tree | iNhlokoshiyane |
| *Croton steenkampianus* | shrub or tree | uHubeshane |
| *Combretum ertthrophyllum* | tree | umDubu |
| *Olea europeaea africana* | tree | Nquma |
| *Syzygium cordatum* | tree | Umdoni |
| *Euphorbia ingens* | tree | umHlonhlo |
| *Mimusops obovata* | tree | umMpumbulu |
| *Dombeya burgessiae* | tree | iBunda |
| *Chromolaena odorata* | herb | iSanbanezwe |
| *Sporobolus spp* | grass | Unsiki |
| *Hyperthelia dissoluta* | grass | isiQunga |