The utilisation of satellite images for the detection of elephant induced vegetation change patterns

by

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Declaration

I, Chenay Simms, hereby declare that the research reported herewith on the topic, “The utilisation of satellite images for the detection of elephant induced vegetation change patterns”, is my own work and that all the sources made use of or quoted in the manuscript have been indicated and acknowledged by means of complete referencing.

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Date

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Date

Acknowledgements

This master's study was not done in isolation. There were a number of people without whom I would not have been able to complete this research.

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Abstract

South Africa's growing elephant populations are concentrated in relatively small enclosed protected areas resulting in the over utilisation of the available food sources. Elephants and other herbivores as well as other natural disturbances such as fires and droughts play an important role in maintaining savannah environments. When these disturbances become too concentrated in a particular area the vegetation composition may be negatively affected. Excessive damage to the vegetation would result from exceeding the capacity of a protected area to provide food resources. The effect of the 120 elephants on the vegetation of Welgevonden Private Game Reserve, is not known. The rugged terrain of this reserve makes it a difficult, time consuming and labour intensive exercise to conduct ground studies. Satellite images can be used as a monitoring tool for vegetation change and improve the quantity and quality of environmental data to be collected significantly, allowing more informed management decision-making.

This study evaluated the use of satellite imagery for monitoring elephant induced vegetation change on Welgevonden Private Game Reserve. The LANDSAT Thematic Mapper multispectral images, acquired at two yearly intervals from 1993 until 2007 were used. However, no suitable images were available for the years 1997, 2001 and 2003. A series of vegetation change maps was produced and the distribution of water sources and fire occurrences mapped. The areas of change were then correlated with the spatial distribution of water points and fire occurances, with uncorrelated areas of change. This was analysed using large animal population trends, weather data and management practices.

On the visual comparison of the vegetation maps, it was seen that over this time period there was some decrease and thinning of woodland, but the most notable change was the increase of open woodland and decrease in grasslands. Using only the digital change detection for the period 1993 to 2007, a general increase in vegetation cover is seen. But this generalisation is misleading, since comparing the digital change detection to the vegetation maps indicates that while vegetation cover may have increased, significant changes occurred in the vegetation types.

Most of the areas of significant change that were identified showed a strong positive correlation with burnt areas. The distribution of the water sources could not be directly linked to the vegetation change although rainfall fluctuations seemed to have accelerated vegetation changes. Years with high game counts, such as 1999, also coincide with very low rainfall making it difficult to differentiate between the effects of heavy utilisation of vegetation and low rainfall. Furthermore, many of the initial vegetation changes could be the result of land use changes due to the introduction of browsers, selective grazers and elephants that allow for more natural utilisation of the vegetation.

Remote sensing makes it possible to successfully track changes in vegetation and identify areas of potential elephant induced vegetation change. Vegetation changes caused by disturbances, such as fire and anthropogenic activities, can be accounted for but it is not possible to conclude with a high level of certainty that the further changes seen are solely a result of elephant damage. Further work is required to reliably isolate elephant induced vegetation changes, as well as to establish the effects these changes have on the ecosystem as a whole.

Keywords: elephants, enclosed protected areas, keystone species, fires, droughts, herbivores, water sources, savannah, vegetation damage, Welgevonden Private Game Reserve, satellite images, monitoring tool, LANDSAT Thematic Mapper.

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Chapter 1
INTRODUCTION

1.1 Background

The African elephant (*Loxodonta africana)* once roamed freely over sub-Saharan Africa but their numbers are declining over much of their former range. This decline in elephant numbers is mainly due to habitat loss and fragmentation, as well as poaching for meat and ivory (Blanc, Barnes, Craig, Dublin, Thouless, Douglas-Hamilton & Hart, 2007). In an effort to halt the downward trend in elephant numbers, CITES has put the African elephant on the endangered species list and has banned trade in elephant products (www.cites.org, 2007). Limited trade in elephant products is allowed only in Southern Africa, as this region's elephant populations are stable and well protected. Of the estimated 689 671 African elephants found in the wild today, Southern Africa has 58% of the total elephant population. However, only 39% of the total available elephant habitat is situated in Southern Africa (Lindeque, 2000; Blanc *et al.*, 2007).

The South African elephant population currently stands at around 18 507 individuals (Blanc *et al.*, 2007). In contrast with the rest of Africa, this number is steadily increasing each year. As human development spreads, the habitat available for this growing elephant population is decreasing. This has resulted in increasing human-elephant conflict, concentrating the remaining elephant populations into relatively small protected areas. In South Africa, most of the protected areas set aside for elephants are enclosed with fences thus preventing elephants and other large animals from moving freely. By cutting off seasonal migration routes and access to alternative resources, these enclosures force elephant populations to over utilise the available food resources.

An average adult elephant eats approximately 150-300 kg of vegetation per day, depending on the vegetation type and time of year, and thus have destructive feeding habits (Bothma, 2002). This has led to elephants being referred to as a keystone species as even in relatively small numbers, they contribute to large scale modification of their habitat. Studies have reported that elephants play an important role in maintaining a viable savannah environment by regulating bush encroachment into grasslands (Augustine & McNaughton, 2004). Their destructive feeding habits can also improve the habitat suitability for some species by opening up access to densely bushed areas, creating new micro habitats, and by stimulating new growth in damaged trees (MacGregor & O'Connor, 2004). When habitat modifications by elephants happen in moderation, habitat heterogeneity is created and maintained (Du Toit, Rodgers & Biggs, 2003; Owen-Smith, 2006; Chongo, Nagasawa, Ahmed & Perveen, 2007).

Adler, Raff and Lauenroth (2001) define spatial heterogeneity as the relationship between the values of one variable observed at different locations. The more spatial heterogeneity is present, the more random the pattern of ecosystem variables and the wider the variety of habitats available. Spatial heterogeneity is important in habitats such as savannahs as it dampens the effects of the extreme temporal variability in resource availability seen in these habitats (Owen-Smith, 2006). This dampening effect is due to the wider the range of possible habitats resulting in more biodiversity, which creates a temporal overlap in resources.

Disturbances such as fires, droughts and the browsing/grazing of herbivores, all help to maintain the heterogeneity of savannas (Owen-Smith, 2006; Chongo *et al.*, 2007). The spatial and temporal availability of water is another important factor in maintaining habitat heterogeneity. In a natural environment, elephant damage to vegetation results in new microhabitats for a variety of other organisms increasing the range of available habitats. Exceeding the carrying capacity of an enclosed area by having too many elephants in too small an area, will result in the over-utilisation of available food resources. Locally concentrated vegetation damage stretching over long periods can cause excessive damage to the vegetation from which the vegetation may not be able to recover. This loss of vegetation is accompanied by the destruction of habitats and ultimately a loss of biodiversity (Dublin, Sinclair & McGlade, 1990; Johnson, Cowling & Phillipson, 1999; Lombard, Johnson, Cowling & Pressey, 2001; Wiseman, Page & O'Connor, 2004).

The effective elephant carrying capacity of a reserve is difficult to determine, especially in an area with a wide variety of habitats. Factors such as vegetation type, the other animal species present on the reserve, topographical features, as well as the annual fluctuations in temperature and rainfall can all affect the effective carrying capacity of an area. The way these variables interact may cause some areas to be less attractive to elephants than others, resulting in them being under-utilised while others are over-utilised. The impact of elephants are thus not spread evenly over an area and is as dependent on where they are as on how many they are (Henley & Henley, 2007; Van Aarde & Jackson, 2007). It must also be kept in mind that the African elephant is only one part of a broader system. Other factors such as drought, fire and other herbivores will also influence vegetation patterns (Dudley, 1999). The impacts of these disturbances, along with those of elephants, are all interlinked and may amplify or mask individual effects (Guldemond, 2006).

The effects of other herbivores, while not as obvious as those of elephants, impact vegetation distribution patterns although their exact contribution to the savannah dynamic is still unclear. Intensive browsing by animals, such as giraffe, stunts the growth of trees and makes them less resilient to other disturbances such as drought or fire. Even small browsers such as steenbok can influence vegetation distribution and density through reducing the recruitment of seedlings (Augustine & McNaughton, 2004; Owen-Smith, 2006).

The distribution patterns of browsers are largely dependent on the availability of water as most large browsers have to drink at regular intervals and thus do not move far from water. By installing artificial water points, the natural distribution patterns of animals are altered and the provision of permanent water removes one of the natural population control measures. Artificial water points also allow water dependent animals, such as elephants, to remain in areas that previously would only have been utilised seasonally. This year round utilisation can result in a very uniform habitat within range of the water points. Organism dependent on seasonally utilised habitat types get displaced or die out completely.

The detrimental effects of artificial water points have been seen in Kruger National Park (KNP) where the provision of permanent water points has resulted in no area in

KNP ever being further that 10 km from water. This has allowed year round grazing pressure, which produces relatively uniform short grass cover over most of KNP with few areas left ungrazed for long. The reduction in population numbers of the rare Roan antelope in KNP was found to be partially due to the disappearance of stands of thick, tall grass where the altricial young of this antelope species could hide (Thrash, 1998).

The role of veld fires in maintaining heterogeneous African savannahs, as well as its use as a management tool, is a controversial topic. Fires were traditionally seen as destructive and actively excluded from protected areas. In recent years, scientists have begun to realise that fire has a key role in savannah ecosystems as they release nutrients held in old plant material, influence herbivore distribution and feeding patterns, and are a necessary element in the germination cycle of many plants (Bond & Archibald, 2003; Mills & Fey, 2005). One of the most important effects of fires is in maintaining the grass/tree balance of savannah ecosystems. Fire kills young woody seedlings thus limiting bush encroachment, yet a regime of frequent fires shifts the balance from climax grass species to pioneer grass and woody species.

A further element that needs to be taken into consideration in protected areas is the effect that tourists and tourist infrastructure have on the ecosystem of the reserve and the way in which conservation policies are implemented. Elephants are one of the most sought after members of the Big 5 with both foreign and local tourists. This popularity has resulted in elephants being reintroduced onto many of the larger private game reserves. Measures to make them more easily visible to tourists, such as the provision of artificial water points and extended road networks, are also often undertaken. Artificially high stocking rates of desirable species are maintained by management practices such as the provision of extra feed and the control of predators. Loss of total biodiversity will also be tolerated at higher levels on such tourist orientated protected areas as long as the main ecosystem functions remain intact.

In the case on Welgevonden Private Game Reserve (henceforth called Welgevonden) a relatively large elephant population of 120 individuals is maintained on 34 200 ha of mountainous bushveld. In its natural state, this area would not have held large herds of game year round as it currently does and this adds unnatural utilisation pressure. The maximum carrying capacity of this area in terms of elephant numbers is not known nor has the threshold for acceptable vegetation change been established. In order to implement an effective elephant management policy for this reserve, the effects on vegetation of the elephants currently on the reserve, needs to be established.

The *Norms and Standards for the Management of Elephants in South Africa* issued at the beginning of 2008 by the South African Department of Environmental Affairs and Tourism (DEAT), makes it mandatory for all protected areas with elephants, or those wanting to introduce elephants, to prepare and submit an elephant management plan (DEAT, 2008). This has resulted in an increased need for accurate, repeatable and cost effective environmental monitoring methods with which to produce ecological information for all elephant conservation areas. Ecological information is essential in order to effectively plan environmental objectives (Gorden, Hester & Festa-Bianchet, 2004). Amongst the most important ecological information are the detection, evaluation and prediction of change. Land cover change is an important variable of ecological systems that can tell managers a great deal about the health of the system.

Welgevonden is very mountainous with its land cover types distributed irregularly across large areas that are not easily accessible. This makes a detailed ground analysis of the land cover changes over the entire reserve difficult, time consuming and labour intensive, creating the need for a more efficient monitoring system for tracking changes. The use of satellite images as a monitoring tool for vegetation change has been successfully used in American and European forestry situations. It has the potential to be implemented as a monitoring tool for South African protected areas as well.

Remote sensing, especially images derived from satellite sensors, provides a cost effective tool with which to assess habitat structure and land cover changes across large areas at regular intervals. The spatial and temporally repeated observations provided by satellite images can significantly improve the quantity and quality of environmental data collected for a protected area that can then be used to map and monitor land cover changes taking place over time (Paolini, Grings, Sobrino, Muñoz & Karszenbaum, 2006).

Satellite sensors traditionally use reflected solar energy (radiation) in the visible and near infrared to thermal infrared regions of the electromagnetic spectrum to generate images. The tonal variations in the image represent the different reflected energy intensities received by the sensor. For a given material, the amount of solar radiation that it reflects is unique. When this amount is plotted over the range of available wavelengths, the material's unique spectral signature is produced (Lillesand, Keifer & Chipman, 2004). It is this important property of matter that makes it possible to identify different substances or classes and to separate them by their individual spectral signatures.

Because most satellite sensors operate in the green, red and near infrared regions of the electromagnetic spectrum, they can be used to discriminate the radiation absorption and reflectance of vegetation. Chlorophyll pigment in green leaves control energy absorption at about 0.65 µm (visible red) and 0.45 µm (visible blue). Most green vegetation reflects solar radiation of the visible wavelengths at 0.55 µm (visible green) and thus appears green to the human eye. Green vegetation, however, most strongly reflects radiation between 0.7 and 1.0 µm (near infrared) and appears bright in the near infrared wavelengths. This near infrared reflectance is also at a higher intensity than most inorganic materials, making it possible to map vegetation fairly accurately using satellite images. Changes in land cover will result in changes in the reflectance values detected by the remote sensors allowing these changes to be tracked (Lillesand *et al,* 2004).

Satellite images have an important spatial component as they are associated with the geographic coordinates of the area being observed and can be used to extract spatial data with Geographical Information System (GIS) techniques. This spatial component of satellite data allows any vegetation changes to be related back to specific ground coordinates, enabling field investigations to be more focused. By using satellite images, the vegetation change across the entire protected area can be monitored over time. The question that this study will try to answer is whether elephant induced vegetation change in an enclosed South African protected area can be analysed using change detection techniques on satellite images. In order to achieve this, a time series of vegetation change maps from satellite imagery will need to be produced and the spatial distribution of artificial water points and fires for that period mapped. In this way the areas of change can be correlated with the distribution of water points and fire. Any uncorrelated areas of change can be analysed using large herbivore and elephant population trends, weather data and management practices before a final analysis of the extent and distribution of elephant induced vegetation change is conducted.

By understanding the effects of the various ecosystem interactions on the spatial distribution of vegetation change, more informed management action might be taken. Long-term ecological monitoring programs are needed to assess trends in and the stability of the ecosystem. The more effective and accurate this ecological monitoring is, the better the management policies that can be implemented. Satellite images offer an objective, reliable and economical tool for monitoring vegetation change over time across large areas. While many studies have been carried out on the use of satellite images to assess habitat structure and land cover changes, these studies have mainly taken place in America and Europe. The different atmospheric and lighting conditions, as well as the diverse vegetation cover found in South Africa result in unique challenges that have not yet been addressed. This has resulted in satellite images being relatively unused in ecological monitoring in this country. As the elephant debate heats up with the ban on elephant culling being lifted, there is a growing need in South Africa for quick, comprehensive and reliable ecological data.

1.2 Location for the study

Welgevonden Private Game Reserve is a 34 200 ha “Big Five“ private nature reserve situated in the Waterberg Mountains, about thirty kilometres northwest of Vaalwater, in the Limpopo Province (see Figure 1.1). The reserve was established in 1993 from mainly cattle farms and is made up of privately owned plots of 500 ha each, which are managed as one entity. One ten-bed game lodge may be erected on each plot and all the lodges have traversing rights over the entire reserve. Currently there are 53 lodges on the reserve (www.welgevonden.org, 2007).

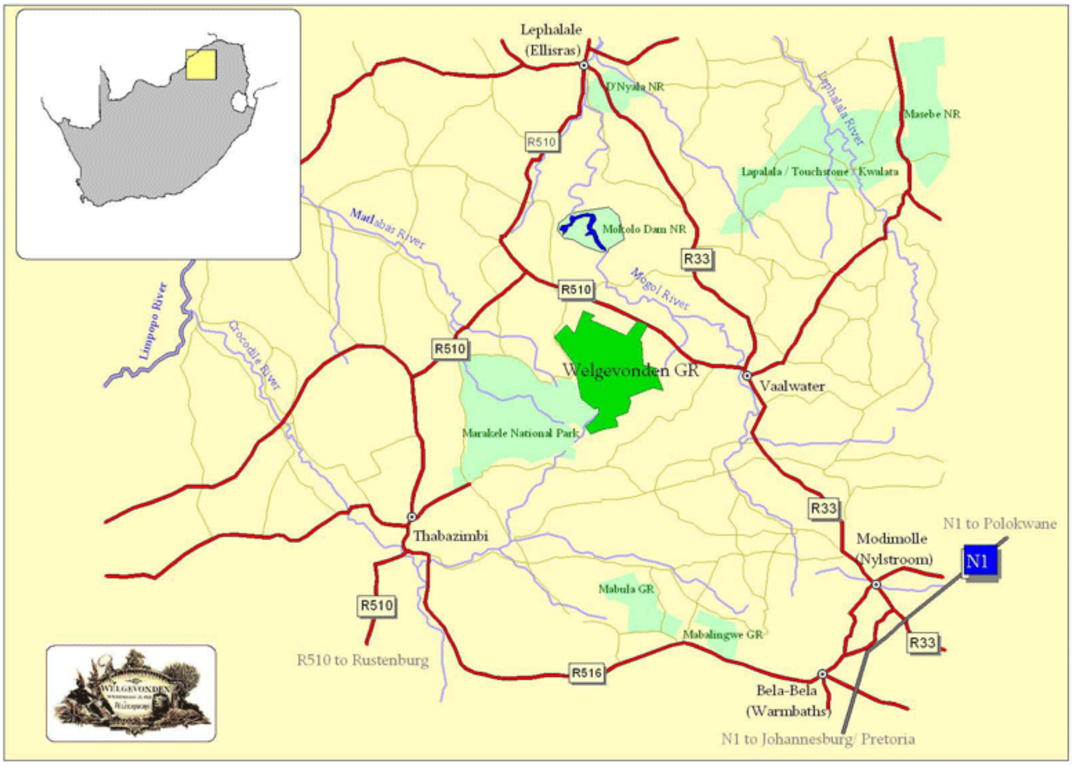


Figure 1.1 **Welgevonden Private Game Reserve** (www.welgevonden.org, 2007)

The Waterberg region formed about 1800 million years ago. The geology of the area is layers of conglomerate rock interspersed by sandstone and shale layers. The uneven erosion of these sedimentary layers has resulted in interesting rock formations and spectacular views. This area forms part of the mineral rich Bushveld Igneous Complex and has large deposits of nickel, chrome and tin with smaller quantities of iron and manganese (Walker, 2005). The sandstone erodes to produce deep sandy soil, which combines with the relatively high rainfall of the area resulting in soils poor in nutrients. In the more mountainous areas, these sandy soils only thinly cover rock layers, while in the drainage lines and valleys clay soils are found. The altitude of Welgevonden ranges from 1080 m to 1800 m above sea level and has an annual rainfall between 650 and 900 mm. The temperatures in this region range from -6.1°C to 39°C, with an average of 18°C.

Welgevonden has a combination of sour Waterberg Mountain Bushveld and sweeter Lowland Bushveld. The deep sandy soils are characterised by African Beechwood *(Faurea saligna*), Common Hookthorn (*Acacia caffra*), Red Seringa (*Burkea* *africana*), Silver Cluster Leaf (*Terminalia sericea*) and Weeping Wattle (*Peltophorum africanum*). White Seringa (*Kirkia acuminata*), Stamvrug (*Englerophytum magalismontanum*), Common Sugarbush (*Protea caffra*), Lavender Croton (*Croton gratissimus*), *Combretum apiculatum, Diplorrhynchus condylocarpon, Pseudolachnostylis maprouneifolia, Albizia tanganyicensis and* Velvet Leafed Bushwillow (*Combretum molle)* are found on the rocky mountain slopes.

There is a shrub layer of Sandpaper Raisin (*Grewia flavescens*), Peeling Plane (*Ochna pulchra*), Blue Guarri (*Euclea crispa*), *Rhus zeyheri, Vangueria infausta, Rhoicissus revoilii* and *Tapiphyllum parvifolium*. A moderate to well developed grass layer is also present with conspicuous species such as Wire Grass (*Elionurus muticus*), Common Russet Grass (*Loudetia simplex*) Rock Three-awns (*Aristida transvaalensis*), Natal Redtop (*Melinis repens*), Golden Bristlegrass (*Setaria sphacelata*) and *Themeda triandra* being found (Van Rooyen & Bredenkamp, 1996). In this vegetation type, fire and grazing are important role-players. The distribution of the various plant species also depends heavily on the slope aspect.

The reserve is stocked with large game such as Giraffe (*Giraffa camelopardalis*), Blue Wildebeest (*Connochaetes taurinus*), Eland (*Taurotragus oryx*), Burchell's Zebra (*Equus burchellii*), Kudu (*Tragelaphus strepsiceros*), Waterbuck (*Kobus ellipsiprymnus*) and Impala (*Aepyceros melampus*). In addition there are also potentially dangerous animals such as Buffalo (*Syncerus caffer*), White Rhino (*Ceratotherium simum*), Lion (*Panthera leo*) and Leopard (*Panthera pardus*). The elephant population on the reserve currently numbers around 120 individuals.

During the wet season, vegetation growth is vigorous resulting in high fuel loads with lightning fires being a relatively common occurrence at the end of the dry season. Recent scientific evidence suggests that fires such as lightning fires with point ignition that occur at differing intervals are far more effective in maintaining habitat diversity across a landscape by preventing bush encroachment and by creating an optimal patch-like mosaic (Du Toit *et al,* 2003) For this reason Welgevonden has moved away from a fixed management-burning regime to a policy whereby lightning fires are closely monitored but allowed to burn. Occasionally it is necessary for management to intervene to prevent fires from burning too large a proportion of the reserve and/or to assist with preventing damage to infrastructure and/or to prevent fires from spreading onto neighbouring properties.

On Welgevonden an active elephant management program has been implemented to maintain a demographically viable population while still maintaining a functioning ecosystem. To this end the numbers and growth rate of the elephant population is controlled. The reserve also actively contributes to the understanding of elephant management through various research initiatives. As elephant populations can double every ten years Welgevonden is continuously exploring possibilities for translocation and slowing down the population growth rate through immunocontraception. Since 2005, immunocontraception of the Welgevonden elephant herds have taken place. On Welgevonden the last calves were born in September 2007. Welgevonden has also become the first reserve where a completely successful laparoscopic vasectomy on an elephant bull was performed in 2006.

1.3 Research problem

Elephants are one of the key drivers behind vegetation change. To monitor these changes, large scale and ongoing ecological data is required so that confined elephant populations can be effectively managed. Ground based vegetation surveys produce reliable small-scale data, but it is uneconomical and impractical when applied to a large area sample. As an accurate vegetation map on which to base environmental management decisions is essential, a different approach to collecting land cover information is needed. Remote sensing can be an economical tool for assessing land cover over large areas, as well as the vegetation changes happening over time. While remote sensing has been successfully applied in numerous vegetation monitoring projects, almost no work has been done using remote sensing to monitor elephant induced vegetation change.

1.4 Aim & objectives

This study aimed to examine the use of satellite images for detecting elephant induced vegetation change patterns. The extent of vegetation change on Welgevonden Private Game Reserve was established using satellite imagery and the contribution of elephants towards this change assessed.

The following objectives were identified:

- Producing vegetation maps of Welgevonden Private Game Reserve from the available satellite imagery;
- Using the satellite images to produce change detection maps of the vegetation on Welgevonden;
- Using GIS technology to do spatial analysis of the change detection maps to assess the effects that water points as well as fires have on the vegetation and identifying areas uncorrelated to the above disturbances.
- Using the large herbivore and elephant population trends and weather data to assess the extent and distribution of vegetation change that may be attributed to elephant damage.

This study was not intended as a detailed vegetation survey but focused on the changes in the distribution patterns and density of woody vegetation on the reserve. To this end only the basic vegetation community structures were classified rather than attempting to classify the species composition. It was assumed that the effects of elephant damage would be most noticeable in changes in the density and distribution of the woody vegetation on the reserve.

1.5 Research design

Of the estimated 689 671 African elephants found in the wild today, 18 507 individuals can be found in South Africa and these numbers are steadily increasing. These elephant populations are concentrated in relatively small enclosed protected areas often over-utilising the available food resources as their numbers increase. Being a keystone species, they play an important role in maintaining a viable savannah environment by creating habitat heterogeneity. Other disturbances such as fires, droughts and the browsing/grazing of herbivores, also help to maintain the heterogeneity of savannahs. Elephant impacts are also not spread evenly over an area and are as dependent on where they are as on how many they are.

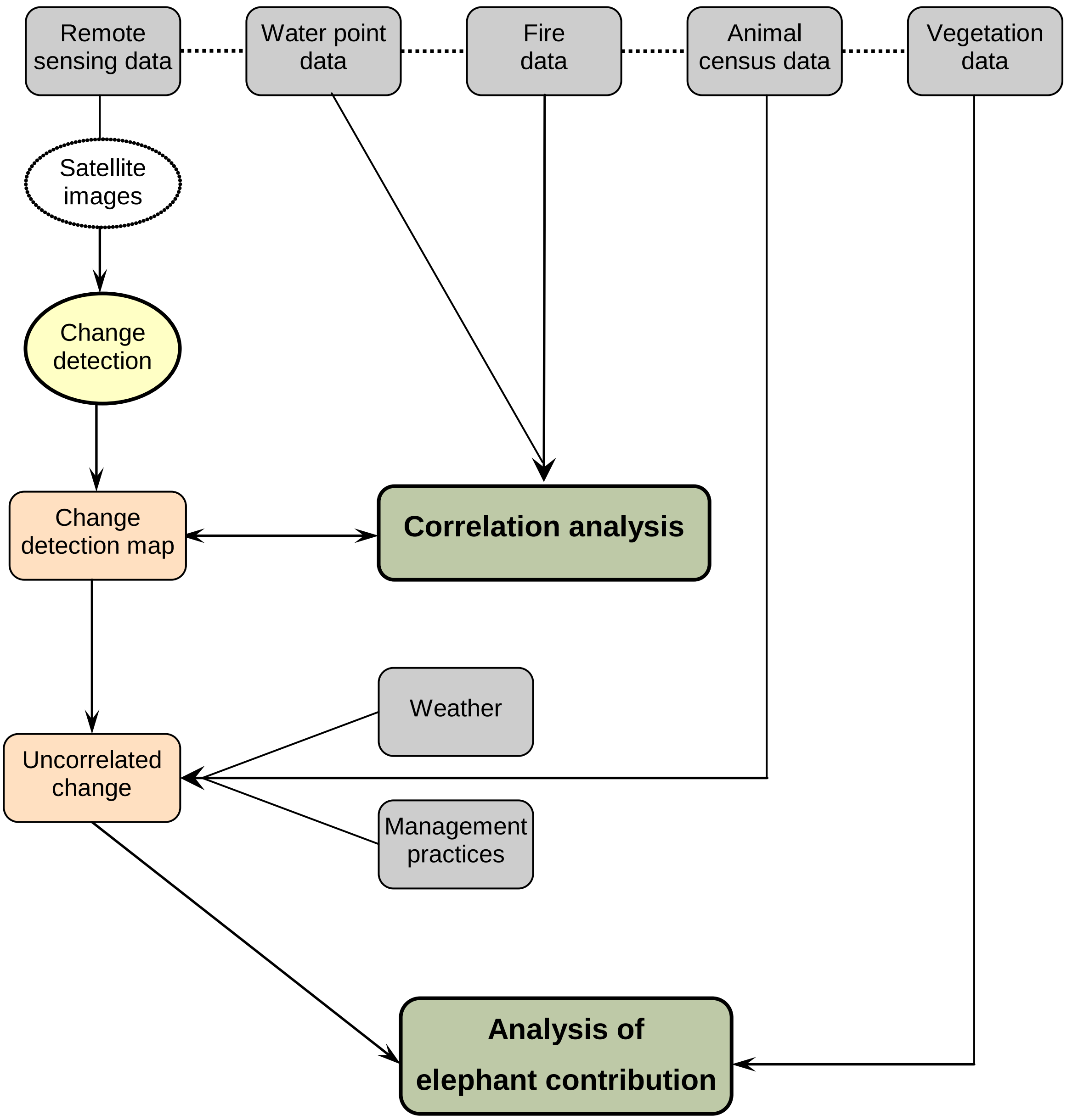


Figure 1.2 **Schematic representation of the proposed research design**

In the case on Welgevonden Private Game Reserve ecological information is needed in order to implement an effective elephant management policy for this reserve. A detailed ground analysis of elephant impacts on this reserve is not practical or economically feasible due to the very mountainous terrain of this reserve. A more efficient monitoring system for tracking land cover changes on this reserve is needed. This is where the use of satellite images has the potential to be successfully implemented as a tool for monitoring vegetation change.

Remote sensing, especially satellite images, provides a cost effective way to assess habitat structure and land cover changes across large areas at regular intervals. This can significantly improved the quantity and quality of environmental data collected, as the vegetation change across the entire protected area can be monitored over time. This study evaluated the use of digital remote sensing analysis techniques for monitoring elephant induced vegetation change in a selected enclosed South African protected area.

Vegetation classification was used to establish the changes taking place in the different vegetation communities. The producing a time series of vegetation change maps from satellite imagery and analysing the spatial distribution of artificial water points and fires for that period in relation to the areas of change identified achieved this. Uncorrelated areas of change were further analysed using large herbivore and elephant population trends, weather data and management practices in order to establish the effects of elephants on the vegetation on the reserve.

By understanding the long-term effects of the various ecosystem interactions on the spatial distribution of vegetation change, more informed management action may be taken. A savannah ecosystem is dynamic with a variety of variables constantly interacting to change the environment. It is not enough to monitor just elephant numbers, as their affects on the entire ecosystem need to be monitored as well. Remote sensing is a valuable tool for providing managers with data that is objective, reliable and economical. Developing a remote sensing based management action plan, will allow a holistic and proactive approach to elephant management.

Chapter 2
LITERATURE REVIEW

2.1 Introduction

The African elephant (*Loxodonta africana)* has become an endangered species and the dwindling population numbers need to be actively conserved. This decline in elephant numbers over most of Africa is mainly the result of habitat loss and fragmentation, as well as poaching (Blanc, Barnes, Craig, Dublin, Thouless, Douglas-Hamilton & Hart, 2007). Elephant numbers are only on the increase in Southern Africa with the population currently standing at about 321 000 elephants, of which 18 507 are found in the enclosed protected areas of South Africa (Blanc *et al*., 2007).

Elephants represent a source of revenue for local communities from the tourist industry through game reserves. For this reason, many of the smaller private conservation areas have re-introduced elephants. This can have a major impact on habitat conservation as increasing the available water points, fire control and the building of tourist infrastructure all result in environmental modification. In confined areas, high elephant numbers can cause unsustainable and often irreversible change to vegetation. A balance between maximum elephant numbers and minimum ecological damage needs to be found. In order to find this balance managers of protected areas need ecological data on which to base management decisions.

At the beginning of 2008, the South African Minister of Environmental Affairs and Tourism (DEAT), Mr. Marthinus van Schalkwyk, issued *Norms and Standards for the Management of Elephants in South Africa*. The Norms and Standards now make it mandatory for elephant owners to prepare and submit an elephant management plan (DEAT, 2008). This decision by Minister Van Schalkwyk has further increased the need for accurate and up to date ecological information.

Reliable ecological data can only be produced using accurate environmental monitoring methods. Field based monitoring methods produce detailed ecological data on a small scale but can be uneconomical and impractical when large scale data sets are required at regular intervals. Remote sensing, especially images derived from satellite sensors, provides a cost effective way to assess habitat structure and land cover changes regularly over large areas. The large spatial and temporally repeated observations provided by satellite images can significantly improve the quantity and quality of environmental data collected for a protected area. This information can be used to map and monitor land cover changes taking place over time (Paolini, Grings, Sobrino, Muñoz & Karszenbaum, 2006).

2.2 Elephants as agents of environmental heterogeneity

Savannah ecosystems are complex and dynamic with many environmental factors interacting over time to produce changes in the ecosystem (Tews, Ester, Milton & Jeltsch, 2006). No one factor, such as elephants, is solely responsible for changes in savannah ecosystems (Dudley, 1999). Disturbances such as fires, droughts and browsing/grazing by herbivores all help to maintain the heterogeneity of savannahs (Dudley, 1999; Owen-Smith, 2006; Chongo, Nagasawa, Ahmed & Perveen, 2007). The spatial and temporal availability of water is another important factor in maintaining habitat heterogeneity. Adler, Raff and Lauenroth (2001) define spatial heterogeneity as the relationship between the values of one variable observed at different locations. The more spatial heterogeneity is present, the more random the pattern of ecosystem variables and the wider variety of habitats will be available. This is an important buffer for the effects of the temporal variability seen in resource availability, as a varied habitat produces an overlap in resources.

There is a delicate balance between environmental disturbances creating heterogeneity and causing habitat degradation. The impacts of disturbances are all interlinked and the effects of each disturbance may be amplified or masked by others (Guldemond, 2006). 'The intermediate disturbance hypothesis' as expounded by Owen-Smith (2006) states that; overall species diversity is increased by disturbances that are not too severe or frequent. Even though diversity may initially be reduced in the disturbed patches, a variety of habitats with their associated species will result at the landscape scale thus increasing heterogeneity. It is persistent or pervasive disturbances that can reduce diversity, as species that are unable to tolerate such pressure will disappear. Such disturbances are often found when areas are enclosed and manipulated by humans and in so doing forcing unnatural utilisation patterns on the ecosystem.

Elephant impacts is one of the most obvious and hotly debated disturbances seen in Southern African savannahs as increased feeding pressure by elephants result in very visible damage. Elephants, being a keystone species, are also regarded as important elements in natural savannah systems as their destructive feeding habits create and maintain heterogeneity (Du Toit, Rogers & Biggs, 2003; Owen-Smith, 2006; Chongo *et al*., 2007). Despite the damage elephants do to vegetation, this is a necessary part of the development of a savannah ecosystem. Elephants open up woody areas allowing easier access to densely bushed areas thus improving the habitat for some species and in this way help to regulated bush encroachment into grasslands (Augustine & McNaughton, 2004). New palatable growth is stimulated in damaged trees at a height that is within the feeding range of smaller browsers (MacGregor & O'Connor, 2004) and nutrients are made available that would otherwise be locked away in tree bark and wood. It is when feeding becomes locally concentrated for long periods of time that vegetation damage becomes a threat to biodiversity (Dublin, Sinclair & McGlade, 1990; Birkett, 2002).

There is, however, still much uncertainty about the long-term impact that elephants in confined areas have on their environment, as the effect of such sustained damage in an enclosed system is unknown. In a literature review conducted by Guldemond (2006), it was found that most short-term studies of elephant impact on vegetation showed a decrease in the abundance of woody vegetation. However, long-term studies found that elephants resulted in an increase in vegetation abundance or otherwise no change in vegetation abundance was seen. Guldemond (2006) also suggests that elephants may affect different habitats differently. He found that elephants in Tembe Elephant Park, South Africa, enhance the spatial heterogeneity of closed woodlands while open woodlands were homogenised.

As elephants are visibly destructive, they have often been the only source of disturbance taken into account when investigating vegetation change. This has resulted in the effect of other animals being overlooked or minimised. Recent studies have shown that other browsers also negatively impact vegetation, though their exact contribution to the savannah dynamic has not yet been established (Styles & Skinner, 2000; Birkett, 2002; Augustine & McNaughton, 2004; Birkett & Stevens-Wood, 2005; Owen-Smith, 2006). Even small browsers such as steenbok, have been found to effect vegetation density by reducing the recruitment of woody seedlings (Barnes, 2001; Augustine & McNaughton, 2004; Owen-Smith, 2006). This can reduce the number of seedlings that reach reproductive maturity and over the long term reduce vegetation diversity. Browsing pressure from giraffe has also been found to have a marked effect on vegetation density and distribution with giraffe having the greatest impact at 3–5 m heights (Birkett, 2002). While they usually do not kill trees outright, they can reduce growth and make the trees more susceptible to disease, drought and other stresses (Bond & Loffell, 2001).

Elephants have traditionally been held responsible for the hedging of Mopane trees (*Colophospermum mopane*) in Botswana's Tuli Block. However, Styles and Skinner (2000) found that eland are also major contributors to the formation of hedges in the 1.5–3 m range. Styles and Skinner (2000) went as far as suggesting that the dependence of elephants on Mopane trees may have been overemphasised and that the role of other large herbivores, such as eland, is much bigger than currently recognised. In a three-year study in Kenya, Birkette and Stevens-Wood (2005) found that while elephants were responsible for 40% of the recorded tree deaths, 33% of the dead trees could be attributed to browsing by Black Rhino and 27% to drought.

Surface water availability is another important driver of ecological heterogeneity (Thrash, 1998; Chamaille-Jammes, Valeix & Fritz, 2007). Trampling and overgrazing around water points due to the local concentration of game has visible effects radiating out as far as 200 m from the water point (Thrash, 1998). The provision of permanent artificial water points has increasingly been seen as one of the main culprits for degradation of natural vegetation. By altering natural distribution patterns of watering points, impacts are moved to and/or concentrated in areas that might not be robust enough to handle the new pressure (Thrash, 1998; Leggett, 2006). This results in erosion around water points and the reduction of biodiversity, as species unable to tolerate the sustained pressure are eliminated.

The provision of artificial water points also affects the behaviour and distribution of animals. This allows water dependent animals to move into and remain in areas, which previously would only have been utilised seasonally, and in so doing alters the natural distribution and abundance patterns of game, as animals are no longer dependent on seasonally variable water sources (Thrash, 1998; Leggett, 2006). Chamaille-Jammes *et al*. (2007) found that the provision of artificial water points was a major cause of local overabundance of elephants, as they now did not need to move far in order to find food and water.

A very uniform utilisation of vegetation results if the seasonal variation in grazing pressure is no longer present. Irregular grazing allows areas of dense and tall stands of grass or shrubs to develop, and the loss of these habitats displaces organisms dependent on them. The effect of too many artificial water points has been seen in Kruger National Park where the provision of artificial water points has resulted in no area in Kruger being further that 10 km from permanent water. Little or no areas of tall stands of ungrazed grass remain. The reduction of Roan antelope numbers in recent years has been attributed to the reduction in the amount of thick stands of grass, which serves as hiding places for the altricial young of this species (Thrash, 1998).

Abundant permanent water also means less competition for this resource in especially the dry seasons, removing one of the natural checks on animal populations. As a result, water dependent animals such as elephants, wildebeest and zebra can increase to the point where the availability of food becomes the main limiting factor of population growth. This shift in environmental dependence results in food sources being over-utilised to the detriment of other organisms.

Studies in the Serengeti have shown that although high elephant density can prevent woodlands from expanding, a further external perturbation such as frequent or severe fire was necessary in order to change the vegetation over from woodland to grassland (Ben-Shahar, 1996; Dublin *et al*., 1990). Once grassland formed, elephant feeding pressure would prevent the vegetation cover from reverting back into woodland (Dublin *et al*., 1990). Skarpe (1991) found that in Botswana, *Acacia erioloba* are vulnerable to fire until their canopies are above 2-3 m. If fire occurs too frequently the woody seedlings never get an opportunity to grow out of such vulnerable height class. An increase in fire incidences can result in a reduction in the density of trees and an increase in the density of the lower height classes (Ben-Shahar, 1996). Combined with elephant feeding pressure, fire can have a far-reaching effect on woody vegetation cover.

While elephants are not solely responsible for changes in vegetation, they are acknowledged as one of the key drivers behind vegetation change. In confined areas elephant impacts must be carefully monitored to ensure that these stay within acceptable thresholds. Exceeding these thresholds can cause excessive damage to the vegetation with the resulting destruction of habitat and loss of biodiversity. This threshold of acceptable damage is difficult to determine, especially at landscape level in a heterogeneous environment. Factors such as vegetation type, animal densities, topographic features and water availability all affect the threshold of acceptable damage of a particular area. This threshold may even vary from year to year as temperature and rainfall fluctuates. The impact of elephants also depends as much on where they are, as on how many they are (Henley & Henley, 2007; Van Aarde & Jackson, 2007).

A variety of factors thus have to be considered when establishing elephant impact thresholds. It is not enough to just monitor actual elephant numbers, but the affect they have on the vegetation of the area needs to be monitored as well. Many of the impacts are cumulative with their full effect only becoming visible over a period of a few years. Long-term ecological monitoring programs are needed to assess trends in vegetation change and the stability of the ecosystem so that the full scale of the impacts can become visible. The more effective and accurate this ecological monitoring is, the better the management policies that can be implemented. Ecological information needs to be objective, economical and easily available in order for management to effectively plan environmental and economic objectives (Gorden, Hester & Festa-Bianchet, 2004).

2.3 Satellite images as a tool for environmental monitoring

Satellite sensors use reflected energy in the visible and infrared regions of the electromagnetic spectrum to produce images. For any given material, the amount of solar radiation that it reflects, absorbs, transmits, or emits varies in each wavelength. When these amounts are plotted over the wavelength range, the connected points produce a spectral signature or curve that is unique to each material (Lillesand, Keifer & Chipman, 2004; Jensen, 2005). It is this important property of matter that makes it possible to identify different objects and distinguish them from one another.

Because remote sensing devices traditionally operate in the green, red, and near infrared regions of the electromagnetic spectrum, they can be used to discriminate vegetation. Chlorophyll pigment in green-leaf chloroplasts absorbs radiation centred at about 0.65 µm (visible red) and also in the blue range (about 0.55 µm). Most vegetation has a green colour as chlorophyll reflects the green wavelengths of visible light. Green vegetation however, most strongly reflects light of wavelengths between 0.7 and 1.0 µm (near IR). As the intensity of this reflectance is usually bigger than from most inorganic materials, vegetation appears bright in the near-IR wavelengths. In multi-spectral images vegetation is characteristically dark in the blue and red bands, lighter in the green band and very noticeably light in the near-IR bands (Short, 2007). This distinctive response seen in vegetation allows vegetated areas to be relatively easily identified and analysed using remote sensing techniques and thus remote sensing, or more specifically satellite images, can be a useful natural resource management tool for gathering ecological information on a large scale at regular intervals.

Plant species richness is a key indicator of biodiversity at the community and regional scales and quantitative as well as qualitative information about plant species richness can be gathered using remote sensing. Rocchini (2007) used spectral heterogeneity of satellite images to predict species richness, which is known as the Spectral Variation Hypothesis. However, the satellite sensors currently available are limited to specific scales of investigation as spectral variability is scene and sensor dependent. Coarser resolution data tend to have mixed pixel problems and are thus less sensitive to spatial complexity. However, the spectral response from different land-cover features in images with higher spectral resolution exhibit higher complexity.

The effects of scale when measuring spectral and spatial heterogeneity and relating it to field data must be kept in mind when using satellite images (Rocchini, 2007).

Assessing the effect that environmental changes have on vegetation and thus also on animal populations, is an important component of environmental management allowing better predictions of the effects of biodiversity reduction or habitat degradation. With limited vegetation information at large temporal and spatial scales, it is difficult to discern the direct and indirect effects of environmental change. The use of Vegetation Indices such as the Normalised Difference Vegetation Index (NDVI) as a means of gathering vegetation information has to a large extent provided sufficient information (Pettorelli, Vik, Mysterud, Gaillard, Tucker & Stenseth, 2005). As ecologists become more aware of the benefits of using satellite images, their use in ecological studies has increased (Nagendra, 2001; Kerr & Ostrovsy, 2003; Pettorelli *et al*., 2005; Revenga, 2005).

While remote sensing is not perfect it is a powerful tool for identifying and classifying habitats, allowing predictions about species distribution to be made and changes from landscape to global level to be detected (Kerr & Ostrovsy, 2003). Information derived from remote sensing can be used for mapping and monitoring land cover changes, especially in the forestry sector (Jha, Goparaju, Tripathi, Ghari, Raghubanshi & Singh, 2005; Katsch & Kunneke, 2006) with vegetation degradation due to disturbances such as livestock grazing, fire, drought and anthropological impacts also being tracked (De Stoppelaire, Gillespie, Brock & Tobin, 2004; Dukiya, 2006).

Traditionally the measuring of species richness is conducted at the species level and while this provides useful information, it is spatially constrained. The use of remote sensing allows for large area characterisations of biodiversity in a systematic, repeatable and spatially exhaustive manner (Duro, Coops, Wulder & Han, 2007). A combination of direct and indirect approaches can derive four key indicators of diversity namely: productivity, disturbance, topography, and land cover. By monitoring these indicators over time at an ecosystem level, can provide an early warning system of potential biodiversity changes. Large area biodiversity monitoring systems can thus provide an initial stratification of key areas where further analysis at a local scale can be focused (Duro *et al*., 2007).

Worldwide land degradation is a serious environmental problem that needs to be monitored. The land degradation of grassland in northeast China was monitored using LANDSAT TM/ETM 6 data, the *Normalized Difference Vegetation Index* (NDVI), and variables (brightness, greenness, wetness) generated by the Kauth–homas Transforms (KT) algorithms as the feature nodes of a DT classifier. An overall accuracy of more than 85% was obtained for the distribution maps of land degradation that were generated (Chen & Rao, 2008). By choosing sensor bands sensitive to vegetation, quick, accurate and economical data sets targeted specifically at vegetation and vegetation change may be generated (Mas, 1999).

Species distribution patterns techniques using remote sensing usually fall into one of three categories. The first category is the *direct mapping* of individual plants or associations of single species in relatively large, spatially contiguous units. The second technique is *habitat mapping* using remotely sensed data, and species habitat requirements. The third category is the use of *direct relationships* between spectral radiance values and field based species distribution patterns. Direct mapping is applicable over smaller extents for detailed information on the distribution of certain canopy tree species or associations. Estimations of relationships between spectral values and species distributions may be useful for the limited purpose of indicating areas with higher levels of species diversity, and can be applied over spatial extents of hundreds of square kilometres. Habitat maps appear most capable of providing information on the distributions of large numbers of species in a wider variety of habitat types. This is strongly limited by the variation in species composition, and best applied over limited spatial extents of tens of square kilometres (Nagendra, 2001).

Further problems incurred when mapping natural vegetation using mid-resolution satellite images and conventional supervised classification techniques are: (1) defining the adequate hierarchical level for mapping; (2) defining discrete land cover units discernible by the satellite; and (3) selecting representative training sites (Cingolania, Renisona, Zaka & Cabidoa, 2004). These problems can be limited through the use of spectral information to objectively select the best training sites. Chust, Ducrot and Pretus (2004) found that as automated-classification procedures of satellite imagery are based on surface reflectance it generally ignores other properties such shape and size of landforms.

In Africa remote sensing has also been successfully implemented in a number of ecological monitoring projects. Serneels, Said and Lambin (2001) have used MODIS images to characterise short-term land cover change in East Africa. They evaluated land use, fire and livestock grazing and found that there was a strong correlation between land use and vegetation response to rainfall variability. Yang and Prince (2000) estimated canopy cover in Zambia using satellite imagery derived from the LANDSAT MSS scanner allowing changes in the vegetation structure to be monitored. Munyati (2000), using LANDSAT MSS and TM sensors, successfully tracked changes in the wetlands of the Kafue Flats.

Botswana has yielded a number of ecological studies using remote sensing with McCarthy, Gumbricht and McCarthy (2005) mapping eco-regions in the Okavango Delta. Cassidy (2007) and Moleele, Ringrose, Matheson and Vanderpost (2002) mapped the burned areas in the Okavango Delta Panhandle by monitoring bush encroachment. Baldyga, Miller, Driese and Gichaba (2007) used Landsat TM images to quantify the timing and rate of these changes in and around the River Njoro watershed located near the towns of Njoro and Nakuru in Kenya's Rift Valley. Vegetation diversity and temporal variability, common to tropical and sub-tropical areas, posed several challenges in disaggregating classified data into subclasses. Campbell, Lusch, Smucker and Wangui (2005) conducted a landscape-scale study combining the analysis of multi-temporal satellite imagery spanning 30 years and information from field studies extending over 25 years to assess the extent and causes of land use and land cover change in the Loitokitok area in the south-east Kajiado District, Kenya.

Relatively little use has been made of remote sensing in South Africa for ecological monitoring. Vegetation degradation detection and mapping using Advanced Very High Resolution Radiometer (AVHRR) data has been conducted by Wessels, Prince, Malherbe, Small, Frost and Van Zyl (2007). In the Eastern Karoo, Archer (2004) used

NDVI and rainfall data to track the effects of commercial stock grazing practices while wetlands were mapped in the Western Cape by De Roeck, Verhoest, Miya, Lievens, Batelaan, Thomas and Brendonck (2008).

While some studies have utilised satellites and GPS technology to track elephant movements (Henley & Henley, 2007), few studies have used satellite images to track elephant related vegetation change. In northwestern Zimbabwe, Murwira and Skidmore (2005) made use of NDVI data to predict elephant movements due to changes in spatial heterogeneity. They found that the presence of elephants could be reliably predicted using changes in intensity and dominant scale of spatial heterogeneity. While the study by Murwira and Skidmore touches on the use of remote sensing for monitoring elephant induced vegetation change, the full potential of this tool has not yet been recognised.

Elephant conservation areas cover large areas and are usually highly heterogeneous making accurate vegetation surveys difficult. Ground surveys, while producing reliable small-scale data, is labour intensive, time consuming, expensive and may not cover the entire area. Without an accurate vegetation map, other ecological data derived for the area will be incomplete and thus unreliable. While the use of satellite images cannot do away with the need for fieldwork, it is a useful tool for supplementing field observations and in this way can reduce both the time and manpower needed to produce results (Jensen, 2005).

2.4 Conservation management on Welgevonden

In many private game reserves the main focus is tourism and this often results in biodiversity objectives being compromised in order to meet the demands made by tourists. This short-term bias toward easy and abundant game viewing, often to the detriment of the ecological integrity of the reserve, may result in habitat deterioration over time. By taking a long-term approach towards the ecological integrity of a reserve, a dynamic and diverse ecosystem will be ensured.

Welgevonden does not rely solely on tourism and is thus able to implement a holistic and ecologically sound management plan. In accordance with current ecological management principles, Welgevonden allows natural disturbances to occur at irregular intervals and intensities. This is done so that the natural heterogeneity of the reserve is preserved rather than allowing an unnatural equilibrium to be reached. Such an approach not only ensures the continued conservation of the reserves biodiversity but also allows the specific game viewing requirements of the tourists to be met (www.welgevonden.org, 2007).

Savannahs are dynamic systems, which rely on a number of interacting influences for its natural functioning. When designing a management plan for such a dynamic system it must be realised that only certain of these disturbances can be influenced by human intervention. The fire management policy, stocking rates, water point management, distribution of salt licks, provision of extra feed, as well as the management of keystone species, are some of the ecological influences that can be managed.

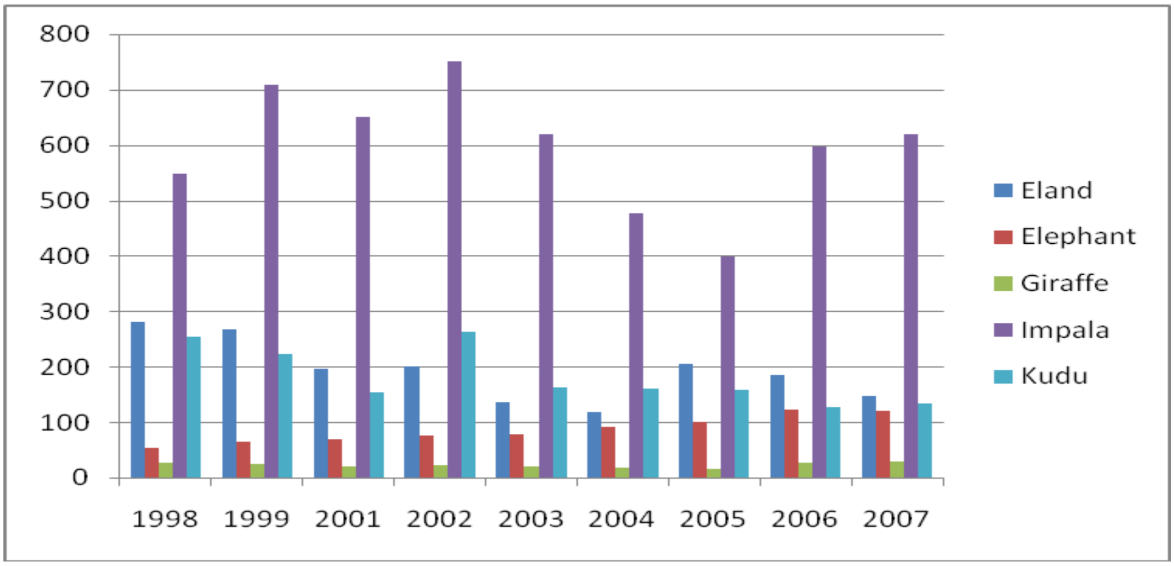


Figure 2.1 **Browser/mixed feeder numbers for Welgevonden Private Game Reserve.**

Many major game species were reintroduced onto the reserved such as lion, white rhino, buffalo sable and gemsbok. Species such as leopard, kudu, giraffe, warthog, bush pig, aardvark and pangolin were already present and have thrived since the establishment of the reserve. The number of game species has increase so dramatically that between 2001 and 2002, 300 head of game had to be removed from the reserve. However, the successful establishment of lions on the reserve has reduced the number of prey species resulting in the need to supplement the numbers of impala, wildebeest and zebra from time to time (see Figure 2.1).

Of the keystone species present on the reserve, two are actively managed, namely elephants and lions. Five lions were introduced onto the reserve with their numbers growing to 20 individuals in 2008. Similar success was established with the reintroduction of elephants with fewer than 50 being released into the reserve to a population that now stands at 120. Both these two species can cause disproportional ecological damage if their numbers are left unchecked.

While demographically viable populations need to be maintained, it is also essential that ecosystem functions be protected. This is especially true in the case of elephant as their population numbers can double every ten years thus posing a serious long-term risk to the reserves vegetation composition and structure. On Welgevonden the elephant population increased by an average of 7.7 individuals per year as seen in Figure 2.2.

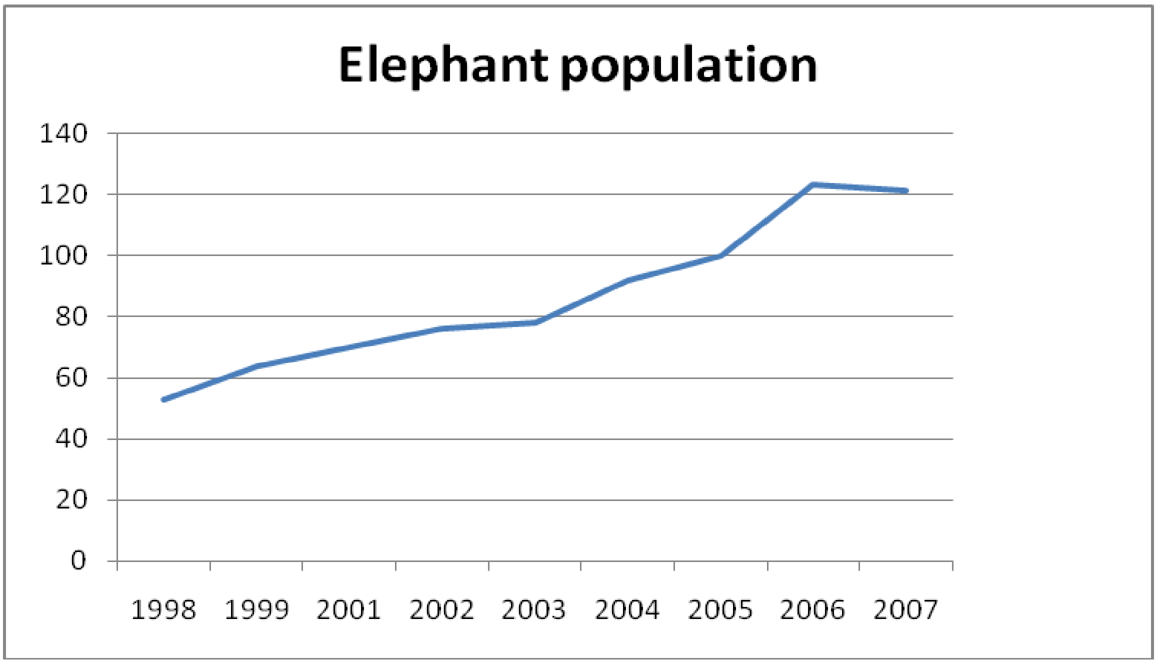


Figure 2.2 **Elephant population growth on Welgevonden Private Game Reserve**

Some of the elephant management strategies undertaken include the translocation of excess animals and the use of immunocontraception to reduce the population growth. Elephant translocation is expensive and there are only a small number of reserves to which excess elephants can still be relocated. The use of a contraceptive vaccine such as *porcine zona pellucida* (pZP) is highly effective, safe and most importantly in an endangered species, reversible. Welgevonden has also undertaken laparoscopic vasectomies on some of their bull elephants as part of their population control measures.

If lion populations are left unchecked, severe pressure is put on prey populations. As lions in protected areas breed fast and have a high survival rate due to lack of competition, their numbers need to be artificially managed. At Welgevonden, excess lions have been translocated, but, as with elephants, the number of reserves able to absorb excess lions is limited. While contraception and culling are further population control options, they are controversial and not always effective. The current control method being tested at Welgevonden is the introduction of natural control measures. In natural lion populations, there is a high turnover rate of pride males and the new pride males usually kill any cubs present in the pride, decreasing the cub survival rate (Bothma, 2002). By increasing the ratio of male lions to females, it is hoped to recreate competition for pride control and thus decrease cub survival.

The fire management policy of Welgevonden follows the relatively new and controversial fire management strategy of allowing lightning fires to burn naturally. Traditional fire management policies require burning of designated blocks at predefined intervals with all other fires actively controlled. While this method is easy to manage, it can result in large areas of very homogenous habitat. By allowing more natural fire behaviour and more natural fire intervals, a heterogeneous patch-like habitat is created.

The encroachment by unpalatable trees and woody species is referred to as bush encroachment. Not only does this reduce the productivity of savannahs by decreases the grazing capacity, but also it increases transpiration, which lowers the soil moisture. Overgrazing by domestic livestock is one of the major causes of bush encroachment in South Africa as livestock graze the same pasture continuously and farmers actively manage natural fires. The reduced grass cover resulting from livestock grazing and also trampling further limits fire intensities on cattle farms. These alterations to the natural fire and grazing regimes favour the spread of woody species into grasslands. The removal of browsers, such as giraffe and elephants, further exacerbates this situation. The reintroduction of herbivores and the return to more natural fires regimes on game reserves has seen a return to a more natural grass/woody plant balance. To prevent bush encroachment, animal numbers, both domestic and wild, have to be managed according to changing vegetation conditions and not preconceived stocking rates. Management strategies have to be implemented that maintain the fine balance between fire frequency/intensity and stocking rates in mind (Hudak, 1999).

Welgevonden has four basic habitat types, three natural and one due to human interference. Mixed *Burkea africana* woodland, *Burkea africana* open woodland and Rocky plateau open woodland occur naturally while historic land use is still visible in the form of old lands. Bush encroachment by woody species such as *Stube vulgaris* and *Dichrostachys sericea* is seen in some areas of the reserve and bush clearing activities forms part of the reserves management plan. The old lands are also actively manipulated to provide much needed year-round forage and is thus managed to enhance grass productivity and palatability. It is hoped that by attracting large numbers of herbivores to these areas highly productive grazing lawns will become established. This will have a number of benefits for the reserve, such as making the game populations more visible and predictable, and reducing the grazing pressure on the less robust areas of the reserve.

2.5 Conclusion

While the African elephant is globally an endangered species, their numbers in many of South Africa’s protected areas are growing at an alarming rate. It is important to find the balance between maximum elephant numbers and minimum ecological damage as high elephant numbers can cause serious damage to vegetation. In order to find this balance, managers of protected areas need sound ecological data on which to base management decisions.

A factor complicating elephant management is the fact that ecosystems are shaped by many environmental factors with no one factor being solely responsible for any changes. In savannahs, disturbances such as water availability, fires, rainfall and browsing/grazing by herbivores all play a role in maintaining the habitat heterogeneity. Habitat heterogeneity is an important buffer for fluctuations in resource availability. However, there is a thin line between creating heterogeneity and causing habitat degradation.

Feeding pressure by elephants is one of the most obvious disturbances seen in Southern African savannahs as it produces very visible vegetation damage. The destructive feeding habits of elephants are an important part of the development of a savannah ecosystem. It is only when elephant damage becomes locally concentrated for long periods that it becomes a threat to biodiversity. There is much uncertainty about the long-term impact that elephants in confined areas have on their environment. Most short-term studies show a decrease in woody vegetation as a result of elephant damage, while long-term studies have found that elephants result in an increase or otherwise no change in vegetation abundance.

Other browsers also negatively impact vegetation with even small browsers such as Steenbok, affecting vegetation by reducing woody seedling recruitment. The availability of surface water is another important ecological driver with the provision of artificial water points affecting the behaviour and distribution of animals. Frequent or severe fire is also important to limit the spread of woodlands into grasslands.

A variety of factors thus have to be considered when monitoring elephant impacts in confined areas. As the effect of many of the impacts only becoming visible over a period of a few years, there is a need for long-term ecological monitoring programs. Effective and accurate ecological monitoring is required in order for managers to effectively plan environmental and economic objectives for elephant conservation areas.

Assessing the effect that elephants have on vegetation is an important component of environmental management allowing better predictions of the effects of biodiversity reduction or habitat degradation. Remote sensing is a tool that has been extensively used in America and Europe for environmental monitoring applications. As ecologists have become more aware of the benefits of using satellite images, their use in ecological studies has increased. Information derived from remote sensing can be used for mapping and monitoring land cover changes and tracking vegetation degradation.

In Africa, remote sensing has also been used in a number of ecological monitoring projects. These have ranged from characterisation of short-term land cover change in East Africa to estimating canopy cover in Zambia, as well as monitoring changes in the wetlands of the Kafue Flats. However, relatively little use has been made of remote sensing in a South African context. Vegetation degradation has been detected and mapped in Limpopo while in the Eastern Karoo, NDVIs were used to track the effects of commercial stock grazing, and wetlands were mapped in the Western Cape.

Almost no work has been done in using remote sensing to monitor elephant induced vegetation change. Some studies have used satellite images to track and predict elephant movements but the full potential of this tool in this field has not yet been recognised. Elephant conservation areas cover large areas and are highly heterogeneous making ground surveys labour intensive, time consuming, expensive and may not cover the entire area. Using satellite images does not exclude the need for fieldwork, as satellite imaging is a useful tool for supplementing field observations and will reduce the time and manpower needed to produce results.

Chapter 3
METHODOLOGY

3.1 Introduction

Remote sensing provides an economical means of assessing land cover and the changes happening across large heterogeneous areas. Observations provided by remote sensing cannot only be frequently repeated but also provide historical observations of most parts of the earth. This significantly improves the quantity of the available environmental data thus improving the quality of the final conclusions based on that data. The use of satellite remote sensing data is ideal for vegetation studies, as most earth observation satellites have been designed for land cover/land use studies. Due to the unique spectral reflectance properties of vegetation, a quick, accurate and economical data set may be generated that is targeted specifically for vegetation change. Furthermore, satellite images are associated with geographical coordinates allowing these images to be used to extract spatial data with Geographical Information Systems (GIS). However, it must be noted that satellite images cannot do away with the need for fieldwork but is merely an added tool for obtaining a good understanding of the ecosystem processes taking place.

3.2 Methods and processes

The overall aim of this study was to examine the utilisation of satellite images as a tool for the detection of elephant induced vegetation change patterns. In order to achieve this aim, the following basic steps, as outlined in Figure 1.2, were used:

- The data needed for the study was gathered. This included the satellite imagery, vegetation maps produced from that imagery, rainfall data, GIS shape files showing the distribution of water points and fires, as well as annual animal census data.

- Vegetation change detection maps were produced using the satellite images in the Image Processing software program, ERDAS Imagine 9.2.
- Making use of the change detection maps, the effect that the distribution of water points and fires has on the vegetation was assessed. This spatial analysis was done ArcGIS 9.3 and resulted in areas of vegetation change uncorrelated to the above disturbances to be identified. Maps of these uncorrelated areas were produced by masking out the areas affected by water distribution and fire on the change detection maps, leaving only the uncorrelated changes visible.
- The large herbivore and elephant population trends and weather data were then used to examine the areas of uncorrelated vegetation change identified in the previous step. The percentage and the distribution of these changes were compared to the census and weather data in order to identify any correlation between the data sets.
- The extent and distribution of vegetation change that may be attributed to elephant damage was then assessed.

For the purposes of this study only the basic vegetation communities present in the study location area will be identified, as the criteria used for establishing vegetation change will be changes in the density of woody vegetation rather than changes in species composition. It was assumed that changes in the density and distribution of the woody vegetation communities would be a reliable indication of elephant induced vegetation change on the reserve.

3.2.1 Data

For this study, a time series of LANDSAT Thematic Mapper multispectral satellite images (LANDSAT TM) were used as the basis for the thematic maps created of the study location area. The LANDSAT TM sensor produces medium resolution images with seven bands ranging in wavelength from 0.45 micrometer (µ) to 2.35 µ with four of the bands falling in the infrared part of the spectrum. Band 1 of LANDSAT TM is not only good at detecting features in water, differentiating between soil and vegetation and distinguishing between forest types but it also enables natural colour images to be produced. Band 2 and 3 are good for vegetation analysis, as healthy green vegetation is picked up well by Band 2 with Band 3 detecting the amount of chlorophyll absorption. Band 4 detects near-IR reflectance, which is the part of the electromagnetic spectrum most strongly reflected by healthy green vegetation. Variations in moisture content can be detected using Bands 5 and 7 while Band 6 can distinguish temperature difference of as little as 0.6°C. When combining Bands 4, 3 and 2, a colour infrared composite image is produced which highlights vegetation in shades of red, the brighter the red the more vigorous the vegetation. Areas appearing green or brown have little vegetation cover with soils appearing light.

While other satellite images are available that have a higher resolution, they have less bands available which reduces the amount of data available for distinguishing vegetation types. As this study is focusing on broad vegetation patterns and not detailed species analysis, images of greater spatial resolution but reduced spectral resolution were felt to be unnecessary. A further advantage of using LANDSAT TM images is the large amount of archived images available. This sensor, carried on board of both LANDSAT 4 and 5, has been acquiring images from July 1982 and is still in operation today.

LANDSAT TM images of Welgevonden were acquired at two yearly intervals from 1993, when Welgevonden was established, until 2007. A two-year interval was chosen as being long enough for changes in vegetation distribution to become visible but short enough that the effects of the individual ecological influences are not lost. Unfortunately due to excessive clouds on some of the images and unavailability of other images suitable for digital analysis, no images were used for the years 1997 and 2003 with visual analysis of sections of the reserve being done for 2001. For this study, summer images were used as the deciduous vegetation is in leaf giving the best indication of changes between woody vegetation and grasslands and reducing the chances of underestimating woody vegetation cover.

Other data that was used included a 20 m Digital Elevation Model (DEM), statistical data and vector datasets. A DEM is digital representations of the elevation variations of the earth surface in other words, the topography. The DEM used in this study is a raster showing the height values at 20-meter intervals across the entire area. Figure 5 is a Hillshade model of the DEM showing the rugged topography of the reserve. In rugged areas such as Welgevonden, the effect that the topography has on the spectral signatures of the images needs to be normalised in order for the images to be correctly analysed. For this reason a DEM was needed to perform topographic normalisation in ERDAS Imagine 9.3.

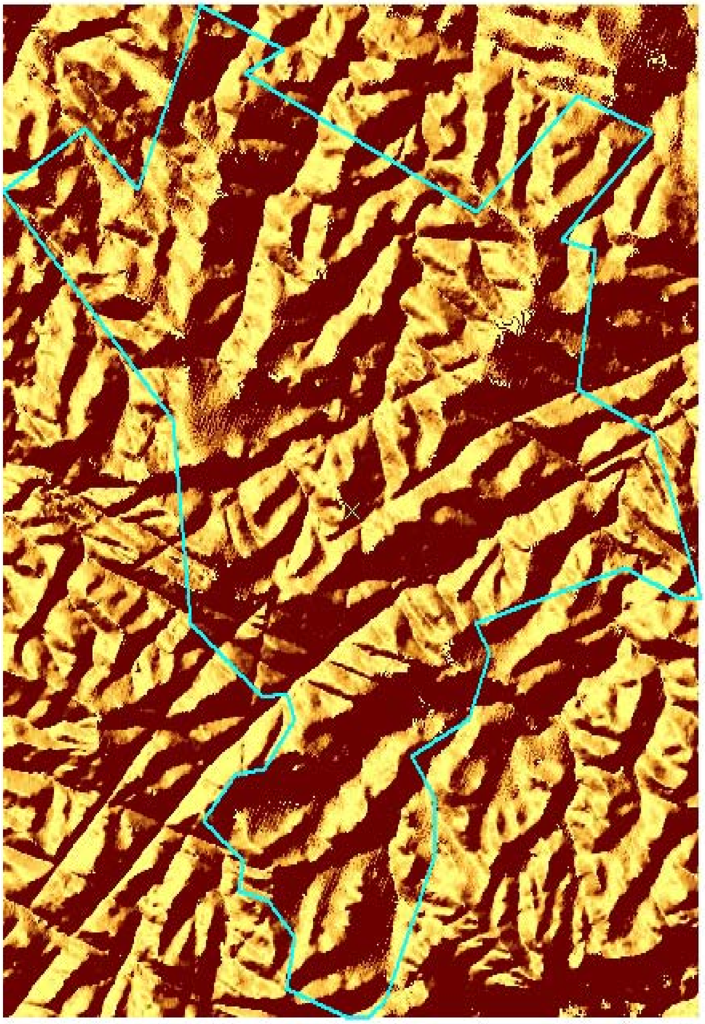


Figure 3.1 **Hillshade model of the topography of Welgevonden Private Game Reserve** (illimination source from the north west)

The vector datasets that were available was annual fire data and the latest vegetation map produced by Welgevonden. Digitising them from the LANDSAT TM images produced a Shapefile layer of the major water points. Welgevonden has conducted a vegetation survey from which the major vegetation types of the reserve were mapped. This data was used as the basis for the class selection for the classification process. Annual fire data was also available in the form of shapefiles that show the position and extent of each recorded fire since 1995. Census data for all of the large herbivores and most of the small herbivores was available from 1998, which could then be used to track animal population trends. A final data set, the annual rainfall data from January 1993 until December 2007, was obtained from the South African Weather Service.

3.2.2 Pre-processing

Before digital image processing of remotely sensed images can take place, the data needs to be corrected for inherent flaws and deficiencies. To correct these distortions, pre- processing of the images need to take place though the amount of pre-processing done will depend on the type of image, severity of the distortions and the information that needs to be extracted from the image. Digital images generally need to be corrected for geometric, radiometric and atmospheric distortions (Lillesand *et al,* 2004 & Short, 2007).

In mountainous areas such as Welgevonden, it is often the case that the spectral responses of objects vary due to differences in illumination and sensor angle that result due to topographic variations. The spectral response of objects is used to group pixels with similar responses into thematic classes for digital classification. When the spectral response of an object varies over the image, the software may see it as different objects thus causing the same object being classified into more than one class. To ensure an accurate classification all the images need to undergo topographic normalisation so that variations in illumination and angle can be standardised. This was done by means of the ERDAS 9.2 Topographic Normalisation tool using the information in the image header file to fill in the sun angle and elevation, as well as the 20m DEM for the reserve.

The satellite images were already georeferenced and in the correct coordinate system, but further geometric corrections were still needed. One of the difficulties of using an image that coves a large geographical area is dealing with the distortions resulting from sensor movement, earth rotation and the curvature of the earth. These distortions may result in slight geometric inconsistencies across the images resulting in the images not lining up accurately with one another. These slight offsets are usually not a problem when only a single image is to be used but as soon as more than one dataset needs to be digitally compared, these offsets can cause errors in the final analysis. To correct these errors, the images were registered to each other in ENVI 4.5.

Before the image-to-image registration was performed on the normalised images, they were subset into smaller images that only showed the area reserve and immediate neighbours. This was done to ensure quicker computing and for a more accurate local registration. The 2007 image was used as the base image throughout the process with all the other images registered to it. Thirty ground control points that are clearly visible on all the images were selected on the base image and then matched in each of the other images. Once a Root Mean Square Error (RSME) of less than 0.3 was given the images were warped to match the base images. The RMSE is an indication of the accuracy of the registration with an RMSE of 0.3 (pixels) for a LANDSAT TM image being an accuracy of ± 10 meters.

Subsets of the registered images were then created showing only the area covered by Welgevonden Private Game Reserve. Using a Shapefile of the boundary of Welgevonden, the reserve was “cut out” of the registered LANDSAT image. Using subsets allows only the area of interest to be used for further visual and digital analysis. This makes for easy identification of the specific area of interest, as well as a saving on disc storage space and computing time.

Before starting the digital analysis of the subset images, a check was done to ensure that all geometric distortions had been accounted for. It was found that most of the mountainous areas to the north of the image lined up well, yet there was still some distortion present in the flatter areas in the south. A second image-to-image registration was done in order to correct these distortions.

3.2.3 Classification

It is essential to have good vegetation maps for the time period under investigation in order to accurately monitor elephant induced vegetation change. Using satellite images, it is possible to create such maps for the entire reserve at different points in time using archived images and digital image classification techniques. Digital image classification works on the principle of identifying the spectral response of the objects of interest and using these spectral responses to assign the image pixels to the relevant classes.

Due to the cellular structure of leaves vegetation absorbs most of the red and blue wavelengths in the visible spectrum but moderately reflects the green wavelengths and has a very strong reflectance in the near-infra red (NIR) portions of the electromagnetic spectrum. For this reason vegetation can be relatively easily identified using red and NIR bands. While the general reflectance pattern is true for all green vegetation, it is possible to distinguish between different vegetation types through spectral variations resulting from physical differences such as leaf shape, size, orientation and water content. The spectral responses of most inorganic materials are very distinct from vegetation making it possible to distinguish accurately between such object types (Lillesand *et al,* 2004 & Short, 2007).

However, in practice it is very difficult to classify specific objects or features as they may form part of a number of different types of structural units or may themselves consist of a number of different materials. The pixel size of the image may also limit the accuracy with which specific objects can be identified. For this reason, most images are classified into broader classes made up of similar objects/features. For example, a woodland may be made up of a number of different tree species and even individual trees of the same species may differ due to factors such as water availability, presence/absence of flowers or even the number of birds roosting in the tree at the time the image was taken. How fine the classification subdivisions are will depend on the imagery being used, the information that needs to be obtained from the image and the skill of the analyst.

The two basic methods of digital classification is unsupervised and supervised classification. For an unsupervised classification, the user defines the number of classes desired and the software then sorts the pixel values into the defined number of statistically similar groups. This method is a good way of seeing how the land cover behaves statistically, thus giving the analyst a good idea as to how the various objects of interest will be differentiated by the software. However, as this study is interested in vegetation communities and not individual vegetation types, it was decided that this method was not suitable as the final classification product.

Supervised classification, on the other hand, makes use of user defined training areas to characterise the spectral responses of all the objects in that area to produce a signature for that specific class. In this way a class can be identified that contains more than one land cover type and using this derived signature, the software identifies other areas that fall within the same range of responses. Ideally when undertaking a supervised classification, ground reference data for the different training areas should be collected, but the use of historic images makes it impossible to collect reference data for each image. It is thus necessary to use other data sources, such as vegetation indices, to accurately identify the different vegetation classes (Lillesand *et al,* 2004 & Short, 2007).

For this study, both the Tasselled Cap and NDVI (Normalised Difference Vegetation Index) analyses were run to establish the separability of the various vegetation communities as identified by the existing large-scale vegetation maps for Welgevonden. The Tasselled Cap transformation has been developed to optimise data viewing for vegetation studies by producing three basic data structure axes. These axes define the vegetation information content into Brightness, Greenness and Wetness. For sensors with a large number of bands, such as LANDSAT TM, three additional axes are defined: Haze, Fifth and Sixth (Dymond, Mladenoff, Radeloff, 2002 & Huang, Wylie, Yang, Homer & Zylstra 2002). A NDVI is the ratio between the red and infrared reflectance of an image. Because vegetation reflects infrared very well but absorbs most of the red wavelength, this ratio highlights vegetation well. Using the images generated by these two processes, the best representative sample of the vegetation types were found and converted to Areas of Interest for later use as training sites.

As this area is fairly heterogeneous, a number of different images were attempted to identify the best base image to use to obtain the most accurate vegetation classification. The pre-processed LANDSAT images were classified along with the NDVI and Tasselled Cap images and a three band infrared composite of the satellite image consisting of the red, near Infrared and mid infrared bands (bands 4, 5 & 7). These images were used in a maximum likelihood supervised classification to produce vegetation maps. Due to the large amount of variation seen in the vegetation types across the image, a number of similar classes were created in order to accurately classify the desired vegetation types. These classes were then merged to produce the simplified vegetation map with the following land cover classes:

- Bare earth – exposed soil and rocks including roads and airstrips;
- Water – open water, mainly dams;
- Grassland – dry grassland with some exposed soil;
- Woody grassland – mixture of dry grass and scattered woody vegetation;
- Riverine/Dense Woodland – dense, vigorously growing trees mostly along the streams;
- Open Woodland – woody vegetation interspersed with grass;
- Woodland – woody vegetation with little/no open areas;
- Fire Scars – recently burnt areas with sparse green grass and woody vegetation. Fire scars were only visible in some of the images, but were distinctive enough from the rest of the vegetation to warrant their own class.

3.2.4 Change detection

While vegetation maps allow general trends in vegetation cover to be identified, in order to examine the effect elephants are having on the reserve, more specific information is needed about what, where, how much and finally why changes are occurring. It is necessary to know what the changes are, where they are happening and how big these changes are in order to answer the question of why change is happening. This information can be gathered using digital change detection.

Digital change detection analysis covers a large range of techniques to identify, describe and quantify the changes taking place between images of the same area at different times. Change detection can be done using classified or single-band images. The change detection method used in this study was Image Differencing that uses single-band images to produces an image that characterises the differences between a pair of before and after images. This method uses the reflectance values of corresponding pixels between two images to identify the amount of change that took place between the two images. As different objects reflect radiation differently, changes in reflectance value would indicate changes in land cover. This difference is computed by subtracting the value of each pixel in the initial image from the corresponding pixel value in the final image with the output defined by user defined change thresholds. A positive change identifies pixels that have shown an increase in reflectance, namely the after image was brighter than the before image, while a negative change identifies pixels that have shown a decrease in reflectance. As the values of matching pixels are compared it is essential that the image properties are as similar as possible (Song, Woodcock, Seto, Pax Lenney, & Macomber, 2001).

For the most accurate change detection results, it is essential that the images are accurately coregistered to avoid misalignment errors. This is due to the fact that change detection works strictly on a pixel-for-pixel comparison. If incorrect pixels are compared with each other then any change detected will be a result of misalignment rather than actual changes on the ground.

It is also important to take into consideration other factors that can cause differences in the reflectance values for scenes of the same area. One of the most important factors is the differences in the sensor. Differences sensors will have different band values, as even those bands collected over the same part of the spectrum may have different wavelength ranges. These differences can result in different pixel values even for the same material. Comparing images with different spatial resolution will also lead to false changes being detected. It is thus important that the images being used have the same pixel resolution.

The collection date and time will also influence the reflectance values of materials. Seasonal changes not only impart the appearance of vegetation but differences in the season and time of day will also alter the solar azimuth and elevation causing changes in the amount of solar radiation a spot receives and thus reflects. Changes in atmospheric conditions will affect atmospheric transmission and scattering of solar radiation. In many cases these changes can be associated with seasonal changes, which may affect for example the water content in the atmosphere. The presence of pollution or haze may also influence the reflectance values of a scene.

The user can define the change threshold representing the amount of change between the two images that is detected. The minimum number of classes that can be specified is two, although generally a minimum of three is used; the first class representing positive changes, the middle class representing no change and the final class representing negative changes.

In ERDAS Imagine, two images are produced as an output for this process, a difference image and a highlight image. The difference image is a panchromatic image that has bright values where the two images were different and dark values where they were nearly the same. The user also defines a threshold value and any pixels that do not fall within the limits of this threshold are set to black or unchanged. The highlight image only assigns colours to pixels that fall within the threshold values in order to indicate the magnitude of the changes between the two images.

This analysis was run on selected bands of the satellite and Tasselled Cap images. The images used were as near to anniversary images as possible and had been topographically normalised and co-registered. These factors as well as obtaining all the images from the same sensor was done to ensure that the change detection was as accurate as possible. Using Tasselled Cap images for the change detection gives a very good indication of the changes in vegetation cover happening over time while the satellite images results in overall land cover changes being seen. By doing a change detection analysis on both these data sets allowed any changes other than vegetation changes to be identified.

For both data sets, an analysis was firstly run on the first and last image in the data set (1993 & 2007) to establish the overall changes that have taken place. Then the first and second images (1993 & 1995) where compared followed by 1995 and 2005 and then 2005 and 2007. The 2001 image was unsuitable for digital change detection due to the amount of cloud cover seen (around 40%) but enough of the ground area was visible that it was feasible to use this image for visual change detection with the 1999 and 2005 images.

The default value of 10% or more increase/decrease in reflectance was used as the starting value for all change detection sets. This resulted in a very broad range of changes being highlighted but also gave a good indication of the general trends. A second change detection was then run using 20% or more increase/decrease and finally a 30% or more increase decrease was run. Where necessary further change detection processes were run. For the satellite images, bands 4, 5 and 7 were each used for these change detection analysis as vegetation has a high reflectance in these infrared bands and any changes in vegetation cover will be highlighted when using these bands. Band 3 of the Tasselled Cap image was used, as this band correlates well with the amount of green vegetation present in an image.

3.2.5 Correlation analysis

While the above analysis gives information on what changes are occurring, where they are happening and how big they are, the question of why these change are happening still needs to be answered. Using the information derived from the image analysis processes in conjunction with the available statistical and vector datasets the correlation between the areas of change and known disturbances will be assessed.

The primary effect of fires on the reserve is an obvious disturbance that is easily identified using the available GIS data layers. In ArcGIS 9.3 the annual Shapefile layers of the fires that took place on Welgevonden were used to identify the areas affected by fires. Each satellite image was overlaid by the fire layers of the three years preceding the date that the image was taken. Added to these layers was the 20% change detection image for the time period covered by the fire layers so that the correlation between the fires and areas of change could be established. The 20% change detection image was used for the fire analysis as it showed the strongest correlation with fire damage compared to the 10% and 30% change images. Finally a mask was constructed of areas where the fire layers and areas of change intersected.

A Shapefile layer of the water sources in the reserve was constructed by digitising the water bodies identified on each of the Tasselled Cap images. As the effects of trampling and overgrazing around water sources are known to radiate out from the water source a 500m buffer created around these points to identify any direct effects of these water sources. This layer was then added to the change layers and a mask created for the areas of intersect.

Once the primary effect of the known disturbances was identified, areas of change not accounted for by the above factors was identified and investigated further. The secondary effect of fires and water points, as well as the effect of rainfall and grazing pressure that is more difficult to identify. It was assumed that these effects would be more dispersed and less prominent and use was made of the 10% change detection images to identify their effect. It was further assumed that the effect of rainfall would be fairly evenly spread across the reserve while grazing pressure would have a more erratic distribution. The change detection images were visually assessed in conjunction with the annual rainfall data to identify any trends between the two data sets. The same method was used with the census data for large herbivore assessed and the correlation between the vegetation changes seen and these data sets.

By using all the data gathered through the above processes the possible effect of elephants on the vegetation of Welgevonden could be analysed. Making use of the vegetation cover maps created, the changes in the vegetation types could be used to identify areas of possible elephant damage. Elephants are mixed browsers and grazers but have the most visible effect on woody plant species. By identifying areas of change in woody plant cover and by correlating them to known disturbances, uncorrelated areas can be identified as areas of possible elephant induced vegetation change.

3.3 Conclusion

While it is beyond a doubt that elephants modify their environment, the long-term effect of these changes is still in question. In order to answer this question studies over the medium- to long-term need to be conducted. However, managers of protected areas need data immediately in order to address current problems and to prevent undesired and possibly irreversible vegetation change. It is here that the use of remote sensing can be a useful tool for providing historic data for an area. By making use of archived satellite images in conjunction with current images, vegetation change information covering a long time period can be gained.

Various digital image classification and analysis techniques can be employed to extract vegetation data over a large area. While an NDVI is a good measure of vegetation vitality, its sensitivity to moisture gradients makes it unreliable as a classification source. The use of Tasselled Cap transformations and composites of the infrared bands offers more accurate classifications. With all classifications it must be remembered that the study location covers a large area and a fair amount of variability is expected even in the same vegetation classes. This needs to be taken into account.

Once the vegetation cover is known, changes in the vegetation composition can be traced. While visual detection of changes is a quick way of getting a general overview, this method can be subject to viewer bias and be time consuming if detailed changes are to be identified. The use of digital change detection can help to highlight areas of change thus focusing the attention on areas of change rather than over the entire area. Due to the high infrared reflectance of certain soils, the use of the infrared bands of the images for the digital change detection could be inconsistent. The Green band of the Tasselled Cap transformation allows a more accurate vegetation change/no change analysis to be made.

Elephants are not considered to be the only agents of vegetation change. The effect of other disturbances must also be considered. By making use of GIS techniques the impact of various disturbances such as fire could be evaluated. By providing a more holistic picture of the contributions of elephants and other disturbances towards vegetation change, long-term satellite data enables managers to make informed and accurate decisions. It will also allow managers to have a better understanding of the carrying capacity of their reserves and to establish realistic thresholds of damage.

Chapter 4
ANALYSIS OF RESULTS

4.1 Introduction

The overall aim of this study was to examine the utilisation of satellite images as a tool for the detection of elephant induced vegetation change patterns. For the purpose of this study only the basic vegetation communities present in the study location area was identified, as the criteria used for establishing vegetation change was changes in the density of woody vegetation rather than changes in species composition.

4.2 Classification

An accurate classification of the vegetation in the study area should form the basis of any vegetation change study. Table 4.1 provides a comparison of the vegetation classes identified through vegetation surveys and the simplified vegetation types that were identified using the satellite images. A large-scale vegetation map based on vegetation surveys conducted by Welgevonden (see Figure 4.1) was available and used as the starting point for the identification of the various vegetation types on the satellite images.

It was found that the classes shown in the Welgevonden vegetation survey was too broad to be easily correlated with the vegetation seen on the satellite images. The Welgevonden vegetation survey classes mainly take into account the woody species composition and disregard vegetation density and land cover such as bare patches of soil. As this study was carried out to track changes in the vegetation cover as well as density, these broad generalised classes do not contain enough detail to be of use for vegetation change detection.

The resolution of the satellite images and the lack of comprehensive ground survey data made it very difficult to classify the satellite images into species-specific classes. For this reason it was decided to produce a hybrid vegetation/land cover map that focuses on woody vegetation density rather than composition. Further considerations were the spectral separability of the classes, as well as the vegetation types most likely to be affected by elephants.

Table 4.1 **Comparison of the Welgevonden vegetation survey classes and the simplified classes of the supervised classification**

Welgevonden vegetation classes	Simplified vegetation classes
• Northern grasslands • Central grasslands with associated termite mounds • Southern grasslands • Western grasslands • Rocky plateau open woodland • *Burkea africana* open woodland: *Faurea saligna* subcommunity • *Burkea africana* open woodland: *Terminalia sericea* subcommunity • Mixed *Burkea africana* woodland: *Englerophytum magalismontanum* subcommunity • Mixed *Burkea africana* woodland: *Diplorynchus condylocarpon* subcommunity • Mixed *Acacia caffra* woodland	• Grassland • Woody grassland • Rocky open woodland • Riverine vegetation • Open woodland • Woodland

As the accurate classification of this fairly heterogeneous area was an important component of this study, time was spent to find the best base image to use for the vegetation classification. The following images were all classified, namely the satellite image, NDVI, Tasselled Cap images and the three-band infrared composite (bands 4, 5 & 7). The training sites for each year were saved as AOI files allowing the same training sites to be used for each image type, thus reducing any user error in defining training sites. All these images were classified using a maximum likelihood supervised classification. The Mahalanobis distance classifier gave almost identical results to the maximum likelihood classifier with the minimum distance classifier being the most inaccurate.

Figure 4.1 **Vegetation map of Welgevonden Private Game Reserve**

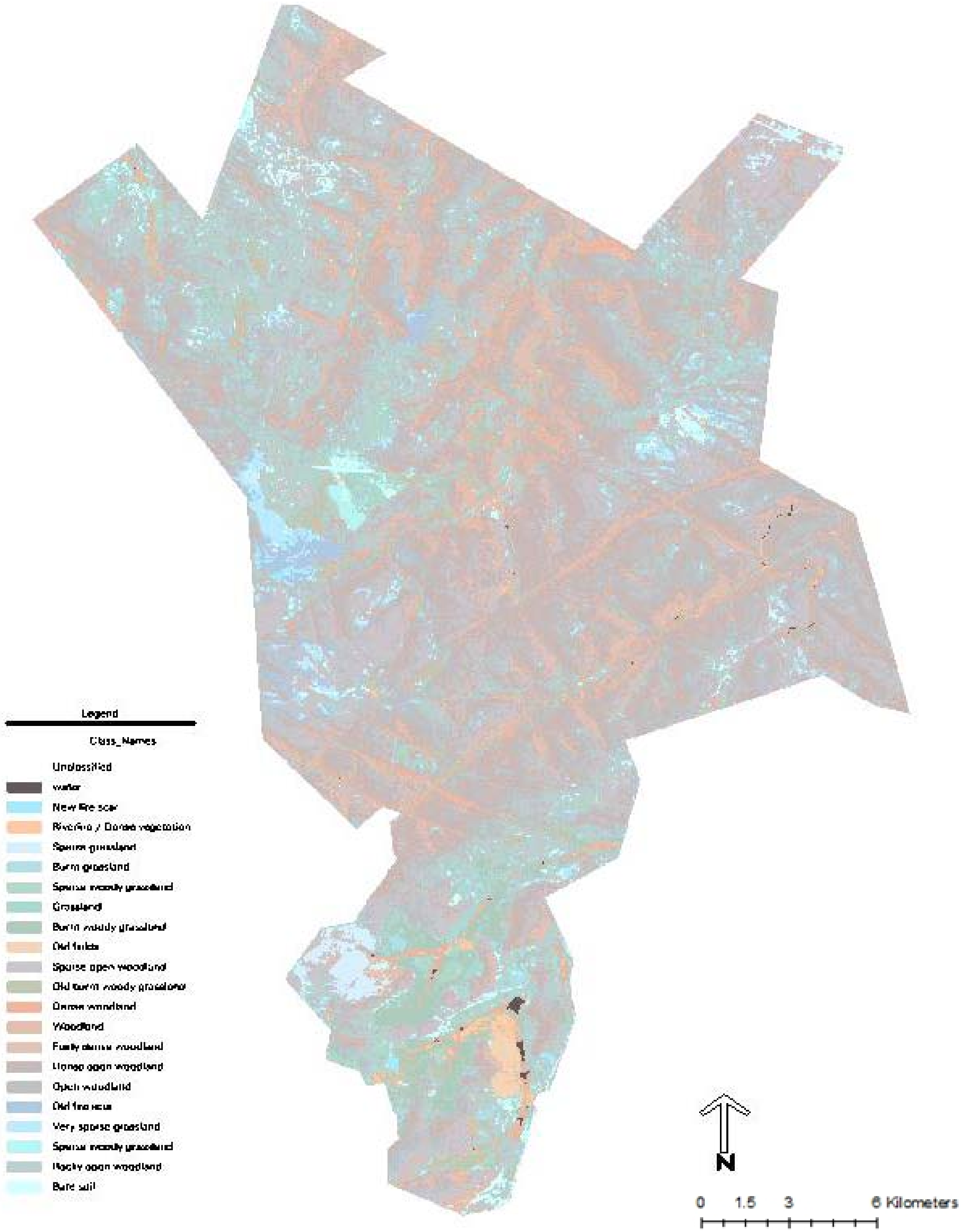


Figure 4.2 **Supervised classification of the land cover of Welgevonden Private Game Reserve: 2007**

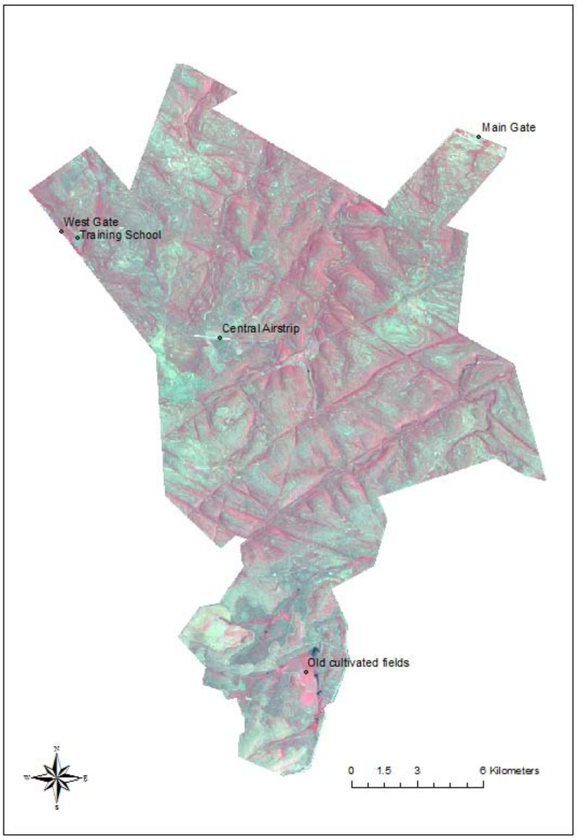


Figure 4.3 **LANDSAT colour infrared image of Welgevonden Private Game Reserve: February 2007**

Of the four datasets used for the classifications, each classified certain features more accurately. The NDVI produced the least accurate classification, as it proved too sensitive to changes in soil moisture. This was not only a problem on individual images but, when using images where gradients in soil moisture was present, similar land cover types got classified into different classes. Using a Tasselled Cap image produced the most consistent woody vegetation classification but gave unreliable results where areas of grassland, sparse grassland and bare soil intersected these woody vegetation classes. The seven band LANDSAT images producing the most accurate general land cover classification but could not reliably distinguish between some areas of woodland and open woodland. The infrared composite gave a consistent classification of both land cover and vegetation and were the vegetation maps used for further analysis. Figure 4.2 shows the classification product of the 2007 three-band LANDSAT composite before being generalised as it compares with the original colour infrared LANDSAT image presented in Figure 4.3.

Certain classes were difficult to consistently classify from year to year. Fire scars is a good example of this, as in some years they are readily visible and accurately classified while in other years they are not easily distinguishable from other vegetation classes. The old fields also differed markedly from year to year. In some years the old fields were covered with vigorously growing green vegetation and in these years proved to be impossible to spectrally distinguish from dense woodland. In other years, the vegetation on the fields was sparse with open soil, and in these years they could be classified accurately into their own class.

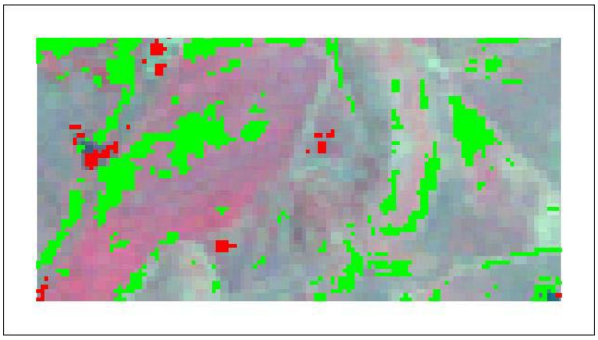
Of the land cover classes identified, bare earth/roads and water proved to be the easiest to classify accurately while riverine vegetation and very dense woodland, as well as other vigorously growing vegetation could not always be easily separated. Woody grassland and open woodland, as well as open woodland and woodland were difficult to distinguish accurately as the transition zone between these vegetation types is usually very gradual and thus not clearly distinguishable. To get around this classification difficulty, the first classification divided these difficult classes into a number of classes with graduating vegetation density. These graduating classes would then be merged into the final vegetation class that would produce the most accurate classification. Special care was taken to ensure that the open woodland and woodland classes were as accurate as possible, as these were the classes considered to be the most vulnerable to elephant induced vegetation change.

Visual comparison of the final vegetation maps showed that while on certain areas of the reserve, woodland has disappeared completely or decrease in density to open woodland, the most notable change over the years is the increase of open woodland into areas previously classed as woody grassland and an almost complete decrease in pure grasslands as these areas are transformed into woody grassland.

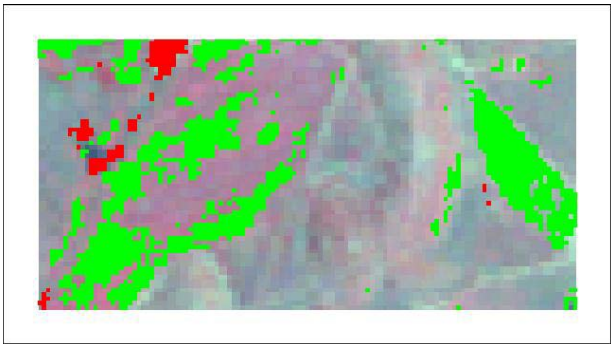
4.3 Change detection

As with the classification the change detection analysis was run on a number of datasets, namely the three infrared bands of the satellite images and the Greenness band of the Tasselled Cap images. It was found that by using the Tasselled Cap images, vegetation change was more accurately highlighted. The change detection analysis run on the images was a basic change/no-change analysis with various change thresholds being used. Using this method in conjunction with the visual change detection using the vegetation maps, allows for a good basic understanding of the amount and nature of changes taking place.

Figure 4.4 shows a comparison of the change detection results gained from a LANDSAT band 4 dataset and the Green band of the Tasselled Cap image. A subset shows the 1993 LANDSAT image and the other subset shows the same area in 1995. Change detection was done using 20% decrease and 20% increase parameters. The green highlighted areas show a 20% or more increase in reflectance values while the red highlighted areas show a 20% or more decrease in reflectance values.



1993-1995: Infrared change detection



1993-1995: Tasselled Cap change detection

1993: LANDSAT colour infrared image

1995: LANDSAT colour infrared image

Figure 4.4 **Comparison digital change detection images based on the infrared band of the satellite images and the Greenness band of the Tasselled Cap images**

When comparing the results from the 1993-1995 infrared and 1993-1995 Tasselled Cap change detection, it can be seen that the vegetation change is portrayed more accurately by the Tasselled Cap image. Certain of the soils in Welgevonden seem to have a relatively high infrared reflectance, resulting in the change detection analysis being distorted in favour of bare soil rather than vegetation. The Tasselled Cap images were used as the main information source for the digital change detection.

The individual image sets were each analysed separately before the general trends across the entire period were studied. The images of 1993 and 1995 are not anniversary images as the available 1993 image was an early autumn image while the 1995 image was a late summer image thus making digital change detection unreliable. However, by using minimum change parameters of 20% or more any areas being highlighted are areas of significant change and unlikely to be due to seasonal variations. The years between 1993 and 1995 showed relatively little vegetation change occurring. Areas of change (both increase and decrease) larger than 20% is largely limited to the southern grassland sections of the reserve with the cultivated fields showing more than 30% increase in vegetation cover with only isolated areas of reduced vegetation cover being seen.

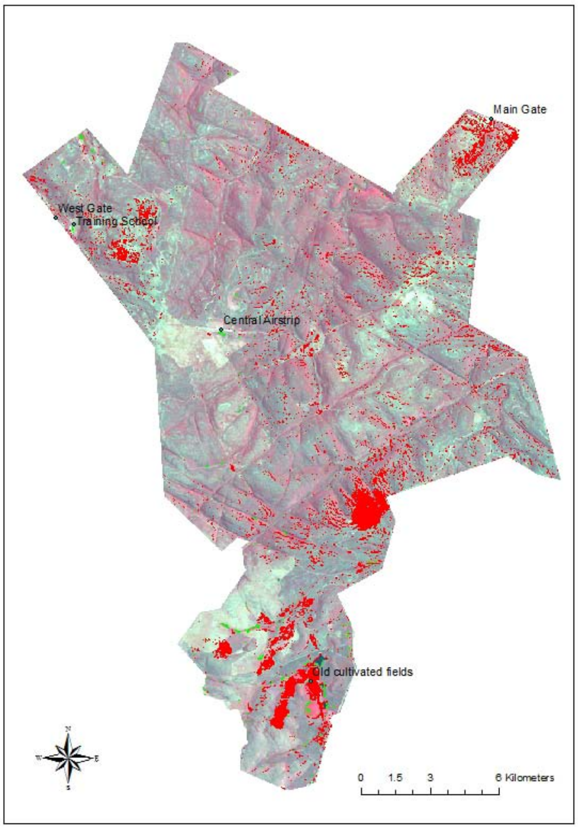


Figure 4.5 **1995–1999: Digital change detection (≥20% change)**

Little significant changes occurred in the vegetation across the reserve during the 1995 to 1999 period (Figure 4.5). Again it was the southern grasslands that showed the most change with the central and northeastern areas of the reserve also showing concentrated change. The bare areas in the southern tip of the reserve changed to woody grassland while some of the woody grassland was transformed to open areas. A fire scar in the south resulted in the open woodland thinning to become more woody grassland although an old fire scar in this region has recovered to open woodland. The southwestern boundary has seen an increase in the woodland and open woodland areas, and the riverine vegetation in this area has increased. Near the central airstrip, the open woodlands have increased slightly, as well as the open woodland and woody grassland to the south of the airstrip. The area around the Training School has gone from grass and bare soil to mainly grass with some increase in woodlands in the north-west corner of the reserve. There was a marked increase in open woodland and woodland in the far northern corner.

Of concern is that in the region west, immediately south and north of the central airstrip, large areas of vegetation have changed from grassland and woody grassland to sparse grass and bare soil. The area immediately around the main entrance gate of the reserve also showed a more than 30% reduction in woody vegetation with a marked decrease being visible further along the northeastern boundary.

Due to the large amount of cloud on the image for 2001, only visual change detection was conducted using this image. The 2001 image shows much more vegetation cover than 1999 with all visible areas showing increased vegetation cover. Especially on the southern tip of the reserve the woody grassland and open woodland noticeably increased from their 1999 levels.

Compared with the vigour vegetation cover of 2001, 2005 generally showed a decrease in vegetation cover. Most of the riverine vegetation was reduced, as well as the woody grasslands, open woodlands and woodlands in the northwestern quarter of the reserve. The woodlands and open woodlands near the central eastern boundary have also decreased noticeably. The areas of significant vegetation degradation were seen in the old cultivated fields, in the grasslands next to the central airstrip and in the northwestern corner of the reserve. The western boundary of the reserve showed a large area of reduced vegetation cover with the south-western grasslands also showing a reduction in the amount of woody vegetation.

There has been an increase in the amount of woodland in the top northern corner with the eastern sections of the reserve showing an increase in woody vegetation cover. The amount of woody vegetation seen in the southern grassland has also increased by more than 30%.

The digital comparison of the 1999 and 2005 images (see Figure 4.6) substantiated the visual findings discussed above as it showed that over this time period there was a general decrease in woodland, open woodland and woody grassland. In the south the old cultivated fields are less vigorous with grass and open patches. The area around the Training school near the West Gate has changed from woody grassland to grassland with a reduction in the riverine vegetation.

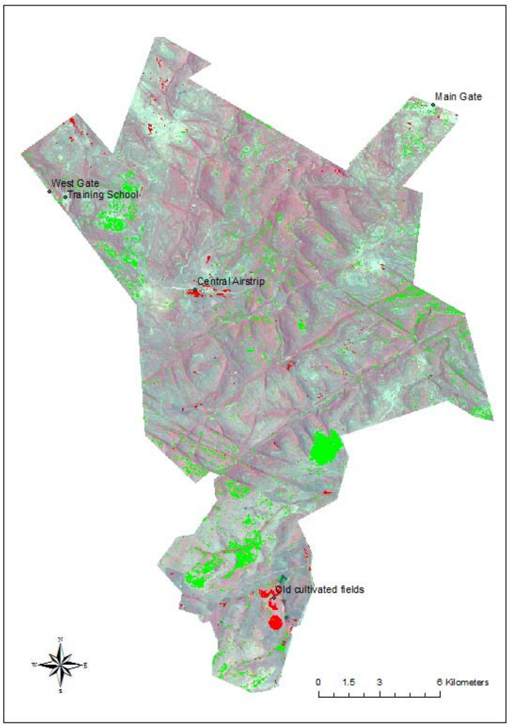


Figure 4.6 **1999–2005: Digital change detection (≥20% change)**

The woodland in the northwestern part of the reserve has been reduced with a large area of the woodland, open woodland and woody grassland near the central part of the northern boundary being converted to grassland and bare soil. Furthermore, the woodland and open woodland south-west of Main Gate shows some thinning while around Main Gate itself the open woodland has been thinned and the woody grassland converted to grass and bare soil.

However, the old fire scars present from 1999 are covered by woody vegetation with a general increase in woody vegetation being seen in the southeastern section of the reserve. The fire scar below the airstrip and the area west and north-west of the airstrip changed from bare earth and some woody vegetation to grassland and woody grassland.

The riverine vegetation along river to the south-east of Main Gate has increased and the woodland and open woodland in this area. A general increase of woody vegetation was seen in the eastern section of the reserve although some areas of woody grassland have been changed to grass and soil. The area on the northeastern boundary has improved significantly from its 1999 vegetation levels.

From 2005 to 2007 a general increase in woodland and open woodland was seen (see Figure 4.7). Some decrease in woody vegetation as well as riverine vegetation was seen on the southern tip of the reserve and a new fire scar near the west boundary resulted in a decrease in vegetation cover being seen in this area. There was a substantial amount of decrease in woody grassland being seen in this area as well.

Moving north there is some thinning of the woody grassland and open woodland with the woodland thinning closer to the central airstrip. An increase in woody grassland is seen to the immediate south and west of the central airstrip. North of the airstrip near the western boundary there was an increase in woody grassland with the woodlands near the northern corner of the reserve having increased along with the woody grassland along the northern grassland. The vegetation around Main Gate has somewhat recovered from the earlier disturbances as have the vegetation along the eastern boundary though the southeastern woodlands have decreased.

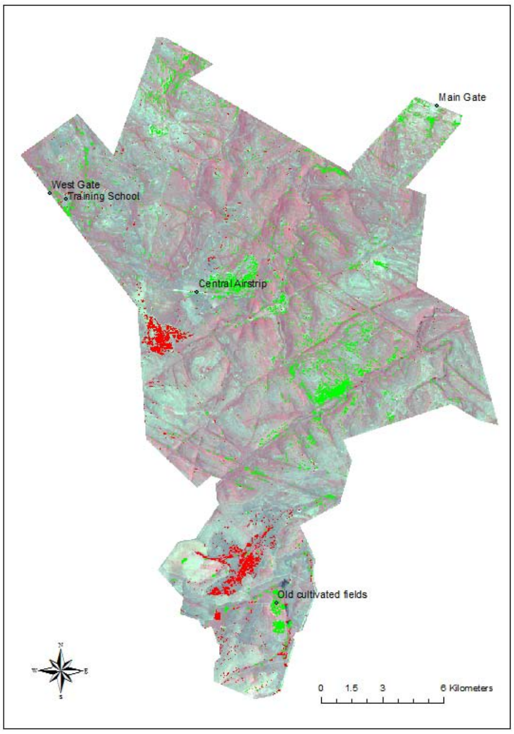


Figure 4.7 **2005–2007: Digital change detection (≥20% change)**

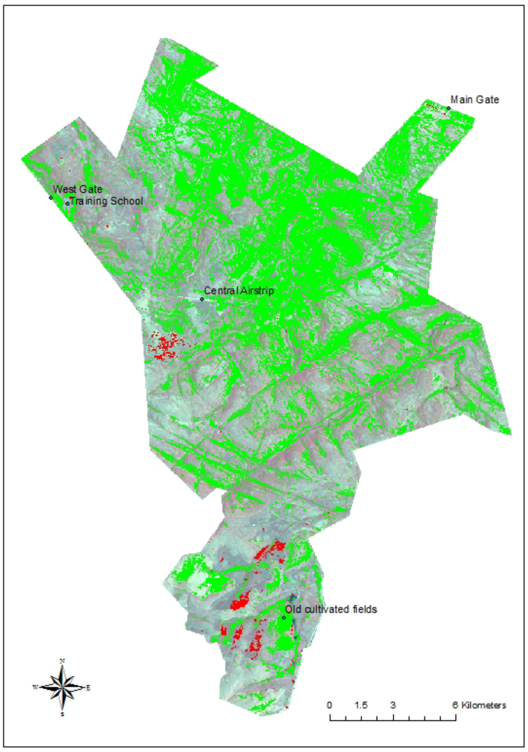


Figure 4.8 **1993–2007: Digital change detection (≥20% change)**

As can be seen from Figure 4.8, the general trend from 1993 to 2007 was an increase in vegetation cover over the most of the reserve. This is however misleading as this general overview hides the changes in the vegetation cover that has occurred.

4.4 Further analysis

The changes that were happening have now been established. Finding the answer to the question "why" is the next issue at hand. Adding the vector data of influences such as fire and water sources to the image analysis performed, correlations between the various disturbances can be identified. By reviewing the fire history of the reserve, it was noted that some areas in the south of the reserve burnt annually with fewer fires occurring in the northern sections of the reserve and fewer of these northern areas being burnt repeatedly. When comparing the spatial distribution of fires with areas of change, there was a strong positive correlation between areas of significant change and fires, as most of the vegetation changes seen in the south can be associated with areas of repeated fires.

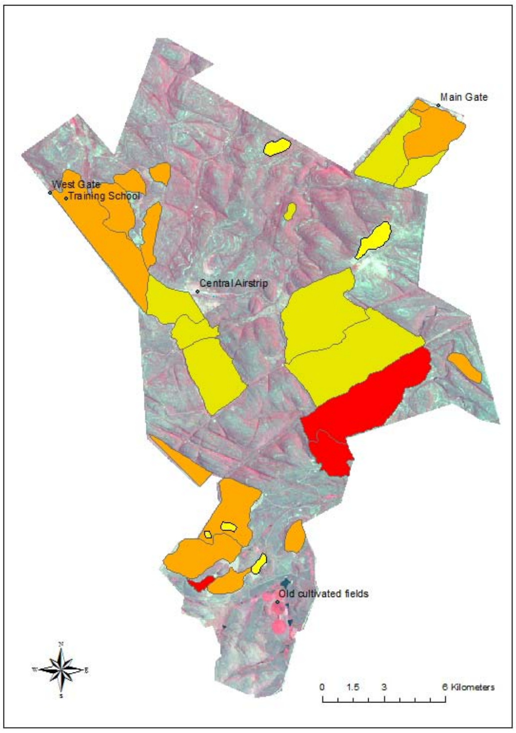


Figure 4.9.1 **1999 LANDSAT image overlaid with fire data from 1996-1999**
(Yellow=1996; Gold=1997; Orange=1998; Red=1999)

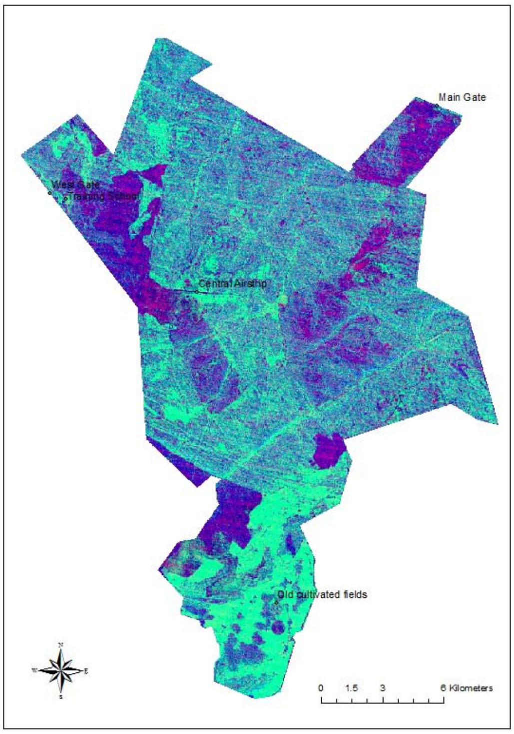


Figure 4.9.2 **Tasselled Cap bands 6, 5, 4**
(Dark blue areas showing correlation with fire scars)

The long-term effects that fires have on vegetation can be clearly seen when viewing the Tasselled Cap images using bands 6, 5 and 4. This band combination shows how visible the effects of fires are even after a number of years. This is illustrated in figures 4.9.1 and 4.9.2 using the 1999 Tasselled Cap image (band combination 6, 5, 4) in conjunction with the fire data of the preceding four years. The very dark blue areas of the Tasselled Cap image show areas that have burnt recently, the lighter dark blue areas having been burnt about a year before the image was taken with two year old burn scars also still being clearly visible.

According to Thrash (1998), the effect of trampling and overgrazing around a water source can be seen as far as 200 m away from the water source. To eliminate these direct effects on vegetation around water sources, a Shapefile layer showing the streams and major dams was used to create an image with a 500 m buffer around these water sources. When comparing this image with the change detection maps, no vegetation reduction could be linked directly to the presence of water sources. However, most of the changes seen, both vegetation increase and decrease, took place in the areas situated close to a number of water sources. The western boundary of the reserve is relatively far from water and other than changes due to fire damage, little or no vegetation changes occurred in this area.

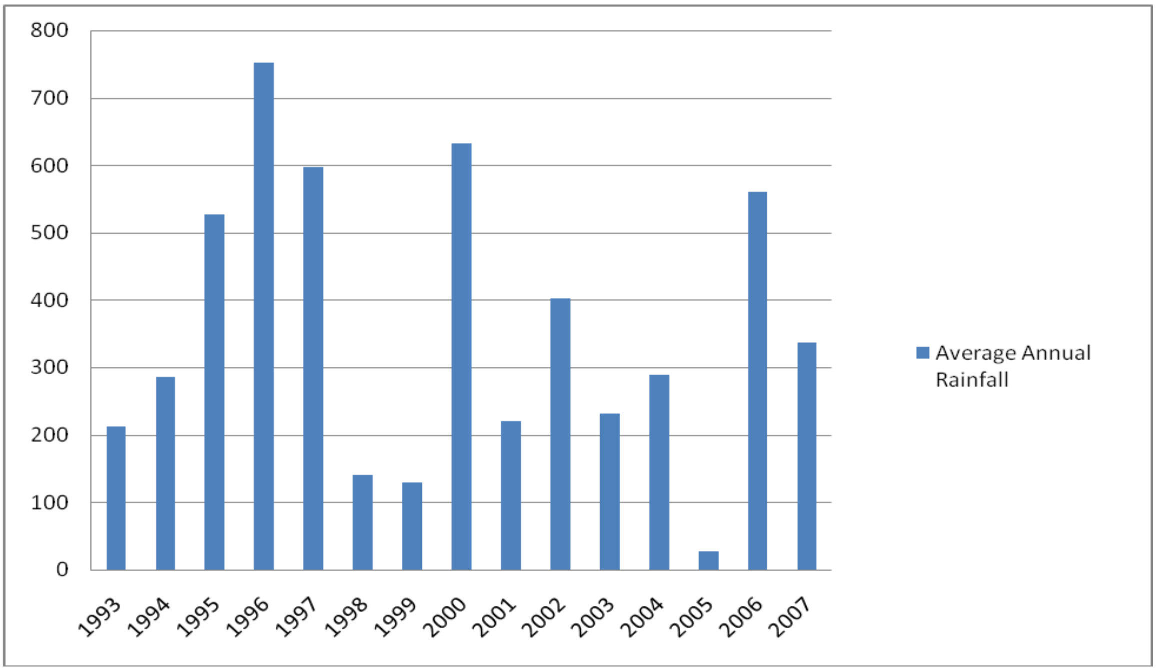


Figure 4.10 **Average annual rainfall data for Welgevonden Private Game Reserve**

A factor that seemed to account for the changes seen in vegetation cover was rainfall, with years of low rainfall having markedly lower greenness and wetness values than wetter years. A fairly uniform amount of vegetation increase or decrease was seen between years that had large differences in rainfall such as 2005 and 2007 (Figure 4.10). These differences were relatively small falling around the 10% change mark. While not resulting in significant change, the rainfall did seem to contribute towards the acceleration of vegetation changes. As years, such as 1999, that were relatively dry also coincide with high game counts, it is likely that some of the vegetation changes seen can be a combination of the stresses of heavy utilisation and low rainfall.

Figure 4.11 shows the results of the annual game counts from 1998 to 2007. Between 1993 and 1998 the game numbers on the reserve rose sharply due to the reintroduction of large game species such as white rhino, buffalo, sable and gemsbok onto the reserve as most of the reserve was previously cattle farms with little or no large game. Most game species have thrived since the establishment of the reserve to the point where 300 head of game had to be removed from the reserve between 2001 and 2002. Further reduction, in especially the numbers of impala, wildebeest and zebra, has resulted from the increase in predator numbers on the reserve. This predator pressure has resulted in the need for further reintroductions of these favoured prey species so that viable population numbers can be maintained.

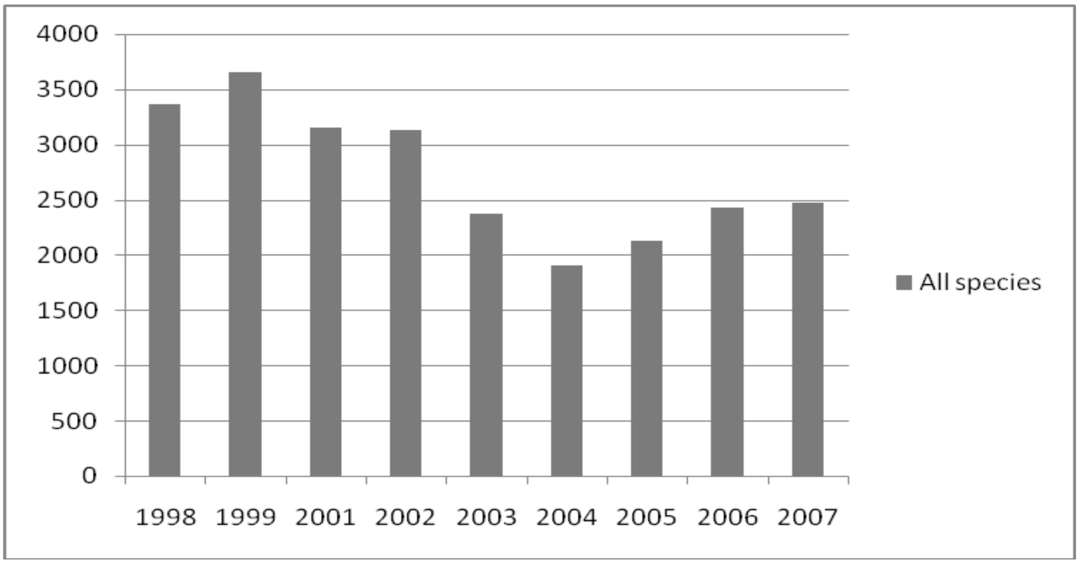


Figure 4.11 **Total species count for Welgevonden Private Game Reserve**

4.5 Conclusion

Managers of protected areas need data promptly in order to address current problems and to prevent undesired and possibly irreversible vegetation change. It is here that the use of remote sensing proved to be a useful tool for providing historic data for Welgevonden. Various digital image classification and analysis techniques were employed to extract the vegetation data for this reserve. Making use of archived satellite images in conjunction with current images, vegetation change information covering a long time period could be gained. Due to the high infrared reflectance of certain soils in Welgevonden, the use of the infrared bands of the images for the digital change detection proved to be inconsistent. The use of Tasselled Cap transformations and composites of the infrared bands offered more accurate classifications.

The location for the study covered a large area and a fair amount of variability was seen, even in the same vegetation classes. The vegetation cover information allowed changes in the vegetation composition to be established. The use of digital change detection highlighted and focused on areas of change. Due to the high infrared reflectance of certain soils in Welgevonden, the use of the infrared bands of the images for the digital change detection proved to be inconsistent. The Green band of the Tasselled Cap transformation allowed a more accurate vegetation change/no change analysis to be made.

Elephants were not the only agents of vegetation change. By making use of GIS techniques the impact of various disturbances such as fire, animal numbers and rainfall fluctuations were evaluated. Fire was found to have a large impact on especially the southern part of the reserve with some sections burning annually. The influence of animal numbers and rainfall fluctuations also had an impact with water availability only having a limited effect on vegetation change.

Chapter 5
DISCUSSION

5.1 Introduction

An ecosystem is a complex and dynamic system, which can be studied at a number of different special scales. Individual organisms and their interactions with their environment can be studied or the global trends can be tracked. For this study the broad vegetation patterns over a time period of 15 years is the scale of interest. Welgevonden Private Game Reserve is 34 200 ha in size with a heterogeneous land cover, fluctuating seasonal conditions and changing animal population structures. In order to efficiently manage such a large diverse area reliable ecological data is needed. Remote sensing can provide this ecological data, as it is a cost effective way to assess habitat structure and land cover changes regularly over large diverse areas.

To this end LANDSAT satellite images were acquired for Welgevonden at two yearly intervals from 1993 until 2007. It was hoped that a two-year interval would be long enough for vegetation change to become visible without losing the effects of the individual ecological disturbances. The images for the years 1997, 2001 and 2003 were, however, either not available or unsuitable due to a large percentage cloud cover. In all cases, summer images were used so as to provide the best characterisation of woody vegetation cover.

Other datasets were also used to help with the analysis and interpretation of the images. These included a 20 m Digital Elevation Model (DEM) for topographic normalisation, Shapefiles of the vegetation cover of the reserve, annual fire data, census data for all of the large herbivores and most of the small herbivores from 1998, and finally the annual rainfall data.

A certain amount of pre-processing of the satellite images were needed in order to obtain the most accurate input data for this study. Geometric and relief distortions had to be corrected and the atmospheric conditions normalised before further digital analysis could take place. After these corrections, the images were subset using the outer boundary of Welgevonden, to allow easy identification of the reserve as well as a saving in disc space and computing time. The subsets were then registered to each other to ensure that all geometric distortions were accounted for.

The basis of any vegetation study has to be an accurate vegetation map and for this study a vegetation map was created from each satellite image using a supervised classification method. A Tasselled Cap analysis was used to find the most representative samples of the selected vegetation classes, which were then used as training sites to classify a three band infrared composite consisting of the red, near infrared and mid-infrared bands of the LANDSAT images.

Digital change detection analyses were used to highlight areas of change using the Green band of the Tasselled Cap images. The analysis was run on in the following series, 1993 and 2007, 1993 and 1995, 1995 and 2005, and 2005 and 2007. As the 2001 image was unsuitable for digital change detection, visual change detection was done with the 1999 and 2005 images. The initial change value used was 10% or more increase/decrease in reflectance with second (20% or more increase/decrease) and third (30% or more increase decrease) analyses also done.

Using the Shapefile layers of the fires their special and temporal distribution was examined. A Shapefile layer of the water sources with a 500 m buffer was also examined for any correlation between their position and areas of change. Finally any areas of change not accounted for by the above disturbances was identified and further investigated along with rainfall data as well as census data for large herbivores.

Using all the data gathered by the above processes the possible effects of elephants on the vegetation of Welgevonden were analysed.

5.2 Vegetation change

Changes in vegetation composition are an important indicator of change in an ecosystem. By monitoring changes in the vegetation of a reserve, management action can be taken before excessive changes occur. In order to study vegetation changes over time, it is important to have a clear understanding of the vegetation trends of the ecosystem. Analysing the occurrences of the various vegetation types at the various points in time can identify these trends. Using the available satellite images, trends in the vegetation cover of Welgevonden could be mapped. These vegetation cover maps were used for visual detection of change and to track how the various vegetation cover types fluctuate.

Prior to 1993, much of Welgevonden was cattle ranches before being incorporated into the game reserve. This conversion will have an effect on the vegetation of the area, as the vegetation utilisation will differ from when it was used for cattle farming. On many cattle farms bush encroachment is a problem as reduced browsing pressure, overgrazing and changing fire regimes enable woody vegetation to out compete the grasses. One of the main factors in maintaining grasslands is high-intensity fires, which became less common as farming activities increased. Add an increase in domestic livestock and a reduction in browser numbers and a more favourable environment for the woody species are created (Hudak & Wessman, 2001; Pienaar, 2006). Many of the changes seen in the vegetation of Welgevonden are as result of the introduction of browsers, selective grazers and elephants, which allows a more balanced utilisation of the reserves vegetation. The building and altering of infrastructure also add to the vegetation changes seen.

When reviewing all the data, it was found that between the years 1993 and 2007 there was a general increase in the woody vegetation cover. Despite this general trend, some areas showed a thinning of the stands of dense woodland and a reduction of the riperian vegetation. This increase in especially woody grassland and open woodland resulted in a sharp decrease in grassland areas. The southern third of the reserve showed the most fluctuation in vegetation cover as well as having a general trend of decreasing woody cover (see Figure 5.1).

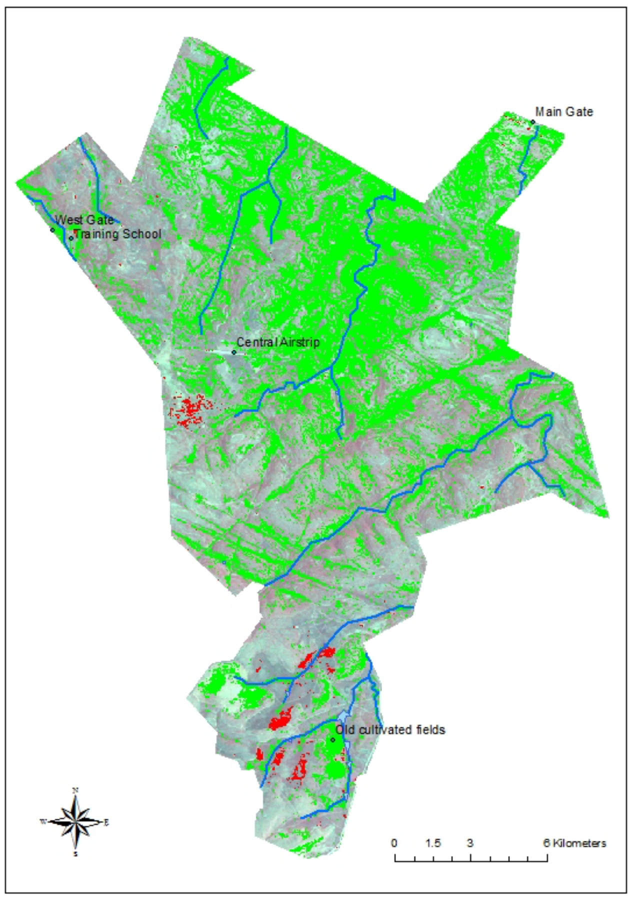


Figure 5.1 **1993–2007: Change detection image (≥20% change)**

The changes that took place between 1993 and 1995 were largely limited to the southern grassland sections of the reserve. This section is one of the more recent additions to the reserve with the cultivated fields shown, still being actively farmed during this period. Most other areas of change can be traced to changes in infrastructure such as building of new roads, airstrips and lodges.

In Figure 5.2 (6, 5 & 4 bands of the Tasselled Cap image for 1993) areas showing signs of being burnt prior to 1993 (the dark blue areas), can be identified. An area running from the north-east to the south-west in the lower sections of the reserve can be identified and a small section on the central western boundary. These burnt areas seem uncorrelated with changes seen from 1993 to 1995.

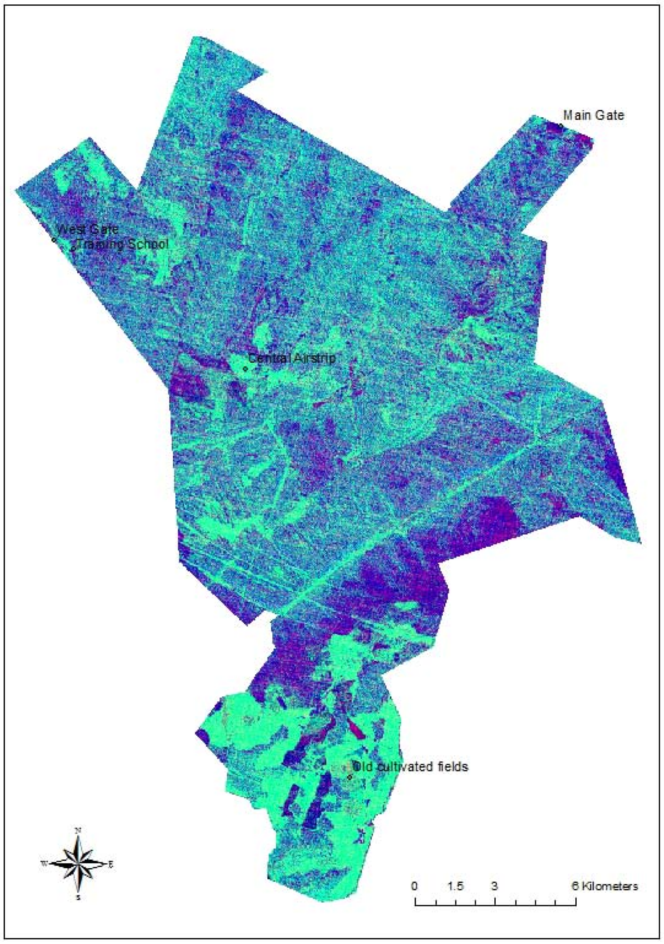


Figure 5.2 **1993: Tasseled Cap image (bands 6, 5 & 4)**

Little general changes occurred from 1995-1999 with the southern grasslands showing the most change because of drastic changes in land use practices, as this area went from irrigated fields to fallow lands. In 1993, this section of the reserve was still being actively cultivated but by 1999 the irrigated fields were fallow. Most other areas of change in the southern part of the reserve are the result of fire damage leading to some increase in woody grassland, but with most other areas becoming less vegetated. There was some increase of woodlands, open woodlands and riverine vegetation in parts of the central and northern areas but a marked decrease in vegetation density to the far north and east. Of concern is the area around the central airstrip that has become noticeably degraded, changing from grassland and woody grassland to sparse grass and bare soil. A similar trend is seen in the central part of the eastern boundary. The damage to the area immediately around the main entrance gate of the reserve can be attributed to infrastructure development.

Of the satellite images under review the image for 1999, showed the most badly degraded vegatation cover. A combination of factors was identified as being responsible for this degredation, namely fires, low rainfall and high animal numbers. Large areas of the reserve suffered fire damage in the three years preceding 1999 with 1998 and 1999 also having particularly low rainfall. In these years the game numbers also reached their highest levels. All of these factors contributed to causing 1999 to have noticably lower vegetation cover than the other years under investigation.

The year 2000 received around five times as much rain as either 1999 or 1998 with 2001 also receiving good rainfall. In general, 2001 shows noticeably more vegetation cover than 1999 with all visible areas showing increased vegetation cover. When comparing 2001 with 2005 a general decrease in vegetation cover between the two years is seen. The northwestern quarter of the reserve shows a decrease in most woody vegetation classes with the exception of the top north corner where there was an increase in the amount of woodland. However, the woodlands and open woodlands near the central eastern boundary have decreased noticeably. Areas of significant vegetation degradation were seen in the old cultivated fields, in the grasslands next to the central airstrip and in the northwestern corner of the reserve, as did the riverine vegetation along the southern watercourse. However, the eastern sections of the reserve show an increase in woody vegetation cover.

Much of the decrease in vegetation cover between 1999 and 2005 can be attributed to the effect of fire, although some increases in vegetation as a result of regeneration of previously burnt areas can also be seen. From 1999 to 2005, there were relatively high animal population numbers and exceptionally low rainfall in 2005. During these years the vegetation types most affected were the grasslands and woodlands, as both these vegetation types have decreased from their previous levels. The changes seen in the woodlands are relatively dispersed and can be as a result of damage by browsers such as elephants. More concentrated damage would be expected from disturbances such as fires. The transformation of grasslands into woody grasslands is most likely due to intensive grazing pressure.

From 2005 to 2007, there was a general increase in woodland and open woodland. Some decrease in woody vegetation on the southern tip of the reserve can again be attributed to fire. Moving north there is some thinning of the woody grassland and open woodland with the woodland thinning closer to the central airstrip. North of the airstrip near the western boundary there was an increase in woody grassland with the woodlands near the northern corner of the reserve having increased along with the woody grassland along the northern grassland. The vegetation around Main Gate has somewhat recovered from the earlier disturbances as have the vegetation along the eastern boundary yet the southeastern woodlands have decreased. This increase in vegetation coincides with decrease in animal numbers and relatively good rainfall. The fires that occurred over this period were also more widely dispersed with fewer areas burning repeatedly.

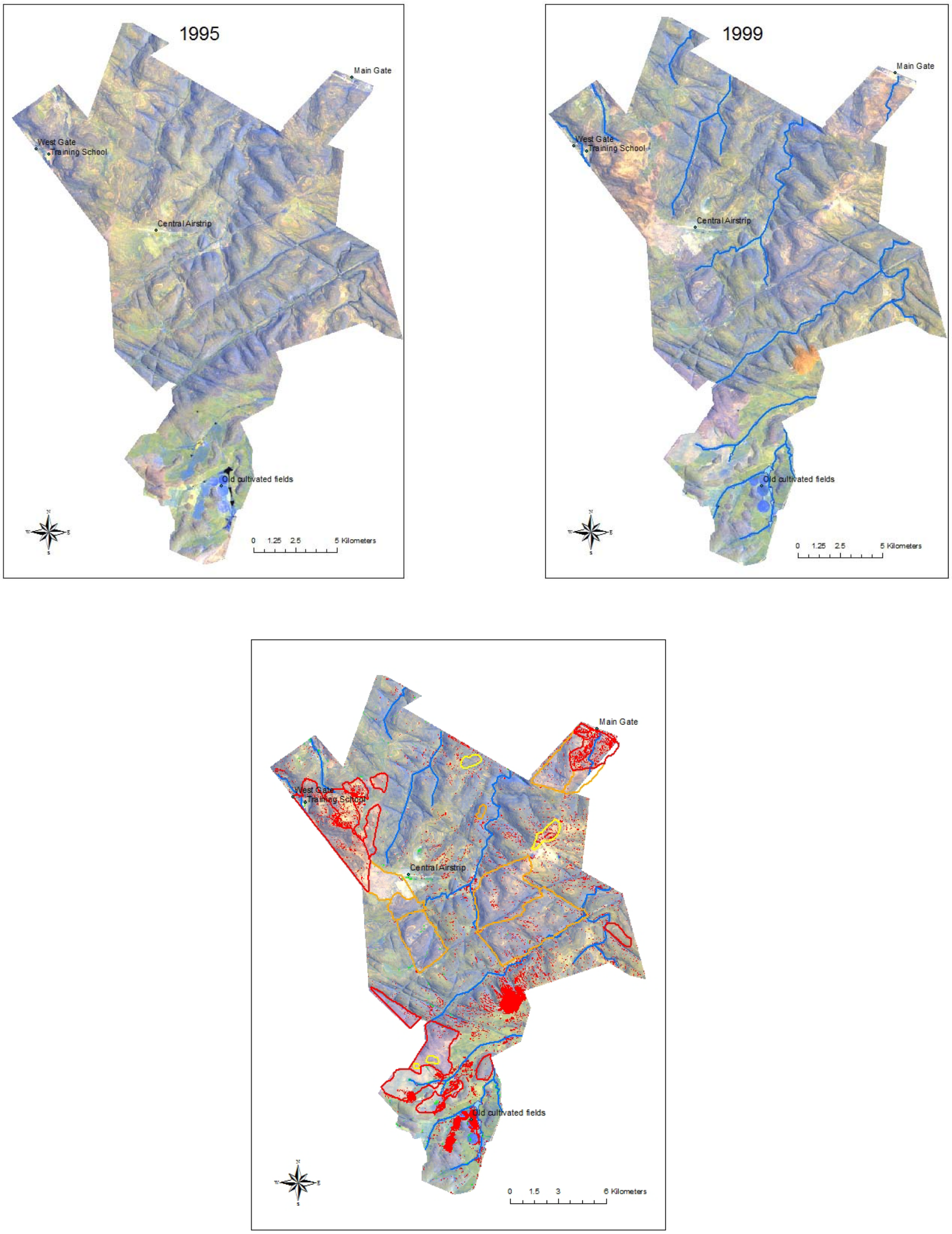


Figure 5.3 **1995 and 1999 Infrared LANDSAT (bands 7, 5 & 4) images with a 1995–1999 change detection (≥20% change) image: Spatial distribution of fires and water sources**

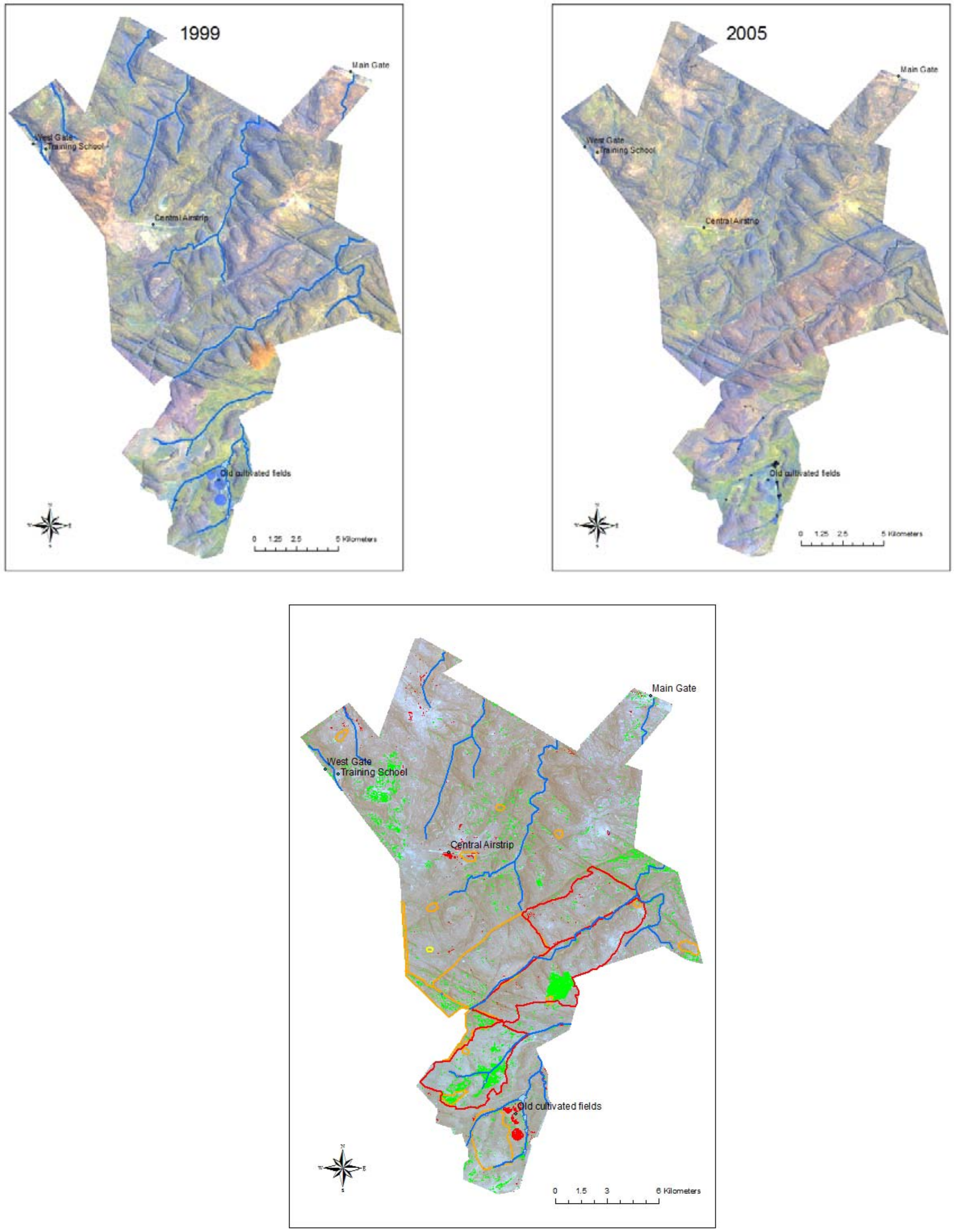


Figure 5.4 **1999 and 2005 Infrared LANDSAT (bands 7, 5 & 4) images with a 1999–2005 change detection (≥20% change): Spatial distribution of fires and water sources**

When reviewing the fire history of the reserve, it was noted that some areas in the south of the reserve have burnt annually with fewer fires occurring in the northern sections of the reserve as well as fewer of these northern areas being burnt repeatedly. There is a strong positive correlation between areas of significant change and fires with most of the vegetation changes seen in the south being associated with areas of repeated fires. While the water sources could not be directly linked to areas of vegetation change, most of the changes observed took place in the areas with easy access to water. The western boundary of the reserve is relatively far from water and other than changes due to fire damage, little or no vegetation changes occurred in this area.

Rainfall did seem to play an important part in the vegetation cover seen with years of low rainfall having less areas of vegetation increase than wetter years. A fairly uniform amount of vegetation increase or decrease was seen between years that had large differences in rainfall such as 2005 and 2007. These differences were relatively small, falling around the 10% change mark. While not resulting in significant change, the rainfall did seem to contribute towards the acceleration of vegetation changes. Years such as 1999, were relatively dry and coincides with high game counts. It is likely that some of the vegetation changes observed can be a combination of the stresses of heavy utilisation and low rainfall.

While the evaluation of the satellite images and the data derived from them enabled vegetation change patterns to be traced, the external data sources such as the fire data was essential to draw accurate conclusions. It is not possible to isolate vegetation changes caused solely by elephants. Firstly, there are so many other factors that contribute to vegetation change that cannot be assessed at this scale but the effects of all these disturbances merge to become difficult to isolate.

This study has shown that while vegetation change is happening on Welgevonden, management practices such as reducing animal numbers and a change in their fire policy seem to have slowed the rate of change. It would also appear that currently the pressure by grazers is a greater problem than elephant

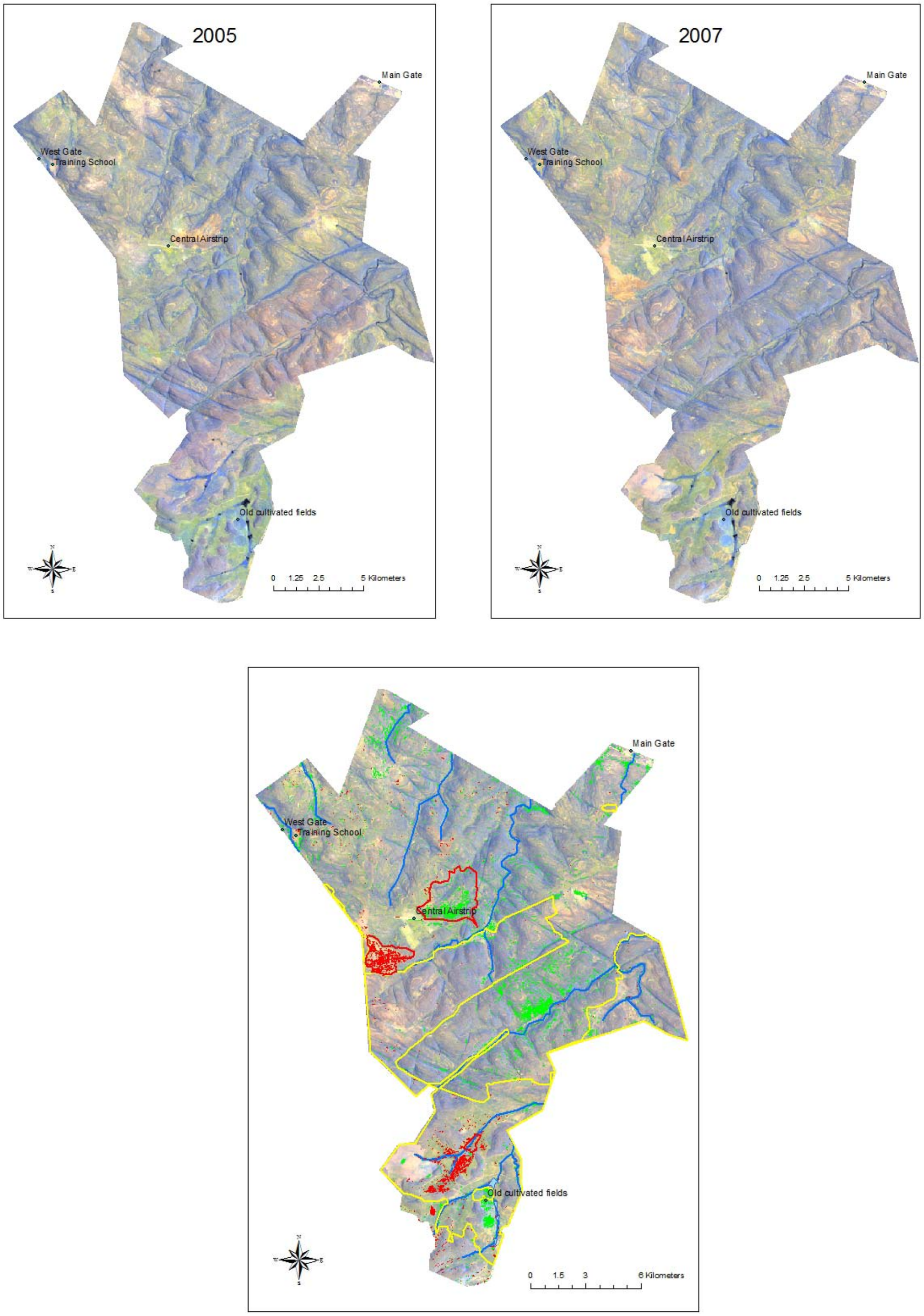


Figure 5.5 **2005 and 2007 Infrared LANDSAT (bands 7, 5 & 4) images with a 2005 - 2007 change detection (≥20% change) : Spatial distribution of fires and water sources**

damage. The reduction in riverine vegetation and woodland density indicates that elephant induced vegetation change is taking place and ongoing monitoring of the reserve should continue.

The use of satellite images for this monitoring is an economically feasible tool as not only is this method relatively inexpensive, but also can provide usable results in a short space of time.

5.3 Conclusion

Most scientists agree that elephants modify their environment but the long-term effect of these modifications on the environment is still in question. In order to answer this question medium to long-term studies of vegetation change is required. However, managers of protected areas need data now in order to address current problems and to prevent undesired and possibly irreversible vegetation change. It is here that the use of remote sensing is a useful tool as it not only provides historic data for an area but also is a continuous source of data. In this way vegetation change information covering a long time period can be accessed immediately.

Because elephants are also not the only agents of vegetation change, the effects of other disturbance must also be taken into account. By making use of post-classification analysis and GIS techniques the impact of various disturbances can be evaluated. By taking into account the effects of a range of ecological influences a better understanding how management decisions affect the ecosystems can be gained resulting in the implementation of informed management policies. Developing a remote sensing based management action plan will allow a holistic and proactive approach to elephant management. The elephant problem will not go away with better monitoring or management strategies but these will buy time in which a solution to the problem may be found. It will also allow managers to have a better understanding of the carrying capacity of their reserves and to establish realistic thresholds of damage.

The use of remote sensing cannot do away with the need for ground surveys, as the ecological implications of the changes observed are not always visible at a spatial resolution large enough to be detected by remote sensing methods. However, this study has shown that the areas in most urgent need of attention can be highlighted and can provide data on the general trends in the vegetation cover.

It was found that there is a strong positive correlation between areas of significant change and fires. Areas subjected to regular fire damage exhibited the greatest vegetation change over time. Rainfall also seemed to play a role in vegetation changes as years with good rainfall showed better recovery of damaged areas than in the years when less rainfall was received. Years with high game counts coincided with dry years thus it was not possible to accurately isolate the effects that game numbers have on vegetation change during these years. While water sources could not be directly linked to areas of vegetation change, though most of the changes seen took place in the areas with easy access to water. Water would thus seem to have at least an indirect effect on the distribution of game and thus on vegetation change.

Vegetation change patterns could be traced using digital analysis of satellite images though the external data sources such as the fire data was needed so that accurate conclusions could be drawn from the data. These vegetation change patterns showed that while vegetation change is happening, management practices resulted in a slowing down of the rate of change. It would also appear that currently the pressure by grazers is a greater problem than elephant damage. Elephant damage to riverine vegetation and woodland seems to be taking place resulting in the need for ongoing monitoring of vegetation change on the reserve.

Chapter 6
CONCLUSIONS

6.1 Introduction

The African elephant (*Loxodonta africana)* population numbers are declining over much of their former range with only an estimated 689 671 elephants left in Africa. Southern Africa has 58% of the total elephant population with the South African population steadily increasing from its current 18 507 individuals (Lindeque, 2000; Blanc *et al*., 2007). The South African elephant populations are concentrated into relatively small protected areas. These enclosed elephant populations are cut off from alternative seasonal resources resulting in an over utilisation of the available food sources.

Elephants play an important role in maintaining savannah environments by regulating bush encroachment that creates new microhabitats and also stimulate new growth in damaged trees (Augustine & McNaughton, 2004; MacGregor & O'Connor, 2004). Other disturbances such as fire, drought, other herbivores and the spatial and temporal availability of water, all help to maintain habitat heterogeneity (Owen-Smith, 2006; Chongo *et al*., 2007). When disturbances, such as fire or elephant damage, become too concentrated, it may permanently change the vegetation composition resulting in the loss of fauna and flora (Johnson *et al*., 1999; Lombard *et al*., 2001; Wiseman *et al*., 2004).

By exceeding the capacity of an enclosed area, to absorb the effects of elephants, excessive damage to the vegetation and destruction of habitats result. The effective elephant carrying capacity of a reserve is difficult to determine as factors such as vegetation type, the other animal species present, topographical features, as well as the annual temperature and rainfall fluctuations need to be taken into account. The impacts of elephants are also not spread evenly over an entire area resulting in the patchy utilisation of the available resources. The impacts of other disturbances such as drought, fire and other herbivores also need to be considered as they are all interlinked and may amplify or mask individual effects (Guldemond, 2006).

In the case of Welgevonden Private Game Reserve, there is a relatively large elephant population of 120 individuals on 34 200 ha. The maximum carrying capacity for elephants on this reserve is not known and the threshold for acceptable vegetation change still needs to be established. Being a very mountainous area, many parts of the reserve are not easily accessible making a detailed ground analysis of elephant impacts difficult, time consuming and labour intensive. A more efficient monitoring system of vegetation changes on this reserve needs to be established, as detailed ground analysis on this reserve is not practical or economically feasible. This is where the use of satellite images as a monitoring tool for vegetation change has potential to be implemented for this protected area. Remote sensing, especially images derived from satellite sensors, provides spatial and temporally repeated observations of large areas that can significantly improved the quantity and quality of environmental data collected. This data can then be used to map and monitor land cover changes taking place over time (Paolini *et al*., 2006).

The question that this study has tried to address is whether elephant induced vegetation change in an enclosed South African protected area, Welgevonden Private Game Reserve, can be analysed using satellite images. In order to achieve this, a time series of vegetation change maps from satellite imagery were produced and the spatial distribution of artificial water points and fires for that period mapped so that areas of change could be correlated with the distribution of water points and fire. Any uncorrelated areas of change could be analysed using large herbivore and elephant population trends, weather data and management practices before a final analysis of the extent and distribution of elephant induced vegetation change was conducted.

For this study a time series of LANDSAT Thematic Mapper multispectral images were used as the basis for the thematic maps created for the study. Images with greater spatial resolution but reduced spectral resolution were not used as this study focused on tracking broad vegetation patterns. Summer images were acquired at two yearly intervals from 1993 until 2007, as this interval was felt to being long enough for vegetation changes to become visible while still allowing the effects of the various ecological influences to be observed. Due to the unavailability of suitable images, no images were used for the years 1997 and 2003 with only limited use being made of the 2001 image. Other data used included a 20 m Digital Elevation Model (DEM), weather and animal census data and vector datasets.

Topographic normalisation is necessary in mountainous areas such as Welgevonden, to normalise differences in illumination and sensor angle as a result of topographic variations. Any slight geometric distortions across the images may result in the different images not lining up accurately, so these small offsets were corrected by registering the images to each other. Subsets of the images were also created of the Welgevonden Private Game Reserve for easy identification of the specific area of interest and saving on disc storage space and computing time.

Once all the pre-processing was completed, a Tasselled Cap and NDVI (Normalised Difference Vegetation Index) analysis was run, to establish the separability of the various vegetation communities on Welgevonden, so that the best representative sample of the vegetation types could be established. Using these training areas, the vegetation on Welgevonden was mapped using a supervised classification process. Digital change detection analyses were run on the time series of images, two consecutive images at a time, for selected bands of the satellite and Tasselled Cap images. This highlighted areas of significant change allowing the investigation to be more focussed.

The information derived from the images was supplemented with GIS analysis of the vector datasets. Areas of change not accounted for by the above processes were investigated further using rainfall data and census data for large herbivore to assess any correlation between the vegetation changes and these data sets. Using all the information gathered from the above processes, the possible effects of elephants on the vegetation of Welgevonden Private Game Reserve could be analysed.

6.2 Elephant induced vegetation change

The main aim of this study was to evaluate remote sensing as a tool for monitoring vegetation change. In order to achieve this aim, an accurate vegetation classification of the reserve formed the basis of this study. Vegetation surveys conducted by Welgevonden produced a large-scale vegetation map, which was used as the starting point for the vegetation classification. However, the Welgevonden vegetation map was spatially too coarse and its classes too detailed to be easily correlated with the vegetation classifications possible using the available satellite images. As the vegetation changes of interest in this study were changes in the vegetation type and density, spatially broad classes did not show enough detail for vegetation change detection while the resolution of the satellite images made it difficult to classify the satellite images into specie specific classes.

Of the four datasets used for the classification, namely NDVI, Tasselled Cap, seven band LANDSAT TM and three band infrared LANDSAT TM images, it was found that:

- the NDVI produced the least accurate classification;

- the Tasselled Cap image produced the most consistent woody vegetation classification;
- the seven band LANDSAT images produced the most accurate general land cover classification;
- the three band infrared LANDSAT TM gave a consistent classification of both land cover and vegetation.

All the vegetation maps produced thus used the infrared LANDSAT TM composite. The final vegetation maps were visually compared and while woodland has disappeared completely or decreased in density in parts of the reserve, the most notable change is the increase of open woodland resulting in a decrease in grasslands though the amount of woody grassland remained roughly the same.

The change detection analysis was found to be the most accurately highlighted when using a basic change/no-change analysis when using the Tasselled Cap images. The years between 1993 and 1995 showed relatively little vegetation changes occurring and largely being limited to the southern grassland sections of the reserve. Isolated areas of reduced vegetation cover were also observed over the rest of the reserve. From 1995 to 1999 little significant changes occurred with the southern grasslands again showing the most change. Vegetation decrease was also seen in the central and northeastern areas of the reserve. The visual change detection of the 2001 image showed that more vegetation cover was present than in 1999 with the southern tip of the reserve having noticeably increased the woody grassland and open woodland. Compared to 2001, 2005 generally showed a decrease in vegetation cover with a reduction in most of the riverine vegetation. The open woodlands and woodlands across the reserve decreased. However, there has been an increase in woodland in the top northern corner and the eastern sections of the reserve. From 2005 to 2007 a general increase in woody grassland and open woodland occurred. In the north there was some thinning of the woody grassland and open woodland with the woodland thinning closer to the central airstrip. The woodlands near the northern corner of the reserve increased, as well as the woody grassland in the north. When examining the period from 1993 to 2007, the general trend was an increase in vegetation cover. This generalisation is misleading as it hides the changes in the vegetation types that have occurred.

The spatial distribution of fires shows a strong positive correlation with areas of change, as most of the vegetation changes seen in the south can be associated with areas of repeated fires. Fires can have a long-term effect on vegetation, as the effects of fire are visible even after a number of years with old burn scars still being clearly visible after two years. The distribution of the water sources could not be directly linked to vegetation change. However, most of the vegetation changes seen occurred in areas with easy access to a number of water sources. A further factor that seemed to account for changes was rainfall, as years of low rainfall had less vigorous vegetation than wetter years. While this did not seem to result in specific change, rainfall fluctuations did seem to accelerate vegetation changes. The relatively dry years such as 1999, also coincide with high game counts so it is likely that some of the vegetation changes seen can be a combination of the stresses of heavy utilisation and low rainfall.

Many of the initial changes seen in the vegetation of Welgevonden were the result of land use changes. The majority of what is now Welgevonden was cattle farms before being converted into a game farm. The introduction of browsers, selective grazers and elephants allowed a more balanced utilisation of the areas vegetation. The first six years showed that there was a general decrease in vegetation cover, which could be ascribed to adaptation of vegetation to new utilising strategies. Large areas were also subject to fire damage with some areas being burnt annually. However, this time period also had high game numbers and relatively low rainfall. All these disturbances could contribute to the general reduction in vegetation cover over this time. With so many possible influences, it is not possible to narrow down any of the vegetation changes to elephants alone.

From 1999 to 2005, there was a decrease in vegetation cover although high animal numbers and exceptionally low rainfall in 2005 could account for this. While fires are still a regular occurrence, their distribution was more dispersed with less areas being burnt regularly. The vegetation types that seem to be most affected are the grasslands and woodlands. The changes seen in the woodlands can be as a result of damage by browsers such as elephants as most of the damage seen to this vegetation type is dispersed rather than concentrated as would be expected due to disturbances such as fires. The transformation of grasslands into woody grasslands is more likely due to pressure by grazers. This trend continues through to 2007 with increases in open woodland and woody grassland resulting in increases in the general woody vegetation cover even while the woodlands showed some thinning. The areas of concentrated change are due to fire damage with the general changes being unrelated to fires or water sources. As the rainfall for these years was relatively high, it is unlikely that these changes can be associated with rainfall fluctuations. Due to increased animal numbers for this period, these changes can most likely be associated with grazing and browsing impacts.

While it is possible to track changes in vegetation over time and to account for disturbances such as fire, it is not possible to conclude that the changes seen on this reserve was as a result of elephant damage. The high elephant numbers and the type of changes observed, makes it highly likely that the elephants on this reserve are contributing to vegetation change but further research will be needed before reliable conclusions can be reached.

The use of remote sensing cannot do away with ground surveys, as the ecological implications of the changes seen were not always visible at a spatial resolution large enough to be detected by remote sensing methods. However, this study has shown that certain deductions can be made and that the areas, in most urgent need of attention, can be highlighted. This allows the limited resources to be deployed when and where they are needed.

6.3 Further research

This project has shown that vegetation changes can be tracked successfully using remote sensing. Areas of potential elephant damage can also be identified by eliminating the effects of fires and human disturbances and by accounting for rainfall fluctuations. However, further work is needed to isolate elephant induced vegetation changes and to establish the effects these changes have on the ecosystem as a whole.

In order to establish the causes of the changes seen in the areas of concern, a two-part approach could be followed; using high resolution satellite images and ground surveys. The use of high resolution images such as IKONOS or Quick bird on selected areas is much more cost effective than using them across the entire area and will give a much more detailed view of the changes being experienced. By correlating this satellite data with data gathered from ground surveys and information on the habitat utilisation by the elephants, a clearer picture of the elephant effects could be gained. Once this correlation is known, it can be tested on other protected areas to evaluate the use of satellite images as a tool for monitoring elephant induced vegetation change across a range of habitats.

6.3 Conclusion

South African elephant populations are concentrated in relatively small protected areas resulting in an over utilisation of the available food sources. Elephants are a keystone species that play an important role in maintaining savannah environments. Other disturbances such as fire, drought, other herbivores and the availability of water, all play a role in maintaining habitat heterogeneity. When these disturbances become too concentrated, it may permanently change the vegetation composition. By exceeding the capacity of an enclosed area, to provide a constant and reliable food supply for its elephant population, excessive damage to the available vegetation results.

The effect of the 120 strong elephant population on Welgevonden Private Game Reserve is not known. A detailed ground analysis will be difficult, time consuming and labour intensive. The use of satellite images as a monitoring tool for vegetation change significantly improved the quantity and quality of environmental data collected for this study.

This study aimed at establishing the use of satellite imagery for monitoring elephant induced vegetation change on Welgevonden Private Game Reserve. LANDSAT Thematic Mapper multispectral images acquired at two yearly intervals from 1993 until 2007 were used. Unfortunately no suitable images were available for the years 1997, 2001 and 2003. A time series of vegetation change maps was produced and the distribution of water sources and fires mapped. The areas of change were then correlated with the water points and fire. Any uncorrelated areas of change were analysed using large herbivore and elephant population trends, weather data and management practices.

On visual comparison of the vegetation maps produced, it was seen that there was some decrease and thinning of woodland but the most notable change was the increase of open woodland and decrease in grasslands. On analysing the change detection, it was found that the years between 1993 and 1995 showed relatively little vegetation changes occurring, with 1995 to 1999 also showing little significant changes. A visual change detection of the cloud covered 2001 image showed that more vegetation cover in all the visible areas compared with 1999 with 2005 generally showed a decrease in vegetation cover. From 2005 to 2007 a general increase in woody grassland and open woodland was seen. Using only the change detection, the period from 1993 to 2007 showed a general increase in vegetation cover. But this generalisation is misleading when this is compared to the vegetation maps, as it can be seen that while vegetation cover may have increased, significant changes occurred in the vegetation types.

Most of the areas of significant change identified by means of the change detection showed a strong positive correlation with burnt areas, while the distribution of the water sources could not be linked directly to vegetation change with rainfall fluctuations seeming to accelerate vegetation changes. Years with high game counts, such as 1999, also coincide with very low rainfall making it difficult to differentiate between the effects of heavy utilisation and low rainfall. Many of the initial vegetation changes will be as result of land use changes, as the introduction of browsers, selective grazers and elephants will allow a more natural utilisation of the vegetation.

It is possible to successfully track changes in vegetation over time using remote sensing. Disturbances such as fire can also be accounted for but it is not possible to conclude with a high level of certainty that the changes are a result of elephant damage. Further work is needed to isolate elephant induced vegetation changes and to establish the effects these changes have on the ecosystem as a whole. In order to isolate elephant damage from other disturbances, the use of high resolution images such as IKONOS or Quickbird will give a much more detailed view of the areas of concern identified in this study. Adding data gathered from ground surveys and information on the habitat utilisation by the elephants, should produce a clearer picture of the influence elephants have on the vegetation in enclosed protected areas.

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