Spatio-temporal dynamics in land use and habitat fragmentation in the Sandveld, South Africa

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Keywords

- Change detection
- Habitat Fragmentation
- Landsat
- Markov Models
- Cell Automated Markov Analysis
- Moderate Resolution Imaging Spectroradiometer
- Normalised Difference Vegetation Index (NDVI)
- Principal Component Analysis (PCA)
- Remote sensing
- Time Series Analysis

Abstract

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The Cape Floristic Region (CFR) in South Africa, is one of the world's five Mediterranean hotspots, and is also one of the 34 global biodiversity hotspots. It has rich biological diversity, high level of species endemism in flora and fauna and an unusual high level of human induced threats. The Sandveld forms part of the CFR and is also highly threatened by intensive agriculture (potato, rooibos and wheat farming), proliferation of tourism facilities, coastal development, and alien invasions. These biodiversity threats have led to habitat loss and are threatening the long-term security of surface and ground water resources. In order to understand trends in such biodiversity loss and improve in the management of these ecosystems, earth-orbiting observation satellite data were used. This research assessed landuse changes and trends in vegetation cover in the Sandveld, using remote sensing images. Landsat TM satellite images of 1990, 2004 and 2007 were classified using the maximum likelihood classifier into seven landuse classes, namely water, agriculture, fire patches, natural vegetation, wetlands, disturbed veld, and open sands. Change detection using remote sensing algorithms and landscape metrics was performed on these multi-temporal landuse maps using the Land Change Modeller and Patch Analyst respectively. Markov stochastic modelling techniques were used to predict future scenarios in landuse change based on the classified images and their transitional probabilities. MODIS NDVI multi-temporal datasets with a 16day temporal resolution were used to assess seasonal and annual trends in vegetation cover using time series analysis (PCA and time profiling).Results indicated that natural vegetation decreased from 46% to 31% of the total landscape between 1990 and 2007 and these biodiversity losses were attributed to an increasing agriculture footprint. Predicted future scenario based on transitional probabilities revealed a continual loss in natural habitat and increase in the agricultural footprint. Time series analysis results (principal components and temporal profiles) suggested that the landscape has a high degree of overall dynamic change with pronounced inter and intra-annual changes and there was an overall increase in greenness associated with increase in agricultural activity. The study concluded that without future conservation interventions natural habitats would continue to disappear, a condition that will impact heavily on biodiversity and significant water-dependent ecosystems such as wetlands. This has significant implications for the long-term provision of water from ground water reserves and for the overall sustainability of current agricultural practices.

Declaration

I declare that "*Spatio-Temporal dynamics in Landuse and habitat fragmentation in the Sandveld, South Africa*" is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

James Takawira Magidi

Signed ………………………………

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Dedication

To my mum and late dad for the unconditional love, motivation support and investing in us

Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CV	Coefficient of variation
DLR	German Aerospace Centre
DN	Digital Number
EOS	Earth Observing System
ER	Electromagnetic radiation
ETM	Enhanced Thematic Mapper
FTP	File Transfer Protocol
GCP	Ground control point
ISODATA	Iterative Self-Organising Data Analysis
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Multispectral Scanner
NDVI	Normalised Difference Vegetation Index
NIR	Near Infra-Red
PCA	Principle Component Analysis
RMSE	Root Mean Square Error
SPOT	System Pour L'Observation de la Terre
TM	Thematic Mapper
USGS	United State Geological Surveys
VI	Vegetation Index

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CHAPTER ONE: INTRODUCTION

1.1 Background

The Cape Floristic Region (CFR) is well known for its rich biological diversity and high level of endemism in flora and fauna (Rouget *et al*, 2003; Cowling, 2004). It covers an area of 87 892 km2 and has a Mediterranean-type climate with wet, cool winters and dry, hot summers (Cowling and Richardson, 1995). There are more than 9 000 vascular species in the region of which 70% are endemic to the CFR (Balmford, 2003; Rouget *et al*. 2003). The high species endemism, unusually high and rich levels of biological diversity and high level of human induced threats are the main factors why the CFR is listed as one of the 34 global biodiversity hotspots (Myers *et al*. 2000; Pierce *et al*. 2002; Balmford, 2003; Cowling *et al*. 2003). It is also one of the only two floral kingdoms listed as biodiversity hotspots (Conservation International, 2007).

The CFR habitat has been affected by agriculture, urban expansion and alien species invasions (CEPF, 2001; Rouget *et al*. 2003; Cowling, 2004). Nearly 30% of the CFR's natural habitats have been transformed and invasive species (alien trees and shrubs) have altered the natural ecosystems and replaced many native species (Rouget *et al*. 2003).

Agriculture is the main cause of habitat transformation in the CFR (Rouget *et al*. 2003) and about 26% of the CFR, 96% of the Renosterveld and 49% of the fynbos have been transformed into agricultural land (CEPF, 2001; Balmford, 2003). The lowlands of the CFR have undergone the most transformation, while most of the montane areas have remained undeveloped and are under conservation (Rouget *et al*. 2003). The Sandveld is part of the Cape lowlands and therefore have suffered habitat transformation mainly due to anthropogenic activities such as urban expansion (increase in population), proliferation of tourism facilities, coastal development, introduction of alien species and intensive agriculture (Holmes, 2003; Mucina and Rutherford, 2006; Knight *et al*. 2007).

1.2 Contributors of Change in the Sandveld

1.2.1 Agriculture

Landuse change due to agriculture dates back to AD 500 when the nomadic Khoi Khoi pastoralists occupied the Western Cape (Joubert, 1995; Pistorius and Todeschini, 2004; Newton, 2007). The Khoi Khoi pastoralists moved seasonally in search of pastures for their livestock, and in the process burnt patches of natural vegetation to stimulate growth of fresh grass for their livestock as well as making the areas accessible (Joubert, 1995; Pistorius and Todeschini, 2004). Changes in the landuse were accelerated by the colonisation of South Africa in the 16th Century by the Dutch, which saw the establishment of the Dutch East India Company to enhance trade (Joubert, 1995; Wilkinson, 2000). As a result people started practicing commercial agriculture to produce food for the Dutch East India Company (Joubert, 1995; Wilkinson, 2000). The "free burghers" were allowed to farm and to rear animals, and were provided with loans so that they could supply the Dutch East India Company with their produce (Joubert, 1995; Newton, 2008).

Since colonisation in the 16th century, there were noticeable landuse changes, which were evidenced by the building of roads and towns and the establishment of agriculture (Wilkinson, 2000). In the Sandveld of South Africa, vast tracts of pristine land have been converted to permanent agriculture, especially potato and rooibos farming (Ashwell *et al.* 2006; CPEF, 2007). More recently, the farmers have moved into intensive irrigation farming, converting their dry land fields into irrigation plots using the central pivot irrigation system. Potato farms are known to contribute greatly to habitat transformation and they also use considerable water resources (Ashwell *et al.* 2006). The farmers harvest about 220 000 tonnes of potatoes in the Northern Sandveld per year, between 6 000 and 7 000 ha of land is used for potato farming yearly (Knight *et al.* 2007; CPEF, 2007). This has led to habitat transformation and fragmentation each year as more farmers opted to shift towards potato and rooibos farming (Ashwell *et al.* 2006; Knight *et al.* 2007; Pretorius *et al.* 2008). Labour associated with potato, rooibos and wheat farming is the major source of employment in the region (Ashwell *et al.* 2006).

The potato-farms in the Sandveld are susceptible to knot nematode or eelworm infection, which affects the quality, health, size, and number of potato tubers produced (Berg, 2006; Noling *et al.* 2005). Affected potatoes then become more susceptible to further bacterial infection and this reduces crop yield and turnover (Berg, 2006; Knight *et al.* 2007). Continual use of the same field for a longer period may increase nematode infections (Berg, 2006). So farmers cultivate potatoes for one year and then leave the plot to lie fallow for a five-year period so to avoid contamination of the potatoes (Berg, 2006; Knight *et al.* 2007). This practice has exacerbated habitat transformation as farmers are clearing more natural vegetation for agricultural purposes (Barrie Low, pers. comm. Knight *et al.* 2007).

About 80% of the natural vegetation in the Sandveld has been greatly transformed between 1989 and 2004 (Knight *et al.* 2007). About 55% of the Leipoldtville Sand Fynbos has suffered transformation because of potato and rooibos tea farming, and 40% of Lambert's Bay Strandveld is threatened by cultivation (Mucina and Rutherford, 2006). Some farmers are not 'resting' their land as this may entail loss of revenues, so they have resorted to using pesticides to deal with the problems of nematodes predation (Knight *et al.* 2007; Nicky Allsopp pers. comm.). Intensive potato, wheat and rooibos farming utilises the centre-pivot irrigation system and is highly dependent on water. This has led to excessive and illegal underground water abstraction which in turn has led to the depletion of wetlands (Ashwell *et al.* 2006; Mucina and Rutherford, 2006; Conrad *et al.* 2008). This illegal underground water extraction has affected the levels of underground water and special habitats such as the Verloerenvlei, a RAMSAR-protected and international recognised wetland (Burgers, 1991). The South African Government through the Department of Water Affairs and Forestry (DWAF) has issued water use rights to the farmers to allow them to extract underground water for irrigation purposes (Knight *et al.* 2007; Conrad *et al.* 2008). The farmers are required to have an abstraction license for surface and underground water extraction, which is provided through the Water User Association (WUA) in the Sandveld (Knight *et al.* 2007; Conrad *et al.* 2008).

1.2.2 Invasive species

In the CFR, alien species like Acacia and Pinus spp. are reported to have transformed 39% of the natural habitat in the Cape lowlands and 26% in the mountainous areas (Mucina and Rutherford, 2006). Many plant species have been introduced for a variety of reasons: some of which are: to stabilise sand dunes, for timber, firewood, as a barrier or as hedge plants (Pierce *et al*. 2002). Some of these invasive species can "survive, reproduce and spread" (Pierce *et al*. 2002) at rapid rates, invading ecosystems and replacing native species. These aggressive invaders have changed the species-rich vegetation into single species stands of trees, and this in turn has caused an increase in standing biomass and reduced stream flow (Van Wilgen *et al*, 1998; Pierce *et al*, 2002). The Sandveld is affected by invasive species such as *Acacia saligna, A. cyclops, Pinus spp*. and Eucalyptus spp., which have out-competed the native species (Mucina and Rutherford, 2006).

The aforementioned factors have contributed to continuous habitat transformation and fragmentation which are major issues in biodiversity conservation (Franklin *et al*. 2002). Habitat fragmentation affects the connectivity of the landscape by causing spatial heterogeneity, which in turn affects occupancy, reproduction and survival of many species (Franklin *et al*. 2002). Ultimately, this can affect gene flow between patches and lead to local extinction of species.

1.3 Use of GIS and Remote Sensing

In order to understand biophysical and human-induced processes that are contributing to land use/cover change and habitat fragmentation there is need to accurately detect and quantify them (Narumalani *et al*. 2004). Increasing availability and accessibility of remote sensing and geographical information systems (GIS) data and software has encouraged the quantification, assessment and analysis of ecosystem function and long term change in the spatial patterns (Narumalani *et al*. 2004; Jensen, 2005). Remote sensing is often used as a tool to detect seasonal and inter-annual vegetation dynamics. Many methods using vegetation indices (VI) such as NDVI (Normalised Difference Vegetation Index) and EVI (Enhanced Vegetation Index) have been developed to monitor trends in vegetation cover and crop phenology (Jakubauskas *et al*. 2002; Sakamoto *et al*. 2005).

1.4 Aim of the research

The broader aim of this study is to investigate spatial and temporal changes in landuse and vegetation cover in the Sandveld.

1.4.1 Specific objectives

- To map landuse using Landsat TM remote sensing imagery,
- To detect the multi-temporal landscape changes from 1990 to 2007,
- To investigate intra-annual and inter-annual changes in vegetation cover using time series,
- To quantify the degree of landuse change using landscape metrics/ fragmentation indices,
- To predict future landuse scenarios

1.5 The Study Area

The Sandveld (Figure 1) which is located between the Olifants and Berg River in the West Coast District of the Western Province,- covers three municipalities namely Matzikama, Cederberg and Bergriver and has a coastal boundary with the Atlantic Ocean. Sandveld is falls in the Greater Cederberg Biodiversity Corridor and is rich in biodiversity (and has endemic and red data species). The Sandveld is characterised by very cold and rainy winter and dry hot summers with temperatures ranging between 6°C in winter and 32°C in summer (Mucina and Rutherford, 2005). The mean monthly temperature ranges between 5 mm to 38 mm (summer and winter respectively). In the Sandveld as the rest of the fynbos biome fire is a very important component and its prevalence is high as the areas is highly flammable due to the presence of flammable oils. Sandveld is confined to the deep acid sands of the West Coast of Tertiary origin, being aeolian and podsolized, but some are derived from the Cape Granite, Table Mountain Group sandstones and Malmesbury Cape shales.

There have been a series of vegetation mapping the Cape Floristic Region and its dates back to the work that was some by John Acocks in 1953 he mapped the Sandveld into four vegetation types which are West Coast Strandveld, Coastal Macchia, Macchia (fynbos) and Coastal Renoster-bushveld.(Campell *et al.* 1981; Moll *et al.* 1983). This was further improved by Boucher in 1981 who mapped the Sandveld into main categories which are:

- Cape Fynbos Shrublands which are the Sand Plain Fynbos. These are the heathlands confined to the acid sands of the West and South Coast of the Cape Floristic Region (Campell *et al.* 1981; Moll *et al.* 1983).

- Cape Transitional small-leafed shrublands i.e. West Coast Renosterveld: This was mapped as Coastal Renosterveld in Acocks vegetation types which are cupressoids and small-leafed shrublands on the Malmesbury shales and Cape granites.(Campell *et al.* 1981; Moll *et al.* 1983).
- Cape Transitional Large Leafed Shrublands i.e. West Coast Strandveld: these are usually open canopy with 40 to 90 % canopy cover (Campell *et al.* 1981; Moll *et al.* 1983).

A further development to vegetation mapping by Low and Rebelo in 1996 added more detailed (new description and classification) system to the Acocks' vegetation types and the vegetation was mapped into 68 vegetation classes for South Africa, Lesotho and Swaziland which has fewer classes than Acocks'. An intensive vegetation mapping was done by Mucina and Rutherford in 2006 with the help of other researchers (Mucina and Rutherford 2006) and it mapped 435 vegetation classes in South Africa, Lesotho and Swaziland (Mucina and Rutherford 2006) and the Sandveld was divided into 13 vegetation types which are:

- Cape Inland Salt Pans
- Cape Lowlands Freshwater Wetlands
- Cape Seashore Vegetation
- Cederberg Sand Fynbos
- Freshwater Lakes
- Graafwater Sandstone Fynbos
- Hopefield Sand Fynbos
- Lambert's Bay Strandveld
- Langebaan Dune Strandveld
- Leipoldtville Sand Fynbos
- Northern Inland Shale Band Vegetation
- Piketburg Sandstone Fynbos
- Swartland Shale Renosterveld

The Fine Scale Biodiversity Planning Project argued that the SA VEGMAP by Mucina and Rutherford was too coarse, so the was need for a fine scale vegetation mapping exercise which was conducted by Nick Helme (Helme 2007). The mapping exercise was based on the SAVEG map but it added several overlooked vegetation types and redrew the boundaries of the some of the classes (Helme, 2007). These vegetation type boundaries were demarcated with the assistance of geology maps, and it was produced with a high degree of precision and accuracy (Helme, 2007). Figure 2 indicates the 19 vegetation classes that were mapped in the fine scale vegetation mapping exercise.

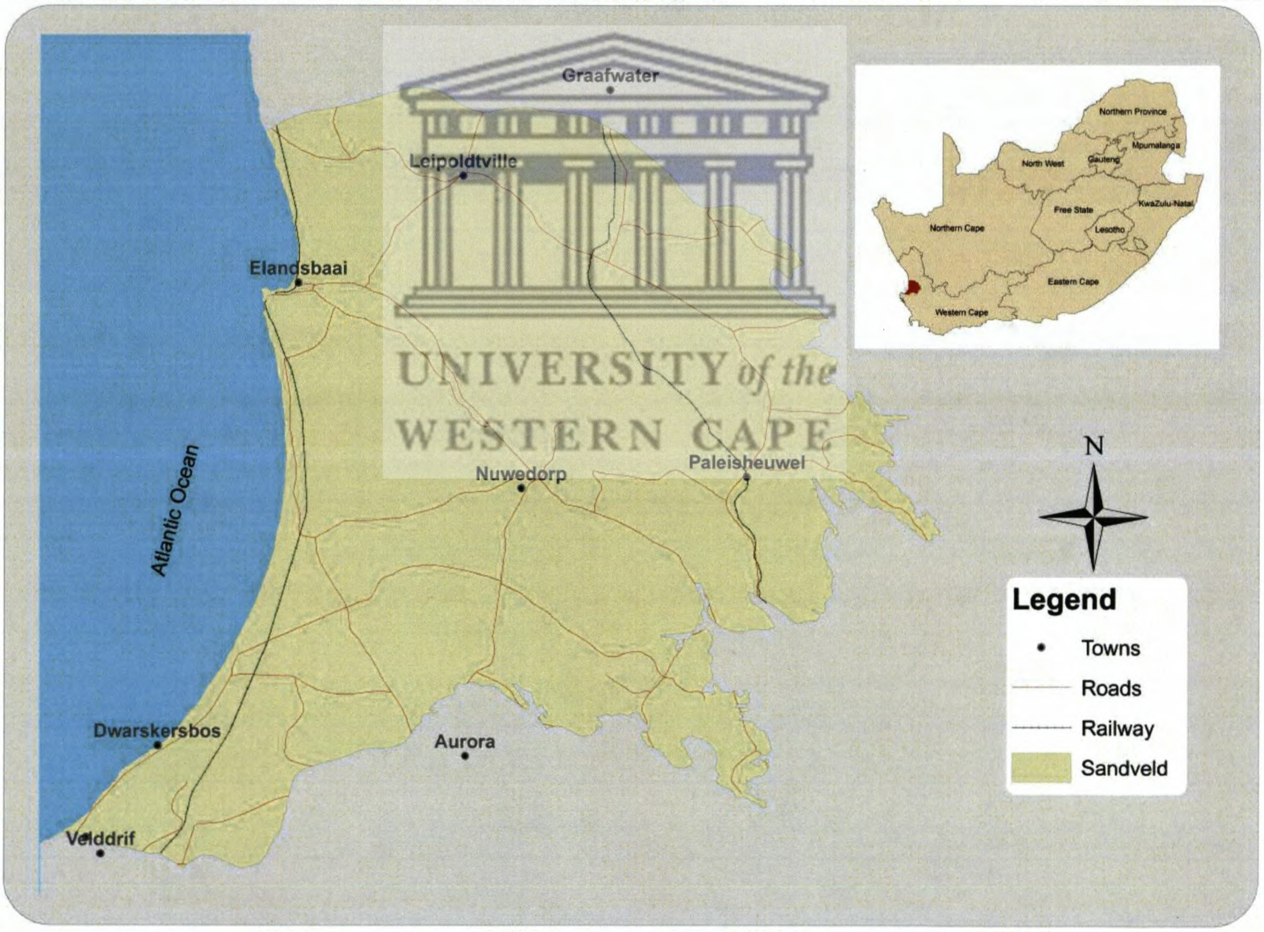

Figure 1: Map showing where the Sandveld Region is located in the Western Cape Province of South Africa.

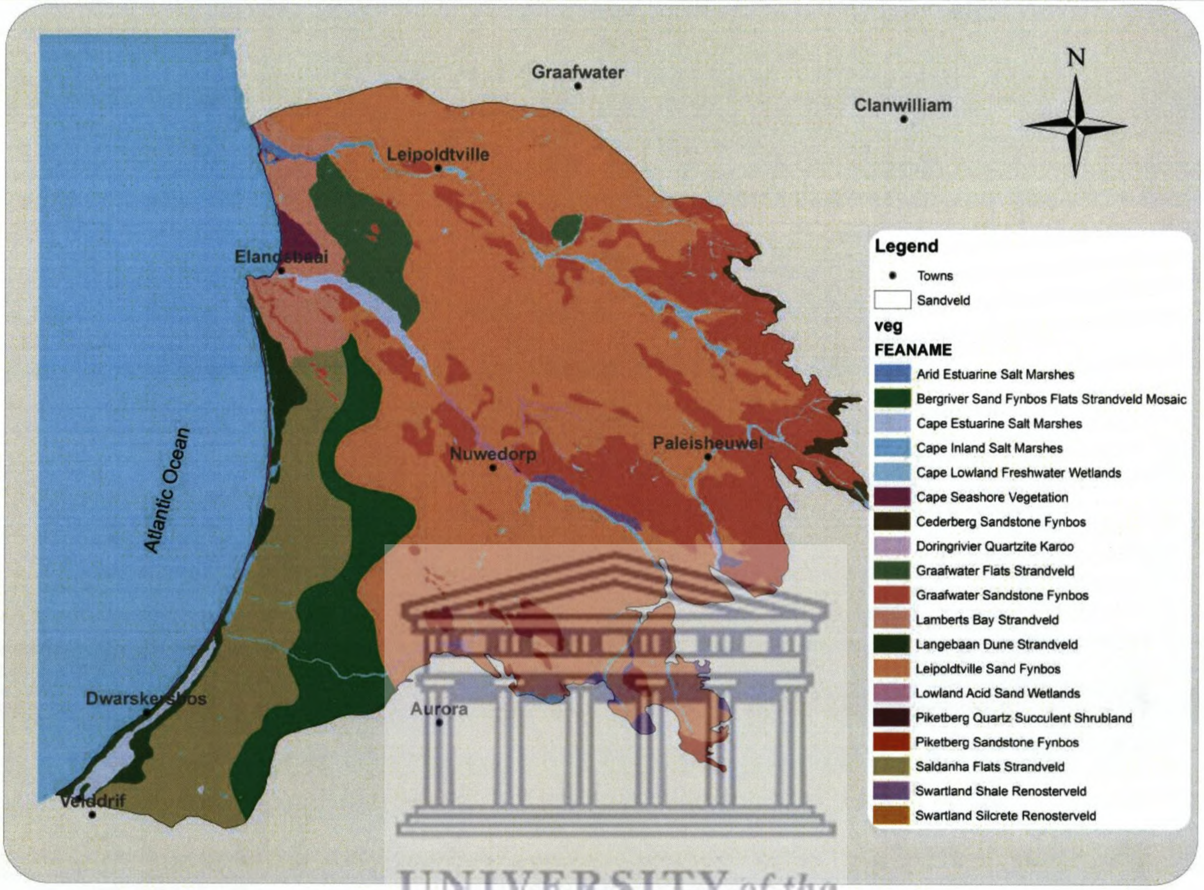

Figure 2: Vegetation types in the Sandveld Region derived from the Fine Scale Vegetation Mapping (Helme, 2007).

CHAPTER TWO: LITERATURE REVIEW

2.1 Remote Sensing concepts

2.1.1 Image Classification Techniques

Image Classification is a process of categorising an image into a fewer number of individual classes, based on the reflectance values (Lillesand and Kiefer, 1987, Jensen, 2005). Remote sensing imagery classifies different feature types that manifest different combinations of digital numbers (pixel values) based on their inherent spectral reflectance and emmittance properties. The overall objective of image classification procedures is to automatically categorise all pixels in an image to land cover classes or themes values (Lillesand and Kiefer, 1987; Jensen, 2005). Two broad approaches exists which are the supervised and unsupervised. In the unsupervised classification procedures pixels are automatically classified based on the similarities of reflectance (Lillesand and Kiefer, 1987; Jensen, 2005; CCRS, 2008). The supervised classification uses the prior knowledge and the training procedures will produce a set of signatures that are the criteria for a set of landuse / land cover classes in the imagery. Image classification is mainly done using the spatial pattern recognition, which is a family of classification procedures that uses the pixel-by-pixel spectral information. Spatial pattern recognition involves categorisation of the image pixels based on their spatial relationships with the neighbouring pixels.

2.1.1a Unsupervised classification

In this procedure the image processing software cluster pixels based on the statistics of the radiometric value/digital number of the pixel, without the intervention of the image analyst or user (Jensen, 2005; CCRS, 2008). Results of an unsupervised classification are usually used to demarcate the training sites, which are a major input in the supervised classification. There are many unsupervised classification algorithms and these include:

- CLUSTER: this method uses the histogram peak technique to classify image data. It bases its classification on the natural grouping of pixels in the image data when they are plotted on a spectral space (Leica Geosystems, 2005; Jensen, 2005, Eastman, 2006)
- ISODATA: stands for Iterative Self-Organizing Data Analysis Technique, which is a method that uses minimum spectral distance formula to iteratively classify the pixels and redefine the criteria of each landuse class. The data is classified until either a maximum number of iterations have been performed or a maximum percentage of unchanged pixels have been reached between two iterations (Ball and Hall, 1965; Leica Geosystems, 2005; Jensen, 2005)

2.1.1b Supervised Image Classification

In this procedure the image analyst supervises the classification by defining small areas, called training sites, on the satellite image. Training sites are representative of the desired land use classes. The effectiveness of the delineation of the training sites is enhanced when the remote sensing analyst is knowledgeable about the geography of the landscape that he/she is classifying and has adequate remote sensing experience (Skidmore, 1989; Jensen, 2005). After delineating the training sites, the software determines the spectral signature of each training site using certain extracted statistics (Leica Geosystems, 2005) and then classifies the images according to a classification algorithm (Jensen, 2005). There are many supervised classification algorithms, these include:

Maximum likelihood classification: this classification algorithm is based on the probability density function associated with a particular training site signature. Pixels are assigned to the most likely class and this will be based on a statistical analysis (Jensen, 2005; Leica Geosystems, 2005).

Minimum distance classification: this procedure calculates spectral distance and pixels are assigned to classes with mean closest to the value of that pixel (Jensen, 2005; Leica Geosystems, 2005; Eastman, 2006).

Parallel Piped Classification: this classification is based on a set of lower and upper threshold reflectance determined for each signature on each band. To belong to a particular class the pixel must exhibit reflectances within the lower and upper thresholds (Jensen, 2005; Leica Geosystems, 2005; Eastman 2006).

2.1.1c Accuracy Assessment

Accuracy assessment or validation evaluates the correspondence of the classified images to the assumed true geographical data as a way of determining the integrity of the classification procedure (Congalton, 1991, Leica Geosystems, 2005). Accuracy of the classified image is judged against the assumed-trued (validated) data derived from aerial photographs, and field visits. The accuracy assessment reveals the degree of correspondence between the classified image and the reality on the ground (Congalton 1991; Jensen, 2005). The statistical validity of the assessment improves as the number of sample increases. Accuracy assessment is usually conducted using:

- An error matrix which simply compares the reference class values to the assigned class values,
- An accuracy totals report that calculates statistics of the percentages of accuracy, based upon the results of the error matrix and
- The Kappa statistics, which is used to measure the degree of agreement between the classified images and assumed true data (Jensen, 2005; Leica Geosystems, 2005).

2.2 Change Detection

Ramachandra (2004) defines change detection as a process that is used to quantify the changes that are associated with landuse and land cover in the landscape using geo-referenced multi-temporal remote sensing information. Change detection is one of the main applications of collecting remote sensing data (Singh, 1989). Remote sensing is also important for monitoring as well as mapping natural resources. Change detection using image processing techniques and geographical information systems can be used to measure the degree of change between two or more dates (Jensen, 2005; CCRS, 2008), and is very useful to understand and assess habitat fragmentation, fire, rate of deforestation, urban growth and coastal development (Ramachandra, 2004;

Geosystems, 2005; Jensen, 2005). There are different change detection techniques and algorithms that are used to monitor changes in landuse and land cover (Jensen, 2005).

Four basic aspects of change detection need to be taken into consideration when monitoring natural resources (Coppin and Bauer 1996). These are:

- Detecting that changes have occurred,
- Determining the nature of the change,
- Measuring the degree of change, and
- Assessing the spatial patterns of change

For change detection to be effective, the two images need to be of the same projection, and the pixels must be aligned and must have the same spatial resolution (Jensen, 2005). In addition to this, the image must be captured at the same time of the day, as this will eliminate errors caused by the different angles of the sun (Jensen, 2005) but this is usually not achieved hence the need for radiometric corrections. After applying the change detection technique, the resultant image, which is characterised by a normal distribution of reflectance, will be divided into three main categories based on a selected threshold (usually the standard deviation) which are: negative change, positive change and no change (Leica Geosystems, 2005; Eastman 2006). Change detection algorithms (Singh, 1989; Coppin and Bauer, 1996; Lievien, 1998) include:

- Change vector analysis (CVA) – is when two remote sensing images are plotted against each other the graph to reveal the magnitude and direction of change over time (CCRS, 2008). CVA uses any number of spectral bands from multi-temporal satellite data to produce change image shows the magnitude and direction of change (Yoon *et al.* 2005)
- Image differencing – is a technique that is used to detect changes between multi-temporal images by finding the difference between each pixel in each image. This technique works properly when the corresponding points coincides and when they are on the same projection (Jensen, 2005; Eastman, 2006)

- The cross-classification procedure is a way of determining the change in the landscape between two dates as it produces quantitative and qualitative results which shows spatial distribution of land use change between two respective dates (Jensen, 2005; Eastman. 2006). The Kappa Index of Agreement quantify the change from the correlation matrix which shows how much of the landuse class has been changed into another category. The Kappa Index of Agreement produced with the table is also a quantitative means of evaluating the changes. Overall, the Kappa Index of Agreement can be used whenever the land cover classes of two-date images must be evaluated for change. It provides an overall change agreement for the two images and per category change agreements.

These algorithms are used to quantify the degree of change between multi-dates and for this study the post-classification procedure was adopted using the images differencing and cross-classification algorithms.

2.3 Habitat Fragmentation

Habitat fragmentation is both an outcome and a dynamic process of the breaking up of a homogenous/continuous landscape into heterogeneous landscapes through landscape transformation, leading to numerous, small and discontinuous patches (Franklin *et al.* 2002). This has both negative and positive effects on occupancy, reproduction and survival of species (Franklin *et al.* 2002). Habitat fragmentation is regarded as the primary cause of biodiversity loss (Wu *et al.* 2003) and is a crucial issue in biodiversity and resources conservation (Franklin *et al.* 2002). Humans have contributed to habitat fragmentation through agriculture, urban development, rural development and forestation. The intensity of these anthropogenic activities and natural phenomena affects the extent and the pattern of habitat fragments (Fahrig, 2001; Cayuela 2007), and the degree of habitat fragmentation affects animal and plant species differently (Fahrig, 2001, Franklin *et al.* 2002). Habitat fragmentation has two main aspects – patch size / area reduction and patch isolation (Turner, 1990). Small habitat patches cannot provide enough resources for many species, leading to population reductions and species extinctions in a patch (Farina, 1998). Generalist species, which are highly adaptable and can make use of a variety of resources, and can outcompete other species (Farina, 1998). The transition of a habitat from a homogenous to a heterogeneous landscape affects the quality of the habitat structure and composition, and causes an increase in edge habitat as well as the reduction in the interior area (Franklin *et al.* 2002). Patch isolation increases the vulnerability of fragment to external pressures and influences (Fahrig, 2001). To reduce the effects of habitat fragmentation some governments have initiatives to establish protected corridors, which will connect, patches natural habitat (Farina, 1998). These corridors will allow species to move between habitats and help maintain genetic diversity which will help in the long-term restoration of ecosystem functioning.

2.3.1 Fragmentation Indices

Changes in the landscape can be monitored using spatial oriented metrics (landscape metrics) which is used to measure multi-temporal landscape parameters. Fragmentation indices quantify the landscape patterns, which have a pronounced ecological significance. Their interpretation requires an awareness of the landscape context. There are a number of landscape metrics that are based on the number, size, shape, and configuration of patches in the natural habitat that can be used to quantify habitat fragmentation (Lausch and Herzog, 2002; Griffith. 2004). Quantification of landscape processes, patterns, and composition using the landscape metrics is necessary for conservation efforts to succeed (Griffith. 2004). These landscape patterns, which are inherent and very crucial in describing landscapes, were used as indicators of ecological functions such as habitat connectivity, number, and size of habitat fragments (Griffith. 2004, Lausch and Herzog, 2002) and these include the following:

2.3.1a Number of Patches

This is the number of contiguous area/patches of the patch type/class. If the number of patches is equal to 1 it means the landscape consist of a single patch. The number of patches is also dependent on the accuracy of the remote sensing information that was used as well as the filter method that was implemented ((McGarigal, K *et al.* 2002).

2.3.1b Patch Size

This is the simplest measure of configuration that represents the spatial character of the patch. This is a patch level index and is a major determinant of habitat fragmentation (McGarigal, K *et al*. 2002).

2.3.1c Edge Density

Edge Density is the perimeter of the patches divided by habitat area (ha). It is supposed to be greater or equal zero. If the Edge Density equates zero it means there is no edge in the landscape. Therefore, edge density works hand in hand with the total edge, so using these two metrics together is redundant (McGarigal, *et al*. 2002).

2.3.1d Mean Shape Index

Shape index equates to the total length of edge in the landscape divided by the minimum total length of edge possible. When the mean shape index is 1 it means the landscape is maximally compact and there are square patches but as the shapes become more and more irregular (complexity of the shape), the index will increase without limit. The shape index must be greater or equal to 1 and can be used as a measure of patch aggregation and disaggregation. With the increase in the shape index the patches increases in the degree of disaggregation (McGarigal and Marks, 1994, 1995, McGarigal, K *et al*. 2002).

2.3.1e Fractal Dimension

Mean patch fractal dimension (MPFD) is another measure of shape complexity that is determined using the formulae below:

$Dimension = \frac{2\log P}{Log A}$, where P is the perimeter of the patch and A is the Area

If Fractal Dimension approaches 1 with simple perimeters and 2 with the patches are complex (McGarigal and Marks, 1994, 1995).

CHAPTER THREE: LANDUSE CLASSIFICATION, CHANGE DETECTION, HABITAT FRAGMENTATION AND PREDICTION OF FUTURE SCENARIOS

3.1 Abstract

The Sandveld forms part of the Cape Lowlands and falls within the Cape Floristic Region (CFR), which is one of the 34 global biodiversity hotspots. The CFR is well known for its rich biodiversity and high degree of species endemism and high levels of biodiversity threats. High biodiversity threats in the CFR are because of population growth, which has led to agricultural activities, invasive alien species and urban development. In this respect remote sensing and GIS technologies are used to monitor these landuse dynamics and quantify the degree of landuse change in the Sandveld. Landsat 5 satellite images of 1990, 2004 and 2007 with a spatial resolution of 30m were used to characterise the landuse of the respective years using the maximum likelihood supervised classification method. Delta (post classification) change detection techniques were employed to assess the dynamics of landuse. Markov stochastic algorithms modelled future scenario in landuse change using landuse images of 1990 and 2007. The Results indicated a continual reduction in the natural habitat and this was quite evident on the multi-temporal landuse maps. Future predictions suggested a 30% reduction in the natural habitat by 2020, implying that the landscape will be highly fragmented and water bodies will be negatively impacted. Without future conservation interventions more natural vegetation will be lost, a condition that will affect heavily on biodiversity and of more significant water-dependent ecosystems such as wetlands. This has significant implications for the long-term provision of water from ground water reserves and for the overall sustainability of current agricultural practices.

Keywords

Change detection, habitat fragmentation, gains and losses, Markov, land change modeller, remote sensing

3.2 Introduction

The Sandveld forms part of the Cape Floristic Region, which is well known for species endemism, and high levels of threats to biodiversity (Myers, 2000). In the Sandveld are sites of conservation importance such as the Verlorenvlei (Elandsbaai), a RAMSAR site, which hosts threatened species (Turpie *et al*. 2002; Conrad *et al*. 2004; Knight *et al*. 2007). There is habitat fragmentation in the Sandveld due to intensive agriculture, (potato, wheat and rooibos tea farming) urban growth (development of tourism facilities) (Holmes, 2003; Conrad *et al*. 2008), and invasive species which are outcompeting the native species (Rouget *et al*. 2003; Knight *et al*. 2007; Pretorius, 2008). As the rainfall is relatively low in the Sandveld, farmers rely significantly on underground water abstraction for irrigation of their farmlands (Conrad *et al*. 2004; Knight *et al*. 2007). Average groundwater recharge in the Sandveld is 234 Mm^3/year (Knight *et al*. 2007), with the potato farming using an average of 46.9 Mm^3/year, implying that twenty percent of the recharge is used for potato farming (Knight *et al*. 2007). This is a major threat to the available water resources as farmers are excessively extracting underground water resources legally and illegally through artesian boreholes (Conrad *et al*. 2008). The Department of Water Affairs and Forestry (DWAF) has granted certain water use rights for farming purposes but some of the farmers are still extracting underground water illegally (Knight *et al*. 2007; Conrad *et al*. 2008).

Intensive farming of potato, wheat and rooibos which are on increase in the Sandveld are the principal economic activities and sources of livelihoods in the Sandveld (Knight *et al*. 2007). Farmers are clearing natural vegetation for agricultural purposes and this has been exacerbated by the five-year rotation of fields that is done to reduce nematode infestation (Barrie Low, pers comm.). Potatoes are susceptible to these root-knot nematodes or eelworms that affect the quality, size and number of potato tubers thereby reducing the market value of the potato (Berg, 2006; Noling, 2005). Using the same field/plot continuously for a long period may increase eelworm infestations and it is recommended to avoid the continual use of a contaminated field (Berg, 2006) and resultantly fields are left to lie fallow for five years to rid nematodes infestations (Knight *et al*. 2007; Barrie Low, pers comm). This has accelerated habitat fragmentation and increased the discontinuity of the natural habitat (Fahrig, 2001; Franklin *et al*. 2002). Species become increasingly isolated with the continual decrease in the natural habitat and they become vulnerable to extinction, (Fahrig, 2001; Franklin *et al*. 2003;

Cayuela, 2007). Conservationists need an understanding of the degree of habitat fragmentation, composition and configuration of natural habitats and landuse dynamics in order to be able to make informed decisions in resuscitating the fragile habitat (Fahrig, 2001; Franklin *et al*. 2002).

To understand biophysical and human-induced processes there is a need to accurately map, detect and quantify changes in landuse (Narumalani, 2004). Increasing availability and accessibility of remote sensing and geographical information systems (GIS) data and software has encouraged quantification, assessment and analysis of ecosystem function and long term changes in the spatial patterns (Narumalani, 2004; Jensen. 2005). In this regard this chapter characterised landuse types in the Sandveld using Landsat satellite imagery, quantified and predicted landuse change using landuse maps of 1990 and 2007.

3.3 Data used

Landsat TM satellite images of 16/10/1990, 09/12/ 2004 and 17/02/ 2007 (path 175 and 83) were acquired from the University of Maryland's Global Land Cover Facility. To avoid geometric errors on the images an image-to-map registration was conducted for all these Landsat images using road data as reference and the root mean square error (RMSE) was 27 m, which is less than a single Landsat TM pixel. Atmospheric correction procedures were not done due to software constraints. However, radiometric correction is unnecessary for post-classification change detection (Jensen, 2005). Geometric correction was followed by the resampling and alignment of pixels in all the images (layerstacking), which is a major requirement in multi-temporal change detection (Jensen, 2005).

Landsat TM (Table 2) has been operational since 1st of March 1984 and it has onboard Thematic Maper (Jensen, 2005; USGS, 2009). Landsat 7 (ETM+) has been operational since 1999 despite a malfunction which occurred in 2003. (Jensen, 2005; USGS, 2009). Landsat images has had diverse applications which includes land surveys, land management, coastal mapping, vegetation mapping, water resource planning, agricultural forecasting, forest management, sea ice movement, and cartography (CCRS, 2008; USGS 2009).

Table 1: Characteristics of the Landsat 5 (Thematic Mapper (TM)) TM and Landsat 7 (Enhanced Thematic Mapper + (ETM+)) Satellites images

	Landsat 5 (TM)	Landsat 7 (ETM+)
Time of Operation	1 March 1984 – Present	15 April 1999 – present
Sensors	TM	ETM+
Temporal Resolution	16 days	16 days
Spatial Resolution	57 x 79 m for MSS 30 m reflective, 120 m thermal	30m, reflective 60m (thermal band) 15m (panchromatic band)
Wavelengths	MSS Band 4 Visible green (0.5 - 0.6 µm) Band 5 Visible red (0.6 - 0.7 µm) Band 6 Near-Infrared (0.7 - 0.8 µm) Band 7 Near-Infrared (0.8 - 1.1 µm) TM Band 1 Visible (0.45 – 0.52 µm) Band 2 Visible (0.52 – 0.60 µm) Band 3 Visible (0.63 – 0.69 µm) Band 4 NIR (0.76 – 0.90 µm) Band 5 NIR (1.55 – 1.75 µm) Band 6 Thermal (10.40 – 12.50 µm) Band 7 MIR (2.08 – 2.35 µm)	ETM+ Band 1 Visible (0.45 – 0.52 µm) Band 2 Visible (0.52 – 0.60 µm) Band 3 Visible (0.63 – 0.69 µm) Band 4 NIR (0.77 – 0.90 µm) Band 5 NIR (1.55 – 1.75 µm) Band 6 Thermal (10.40 – 12.50 µm) Band 7 MIR (2.08 – 2.35 µm) Band 8 PAN (0.52 - 0.90 µm)

3.4 Methodology

3.4.1 Image classification and Accuracy assessment

Due to dynamic changes in the landscape, training sites were demarcated for each image. Training sites and land classification systems were derived C.A.P.E. Fine Scale biodiversity Planning land cover that was produced from a SPOT 5 imagery of 2005 (Thompson, 2007). The following predefined landuse classes were classified in each image:

- Water: open water including dams, ocean and rivers
- Natural Vegetation: natural (pristine) and semi-natural untransformed habitat
- Wetlands : intermittently flooded ecosystems, including vegetated and non-vegetated swampy areas

- Open Sands: bare sandy areas especially along the coastline
- Agriculture: centre-pivot irrigated intensive farmland and cultivated semi-commercial / subsistence farming and low intensity farming
- Disturbed Veld: disturbed shrub- and grassland
- Burnt Areas/ Fire Patches: bare areas due to recent fires. This landuse class was characterised in 2004 and 2007 as the fire occurred in 2003.

Smaller training sites were demarcated to help improve the accuracy of the classification accuracy as signatures of bigger training sites were overlapping into each other. A maximum likelihood classifier (Supervised Classification module (ERDAS IMAGINE 9.2 (Leica Geosystems, 2005)) was run on the pre-processed imagery, producing the predefined landuse classes. To improve the classification the following post-classification procedures were conducted:

a) Contiguity analysis (GIS Analysis in ERDAS IMAGINE (Geosystems, 2005))
    (i) Clump (in ERDAS IMAGINE 9.2 (Geosystems, 2005)): contiguous groups of pixels were included in one class
    (ii) Eliminate (in ERDAS IMAGINE 9.2 (Geosystems, 2005)): regions that were too small to be considered valid were eliminated (Leica Geosystems, 2005)
b) Recode (in ERDAS IMAGINE 9.2 (Geosystems, 2005)): Classes were combined to reduce the number of classes by reassigning some of the classes into new ones. Resultantly all the landuse classes were recoded into eight classes.
c) Neighborhood functions (in ERDAS IMAGINE 9.2 (Geosystems, 2005)) were used to filter the classified images using the 3x3 matrix.
d) Accuracy assessment (ERDAS IMAGINE 9.2 (Geosystems, 2005)) was used to evaluate the correspondence of the classified landuse maps to the “assumed true” geographical data as a way of determining the integrity of the classification procedures (Congalton, 1991; Leica Geosystems, 2005). This was conducted using a set of 100 randomly generated waypoints and GPS points collected from field

visits. The accuracy of the landuse maps was judged against ground-based photographs acquired during the field verification process, field verification and Google Earth.

3.4.2 Landuse Change Analysis

Cross-tabulation of landuse maps (1990, 2004 and 2007) and determining the gains and losses in each landuse class was conducted using Land Change Modeller, (IDRISI Andes (Clarks Lab, 2006)). The following parameters were derived:

- contributors of change in each landuse class percentage change (of each landuse class)
- net change of each landuse class
- Persistence of the landuse class: the landuse that did not change between the two respective dates.
- Gains and losses of each landuse class: Gains are the positive changes in landuse, where other landuse classes were converted into the respective landuse class. Losses are the negative changes in landuse use when the respective landuse class is converted into other landuse types.

The CROSSTAB function (IDRISI Andes (Clarks Labs, 2006)) was used to determine the Kappa Index of Agreement between the Landuse maps.

Prediction of future landuse change was done using the MARKOV (IDRISI Andes (Clarks Lab, 2006)) and CA_MARKOV modules (Cell Automated Markov Analysis) (IDRISI Andes (Clarks Lab, 2006)). MARKOV (IDRISI Andes (Clarks Lab, 2006)) was used to set transitional probabilities and transitional areas between 1990 and 2007 using the respective landuse map. CA_MARKOV produced the predicted landuse map of 2020 using 100 iterations based on the transitional probabilities and transitional areas.

3.4.3 Habitat Fragmentation

Patch Analyst 4 (Rempel 2008; Elkie *et al.* 1999), an extension of Arc GIS (ESRI, Redlands, Calif.) and Arc View (ESRI, Redlands, Calif.) which is a modified version of FRAGSTATS (McGarigal *et al.* 2002) was used to calculate fragmentation statistics for 1990 and 2007. Habitat fragmentation indices were determined for fragments that are greater than 0.1 ha in size, using the natural vegetation, wetlands and water landuse classes derived from the respective landuse maps. The following fragmentation indices were determined:

- Area Weighted Mean Shape Index
- Mean Shape Index
- Edge Density m/ha
- Mean Patch Size (ha)
- Number of Patches
- Median Patch Size (ha)
- Total Areas of the Natural Patches (ha)

3.5 Results

The accuracy of the landuse classification for the 2007 landuse was 80% and the overall Kappa statistic, which expresses the proportion reduction in error (Leica Geosystems, 2005; Congalton, 1991), was 0.71.

Natural vegetation which comprises pristine (natural) or semi-natural and untransformed environments covered an area 46% of the total area in 1990, 38% in 2004 and 35% in 2007(Table 2). There is a 17% loss in natural vegetation between 1990 and 2004 and consequently an 11% reduction between 1990 and 2007 . Agricultural lands covered 33% of the total area in 1990, this increased to 38% 2004 and however it was reduced to 35% in 2007 (Table 2). The disturbed veld covered an area of 16% of the total area in 1990 and it increased by 17% 2007 There was also evidence of fire disturbances, which destroyed the natural habitats and agricultural lands and this was evident in landuse of 2004 (Figure 4) and 2007 (Figure 5). About 6 135 ha of land were affected by the 2003 veld fires which coincided with the drought periods.

Table 2: Areas and proportion of landuse classes for 1990, 2004, and 2007 as well as percentage change of land use class area between 1990 and 2004, and 1990 and 2007.

Landuse Classes	1990		2004		2007		% Change (1990-2004)	% Change (1990-2007)	% Change (2004-2007)
	Area	Proportion	Area	Proportion	Area	Proportion			
Agriculture	65 588	33%	75 702	38%	68 872	35%	15%	5%	-9%
Burnt Areas			6 135	3%	5 844	3%			-5%
Disturbed Veld	32 315	16%	32 310	16%	3 3779	17%	-0%	5%	5%
Natural Vegetation	91 656	46%	76 089	38%	8 1642	41%	-17%	-11%	7%
Open Sands	1 226	1%	582	1%	764	0%	-52%	-38%	31%
Water	1 578	1%	1 309	1%	1 272	1%	-17%	-19%	-3%
Wetlands	6 647	3%	6 882	3%	6 836	3%	4%	3%	-7%
Total Area	199009		199 009		199 009				

3.5.1 Landuse classification

Figure 3: Landuse map of 1990 of the Sandveld, South Africa based on the maximum likelihood classification of the Landsat TM satellite image (175/83) of 16 October 1990.

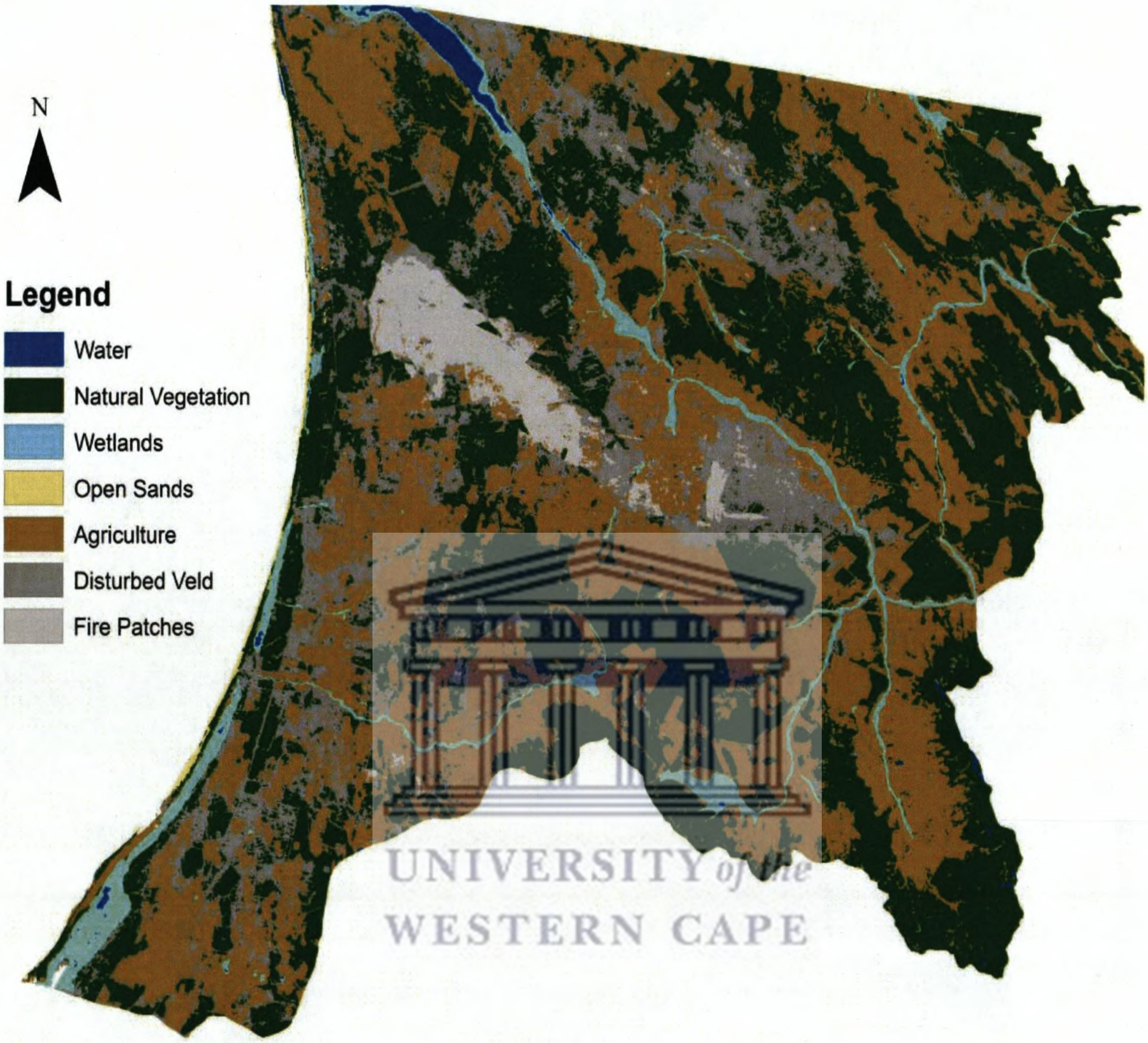

Figure 4: Landuse map of 2004 of the Sandveld, South Africa based on the maximum likelihood classification of the Landsat TM satellite image (175/83) of 9 December 2004.

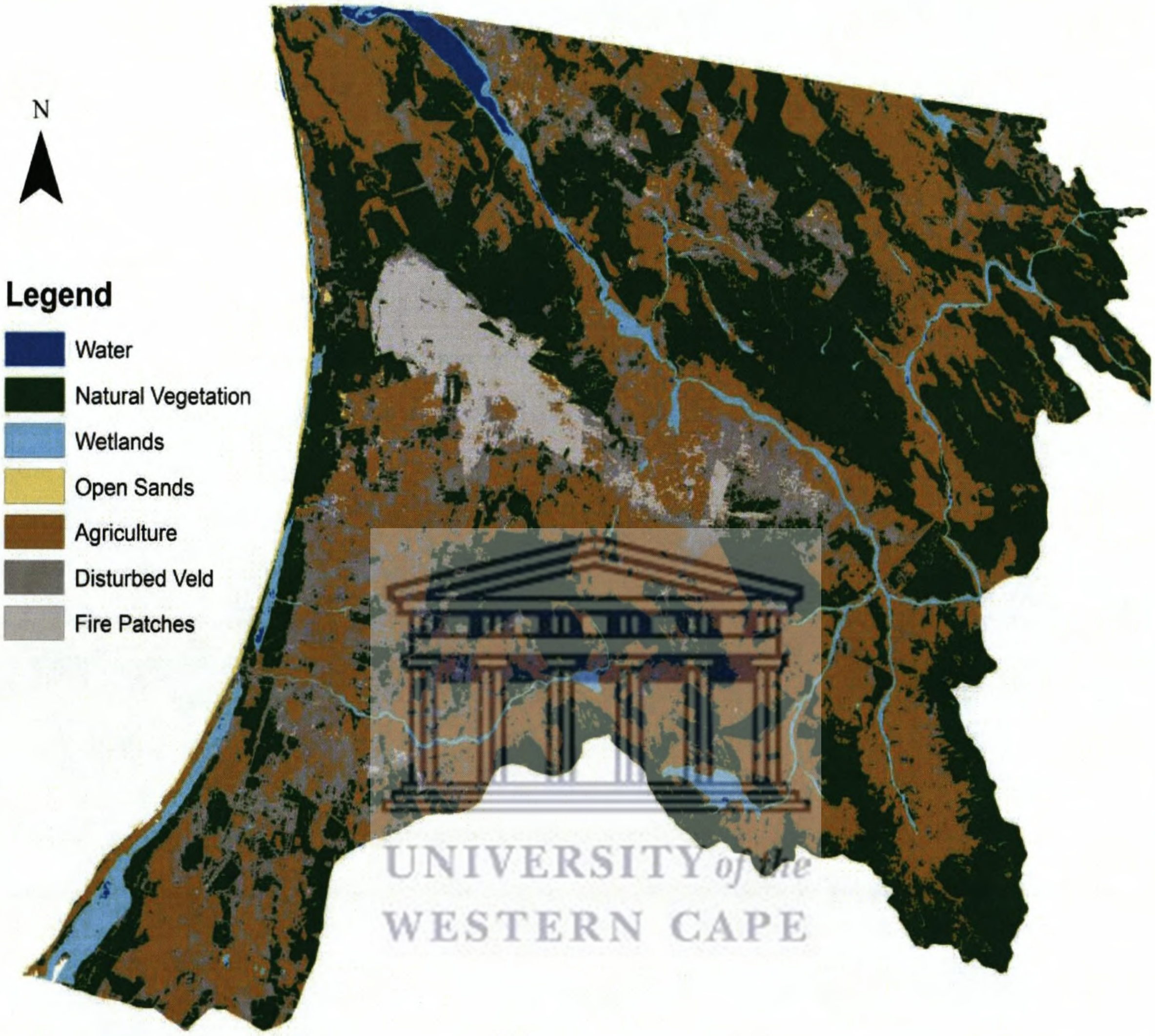

Figure 5: Landuse map of 2007 of the Sandveld, South Africa based on the maximum likelihood classification of the Landsat TM satellite image (175/83) of 17 February 2007.

3.5.2 Landuse Change Analysis in Fire Patches

The extensive fires, which occurred in 2003 destroyed natural, near natural and degraded habitats and led to the loss of 3 335 ha of natural vegetation, and 658 ha of agricultural lands (Table 3). Some habitats (280ha) that were classified as fire patches in 2004 were used for agriculture in 2007 but 5 844 ha of the fire patches persisted between 1990 and 2007.

Table 3: Proportions of landuse classes of 1990 that were affected by the 2003 fires masked from the landuse map of 1990.

Landuse Classes	**Area (ha)**	**Proportion (%)**
Water	2	0.03%
Natural Vegetation	3 335	54%
Open Sands	261	4%
Agriculture	658	11%
Disturbed Veld	1 879	31%
Total Area	921	100%

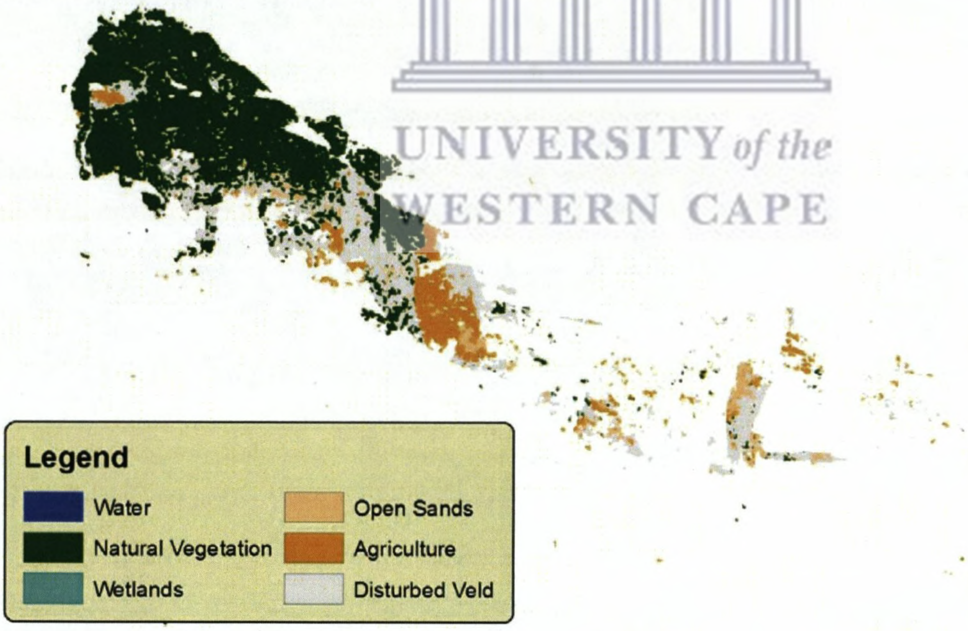

Figure 6: Landuse classed of 1990 that were affected by the 2003 fires. This was extracted from the landuse map of 1990 using the fire mask.

3.5.3 Change Analysis between 1990 and 2007 (excluding the fire patches)

Table 4: Proportion of landuse classes that were not affected by the 2003 fires derived from the classified map of 1990, 2004 and 2007.

Landuse Classes	**1990**	**2004**	**2007**
Agriculture	64 930	75 702	68 593
Disturbed Veld	30 436	32 310	33 779
Natural Vegetation	88 321	76 089	81 630
Open Sands	964	582	764
Water	1 577	1 309	1 272
Wetlands	6 647	6 882	6 836
Total Area	192 874	192 874	192 874

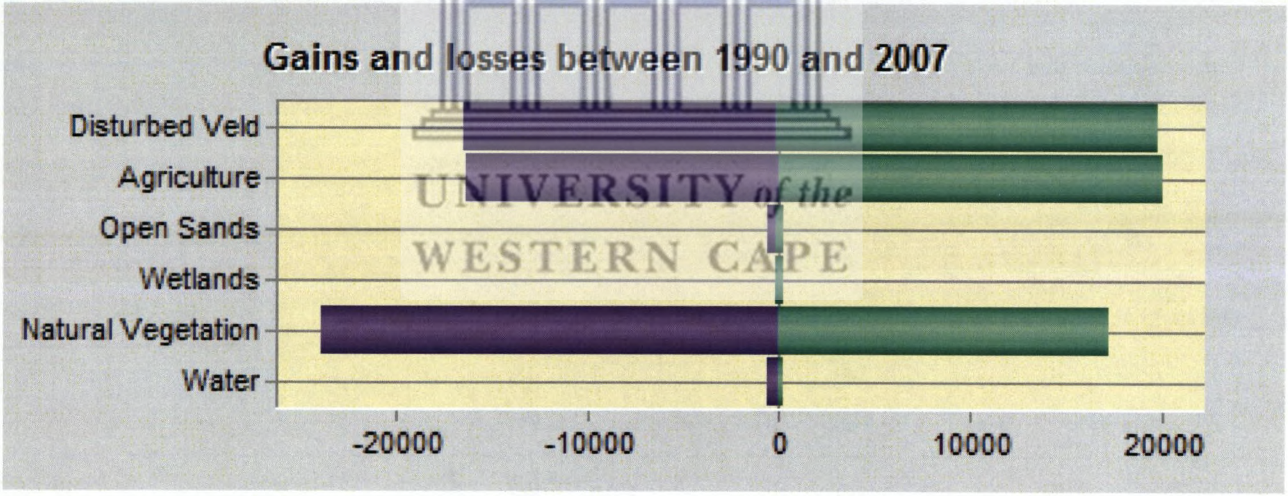

Figure 7: Gains (hectares) and losses (hectares) in landuse between 1990 and 2007 derived from the cross-tabulation of the landuse maps of 1990 and 2007 using the Land Change Modeller. The green and purples are the gains and losses respectively. This image was acquired from a screen shot the Land Change Modeller (Idrisi Andes) results.

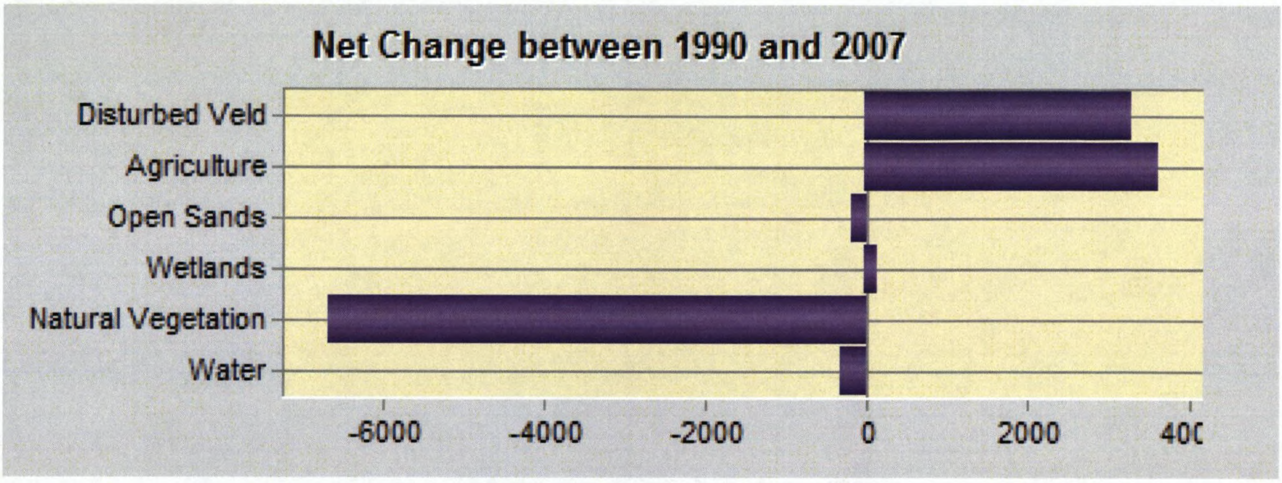

Figure 8: Net Change (hectares) in landuse classes between 1990 and 2007 based on the landuse maps of the respective years. This image was acquired from a screen shot of the Land Change Modeller (Idrisi Andes) results.

3.5.3a Changes in Natural Vegetation

There were changes in the natural vegetation between 1990 and 2007 as a result of anthropogenic activities in the area, 23 929 ha of natural vegetation were lost, 64 392 ha persisted, and 17 238 ha were gained (Figure 9). Losses in natural vegetation are mainly attributed to agriculture, as the change analysis revealed that 12 160 ha were transformed to agricultural land and 11 499 ha to disturbed veld (Figure 8).

Figure 9: Gains, losses and persistence of natural vegetation between 1990 and 2007 in the Sandveld, South Africa generated from the cross-tabulation of landuse maps of 1990 and 2007 using the Land Change Modeller (IDRISI ANDES). The white gaps between the gains, losses and persistence on the map represent some landuse classes that were and are not natural vegetation.

3.5.3b Changes in Agriculture

Gains in agricultural lands amounted to 16 392 ha and losses were 19 805 ha between 1990 and 2007(Figure 7, Figure 8 and Figure 10). The five-year rotation of potato fields which is used as alternative to get rid of nematodes infestation has led to 5 285 ha of the agriculture land being converted into disturbed veld.

Figure 10: Gains, losses and persistence of agriculture between 1990 and 2007 in the Sandveld, South Africa generated from the cross-tabulation of landuse maps of 1990 and 2007 using the Land Change Modeller (IDRISI ANDES). The white gaps between the gains, losses and persistence on the map represent some landuse classes that were and are not agricultural land.

3.5.3c Changes in Disturbed Veld

The main contributors of change in the disturbed veld are natural vegetation and agriculture (both intensive and less intensive) as they positively contributed to 11 499ha, and 8 034 ha respectively between 1990 and 2007. These two landuse classes also contributed negatively to disturbed veld by 7 614 ha (agriculture) and 8 789.40 ha (natural vegetation) (Figure 11).

Figure 11: Gains, losses and persistence of disturbed veld between 1990 and 2007 in the Sandveld, South Africa generated from the cross-tabulation of landuse maps of 1990 and 2007 using the Land Change Modeller (IDRISI ANDES). The white gaps between the gains, losses and persistence on the map represent some landuse classes that were and are not disturbed veld.

3.5.4 Mapping Persistence

Persistence of landuse classes between 1990 and 2007 (Figure 12) mapped using the Land Change Modeller were used to determine areas of each landuse class that remained unchanged (persisted) between the two years. Results showed that 14 548 ha of water, 845 432 ha of natural vegetation, 76 465 ha of wetlands, 6 469 ha of open sands, 841 131 ha of agricultural lands and 359 000 ha of the disturbed veld persisted between the two years (Figure 12).

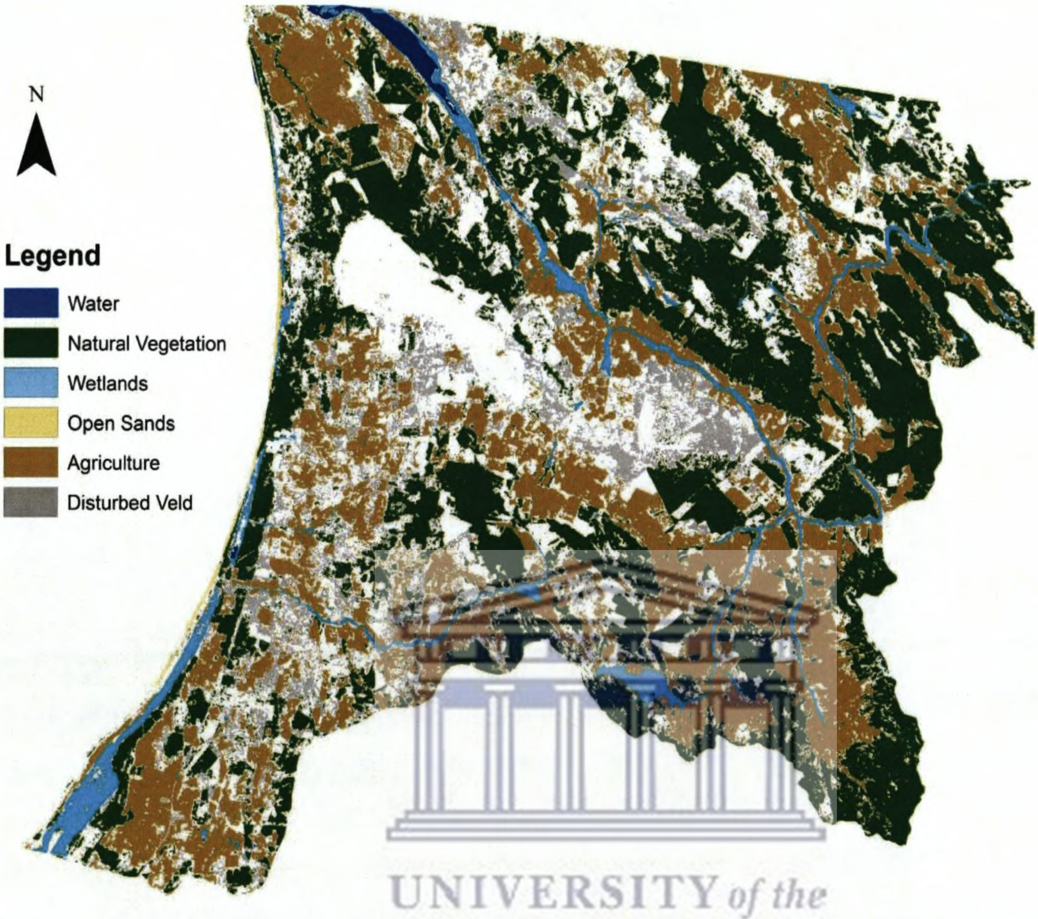

Figure 12: Landuse classes that remained unchanged between 1990 and 2007 in the Sandveld, South Africa derived from cross-tabulation of the landuse map of 1990 and 2007 using the Land Change Modeller. (IDRISI Andes). The white gaps between the persisting landuse classes are the landuse classes that changed between 1990 and 2007.

Table 5: The Kappa Index of Agreement between the landuse map of 1990 and 2007 calculated from the cross-tabulation of the landuse map of 1990 and 2007 using the CROSSTAB module in IDRISI.

Landuse Class	**Kappa Index of Agreement**
Water	0.80
Natural Vegetation	0.72
Wetlands	0.96
Open Sands	0.48
Agriculture	0.64
Disturbed Veld	0.36
Overall	0.77

3.5.5 Predicted landuse change in 2020

Predictions show that 77% of the natural vegetation will persist between 2007 and 2020 and there is 11% chance that natural vegetation will be converted to agricultural lands (Table 6).These simulations also shows that 79% of the agricultural lands remain unchanged by 2020, while 10% of the agricultural lands that will be re-vegetated and 12% will be turned to disturbed veld. There is a 52 % of disturbed veld that is likely to persist between the 2007 and 2020 with agriculture and re-vegetation becoming the main contributors of change (Table 6). There is a decrease in water and natural vegetation by 19% and 8% respectively between 1990 and 2007 and the predictions estimates a further decrease in both water and natural vegetation by 13% and 4% respectively between 2007 and 2020 (Table 7). There is continual increase in the wetlands by 3% between 1990 and 2007 and the predicted map suggests a further increase by 2% (Table 7). There is an increase in the disturbed veld and agricultural lands by 11% and 6% respectively between 1990 and 2007. Predictions suggest a further increase of 3% and 8% for disturbed veld and agricultural land respectively.

Table 6: The transitional probability of landuse change between 2007 and 2020 derived from the Markov Analysis based on the landuse classifications of 1990 and 2007.

Given:	Probability of changing to					
	Water	Natural Vegetation	Wetlands	Open Sands	Agriculture	Disturbed Veld
Agriculture	0	0.10	0	0	0.79	0.11
Disturbed Veld	0	0.26	0	0	0.22	0.52
Natural Vegetation	0	0.77	0	0	0.11	0.12
Open Sands	0	0.04	0	0.46	0.20	0.30
Water	0.71	0.10	0.15	0.01	0.02	0
Wetlands	0.01	0	0.99	0	0	0

Figure 13: Predicted Landuse map of 2020 derived from the Cell Automated Markov Modelling using landuse maps of 1990 and 2007 in the Sandveld, South Africa. The white gaps on the map is the portion that was affected by the 2003 fire, the fire area were masked out of the analysis.

Table 7: Spatial extent of landuse classes in 1990, 2007 and 2020, and percentage change between 2007 and 2020.

Land use classes	Landuse 1990	Landuse 2007	% Change (1990 and 2007)	Predicted Landuse 2020	Predicted % Change (2007 and 2020)
Water	1 577	1 272	-19%	1 113	-13%
Natural Vegetation	88 321	81 630	-8%	78 677	-3%
Wetlands	66 467	6 836	3%	6 944	2%
Open Sands	964	764	-21%	710	-7%
Agriculture	64 930	68 593	6%	70 729	8%
Disturbed Veld	30 436	33 779	11%	34 778	3%

3.5.6 Habitat Fragmentation Indices

There was a 19% decrease in the area of natural vegetation between 1990 and 2007 and the predicted landuse suggested further decrease in the area by 3% between 2007 and 2020. This was substantiated by a decrease in the number of patches of a viable size. There are 3 835 habitat fragments that were greater than 0.1 ha in 1990 which were reduced to 2 574 in 2007. The predicted landuse map revealed only 994 habitat fragments larger than 0.1 ha will remain by 2020 (Table 7). The mean patch size increased from 26.33 ha to 35.13 ha between 1990 and 2007 and it was predicted to increase to 87.92 ha in 2020. The total size of all habitat fragments was 100 961 ha in 1990, 90 415 ha in 2007 and 87 3930 ha in 2020 (predicted) (Figure 13). Edge densities decreased from 81.47 m/ha in 1990 to 68.23 m/ha in 2007 and there will be a predicted increase of edge density to 56.26 m/ha in 2020 (Table 7). Patches of natural habitat are irregular, and change in mean shape index from 1.55 in 1990 to 1.53 in 2007 and 1.67 in 2020 (predicted). The Area Weighted Mean Shape Index, which is the average perimeter to area ratio for the class weighted by the size of patches decreased from 36.96 in 1990 to 25.58 in 2007 and 23.16 in 2020 (Table 7).

Table 8: Fragmentation indices based on the landuse maps of 1990, 2007 and the predicted one of 2020.

Fragmentation Indices	**1990**	**2007**	**2020**
Area Weighted Mean Shape Index	36.96	25.58	23.16
Mean Shape Index	1.55	1.53	1.67
Edge Density (m/ha)	81.47	68.23	56.26
Mean Patch Size (ha)	26.33	35.13	87.92
Number of Patches	3835	2574	994
Median Patch Size (ha)	0.63	0.63	1.71
Total Areas of the Natural Patches (ha)	100 961	90 415	87 393

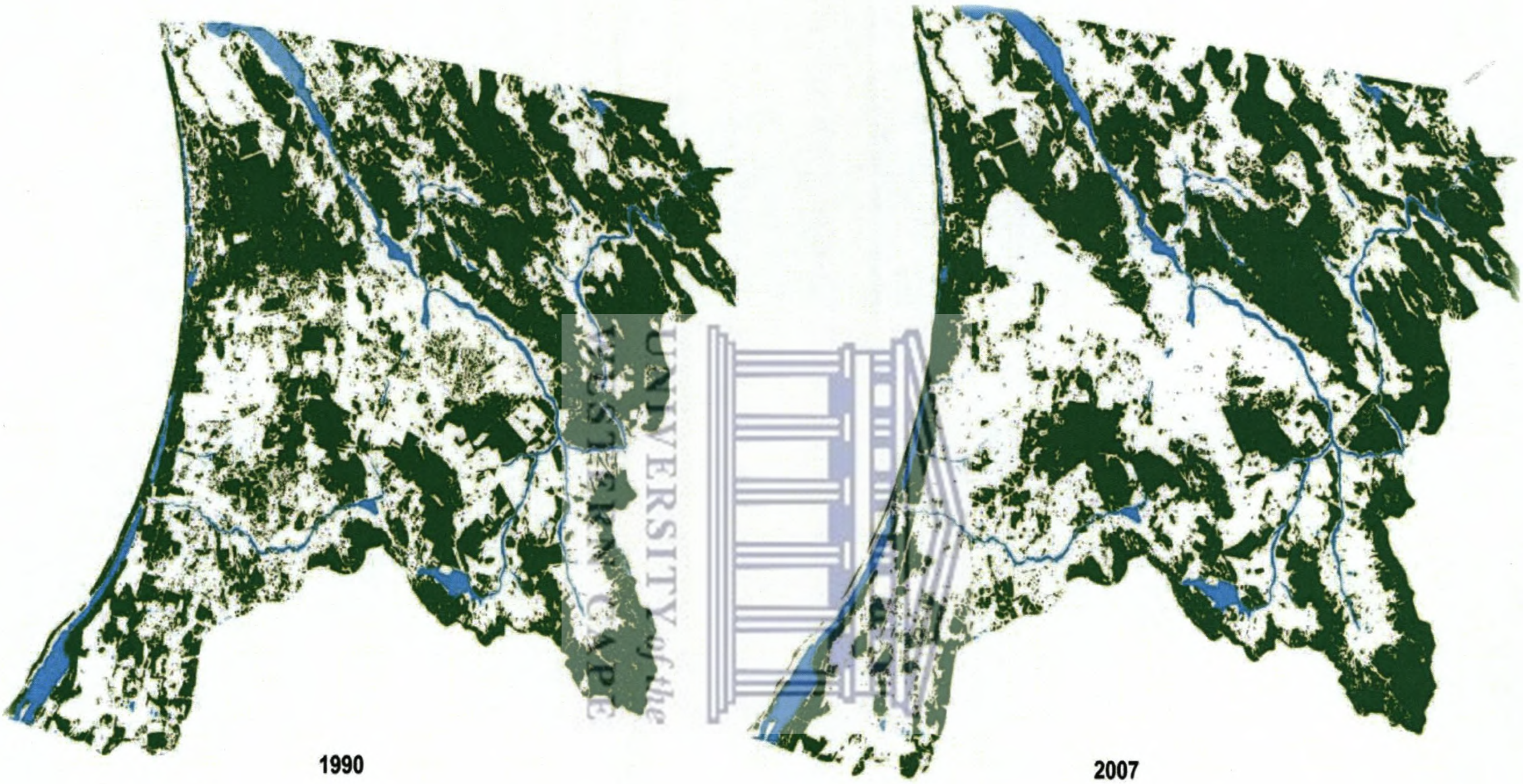

Figure 14: Habitat fragmentation between 1990 and 2007 derived from the Landuse maps of the respective years; GREEN and BLUE are the terrestrial and aquatic landscapes respectively.

Table 9: Proportions of remaining vegetation in the natural vegetation landuse class derived from the landuse map of 1990, 2007 and the predicted one of 2020.

FSP VEGETATION TYPES	Ecosystem Status	Conservation Target	Area of Each Vegetation Type	Area 1990 (ha)	% Remaining 1990	Area 2007 (ha)	% Remaining 2007	Area 2020 (ha) Predicted	% Remaining 2020 Predicted)
Bergriver Sand Fynbos /Flats Strandveld Mosaic	EN	30%	18 021	6 675	37%	4810	27%	4609	26%
Cape Estuarine Salt Marshes	LT	24%	3 286	14	0%	8	0%	8	0%
Cape Inland Salt Marshes	LT	24%	958	39	4%	29	3%	26	3%
Cape Lowland Freshwater Wetlands	LT	24%	3 347	48	1%	39	1%	30	1%
Cape Seashore Vegetation	LT	20%	417	128	31%	28	7%	10	2%
Cederberg Sandstone Fynbos	LT	29%	1 014	950	94%	939	93%	938	93%
Doringrivier Quartzite Karoo	LT	19%	194	95	49%	96	49%	87	45%
Graafwater Flats Strandveld	EN	29%	932	173	19%	60	6%	52	6%
Graafwater Sandstone Fynbos	LT	29%	27 713	21 118	76%	21 910	79%	21 578	78%
Lambert's Bay Strandveld	LT	24%	3 954	344	9%	487	12%	435	11%
Langebaan Dune Strandveld	LT	24%	5 288	3 117	59%	3 014	57%	2879	54%
Leipoldtville Sand Fynbos	VU	29%	85 826	33 433	39%	29 550	34%	28142	33%
Lowland Acid Sand Wetlands	LT	24%	1 203	34	3%	28	2%	24	2%
Piketberg Quartz Succulent Shrubland	VU	26%	15	1	5%				
Piketberg Sandstone Fynbos	LT	29%	11 186	9 488	85%	9 564	85%	9367	84%
Saldanha Flats Strandveld	VU	24%	28 198	10 331	37%	8 412	30%	8113	29%
Swartland Shale Renosterveld	CR	26%	7 132	2 291	32%	2 617	37%	2377	33%
Swartland Silcrete Renosterveld	CR	26%	114	24	21%	38	34%	29	25%

3.6 Discussion

3.6.1 Landuse Classification

With an increase in agricultural and coastal developments in the Sandveld, an up-to-date landuse map can help in the planning and resource management purposes. There is need to incorporate for high accuracy information such as aerial photos or high-resolution images that will enable conservationists to detect small landuse features such as cultivation strips and circular plots without generalising their boundaries. The spatial resolution of Landsat (30 m) makes landuse mapping difficult as compared to other platforms such as IKONOS (4 m), SPOT 5 (2.4 m) and QUICKBIRD (less than 2 m) (Jensen, 2005; CCRS, 2008). Some parts of the Sandveld have strips of cultivation areas and natural vegetation that are less than 30m wide (Figure 16), which were not mapped explicitly using Landsat but are quite explicit on the C.A.P.E. Fine Scale Biodiversity Planning landuse map (Mucina and Rutherford, 2005; Thomson, 2007,). This highlights a need to adopt high-resolution images for this purpose but unlike other remote sensing platforms (IKONOS, ASTER); Landsat missions can allow long term monitoring using data from 1970s, 1980s and 1990s (Jensen, 2005). Landuse classifications failed to separate alien vegetation and natural vegetation as they have the similar spectral signatures (Mark Thomson pers comm.). Some invasive alien species in the Sandveld e.g. Eucalyptus *spp*, are present mainly in the small wooded areas surrounding farmhouses and this makes it difficult to map these species using low-resolution satellite images. QUICKBIRD and IKONOS have been used to map alien species in Makaha Valley in Hawaii (Suzuki, 2006) and an automated image segmentation, distribution modelling and aerial image based texture analysis was in the Nevada Mountain in California (Dobrowski, 2008). So the best option for the Sandveld is to do an object oriented classification using high resolution satellite images in the Sandveld.

3.6.2 Changes in Agriculture and Disturbed Veld

There is a significant difference between the landuse map of 1990, 2004 and 2007 in respect to the coverage of each landuse classes (Table 2). There is reduction in natural habitat and a considerable increase in disturbed veld and agricultural lands (Table 2). Kappa Index of Agreement (Table 5) between landuse classes which shows the probability of landuse change was further to explain spatial trends in landuse between 1990 and 2007 (Pontius Jr, *et al.* 2000; Eastman, 2006). Kappa Index of Agreement determines the degree of persistence of a landuse class between two years, a high Kappa Index of Agreement suggests that there is a good agreement between landuse classes and a lower value suggest a higher degree of landuse change (Pontius Jr, *et al.* 2000; Jensen, 2005; Eastman, 2006). Analysis of each landuse class shows that disturbed veld have the lowest Kappa Index of Agreement of 0.36 which implies that the highest degree of landuse change occurred in the disturbed veld (Pontius Jr, *et al.* 2000). This reflected that many centre pivot irrigations are followed by a long fallow period due to the nematode predation in the Sandveld. Landuse change analysis also reveals an overall increase of 11% in disturbed veld between 1990 and 2007. The overall Kappa Index of Agreement for agriculture lands is 0.65 or 65% showing that between 1990 and 2007 there is 65% persistence of agricultural lands and 35% change. Figure 7 and Figure 8 suggests that most of the reduction in natural vegetation has been as a result of intensive farming which led to the establishment of centre pivots plots (Knight *et al.*, 2009). Areas marked (1) on Figure 15 is the natural vegetation and those marked 2 is the central pivot irrigation plots and this reveals that agriculture is the main driver of landuse change in the Sandveld as it has contributed to negative changes in the natural productivity of the Sandveld (Mucina and Rutherford, 2006; Knight *et al*, 2007).

A prognostic approach was undertaken to predict the future scenarios in landuse change and this suggested a continued increase in the agricultural lands which will in turn increase the disturbed veld. It was predicted that agriculture is going to increase by 8% in 2020 and disturbed veld by 3%. If sustainable harvesting guidelines for potatoes and rooibos tea are not implemented in the Sandveld the natural habitat ecosystem is likely to continue to be affected by the increase in the agriculture footprint (Knight *et al.* 2007; Pretorious, 2008). Agricultural expansion is the known contributor to habitat fragmentation together with urban expansion and rural resettlement and it has modified landscapes and diminished their natural productivity (Ruiz-Luna, 1999).

3.6.3 Changes in the Natural Habitats

There is progressive habitat loss and fragmentation in the Sandveld which has brought about change in the landscape connectivity of the areas (Figure 14). This issue is of major concern globally as it is a biodiversity threat and represents some ecological effects on the natural habitats (McGarigal and McComb 1999; Hess *et al.* 2005; Mendoza *et al.* 2005). Determining the degree of habitat fragmentation using landscape metrics constitutes a conservation issue. Habitat fragments in the Sandveld followed the theory of island biogeography that as the sizes of natural habitat patches become smaller, the distance between these patches increase and the rate of reproduction of species decreases (McGarigal and McComb 1999). Loss of habitat in the Sandveld was measured using patch size, percentage natural remaining in each vegetation type, shape index and total area of the natural habitat. Outcomes of this study show an increase in the average patch size from 1990 to 2007 (Trani, 1999). There is continual disappearance of natural fragments in the farming areas but some areas e.g. Piketburg mountain are left intact hence an increase in the mean patch size (Figure 14), the same applies to the number of patches which are decreasing with time. A decrease by area in both aquatic and terrestrial ecosystems was observed, and numerous small habitat fragments disappeared between 1990 and 2007, with more expected to have disappeared by 2020. The surrounding matrix of human behaviour led to the continual decrease in patch size and increase in the isolation of habitat fragments thereby undermining the biological integrity of the ecosystem (Bender, *et al.* 1998; McGarigal and McComb, 1999; Pfister, 2004).

Shape index measures the complexity of a patch comparing it to the standard shape (shape or circle) and the results of the analysis agree with a lot other researches that as the degree of habitat fragmentation increases patches loses their regular shape and they become complex hence an increase in shape index (Santiago and Javier, 2001). Increase in intensive wheat, potato and rooibos tea farming in the accelerated habitat fragmentation; this in turn reduced the size and connectivity of natural habitats, which makes the landscape unfavourable for both plant and animal species as it inhibits gene flow between patches (McGarigal and McComb 1999). The degree of habitat fragmentation (number and size of patches, connectivity of fragments affects the persistence of species populations (McGarigal and

McComb 1999). Habitat fragmentation affects the persistence and abundance of biodiversity and resultantly species will migrate to neighbouring tracts of natural (McGarigal and McComb 1999; Holmes, 2003; Pfister, 2004).

3.6.3a Changes in Natural Vegetation

Natural vegetation in the Sandveld decreased by 8% between 1990 and 2007 and predicted natural vegetation shows a continual reduction in the productivity of the natural habitat by 11%. This is the world's environmental challenge as vast natural landscape has disappeared due to man-induced activities (Turner, 1996). Each year Colombia is losing 200 000 hectares of its natural forest due to small scale agriculture, mining, energy development, palm oil plantations, infrastructure development, large scale agriculture and cocaine trade and this has threatened 18% of the endemic species (Turner, 1996; Armenteras, 2006; Áalvarez, 2007). Positive changes (gains) in the natural vegetation are mostly due to alien species invasion, which is a major, environmental threat in South Africa (Richardson, 2004; Mucina and Rutherford, 2006) and re-vegetation (restoration) (Figure 9). Alien species were classified as natural vegetation because it was difficult to differentiate the spectral signatures of both alien species and natural vegetation (Mark Thompson, pers comm.), there will be need to manually digitise the extent of the invasive species as what was done in the C.A.P.E Fine Scale Biodiversity Planning Project.

Sandveld comprises of many vegetation types (Figure 2) which were mapped C.A.P.E. Fine Scale Biodiversity Planning Project in 2007 (Helme, 2007). Landuse changes affected these vegetation types and Table 9 suggests that there has been some decline in the areas covered by each vegetation type. The percentage of natural remnants in each vegetation type was benchmarked against their conservation targets (Mucina and Rutherford, 2006) to evaluate if the vegetation type is well conserved or is vulnerable in the Sandveld. So these vegetation types are grouped into two categories which are: well conserved and poorly conserved.

(i) Well Conserved Vegetation Types.

Cederberg Sand Fynbos is nationally classified as a least threatened vegetation type (Mucina and Rutherford) and originally covered 1 014 ha in the Sandveld (Table 9). Only some 94% of the area was natural in 1990 which was further reduced to 93% by 2007 (Table 9) and 93% in 2020 (predicted)(Table 9) which is far above the conservation target of 26% (Mucina and Rutherford) so this vegetation type is well conserved in the Sandveld.

Langebaan Dune Strandveld is threatened by urban growth and intensive farming as well as intrusion by *Acacia cyclop* and *A. saligna* (Mucina and Rutherford, 2006). Langebaan Dune Strandveld originally covered an area of 5 286 ha (Table 9) and is nationally classified as a least threatened vegetation types (Mucina and Rutherford, 2006). Of the 5 286 ha only 59% was natural by 1990 and it was further reduced to 57% in 2007(Table 9) and 54% in 2020 (predicted) (Table 9). The proportion of the natural habitat in 2007 and 2020 is above the conservation target of 24% (Mucina and Rutherford, 2006) and this means Langebaan Dune Strandveld is meeting the conservation target.

Swartland Silcrete Renosterveld is a critical endangered vegetation type which is threatened by agriculture (overgrazing and use of pesticides) and invasive aliens (*Acacia saligna, A. mearnsii, Prosopis and Eucalyptus*) (Mucina and Rutherford, 2006). The predicted landuse map suggested that the natural remnants will be 25% in 2020. This vegetation type covered an area of 114 ha and in 1990 only 21% of its total area in the Sandveld was natural and this was increased to 34% in 2007 due to re-vegetation (Table 9). The predicted landuse map suggested that the only 25% of the total areas will remain natural by 2020 (Table 9). With the conservation target of 26% (Mucina and Rutherford, 2006) the Swartland Silcrete Renosterveld is well conserved and there is need for some conservational measure so that the remaining natural habitat is not go below the conservation target as predicted.

Doringriver Quartzite Karoo is classified by Mucina and Rutherford (2006) as a least threatened vegetation and it covered an area of 194 ha in the Sandveld (Table 9). In 1990, 49% of this vegetation type was natural and remained the same in 2007 and the predicted change for 2020 (Table 9) suggested a further decrease in the natural habitat by 2% (Table 9). Doringriver Quartzite Karoo has a conservation target of 19% (Mucina and Rutherford, 2006) the vegetation type is well conserved.

Swartland Shale Renosterveld is nationally classified as a critically endangered vegetation type (Mucina and Rutherford, 2006) and originally covered 7 132 ha (Table 9). Only some 32% of its total area was natural in 1990 and in 2007 it was 37% (Table 9). The stochastic modelling results suggested that the proportion of natural habitats will be 33% in 2020 (Table 9). Swartland Shale Renosterveld is and will be meeting it conservation target of 26% (Mucina and Rutherford, 2006).

Piketberg Sandstone Fynbos is nationally classified as a least threatened vegetation type (Mucina and Rutherford, 2006) and it covered an area of 11 186 ha in the Sandveld (Table 9). The vegetation is considered well conserved in the Sandveld as the proportion of natural habitat is above 80% for 1990, 2007 and for 2020 (predicted) (Table 9) and this exceeds the conservation target of 29% (Mucina and Rutherford, 2006).

Leipoldville Sand Fynbos which is classified as a vulnerable vegetation type has a conservation target of 29% (Mucina and Rutherford, 2006) and is considered to be well conserved in the Sandveld as the remaining natural habitat for 1990, 2007 and 2020 (39%, 34 and 33% respectively) (Table 9) is above the conservation target.

Graafwater Sandstone Fynbos is classified as least threatened (Mucina and Rutherford, 2006) and it originally coved an area of 27 713ha. The remaining natural habitats in the Graafwater Sandstone Fynbos have a proportion of 76%, 79% and 78% for 1990, 2007 and 2020 respectively (Table 9). Even though this vegetation types is threatened by agriculture and invasion of alien species such as Acacia cyclops and A. saligna and has a conservation target of 29% and it is well conserved (Mucina and Rutherford, 2006).

Saldanha Flat Strandveld is one of the vegetation types that are well conserved in the Sandveld as it has the natural remnants that are above its conservation target of 24% (Mucina and Rutherford, 2006). It covered an area of 28 198 ha and the remaining natural habitats have proportions of 37%, 30% and 29% for 1990, 2007 and 2020 respectively (Table 9). Even though Saldanha Flat Strandveld is nationally classified as vulnerable, it is meeting its conservation target of 24% in the Sandveld (Mucina and Rutherford, 2006).

(ii) Poorly Conserved Vegetation Types

According to Mucina and Rutherford (2006) Cape Seashore Vegetation is nationally classified as a least threatened vegetation type with a conservation target of 20% (Mucina and Rutherford, 2006). This vegetation type originally covered 417 ha in the Sandveld but in 1990 only 31% had remained and this further reduced to 7% in 2007. The predicted landuse map suggested only 2% will remain in 2020. So in the Sandveld the remaining 7% need to be incorporated in the protected area network and there is also need for an additional 13% to meet the conservation target.

Lowland Acid Sand Wetlands which is vulnerable to invasive species (*Acacia saligna, A. longifolia, A. mearnsii*) has been classified by Mucina and Rutherford, (2006) as a least threatened vegetation type with a conservation target of 24% (Mucina and Rutherford, 2006). In 1990, 3% of this vegetation type was natural, in 2007 it was reduced to 2% and the predictions suggested it will remain at 2% (Table 9). With the conservation target of 24% (Mucina and Rutherford, 2006) there is need for an additional 22% so that Lowland Acid Sand Wetlands will meet its conservation target.

Cape Lowlands Freshwater Wetlands is also poorly conserved in the Sandveld as the remnants were 1% of the total area for 1990, 2007 and 2020 (Table 9). With these low level of natural remnants in the Cape Lowlands Freshwater Wetlands, which cannot meet the conservation target of 24% (Mucina and Rutherford, 2006) there is need to include the 1% in the protected area network and identify an additional 23% to facilitate ecosystem functioning in this vegetation type.

Lambert's Bay Strandveld is nationally classified as least threatened with a conservation of target of 24% (Mucina and Rutherford, 2006). Originally, this vegetation type covered an area of 3954 ha and by 1990 only 9% had remained, it increased to 12% in 2007 and the predicted map suggested a further decline to 11% (Table 9). To ensure ecosystem functioning the remaining 12% needs to be included in the protected area network as critical biodiversity areas and there is need to identify an addition 12% in order to meet the conservation target.

Bergriver Sand Fynbos - Flats Strandveld Mosaic (Hopefield Sand Fynbos) is extremely fragmented and has some endemic and Red Data book listed species (Helme, 2007). There is intensive pressure on this vegetation type as a result of wheat, rooibos and potato farming that is underway in the Sandveld (Helme, 2007). This vegetation type originally covered an area of 18 021 ha and only 37% was in the natural state in 1990 which dropped to 27% in 2007 and 26% in 2020 (predicted) and this is below the conservation target of 30%. So there is need to fully protected these remnants and identify an additional fragments to ensure a viable ecosystem.

Cape Estuarine Salt Marshes is least threatened (Mucina and Rutherford, 2006) and it originally covered 3 286 ha in the Sandveld but in 1990, 2007 and 2020 (predicted) the remaining natural vegetation is less than 1%. With a conservation target of 24% (Mucina and Rutherford, 2006) there is need to identify areas to conserve so that Cape Estuarine Marshes can be restored to natural.

Graafwater Flats Strandveld is nationally classified as an endangered vegetation type and it covered an area of 932 ha in the Sandveld. By 1990 only 19% of the natural had remained and this was reduced to 6% in 2007 and 6% in 2020 (predicted). With the conservation target of 29% this vegetation type is poorly conserved there need to include the remaining 6% into the protected areas network and to identity additional fragments to so that the conservation target can be fully met.

Piketberg Quartz Succulent Shrubland is ranked the most transformed mountain fynbos in the Fynbos biome (Mucina and Rutherford, 2006) and is classified as a vulnerable vegetation type with a conservation target of 26% (Mucina and Rutherford, 2006) and the landuse analysis suggested that this vegetation type is now extinct in the Sandveld (Table 9).

Cape Inland Salt Marshes is classified as least threatened and it originally covered an expanse of 958 ha which was reduced to 4% in 1990, 3% in 2007 and 3% in 2020 (predicted) (Table 9). Cape Inland Salt Marshes has a conservation target of 24% which cannot be met with the remaining natural habitat so there is need to identify some fragments to incorporate in the protected area network to ensure a viable ecosystem.

3.6.3b Changes in the Water Resources

The combination of Intensive irrigation schemes and drought in the Sandveld has led to the decrease in surface water, which is threatening the sustainability of the entire landscape level agricultural practices. There is general succession of water bodies to wetlands to natural vegetation as some of the water bodies in 1990 were mapped as wetlands in 1990 and in the predicted landuse map (Table 7). These successions are propagated by intensive underground extraction to support agricultural activities. South Africa through the Working for Water programme is addressing the invasive alien species which pose a direct threat to both biological diversity and water security (Richardson, *et al.* 2004; Zimmermann *et al.* 2004). The main problems in most wetlands is invasive aliens especially *Acacia Cyclops* and *A. saligma* and this a major threat that need to be addressed as it reduced the amount of water (Richardson, 2004). Reduction of water resource will continue to increase as suggested by the Markov predictions. Intensive underground water extraction in the Sandveld can negatively impact on the groundwater reserves if uncontrolled. Analysis of vegetation types in the Sandveld revealed that most of the wetlands vegetation types are below the conservation status and there need to implement some strict conservation measures to safeguard them. Fencing of all the wetlands to avoid trampling by human being and their livestock is the best way to conserve these wetlands (Helme, 2007).

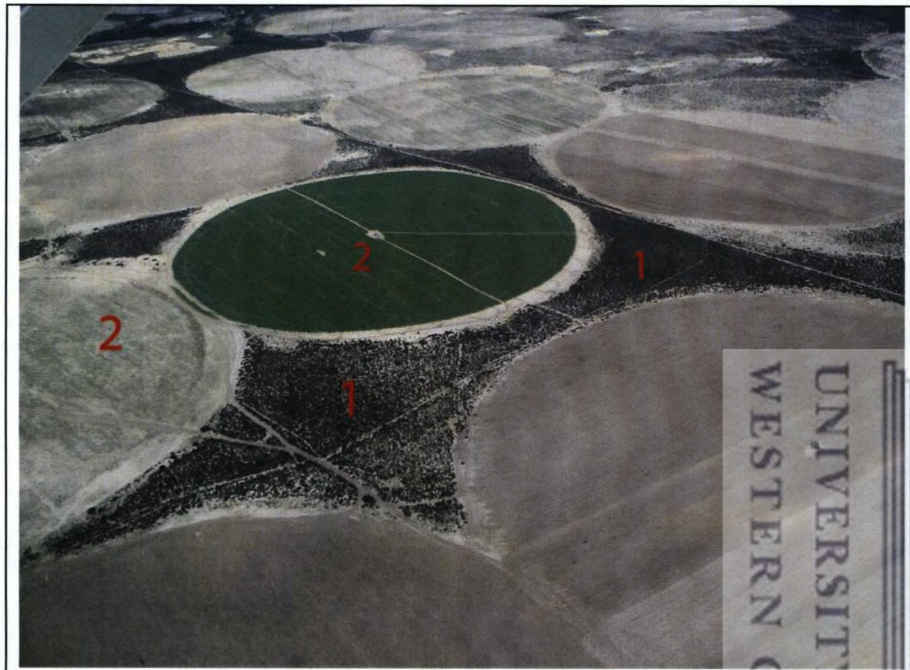

Figure 15: Circular Irrigation Plots (2) and it surrounding patches of natural vegetation (1) b which shows a high degree of habitat fragmentation in the Sandveld of South Africa (Photograph: C.A.P.E. Fine Scale Biodiversity Planning Project)

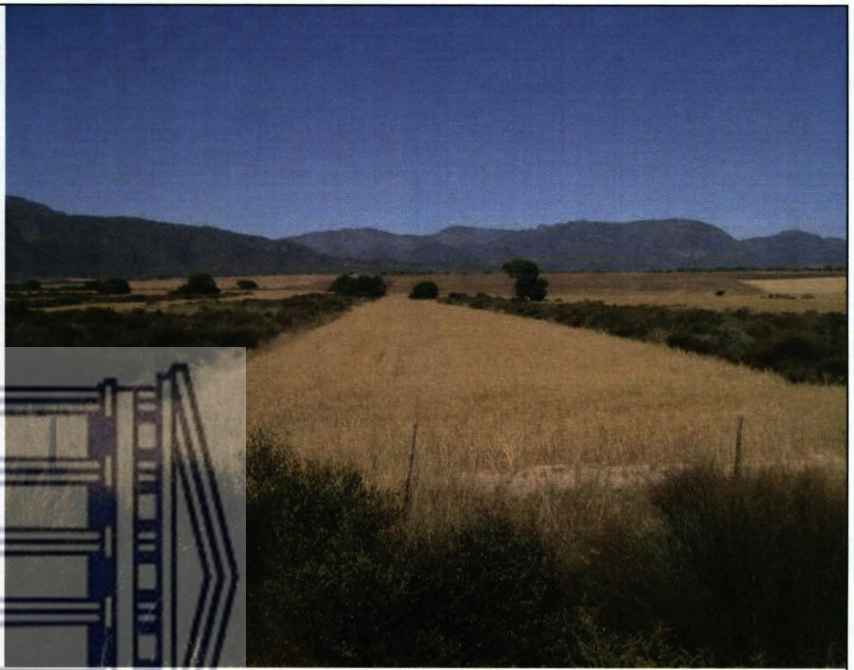

Figure 16: Windrow strips of natural vegetation that is used as windbreaks for young plants and to prevent erosion (Helme, 2007). These strips are less than 30m wide and were difficult to map using Landsat. (Photograph: James Magidi).

3.6.4 Prediction of Future Scenario

Simulation of future landuse change scenario in the Sandveld based on the landuse maps of 1990 and 2007 used the Markov module to extract the probability that each landuse class will change to other landuse classes. It also produced the transitional areas, which shows the number of pixels that are expected to change from one land use class to the other. Transitional probability and transitional areas combined with a cell-automated procedure established the simulated/predicted landuse map of 2007. Results of the cell automated Markov models are focused predominantly on providing the knowledge of how much, where, what type of land use changes has occurred from 2007 to 2020. The cellular automated simulation models, allows for predicting future land development based on probabilistic estimates using Monte Carlo simulations methods (Clarke and Gaydos, 1998). However, it would be questionable to expect the landuse classes to be stationary over time but it might be practical to regard these landuse changes to be reasonably stationary if the time frame is too short. The problem with the CA Markov Models is that it does not account for the contributors (drivers) of landuse change; it does not show the spatial trends and it assumes that the changes that have happened in the past will continue in the future (Eastman, 2006; Roy Cole, np). Markov Models lacks a sense of geography (insensitive to spatial processes) but the Cellular Automata Markov analysis adds the spatial dimension to the predictions (Eastman, 2006; Roy Cole, np).

3.7 Using landuse change results in the existing Conservation Plans

Systematic conservation plans (Figure 17) for the Sandveld and surrounding area was completed by the C.A.P.E. Fine Scale Biodiversity Planning Project (FSP) (Pence, 2008) and it followed the norms and standards for Bioregional Plans which highlights three characteristics of representation, persistence, targets, efficient and conflict avoidance (Pence, 2008). The results of the analysis include six categories which are (Figure 17):

Critical biodiversity areas (CBA) represent terrestrial and aquatic sites that are needed to meet biodiversity pattern targets and biodiversity process objectives (Pence, 2009). Any loss in these critical biodiversity areas will affect the conservation targets and they should be managed in such a way that they remain as natural as possible (Pence, 2008).

Critical ecological support areas (CESA) are zones that are necessary to prevent the degradation of the CBAs and they need be protected and managed and Other Ecological support areas (OESA) prevent the degradation of CBAs, CESA and protected areas (Pence, 2008).

These critical biodiversity areas and support areas presents the biodiversity corridors that will enhance gene flow as they connect habitat fragments. In metapopulation theory, habitat fragmentation will cause individual species to be distributed among habitat patches, so the creation of corridors will enhance the movement between habitat patches thereby lowering the time it will take to re-colonise a patch. These CBAs, CESAs and OESAs which are to be preserved will function as (Hess *et al*. 2001):

- Conduit – they will allow some organisms to move from one patch to the other and they will not reside with the corridor. They are used as passages.
- Habitat: some organisms with reside and reproduce within the corridor.
- Barriers: to some these corridors will be a barrier of movement e.g. the CBAs Terrestrials will be a barrier to aquatic organisms.
- Sources: some organisms will emanate from the corridor.
- Sinks: these corridors can be sinks or traps to organisms.

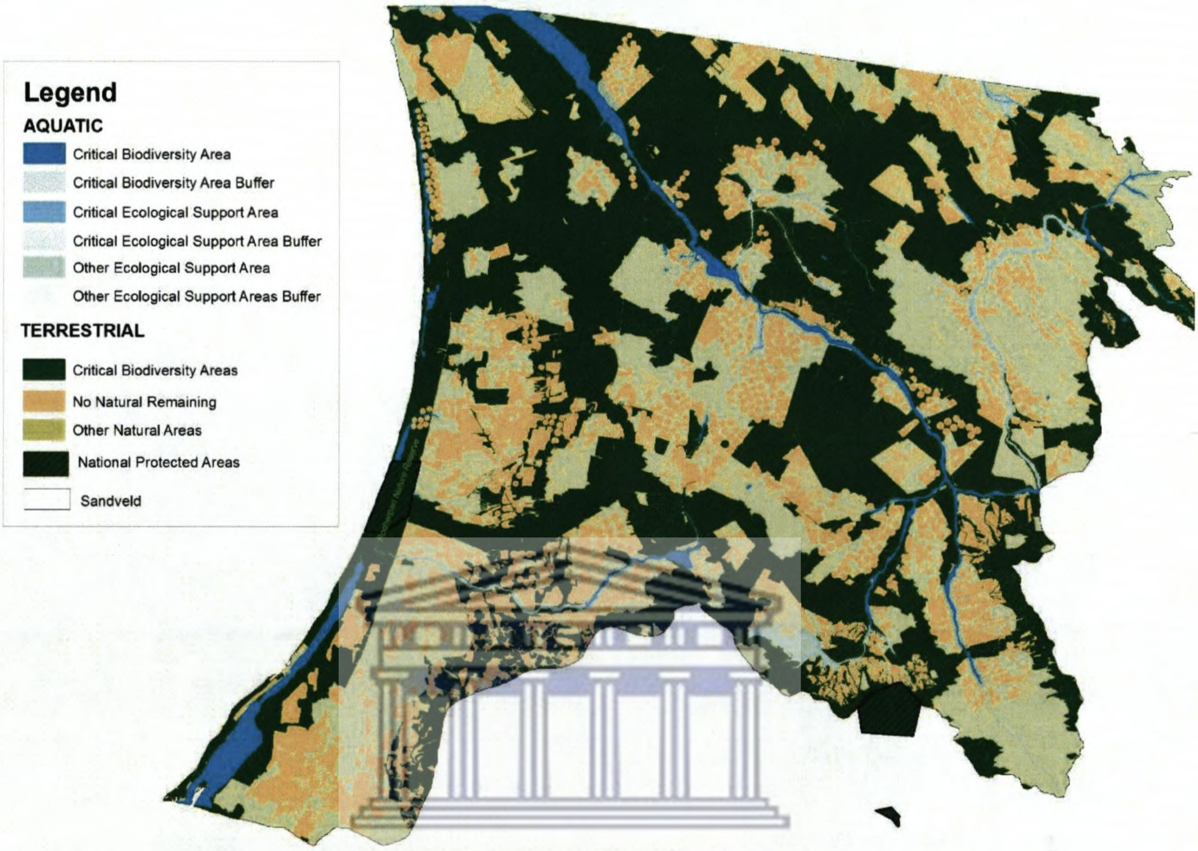

Figure 17: Systematic Conservation plan for the Sandveld based on the Marxan spatial solutions (C.A.P.E. FSP, 2009).

There are some few conflicts in the Sandveld Conservation Plan that need to be examined at micro-level and this will help improve these biodiversity corridors. Some vegetation types with the remaining natural areas below the conservation targets include:

- Bergriver Sand Fynbos,
- Cape Easturine Salt Marshes,
- Cape Lowlands Esturaines Marshes,
- Cape Lowand Freshwater Wetlands,
- Cape Seashore Vegetation,

- Graafwater Flats Strandveld,
- Lamberts Bay Strandveld and
- Lowland Acid Wetlands (Table 9).

Effectively 100% of these remnants need to be included in the protected areas network and additional areas need to be identified for conservation in order to meet the conservation target of each vegetation type. Bergriver Sand Fynbos is the only vegetation type shown in red on Figure 18. This implies that the remaining vegetation types need to be fully protected in order to meet the biodiversity pattern targets and ecological process objectives.

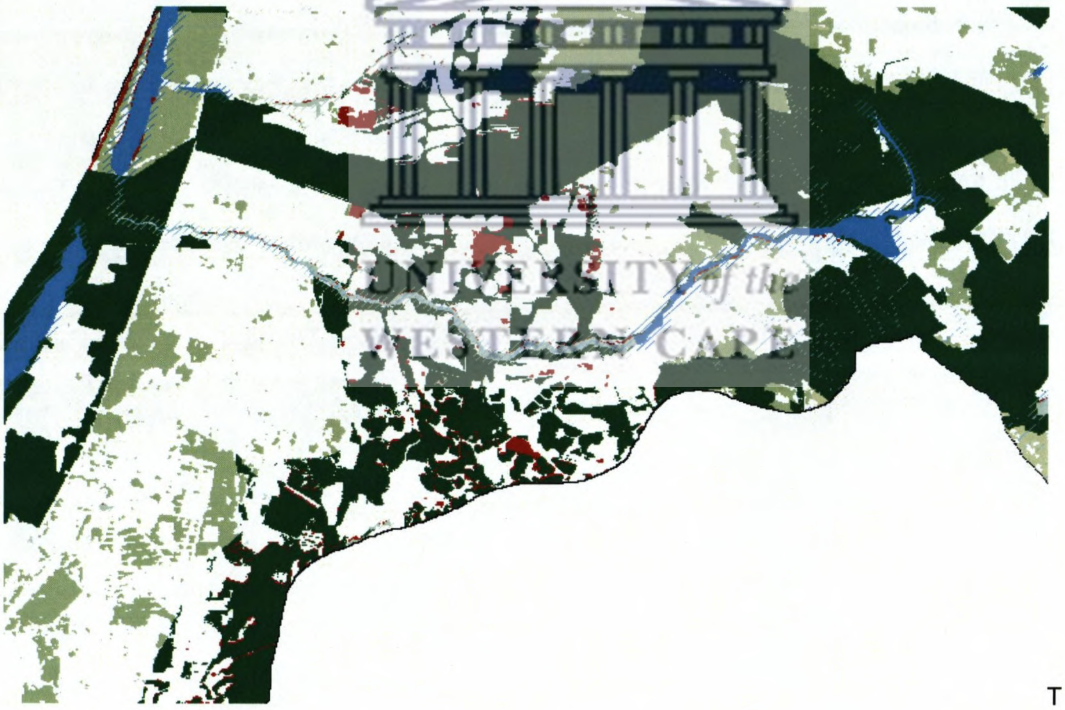

Figure 18: The conservation plan for part of the Sandveld close to the Rocherspan Nature Reserve, which shows some of the vulnerable areas (in RED) that need to be incorporated as Critical Biodiversity Areas.

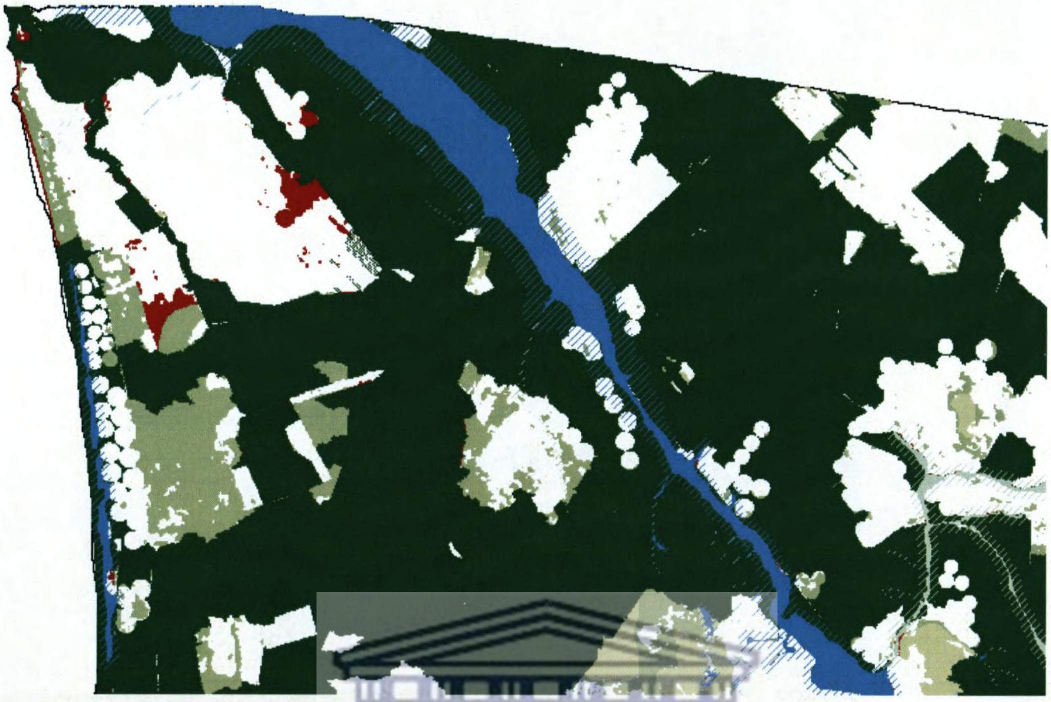

Figure 19: The conservation plan for part of the Sandveld which shows some of the areas (in RED) that need to be incorporated as Critical Biodiversity Areas.

Change detection methodologies combined with the C.A.P.E. Fine Scale Biodiversity Plans will help in monitoring and evaluating conservation activities in the Sandveld. Landuse classification procedures, change detection, change modelling and using landscape metrics to determine habitat fragmentation can be a conservation tool to assess the quality of the landscape and will help identify conservation management zones based on the landscape patterns.

3.8 Conclusion

Landuse change analysis using the IDRISI Land Change Modeller has demonstrated the application of GIS and Remote Sensing in monitoring ecosystem health between two dates. Cell Automated Markov Modelling provided a prognostic approach to the analysis by forecasting future change in landuse patterns. It suggested that landuse patterns in the Sandveld will continue to be modified by human induced activities and these will affect the natural productivity of the study areas. Farmers are destroying the natural vegetation for agricultural purposes and this is accelerated by the system of cropping for a year then allowing it to lie fallow for a period of five years. An understanding of these landuse changes provides conservationists with the basis for landuse decision making. Landscape metrics coupled with spatial techniques will contribute positively to the awareness of landuse/landscape dynamics. Forecasting landuse change can assist resource managers to identify micro biodiversity "hotspot" within the study areas and target them for conservation. These principles of landuse change and stochastic modelling to predict future scenarios are can be used to monitor and evaluate conservation initiatives. Two dates change detection is useful but more information can be extracted the analysis it is coupled with a time series analysis of NDVI datasets such as MODIS NDVI as it will show the spatio-temporal variation using images with short temporal resolution. These time-series analysis provides a rich source of information on the spatio-temporal dynamic nature of earth surface processes, and it monitors land cover change, phenology, as well as vegetation-climate dynamics.

CHAPTER FOUR: SPATIO-TEMPORAL VARIATIONS IN VEGETATION COVER USING MODIS NDVI

4.1 Abstract

Natural habitats of the Cape Floristic Region (CFR) are increasingly being lost through natural phenomena such as drought, but more importantly through human induced activities such as agriculture, introduction of invasive species and urban development. The ecosystems in the Sandveld, which forms part of the CFR, is highly transformed and fragmented due to intensive agriculture and coastal development. With this accelerated habitat transformation there is need for long term land surface monitoring to assess trends and variability in vegetation cover. MODIS NDVI datasets were used to understand the spatio-temporal variability in ecological processes in the Sandveld. NDVI is a slope-based vegetation index derived from the reflectance values of Near Infrared and Red portions of the electromagnetic spectrum, which is used to quantify photosynthetic capacity, moisture stress, and vegetation productivity. Time series analysis using the standardised principal component analysis and temporal profiles methods were used to assess the spatio-temporal variability in vegetation cover. These provided a rich source of information on the spatio-temporal dynamic of vegetation cover and it monitored phenology and vegetation-climate dynamics. Results suggested that the landscape has a high degree of overall dynamic change with pronounced inter and intra-annual changes and an overall increase in greenness associated with increase in agricultural activity.

Keywords

Times series analysis, standardised principal component analysis, temporal profiles,

4.2 Introduction

Natural habitats of the Cape Floristic Region (CFR) are increasingly being lost through natural phenomena such as drought, but more importantly, through human induced activities, such as agriculture, introduction of invasive species or urban development (Rouget *et al*. 2003). The CFR is one of the 34 global biodiversity hotspots, which are well known for high species endemism, and are highly threatened from the above-mentioned factors (CEPF, 2001; Rouget *et al*. 2003; Cowling, 2004). Upland habitats in the CFR are generally pristine, whilst those of the Cape Lowlands are highly fragmented because of agricultural activities (Rouget *et al*. 2003). The Sandveld, which falls in CFR, is highly fragmented because of intensive agriculture (rooibos tea, wheat and potato farming) and coastal development (Holmes, 2003; Knight *et al*. 2007). Nematodes predation on potato fields necessitated the rotation of fields to maintain yields, and this has exacerbated habitat fragmentation (Barrie Low, pers comm.). Due to erratic rains in the Sandveld, farmers are dependent on legal and illegal underground water mining for their centre pivot irrigation systems which in turn increase habitat fragmentation (Conrad *et al*. 2008). With this accelerated habitat transformation there is need for long term land surface monitoring to assess trends and variability in vegetation and landuse cover. There is need for an assessment of vegetation dynamics using remote sensing techniques and use the data to understand inter-seasonal and intra-seasonal variability in vegetation cover.

NDVI is a slope-based vegetation index that is derived from the reflectance values of near infrared and red portions of the electromagnetic spectrum, and is used to quantify photosynthetic capacity, moisture stress, and vegetation productivity (Chandrasekar, 2006; Weiss *et al*. 2004). NDVI is calculated as follows:

$$NDVI = \frac{(\rho^{NIR} - \rho^{RED})}{\rho^{NIR} + \rho^{RED}}$$

Where ρ^{NIR} is the reflectance value of the NIR band and ρ^{RED} is the reflectance value of the red band (Jensen, 2005). Chlorophyll, which is the primary photosynthetic pigment in the plant absorbs visible light in the 0.4 to 0.7 µm bands but reflects infrared light in the 0.7 to 1.1 µm wavelengths

(Jensen, 2005; CCRS, 2008). Healthy vegetation reflects more infrared light and absorbs more red and blue portions of the electromagnetic spectrum that is affected by atmospheric scattering, hence the use of red and near infra-red bands to calculate NDVI (Jensen 2005; CCRS, 2008). In arid areas there is less absorption of the visible light and low reflection of the infrared light, thereby a low NDVI value (Jensen, 2005; CCRS, 2008). NDVI values range from -1 to +1 where 0 to1 represents high plant productivity, and -1 to 0 represent no vegetation cover, presence of clouds, water or glaciers (Weiss *et al.*2004; Jensen, 2005).

There are many remote sensing algorithms that can be used to detect changes using multi-temporal satellite images and these include time series analysis (principal component analysis and time-profiling) and image differencing (Jensen, 2005), which were used in this study. Principal component analysis (PCA) is a multivariate statistical technique that is used to reduce redundancy in the multi-spectral bands in remote sensing imagery that have similar spatial structure (Ricotta, 1999; Eastman 2006). It is used to transform correlated datasets and compress them into a set of uncorrelated and independent bands, which are ranked according to variance, called principal components (PC) (Ricotta, 1999; Jensen 2005). There are two types of PCA, which are standardised and unstandardised. It was concluded that standardised PCA is better than unstandardised PCA, as standardisation of the PCA helps to eliminate some errors for an effective time series analysis (Roberts, 1984; Anyamba, 1998; Jensen, 2005). PCA is also used as a de-speckling and de-striping technique to reduce noise e.g. atmospheric interference on remote sensing imagery (Ricotta 1999, Jensen 2005). Standardised PCA is applied in time series analysis by analysing the principal component images (the spatial output) and their respective loadings (Eastman 2006) and this is done using single band data such as Normalised Difference Vegetation Indices (NDVI)(Anyamba, 1998). To assist in the spatio-temporal analysis PCA factors loadings, which are measures of correlation between the principal components with the original datasets, were used (Regina, 2003). The main challenge in interpreting principal component (PC) is in assigning of meaning to a PC (Jensen, 2005) and linking the variation of each PC to the changes in the vegetation cover (Roberts, 1994; Rigina, 2003; Li, 1998). Time-profile system assesses the spectral value e.g. NDVI of an area or point over a period of time and plots a graph that shows temporal changes in the spectral value at that particular pixel (point) or area (Eastman, 2006). Temporal-profiles of the NDVI values were compiled for each landuse class using four main statistical parameters: maximum NDVI, minimum NDVI, mean NDVI and coefficient of variation (*CV*). The main reason of using the NDVI extremes such as minimum NDVI, maximum NDVI and *CV* was that the response of some ecosystems to major disturbance such as droughts may not be evident in the mean NDVI (Barbosa, 2006). Mean NDVI is a surrogate of annual primary productivity and is sensitive to changes in photosynthetic activity (Barbosa, 2006). Minimum NDVI values are sensitive to the transitions in natural vegetation and the maximum NDVI is sensitive to land use changes (Baldi, 2008) and *CV* is a measure of variability in data. This chapter is aimed at assessing the spatio-temporal dynamics in vegetation cover Sandveld Normal Difference Vegetation Index (NDVI).

4.2.1 Brief description of MODIS Data

The MODerate Resolution Imaging Spectroradiometer (MODIS) is a low resolution hyperspectral, sun-synchronous, near polar orbiting satellite sensor aboard EOS Terra and Aqua platforms that were launched in December 1999 and May 2002 respectively (Justice *et al*. 2002; Jensen, 2005). MODIS is aimed at providing long-term observations that will help scientists derive information of the dynamic changes in the earth's terrestrial system (Jensen 2005). MODIS utilises 36 spectral bands, which ranges between 0.405 and 14.385 µm. It has two bands in the Red / Near Infrared (NIR) with a spatial resolution of 250 metres, five bands in the Blue/Green/NIR/Mid Infrared (MIR) portion with a spatial resolution of 500 metres. The remainder is in the Visible and Near Infrared (VNIR)/Mid Infrared (MID)/Thermal Infrared (TIR) with a spatial resolution of 1000 metres (Jensen 2005, Justice *et al* 2002). MODIS data are available in real time as 16–day NDVI and EVI composites at 250, 500 and 1000 m spatial resolutions (Chen *et al*. 2005). EVI data is derived from red, near infrared and blue portions of the electromagnetic spectrum, whereas the NDVI is derived from red and infrared only (Chen *et al*. 2005). There is correlation between the EVI and NDVI data insofar as the soil background and aerosol are eliminated (Huete *et al*. 2002; Chen *et al*. 2005)

MODIS (NDVI) multi-temporal images with a spatial and temporal resolution of 250m and 16 days respectively were downloaded from the Earth Observation System (EOS) Data Gateway. These 163 images covered a period from February 2000 to December 2006. The MODIS Projection Tool was used to reproject the datasets so that they were compatible with ERDAS IMAGINE 9.2 (Geosystems, 2005) and IDRISI Andes (Clarks Lab, 2006). This was followed by the TISEG correction, which removed all the anomalies. All the 163 MODIS images were then layerstacked, (ERDAS IMAGINE, Leica Geosystems, 2005) so that pixels can align. A time series analysis was done for all the 163 images using two methods, the standardised principal component analysis and the time-profile method using landuse classes.

4.3 Methodology

4.3.1 Rainfall Response

Rainfall is the main driver of vegetation change in any ecosystem and there is need to analyse rainfall variability. The rainfall data used in the analyses was acquired from the South Africa Weather Service (www.weathersa.co.za). Mean monthly rainfall from January 2000 to December 2006 was used to analyse the trends in rainfall dynamics in the Sandveld.

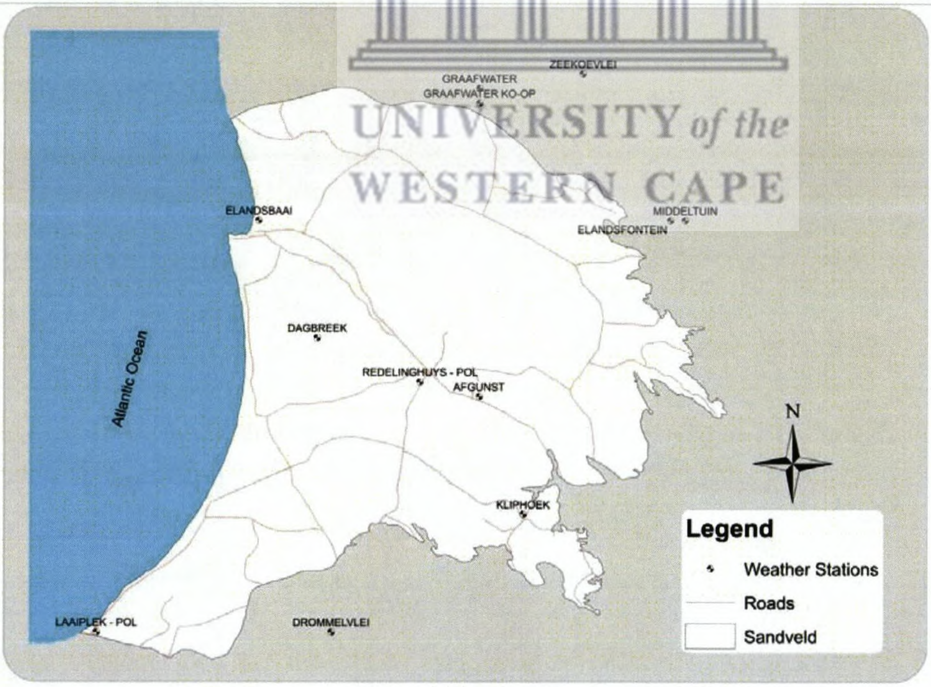

Figure 20: The sparse distribution of weather stations in the Sandveld, and the rainfall data that was used in this research were acquired from these stations (www.weathersa.co.za).

4.3.2 Time Series Analysis using Standardised Principal Component Analysis

The TSA module in IDRISI Andes (Clarks Labs, 2006) was used to run the standardised principal component analysis, producing 10 principal components, Eigen values, variances and their corresponding factor loadings. Factor loadings of each principal component were analysed using Microsoft Excel (Microsoft, 2007) to identify seasonal, inter-annual variability and trends in vegetation cover.

4.3.3 Time Series Analysis using time profiles

Landuse classes derived from the landuse classification (Chapter 3) were used as the input vectors in the temporal-profile analysis using the Z-Profile module (ENVI 3.0, ITT Visual Information Solutions 2003). Time series analysis using temporal profiles employed four statistical parameters: maximum NDVI, minimum NDVI, mean NDVI and coefficient of variation (*CV*) and the graphs of NDVI variations were plotted in Microsoft Excel (Microsoft, 2007). Landuse classes that were used to run the temporal profile time series analyses are:

- Water
- Wetlands
- Natural Vegetation
- Wetlands
- Agriculture
- Fire Patches
- Disturbed Veld

4.4 Results

4.4.1 Rainfall variation

There are seasonal variations in rainfall in the Sandveld with the highest rainfall occurring in winter and the lowest in summer (Figure 21). There is lower rainfall than normal between 2003 and 2004, which can be attributed to the drought.

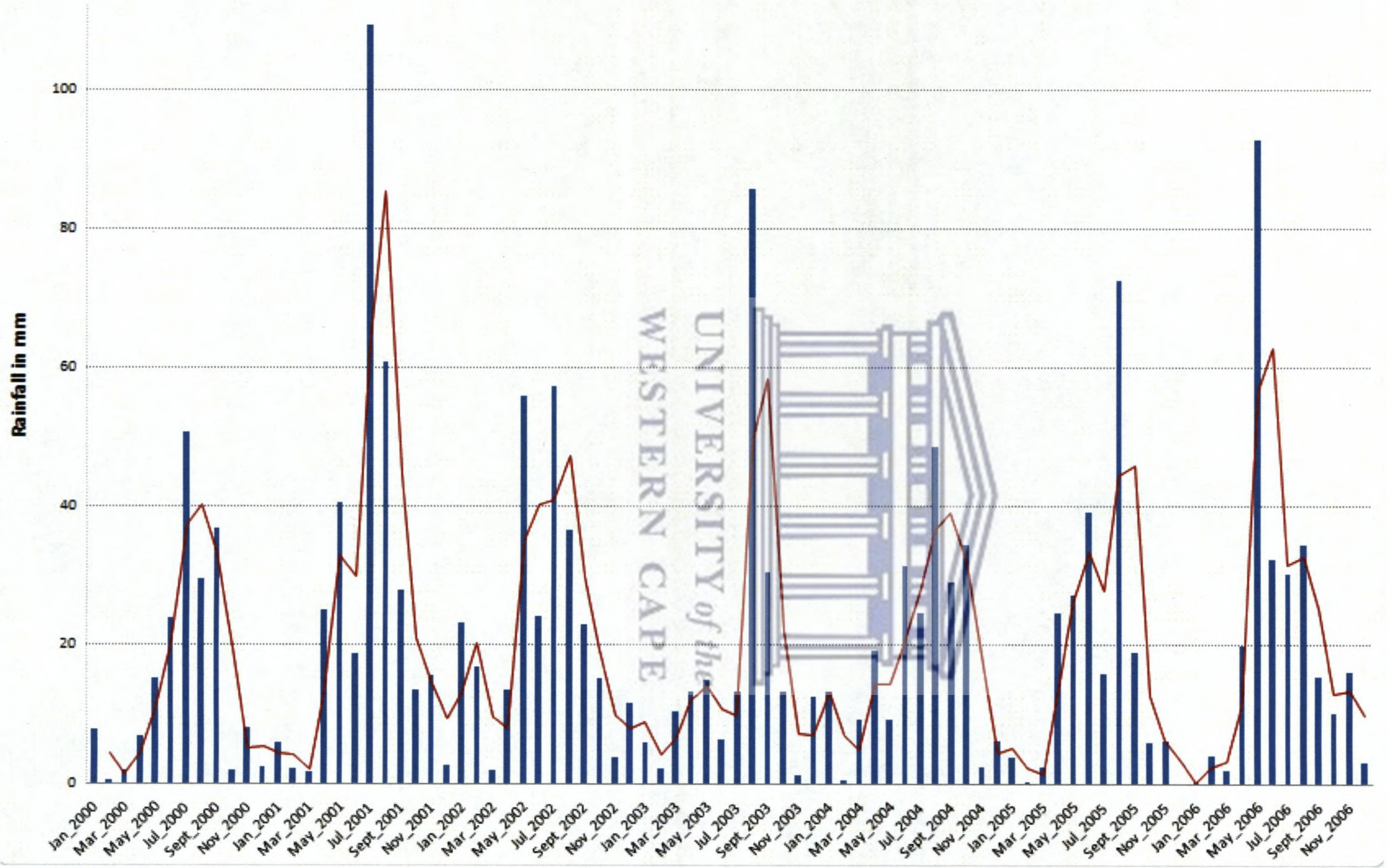

Figure 21: Average monthly rainfall in mm (blue bars) and rainfall trend line (red line) of10 weather stations in the Sandveld region between 2000 and 2006.

4.4.2 Standardised Principal Component Analysis (Time Series Analysis)

Spatial outputs are reflected in the form of principal components, the temporal outputs in the form of factor loadings. The first principal component (Figure 22) accounted for 93.63% (Table 10) of the variance and had high factor loadings ranging from 0.92 to 0.98. The lowest factor loadings of 0.92 occurred in winter of 2003 (June). Factor loadings of the first principal component indicated a high correlation with the original NDVI images (Figure 26). Though there is a remarkable uniformity in the factor loadings, there are some notable deviations, which show how the characteristic NDVI differed from the original NDVI image of that particular time. The second principal component (Figure 23) is the first change component with sinusoidal low and high peaks on the factor loadings with a minimum and maximum value of -0.15 and 0.25. This second principal component explains 1.25% of the variance in the original NDVI bands, as calculated from the residuals after the variance for the first principal component was removed (Eastman and Folk 1993, Eastman 2006). The third principal component (Figure 24) is derived from residuals of the first and the second principal components, and accounted for 0.58% of the variation in the NDVI images. Correlation between the third principal component and the original NDVI images fluctuates between negative and positive (Figure 26). Green areas of the third principal component corresponds to areas under intense agriculture, while the brown areas show areas of natural vegetation and water bodies, e.g. the Elandsbaai water body is quite evident on the image (Figure 24).The fourth principal component (Figure 25) accounted for 0.38% of the variance with its factor loadings ranging between -0.1 to 01.

Table 10: Variance of principal components derived from the standardised principal component analysis that was run using the MODIS NDVI from 2000 to 2006

Principal component	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	PC 9	PC 10
Percentage Variance	93.63	1.25	0.58	0.38	0.24	0.22	0.21	0.13	0.12	0.12

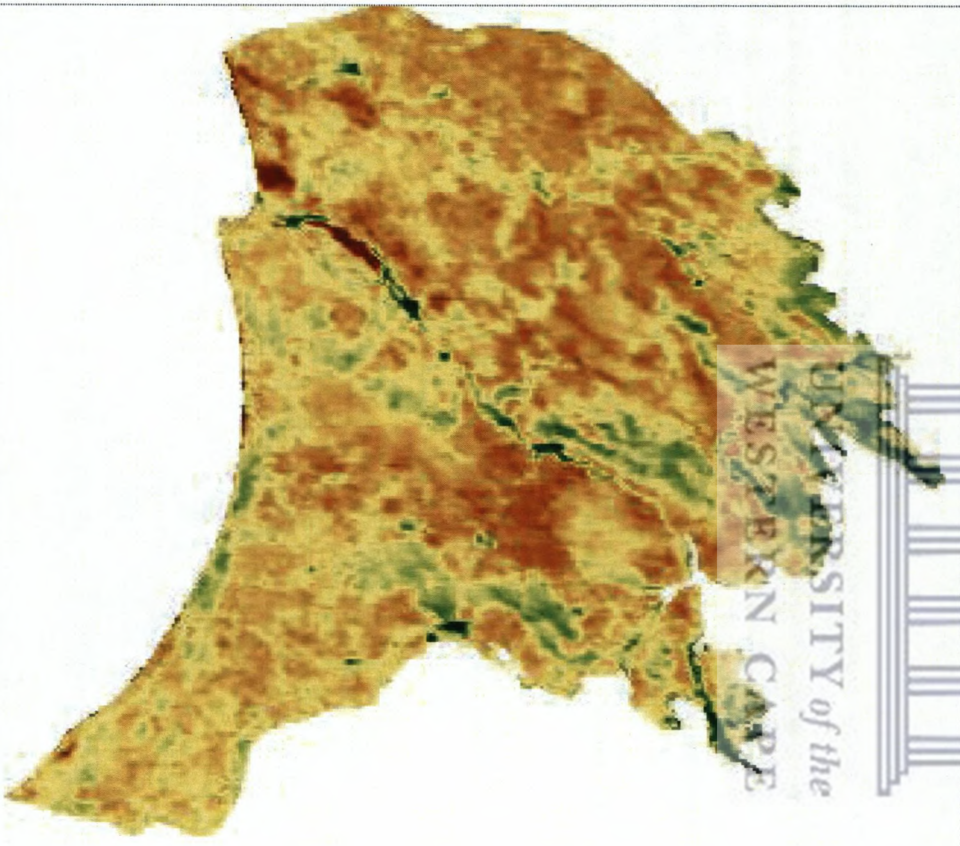

Figure 22: The first principal components derived from the standardised principal component analysis of MODIS NDVI data of 2000 – 2006.

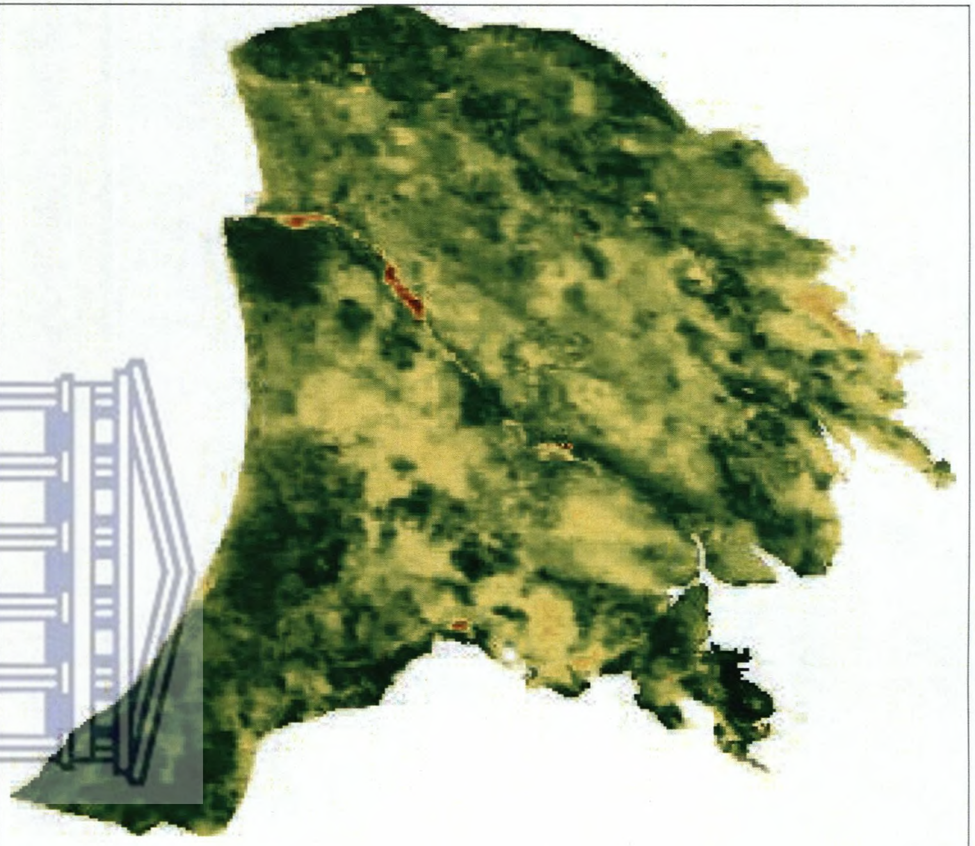

Figure 23: The second principal components derived from the standardised principal component analysis of MODIS NDVI data of 2000 – 2006.

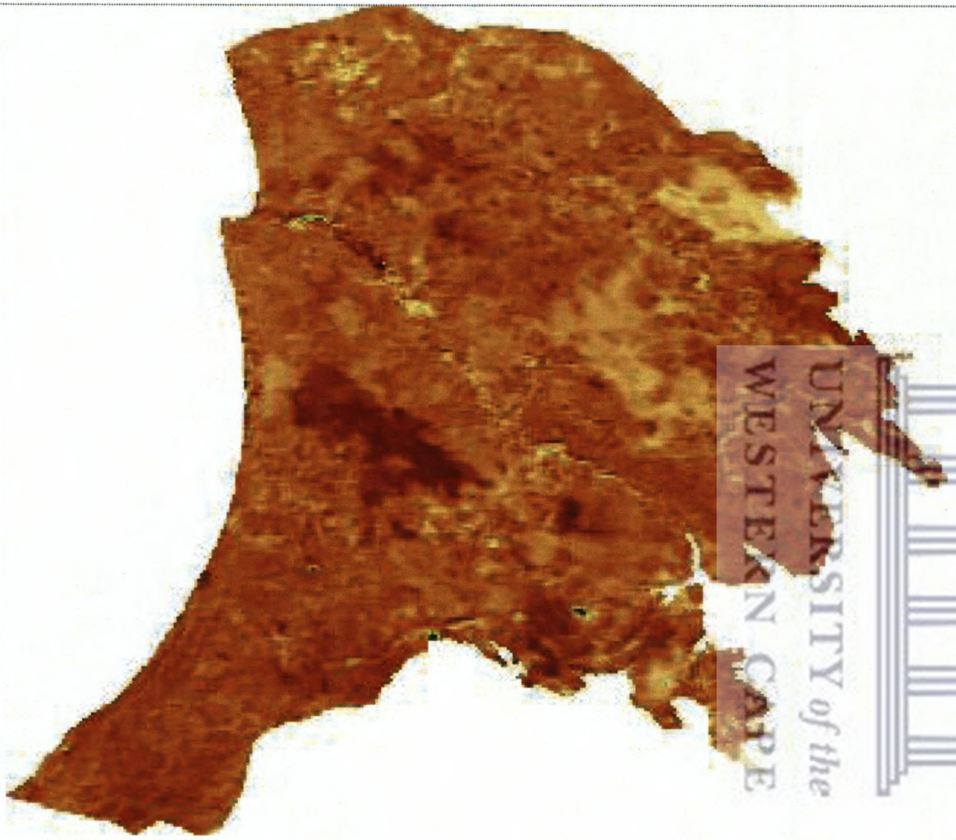

Figure 24: The third principal components derived from the standardised principal component analysis of MODIS NDVI data of 2000 – 2006.

Figure 25: The fourth principal components derived from the standardised principal component analysis of MODIS NDVI data of 2000 – 2006.

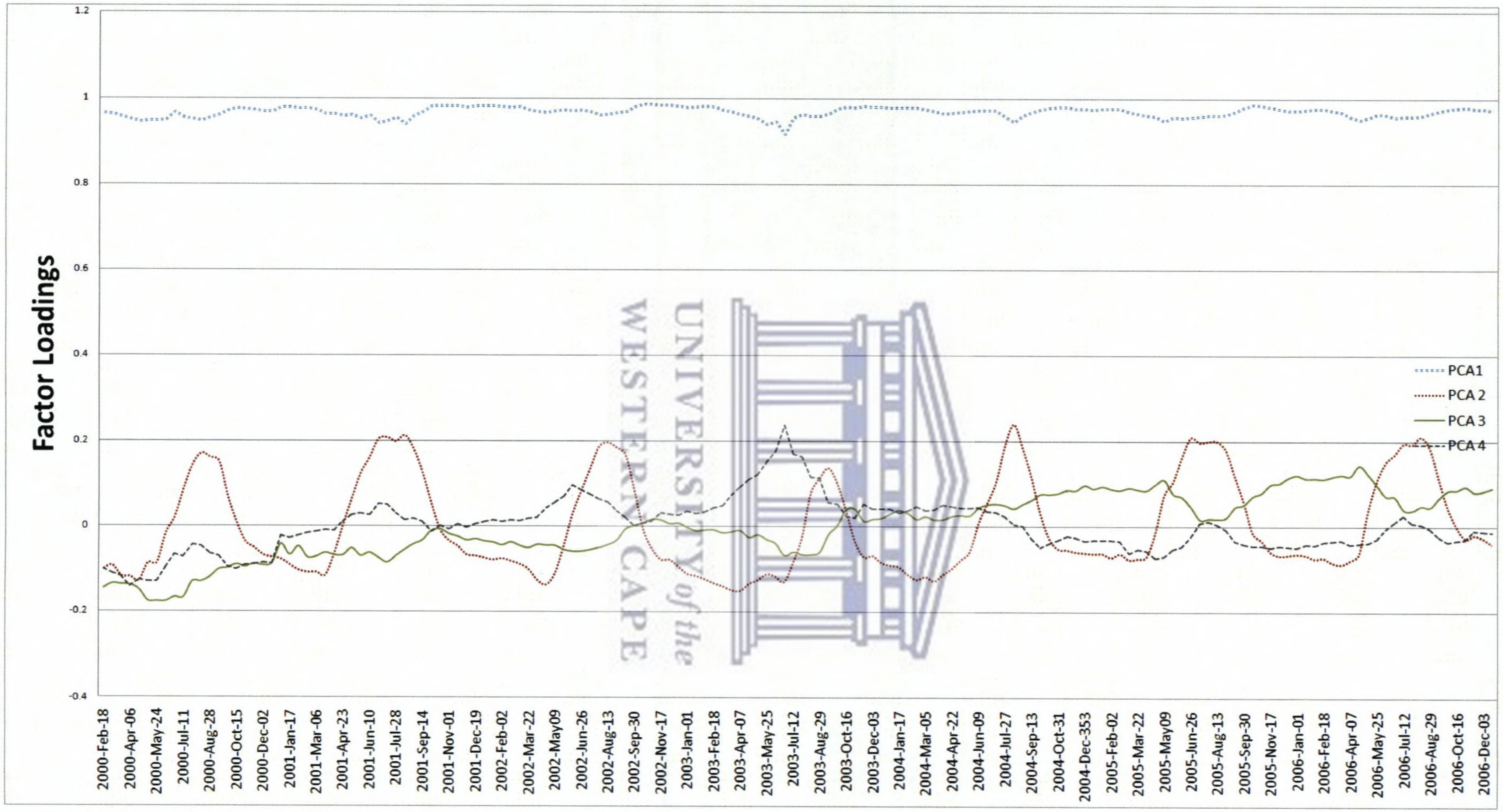

Figure 26: The correlation of each principal component with the original NDVI images and the mean NDVI graph derived from the time series analysis of MODIS NDVI data of 2000-2006.

4.4.3 Time Series Analysis using profiles

Temporal profiles for the whole study area show sinusoidal and unimodal cycles in the mean and maximum NDVI curves with peaks in winter and nadirs in summer, following rainfall patterns (Figure 21). The maximum NDVI values range from 0.8 to 1 with a mean NDVI of between 0.25 and 0.5 and a minimum NDVI at zero (Figure 27). The *CV* ranges between 25% and 37% with the highest variation occurring in June 2003, which coincides with drought and subsequent fires that affected the vegetation cover (Figure 27).

Temporal profiles for natural vegetation had a maximum NDVI ranging between 0.6 to 1 with the lowest maximum NDVI value in October 2003 and October 2004 coinciding with the drought period (Figure 28). Mean and maximum NDVI show a sinusoidal pattern with peaks occurring in winter and nadirs in summer similar to the patterns of rainfall in the Sandveld. There is a constant reduction in the *CV* from 2000; it dips as low as 0.2 in 2003. This is attributed to the 2003 wild fires, which destroyed natural vegetation and croplands (Figure 28). After 2003, the *CV* continued at a value of 0.2 (Figure 28).

Disturbed veld, cultivated farmland, and agricultural lands exhibited similar characteristics in their time profiles. The *CV* of all these classes shows some degree of seasonality with winters having a high *CV* variation and low variation observed in summer. Their mean and maximum NDVI revealed an element of seasonality with high amplitudes in some of the landuse classes, such as disturbed veld. The disturbed veld has distinct seasonal variations in both maximum and mean NDVI and the maximum NDVI ranges between 0.3 and 0.9.

Wetlands temporal profiles revealed some level of seasonality, both in the mean and maximum NDVI. The maximum NDVI ranged between 0.75 and 1 and mean NDVI ranged between 0.3 and 0.5. It had a fluctuating *CV* curve which ranged between 30% and 43%. Water areas did not show any patterns in mean, maximum and minimum NDVI curves. The behaviour of mean NDVI profiles in the fire patches (Figure 29) prior to 2003 revealed some seasonality in the level of greenness and it was quite evident that the fires occurred in 2003 as the mean NDVI was reduced to value less than 0.2, as a result of the reduction in photosynthetic potential. The *CV* in the fire patches were around 20% and high variation of up to 27%, 42% and 31% in 2003, 2005 and 2006 respectively (Figure 29).

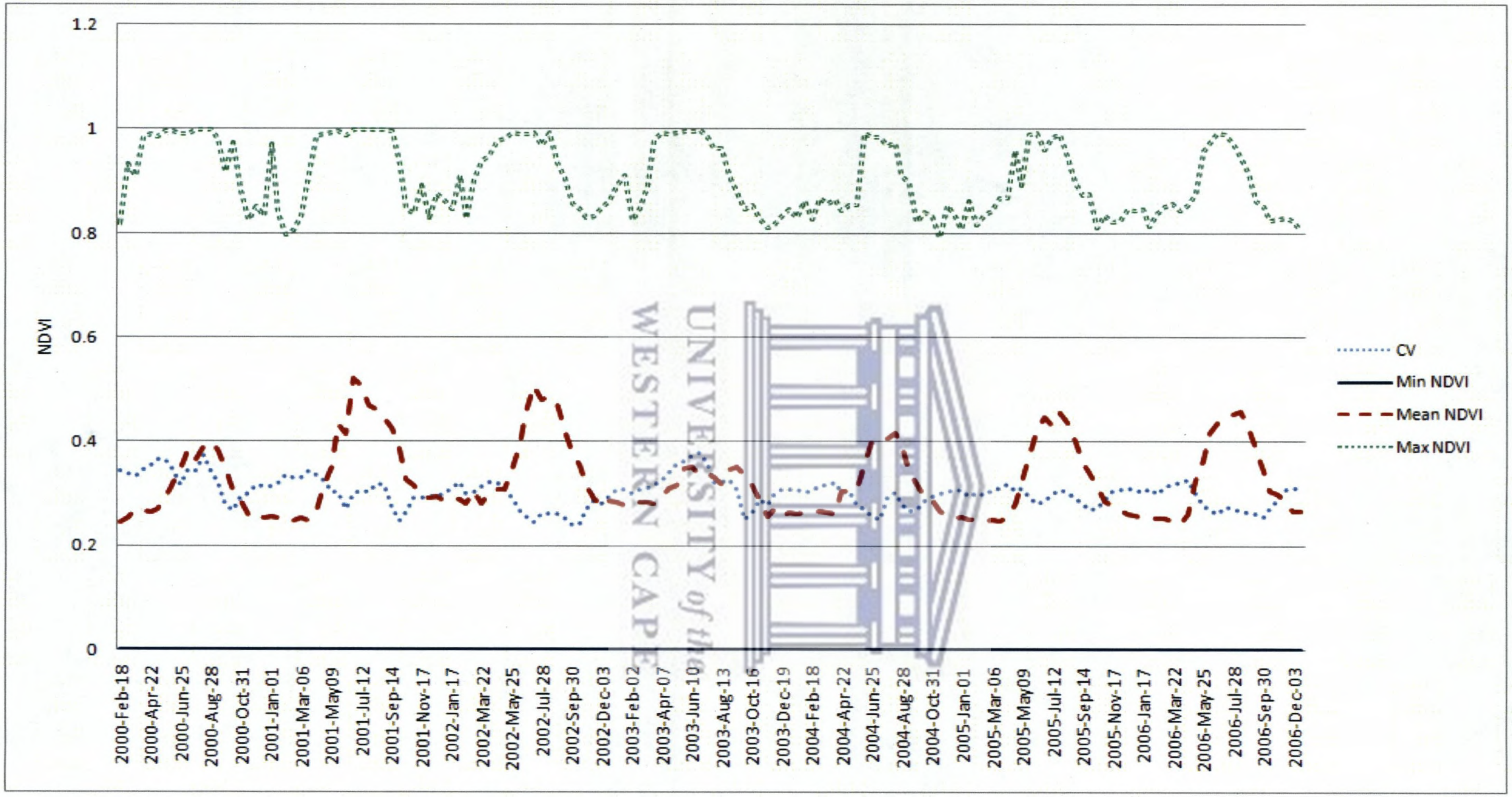

Figure 27: Seasonal and inter-annual variation in NDVI for the whole study derived from the time series analysis (profiling) of the MODIS NDVI data of February 2000 to December 2006.

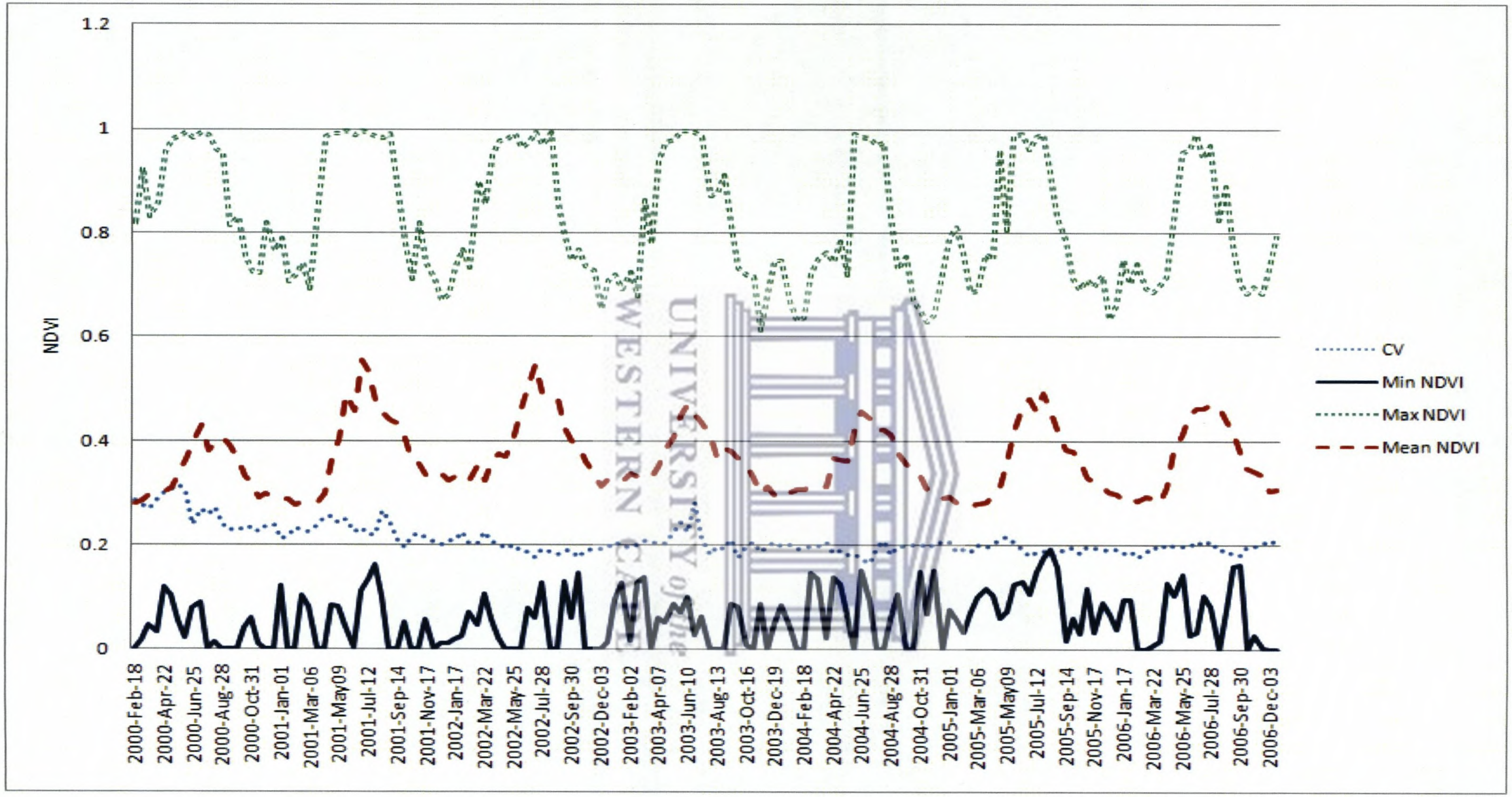

Figure 28: Seasonal and inter-annual variation of vegetation vigour in natural vegetation derived from the MODIS NDVI data of Feb 2000 to December 2006.

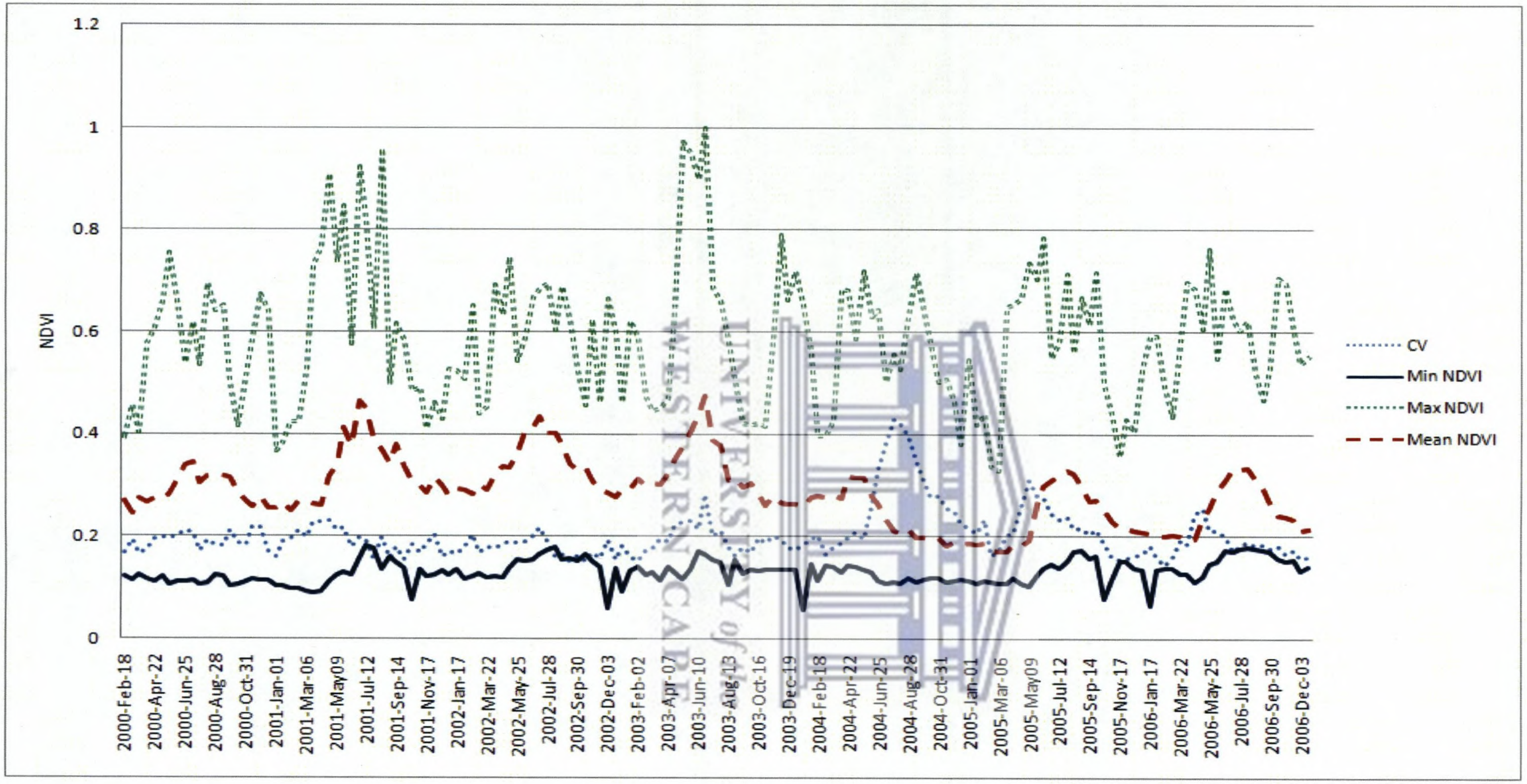

Figure 29: Seasonal and inter-annual variations in NDVI in the fire patches derived from the MODIS NDVI data.

4.5 Discussion

Rainfall followed, a sinusoidal pattern with peaks in winter and nadirs in summer following the trends in the CFR Mediterranean rainfall which is characterised by high winter rains and dry summer with low rainfall levels (Cowling, 2004).The rainfall analysis revealed an uneven sinusoidal curve, which is attributed to uneven rainfall patterns and drought regimes in the Sandveld (Cowling, 2004). Spatial distribution of weather stations in the Sandveld made it difficult to interpolate the rainfall data (interpolating can be defined as predicting the values of areas where rainfall is not recorded using geostatistics). Interpolated rainfall images were to be regressed against the NDVI images to determine the relationship, which exist between rainfall and NDVI. Goovaerts (1999) argued that an accurate spatial distribution requires a very dense network of measuring equipment, which is not the case in the Sandveld. Interpolating rainfall would help understand the relationship which exists between rainfall and vegetation cover (NDVI) in the Sandveld Newton (2008) found that there is a positive correlation between rainfall and NDVI in the Renosterveld. Studies in the Amazon Basin and Brazil revealed that NDVI relates to the changing patterns of precipitation in drier climates but in the rainforests, NDVI is exponentially related to the leaf area index (Santos and Negri, 1997). In the semi-arid part of Iran, NDVI is related to lagged rainfall (Damizadeh *et al*, 2001). Santos and Negri (1997) argue that NDVI losses sensitivity to vegetation process with the increase in the layer of leaves such as in the rainforests. In Senegal, there is a strong relationship between NDVI and rainfall (Li *et al*. 2004).The authors concluded that NDVI is a sensitive indicator of the seasonal and spatial variation in rainfall in the semiarid region and in the forest areas NDVI is not affected by the variations in rainfall. There is a hypothesis that NDVI is only limited by changing rainfall patterns in dry regime but not in the wet regime (Santos and Negri, 1997). Since the Sandveld is in a dry region were rainfall is quite erratic it means that there is likely to be a positive correlation between NDVI and rainfall and there is a similarity between the rainfall data and the NDVI temporal profile So rainfall data can be used as a surrogate for NDVI data in the semi-arid region (Barbosa, 2006).

Principal component analysis was used to gain an understanding of the main source of variation in the Sandveld between 2000 and 2006. The first principal component, which has high variance, expressed the characteristic response/value of all the bands (Eastman, 1992; Eastman and Fulk, 1993), it explained the pattern that accounts for the greatest degree of variation among the bands (Eastman, 1992, 2006). It represented albedo or overall brightness, which is the characteristic NDVI (Eastman, 1992, 2006). There was a dent on the factor loading graph of the first principal component in July 2003 which coincided with the fire and it revealed that fire is a local event in the Sandveld.

The second principal component which is the most important in assessing variations in vegetation cover represented seasonal variations in vegetation cover (Eastman, 2006) and this was highly emphasised by the factor loadings, which follow a sinusoidal curve, and have positive loadings on the near-infra-red band and negative loadings in the visible bands (Eastman, 2006). This principal component correlated positively with winter NDVI images and negatively with the summer NDVI images and showed the seasonal variation with a six-month sinusoidal pattern with negative loadings in summer and positive loadings in winter, and this followed the rainfall patterns. This cyclical pattern was disturbed in 2003 and 2004 by drought and fire regimes which affected the photosynthetic productivity. In 2003 the mean NDVI was very low and it suggested that there was low rainfall as the factor loadings are revealed very short winters of 2003 and 2004. In winter of 2003 the Mean NDVI value was on average less than 0.4 which suggested low photosynthetic productivity due to low agricultural activities.

Factor loadings of the third principal component revealed long term trends which suggested an increase in greenness from 2000 to 2006. There was a general trend from negative to positive factor loadings during the study period, which can be attributed to the increase of agricultural activities, especially the increase of intensive potato and rooibos tea farming. Natural disturbances were also evident in this long term trends, for example the 2003 and 2004 drought period, which was characterised with low rainfall and low agricultural activity and the 2003 fires which disturbed the agricultural potential of the area. There are positive and negative anomalies on this principal component, the greener areas have positive anomalies whereas the areas in brown have negative anomalies. The forth principal component revealed some anomalies in the Sandveld; there is a sudden peak in the factor loadings in 2003 which suggested some major disturbances due to drought and fires.

These results from the principal component analysis were augmented by the time series analysis using temporal profiles of each landuse class. NDVI profiles for most of the landuse classes were characterised with a sinusoidal curve that showed high vegetation cover (NDVI) in winter and low in summer. In the fire patches there was sudden increase in the *CV* in 2003 which coincided with the dates when the fire and drought occurred. According to Weiss *et al.* (2001) a high NDVI *CV* represents a greater change in vegetation cover and a low *CV* indicates a low variability in the vegetation cover (Scott, 2006). The difference between maximum and minimum NDVI was quite high which implies high photosynthetic activity, which was attributed to high agricultural activities (Barbosa, 2006). The *CV* ranged between 25% and 37% with the highest variation occurring in June 2003, which coincided with drought and subsequent fires that affected the vegetation cover. Due to the drought the water level in the rivers and dams was reduced which affected agricultural production, hence the low level of greenness. High amplitudes showed the photosynthetic variability, the high peak shows high NDVI performance and nadirs show low NDVI, i.e. low greenness, levels. The curves (maximum and mean NDVI) showed that the disturbed areas also responded to these seasonal variations, as the NDVI is low in summer and high in winter, which corresponds to the rainfall patterns of the area.

Seasonal variations in the fire patches were as evident before 2003, but after the fire, the seasonality of mean NDVI was disturbed and it began to be defined after 2004. This shows the increase in greenness due to the re-vegetation of the burned area and the presence of farming activities.

4.6 Conclusion

NDVI has been used successfully in this research to analyse spatio-temporal variation and trends in vegetation productivity. It is a tool that can be used by terrestrial ecologists to gain a better understanding of the vegetation dynamics. In this research NDVI variations revealed the impacts of droughts and fires and some seasonal variations in the vegetation cover. The seasonal variations followed the rainfall trends with high NDVI values in winter and low in summer, which entails higher vegetation productivity in winter than in summer.

There is an increase in greenness between 2000 and 2006 because of the increase in agricultural activities which has led to increased habitat fragmentation. There is also evidence of natural disturbances in the area; there was a drought in 2003 and 2004 and natural fires in 2003, which reduced vegetation cover as well as agricultural productivity. Of significance is the pronounced seasonal variation in the areas, which are well reflected, in the second principal component and the temporal profiling results.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This research comprised of five main components, which are multi-temporal image classification of the Landsat satellite imagery, landuse change, habitat fragmentation, prediction of future scenarios and time series analysis. It has demonstrated the strength of using remote sensing technologies to produce accurate landuse maps and to perform landuse change statistics of the Sandveld from 1990 to 2007. The following conclusions were drawn from the research:

5.1.1 Multi-temporal Landuse classification

The multi-temporal landuse classification produced the following seven land use classes based on the maximum likelihood classification and these are:

- Agriculture, - this comprises of combined cultivated farmlands and irrigation plots. Initially they were mapped separately but they were overlapping as they have similar radiometric characteristics (spectral signatures).
- Disturbed Veld: These are landscapes that were left to lie fallow in order to reduce the infestation of nematodes in the potato fields (Berger, 2006).
- Fire patches: There was a major fire in 2003 which destroyed both natural habitats and farmlands and it was mapped in the 2004 and 2007 landuse maps
- Natural Vegetation: This landuse classes included natural and semi-natural landscapes
- Open Sands: this was just the sands that are available along coastlines.
- Water: These were natural water bodies and dams. They were explicit mapped with few overlapped with wetlands.

- Wetlands: This includes the vegetation and non-vegetated wetlands and it with rivers and some water bodies. The analysis was enhanced by the data from the Freshwater Group who mapped all the wetlands in the Cape Lowlands for the C.A.P.E. Fine Scale Biodiversity Planning Project

Urban area were masked out in the analysis as they are difficult to map using low resolution satellite images such as Landsat. Using Landsat imagery to discriminate distinctively the spectral signature of urban areas and it surrounding is still problematic (Herold *et al*. 2002). The distinction of built up area and bare soils/ rock is quite difficult as they have the same spectral response and to avoid complication urban areas in the Sandveld were masked out. The overall accuracy of landuse classification was 80% which according to Jenson (2005) is acceptable and the Kappa Statistic was 0.71 or 71%.

5.1.2 Landuse Changes and Habitat fragmentation

There was increased habitat fragmentation between 1990 and 2007 in the Sandveld which was due to increased in agriculture, mainly intensive potato, rooibos tea and wheat farming and wild fires. There was 11% loss in the natural vegetation and 30% increase in both disturbed veld and agriculture between 1990 and 2007 which was exacerbated by the five-year rotation of farmlands especially potato farms to reduce nematodes predation (Knight, *et al*. 2007). Wild fires which are part of the fynbos ecosystems contributed also to the habitat fragmentation (Mucina and Rutherford, 2006). Gains in the natural vegetation were as a result of re-vegetation and alien species invasions (Cowling, 2004). There was a decrease in the size of wetlands and water bodies which was as a result of increased legal and illegal underground water extraction for irrigation purposes and thereby negatively affecting the underground reserves (Knight, *et al*, 2007; Conrad, *et al*. 2008). This led to the succession of wetlands and some water bodies into natural vegetation.

There was a continual habitat fragmentation in the Sandveld which led to the disappearance of habitat fragments which in turn increased the distance between patches. There was a decrease in the number of patches from 1990 to 2007 and some habitat fragments disappeared. Results of the analysis agree with previous studies, as the degree of habitat fragmentation increases habitat patches lose their regular shape and they become complex hence the shape index increases (Santiago and Javier, 2001). Increase in agriculture activities in the Sandveld has increased habitat fragmentation; this in turn reduced the size and connectivity of natural habitats. This makes the landscape unfavourable for both plant and animal species as it inhibits gene flow between patches. Continued conversion of natural vegetation into agriculture land or disturbed veld increased the distance between patches, leading to the migration of species to neighbouring tracts of natural habitat and altered the homogeneity of the within a landscape. A decrease in both aquatic and terrestrial ecosystems was observed, and small habitat fragments disappeared between 1990 and 2007, with more disappearing on the predicted landuse map of 2020. Landuse change analysis methods were also used to identify micro-biodiversity "hotpots" within the landscape using vegetation types. If the natural remnants in a vegetation types are below the conservation target then 100% of those remnants need to be in cooperated in the protected area network and additional habitats needs to be identified for conservation to achieve the conservation target.

5.1.3 Prediction of Future Scenarios

A prognostic approach using Markov stochastic modelling predicted future scenarios in landuse changes between 2007 and 2020. The predicted landuse map of 2020 revealed a 30% loss in the natural vegetation between 2007 and 2020 which means a continual increase in habitat fragmentation. The predicted landuse maps showed that 70% of the natural vegetation is likely to remain intact by 2020 and 30% will be turned into other landuse use classes such as agriculture and disturbed veld. There is a predicted increase in the agricultural areas and disturbed veld by 2020 which will in turn increase habitat fragmentation. Aquatic and terrestrial ecosystems natural habitats covered 54.5 % of the total landscape area in 1990, which declined to 45.6% in 2007 and a predicted 41% by 2020. Fragmentation indices from the predicted landuse map of 2020 revealed that there would be a continual decrease in the natural habitat as there is a predicted decrease in the mean patch size by 2020 and a predicted disappearance of some of the small patches.

5.1.4 Time Series Analysis

Spatio-temporal analysis revealed seasonal variations in vegetation from 2000 to 2006 with winter seasons exhibiting high vegetation cover as compare to summer seasons and these suggested that the Sandveld have high degree of dynamic change. The first principal component accounted for the highest variance and its factor loadings are highly correlated to the original NDVI images (Eastman, 1992; Eastman and Fulk, 1993). The second principal component which is the change component showed the seasonal variations with a six-month sinusoidal pattern, with negative loadings in summer and positive loadings in winter, following natural rainfall patterns (Eastman, 1992, 2006). This principal component correlates positively with winter NDVI images and negatively with the summer NDVI images. These cyclical patterns were disturbed in 2003 and 2004 by drought and fire regimes which affected the photosynthetic productivity of the Sandveld. The third principal component revealed a general trend from negative to positive, which is associated with an increase in greenness because of the increase in agricultural activities in the area. To augment the above results of the standardised principal component analysis, temporal profiles for each landuse classes assessed the seasonal and unimodal variations in the minimum, mean and maximum NDVI curves. The coefficient of variation (*CV*) outlined major disturbances that occurred in the Sandveld mainly the drought and fires, which occurred between 2003 and 2004. The difference between maximum and minimum NDVI was high which implied high photosynthetic activity, which is attributed to high agricultural activities (Barbosa, 2006).

5.2 Limitations and Strategy for future Study

Some Landsat images that were made available to the research (Winter Landsat images) proved difficult to classify as the signatures of wetlands and agricultural lands were overlapping. Attempts to use ATCOR to correct atmospheric and topographic errors were unsuccessful, so all the winter images were not used in the landuse classification and landuse change analysis. These winter images would have added a component of seasonality trends to the landuse change.

Another limitation to the remote sensing classification was extensive cloud cover, which obscured much of the areas in the Sandveld, the different depths and intensities of clouds and their associated shadows resulted in wide variation in signal. This caused considerable disturbances in the image classifications so all the image with clouds were not finally used. Mapping landuse classes using Landsat images was not the best option because Landsat images have a spatial resolution of 30m and it will be difficult to properly demarcate some of the classes such as the circular irrigation plots. In the future, it is recommended to use high-resolution images such as IKONOS, SPOT and QUICKBIRD as they have better resolutions. In future researches the use of microwave remote sensing such as RADAR is highly recommended to map water bodies and wetlands.

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APPENDIX

APPENDIX I – Randomly Selected Points Used In Accuracy Assessment (UTM 34S)

Name	X - Coordinate	Y - Coordinate
ID#1	256805	6410797
ID#2	286295	6414997
ID#3	284105	6376027
ID#4	262385	6345277
ID#5	244955	6420127
ID#6	249365	6399697
ID#7	291065	6401707
ID#8	233705	6372187
ID#9	284765	6348607
ID#10	253445	6362827
ID#11	292655	6370777
ID#12	259745	6338647
ID#13	289235	6349477
ID#14	228365	6409207
ID#15	275855	6363397
ID#16	284495	6416257
ID#17	267215	6405247
ID#18	279785	6383557
ID#19	228035	6379417
ID#20	283115	6415867
ID#21	246485	6361957
ID#22	292595	6340477
ID#23	223055	6412837
ID#24	261845	6346867
ID#25	274535	6404407
ID#26	288005	6343177
ID#27	277745	6344497
ID#28	256985	6405127
ID#29	279485	6392257
ID#30	282695	6349027
ID#31	266555	6378277
ID#32	292745	6391837
ID#33	297095	6394807
ID#34	285815	6348067
ID#35	232505	6378637
ID#36	288395	6409297
ID#37	279275	6359317
ID#38	294935	6370867
ID#39	259535	6344677
ID#40	291575	6376567
ID#41	259145	6407707
ID#42	220745	6381277
ID#43	244745	6389287
ID#44	234065	6346417
ID#45	226505	6409777
ID#46	238145	6344137
ID#47	274745	6381817
ID#48	222125	6339247
ID#49	280445	6398677
ID#50	231965	6332377
ID#51	296045	6329707
ID#52	220325	6347647
ID#53	244475	6395497
ID#54	294275	6415477
ID#55	260585	6356977
ID#56	240155	6380737
ID#57	233345	6332407
ID#58	237215	6395527
ID#59	290165	6350407
ID#60	239705	6356257
ID#61	255755	6367627
ID#62	236825	6366427
ID#63	273305	6336727
ID#64	230495	6351517
ID#65	222995	6374947
ID#66	254015	6362917
ID#67	225695	6401887
ID#68	263945	6374977
ID#69	243815	6388957
ID#70	248885	6401467
ID#71	242315	6336817
ID#72	287525	6345937
ID#73	273425	6396937
ID#74	224825	6394987
ID#75	239495	6352837

ID#76	267665	6407677
ID#77	296525	6354367
ID#78	271505	6357127
ID#79	232265	6389347
ID#80	291725	6334297
ID#81	271625	6375397
ID#82	268955	6343297
ID#83	282605	6395797
ID#84	271475	6330577
ID#85	232445	6414307
ID#86	235835	6376147
ID#87	247925	6413827
ID#88	251045	6376957
ID#89	249305	6361057
ID#90	219635	6361987
ID#91	272975	6366397
ID#92	276635	6386257
ID#93	240245	6397477
ID#94	285125	6381367
ID#95	228125	6409627
ID#96	245225	6377977
ID#97	257615	6420007
ID#98	243185	6359917
ID#99	278105	6421177
ID#100	278375	6418477

APPENDIX 2: Cross Tabulation Of The Landuse Maps

```
Cross-tabulation of 1990_mc (columns) against 2004_mc (rows)

                 0         1         2         3         4         5         6         7         8      Total
           ---------------------------------------------------------------------------------------------------
     0 |   1772901         0         0         0         0         0         0         0         0 | 1772901
     1 |         0      9002        35       359       274        53         2         1         0 |    9726
     2 |         0      3476    792031     10239      2851     36084     71440     68980         0 |  985101
     3 |         0      1842      5881     51182       671         0         0         0         0 |   59576
     4 |         0        54       723       146      4004      1593       604       109         0 |    7233
     5 |         0       123     68659         0      6947     88965     99294     24285         0 |  288273
     6 |         0         7     64308         0       700     83847    225769     36959         0 |  411590
     7 |         0         5    149915         0      8607     39026    115978     71521         0 |  385052
     8 |         0         0         0         0         0         0         0         0       982 |     982
     9 |         0         0     45364         0      2433      1836      9080      1625         0 |   60338
           ----------------------------------------------------------------------------------------------------
Total  |   1772901     14509   1126916     61926     26487    251404    522167    203480       982 | 3980772

        Chi Square =14974540.00000
                df =         72
           P-Level =    0.0000
        Cramer's V =         0.6857

        Proportional Crosstabulation

                 0         1         2         3         4         5         6         7         8      Total
           ---------------------------------------------------------------------------------------------------
     0 |    0.4454    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000 |  0.4454
     1 |    0.0000    0.0023    0.0000    0.0001    0.0001    0.0000    0.0000    0.0000    0.0000 |  0.0024
     2 |    0.0000    0.0009    0.1990    0.0026    0.0007    0.0091    0.0179    0.0173    0.0000 |  0.2475
     3 |    0.0000    0.0005    0.0015    0.0129    0.0002    0.0000    0.0000    0.0000    0.0000 |  0.0150
     4 |    0.0000    0.0000    0.0002    0.0000    0.0010    0.0004    0.0002    0.0000    0.0000 |  0.0018
     5 |    0.0000    0.0000    0.0172    0.0000    0.0017    0.0223    0.0249    0.0061    0.0000 |  0.0724
     6 |    0.0000    0.0000    0.0162    0.0000    0.0002    0.0211    0.0567    0.0093    0.0000 |  0.1034
     7 |    0.0000    0.0000    0.0377    0.0000    0.0022    0.0098    0.0291    0.0180    0.0000 |  0.0967
     8 |    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0002 |  0.0002
     9 |    0.0000    0.0000    0.0114    0.0000    0.0006    0.0005    0.0023    0.0004    0.0000 |  0.0152
           ----------------------------------------------------------------------------------------------------
Total  |    0.4454    0.0036    0.2831    0.0156    0.0067    0.0632    0.1312    0.0511    0.0002 |  1.0000

  Kappa Index of Agreement (KIA)
------------------------------

Using 2004_mc as the reference image.

Category        KIA
--------     -------

       1      0.9253
       2      0.7266
       3      0.8569
       4      0.5506
       5      0.2620
       6      0.4804
       7      0.1419


Using 1990_mc as the reference image.
```

```
Category         KIA
--------       -------

       0       1.0000
       1       0.6195
       2       0.6051
       3       0.8239
       4       0.1496
       5       0.3034
       6       0.3669
       7       0.2820
       8       1.0000


Overall Kappa          0.6579


Cross-tabulation of 2004_mc (columns) against 2007_mc (rows)

                 0          1          2          3          4          5          6          7          8          9
Total
         -----------------------------------------------------------------------------------------------------------
-------
      0 |  1772901          0          0          0          0          0          0          0          0          0 |
1772901
      1 |        0       9381       1039       2148        128        292         10         10          0          0 |
13008
      2 |        0         21     812848       6881         19      24389      20547      68739          0       1150 |
934594
      3 |        0         91       9382      50147         32          0          0          0          0          0 |
59652
      4 |        0        228       2048        400       6016       4016        804       3577          0          0 |
17089
      5 |        0          5      31289          0        348     120482      95088      31917          0       2303 |
281432
      6 |        0          0      43880          0        642      83559     250084      85627          0          0 |
463792
      7 |        0          0      74081          0         48      46756      43540     195182          0          0 |
359607
      8 |        0          0          0          0          0          0          0          0        982          0 |
982
      9 |        0          0      10534          0          0       8779       1517          0          0      56885 |
77715
          ----------------------------------------------------------------------------------------------------------
--------
Total   |  1772901       9726     985101      59576       7233     288273     411590     385052        982      60338 |
3980772


        Chi Square =20540136.00000
                df =       81
           P-Level =   0.0000
        Cramer's V =        0.7572


        Proportional Crosstabulation

                 0          1          2          3          4          5          6          7          8          9
Total
         -----------------------------------------------------------------------------------------------------------
-------
      0 |   0.4454     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 |
0.4454
      1 |   0.0000     0.0024     0.0003     0.0005     0.0000     0.0001     0.0000     0.0000     0.0000     0.0000 |
0.0033
      2 |   0.0000     0.0000     0.2042     0.0017     0.0000     0.0061     0.0052     0.0173     0.0000     0.0003 |
0.2348
```

```
       3 |     0.0000    0.0000    0.0024    0.0126    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000 |
0.0150
       4 |     0.0000    0.0001    0.0005    0.0001    0.0015    0.0010    0.0002    0.0009    0.0000    0.0000 |
0.0043
       5 |     0.0000    0.0000    0.0079    0.0000    0.0001    0.0303    0.0239    0.0080    0.0000    0.0006 |
0.0707
       6 |     0.0000    0.0000    0.0110    0.0000    0.0002    0.0210    0.0628    0.0215    0.0000    0.0000 |
0.1165
       7 |     0.0000    0.0000    0.0186    0.0000    0.0000    0.0117    0.0109    0.0490    0.0000    0.0000 |
0.0903
       8 |     0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0000    0.0002    0.0000 |
0.0002
       9 |     0.0000    0.0000    0.0026    0.0000    0.0000    0.0022    0.0004    0.0000    0.0000    0.0143 |
0.0195
          -----------------------------------------------------------------------------------------------------
--------
Total    |     0.4454    0.0024    0.2475    0.0150    0.0018    0.0724    0.1034    0.0967    0.0002    0.0152 |
1.0000


  Kappa Index of Agreement (KIA)
------------------------------

Using 2007_mc as the reference image.

Category        KIA
--------     -------

       0      1.0000
       1      0.7205
       2      0.8269
       3      0.8382
       4      0.3509
       5      0.3835
       6      0.4861
       7      0.4938
       8      1.0000
       9      0.7278


Using 2004_mc as the reference image.

Category        KIA
--------     -------

       0      1.0000
       1      0.9644
       2      0.7715
       3      0.8393
       4      0.8310
       5      0.3737
       6      0.5559
       7      0.4579
       8      1.0000
       9      0.9416


Overall Kappa         0.7527
```

APPENDIX 3: The Result Of The NDVI Profiles

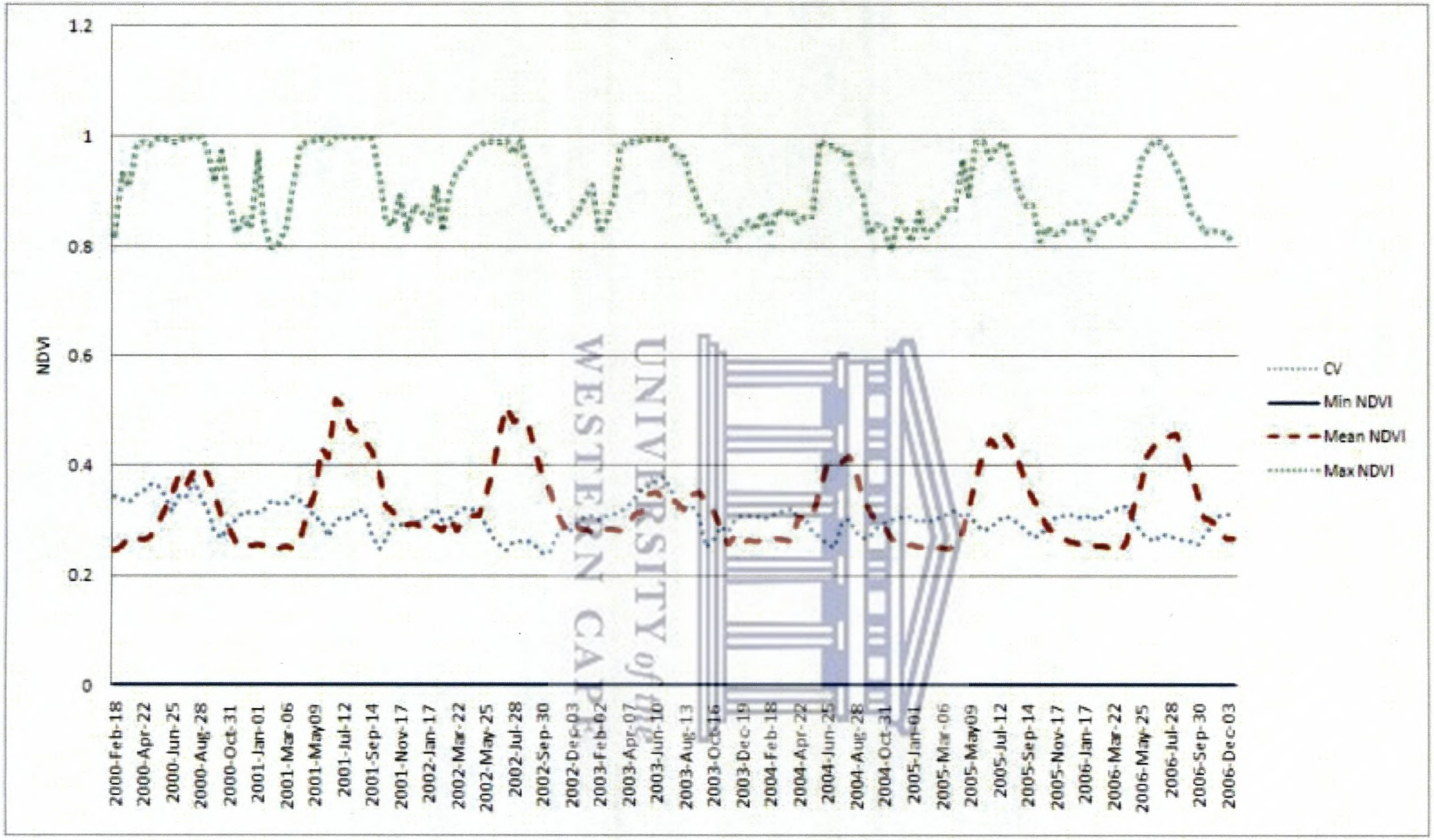


Figure 30: Seasonal and inter-annual variations in NDVI produced from the temporal profile of the whole study area using MODIS NDVI data.

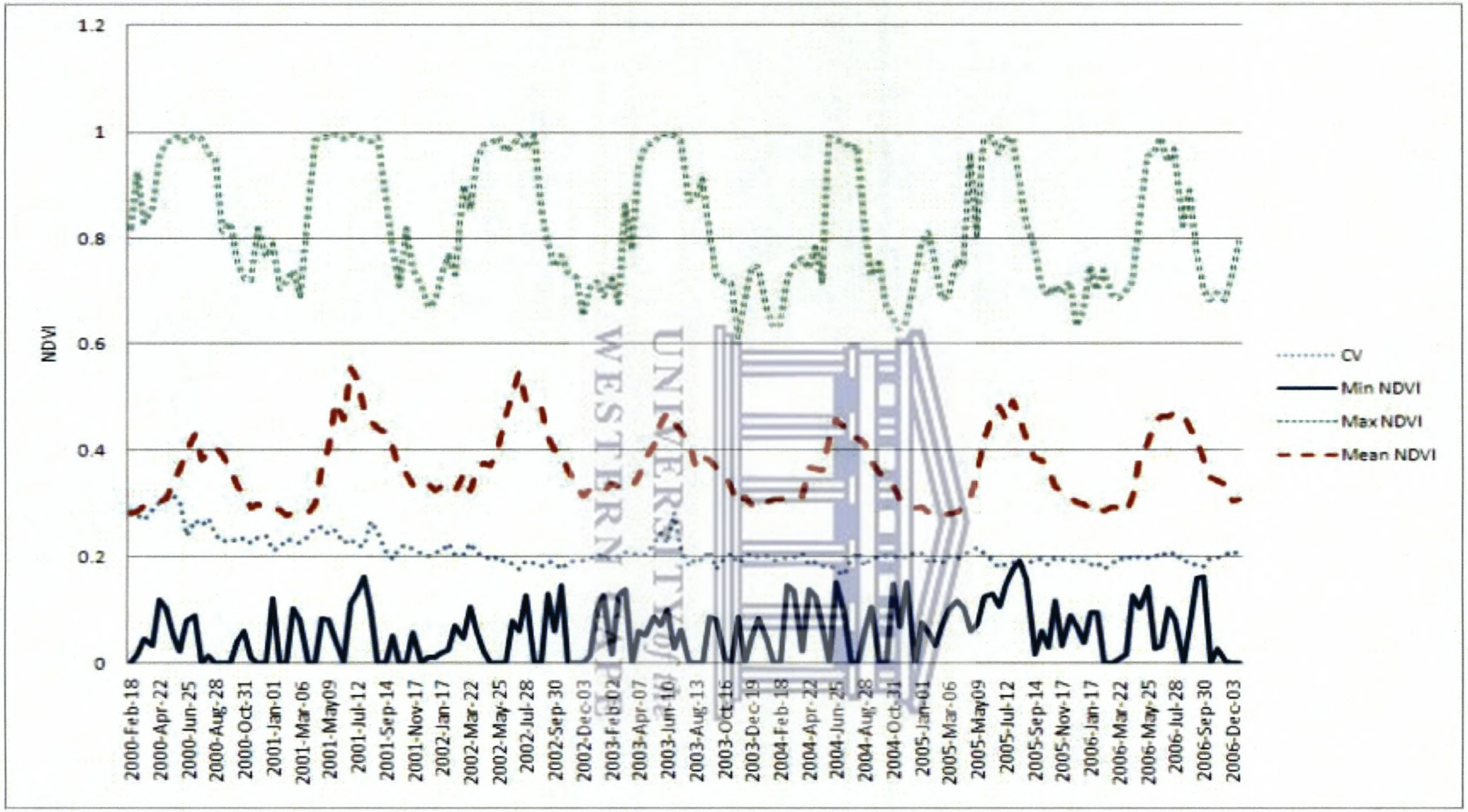


Figure 31: Seasonal and inter-annual variations in NDVI produced from the temporal profile of natural vegetation using MODIS NDVI data.

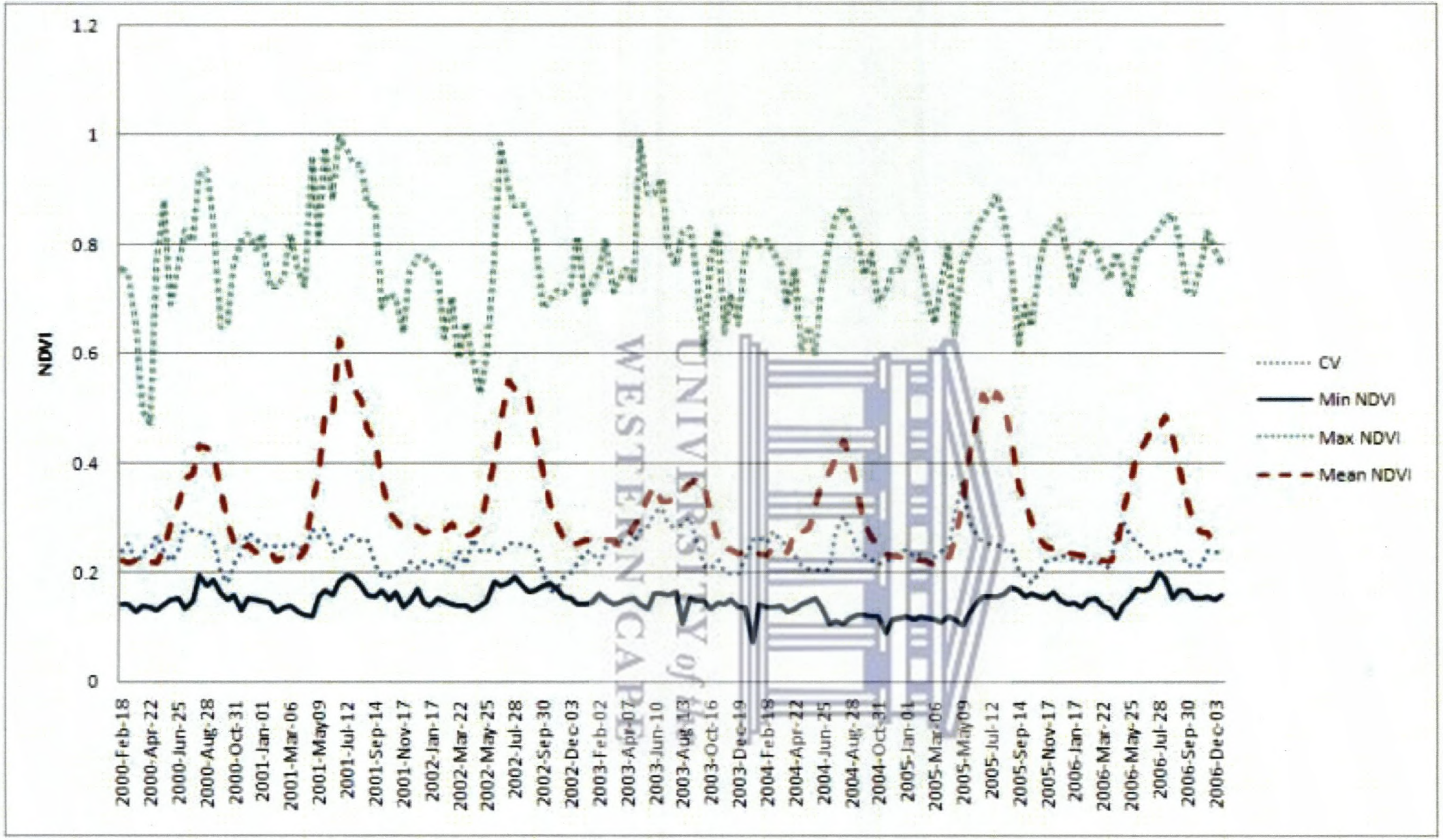


Figure 32: Seasonal and inter-annual variations in NDVI produced from the temporal profile of agricultural lands using MODIS NDVI data.

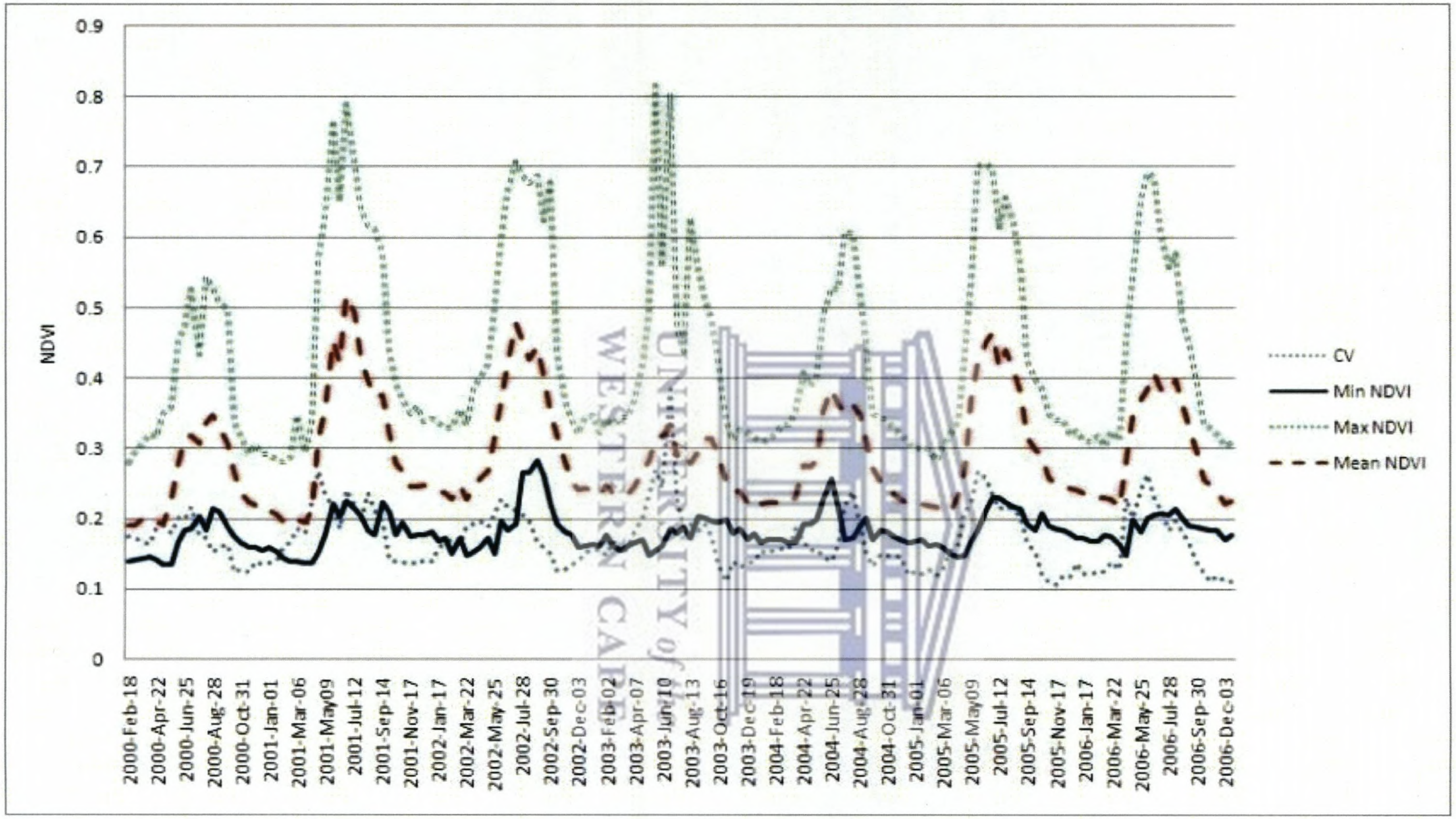


Figure 33: Seasonal and inter-annual variations in NDVI produced from the temporal profile of fire patches using MODIS NDVI data.

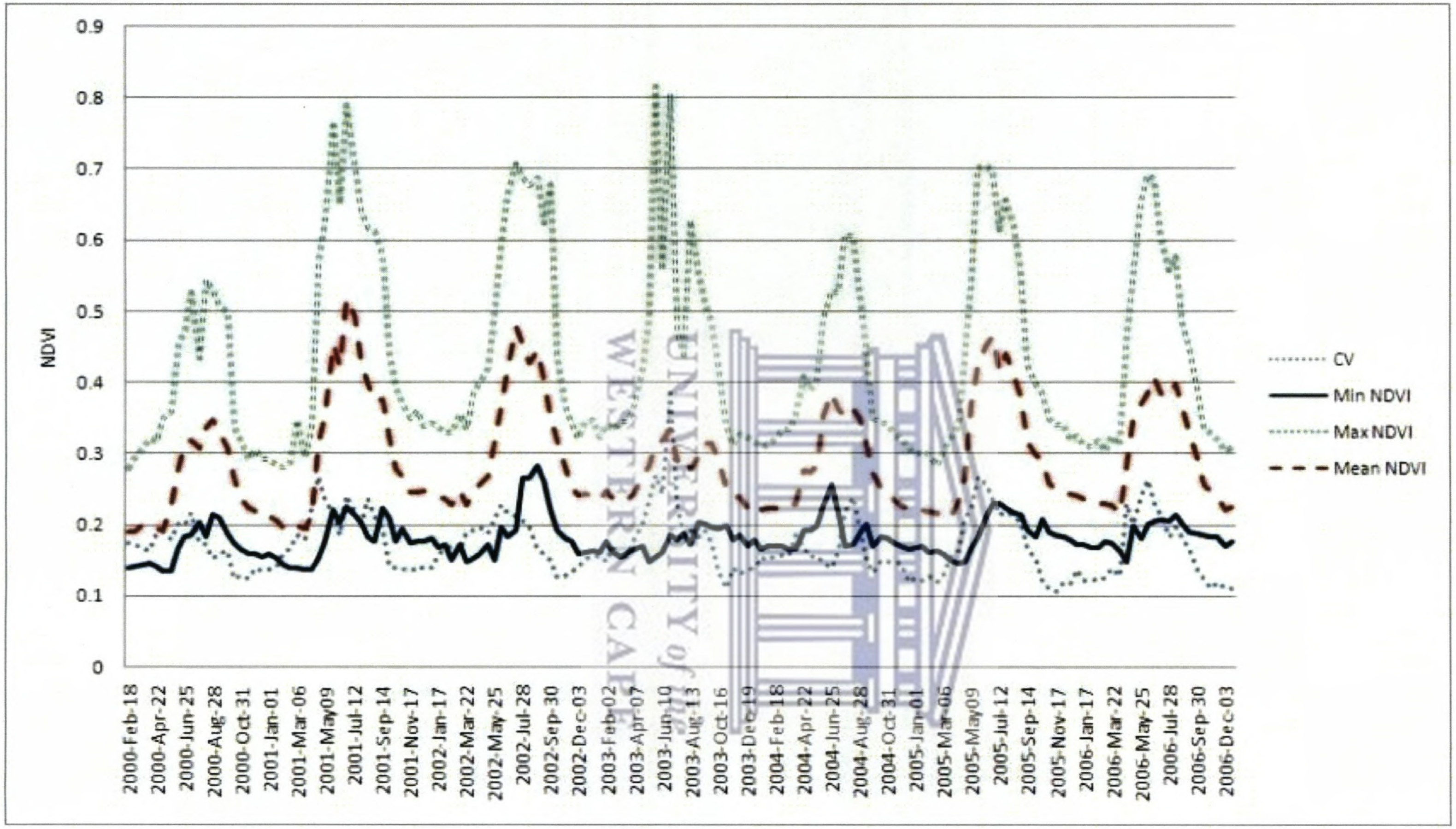


Figure 34: Seasonal and inter-annual variations in NDVI produced from the temporal profile of fire patches using MODIS NDVI data.

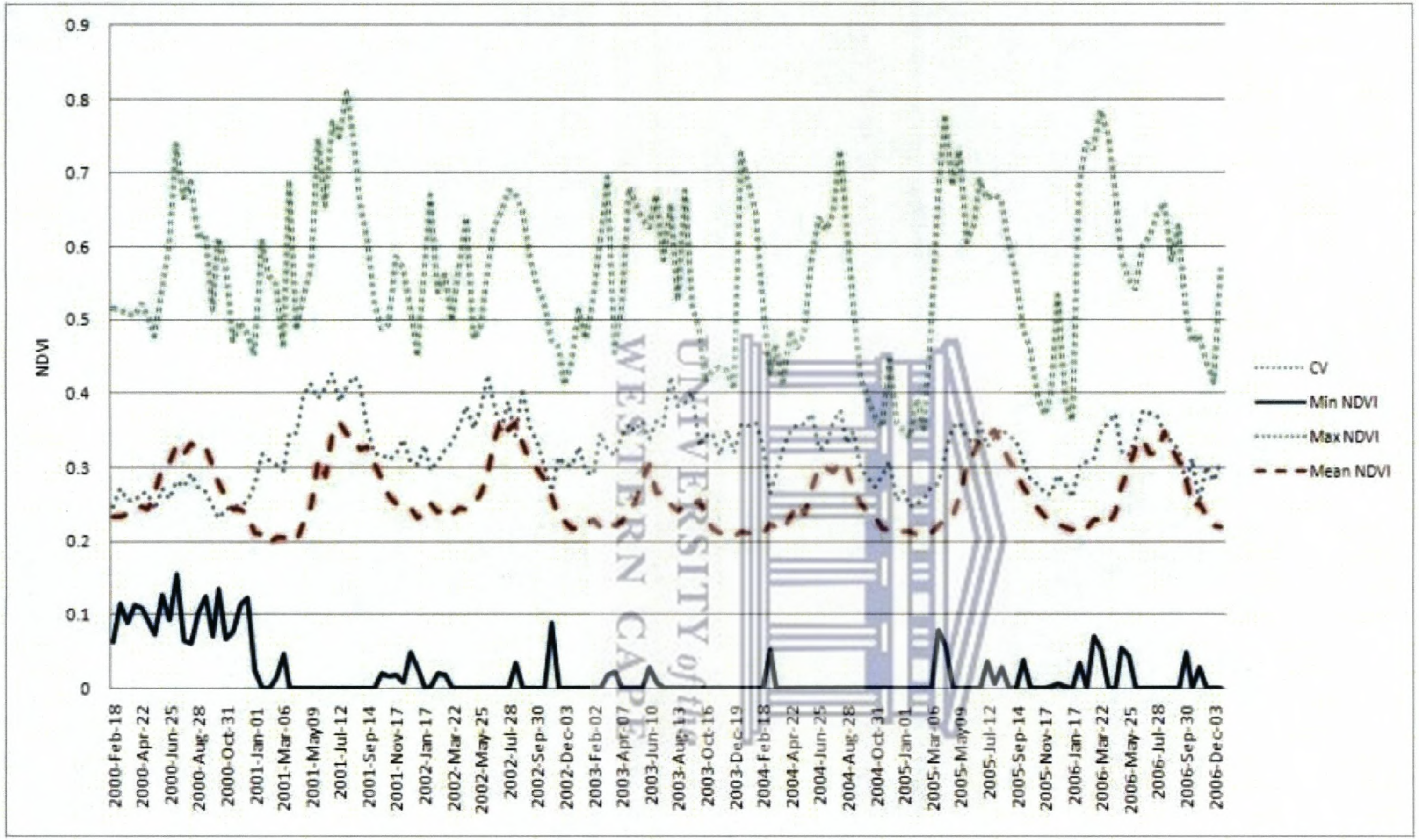


Figure 35: Seasonal and inter-annual variations in NDVI produced from the temporal profile of open sands using MODIS NDVI data.

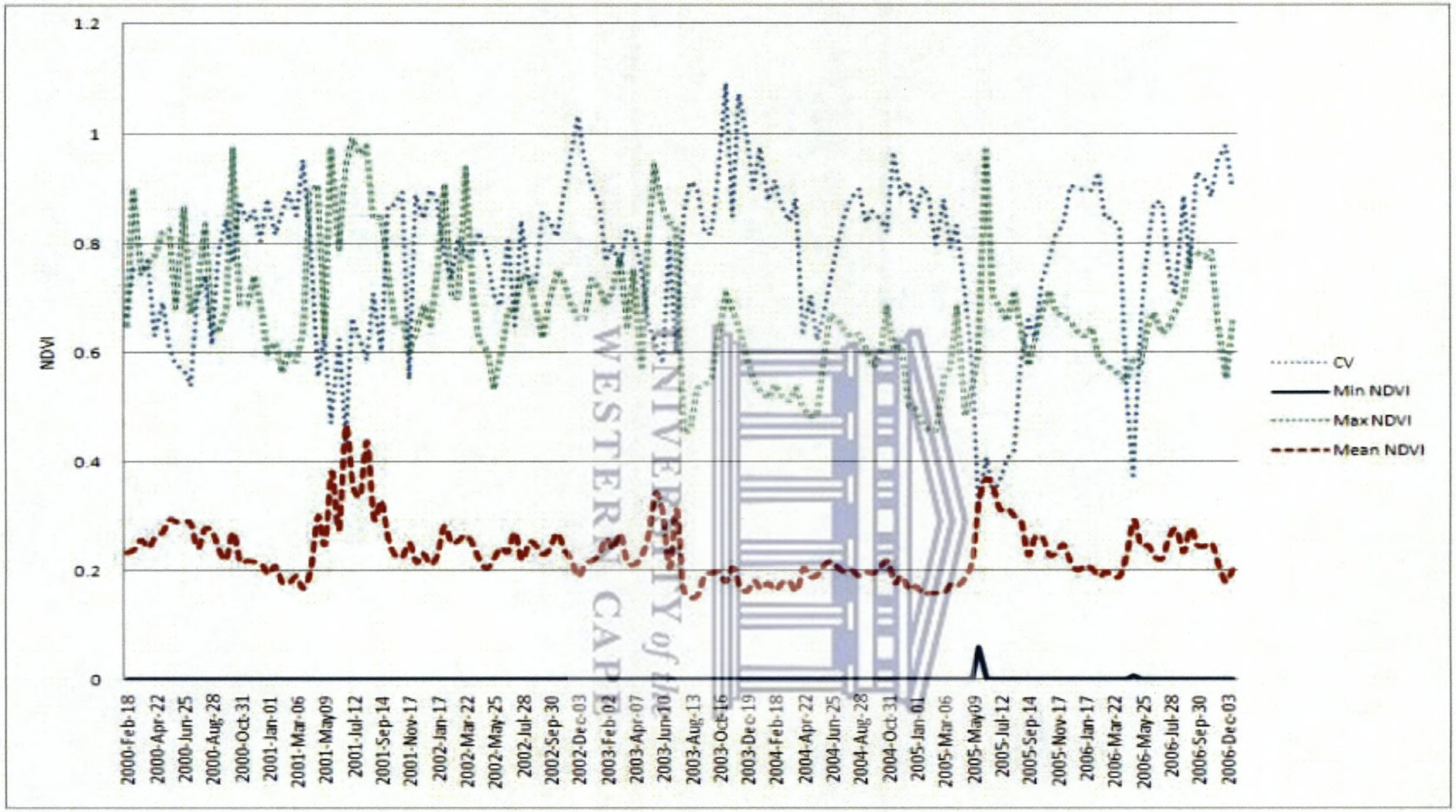


Figure 36: Seasonal and inter-annual variations in NDVI produced from the temporal profile of water using MODIS NDVI data.

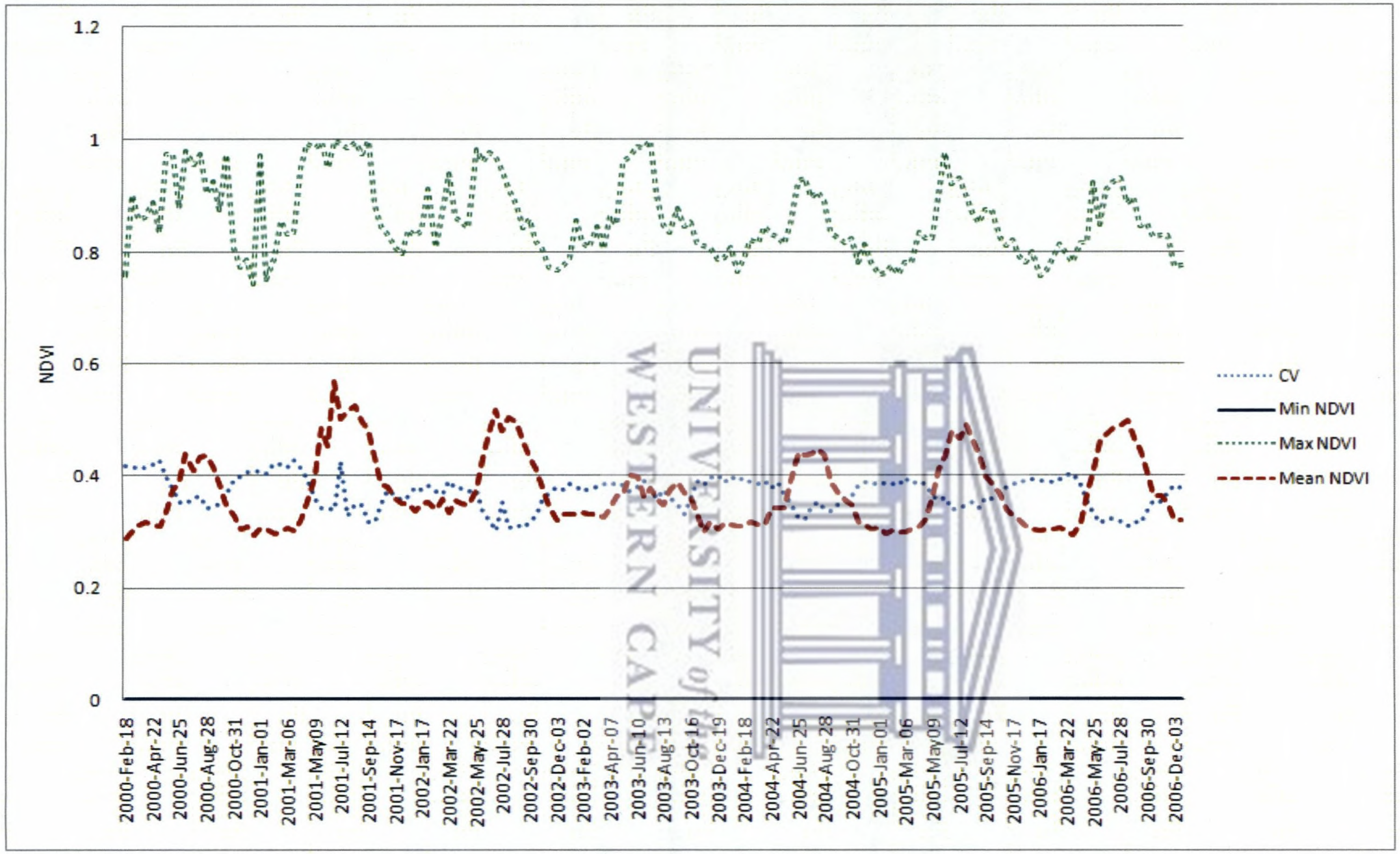


Figure 37: Seasonal and inter-annual variations in NDVI produced from the temporal profile of water using MODIS NDVI data.

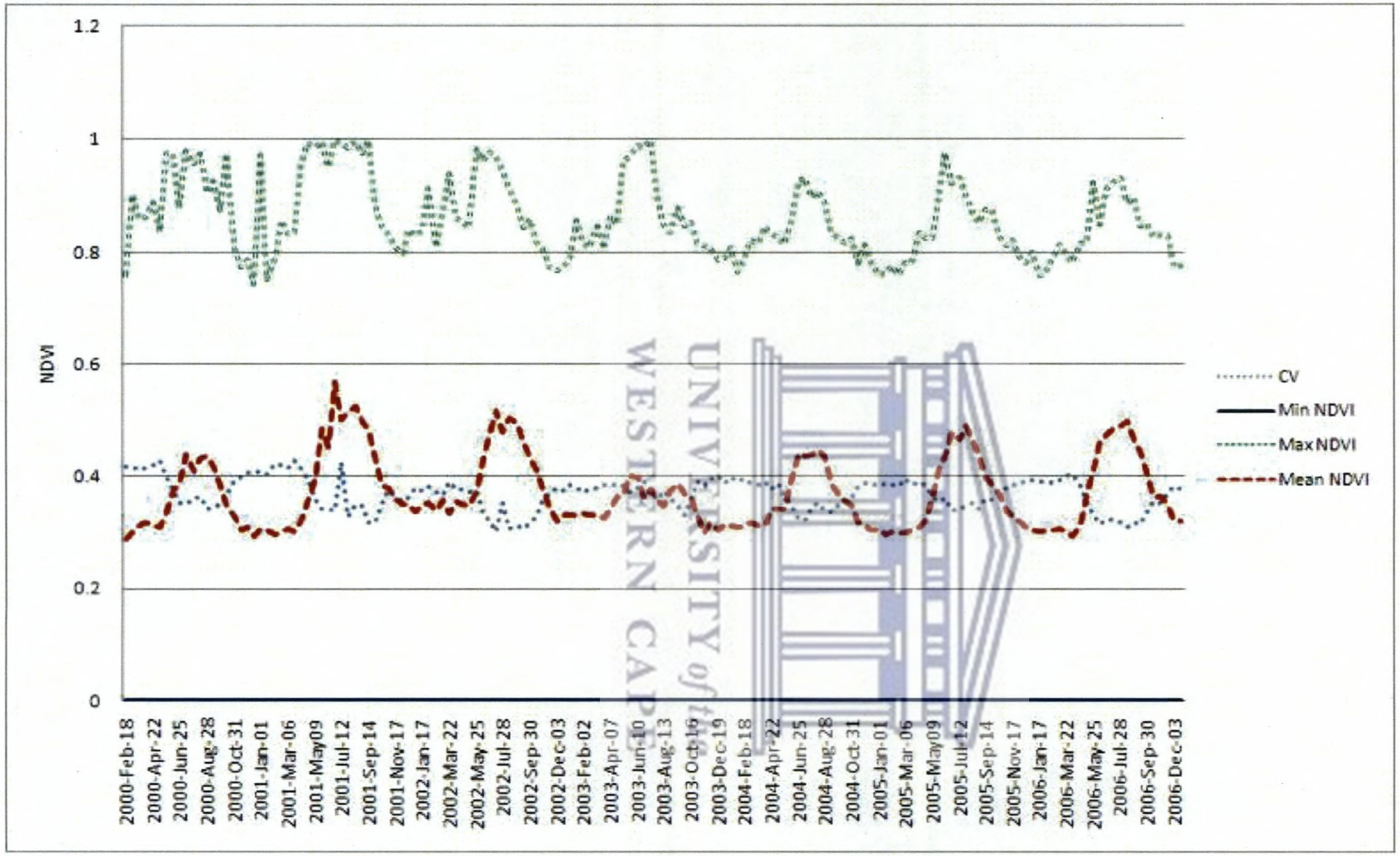


Figure 38: Seasonal and inter-annual variations in NDVI produced from the temporal profile of wetlands using MODIS NDVI data.

APPENDIX 4: Style Of The South African Geographical Journal

THE SOUTH AFRICAN GEOGRAPHICAL JOURNAL

STYLESHEET FOR CONTRIBUTORS

Authors **must** adhere to the style as laid out here when preparing manuscripts for submission to the *Journal*. Failure to do so will delay refereeing and publication. Note: S.I. units must be used throughout; tables should be appended on separate sheets; a separate list of figure captions must precede the figures; and figures should be appended on separate sheets. Figures must be clear and legible for reproduction at single column width; computer graphics of high quality are only acceptable if the linework and lettering is comparable to conventional productions.

The first page of the typescript should contain the title of the paper and the name(s) and full address(es) of the author(s) in the style shown eg:

RAINFALL AND AGRICULTURE IN THE EASTERN CAPE, 1900-1994

M.E. JAMES and R.V.B. DEANE

M.E. James
Department of Environmental & Geographical Science
University of Cape Town
Rondebosch
7700 South Africa

R.V.B. Deane
Department of Geographical & Environmental Sciences
University of Natal
King George V Avenue
Durban
4001 South Africa

The second page must repeat the title of the paper, followed by an **abstract** of approximately 100-200 words in which the principal findings of the research should appear.

RAINFALL AND AGRICULTURE IN THE EASTERN CAPE, 1900-1994

Abstract

Climatological records show dramatic variability of rainfall in South Africa as a whole during the twentieth century. In theory, agricultural productivity should match these variations, a proposition that is tested with specific reference to crop yields in the eastern Cape. Strong associations do indeed exist between rainfall patterns and agricultural activity. Other changes, such as variations in farm size and farming technologies, appear to exert little effect.

The introduction (and subsequent text) must be typed in double-spacing. The introduction should not contain any subheadings. Leave a space between paragraphs. References to be cited as shown. List citations in ascending date order, and alphabetically within the same year. One or more publications by an author in the same year must be distinguished by appending letters a, b, c to the citations. Main headings should be in bold type.

Introduction

Throughout the history, human activity on the land has been governed by the availability of water. In all the available historical research, however, little attention has been given to quantitative estimates of the precise relationship between .... Furthermore, in South Africa, data are now available for the first time which allow detailed examination of the effect of changes in farming practices on crop yields.

In their discussion the historical geography of agriculture, both Smith (1977) and Andrews (1978) show a keen awareness of the climatological constraints ...

Indent and punctuate particular points as shown, and designate alphabetically. The expression *et al.* is used when the work of more than two authors of one work is being cited. Use 'n.d.' to show that a work has no publishing date. Footnoted material to be marked with a superscript.

Rainfall Variability in South Africa

The principal rainfall variations in South Africa have been studied only recently (Reed, 1994). Preliminary screening of climatological data in Southern Africa by Deane (1980, 1983b) shows that numerous sites in the eastern Cape are subject to extreme variations (Fig. 1). Data on precipitation at selected mission stations in the nineteenth century show that:

(a) rainfall was heaviest in summer;

(b) rainfall exhibited great variations within decades^1; and

(c) yields varied in concert with rainfall, with a lag of several months (Parker *et al.,* n.d.).

These findings differ markedly from those reported in the study undertaken ten years ago during storm conditions (Brown, 1986), but approximate those made by Gill (1989).

Type subheadings in italics, aligned with the left margin of text. Avoid placing subheadings directly after a main heading. Refer to Figures and Tables as shown. Quantities less than ten should be expressed verbally, otherwise numerically.

Agriculture in the Eastern Cape

Information pertaining to crop yields at 1 117 Cape farms disclose a strong geographical variation which is best understood in terms of two major regions.

The Northern District

The two most distinctive features of yields in this part of the country are ... (Figs 2 and 3). Altogether, ten per cent of the crop yields ... Precipitation at each of the stations shows a very pronounced diurnal variation (Table 1). Early morning and early evening patterns are similar excepting at land lying higher than 1 000 m, but at all other times ...

The Southern District

There are three notable components evident in the eastern zones of the study area (Deane, 1993a). As suggested elsewhere (Francis, 1977, 1978) these accord well with observations that ...

Direct quotations should be cited using double inverted commas and must contain a page(s) reference. Direct quotations which are more than three lines in length should be inset from both margins and typed in single spacing without inverted commas. Avoid ending a paragraph with a long direct quotation.

Rainfall-Agriculture Relationships

In her landmark study, Tessig (1965, p.89) proposed that in dry areas especially, regional studies of arable and pastoral activity which failed to attend to climatic constraints were `a charade'. Others have made the same argument (Yelch, 1962; Bore, 1988), although Tedious (1977, pp. 286-287) has noted that:

> Direct links between climate and agriculture are never proven absolutely until the likely mediating affect of human agency can also be ascertained, and this is the true challenge facinginterdisciplinary research science today.

Taking these various opinions into account, and bearing in mind the well known warning given in 1902 by a Government minister,[2] who ...

Equations should be laid out as shown below:

The relationship between rainfall and production of maize may be expressed as follows:

$$P = 1,53R + 0,86T \qquad (1)$$

where P is production in tonnes ha^{-1}, R is January-March rainfall in mm, and T is a measure of technology levels (Gill, 1989).

Do not introduce new material in the conclusion, and do not use point form in this section. Acknowledgements should follow immediately after the text.

Conclusion

In the eastern Cape during the twentieth century the nature of agricultural activity correlates extremely strongly with patterns of rainfall. On the one hand, ... On the other hand, ...

Taking into account the major differences pinpointed in the Cape region, it is reasonable to suppose that...

Acknowledgements

Grateful thanks are due to M.J. Mouse who drew the maps, and to the Dollar Foundation which provided financial support for the research. The conclusions reached are solely those of the authors.

Footnotes should be kept to a minimum and must be collected numerically at the end of the typescript. Use small superscript digits to number the notes, and indent the text of the notes. Notes should be used for archival references and **not** as a device for elaborating the text or making asides.

Notes

[1] Central Archives Depot, Pretoria (CAD), Department of Agriculture (DA) 468 (12/345): Memoranda concerning production of grain in the colonies, March 1976 - December 1993

[2] CAD, DA 469 (47/521): Minister of Lands to Prime Minister, 12 October 1902

[3] *Ibid.*, 9 December 1902.

The reference list

The reference list is **not** a bibliography and must contain only material which is cited in the text. **Complete information should be provided for every reference**. Organise the references alphabetically without numbering. The initials of authors and/or editors must appear behind the surname(s). Use the convention 'Anon.' to refer to unknown authors. Do not use '*et al.*' in the reference list. Date of publication must appear as in the examples. Punctuate all material exactly as shown. The only words which are capitalised in the titles of journal articles are proper nouns. The titles of journals should **not** be abbreviated. Book and periodical titles should be italicised. Volume numbers must be included for journals, but part numbers should only be used if the pagination in successive issues is not sequential. The names of book publishers and city/town of publication must be included. Monographs and dissertations/theses to be cited in the style shown. Leave a blank line between references.

References

Anon., 1943: The roaring coastal winds, *South African Panorama,* 24 (7), 2-6.

Barnes, J., Smith, M.L.B. and Frames, R. (eds), 1953: *Readings on Energy Potential in the Far East,* Hutchinson, London.

Deane, R., 1980: Trapped waves in the atmosphere, *Journal of Atmospheric Research,* 56, 1-23.

Deane, R., 1993a: Wind patterns and energy, *Science,* 123, 34-49.

Deane, R., 1993b: Assessment of wind power potential, *Journal of Applied Climatology,* 23, 1654-1659.

Francis, L., 1977: Patterns of pollen distribution in the Cape, *South African Geographical Journal,* 23, 11-19.

Francis, L., 1977: Wind and pollen dispersion: a botanical view, *Botany, 87, 94-105,*

Gill, A.E., 1977: Coastal lows from the synoptic point of view, *Quarterly Journal of the Royal Meteorological Society,* 14, 77-99.

Hunter, I.J., 1994: The Weather of the Agulhas Bank, Unpublished M.Sc. Dissertation, University of Natal, Durban.Kirby, M.J., 1976: The problem of wind power, in Jones, A.B. (ed.), *Estimating Techniques for Climatologists,* Oxford University Press, Oxford, pp. 123-129.

Parker, N.J., Ray, P., Band, T., Luk, O. and Farr, R., n.d.: *Mission Stations of the Eastern Cape,* Bantam Press, New York.

South Africa (Republic), 1976: *Annual Report of the Department of Water Affairs,* Government Printer, Pretoria.

Sample figure and table captions

These should be presented on separate sheets immediately preceding the figures.

Figure Captions

Figure 1: The spatial variation of rainfall off the east coast in the summer of 1949 (from Wetty, 1954).
Figure 2: The geography of crop yields.
Figure 3: Rainfall - crop yield relationships, 1944-1954.

Table Captions

Table 1: Farm size classification in the Cape, 1956-1978 (Source: South Africa (Republic), 1976).

APPENDIX 5: Poster Presented at the Biota Conference, Spier, Stellenbosh, SA

UNIVERSITY *of the* WESTERN CAPE

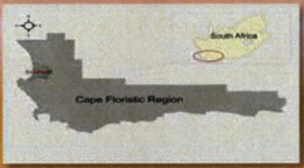
Land use/cover changes in the Sandveld, South Africa

BIOTA

James T Magidi[1], Dr Richard S Knight[1], Dr Cornelia B. Krug[2]

[1]Biodiversity and Conservation Biology Dept, University of the Western Cape, Bag X17 Bellville, 7535 South Africa
[2]Dept of Zoology, University of Cape Town, P Bag X3 Rondebosch, 7701, South Africa

Introduction

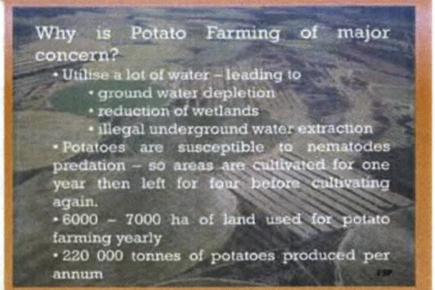


Cape Floristic Region (CFR)

- One of the 34 biodiversity hotspot
- High Degree of species endemism
- 70% Transformed due to
  - Agriculture –Lowlands & Renosterveld
  - Invasive Species
  - Urban Development

Why Sandveld?

- It is part of the CFR Lowlands
- Generally low rainfall
- Important part of the Greater Cederberg Biodiversity Corridor, connection uplands and lowlands
- It has these vegetation types:
  - Piketberg Sandstone Fynbos
  - Leipoldtville Sand Fynbos
  - Lambert's Bay Strandveld
  - Graatwater Sandstone Fynbos
- It is transformed due to the growing of:
  - Potato
  - Wheat
  - Rooibos



Why is Potato Farming of major concern?

- Utilise a lot of water – leading to
  - ground water depletion
  - reduction of wetlands
  - illegal underground water extraction
- Potatoes are susceptible to nematodes predation – so areas are cultivated for one year then left for four before cultivating again.
- 6000 – 7000 ha of land used for potato farming yearly
- 220 000 tonnes of potatoes produced per annum

Methodology

Data Acquisition (Landsat)
- 1990
- 2004
- 2007

Pre-processing
- Radiometric
- Geometric

Multi-temporal Image Classification
- Training sites
- Maximum likelihood classifier
- Clump, Eliminate, Recode
- Filtering

Accuracy Assessment
- Google Earth
- Aerial Photos
- Site Visits

ERDAS Imagine

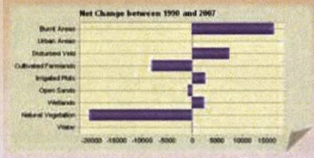
Change Detection
- Gains and losses in Landuse
- Contributors of Landuse change
- Kappa Index
- Landuse Persistence

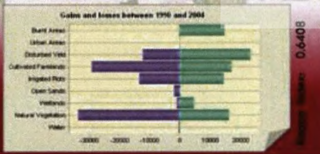
Predicting Future Scenarios
- Markov Chain Analysis
- Determining probabilities of change

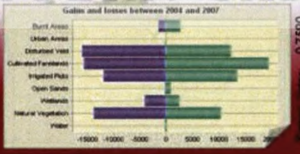
IDRISI ANDES

Change Analysis

Multi-temporal Landuse Maps







Categories	1990		2004		2007		Change in 1990-2007	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Water	1302.81	0.66	873.34	0.44	1170.72	0.59	-133.09	-10.35
Natural Vegetation	101432.44	51.04	84409.29	42.48	81130.33	40.82	-20302.11	-20.02
Wetlands	5640.12	2.84	9586.80	4.83	8167.95	4.11	2527.83	44.82
Open Sands	2317.05	1.17	632.52	0.32	1482.93	0.75	-834.12	-36.00
Irrigated Plots	19351.08	9.74	20460.87	10.30	22048.92	11.10	2697.84	13.94
Cultivated Farmlands	50270.31	25.30	38320.29	19.28	42278.94	21.28	-7991.37	-15.90
Disturbed Veld	18313.20	9.22	29279.88	14.74	25860.78	13.01	7547.58	41.21
Urban Areas	88.38	0.04	88.38	0.04	88.38	0.04	0.00	0.00
Burnt Areas	0.00	0.00	13053.02	7.38	16489.44	8.30	16489.44	

Predicting Future Scenarios

Probability of Landuse change by 2020

Given	Probability of changing to								
	Water	Natural Vegetation	Wetlands	Open Sands	Irrigated Plots	Cultivated Farmlands	Disturbed Veld	Urban Areas	Burnt Areas
Water	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Natural Vegetation	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wetlands	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Open Sands	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Irrigated Plots	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cultivated Farmlands	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Disturbed Veld	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Urban Areas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.00	[illegible]
Burnt Areas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Mapping Persistence

Persistent Landuse classes between 1990 and 2007

Landcover summary

BIOLOG

pt
Projektträger im DLR

Federal Ministry of Education and Research