A FINE-SCALE CLASSIFICATION OF LAND COVER IN THE NORTH-WEST SANDVELD

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in the Faculty of Science at Stellenbosch University.

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December 2012

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DECLARATION

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SUMMARY

A land cover classification showing the landscape structure of a given area is necessary to make appropriate measures for environmental planning. The environmental impacts from insensitive human activities have led to a severe loss of biodiversity in the Cape Floristic Region over time. The natural biodiversity of the North-West Sandveld in particular, has suffered severe loss and a high level of fragmentation. The rapid growth of certain agricultural practices in the Sandveld has led not only to loss of biodiversity, but the secondary effects of excessive water extraction, invasive alien fauna and flora species and harmful run-off from toxic herbicides and pesticides. To plan effectively, an accurate map of a suitable resolution needs to be created to effectively display spatial information.

The primary aim was to demonstrate that a semi-automated fine-scale, land cover classification using object-oriented image analysis is possible for a large local area to examine the environmental issues pertaining to the Sandveld. Towards this aim, a model to classify land cover of the study area was developed and its effectiveness analysed and interpreted. To meet these requirements, pre-processed SPOT 5 satellite imagery was used to digitize certain classes and to generate frame, border and Normalized Differentiation Vegetation Index (NDVI) layers for the object-oriented classification in eCognition. The accuracy of the results was determined using the Kappa coefficient which gave an accuracy level of 70%. The environmental impacts were determined after area calculations were done on each class.

The results showed that the natural areas still made up the greatest percentage of the Sandveld but that it is highly fragmented, especially along the coast and many areas, although left in a natural state, were being overgrazed by livestock. The temporary irrigated, temporary non-irrigated strip agriculture and permanent agriculture classes made up the most of the remainder of the areas and had the largest impact on the Sandveld's biodiversity. For the biodiversity of the Sandveld to remain intact, a balance between enforcing the law and encouraging inhabitants of the Sandveld to encourage more environmentally balanced practices needs to be created. Stewardship programmes and education will greatly enhance the effectiveness of any conservation efforts.

Key words and phrases: Object-oriented classification, eCognition, land cover, agriculture, corridors, fragmentation, land use, biodiversity

OPSOMMING

'n Landbedekkingsklassifikasie wat die landskapstruktuur van 'n gegewe gebied aandui, is noodsaaklik om gepaste omgewingsbeplanning toe te pas. Die effek van intensiewe menslike aktiwiteite op die omgewing oor 'n lang tydperk, het gelei tot die verlies van biodiversiteit in die Kaapse Blommestreek. Die natuurlike biodiversiteit van veral die Noordwes Sandveld is deur ernstige verliese, asook 'n vlak van fragmentasie beïnvloed. Behalwe dat die vinnige toename van sekere landboupraktyke in die Sandveld gelei het tot die verlies van biodiversiteit. Sekondêre faktore soos die oormatige water-ontrekking, indringerspesies van fauna en flora en die afloop van skadelike onkruiddoder en pes-weerende middels in rivierstelsels is ook verantwoordelik vir verlies van biodiversiteit. Om effektiewe beplanning moontlik te maak, is die skepping van 'n akkurate kaart met 'n geskikte resolusie wat die ruimtelike inligting effektief voorstel, nodig.

Die hoof doel van hierdie studie was om 'n semi-geoutomatiseerde fynskaal landbedekkingsklassifikasie in 'n groot plaaslike gebied wat die omgewingskwessies rakende die Sandveld te bestudeer en demonstreer, deur gebruik te maak van objek-gerigte beeldanalise. Die effektiwiteit van 'n model wat ontwikkel is om die studiegebied te klassifiseer, was ontleed en geïnterpreteer. Om hierdie vereistes te bevredig, is voorverwerkte SPOT 5 satellietbeelde gebruik om sekere klasse te versyfer, asook om raam-, grens- en genormaliseerde plantegroei differensiasie indekslae vir beeldgerigte klassifikasie in eCognition te skep. Die akkuraatheid van die resultate was bepaal deur die Kappa-koëffisiënt wat 'n akkuraatheidsvlak van 70% gelewer het. Die omgewingsimpakte was bepaal deur opperlakteberekeninge vir elke klas te maak.

Die resultate dui aan dat natuurlike gebiede steeds die grootste persentasie van die Sandveld beslaan, maar dat dit hoogs gefragmenteerd is, veral langs die kuslyn en dat baie gebiede, wat wel steeds in 'n natuurlike toestand is, oorbewei word deur vee. Die tydelike spilpuntbesproeide landbougebiede, tydelike nie-besproeide strooklandbou en permanente landbouklasse, beslaan die meeste van die oorblywende landbedekking van die Sandveld. Hierdie klasse het ook die grootste impak op die studiegebied se biodiversiteit. Om die biodiversiteit van die Sandveld te behou, moet 'n balans tussen die afdwing van wetgewing en die aanmoedig van meer omgewingsgebalanseerde praktyke in die Sandveld gevind word. Rentmeesterskap programme en opvoeding sal die effektiwiteit van enige bewaringspogings aansienlik verbeter.

Sleutelwoorde en frases: Objek-gerigte klassifikasie, eCognition, landbedekking, landbou, korridors, fragmentasie, grondgebruik, biodiversiteit

ACKNOWLEDGEMENTS

First, I sincerely thank my supervisor Prof JH van der Merwe of Stellenbosch University for his on-going patience with me and for his support. Second, I thank my dear parents who have always believed in me and have given me the financial support to make this happen. Their unconditional love is appreciated. Last, I thank Graham who has always offered his love and understanding during these years of study.

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ACRONYMS

BA	Basic (environmental) assessment
BHUs	Broad habitat units
BWI	Biodiversity wine initiative
C.A.P.E	Cape Action for People and Environment
CFR	Cape Floristic Region
CL	Confidence level
CMAs	Catchment management agencies
CNES	Centre National d'Etudes Spatiales
CPU	Computer processing unit
DEM	Digital elevation model
DWAF	Department of Water Affairs and Forestry
DN	Digital numbers
GCBC	Greater Cederberg Biodiversity Corridor
GCPs	Ground control points
GEF	Global Environment Fund
GIS	Geographical information systems
GPS	Global positioning system
IPW	Integrated production of wine
KIA	Kappa Index Assessment
LIDAR	Light detection and ranging
NDVI	Normalized differentiation vegetation index
NEMA	National Environmental Management Act
NIR	Near infrared
NLC	National land cover
NN	Nearest neighbour
NOAA	National Oceanic and Atmospheric Administration
PCA	Principal component analysis
OOA	Object oriented analysis
OOC	Object oriented classification
RAM	Random access memory
SAC	Satellite Applications Centre
SPOT	Satellite Pour l'Observation de la Terra
VHR	Very high resolution
WUAs	Water users associations

CHAPTER 1: THE IMPORTANCE OF LANDSCAPE STRUCTURE

As the human population has steadily increased, so the earth has become increasingly more dynamic. Changes occur more rapidly than the environment has ever been used to, and as a result the landscape and the functions that support it have been put under tremendous strain. Human technological advances have proved crucial to new development strategies and methodologies that, in many cases, have eventually been detrimental to the preservation of our planet. Particularly in the field of environmental geography, there has never been a more important time than now to analyse the effects the clashes between nature and man have had in the past and present. As the reality of global warming has awakened many world leaders to take a stance on carbon emission, each and every country has a responsibility to respond to the worldwide call to protect the natural environment. Habitat loss and degradation impair ecosystem function and reduce the value of ecosystem services for humans (Kerr & Ostrovsky 2003). No longer can the plight of dwindling water resources and rapidly-disappearing biomes be ignored. Kerr & Ostrovsky (2003) has emphasised what all nations are fully aware of – that time is short and the need to be able to predict changes in the natural environment has never been greater.

Remote sensing has for some time played a vital role in environmental analysis. Satellite image classification has been developed over the last thirty years and more recently research emphasises preclassification of images, feature extraction and automated information retrieval (Blaschke 2005). The earth's surface is difficult to observe from ground level since features cover such vast areas over uneven topography, and furthermore, the changes that have occurred over a given time period can only be viewed through snapshots over that time. Various sensors are specific to the targets they observe enabling remote sensing specialists to prepare scientific responses to environmental change (Kerr & Ostrovsky 2003). Remote sensing imagery is one of the most effective tools in gathering indispensable land cover information. Remote sensing scientists are able to identify highly transformed areas and to investigate the potential influence of land cover on regional biodiversity. However, although remote sensing is an invaluable tool for environmental analysis, the skills required to utilise the technology have not been fully implemented. Particularly in Africa, there remains a large deficit of skilled scientists able to provide products to decision makers that require them. Remote sensing technology has advanced and the availability of data applicable for global, regional and local environmental monitoring has greatly increased over recent years (Ehlers, Gähler & Janowsky 2003). Large amounts of information have been provided, but without the necessary

knowledge to use it, the world's environmental problems persist. Therefore, producing methodological products using all available imagery would take too long for it to be effective. Developmental and environmental changes are taking place too quickly for time not to be an issue. Analytical outputs need to be delivered as quickly and as frequently as possible, but the accuracy of the product must not be compromised. Remote sensing allows for many measurements to be taken, such as habitat details (land cover classification), their biophysical properties (integrated ecosystem management) and the changes that take place across these landscapes (change detection) (Kerr & Ostrovsky 2003). For one to measure the status of a habitat it is important to know its current and past conditions. Knowing what one is dealing with allows for modelling that can predict patterns if current trends persist without remediation.

Both mapping and monitoring represent important prerequisites for defining and implementing decisions and development plans for the protection and sustained use of land resources (Hill et al. 1995; Sommer, Hill & Mégier 1998). For products to be produced quicker but with the same accuracy as the manually-created maps, an accurate and effective procedure should be developed that effectively classifies the image, yet maintains a high level of accuracy. The overall aims of this research focus is on land cover classification, the semi-automation of the procedures involved and the environmental patterns the results produce. The following sections present the rationale for the study, the real-world problem that exists as well as the location in which the problem occurs, namely the north-west Sandveld. The aims and objectives that will be pursued are discussed and the underlying theoretical framework is expanded thorough the course of the chapter.

1.1   LINKING ENVIRONMENTAL ISSUES WITH MAPS

From an environmental perspective, the Cape Floristic Region (CFR) has been subjected to too much change over the last ten years. Being one of the species-richest biomes in the world and contained entirely within the borders of South Africa, there is a dire need for preservation of this magnificent natural heritage. The problem with the Western Cape region of the CFR is that the rate at which the natural biodiversity is being destroyed is reaching levels of serious concern (Rouget, Richardson & Cowling 2003). The destruction has happened mainly through the rapid growth of agricultural activities and urban expansion.

Consistent and accurate land cover classification systems are instrumental in providing nature conservationists with the tools to monitor species and make management decisions (Keramitsoglou et al. 2005). Traditional field-based measurements, as conducted by natural scientists are limited in their capability to map large areas with a high accuracy. Data acquired by aerial and/or space

means, allows for more extensive and precise methods to collect data to map the spatial phenomena of an area. The newer high-resolution spatial imagery has become popular in conservation monitoring since it provides good quality and recent availability of observational aerial images for large areas. Ground surveys involving in situ inspection of the surface layout compliment imagery obtained remotely, either from satellites or from aerial surveys by airplane.

High monetary and manpower costs determine that management decisions are often based on limited data for very large areas (McDonald & Cowling 1995). Ground surveys can be limited by the large extent of inaccessible areas. A snapshot in time promotes the analysis of the landscape and its use patterns, and it classifies where remnants of natural vegetation remain. Plans to develop linking corridors between minimally-disturbed vegetation islands can be designed using a current and accurate map.

The level of detail on a land cover map depends on the map's scale which is dictated by the purposes of the map. Mapping a broad habitat unit distinguishing urban from non-urban areas, requires imagery with a coarser resolution to be cost-effective. However, if a high level of detail is important regarding the features to be extracted, the data used needs to have a much finer resolution. The classification method used must accommodate these requirements. In South Africa, data availability and cost determine imagery choice. South Africa does not own a high-resolution commercial satellite. SumbandilaSat was launched as an experimental satellite in September 2009, but the six-meter resolution imagery only became available in late 2010 and is subject to some technical constraints. Therefore, South Africa still relies heavily on imagery acquired by international commercial satellite companies. The Satellite Applications Centre (SAC) located in Hartebeeshoek, Gauteng has promoted a 'data democracy' policy regarding access to satellite data. The ethos is that satellite imagery should be available to all end-users in government departments that assisted in funding the data democracy initiative. SAC has developed partnerships with numerous government stakeholders to reach an agreement about which imagery will be most suitable for the needs of the country. The unanimous preference was for SPOT 5 imagery that provides an adequate resolution of the entire country on an annual basis. To minimise the financial implications for all the parties concerned, each stakeholder invested a fixed amount to fund the project for three years. South Africa is thus able to attain a countrywide yearly coverage at a resolution of 2.5 m with a true colour composite mosaic. The imagery would be freely available for any government department that falls under a main stakeholders 'umbrella'. The data democracy policy has also paved the way for satellite imagery to become freely available to all universities conducting research.

1.2   PROCEDURES FOR IMAGE CLASSIFICATION

The influx of transmitted information and imagery has become so vast that the rate at which it is processed is too slow for a continuous flow between data capture and end-product delivery. For the end-user to receive products delivered both accurately and efficiently standard procedures are needed that can be applied to many images. Hu & Tao (2002) used an automated procedure to extract road information from high-resolution satellite imagery. They emphasised that the automated procedure holds great potential for the reduction of database development updating costs and turnaround time because the satellite images have large coverage, less unit cost and high temporal resolution. Using a new image-processing application from Definiens Imaging GmbH called eCognition, automated and semi-automated protocols defining the rules that separate land cover classes within an image, can be developed. Depending on the features required to be extracted and classified as well as the extent of the image, multiple analysts can each concentrate on single classes and combine the rule-sets to create one large dataset that efficiently classifies all classes in the target area. Standard libraries for automatic image analysis have the potential to evolve into related structures like libraries for numerical recipes (De Kok & Wezyk s.a.). Developing a protocol that effectively classifies an image, demands a considerable amount of time for testing rules (protocols) which best fit each class. Once developed, these protocols can be applied to a multitude of images and ideally the processes can run independently of the user who developed the classification model. Automation is in its infancy in South Africa and will take some time to become absorbed into the South African remote sensing fraternity. The high level of scope for future developments in the country offers much potential for semi-automated to automated procedures to have a significant impact on the way in which images are processed.   The rationale for the study, the aim and objectives, the research design, and the study area are introduced in the following sections.

1.3   WHY DO WE NEED A MAP?

The rationale for this research project has two sides. The first is to look at the study area from an environmental perspective because this vantage point indicates why the Sandveld area needs to be preserved. By understanding the stresses placed on the Sandveld, the need for a spatial approach to the region's woes becomes clear. The second is to determine if this information can be relayed accurately using newer technology in the form of object-oriented classification methods.

A map depicting relevant spatial phenomena is an essential aid to an in-depth conservation plan to protect the region's natural biodiversity. The map must be derived from a suitable classification

model developed specifically to highlight and classify the desired land cover classes in the Sandveld area. Unfortunately a large deficit exists in the skills needed to conduct adequate semi-automated classification procedures in South African contexts. Many local institutions have in the past and continue to classify images using pixel-based approaches, but an object-oriented approach is rarely used.

1.4   THE RESEARCH PROBLEM

The CFR has been delimited as an area of 87 892 km² by Cowling & Heijnis (2001). According to Cowling et al. (2003), Rebelo (1992) and Younge & Fowkes (2003) the CFR is one of the world's critical biodiversity hot spots. It is the smallest of the world's six biomes and the only one found entirely within the borders of one country (Younge & Fowkes 2003). Of the approximately 9000 species within the CFR, 70% are endemic (Rouget, Richardson & Cowling 2003). Despite the prestigious status of the CFR, there have only been meagre conservation efforts to preserve South Africa's precious commodity. The Sandveld region has long been an area of high concern regarding preserving the region's biodiversity. For many and varied reasons the implementation of an environmental plan has taken long to come to fruition. Improper plans for conservation legislation have led to rapid and non-conservative growth patterns in the Sandveld area, particularly concerning agricultural activities. Such rapid growth has certain consequences of which two crucially important ones are water availability and loss of biodiversity. This real-world problem relating to issues in the Sandveld is communicated below.

The real-world problem concerning the Sandveld region involves two issues. The first is that there is a paucity of maps of overall landscape structure of the region. An indication of an area's characteristics can provide much information to conservationists. The spatial information can assist in measuring water consumption, establishing existence of corridors between different types of agricultural classes and showing general trends in agricultural shift. Corridors are channels between agricultural areas that facilitate connectivity between fragments of natural vegetation.

The second issue pertaining to the Sandveld and CFR is that newer classification methodologies have not been explored. Land cover classification has for many years been done by using aerial photographs, satellite imagery and fieldwork based on visual pattern recognition followed by field validation. Although this traditional approach is quite useful, it is costly and time consuming, and the stand delineation process is highly subjective (Pascual et al. 2008). Various technological advances using different tools to obtain spatial information are needed. As technology changes, so

do the methods to effectively classify the imagery, particularly concerning medium- to high-resolution satellite imagery.

These two problems constitute an overarching challenge. There is a need for a land cover classification system that can classify the heterogeneous landscape structure of the Sandveld to show the environmental impact of man's activities in the region. The methodology requires the development of a model to perform the procedures required to generate an accurate map.

1.5   AIM AND OBJECTIVES

The aim of the Sandveld study is to demonstrate that a semi-automated fine-scale land cover classification using an object-oriented image analysis is possible for a large local area to examine the environmental issues of the Sandveld. A model to classify the study area's land cover must be developed and its effectiveness analysed and interpreted. The main objectives that must be reached to achieve the main aim are to:

1. Delineate the study sub-areas and obtain satellite imagery for classification.
2. Stipulate and define the required land cover classes.
3. Develop a semi-automated model that classifies land cover.
4. Implement the model for the study sub-areas.
5. Conduct an accuracy assessment of the classification.
6. Produce a map illustrating the landscape structure.
7. Conduct an analysis from an environmental perspective.
8. Report on the findings of the classification.

The intentions of why one should investigate the problems associated classifying the Sandveld's land cover has been described. The boundaries of the study area and the specifics of how the study will proceed will be described in the coming sections.

1.6   THE STUDY AREA

The planning domains used to demarcate the areas requiring conservation were defined by Cape Action for People and the Environment (C.A.P.E.). The planning domains were primarily defined by ecological boundaries and characteristics (e.g. threatened lowland ecosystems, river systems and biogeography). Wherever these ecological systems stopped short of municipal boundaries, the planning domain was extended to encompass the entire municipality of interest (Pence 2008). The boundary line was then buffered by 5 km to ensure that the entire shoreline was included. Figure 1.1

shows the location of the Sandveld study area in relation to the Western Cape and South Africa. The areas within the planning domain extend from Eland's Bay in the south to Lutzville in the north. The western areas include Clanwilliam and Citrusdal. The area extent of the study is 8220.58 km².
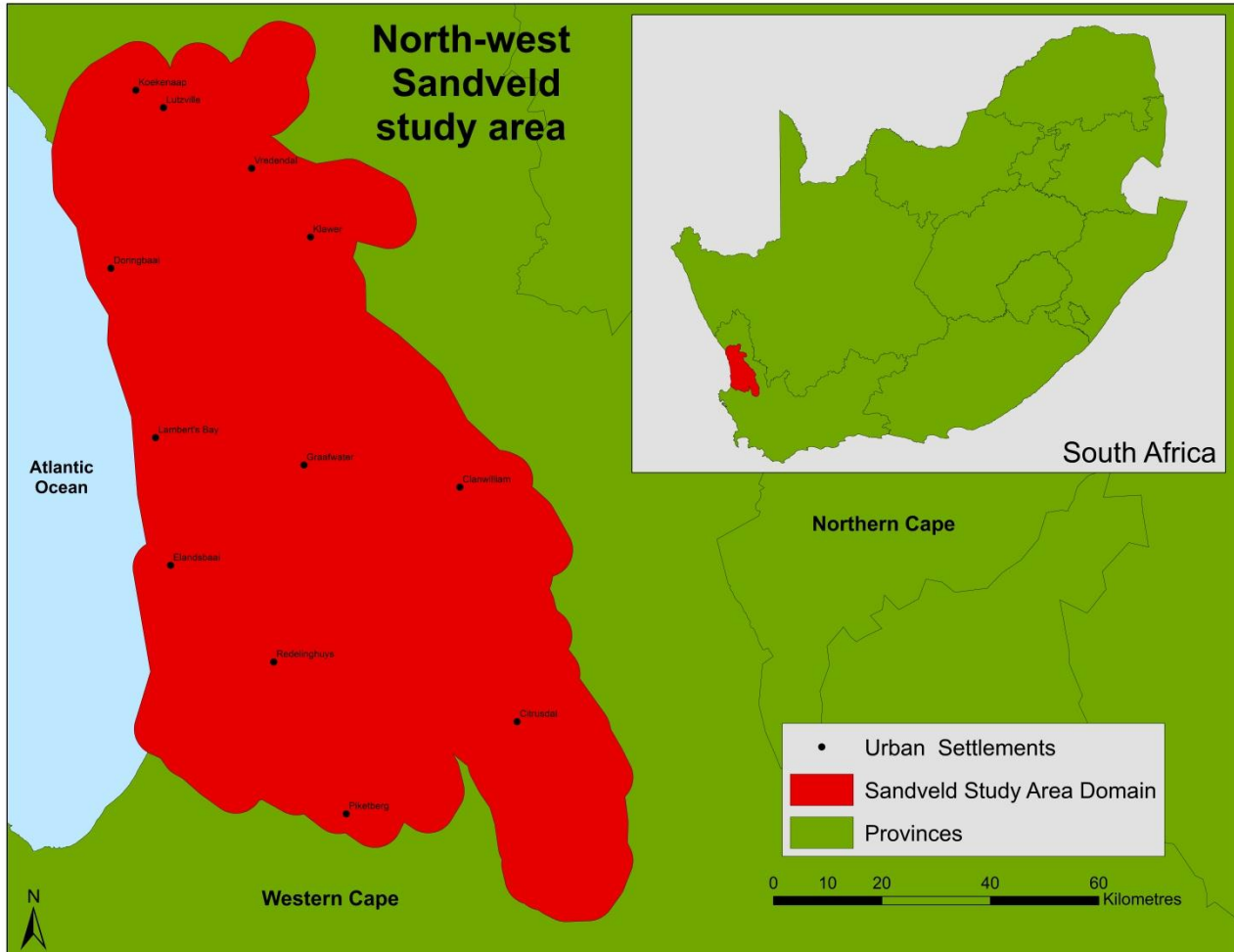
Figure 1.1 Location and demarcation of the Sandveld study area

The study area was demarcated without knowing what existed in the landscape. Two preliminary field excursions were undertaken to familiarise the author with the area. The first field trip was a one-day workshop involving experts in various fields. The team drove through the study area stopping at places for discussions about local issues. These issues varied from threatened vegetation types, human activities resulting in landscape changes to other activities such as unscrupulous agricultural practices.

The second field excursion was a four-day exploration of the study area. The excursion was done in a similar way to that of Gamanya, Maeyer & De Dapper (2009) who conducted a field survey using a global positioning system (GPS), laptop and resolution enhanced satellite imagery. Methodologies conducted by different authors for other studies acknowledge different information at each point

depending on what they are looking at, but the essence of how it is done remains the same. Using a Landsat satellite image enlarged to A3-size (and inserted into a plastic sleeve) as orientation, the area was traversed by car along accessible roads. Landscape features seen on the excursion were located on the corresponding A3-size imagery and notes made. The purpose of the four-day excursion was to get an idea on the types of land cover classes that exist in the Sandveld and where they occur.

The study area has been delineated with the relevant urban areas displayed in Figure 1.1. The research design involving the procedural stages to execute the study is presented and discussed in the next section. All the steps are summarised to give the reader a full understanding of what is to follow through the course of the thesis.

1.7   RESEARCH DESIGN

The research design illustrated in Figure 1.2 shows the processes of the classification and environmental analysis. The real world problem, the study's main aim and the objectives have been summarised according to their discussions in the above sections of Chapter 1. Their summaries give the reader an easily accessible review at any point to be reminded of the important arguments for classifying the Sandveld's land cover. Following the first three starting points, the design has been separated into three main phases: 'Project ignition', 'Model development and implementation' and 'Environmental analysis and results accuracy'. Each of these three phases have been outlined below.

The project ignition phase covers the steps needed to conduct the study successfully, namely gaining additional knowledge through a literature review and acquiring the required satellite imagery. This phase is crucial in ensuring that solid foundations are laid for the developmental steps ahead. The model development and implementation phase covers all the technical applications to classify the imagery. Principally it involves the generation of an accurate map to enable the next phase to be done. The phase of environmental analysis and accuracy uses the map generated to analyse the effects of the activities in the Sandveld on the landscape structure. The accuracy of the map essentially determines the successfulness of the classification. The final product phase analyses the map and draws conclusions about the methodology and the environmental analysis.

The reader is able to revert back to the research design as the steps progress. With an outline of the required steps displayed graphically it allows the reader to visually interpret where in the project phases one is.

Real-world problem

Develop a land cover classification system to classify land cover of the Sandveld to show the environmental impact of man's activities.

Aim

Design and implement a model to classify land cover of the north-west Sandveld and analyse the environmental impacts.

Objectives

- Delineate the study sub-areas and obtain satellite imagery for classification.
- Stipulate and define the required land cover classes.
- Develop a semi-automated model that classifies land cover.
- Implement the model for the study sub-areas.
- Conduct an accuracy assessment of the classification.
- Produce a map illustrating the landscape structure.
- Conduct an analysis from an environmental perspective.
- Report on the findings of the classification.

Project ignition

Literature Review

- History of the CFR.
- Impacts on biodiversity and corridor generation.
- Remote sensing in studying environmental impacts.
- Object-oriented classification systems.

Imagery Pre-processing

- Obtain SPOT 5 imagery of the study area.
- Orthorectify imagery.
- Prepare border, frame and NDVI layers.
- Prepare ancillary vector layers.
- Object-oriented classification systems.

Model development and implementation

Model Design

- Define required land cover classes.
- Edit customised features.
- Determine best classification parameters per class.
- Conduct a multi-resolution segmentation.
- Test and classify classes per sub-region.

Model Implementation

- Apply rule-set across full northern, western and eastern sections.
- Visually assess classification
- Conduct a manual classification on required misclassified classes.
- Export each tile from eCognition to ArcGIS for accuracy assessment

Environmental analysis and results accuracy

Environmental Analysis

- Determine the distribution of each class in the study area.
- Calculate the total surface area per class.
- Analyse environmental impacts of each class.

Accuracy of results

Calculate accuracy of each class and overall accuracy using an error matrix

Final Product

Generate a final report on the successfulness of the classification model designed and report on the environmental findings.

Figure 1.2 Research design for study procedural steps

Once the research design has been laid with the required steps displayed in context of the research as a whole, the overall structure of the research can be planned. A brief overview of each section is established below.

1.8   REPORT STRUCTURE

The literature review in Chapter 2 will deliberate on the various aspects relating to changes in landscape structure of the Sandveld as well as the technical aspects of object-oriented classification systems. The topics will include the history of the Cape Floristic Region (CFR), the impacts that have affected its' biodiversity, and ways in which biodiversity can be preserved. On the technical front, the concepts behind using remote sensing in assessing landscape structure and object-oriented classification methods are described.

The objective following Chapter 2 is to create and implement a model that has been created to classify land cover of the north-west Sandveld. The process chain for the creating of the model is quite lengthy and therefore the process has been split between two chapters. Chapter 3 will include discussions regarding gathering all required imagery and ancillary layers. Subsequent steps comprise preparing the imagery for the classification and include edge detections as well as plant vigour calculations. In Chapter 4, the classification steps are done in eCognition using all required layers. The model is then applied to the study area across three sub-divisions. Chapter 5 goes on to determine the accuracy of the map generated and to use the results to analyse the environmental facets affected by activities in the Sandveld. Chapter 6 recaps the steps taken to achieve the results displayed in the final classified map. The final conclusions are made based on the results for both the environmental and technical perspectives. Furthermore, opportunities for future research applications will be made.

Chapter 1 has given the foundation points and arguments for why a study of this study should be embarked upon. The aims and objectives have been described and the procedural steps outlined for what follows for the duration of the study A practical solution to the Sandveld's problems will be tested and the results analysed as the progression of the following chapters proceed. Chapter 2 will now ensue with the literature review and will explain all concepts and theoretical knowledge.

CHAPTER 2: USES OF SATELLITE IMAGERY IN ENVIRONMENTAL MANAGEMENT: A REVIEW

To understand the classification of land cover for biodiversity conservation and how it is planned to be used the relevant literature must be consulted. This requires an assessment of the literature on current land cover classification systems that can effectively map the landscape of the Sandveld at a resolution that shows all required classes in sufficient detail. The literature needed should cover the following topics:

1. Studies on the structure of the Cape Floristic Region with emphasis on the north-west areas of the CFR.
2. Literature on corridors and their importance.
3. Studies on bio-diversity of the CFR.
4. Land cover mapping systems.
5. Studies on eCognition and applications in South Africa.

Before the literature review begins, the definitions of the terminology applied throughout will be presented. Following from there, the environmental issues pertaining to the CFR as a whole and locally within the Sandveld are discussed. These aspects include, initial studies done on the CFR and its structure as a result of past and present activities; biodiversity degradation as a result of the actions that have taken place and continue to do so; and corridors and their uses in preserving bio-diversity. The second component will be the technical issues relating to land cover mapping systems and how it has been mapped in South Africa in the past; the software that will be used, namely eCognition and its uses in mapping of the earth's surface and the effectiveness of the software in mapping land cover at a fine scale; and the uses of new technology such as eCognition in South African land cover mapping.

2.1 DEFINITIONS OF TERMINOLOGY USED

Definitions of various terms are given here so that one has an understanding of the terminology used as taken from Dale et al. (2000), Anderson et al. (1976) and Beier & Noss (1998):

- *"Land cover* is the ecological state and physical appearance of the land surface" Dale et al. (2000). According to the authors, land can be converted from one type of cover to another

without actually changing its use, for example a centre-pivot irrigated agricultural stand can shift from bare soil to growing green foliage, but the intended use has not changed.

- *Land use* refers to the actual purpose land serves for human beings, such as pasture for livestock, timber forest, irrigated agriculture, rain-fed agriculture or human settlements. Changes in land use can have more significant impacts on the land such as pasture land being converted to irrigated agriculture.

- *Biodiversity* refers to the variety of life and ecological systems at scales ranging from local small scale populations to broad landscapes. Species richness, as in the number of organisms, is a common definition of biodiversity.

- *"Corridors* can be defined as a linear habitat, lying in a heterogeneous landscape that connects two or more larger blocks of habitat and that is proposed for conservation on the grounds that it will enhance or maintain the viability of specific wildlife populations in the habitat blocks" (Beier & Noss 1998).

The key point of the above statements is to clarify the differences between land cover and land use since they are easily confused. Biodiversity is an important concept regularly mentioned in the forthcoming sections. Corridors are an element of conservation that is important to consider in terms of fragmentation of natural areas.

2.2   HISTORY OF THE CFR CONSERVATION

During the early years of the 20th century the conservation focus tended to be on game rather than the floral reserves that dominated the CFR. The initial drive to preserve various ecosystems as wholes started from concern about the protection of water catchment areas. These areas were earmarked for afforestation with alien pine. Additionally, according to Gelderblom et al. (2003) the conservation momentum was lost in the late 1980s due to increasing demands on government spending under apartheid sanctions. This resulted in conservation organizations being unable, because of staff shortages, to adequately manage the areas under their control. In 1986, only 0.9% of the CFR was preserved in provincial nature reserves (Rebelo 1992). Over the years it has become increasingly apparent that the need for greater biodiversity in the CFR and the rest of the world is of paramount importance. A factor detailed by Rebelo (1992) is that up to 80% of the land in the CFR is privately owned and that conservation legislation is emphatically restrictive inadequately enforced and provides few economic incentives.

Winter, Esler & Kidd (2005) agree with these sentiments and add that the only way to protect natural landscapes is through voluntary conservation by landowners. In this regard, Winter, Esler & Kidd (2005) used an index to measure the conservation attitudes of landowners, emphasizing that their participation is a critical step for conservation. A structured plan needed to be implemented for preserving the natural biodiversity of the region as well as to liaise with inhabitants of the local area to encourage their participation in the conservation efforts. Initiatives such as the Cape Action for People and the Environment (C.A.P.E) 2000 project, funded by the Global Environment Fund (GEF), were developed to strengthen the environmental drive. The project's main aims were to reinforce institutions, support conservation education, co-ordinate and monitor progress, unleash the potential of protected areas, and to involve people in conservation stewardship to manage watersheds using conservation principles (CAPE 2009).

Lead by the historical studies of the CFR, researchers have studied its current configuration resulting from past practices. The common main aim of these studies, as stated by Cowling & Heijnis (2001), is what to conserve and where in terms of what can be restored or left pristine. The various studies have focused on different objectives, depending on the main aim of the project. To understand and ultimately be able to review the historical changes over time, the concept of broad habitat units (BHUs), initialised by Cowling & Heijnis (2001), has been used for systematic conservation planning of the CFR. BHUs are derived by intersecting coverages of homogeneous climate zones, geology and topography in a geographic information system (GIS). BHUs have been used extensively in determining the status of the CFR regarding biodiversity. It is important to understand the general layout of a particular landscape by using BHUs, as these will assist in classifying certain areas at a finer scale.

Rouget, Richardson & Cowling (2003) determined the current configuration of the CFR to see if there was a bias for already pristine areas toward the creation of conservation areas and representative biodiversity by using BHUs and the spatial components identified by Pressey, Cowling & Rouget (2003). Their study focused on conservation areas and the processes that influence their current configuration. The results showed that there has been a century of ad hoc conservation decisions that have led to a bias in the structure of the conserved areas in the CFR. Using BHUs to determine the general layout of the landscape is a first step in analysing land cover in the CFR. However, BHUs only consider areas as a whole and not specific land cover classes at a finer scale. Rouget, Richardson & Cowling (2003) combined 14 GIS layers from various conservation agencies into a single layer. These layers were vector files of all conservation areas in the CFR. Vector layers only show outlines of demarcated areas but not any other activities in the

region. Another problem with using BHUs to analyse a landscape is that they are only suitable for scales of 1:250 000 or larger (Cowling & Heijnis 2001). Consequently, it is very effective for region wide planning objectives. But for particular areas of concern, a finer scale is required. Regional and local planning objectives have different uses in conservation. The consensus is that the scale of spatial information is key when conservation decisions are made.

Rouget (2003) has considered the measuring of conservation value according to fine and broad scales and the implications of each. The spatial resolution of data collection, habitat classification, and size of planning units can greatly affect the outcomes of conservation planning (Rouget 2003). Cowling et al. (1996) conducted a preliminary overview of the CFR using 1:10 000 mapping units, but it was only an overview and not a thorough exercise to determine the actual configuration of the CFR. Cowling & Heijnis (2001:7) have highlighted the importance of scale by asserting that "The fact that none of the previous CFR-wide treatments has produced a map at a scale fine enough for effective conservation planning, suggests that this is not a trivial task." They also insist that for an effective implementation, the conservation system must be subject to finer-scale planning, probably at a scale of 1:50 000 or larger. Rouget (2003) has compared targets for conservation value at fine and broad scales using various layers, such as BHU vegetation maps and maps showing transformation progression. In fragmented or heterogeneous landscapes, such as the Sandveld, fine-scale conservation planning might be more effective in preserving habitat diversity (Rouget 2003). Furthermore BHUs and other surrogates can be complemented with a fine-scale biodiversity assessment.

This historical overview has revealed how past conservation efforts and human activities have affected the current state of the CFR and how scale can affect the level to which landscape structure can be analysed. This provides an understanding of how and why the landscape is in its present form. Against this background of effects on landscape structure, the next section looks at how biodiversity has been affected in the north-west Sandveld.

2.3   IMPACTS ON BIODIVERSITY

The biodiversity of a region is disturbed by the human activities. Agricultural, as well as urban activities, impact the sustainability of biodiversity of sensitive areas. The transformation of the CFR has resulted in superficial alterations of the habitat structure. Also, there has been a shift in the factors affected by this transformation. Cowling & Pressey (2001) point out that land should be given a level of consideration according to its level of irreplaceability and vulnerability to biodiversity loss. They emphasise that the ultimate goal of conservation planning should be the

designing of systems enabling biodiversity to persist in the face of natural and human-induced change.

Concerning the conservation of biodiversity, landscape structure has had a significant impact on local diversity and community structure (Dauber et al. 2003). Duelli (1997) has noted that biodiversity can be seen as one measure of environmental quality. The author approached the evaluation of bio-diversity at two different scales using an assessment of two models. The first scale used the diversity of arthropods, and the second scale determined overall landscape structure. Assessment of the landscape using remotely-sensed data was not done but Duelli's (1997) work does provide valuable information about the effects fragmented landscapes have on biodiversity. The overall structure of the surrounding landscape clearly affects the local diversity of the area since activities there are likely to have knock-on effects on adjoining areas. Composition of the landscape is one of the key factors explaining species richness (Dauber et al. 2003). In the case of the north-west Sandveld, the structure of the landscape has had a significant impact on the biodiversity, especially since many areas in the Sandveld have suffered from high levels of fragmentation as Helme (2007) has pointed out. One must agree with Dauber et al. (2003) that spatio-temporal dynamics, boundary characteristics or neighbourhood effects contribute to variations in species richness and community composition.

From an environmental perspective, many methodologies have been used to assess either past or present landscape structure. They have all aimed at emphasising that the CFR desperately needs conservation due to the impacts on its biodiversity. Midgley et al. (2002, 2003) have assessed the potential impact of climate change on plant diversity in the CFR; while Rouget et al. (2003) looked at the current status of reserves. BHUs were used extensively by Cowling & Heijnis (2001), Lombard et al. (2003) and Pressey, Cowling & Rouget (2003). Threats to biodiversity have been studied by Lochner et al. (2003) and Rouget et al. (2003). Work concerning the conservation of the CFR has focused on topics such as estimating the costs of implementing conservation plans (Frazee et al. 2003) the economic value of the CFR (Turpie, Heydenrych & Lamberth 2003) and overviews of the various conservation action plans initiated (Younge & Fowkes 2003). Journalists have written about the CFR, particularly about threats to it. Yeld (2005) has written about changing climate and its effects on the Western Cape's water supply, agriculture, people and biodiversity. Merten (2005) highlighted the threats that potato farmers are posing to the fynbos of the Sandveld. Pointing out that satellite imagery has revealed that an average of 2.7 ha of fynbos has been lost every day over a period of several years through unauthorised land-clearing. Bottom-up approaches have been followed to determine influences for landscape structure such as assessing the attitudes of

landowners (Winter, Esler & Kidd 2005), assessing groundwater recharge (Conrad, Nel & Wentzel 2004) or the actual vegetation of the CFR (Low & Rebelo 1996; Rebelo 1992 and Willis et al. 1996). Much of the available land for corridor generation is on privately owned farms, and the participation of the farmers is important as Winter, Esler & Kidd (2005) has emphasised. For portions of pristine land to be dedicated to preserving natural biodiversity, the gains and benefits of conserving them needs to be convincingly explained and landowners encouraged to take part. Remote sensing techniques have been used in many studies, some more specific than others. Van den Heever (2000) used remote sensing to detect the presence of strip cultivation in the Sandveld which gives a good indication of the landscape structure in the area.

Another example of how biodiversity has been affected by insensitive practices is through groundwater extraction. The Sandveld is an area where significant groundwater abstraction occurs for both municipal and agricultural purposes (Conrad, Nel & Wentzel 2004). Sandveld towns such as Piketberg, Lamberts Bay and Vredendal all require additional groundwater or municipal water available for urban dwellers. Conrad, Nel & Wentzel (2004) analysed the local geology and geohydrology of the area to determine recharge rates of water in the Sandveld. The availability of water impacts heavily on biodiversity patterns that form since the dependency of water differs between plant species. It is predicted that areas requiring significant quantities of irrigated water will be located in areas where the water table is high. Although Conrad, Nel & Wentzel (2004) did not do a comparison on landscape patterns and ground water availability since it was a geo-hydrological report, a map linking these elements reminds one that a detailed description of the landscape is required.

A feature the review of biodiversity impacts uncovers is that many of the studies are conducted in isolation. Biodiversity conservation requires a combination of knowledge of both the status of the landscape, as well as the factors affecting it as a whole. Instead of using only BHUs, arguing the element of scale or studying geo-hydrology, an integrated approach is called for to determine past and present patterns and to make predictions of how these patterns will change. One such approach has been to use corridor formation through the active involvement of landowners and will be discussed below.

2.4   CORRIDORS AND THEIR ROLE IN PRESERVING BIODIVERSITY

Because one cannot erase the past, patterns in the current landscape cannot be changed in areas where land transformation is irreversible. It is thus important to identify areas that can be saved because they have not been heavily impacted on. According to Dale et al. (2000), habitat

fragmentation is the alteration of a previously continuous habitat into spatially-separated and smaller patches. Such habitat fragmentation results from human land use dynamics and human activities which are capable of both increasing and decreasing fragmentation. The majority of land in the north-west Sandveld region is privately owned and many natural areas are linked through the boundary lines of individual farms. Corridors provide linkages between fragments of natural vegetation that ensure there is a passage for biodiversity to flow between each fragmented area. Conserving species and habitats, often referred to as biodiversity pattern, is not enough (Barodien 2005). A once off snapshot is initially needed to determine the starting point for creating corridors.

The Greater Cederberg Biodiversity Corridor (GCBC) project has a principle goal of corridor planning to restore connectivity across the landscape (Ashwell et al. 2006). The only way to develop corridors effectively is through the involvement of landowners in the Sandveld region since they are able to set aside parts of their land for conservation. For this to be undertaken, conservationists need to know what landowners' understanding is of preserving important pristine areas and then to convince them about the necessity for a portion of their land to be committed to biodiversity preservation.

A fine-scale map of the landscape provides much information of what is where. The extent of an urban boundary, the number and size of centre-pivot irrigated areas, the area of ploughed fields and the existence of natural areas in its various states of transformation is required. With an understanding of what has created the present landscape, one can make informed decisions concerning conservation priorities. The environmental section of the literature review aimed to give an historical background to the CFR and more specifically the Sandveld region. It also shed light on the outcomes of past practises. This advances an understanding of how and why the Sandveld region is so fragmented.

Since there are various methods to achieve the intended objectives, the following sections of the literature review explain the concepts involved in this study and documents previous works that have used eCognition to classify high-resolution satellite imagery.

2.5 REMOTE SENSING IN ASSESSING LANDSCAPE STRUCTURE

The fate of biodiversity is intimately linked to the use of land for agricultural production (Mattison & Norris 2005). Agriculture encroaches extensively on natural land and affects the natural processes that occur there. Mattison & Norris (2005) point out that the monitoring of land use and land cover threats to biodiversity can be determined and the associated risks measured. Tapiador &

Casanova (2003) affirm that all regional tasks require knowledge about the condition of the space in which proposed actions will be carried out. Economic planning, environmental studies and resource management of any country require accurate and current information on precisely what exists and where (Haack & Bechdol 1999; Lioubimtseva & Defourny 1999). Anderson et al. (1976) long ago insisted that land use and land cover had become increasingly important as South Africa planned to overcome the problems of haphazard planning, uncontrolled development, deteriorating environmental quality, loss of prime agricultural lands, destruction of important wetlands and loss of wildlife habitat.

The developments of remote sensing in three key areas are, according to Haack & Bechdol (1999), i) the development of sensors capable of collecting information in new portions; ii) the use of space-borne platforms including orbiting and geostationary satellites; and iii) the incorporation of technology, i.e. computers in data acquisition and utilisation. Lioubimtseva & Defourny (1999) assert that geographical information systems (GIS) and remote sensing are extremely useful tools for classifying land use and land cover. They also maintain that there is a pressing need for data sets to be integrated at national and regional levels. Furthermore, remote sensing is an invaluable tool for acquiring large volumes of information on spectral properties and the structure of a landscape, and large-scale detailed landscape maps can be derived from satellite images classified for land cover (Lioubimtseva & Defourny 1999).

Land cover classifications are used extensively around the world to determine real-world structure of landscapes. Such classifications have been well documented as they have served various purposes. Depending on what is required, remote sensing can provide a variety of information for diverse purposes of analysing landscape structure. The adverse effects of human disturbance on the diversity and abundance of species is stimulating the development of new techniques to inventory global data (Griffiths & Eversham 2000). To monitor change in a landscape and ultimately in the natural areas that have formed due to this change, regular, up-to-date data is required at a suitable at habitat-level scale. Griffiths & Eversham (2000) point out that the digital nature of land cover information from satellite imagery enables the derivation of a large number of landscape metrics. Authors such as Anderson et al. (1976), Klemas (2001), Moody & Woodcock (1995), Pikha & Zinck (2001), and Thompson (1996) concur. The message is clear, remote sensing is an invaluable tool for environmental assessments.

Klemas (2001) used remote sensing to detect landscape-level coastal environmental indicators. The author required a more holistic view of ecological patterns for a large coastal region using suitable

satellite imagery coverage. Remote sensing and GIS have the ability to collect structure and analyse coastal management-relevant spatial information (Klemas 2001). The north-west Sandveld covers an area where climate and geology change significantly from north to south resulting in changes in the natural vegetation as well as the types of agricultural activities. According to Klemas (2001), remote sensing specialists can monitor landscape-level environmental indicators such as changes in size and configuration of coastal habitats and vegetation cover.

An area's characteristics can be classified using remote sensing methods in many ways. The satellite imagery to be used is largely influenced by the detail of the information to be classified. Pixel-based, and more recently, object-based classification systems have been the most widely used type for classifying satellite imagery. An object-oriented classification system is used in this study to classify the land cover of the Sandveld. This system is examined in the following sections by reviewing works of a similar nature done by other researchers.

2.6   OBJECT-ORIENTED CLASSIFICATION SYSTEMS

For one to understand the methodology to be applied in classifying land cover in the north-west Sandveld, an understanding of how similar methodologies have been conducted in other studies. The foregoing part of the literature review surveyed studies done in an environmental context. The following sections of the literature review focus on object-oriented classification mechanisms.

High-resolution imagery has become a popular choice for remote sensors since its advances in technology have made it readily available. There are many satellites in space today such as IKONOS, GeoEye-1, Quickbird, Worldview-1, ASTER, Cartosat, ResourceSat, SAC-C, Landsat, Modis, NOAA and SPOT, that have provided remote sensing specialists access to vast amounts of information at local, regional and global scales (Ehlers, Gähler & Janowsky 2003). High-resolution imagery particularly has a high density of pixels, and since most classifiers in software packages conduct classifications using the properties of each pixel, high-resolution satellite imagery creates a challenge different to that of lower resolutions. Smaller pixel sizes combined with fewer spectral bands in aerial photography and high-resolution imagery can create classification problems due to greater spectral variation within a class and a greater degree of shadow (Laliberte et al. 2004).

Although the concept of grouping pixels into objects is not entirely new there have been recent developments in the object-oriented concept that made it become possible to process very-high-resolution imagery. As Blaschke & Strobl (2001:12) assert when describing remote sensing "The ultimate goal is to mirror, elucidate, quantify and to describe surface patterns in order to contribute

to an understanding of the underlying phenomena and processes." Remote sensors are trying to achieve this same aim regardless of the methodology used. However like all technological fields, new developments are occurring continuously and opinions changing about which method is best suited for different situations. Since Definiens Imaging launched its software (eCognition) in 2000, rapid development of object-oriented methods of image classification has been observed (Lewinski & Bochenek 2008). eCognition has facilitated a wide scope in research and development in the area of object-oriented classification since there are many avenues to explore regarding the use of different raster and vector layers.

The foundation for object-oriented analysis (OOA) is that the basic processing unit is groups of pixels known as image segments or objects instead of individual pixels (Definiens Imaging GmbH 2004). The degree to which pixels are grouped together into image objects depends on the scale used. The smaller each image object, the greater degree of detail in the final map. How pixels are grouped together will be discussed further later on in this chapter. Concerning the benefits of object-oriented classifications for image analysis in relation to landscape structure, Blaschke (2005) confirms that environmental remote sensing is dominated by land use and land cover classifications and the resultant tangible objects are desirable in many applications. The author concludes that many environmental management applications necessitate the control and use of object-based land cover distributions. Laliberte et al. (2004) support Blaschke (2005), by stating that it is more appropriate to analyse objects as opposed to pixels because landscapes consist of patches detectable in the imagery with OOA.

The introduction of high-resolution sensors such as Quickbird, Worldview-1 and -2, Pleiades, GeoEye-1 and IKONOS has created a need for a suitable classification method to accompany them. Since the classifying methodology used for the Sandveld area will be an object-oriented one, it will not be necessary to discuss that particular method here. It is important to note however the reasons for choosing an object-based classification system. Zhou & Troy (2008) have emphasised that conventional pixel-based methods are inadequate for classifying high-resolution multispectral images. The concepts of object-oriented classification systems will be discussed in the following sub-sections to ensure that the reader understands the concepts used throughout the course of the Sandveld classification.

2.6.1   The segmentation

eCognition has been extensively used and the principles of segmentation have been rehearsed in a number of works, for example Benz et al. (2004), Benz & Schreier (2001), Blaschke (2005),

Laliberte et al. (2004), Willhauck (2000) and Zhong et al. (2005). These authors have explained the concepts that are needed to understand the processes for classifying land cover. Their explanations and those of others will be recounted below.

We humans think and make perceptions as humans. We are not computers and do not programme what we see in the world by numbers. Therefore, is it not better that when software analyses an image, it is seen as humans do? When humans see things, they are performing a complex mental procedure known as image understanding (Definiens Imaging GmbH 2008). Our eyes automatically look at an area and register certain areas according to their shape, colour and size. Thus, the things we see become objects.

When looking at Figure 2.1, we see that the area has a green background with three different shapes inside. Our brains register each one of these shapes individually and they are sorted as three different objects. Each object has a relationship to the scene, a relationship to other objects and characteristics about itself. Similar to human vision, the Definiens concept of image understanding is based on a correct segmentation of the visual image content of interest against other visual image content. Segmentation is performed by splitting the image into zoned partial areas of differing characteristics. The segments are called image objects. Segmentation is defined as the subdivision of an image into separated regions or objects on the grounds of some form of similarity of reflection values and shape of polygons (Definiens Imaging GmbH 2004).
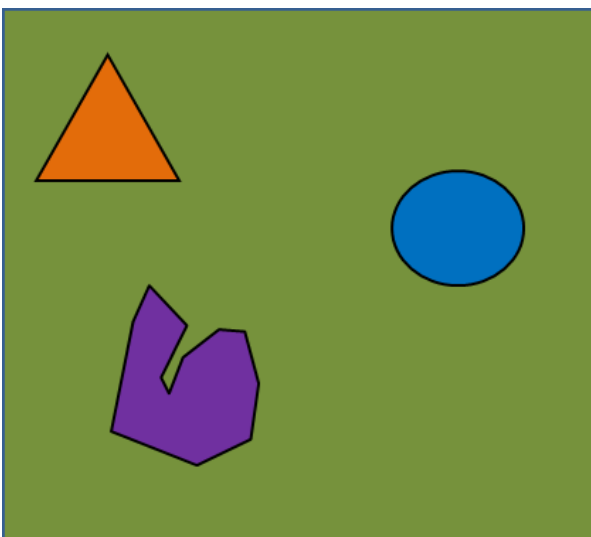
Figure 2.1 Image with different objects

eCognition's multiresolution segmentation is a bottom-up region-merging technique starting with one-pixel objects (Benz et al. 2004; Zhong et al. 2005). This means that the process starts with a single pixel and through a series of calculative steps, pixels are grouped together until a threshold is

met. Parameters set at the beginning of the segmentation exercise determine the thresholds reached. Segmentation parameters are based on three determinants: scale, colour (spectral information) and shape (smoothness and compactness) (Laliberte et al. 2004). The colour parameter balances the colour homogeneity of a segment on one hand and the homogeneity of shape on the other (Willhauck 2000). Colour and shape can be weighted from zero to one while scale is a unitless parameter related to image resolution (Laliberte et al. 2004). The segmentation process can be run at various scales and each scale lies in a separate level, meaning that pixels can be grouped into smaller objects at the first level and move up to larger objects with more pixels grouped together. Repeated segmentations with different parameters create a hierarchical network of sensible image objects and each object knows its relationships to its neighbour objects and sub- and super-objects (Willhauck 2000). Figure 2.2 shows how pixels with similar characteristics are grouped together into the same object. For example, for the vineyards (red areas) to be extracted entirely, shape and colour parameters are emphasised. The brightness index which assigns a value to an object based on its brightness, and normalised differentiation index (NDVI) are good determinants for segmenting the lighter yellow areas of low vegetation growth.

Figure 2.2 Segmentation showing clearly defined objects according to spectral characteristics

A complete classification task consists of subtasks, which have to operate on objects of different sizes (Benz et al. 2004). The segmentation at different layers works on a hierarchical structure

where each object knows its neighbouring object as well as its sub-objects (those objects in a level below) and its super-objects (those objects in a level above). Zhong et al. (2005) give a good description of hierarchical image segmentation. They point out that segmentation at a coarser level of detail can be produced from simple merges of regions from segmentations at finer levels of detail. Figure 2.3 displays a simplistic description of how a super-object is reduced to smaller sub-objects in each level. Each level is created below the one preceding it. Thus the last level segmented at the smallest level is Level 4. Following Level 4, larger objects are created at Level 3 and so on. Another factor Blaschke et al. (2000) point out is that image data exhibits characteristic textural information which is often neglected in common classifications. The texture of an image can be determined according to its smoothness or its coarseness (Blaschke et al. 2000).
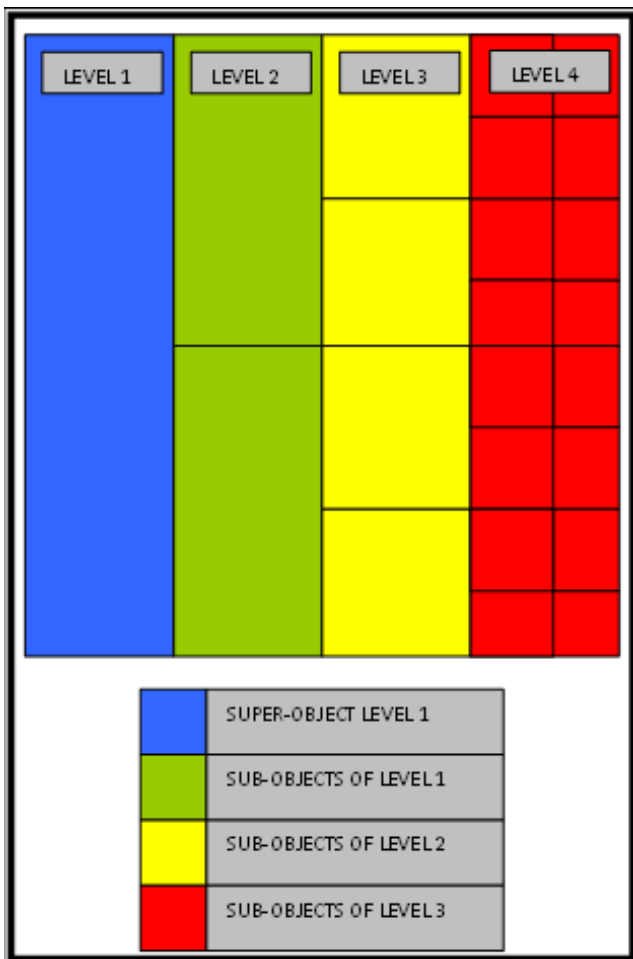
Figure 2.3 Pictorial description of image object levels

What has been described above was explained graphically with the aid of the satellite image in Figure 2.4, which shows the result of a multi-resolution segmentation process. A threshold is applied that factors the size that the objects will be. A threshold is a numerical value assigned to the segmentation. Figure 2.4 clearly illustrates how the objects increase in size as the threshold increases. Colour, shape and texture are assigned weights commensurate with their importance. The

higher the weight value the more important the criterion. If the weight value of colour and shape is high and that of texture low, eCognition will weight the former two with more importance.
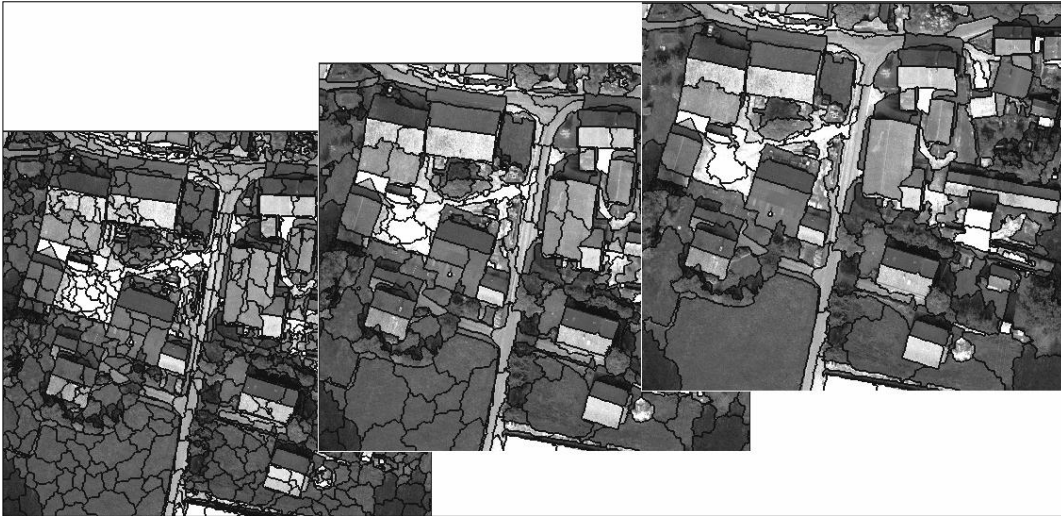
Source: Definiens Imaging GmbH (2008: 27)

Figure 2.4 Image object levels with differing thresholds

The segmentation process is the basis of the object-oriented principle and is therefore the most important step. Following the segmentation phase, the classification of the image objects can begin. All subsequent analyses of the imagery will be based on the image objects generated because each object has a relationship to the scene, its neighbour, super- and sub-objects as well as having its own characteristics and numerical values. The concepts of and literature on object-oriented classification systems are discussed in the next section.

2.6.2   The classification

The classification process comes after the segmentation process and it forms the core of the processing chain. A class can be defined as a category of image objects (Definiens Imaging GmbH 2008). A class can be used to simply label image objects or describe its semantic meaning. Classification is a procedure that associates image objects with an appropriate class labelled by a name and a colour. Figure 2.5 exhibits the legend used in an example classification. Each class classified is assigned a colour used as reference in the product.
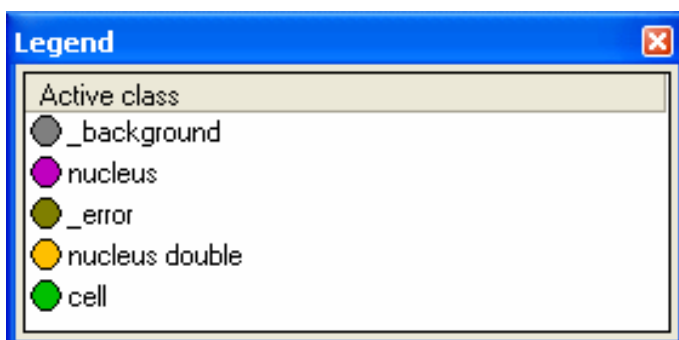
Source: Definiens Imaging GmbH (2008:389)

Figure 2.5 Class classifications with associated colour in the legend

The classification uses a hard classifier system involving a threshold condition that assigns a maximum or minimum value that defines the class according to the feature used. Figure 2.6 shows four parameters assigned to classify a class. Descriptions of each area are:
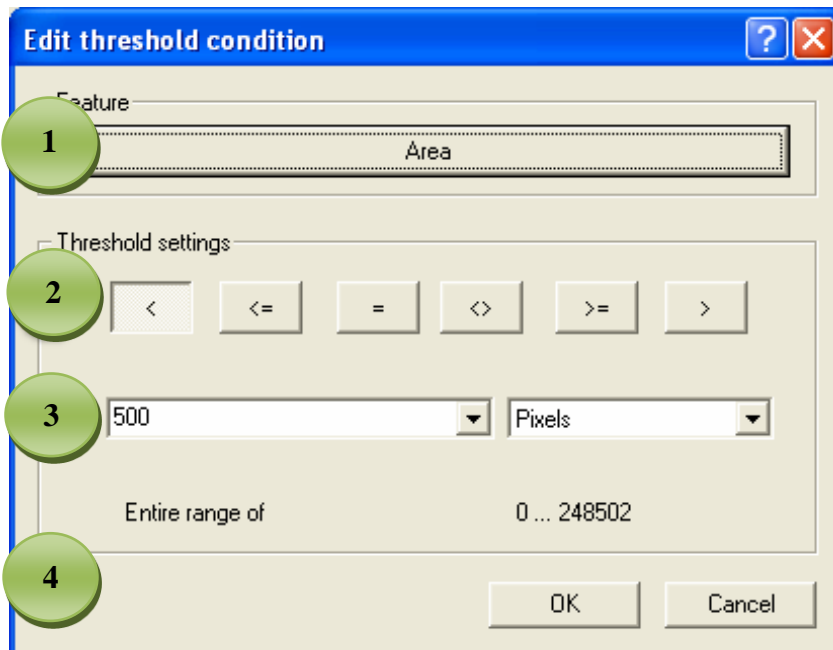
Source: Definiens Imaging GmbH (2008:218)
Figure 2.6 Threshold condition to assign classes in eCognition

1. The feature that is taken into consideration, in this case it is 'Area'.
2. Threshold settings which can be *less than*, *greater than*, *equal to* or *within*. In Figure 2.6 it has been assigned the *less than* setting.
3. The threshold value assigned. Therefore all objects that have a value of less than 500 for the feature 'Area' will be assigned the class that the rule was set up for.
4. The entire range for all objects in a scene. Every object in a scene is given a value according to the feature analysed. In Figure 2.6 it is 'Area'.

Once the setting up of each classification parameter for each class has been completed, the classification process can begin. Certain conditions are selected to fully classify a class. The number can vary from 1 to 100 or more conditions and involve a detailed analysis of all groups of objects belonging to a particular class.

2.6.3   Application of object-oriented classifications

Land cover classifications of urban environments have been commonly applied in eCognition as well as extraction of features that fall within this class. Frauman & Wolf (2002), Nobrega, O'Hara & Quintanilha s.a., Zhou & Troy (2008) all applied object-oriented analysis in urban settings.

Although the Sandveld does not have large urban patches, some leads can be taken from these sources to assist in developing the Sandveld model. One of these is the calculation of NDVIs as that done by Nobrega, O'Hara & Quintanilha (s.a.) and Zhou & Troy (2008).

To get an appreciation of the work required for SPOT data, literature was sourced that applied the principles of classifying high-resolution imagery similar to those to be used in this study. Lewinski & Bochneck (2008) used SPOT 5 imagery to do a land cover classification of Poland. The SPOT data was pre-processed in PCI Geomatica. Kressler, Kim & Steinnocher (2003) used SPOT 5 imagery, but only applied the segmentation on the pan band. The intention was to show that one can conduct a classification, although not fully automatically and not completely on just the pan band of an image. The results showed that a classifier should not rely only on the spectral values of individual pixels but rather on a number of features (Kressler, Kim & Steinnocher 2003). To prepare the SPOT 5 imagery for the classification, it is crucial to understand the required pre-processing steps.

OOA has been used considerably in land cover classifications across the agricultural and forestry landscapes. Blaschke (2005), Crase & Hempel (2005), Syed, Dare & Jones (2005) and De Kok & Wezyk (s.a.) have all applied the object-oriented technique. In all these studies the purpose has been to create separate parcels that effectively define each class within a land cover classification. Since these are not South African examples, only the theoretical knowledge has been taken. Syed, Dare & Jones (2005) used high-resolution imagery as well as LIDAR data to classify an image. The LIDAR data was used to create a digital elevation model (DEM) that, in conjunction with the high-resolution imagery created a suitable foundation for classification. A DEM was used for classification in the Sandveld study, so it is important to appreciate the relevance of this type of information being used to make a segmentation and ultimately the classification more successful.

There are many varied examples of classification studies in the literature that can be discussed, but the principles largely remain the same. These principles must now be applied to the classification of the Sandveld's land cover. This review of the literature has visited the two facets that encompass the Sandveld study. The environmental context addressed the issues of the CFR and the Sandveld specifically. The environmental issues have been a departure point to recognise the usefulness of using satellite remote sensing as a tool in evaluating landscape structure. OOA is one method of classifying satellite imagery but has not been applied in many South African examples.

2.7 A STANDARDISED LAND COVER CLASSIFICATION SYSTEM

Land cover classification systems using satellite remote sensing techniques continue to be used in various fields of natural science. Most land cover (and land use) classification schemes have been developed around specific user objectives (namely agriculture and conservation), and are often influenced by actual data capabilities (Thompson 1996). To combat these biases, the National Land Cover Database project (NLC) has produced standardised digital land cover data for South Africa, Swaziland and Lesotho (Harrison et al. 2001). There are 31 land cover classes and they derive from Thompson (1996). The NLC is based on three hierarchical levels, namely:

- Level I: 12 broad land cover types that can be identified off high-resolution imagery, including SPOT, without the use of ancillary data.
- Level II: 23 subclasses that can be identified from remote sensing data without the use of ancillary data, providing the data format is suitable.
- Level III: Flexible, user-defined subcategories developed by individual planners and remote sensing analysts for specific purposes.

A hierarchical structure gives flexibility to the user and it has been emphasised by Anderson et al. (1976) on whose work many standardised classification systems are based. It is important none the less that any land cover classification project undertaken conforms to a standard at local and international scales.

Thompson (1996) has provided descriptions of all land cover classes to be used in the NLC, but for the purposes of this classification exercise in the Sandveld, only those classes pertinent to this study are described and defined. These classes are outlined in Table 2.1. Both Anderson et al. (1976) and Thompson (1996) omit infrastructures such as roads and railways because they are considered to be land use categories and thus fall outside the scope of a land cover project. Contrarily, these are included in the Sandveld classification since they exert certain stresses on the landscape and its structure.

The classes described in the table are based on a standardised system. Thompson (1996) has stipulated that the Level III classes are based on user-defined subcategories developed by individual planners and that the three levels are interchangeable. This flexibility allows the definition of some classes used in the Sandveld land cover classification to be more user-specific. These class definitions are specified in Chapter 3.

Table 2.1 Class names and definitions

Level I (All classes)	Level II (Required class)	Definition
Thicket, bush land, scrub forest, high fynbos	High fynbos	Fynbos communities between 2 and 5 m in height with >70% height cover. Composed of evergreen bushes typically growing in infertile soils.
Scrubland and low fynbos	Low fynbos	Small-leaved, evergreen plants growing on infertile soils. Karoo vegetation included.
Water bodies	Water	Areas of (generally) open water. Includes natural and man-made water bodies. Class can be divided into actual feature, e.g. river or canal.
Wetland	Wetland	Natural or artificial areas where the water level is at/near the land surface on a permanent or temporary basis.
Barren lands	Bare rock/soil	Natural areas of exposed sand, soil or rock with no/little vegetation cover. Examples include rock outcrops, dune and beach sand, dry river beds and gravel plains.
Cultivated land	Permanent crops	Lands cultivated with crops that occupy the area for long periods of time and are not replanted after harvest. Includes vineyards and citrus orchards. Class name can include crop type.
	Temporary crops	Lands under temporary crops harvested at the completion of the growing season; remains idle until planted. Includes maize, wheat, lucerne and potatoes. Class name can include crop type. *
Urban/built-up	Urban/built-up	An area where there is a permanent concentration of people, buildings and other man-made structures and activities.

Source: Thompson (1996: 36-41)

∗ Note: Can fall under a Level III description of irrigated/non-irrigated. Irrigated areas are characterised by numerous farm-scale irrigation dams, close to major water sources and/or centre-pivot irrigation systems.

Following from conceptualising the environmental facet of this study, the technical information must be relayed to gain the full grasp of the concepts used in later chapters. The opening sections will be on object-oriented classification systems and followed by how these concepts are applied in eCognition. The fundamentals have been explained to continue to the following chapter. Chapter 3 discusses at length the development of the model used and its application to the Sandveld situation.

CHAPTER 3: IMAGERY, DATA ACQUISITION AND PREPARATION

The objective to classify land cover in the north-west Sandveld requires the development of a semi-automated model. This model building exercise involves data preparation, the creation of a 'project' in eCognition and the designing of the rules themselves to be applied to satellite imagery. The creation of the model begins with steps taken to introduce the imagery into the software and prepare it for the classification. The model is then developed further and tested on single tiles that represent different areas to be classified. Once the processing steps are deemed successful, they are applied to all the tiles that require a particular rule-base. Chapter 3 covers acquiring the imagery and preparing all available data for the classification process.

Access to accurate information regarding land use and land cover change is essential to decision makers concerned with environmental affairs. Satellite imagery can provide important spatial information for estimating levels and rates of deforestation, habitat fragmentation, urbanization, wetland degradation and many other landscape-related phenomena (Vogelmann et al. 2001). One can deduce from this that remotely-sensed information is an invaluable tool in determining the land cover situation existing in a particular area. The quality of the information derived from satellite imagery is influenced by data quality, analysis techniques and interpretations, and numerous temporal/phonological considerations (Vogelmann et al. 2001).

3.1 ACQUISITION OF SATELLITE IMAGERY

The original imagery intended for the classification of the Sandveld's land cover was colour aerial photography flown in 2003 and obtained from the Department of Water Affairs and Forestry (DWAF). This imagery has great potential use, but unfortunately is afflicted by problems of quantity and quality. Regarding the quality of the imagery, many radiometric anomalies are present in the dataset making many areas difficult to view. Colour banding exists throughout the dataset and this interferes with the quality of the aerial photographs. Figure 3.1 shows the distinct colour-banding present in the south section. When trial segmentation tests were done on the imagery, the segmentation algorithms picked up colour-banding anomalies that interfered with the classification. Regarding the quantity of the imagery, there was limited coverage by aerial photographs as seen in Figure 3.1. Therefore, with the whole study area not being covered, aerial photography was deemed unsuitable for the classification. Furthermore, should two different datasets be used, the rule base applied to the data would have to allow for disparate spectral and textural characteristics.
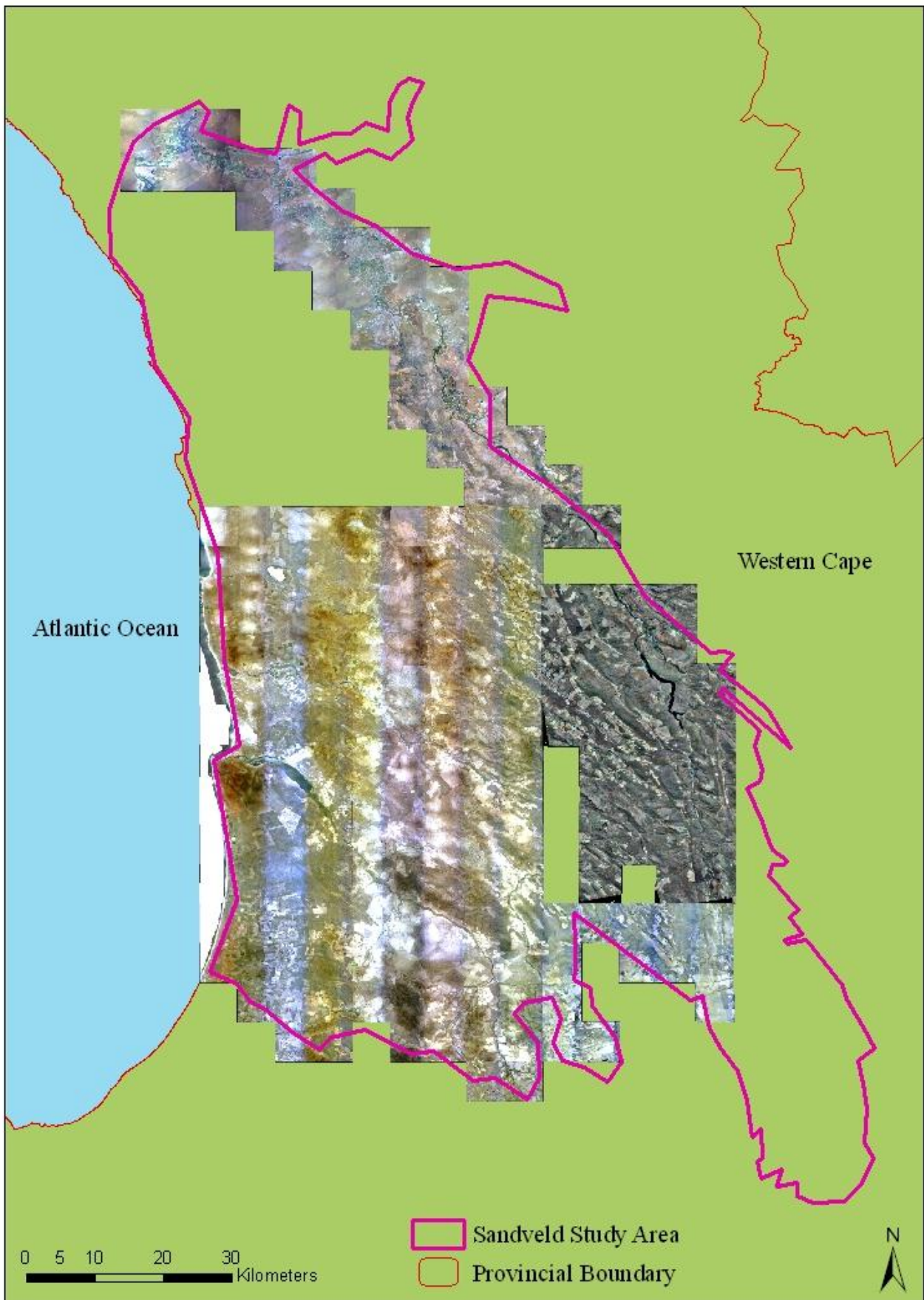
Figure 3.1 Available orthophotos for the study area showing the distinct colour banding

The alternative to the aerial orthophotos is imagery with resolution closest to that of aerial photography but with coverage of the entire area. The imagery considered the best possible available for the Sandveld classification is that available from Satellite Pour l'Observation de la Terra (SPOT). Owned by Centre National d'Etudes Spatiales (CNES), SPOT is a high-resolution optical imaging system operating from space where the first satellite has been in flight since 1986. Despite increasing competition, SPOT still remains a leading standard in earth observation. A comparison of SPOT 5 with the DWAF aerial photography is shown in Figure 3.2 where the differences in the datasets can be clearly seen along with the benefits of using SPOT 5.

A   **B**
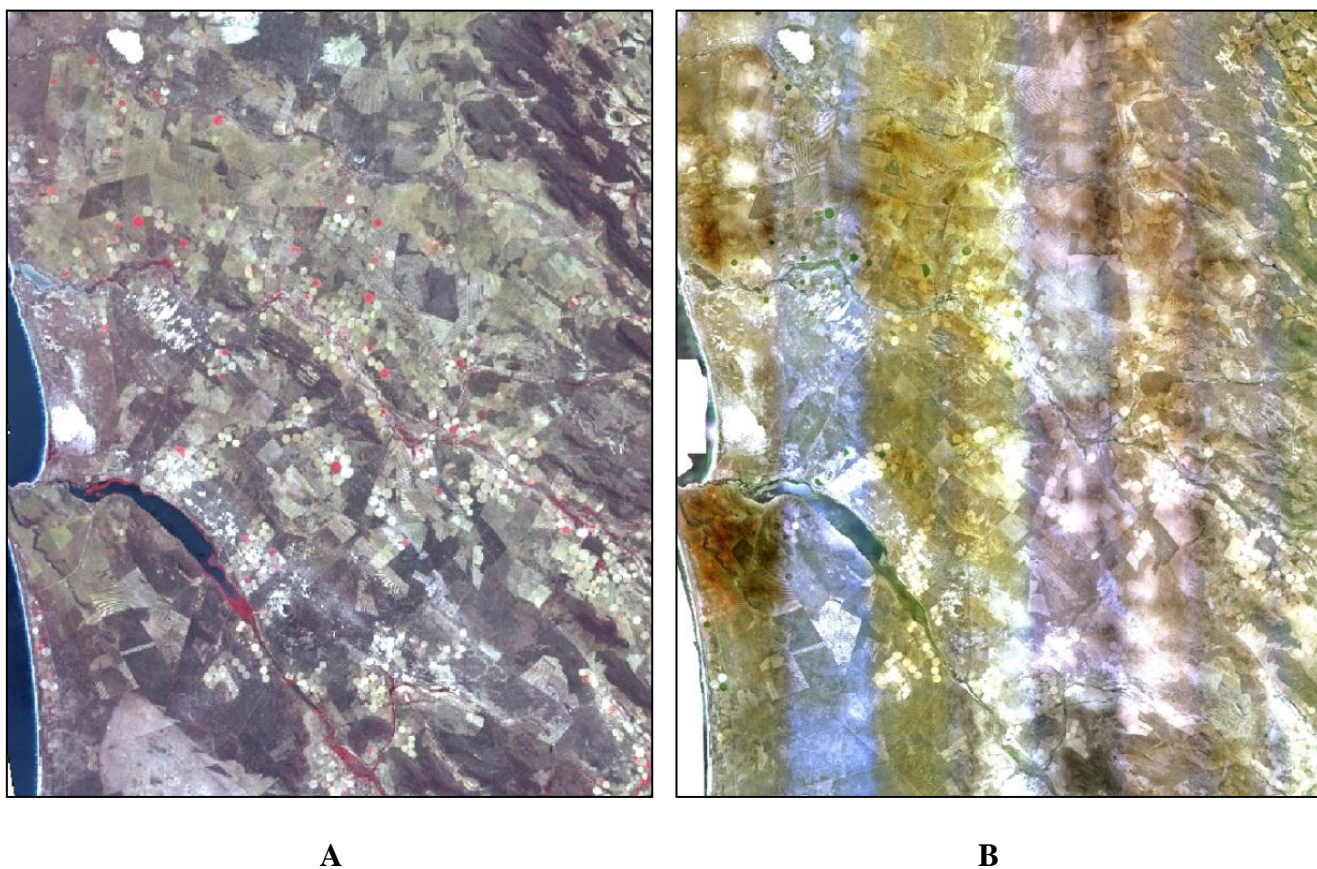
Figure 3.2 Comparison of SPOT 5 (A) data with DWAF aerial photography (B)

The technical information shown in Table 3.1 shows the benefits of using SPOT 5 imagery. The products of SPOT 5 include a panchromatic band (black and white) and a multispectral band. By merging the 2.5 m panchromatic and 10 m multispectral bands, the final product is a fused 2.5 m colour-composite image. The higher resolution is eminently suitable for analysis of agricultural activities and it allows for a detailed inspection of the landscape. A clear advantage of SPOT 5 over aerial photography is that there are four spectral bands with which to work. The spectral bands include the near infrared and red bands that permit the calculation of the normalised differentiation vegetation index (NDVI). When sunlight strikes objects, certain wavelengths of this spectrum are

absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm) (Weier & Herring 1999). NDVI is a simple numerical indicator used to analyse remote sensing measurements and assess whether a plant contains live green vegetation or not, that is whether plants are growing or not. The footprint of the imagery is 60 by 60 km.

Table 3.1 SPOT 5 technical information

Products	Panchromatic: 2.5 m – 5 m Multispectral: 10 m
Spectral bands	P (Panchromatic); B1 (green); B2 (red); B3 (near infrared); B4 (SWIR)
Footprint	60 x 60 km
Revisit interval	2 to 3 days
Global archive	> 14 million images since 1986
Viewing angle	Cross-back +/- 27º Forward/backward stereo-viewing with SPOT 5
Location accuracy	< 30 m with SPOT 5
Processing levels	1A, 1B, 2A, 2B, Ortho

The swath of the imagery means that 9 scenes as shown in Figure 3.3 cover the entire study area. The SPOT 5 imagery was acquired from the Satellite Applications Centre (SAC) where a full catalogue of the latest imagery is available. The benefits of the SPOT 5 imagery can be deduced from the technical information in Table 3.1. The resolution of the products varies from 2.5 m in the panchromatic band, to 10 m in the multispectral bands. When the product is pan-sharpened, as done for the Sandveld study, the resolution is re-sampled to a 2.5 m pan-fused colour product. The four spectral bands and the wide swath are considerable advantages for using the imagery for classification purposes. The small angle of incidence (viewing angle) ensures that the locational accuracy of the imagery is maintained. Where possible, an angle of incidence of less than 12° supplies an image of suitable accuracy.
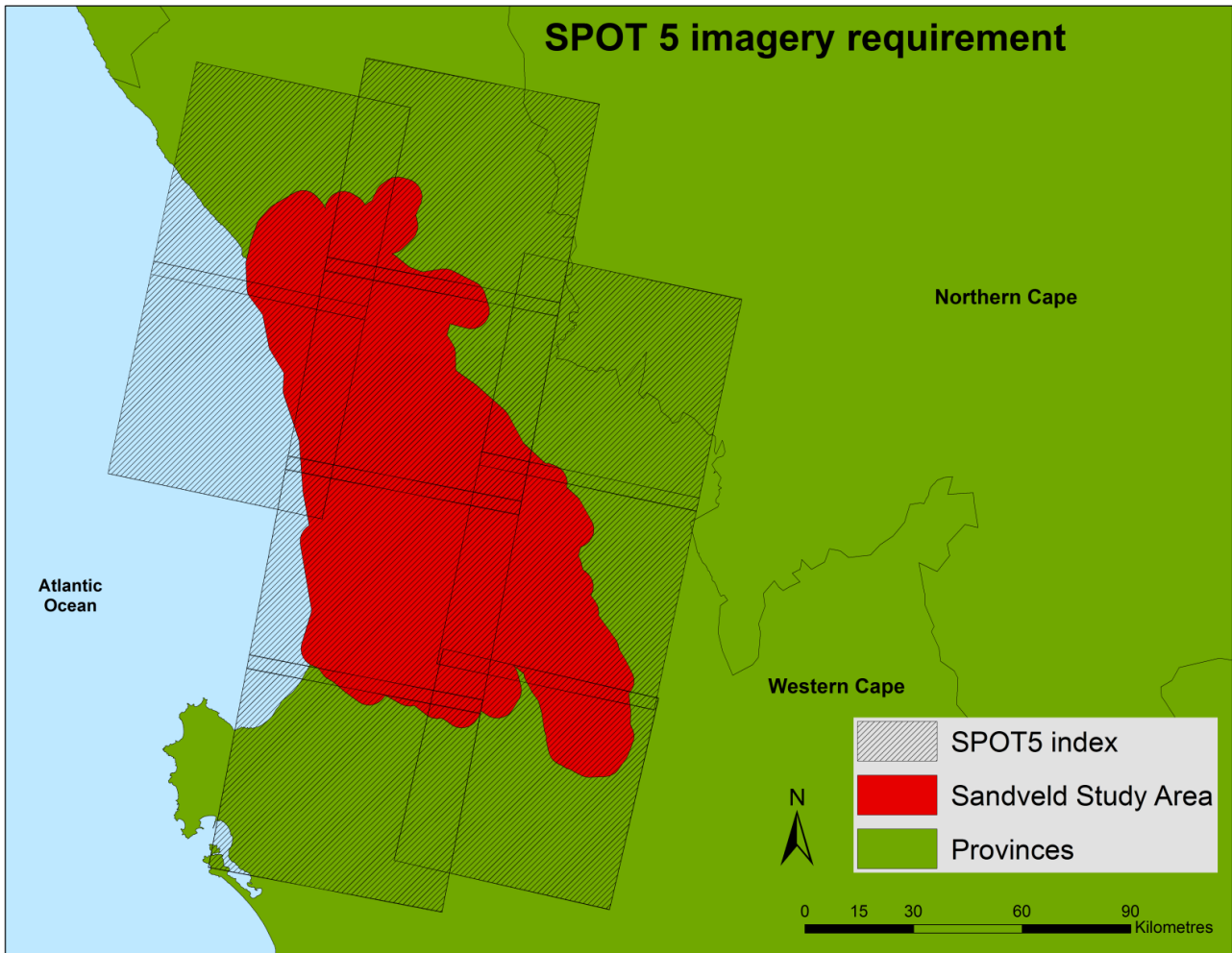
Figure 3.3 SPOT 5 imagery coverage over the Sandveld study area

Given an appreciation of the technical specifications of the SPOT 5 imagery, one can then proceed with the pre-processing of the imagery to fully prepare it for the classification procedures.

3.2   PREPROCESSING OF THE SPOT 5 IMAGERY

Pre-processing of the imagery is the first stage of preparing the satellite imagery for the classification process. The steps involved are revealed in Figure 3.4 and are discussed briefly below.
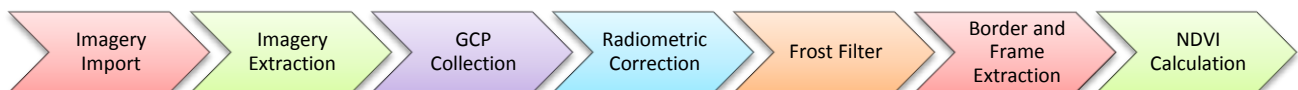
Figure 3.4 Process flow of pre-processing steps preceding classification.

The first step was to import the imagery from the satellite into the database. Then the data was extracted from its raw TIFF format into a workable PCIDisk file (.pix format). In the .pix format the

scenes can be orthorectified by collecting ground control points (GCPs) using reference imagery from older available orthorectified datasets. Once a sufficient number of GCPs have been collected (up to 300 can be collected), the orthorectification model can be run on the imagery. Orthorectification gives the imagery the geographical reference required to ensure all datasets displayed share the same projection and geographical location. The imagery and ancillary data for this project has been projected into WGS84 format with the measuring unit in metres. Radiometric correction ensures that interferences such as dust or haze are removed. Once these preliminary steps have been completed, the preparation for the imagery for the classification process can commence.

3.3   IMAGE PREPARATION

Once the imagery has been orthorectified and placed in its correct geographical location, image preparation is the next step. Image preparation involves applying a frost filter to the imagery, border and frame extraction and calculating the NDVI. These steps create additional layers necessary to assist the segmentation process and ultimately the classification.

3.3.1   Frost filter application

Following orthorectification of the imagery, the next step is to apply a frost filter to the imagery. A frost filter is primarily used on radar imagery to remove high-frequency noise while preserving high-frequency features (edges) (PCI Geomatica 2010). Since SPOT 5 imagery contains a large number of pixels due to its high resolution, it would take a significant amount of time for eCognition to acknowledge and process each pixel during the segmentation process. Consequently, a filter must be applied to smooth pixels but leave edges and sharp features unaltered. Although a frost filter is primarily applied to radar imagery, in imagery such as SPOT 5 it can be used instead of a Lee filter for suppressing speckle, while still preserving edges (Liu & Jezek 2004). A speckle filtering consists of moving a kernel over each pixel in the image and applying a mathematical calculation using the pixel values under the kernel and replacing the central pixel with the calculated value. The kernel is moved along the image one pixel at a time until the entire image has been covered. By applying the filter, a smoothing effect is achieved and the visual appearance of the speckle is reduced (Mansourpour, Rajabi & Blais 2006). Because the edges have been preserved, the next preparation step is to apply border and frame extraction to the image that has been smoothed. Segmentation in eCognition groups pixels according to weights assigned to the process in keeping with spectral, textural and shape characteristics. To ensure that the edges of features in an image are enhanced, an edge detection of these images must be done. Once the frost filter has been applied, the extraction of borders is done through processes conducted in Erdas Imagine. Erdas

Imagine's model maker is a useful tool for conducting individualised processes on the imagery. The appropriate exact models designed in this study are discussed in the sections devoted to border and frame extraction below. There are two main forms of border extraction, named *border* and *frame* here. The filters applied to extract border and frame are separate additional processes described graphically by De Kok & Wezyk (2005).

3.3.2 Border extraction

For borders to be extracted successfully, a maximum amount of contrast between areas of differing spectral characteristics is a prerequisite. These contrasts facilitate the creation of borders through selective filters applied in models in the Erdas Imagine platform. There are many filters that can be used to remove noise, particularly from imagery with a high resolution. The principal way of determining which filter is best for an image is to apply each one experimentally. A visual inspection revealed that the most suitable filter is a Lee-sigma filter found in the radar interpretation area of Erdas Imagine. A Lee-sigma filter uses the statistical distribution of the digital number (DN) values in the moving window to estimate what the pixel of interest should be. Speckle in imaging radar can be mathematically modelled as a multiplicative noise with a mean of 1 (Erdas Imagine Geospatial Imaging 2009). Applied with a coefficient variance of not more than 5, noise was removed rendering the model to be applicable to the image. The creation of the model is shown graphically in Figure 3.5.
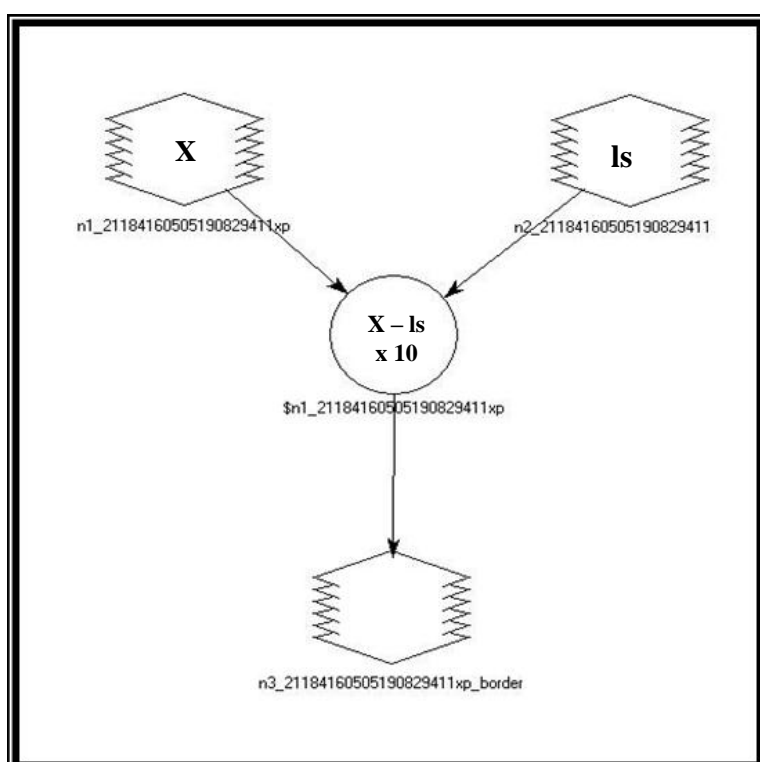
Figure 3.5 Model to obtain border of image

With a filter applied to the image, the border can be extracted from it by means of model maker in Erdas Imagine. As shown in Figure 3.5, there are two input parameters {X} and {ls}. The first input is the original image and the second the image the Lee-sigma filter was applied to. The function in the model is the Lee-sigma filter (ls) image subtracted from the original image and then multiplied by 10 (De Kok & Wezyk 2005). The output is an image from which edges have been extracted and the surrounding areas darkened so that there is a stark contrast between the two, enabling the edges to be seen very clearly. The result, illustrated in Figure 3.6, shows borders that have been extracted successfully. The borders of the orchards are clearly defined as well as the lines of the road.
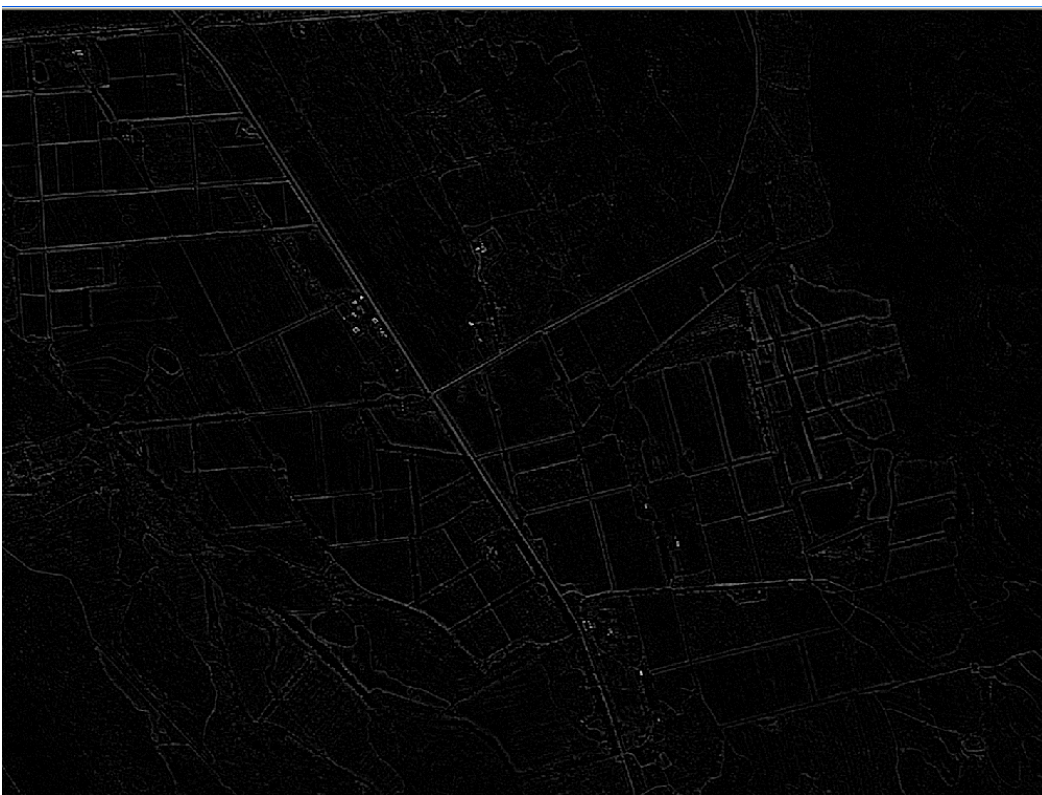
Figure 3.6 Result of border extraction for classification

The extraction of frame will be the continuing step from generating the border layer and is discussed below.

3.3.3 Frame extraction

The second phase of extracting boundary lines is to calculate frame. Frame is the inverse of border and thus the values of the pixels are offset outside the boundary lines of border. That is, the values are the opposite of border where, for example if the value of a pixel lying on the edge of a feature in the border image is 1 (an edge, i.e. white) and another pixel is 5 (no edge, i.e. black), the image containing frame will have the inverse, thus value 1 = 5 will show the value 5 = 1.

The first step to achieving frame is to invert the histogram of the image in Erdas Imagine's model maker. As seen in Figure 3.7A, the input is the original image X. The function is to multiply X by (-1) (De Kok & Wezyk 2005). The procedure multiplies all image values by -1 and inverts the image's histogram to a negative. Inverting the histogram of the image creates the first step needed to calculate frame. Following the inversion process, the Lee-sigma filter can be applied to the image again, but this time it is done on the negative image created and not on the original image as done in border extraction. Again, the coefficient of variance must exceed five.

A   **B**
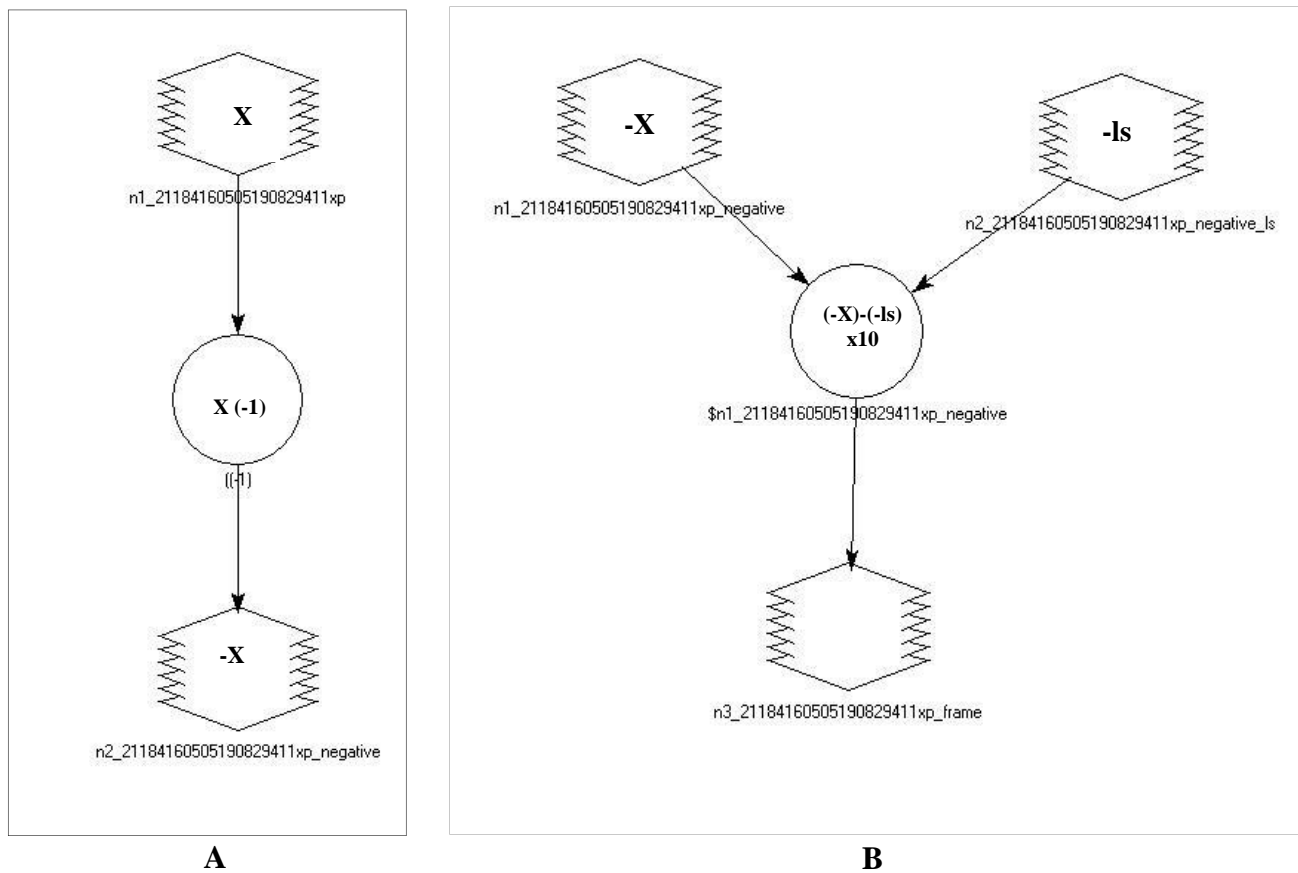
Figure 3.7 Inverting histogram model (A) and model to obtain frame (B)

When the filter has been applied to the negative image, it can then be applied in the same model used for border extraction. In Figure 3.7B the original image is the negatively derived image and the .ls image is the negative image that has had the Lee-sigma filter applied to it. The resulting image is the inverse of border. Figure 3.8 displays the edges that are now the inverse of border. A comparative analysis of Figures 3.6 and 3.8 show that the edges are the opposite. Where the edges in the border image are highlighted white and lie *within* the feature boundary, the edges of the frame image are highlighted in white *outside* the feature boundary. During the segmentation process in

eCognition, the parameters can be set to segment only the border and frame layers to ensure optimum extraction of features.
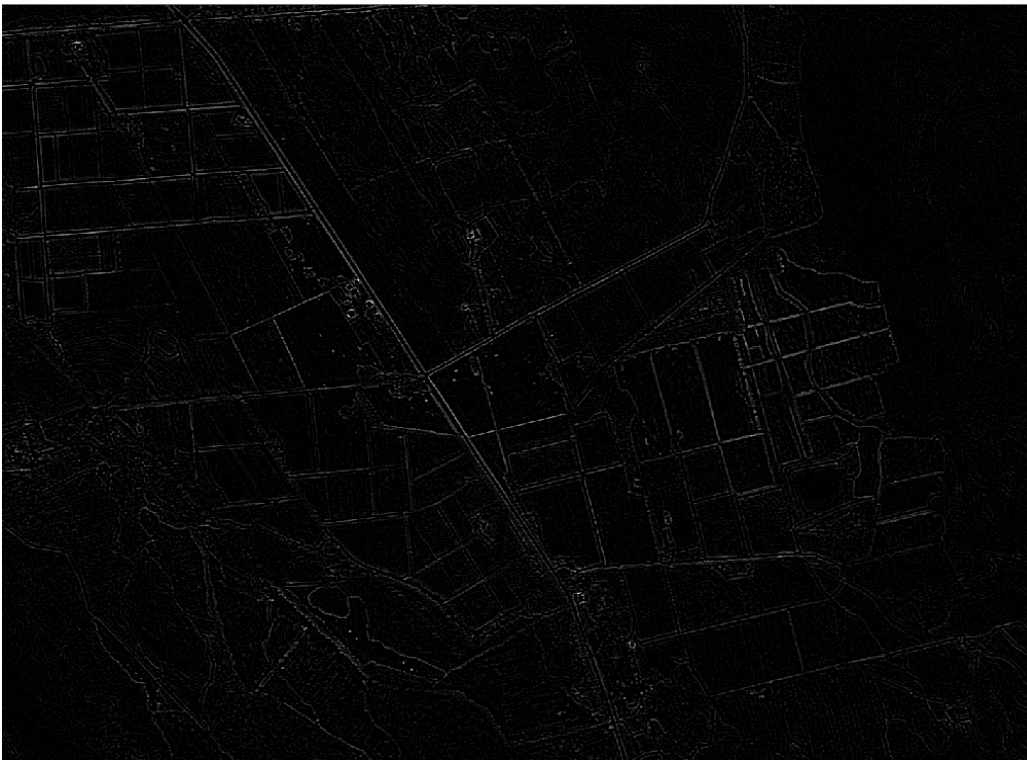
Figure 3.8 Result of frame extraction for classification

The border and frame layers are two very important elements used to determine the fine edge boundary lines of certain features. Proceeding from the border and frame extraction is the generation of an NDVI layer from the multispectral band of the SPOT 5 image.

3.3.4   Calculating NDVI

The normalised differentiation vegetation index (NDVI) is a measure of plant vigour in an image. Typically, an area that is irrigated or has high water availability will show plants that are growing and therefore photosynthesising. Using NDVI as an additional layer in the classification will assist in segmenting and later classifying plant groups from either agricultural fields or natural areas.
The NDVI is calculated as follows:

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

RED   Red band
NIR   Near-infrared band

This equation is sourced from Carlson & Ripley (1996). NDVI correlates with photosynthetic activity of vegetation and provides an indication of the "greenness" of the vegetation (Defries, Hansen & Townsend 1995). Image values where the vegetation is dense have positive values, whereas areas with less dense vegetation or bare sand or soil show negative values. Assisting with linear features, which include roads, railways and canals as well as other structures such as centre-pivot irrigated agriculture, digitised vector layers are used. The additional raster layers are included in the discussion below.

3.4 ANCILLARY VECTOR AND RASTER DATA

Ancillary data forms part of the additional layers used in the classification to improve the overall accuracy. Vector data includes shapefiles that can be used as additional information to assist the classification or used on their own in the segmentation. The vector layers include points, lines and polygons. Raster datasets in the form of aerially remote-sensed imagery is used as a visual tool to assist in the classification. The nature of vector and then raster layers are sketched below.

To ensure that all features in an image are extracted, there may be a need in some instances for additional vector information in the form of shapefiles. Since objects having the same spectral, textural and shape characteristics are grouped into objects, it is possible for some objects to be grouped incorrectly and consequently be classified incorrectly. In very-high resolutions (VHR) of one meter or less, road extraction by segmentation is an easier process since the features are clearly distinguishable from the surrounding areas. Correct grouping of edges by an autonomous process is difficult, although not impossible (De Kok, Wezyk & Weidenbach 2008). SPOT 5 imagery has a spectral resolution of 2.5 m so there will be some instances where the software cannot for example distinguish a dirt road from a fallow field next to it. Therefore a requirement for successful model application is to use shapefiles that can be segmented to ensure that certain features are classified separately. These features include canals, rivers, roads, railways and centre-pivot irrigation circles. Many centre-pivot irrigation circles are periodically left fallow in a systematic programme of shifting cultivation so that the spectral difference between these circular areas and the surrounding land is difficult for the eCognition segmentation process to recognise. Such pivots must nonetheless be classified as centre-pivot irrigation circles since they will be ploughed again in the future. Calculating the border and frame layers did result in some circle edges being distinguished, although not all the edges were shown. A process of digitising each circle into a shapefile will ensure that every centre-pivot irrigation circle is classified.

Raster data is required for further visual checking to assist in distinguishing features that may be too small to see on a 2.5 m SPOT 5 image. The ancillary imagery is the DWAF aerial photography. Although the 2003 aerial photography is unsuitable for the classification model, the imagery has a higher resolution than SPOT 5 and will aid in classifying features that are difficult to distinguish.

3.5   PROCESSING INFRASTRUCTURE

eCognition places high demands on the processing power of an operating system such as Windows. Processing power requirements are largely dependent on the size of the dataset in the classification. The computational requirement is a large amount of RAM – a minimum of 4GB with 8GB being optimal. Since the process takes considerable time, there must be available memory to ensure that the software's process can run independently. A central processing unit (CPU) of 3.00GHz and the latest processor available will ensure that maximum processing power is available. In preliminary attempts to classify the imagery in eCognition, the computer regularly failed to process the large amounts of data due to memory failures. To prevent a system overload and failure of the software to process large quantities of information in the form of large-size imagery, the sizes of files had to be reduced each time a process was run. Tiling is a process whereby the entire area is separated into squares of equal pixel size allowing each tile to be run independently of the overall image. The details and method for creating tiles and details about them are discussed in Chapter 4.

No project can progress smoothly without proper preparations. The foundations have been laid through the pre-processing steps in Chapter 3 and can be used in the proceeding classification steps. The processing platform moves from PCI Geomatica and Erdas Imagine to eCognition for the duration of Chapter 4.

CHAPTER 4: THE CLASSIFICATION MODEL

Chapter 3 has explained the steps required to prepare all imagery and data for the classification process. As explained, without thorough preparations of the imagery, the classification steps cannot proceed efficiently. The various steps that will be described in this chapter constitute a semi-automated model classifying the north-west Sandveld's land cover. Through the course of Chapter 4, the steps required to produce a classification are laid out. The process tree runs from defining the classes required in the classification through to each procedure required in eCognition.

4.1   CREATING A WORKSPACE

The first step when starting the classification is to create the workspace, which is a container for projects saved as an eCognition .dpj file. Figure 4.1 shows the workspace project open with the entire study area on the right and the individual tiles on the left.
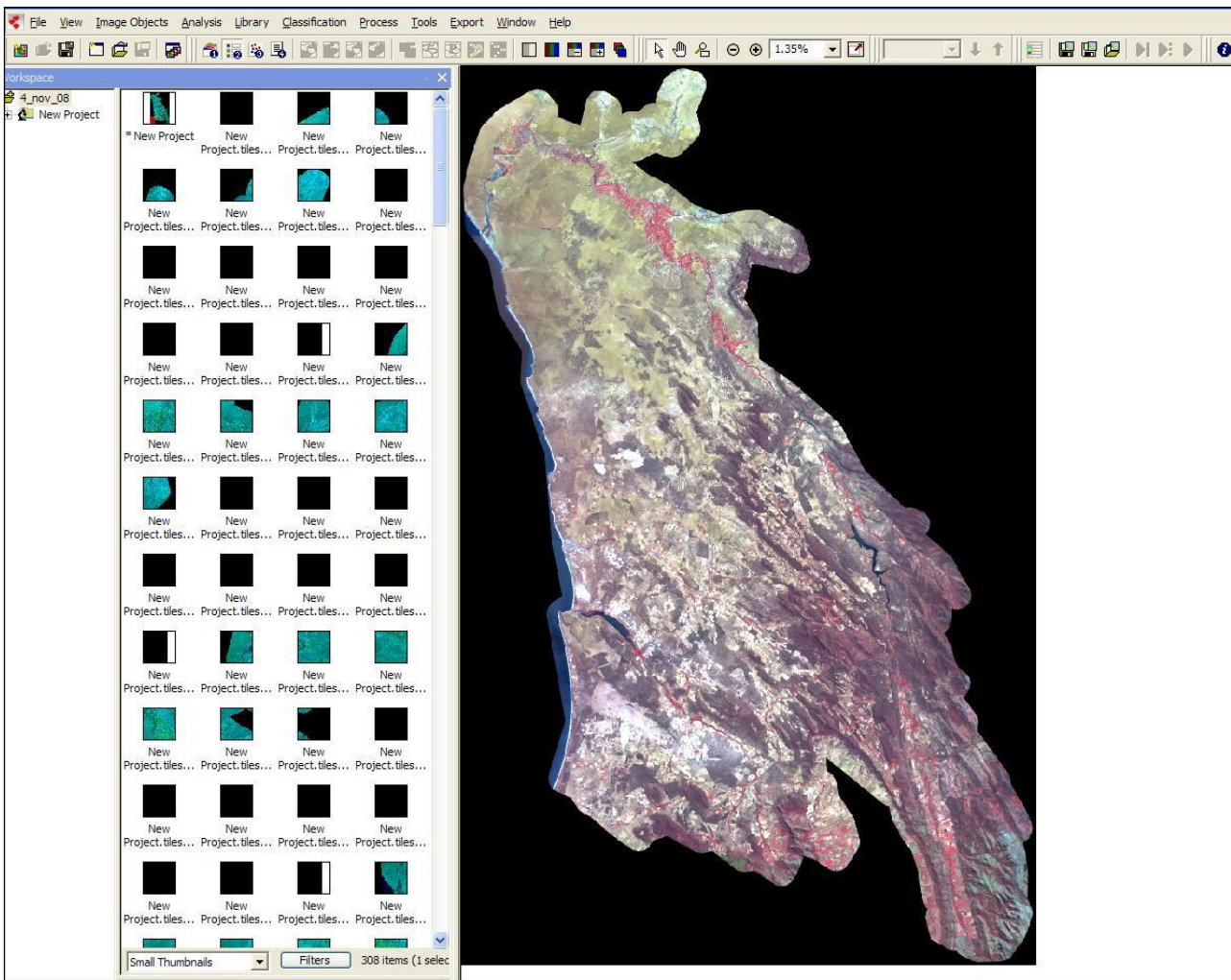
Figure 4.1 Workspace showing individual tiles

eCognition divides the area evenly into tiles of dimensions specified. i.e. 3000 x 3000 pixels. Some tiles do not have any landmass to classify (black areas) and can be deleted. The workspace ensures that the study area is broken into segments or tiles small enough to process. Image size is theoretically limited to 2^{62} pixels (Definiens Imaging, GmbH 2004) or 3000 by 3000 pixels. The processing power required by eCognition is significant and the software allocates a related temporary folder in which to deposit files used in the processing steps. It is important to ensure that there is sufficient amount of computer memory/disk space in the drive that has been allocated. A rule of thumb is that in a state of maximal complexity one pixel needs eight bytes of disk space (Definiens Imaging GmbH 2004). A workspace bundles references to image data, project, exported result values and the used rule-set. Furthermore, it includes the import and export templates, result statuses and metadata (Definiens Imaging GmbH 2008). No additional datasets have been added. To conduct the segmentation, the additional information needs to be added into the project.

Before any other classification steps can proceed, the class names and definitions need to be described. Section 4.2 will set out to define the land cover classes. The project can then progress to rest of the model's required stages.

4.2 LAND COVER CLASS DEFINITIONS

Before classification can commence, land cover classes have to be defined. The land cover classes are based on those set out in Section 2.6 and defined by Thompson (1996). Table 4.1 lists the classes set for this study, and provides definitions that characterise them. The classes have been divided into Level I and Level III divisions, as formulated by Thompson (1996). These two classes are noteworthy. First the 'natural vegetation' super-class has been divided into three Level III subclasses to ensure there is a representative of all vegetation categories in the Sandveld area. Second, the 'agriculture' super-class is divided into four Level III subclasses to a range of cultivation practises typical of Sandveld agriculture. The focus of the study is to determine the landscape effects of agriculture in the north-west Sandveld, since it is this class that has had and remains to have the most significant impacts in the area. Open-cast mining and quarries do pose threats in the northern section but their impacts are small compared to those of agriculture. The 'burnt area' subclass has been added to the barren land class to show that it is possible to include such special classes.

Table 4.1 Classes used in the classification of the Sandveld's land cover and their definitions

Level I	Level III	Definition
Natural vegetation	High fynbos	Fynbos 2-5 m in height. Dense cover. Typically in areas with little to no disturbance from human activities. Can include alien species.
	Medium fynbos	High fynbos showing some signs of degradation through grazing or water abstraction. Typically in areas with high levels of human activity. Can include alien species.
	Low fynbos	Small leaved low height plants including low density Karoo-type vegetation. Heavily degraded or overgrazed areas that still show low-density vegetation. Can include alien species.
Water bodies	Water	All water bodies, natural and man-made excluding rivers and canals.
	Rivers	All primary and secondary rivers.
	Canals	All digitised canal routes.
	Wetland	Natural or artificial areas where the water level is at/near the land surface on a permanent or temporary basis.
Barren land	Bare rock/soil	Natural areas of exposed sand, soil or rock with no/little vegetation cover. Includes open-cast mines, quarries, dunes, beaches, salt plains.
	Burnt area	Any area that has been subject to fire
Agriculture	Permanent crops	Cultivated crops that are not replanted after harvest. Irrigated/non-irrigated: includes vineyards, citrus orchards and tomato vines.
	Temporary irrigated crops	Irrigated crops. Includes centre-pivot irrigated circles.
	Temporary non-irrigated – plain	Rain-fed crops grown in a plain-like structure. No strips/wind breaks between rows. Includes wheat and other rain-fed grains.
	Temporary non-irrigated – strip	Rain-fed crops grown in strip-like structure with natural/planted windbreaks. Includes Rooibos and rain-fed grains.
Urban, transport, utilities	Urban/built-up	Any man-made structure. Includes urban areas, houses, rail stations, barns or any structure not natural.
	Roads	All main and secondary roads. Excludes rows between vineyards/orchards.
	Railways	All railway lines.

4.3   MODIFYING THE PROJECT

Once the workspace has been created and defined, all additional layers can be added into the project. Figure 4.2 shows the 'Modify Project' dialogue used to insert the additional layers into the project. There are two separate sections in the dialogue into which all information needed for the project is inserted. The first being the 'Image Layer' box seen far left in Figure 4.2. All raster information is included here, namely the image layers, the NDVI layer, the border layer and the frame layer. The additional information needed, known as thematic layers, are added lower down in the 'Thematic Layer' box. These are additional layers added to a scene that is related to the image content (Definiens Imaging GmbH 2004). The thematic layers added are the vector information, namely the roads, railways, canals and the centre-pivot shapefile layers. The image layers and thematic layers can be added and removed when necessary depending on whether they are needed in the classification or not.
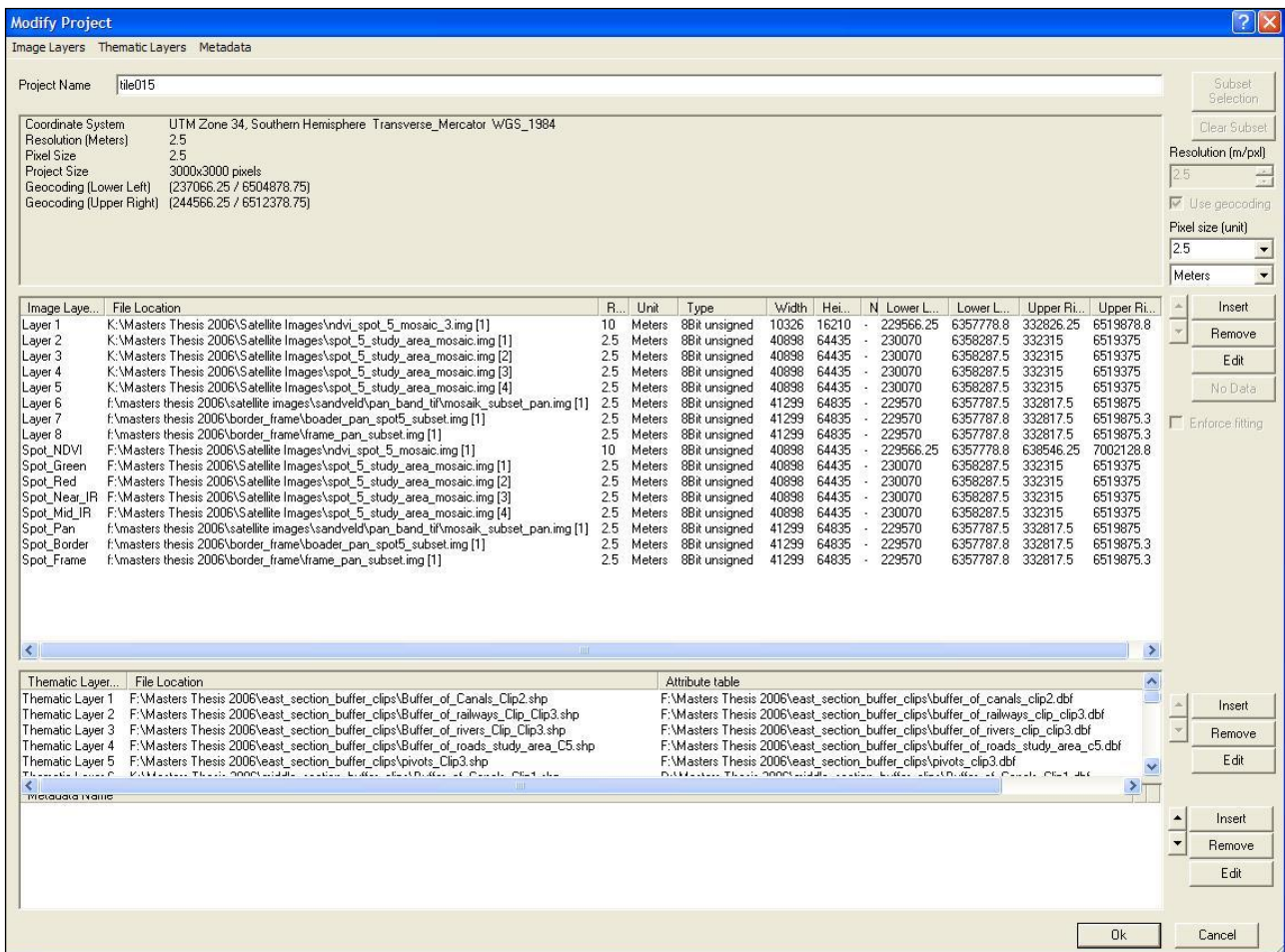
Figure 4.2 Loading the data into eCognition using the 'Modify Image' dialogue.

If the segmentation layers are used during the segmentation process, the segmentation will automatically create objects from the thematic layers and will continue to segment objects falling

within these layer boundaries. Before the classification can go on, alias names for all layers must be given and are communicated in Section 4.4.

4.4   ALLOCATING AN ALIAS

Before the multiresolution segmentation can proceed, image layer aliases must be defined. An image layer alias is the name assigned to a layer used in the project that is compatible with all rule-sets applied to that particular project. The names assigned to each layer are used in the rule-base that is adopted. The 'Manage Aliases for Layers' box is shown in Figure 4.3.
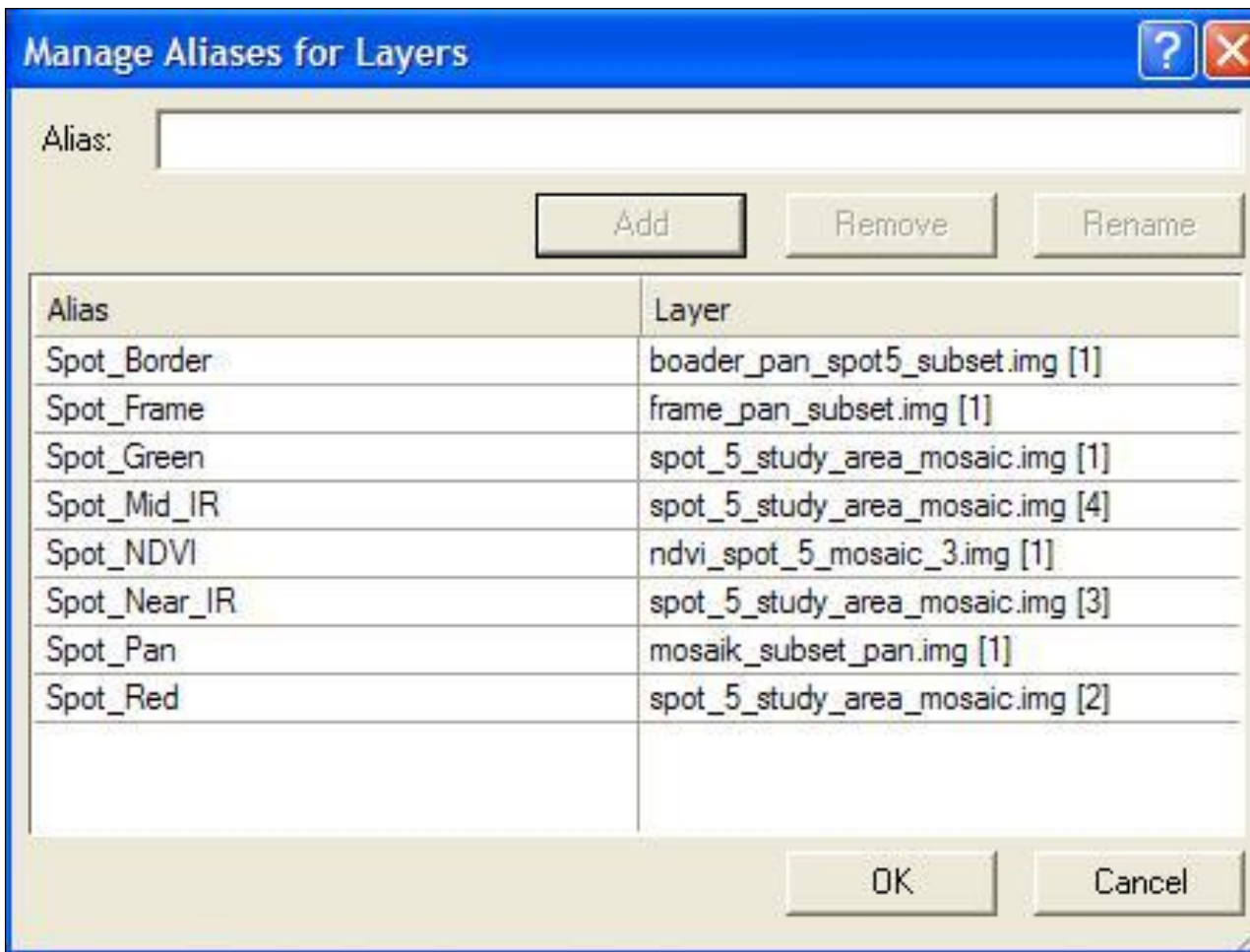
Figure 4.3 Image layer alias dialogue

The names of the layers can be complicated and often it is difficult to determine what the layer is. For example, as shown in Figure 4.3 'Spot_5_study_area_mosaic_img [1]' has been given the alias 'Spot_Green'. The dialogue creates an easier way of determining what each layer represents. The names of the layer aliases are listed in Table 4.2.

Table 4.2 Description of alias names of data used in the classification

Layer	Description
spot_green	SPOT 5 Green Band - band 1
spot_red	SPOT 5 Red Band - band 2
spot_nir	SPOT 5 Near IR - band 3
spot_swir	SPOT 5 Short Wave IR - band4
spot_pan	SPOT 5 Pan band
spot_border	SPOT 5 Pan band border extracted
spot_frame	SPOT 5 Pan band frame extracted
spot_NDVI	SPOT 5 Derived NDVI

Once all the required data has been loaded into the software, the multiresolution segmentation step can be undertaken. Care must be taken that all required data has been loaded before the segmentation process begins since this is one of the more time-consuming steps. The requirements for the actual classification of all classes are explained systematically in Section 4.5.

4.5   THE CLASSIFICATION PROCESS TREE

The process tree is the defining tool used in eCognition that classify the image semi-automatically. The process tree means that the user does not have to be involved in the classification process at every step since each is done automatically. A process tree consists of all the steps that a user would normally do in chronological order and is the control panel of the entire classification process. All steps are included from classifying image objects through to exporting the results. A user can, at any point, stop the process or let the entire process tree run its course. Figure 4.4 shows the steps in a protocol dialogue. Every project will have a different order of steps taken. Figure 4.4 shows the steps taken for one tile for the Sandveld classification. Since the steps are in chronological order, the first step will be the multiresolution segmentation. Following the segmentation process, the thematic layers are classified. Continuing from the thematic layers, other classes are classified. The protocol steps can amount to thousands of rules but each one can be applied individually or automatically without any intervention from the user.
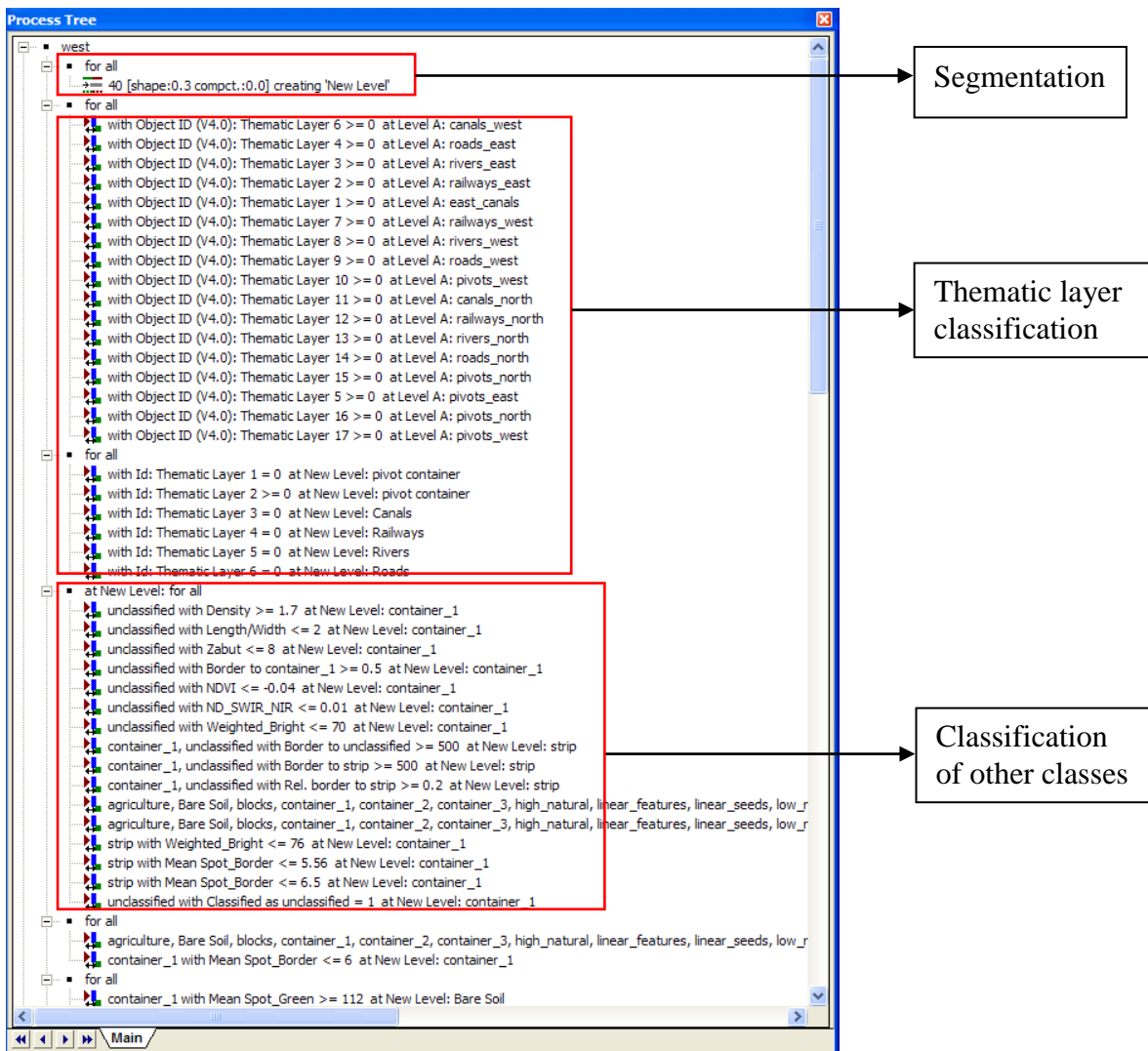
Figure 4.4 Process tree showing rules and procedures for the classification

The classification process tree can operate independently for each tile in the workspace or it can be run over the entire dataset for all tiles. The first procedure that must be placed in the process tree is the multiresolution segmentation whose concepts are explained below.

4.6   MULTIRESOLUTION SEGMENTATION

The backbone of object-oriented image analysis is the image objects derived from the multiresolution segmentation. In the segmentation process, a meaningful statistic is calculated for each object in an increased uncorrelated feature space using shape, texture and topological features (Benz et al 2004; Syed, Dare & Jones 2005). For this reason, the first step in eCognition is always to extract image object primitives, which become the building blocks for subsequent classifications (Definiens Imaging GmbH 2004). Multiresolution implies the ability to segment the same image at varying resolutions (Definiens Imaging GmbH 2004). The resolutions are the objects created at each level ranging from the smallest objects to the largest objects. Figure 4.5 shows the multiresolution parameters required before the segmentation can begin. There are three main

sections of the 'Algorithm Parameters', namely, 'Level Settings', 'Segmentation Settings' and 'Composition of Homogeneity Criterion'. Each is discussed separately below.

4.6.1 Level settings

The level settings allow the user to determine at which level the segmentation in question must lie, that is whether the layer must be placed at a first, second or third level, which will create the super- and sub-objects for any layer above or below each one. The levels are given a name such as Level A, B and C as shown in the example in Figure 4.5.
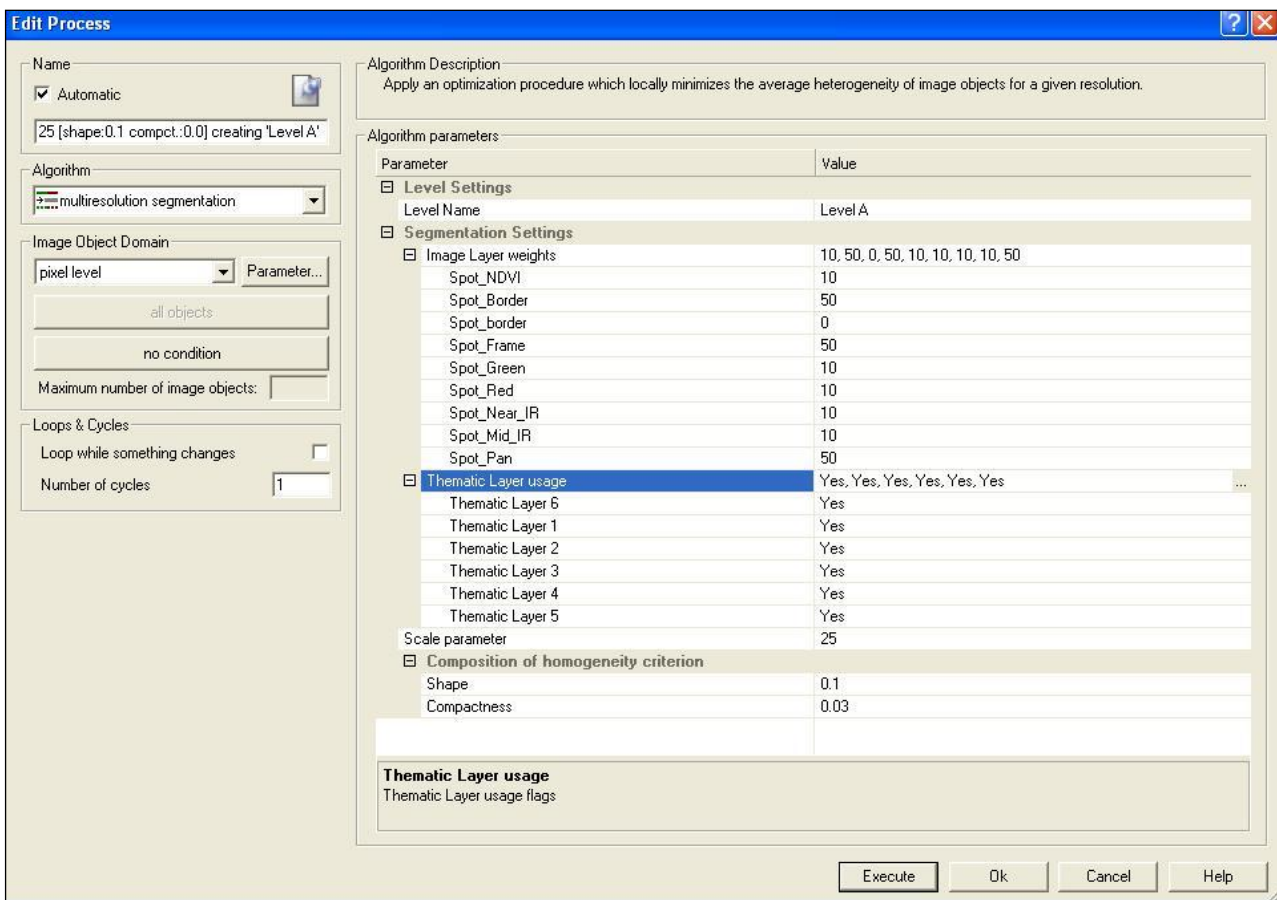
Figure 4.5 Multiresolution segmentation parameters

The parameters for the segmentation need to be set to ensure that the object size will encompass the required classes. The parameters are outlines below.

4.6.2 Segmentation settings

In the segmentation settings section, the weight value of each layer determines how much emphasis is placed on that particular layer during the segmentation. In Figure 4.5 one can see the layer weights assigned, for example Spot_NDVI has been assigned a weight of 10 and below that, Spot_Border has been given 50. Consequently, the multiresolution segmentation will place more

emphasis on the border layer than on the NDVI layer. In this example, the segmentation ensures that all edges are defined as clearly as possible, so that the border and frame layers have been given the highest weights (50) while the rest of the layers are given a weight value of 10.

Below the 'Image Layers Weights' is the 'Thematic Layer usage' section. The options are only 'Yes' or 'No'. The thematic layers in Figure 4.5 have all been assigned 'Yes' in the segmentation and therefore will be used.

'Scale Parameter' is the last option in the segmentation settings section. Scale parameter is an important parameter of the multiresolution segmentation algorithm and it is used to determine the upper limit for a permitted change of heterogeneity throughout the segmentation process. The scale parameter determines the average size of image objects with a higher scale parameter creating larger objects and a lower one creating smaller objects (Definiens Imaging GmbH 2008).

4.6.3   Composition of homogeneity criterion

The last element in Figure 4.5 comprises of the shape and compactness criteria, which form the basis of homogeneity. The composition of homogeneity criterion is calculated as a combination of colour and shape properties of both the initial and the resulting image objects of the intended merging. Here the colour homogeneity is based on the standard deviation of the spectral colours. The shape homogeneity is based on the deviation of a compact or a smooth shape from objects (Definiens Imaging GmbH 2004).

Both of these criteria are weighted according to the requirements of the classification or how important that particular factor is when pixels are grouped. If one is classifying an area where there are numerous vineyards and orchards, the shape criterion will be very important since features such as these are usually square in shape. Compactness is defined by eCognition as the ratio of the area of a polygon to the area of a circle with the same perimeter (Definiens Imaging GmbH 2004).

The objects resulting from the segmentation process are shown in Figure 4.6 with (A) being the image before segmentation and (B) the image after the segmentation process. Upon visual inspection of the unsegmented image, the groups of pixels are clearly visible. The human eye will automatically distinguish features that are different colours and shapes. As posited in Section 2.7.1 the segmentation process 'thinks' the same way and automatically groups pixels that are distinctly similar.

A   **B**
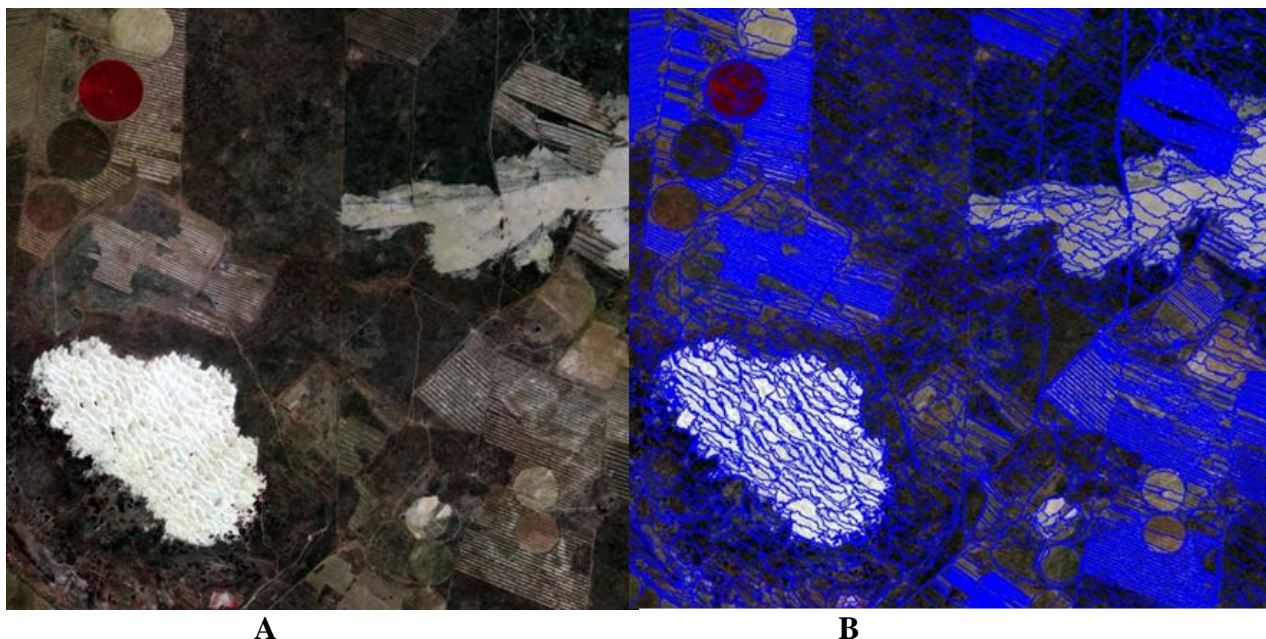
Figure 4.6 Segmentation results showing before (A) and after (B) the segmentation process

The segmentation is based on a nearest neighbour re-sampling method by which pixels are selected and adjacent similar pixels are aggregated into segments as long as the heterogeneity in the spectral and spatial domains is minimized (Benz & Schreier 2001). Region-growing algorithms cluster pixels starting with seed points that grow into regions until a certain threshold is reached (Blaschke et al. 2000). If a pixel can no longer fit into the same criteria as those neighbouring it, it will start a new seed and ultimately a new object is formed. Once all criteria have been weighted, the segmentation process can commence. The segmentation process may take a significant amount of time depending on the size of the image being classified.

4.7   CUSTOMISED FEATURES

One of the steps in the creation of suitable rules is the development of customised features within the eCognition platform using the features available. Customised features allow the user to create new features adapted to the user's needs (Definiens Imaging GmbH 2008). The customised features are derived from the features available in the 'Feature View', as seen in Figure 4.7. These existing features, variables and constants are combined via arithmetic operations (Definiens Imaging GmbH 2008). In the 'Managing Customised Features' dialogue, one adds certain features, which link to the 'Edit Customized Features' dialogue. In the dialogue, one is able to use the available features and combine them to create rules that can be used to isolate certain classes. For example in Figure 4.7 the highlighted customised feature has been named Pan_BF meaning it is a combination of using the SPOT 5 pan band with the calculated border and frame layers (BF). In the 'Edit Customized Feature' dialogue the combination involves dividing the pan band with the sum of the border and frame layers. When the rule is applied to a tile, only the pan band and its association

with the border and frame layers are considered. When applying the newly-created rule in the feature view, the objects falling within the specified range of the Pan_BF feature will be highlighted. Using the more specialised rules, certain classes can be drawn out where the features required are more focused.
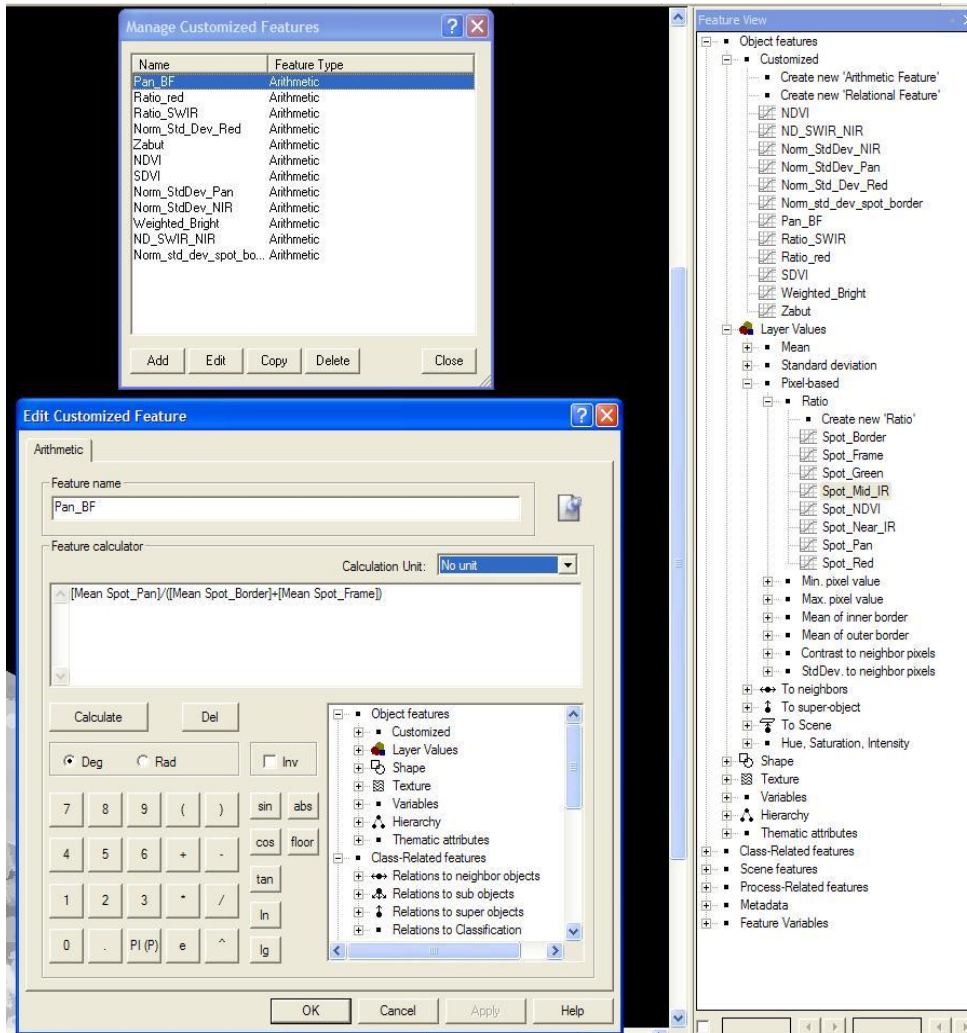
Figure 4.7 Customised features used in eCognition

Each area in a classification has different features that need to be classified so that there are different customised features that dominate in each section. The full list of customised features appears in Table A1 of Appendix A. The customised features allow a more specific classification to be used in conjunction with the pre-defined rules already in eCogntion.

4.8   FEATURE VIEW

The characteristics of each object can be defined in the eCognition platform in numerous ways. One cannot apply every single option, rather find the method that best suits a particular project and apply it. For the Sandveld exercise the methodology uses the concept of *exclusion* as discussed in

Section 2.7.1. eCognition can also apply the fuzzy classification principle where instead of the typical true and false logic, the system works on a more multivalued approach of [0….1], where 0 means false and 1 means true, and everything in between represents a transition between true and false (Benz et al. 2004).

To start the process of determining which rules are best for each class the 'Feature View' application is used. eCognition applies image recognition in the same way the human eye does. In looking at Figure 4.8 the human eye automatically recognises areas of varying scales of grey to white. We do not quantify the image in numbers according to their grey scale. Additionally, to the human eye this is nothing more than a grey-and-white image. eCognition has ability to relate the numerical values based on the feature being observed in a graphical way for the human eye to understand. There are hundreds of rules that can be applied to an image to classify classes. If brightness is considered and used in the feature view dialogue, eCognition will display an image according to each object's brightness values. Each scale of grey to white thus has a value. One can select a range, using the exclusion principle to determine objects that have the same brightness value range using the 'Feature View' option. The classification will classify all image objects residing within this range.
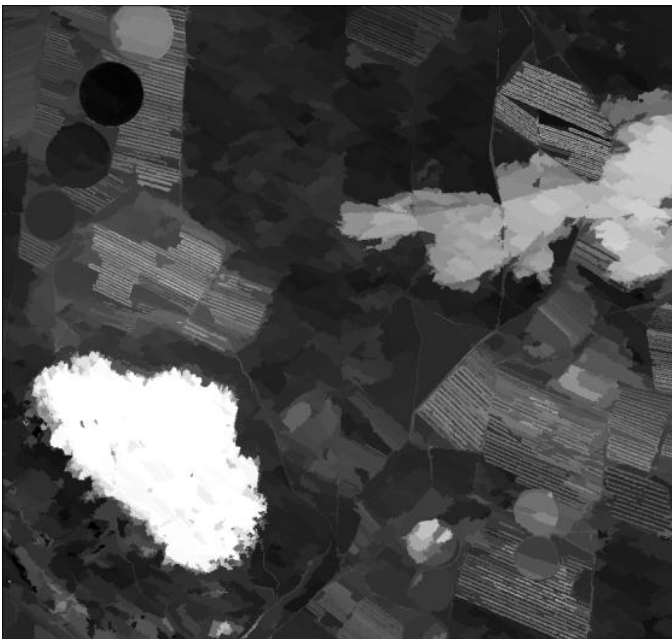
Figure 4.8 eCognition's feature view applied to a tile

The process is continuous and objects are "thrown out" of a particular class' classification should they fall within a specified range. A class can be created called *Container One* for example. It is not assigned an official class name as it is used as a base container from which classes are derived. Every time a rule excludes a class from *Container One* it is assigned a class or left out of that

classification stage. What remains is any feature that could not fit into any class according to the features selected. To best understand the steps taken in applying an exclusion principle, a step-by-step process is shown below in Figure 4.9.
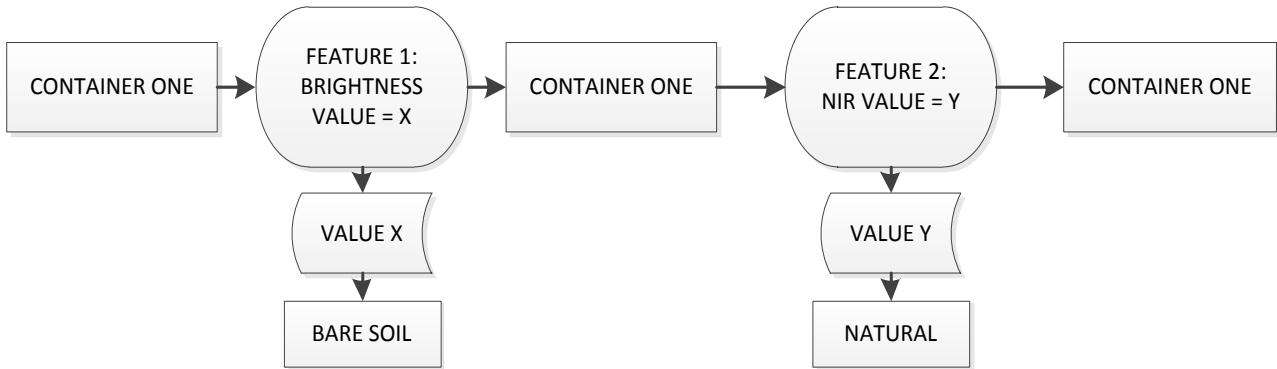
Figure 4.9 Exclusion process to derive classes

Following segmentation, the succeeding step is to use the feature view to test for a particular feature one would like to have distinguished. In Figure 4.9 the feature brightness is used. If the value is *x* the feature is bare soil, and if the feature value is anything other than *x*, it remains in *Container One*. The process is repeated for the next feature, near-infrared (NIR) and the process continues until all classes have been classified. *Container One* will become an empty vessel no longer containing any objects to classify. In most cases it may take several exclusion rules to get to the final class needed to be classified.

Each step described above has been the foundations for the classification process on the Sandveld. The imagery was prepared by ensuring all edges were accentuated by the border and frame calculations. Edge detections form an integral part of the segmentation process since they enhance the creation of image objects. The NDVI image provides an additional layer to assist the classification as do the vector layers. Moving forward into eCognition the prepared layers were tiled and placed into a project. The tiles allow each project to be classified individually to not over extend the processing power of the computer. The steps required to conduct the multiresolution segmentation have been described. The departure point from here is to conduct the classification on the Sandveld for each regional sub-area.

4.9   THE THREE BROAD REGIONAL DIVISIONS

The study area has been divided into three broad sections, each encompassing a predominance of certain features. The subdivision was also done due to the size and variety of inland cover types in the study area. The divisions were created for the purpose of creating rule-sets that concentrate on

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classifying the dominant classes in each section. Since there are no distinct lines between areas of differing biodiversities, there is a 5 km overlap to account for the graduated change between each area. The differences in climate from north to south and terrain gradient from east to west mean that the vegetation and agriculture differ depending on the area visited. Information and insight gained from the initial workshops the author attended in the area, and from the initial exploration excursion through the study area, the author has identified how the study area should be divided. Figure 4.10 shows the division into the three areas used in the classification. The boundaries are not restrictive and classification rules do not have to be area-bound. They are considered a guide to use and to facilitate a sufficient separation for each rule-set.
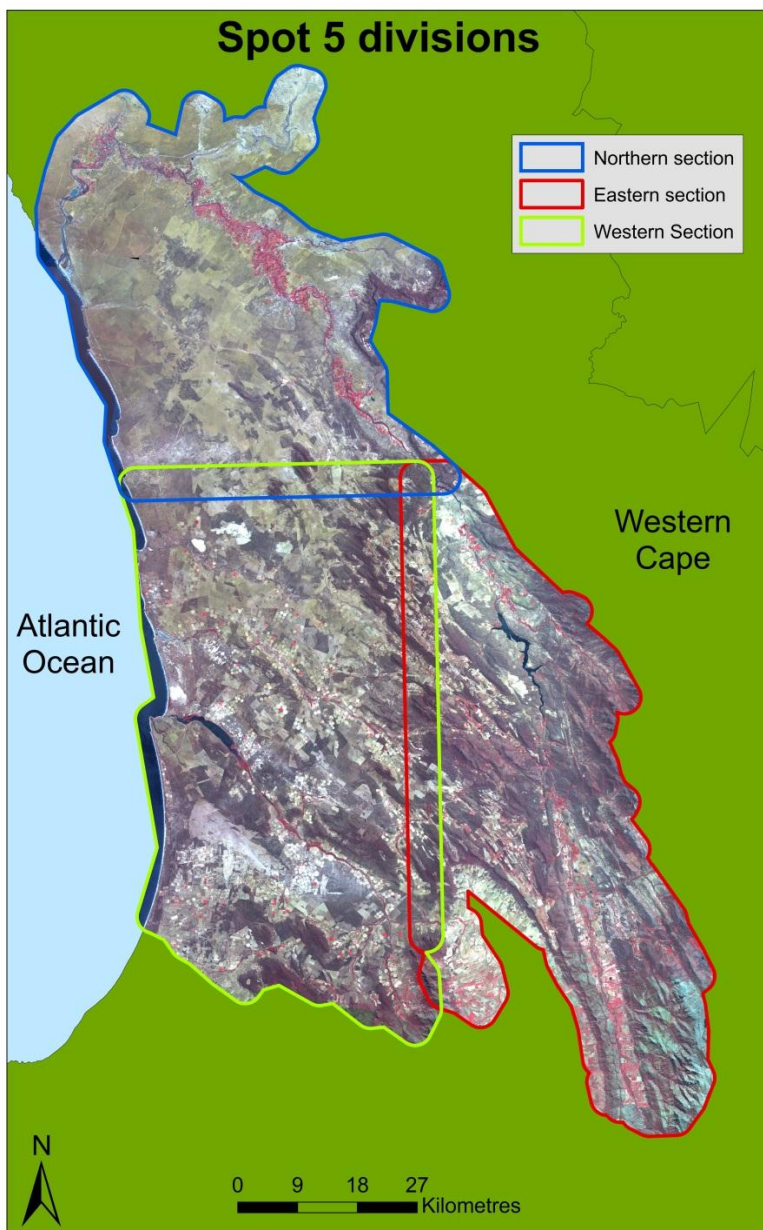
Figure 4.10 Study area showing the three broad divisions of the northern, eastern and western sections.

In the next three subsections the nature of the three areas is examined to provide an understanding of the landscape structure and how the rule-sets are developed in conformity with the features present in each area. The northern reaches ('Northern section' in Figure 4.10) primarily have Karoo-type vegetation and a predominance of bare rock, bare soil and vineyards along river banks. The area is heavily transformed (for grapevines and tomatoes) in the lower reaches of the Olifants River, but relatively intact elsewhere (Helme 2007). The west of the study area ('Western section' in Figure 4.10) is predominantly covered by coastal fynbos and the major environmental pressures are from agriculture (potatoes, rooibos and wheat), alien plant invasions, pine plantations and silica sand quarrying (Helme 2007). The eastern portion of the study area ('Eastern section' in Figure 4.10) mainly contains undisturbed natural areas that lie within mountainous regions, as well as orchard-type agriculture along river banks. The vegetation has hardly been transformed, mostly due to the mountainous terrain and occurrence within formal conservation areas. Small areas have been impacted by roads, gravel quarrying, protea farming and pine plantations (Helme 2007). These three subdivisions of the north-west Sandveld are dealt with separately in reporting the segmentation process.

To develop the correct steps and classification parameters for the generation of the model, sample areas from each of the three sections have been selected that best represent each one. These are discussed below in turn.

4.9.1   The northern section

In the northern section the Namaqualand Riviere (SANBI vegetation class along arid river valleys) typically has broad river valleys, with silty loams and patches of deep sand with outcropping bedrock in places. Deep red sands and loamy sands derived from the original Orange River mouth, run through the area (Helme 2007). The homogeneity of this area is somewhat greater than that of the western and eastern sections. The bulk of the northern section is covered by dry succulent Karoo vegetation that has significant spectral differences from the rest of the study area. Bounded in the east by the Bokkeveld escarpment, the plain consists of expanses of white quartz pebbles that cover the gently-rolling hills of the area, giving shelter to its unique dwarf plants (Critical Ecosystem Partnership Fund 2003). The area's natural vegetation is severely transformed (for cultivation of grapevines and tomatoes) in a narrow riverine band along the lower reaches of the Olifants River, but natural vegetation is relatively intact elsewhere (Helme 2007). Small-scale mining for gypsum, diamonds, limestone and marble, overgrazing and the illegal removal of rare and spectacular species for national and foreign plant collections are the greatest pressures on the northern section. Heavy grazing in certain areas may inhibit recruitment of indigenous seedlings (Helme 2007). To

the east is the Vanrynsdorp gannasbosveld comprising succulent Karoo vegetation. Erosion potential is high and the area is often overgrazed resulting in the destruction of biogenic crust and consequent erosion (Helme 2007). Along with the different agricultural types there are rural towns and agricultural farm dwellings. The rules have to separate the fabricated agricultural areas from the areas of exposed rock to the very north of the study area. Challenges for accurate classification exist where towns and bare rock are spectrally similar and liable to be classified in the same class. Table 4.3 shows the parameters set in the eCognition multiresolution-editing window for the northern section. The settings for the algorithm parameters have been discussed in Section 4.6. The values have been set for the level, segmentation and composition of homogeneity criterion settings and are discussed below.

Table 4.3 Classification parameters for the northern section

Algorithm parameters		Value
Segmentation settings		
	Spot_NDVI	10
	Spot_Border	50
	Spot_Frame	50
	Spot_Green	10
	Spot_Red	10
	Spot_Near_IR	10
	Spot_IR	10
	Spot_Pan	50
	Thematic layers (all)	Yes
	Scale Parameter	25
Composition of homogeneity criterion		
	Shape	0.1
	Compactness	0.03

Image layers can be weighted depending on their importance or suitability for the segmentation result (Definiens Imaging GmbH 2008). The vineyards present in the area mean that borders are important and therefore the border and frame layers have been assigned higher weights of 50 along with the pan layer since the 2.5 m resolution helps to detect edges clearly. The rest of the layers have been assigned a value of 10 since they will not have a strong influence on the segmentation.

The scale parameter analyses the homogeneity of the area and results in objects that are either larger or smaller. If the area consists primarily of the same landscape type, the scale parameter can be set high at a value of approximately 50-80. The scale parameter for the northern section has been set to 25 to optimise the creation of objects. The only way to determine the best possible scale parameter is by a series of experimental tests.

The shape and compactness criteria can be set in a range of 0.1 to 0.9. The compactness criterion is derived from the shape of the objects and determines whether they will be smooth or compact. The higher the value the more compact the images will be. For the northern section, this has been set to a shape of 0.1 and compactness of 0.03. Consequently, the image objects will be influenced largely by colour and they will be relatively small. One has no clear idea what values to select. The initial assumption of what values to choose depends on the features that need to be extracted.

The results for the multiresolution segmentation are shown in Figure 4.11 where the vineyards have been segmented very neatly, while the lighter non-irrigated areas have been segmented in accordance to the brightness of the other features occurring there. Areas of bare rock and urban settlements have been identified and placed into their own objects. The road, river and canal thematic layers have been segmented separately. The model had a good success rate in grouping pixels into the different spectral, textural and shape characteristics in the northern section.
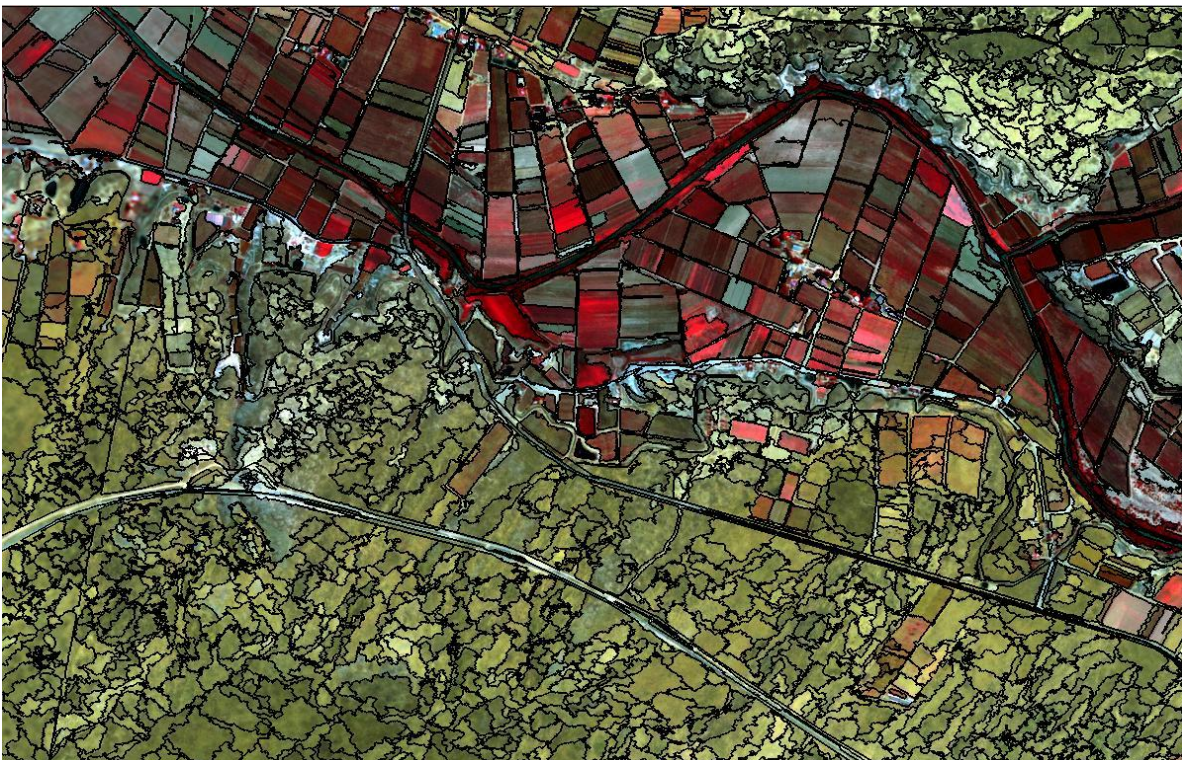
Figure 4.11 Segmentation of the northern section

Looking at the sample classification for the representative area in Figure 4.12, it is clear the classification was effective. The vineyard rows were included into the 'permanent agriculture' class since these form part of the structure of that type of class. The bare soil class which included bare rock areas were easily classified since they are spectrally very different from areas of natural vegetation. Riverbank areas, that comprise of sediment deposits carried from the Olifants River, were included in the bare soil class. In some instances, manual classification was needed to rectify any problems that may have occurred through misclassifications.

Figure 4.12 Classification result for the sample area of the northern section

The northern section sample showed a good contrast between the natural areas and the agricultural areas since most, if not all, agricultural practices are focussed on the banks of the Olifants River.

4.9.2   The western section

The western section is characterised by three types of agriculture, namely strip-structured, rain-fed and centre-pivot irrigated. The area is bounded by the coastline in the west and the base of the Cederberg in the east. The temporary rain-fed agriculture comprises grain farming of wheat and barley. The centre-pivot irrigated agriculture has some unique characteristics regarding its

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classification. The circles in which the crops are grown exhibit varying stages of cultivation. The fields are initially ploughed, then the crop grows and is finally harvested. The plough-to-harvest cycle can be performed many times until the circle is rested and left fallow for a period depending on the type of plant grown. During the fallow weeds and other vegetation grow over the circle. The spectral differences between these circles during the stages of their life cycle create a distinctive challenge to classifiers compared to other features. When a circle has been ploughed the bare soil will be easy to distinguish spectrally, however when left fallow for long, the differences between the vegetation surrounding the circle and the vegetation growing within the fallow circle can be very similar. The dynamics of the circle life cycle were observed during the field excursion done, as well as during the field workshops. To ensure that all circles are classified regardless of being fallow or not thematic layers must be used. Each circle is thus accounted for and in the segmentation process, the circles are shown and classified. Table 4.4 shows the multi resolution parameters set for the western section.

Table 4.4 Classification parameters for the western section

Algorithm parameters		Value
Segmentation settings		
	Spot_NDVI	50
	Spot_Border	50
	Spot_Frame	50
	Spot_Green	10
	Spot_Red	10
	Spot_Near_IR	10
	Spot_IR	10
	Spot_Pan	50
	Thematic layers (all)	Yes
	Scale parameter	40
Composition of homogeneity criterion		
	Shape	0.1
	Compactness	0.03

The two main features the segmentation must identify as clearly as possible are centre-pivot irrigated agriculture and strip cultivation. Since the pivots have been included as thematic layers, it

is only necessary to ensure that their thematic layers are included in the segmentation. The narrow strips that strip cultivation creates are texturally different and must be defined according to the density and compactness parameter. The border and frame layers have been given a weight of 50 owing to their importance. The pan band assists in extracting edges of the various features and giving the layer a weight of 50 ensures that the edges are detected optimally. The NDVI calculation, weighted at 50, is a useful tool to determine vegetation that either is irrigated or receives large amounts of water from natural sources, such as those being close to wetlands.

The scale parameter was set to 40 following experimentation. The strips present in the western section should be segmented as wholly as possible so that the thin strip objects are not broken up into separate pieces, hence the chosen scale parameter value. The homogeneity criterion has been set to the same as that for the northern section. This is to ensure that the shape of the area is kept a priority. The strips need to be segmented clearly for the classification to be as accurate as possible. Since the centre-pivot irrigated circles are segmented using a thematic layer, the criterion parameters do not need to be weighted to segment out the circles. The segmentation results are shown in Figure 4.13. The areas of strip-cultivated agriculture have been segmented with a clear division between the light and dark lines. The darker and lighter natural vegetated areas have been distinguished separately as well as the centre-pivot irrigated circles.
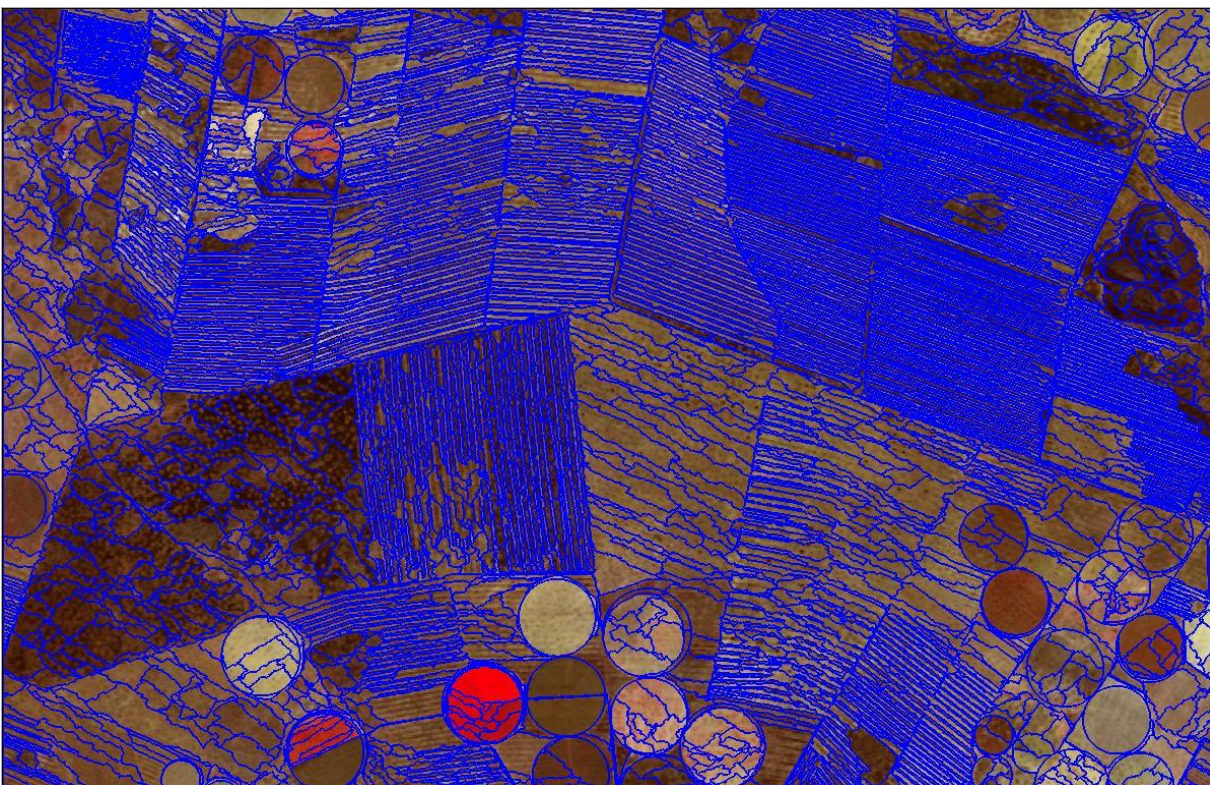
Figure 4.13 Segmentation result for the western section

The sample area must be as representative of the whole western section as possible to ensure all classes are classified. The western section of the north-west Sandveld is the most heterogeneous and therefore the most challenging to the classification. The inclusion of the thematic pivot vector layer allowed for all pivots to be classified accurately. Figure 4.14 shows the classification results with the centre-pivot irrigated circles satisfactorily classified so that calculations based on their area can be done. Temporary non-irrigated strip agriculture was classified extremely well due to the length and width of the objects. To combat any misclassifications, additional rules were set to eliminate a class according to its shape characteristics. Brightness was a key factor in eliminating the 'bare soil' class within strips along with a length/width ratio. A typical feature of the western section is salt pans or inland salt marshes and care must be taken that where encountered they are classified correctly.

Figure 4.14 Classification result for sample area of the western section.

It is expected that the western section will yield the most misclassifications because the landscape structure is so heterogeneous. Careful analysis of all classes in this area is essential to ensure minimal misclassifications.

4.9.3   The eastern section

The eastern section comprises mainly the Cederberg range as well as the rain-fed agriculture in the south east of the area. Consisting primarily of Table Mountain sandstone forming part of the Cape Fold Belt, the rocky texture and colour give the mountainous areas a distinct pattern for rule

development. The non-irrigated agriculture is mainly the cultivation of wheat, barley and other grains. This was discerned from field observations since very limited information is available about the agricultural practices in the area. Vegetation in the Cederberg is predominantly mountain fynbos (Helme 2007). In the valleys there is widespread orchard agriculture growing, principally citrus farming. Strip cultivation is interspersed along the mountain ranges. The topography of the area is undulating and the temporary non-irrigated strip agriculture is practised in strips that run along the contours of the mountain slopes, since rocky outcrops prevent the creation of square fields. At the foot of the mountains, the typical strip-cultivation structure is common.

Table 4.5 lists the algorithm parameters for the eastern section. The different types of agriculture mean that there is a variety of textural, shape and colour characteristics to be defined within the rule-base. Border, frame, NDVI and the pan band are weighted at 50. The remaining four layers are given a weighting of 10 each. All the thematic layers have been used for the classification. The bulk of the eastern section comprises the mountainous Cederberg range. If the scale parameter is set to any value lower than 50 many objects become superfluous. The optimal object creation to feature extraction ratio was determined as 50. The homogeneity criterion has remained the same for all sections and thus the eastern section has not changed. The criterion has ensured that all features are extracted for the classification process.

Table 4.5 Classification parameters for the eastern section

Algorithm parameters		Value
Segmentation settings		
	Spot_NDVI	50
	Spot_Border	50
	Spot_Frame	50
	Spot_Green	10
	Spot_Red	10
	Spot_Near_IR	10
	Spot_IR	10
	Spot_Pan	50
	Thematic Layers (ALL)	Yes
	Scale Parameter	50
Composition of homogeneity criterion		
	Shape	0.1
	Compactness	0.03

The final segmentation results are shown in Figure 4.15 where the combination of all parameters offers the best possible solution to the segmentation. Shadows formed a special challenge compared to the other areas. The thematic layers ensured that any of the linear features that meandered through the mountain valleys would be segmented and classified later. Shadows were segmented separately and this has to be taken into account in the classification.
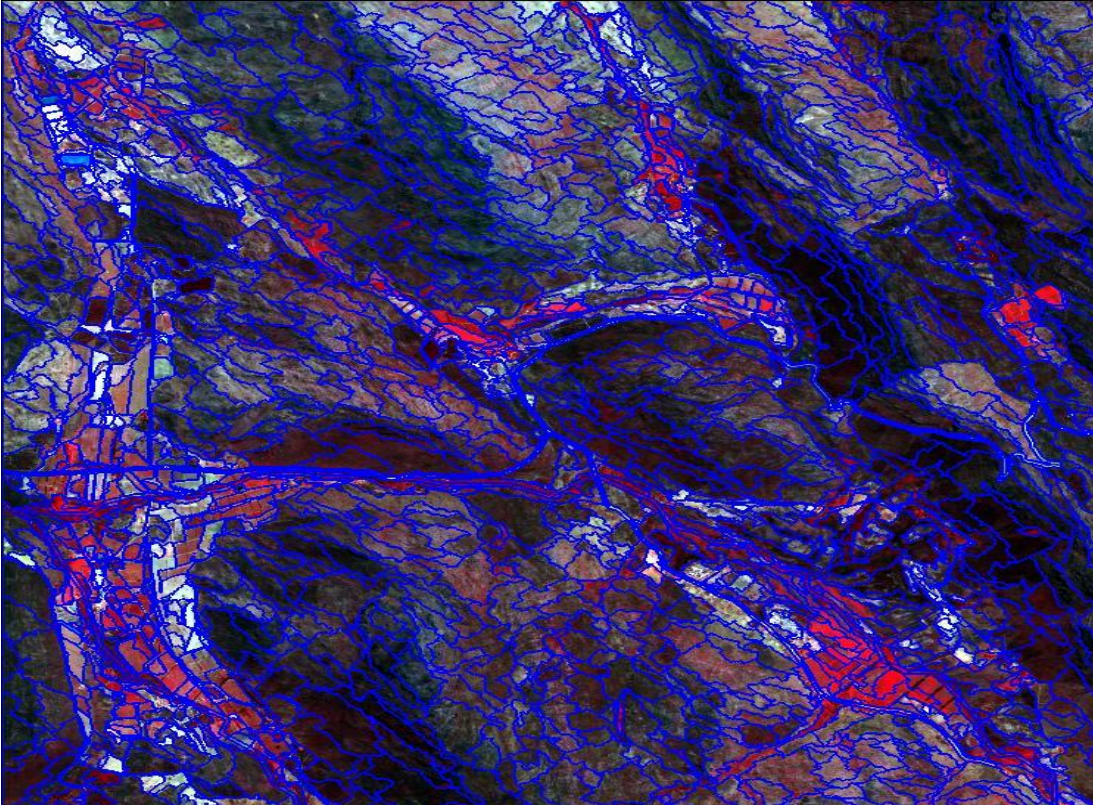
Figure 4.15 Segmentation results for the eastern section

The eastern section is structurally diverse, with perennial trees and shrubs, restios, annuals and bulbs. Succulents are relatively rare but alien vegetation is now a striking feature of the flood plains, with exogenous shrubs, grasses and trees being prominent (Helme 2007). The area has many types of agriculture existing together and often overlapping. Rooibos tea, being very common in the area is grown in open fields and not in distinct strips like that grown on the flatter and drier wind-prone western coastal areas. Figure 4.16 shows the classification results for the sample area of the eastern section. Using the green bands of the SPOT image as well as brightness and maximum difference, the various land cover areas were separated to a good degree. The orchard areas were classified easily since the NDVI calculations successfully distinguished the deep green citrus trees. The border criterion prevented misclassifications of densely-vegetated wetlands in river valleys into the permanent agriculture class due to the open rows between the orchard rows as well as their square shape. The areas most easily classified were the high natural and low natural classes.
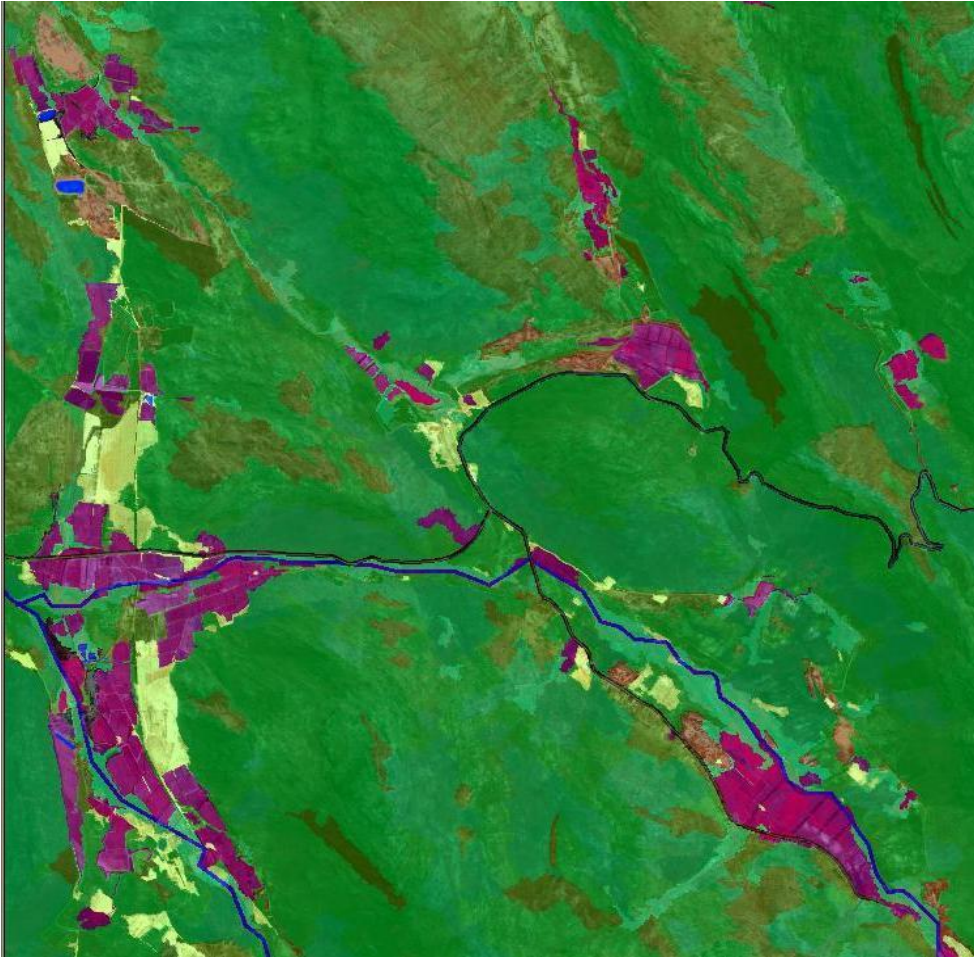
Figure 4.16 Classification result for the sample area of the eastern section

The steps in the classification process and their principles have been expounded. The rule-bases were developed and tested on single tiles representative of each general area. The rules developed must be applied to the entire study area. In some cases an area may constitute a mixture of two areas, for example it may contain features of the northern section and also features of the western section at the buffer zones. After visual inspection of the results the protocol was altered slightly to include certain features in the classification.

4.10   ASSESSMENT OF THE OVERALL CLASSIFICATION

The classification was done on the whole study area and each tile in the workspace has to be analysed to ensure that the classification was successful. A total of 186 tiles were classified, each with an extent of 3000 by 3000 pixels. In some instances objects were misclassified and had to be adjusted manually. Since field observations were undertaken and literature is available on the types of vegetation, the manual classification step was possible. For example, in areas where the distinction is clear but the object classified did not belong to the class the protocol assigned, rectification was done based on human sight. Objects can belong to more than one class given that the characteristics can be similar in many respects. In this regard Benz & Schreier (2001:17) has

observed that: "A completely reliable classification is not possible for all classes over the whole data set. It is helpful to perform automatic classification in a semi-automatic environment and to mark the few uncertain objects for subsequent manual inspection. Using eCognition's rule-based classification and the feature 'membership in a class' it is possible to clearly visualise misclassifications among distinct classes and to view this information not only in a statistical way, but also for each image object and thus as additional thematic layer, manual corrections are easily possible as well." The manual classification step is necessary to achieve a level of accuracy that renders the project successful. It is not uncommon to apply the manual method to achieve the required results. Crase & Hempel (2005) manually attributed areas around a mine that had a similar signature to that of burnt areas and likewise some areas were assigned to either swamp or mangrove. Once all classes have been correctly classified, the classification must be exported from eCogntion.

4.11 EXPORTING THE CLASSIFICATION

The classification results must be exported into ArcGIS to create the maps required for analysis. The exportation requires a separate rule-base that can be altered for each of the three study area sections so that all the correct classes are exported as a vector shapefile. The rules that were applied are presented in Figure 4.17. Each class has a certain number of objects that have been assigned its specific class name. The example shown in Figure 4.17 is the low natural class. The 'Update Variable' tab gives the option of 'yes' or 'no' in numerical terms with 'yes' = 1 and 'no' = 0. Every object that has been assigned the classification of low natural will be equal to 1. Any other class will not be assigned the value or name of low natural. The function then exports the class individually as a shapefile that contains the classification code and number. Each class has to be listed and exported individually and great care must be taken to ensure every class is included. If every class is not exported the result is missing data in ArcGIS (ESRI 2009). As set out in Section 4.1, the workspace retains all relevant information for the classification, including all metadata assigned to the classes. The information can be used later to display the classes correctly and make accurate area calculations.

The final rule that exports each class as a shapefile is shown in Figure 4.18 below. The 'Export Item Name' is a name given to each tile. In this instance each tile was named its respective number ('tile 191'). The other variables are shown in Figure 4.18 below that automatically exports the shapefiles for each class in each tile and sends them to the directory where they can be accessed when working in ArcGIS. The process must be applied across each tile for the entire workspace. Empty tiles, that are black tiles with no imagery, have been excluded. Once all objects have been exported, the

proceeding step is to analyse the results of the classification in ArcGIS. Each tile can be dealt with individually to alter the presentation for the production of a final map.
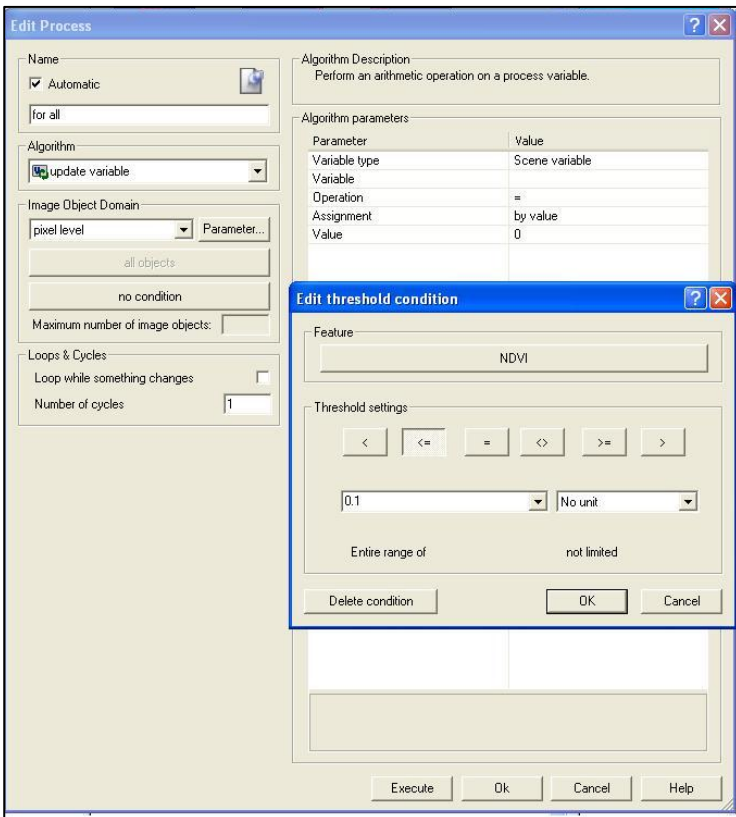
Figure 4.17 Rules applied to each class to export the classification from eCognition to ArcGIS
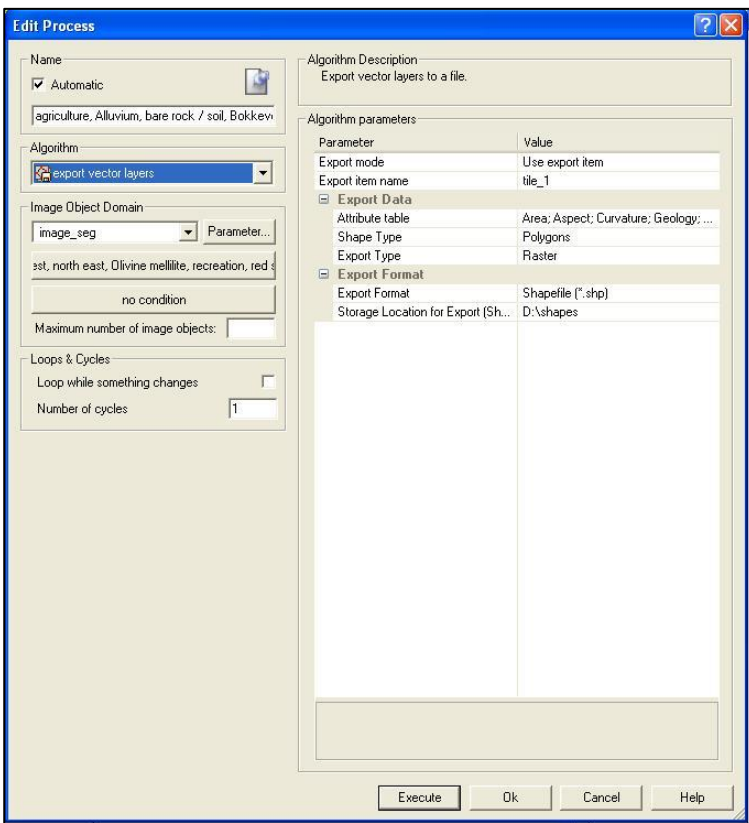
Figure 4.18 Final rule for exporting all classes to ArcGIS

Once all objects have been exported, the proceeding step is to analyse the results of the classification in ArcGIS. Each tile can be dealt with individually to alter the presentation for the production of a final map.

4.12   VISUALISING THE CLASSIFICATION RESULTS

Once all the tiles have been exported as shapefiles from eCognition to ArcGIS, the final phase can begin. The final phase will be the creation of the final map used to analyse the results and assess accuracy. The maps must be displayed with all values available in the symbology area of the layer properties dialogue. Figure 4.19 shows the progressive steps taken to present the final classification for each tile. The exported shapefile (1) shows the classification in its raw format straight from eCognition. The following step begins displaying all classes (2) but at this stage not in the representative colours. The final step is to change the colours (3) to create the final display. The process continues for each tile until every exported tile is exported and displayed correctly into ArcGIS.
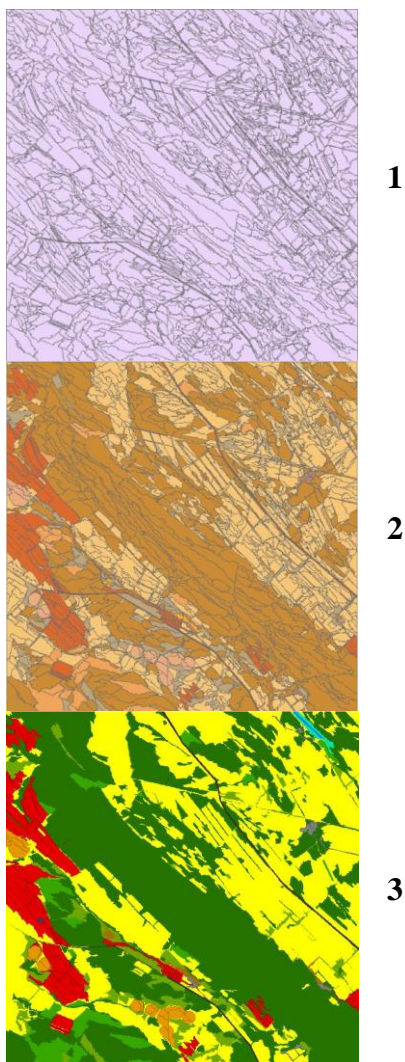
Figure 4.19 Succession of exported shapefile (1), all classes displayed (2) and final display (3)

Chapter 4 has dealt with designing and implementing a model that classifies the land cover of the north-west Sandveld region using a semi-automated process. Each step used has been systematically explained to achieve the final result. All tiles have been classified and exported into ArcGIS for the creation of the final product. The final land cover map has been presented in Appendix D and it is recommended that the reader has the map open for the succeeding Chapters 5 and 6. In Chapter 5, deductions can be calculated in terms of the overall landscape structure using the classified map. Once calculations and deductions have been made regarding the landscape structure, the model is going to be assessed in terms of its accuracy and effectiveness. The overall conclusions regarding the environmental analysis will be followed by the conclusions of the study as a whole in Chapter 6.

CHAPTER 5: ENVIRONMENTAL ASSESSMENT AND RESULTS ACCURACY

If one returns back to the original aim assigned to complete the steps of the research, one is reminded of the following: to develop and implement a model that effectively classifies land cover of the north-west Sandveld, and to use the generated map to assess the environmental impact that agricultural activities have had on the area. Introductory sections have been to give the reader an understanding of the study area in question and why there is a dire need for a suitable map of the Sandveld area. Part of C.A.P.E's priorities in protecting biodiversity has been to identify targets for conservation of biodiversity patterns and ecological processes (Younge & Fowkes 2003). A means of identifying patterns in biodiversity changes is through a suitably high-resolution map providing a snapshot of the current structure of the landscape.

Having embarked on a journey of developing a classification model, the aim has been to use the developed model across the Sandveld study area as a whole. One cannot determine the overall successfulness of the classification until all tiles are classified, however as long as the representative tiles have been selected correctly, the results will reflect what has been shown in the sample tiles.

The followings sections of Chapter 5 examine the classification across all tiles in each of the region's three divisions to which the rules were applied – the northern, western and eastern sections. Subsequent to the classification step, the overall accuracy of the classification can be determined. Once the accuracy has been determined and considered correct, the assessment of the land cover can commence. The assessment involves calculation of the area size of each class as well as providing an indication of how certain classes have been affected by human activities.

5.1   THE CLASSIFICATION

Clearly, each of the three sections is significantly different in landscape structure and no doubt different rules are needed to classify the structures. The classification is time consuming and care must be taken to ensure that uninterrupted time is allowed for the software and hardware to perform the required tasks. eCognition in particular requires a substantial amount of processing power and time to classify each class satisfactorily.

The classifications were run on each land cover class after it was determined that the best possible rule-set had been derived for each of the three sectors. The classification results for and conclusions

about each will be discussed separately. It is noteworthy that the rules can be migrated between each protocol for each area and if there is a class that exists within a small area of a neighbouring study region, the rules used to extract that class can be used in that classification. One must ensure that the classification of some objects is not affected by using rule-sets for different areas and thus it is recommended that an initial test area is assessed as to whether the rule-set will affect the overall classification greatly or not.

5.1.1   The northern section

The protocol for the northern section manifested as the most successful due to the homogeneity of the region. The vineyard areas were classified most efficiently as well as the bare soil areas. The favourable outcome can be largely attributed to the spectral and shape characteristics of these areas. The effectiveness of the protocol showed in the classification results. Figure 5.1 illustrates the results. The area mainly comprises temporary non-irrigated strip agriculture, low fynbos vegetation and permanent agriculture along the river banks. The classes mainly remained within clusters along river banks or in the open flat areas.

As can be seen in Figure 5.1 the temporary non-irrigated class makes up a large proportion of the area whilst the permanent agriculture remains a dominant class. Centre-pivot irrigated circles are lightly scattered across the area but at this stage do not impose a large threat in terms of area removal. Their impacts however must not be ignored since future growth can happen rapidly. The high levels of fragmentation of the natural areas can be seen as the low, medium and high fynbos areas are interspersed amongst the agricultural classes.

Even prior to calculating area size, it is clear that the temporary non-irrigated strip class makes up a large proportion of the northern section. The permanent agriculture class comprising vineyard and orchard agriculture has been concentrated along the banks of the Olifants River of which the severe impacts will be discussed later. The centre-pivot irrigated agriculture classes is not a dominant feature. The high level of fragmentation of the natural classes is evident, particularly in the areas between the agricultural classes. In the far north east corner there is a high proportion bare soil and exposed rock.
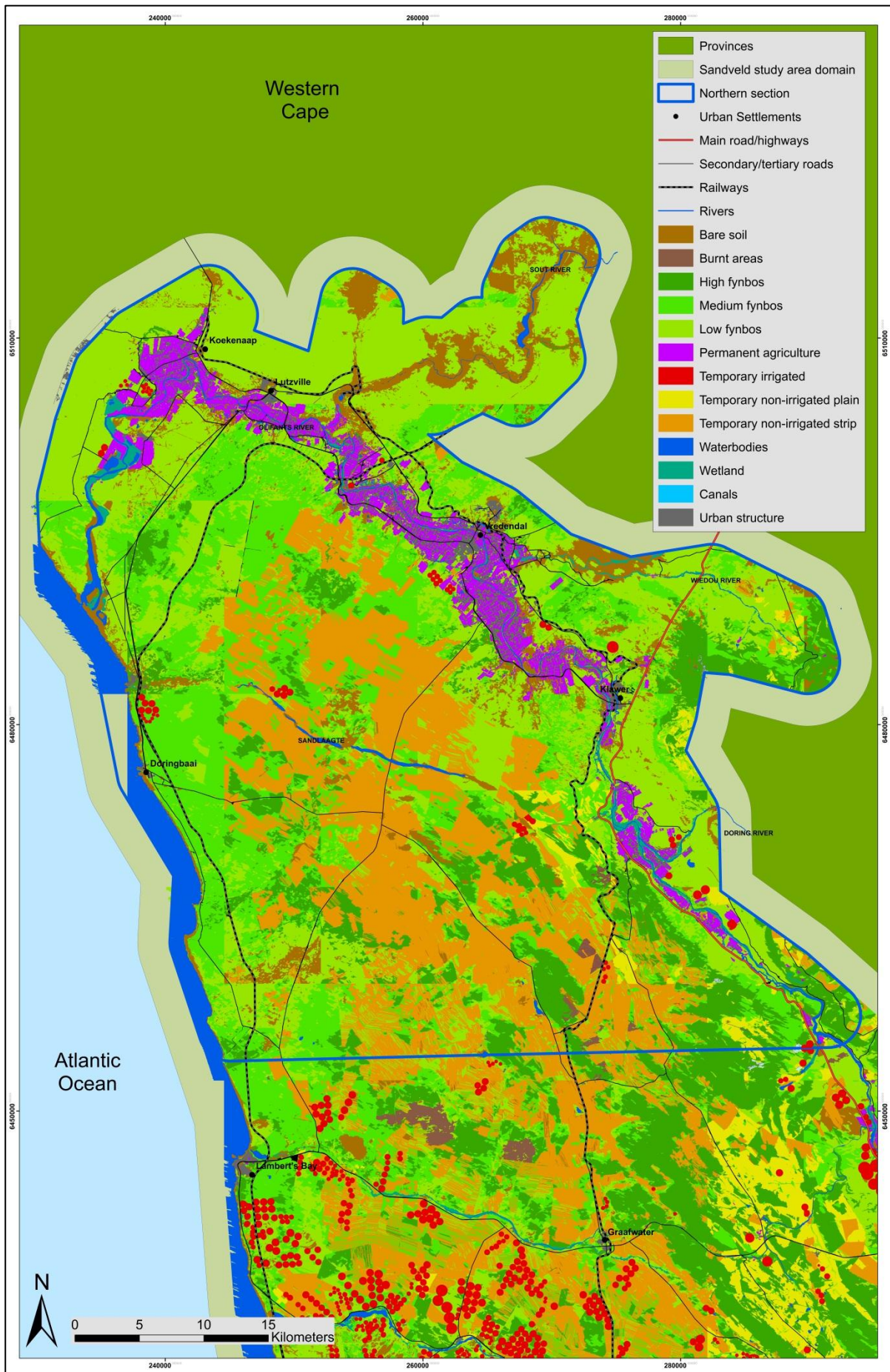
Figure 5.1 Land cover in the northern section

The second of the three divisions is the western section which will now be described with the adjoining map of the area. The eastern section's classification will be described last. Once the three areas have been displayed, the discussions on their accuracy will follow.

5.1.2   The western section

The second protocol developed was for the western section. Figure 5.3 shows the classification done over a very heterogeneous area with numerous classes existing over the entire area. The centre-pivot inclusion of the vector layers enabled a more successful classification of that particular class. The only class that the protocol struggled to classify effectively was the urban class. The urban class' protocol was developed separately and incorporated into the main rule-base to enable that class to be classified correctly. Observable in the map is that the western area has been heavily transformed by agricultural practices, showing very small fragments of natural vegetation. The evidence of an abundance of centre-pivot irrigated fields along river banks is a clear manifestation of a lack of mandatory control in the past. Their dependence on water is clear when looking at the patterns that have emerged in these lower coastal areas of the Sandveld. The temporary non-irrigated strip class is also dominant in the western section.

An intriguing pattern emerging in the lower coastal areas is the presence of centre-pivot agricultural fields lying among temporary non-irrigated strip fields. The pattern indicates evidence of farmers changing the use of their land for crops such as rooibos tea to potatoes. Figure 5.2 shows the phenomenon clearly. Also interspersed among the pivots are areas of low natural vegetation that in some cases are used for grazing. High vegetation areas extend toward the eastern half of the region where the topography limits the expansion of agriculture.
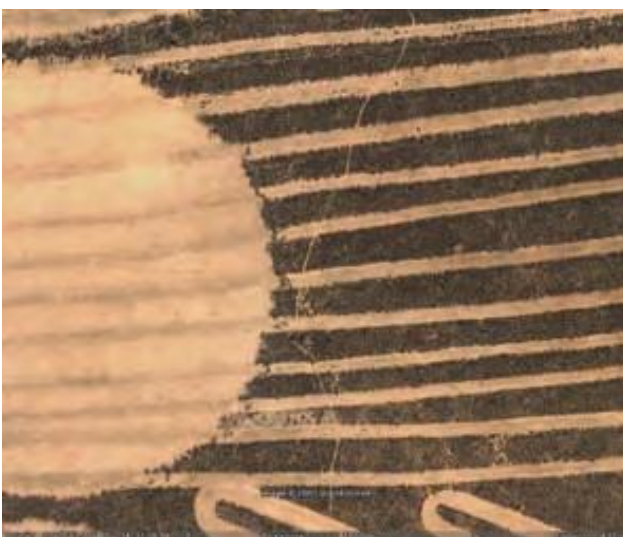
Figure 5.2 Conversion of old strip fields into centre-pivot irrigated field
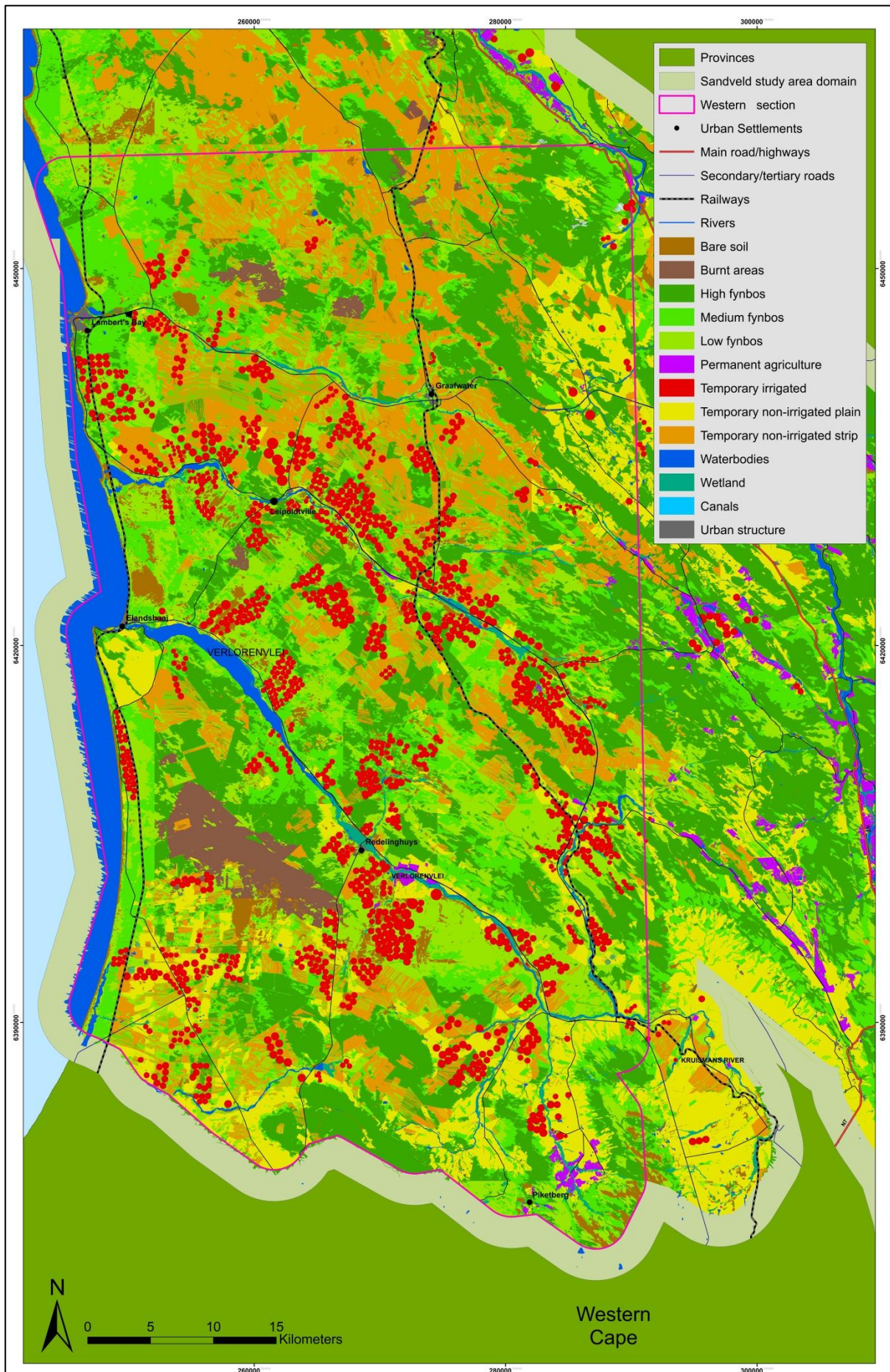
Figure 5.3 Land cover of the western section

The final section of the Sandveld study area's sub-divisions is the smallest of the three areas. The eastern section is described below with the relevant map.

5.1.3 The eastern section

The eastern section was the most challenging to the classification process. Many classes exhibited the same or similar spectral, textural and shape characteristics and the protocols often confused some classes. Some manual classification was needed to ensure that all objects were assigned to the correct class. The mountainous nature of the area meant that objects that lie in valleys and in the shadows of hill slopes were misclassified. Care was needed to ensure that the features in the shadow areas were extracted by the rule-set despite features that could alter the classification. The benefits of using object-oriented classification parameters are that objects falling in shadows can be considered on their own. A rule can consider only these shadowed objects and request further rules to classify the sub-objects within them according to their spectral, textural and shape characteristics.

The areas west and south-west of Clanwillam are where the structural diversity is clearly seen. Undulating surfaces stemming from the Cederberg range mean that many agricultural practices do not take a 'typical' form seen in the northern section. During the field excursions through the eastern section in particular, it was observed that many fields are temporary non-irrigated strip agriculture but may be difficult to decipher on a satellite image with a resolution of 2.5 m. Soutbos strips between areas of cultivation are a common sight in the eastern section so that in some cases the segmentation parameters were able to detect their edges from the border and frame extractions. Ultimately, there are some areas that have strip-cultivated areas interspersed with temporary non-irrigated plain agriculture. Where possible, any misclassifications were rectified manually. The results of the classification are shown Figure 5.4.

Permanent agriculture is present along the river banks and citrus orchards are the main agricultural crop in the south east corner of the eastern section. These are the key supporting agricultural activities for the Ceres and Citrusdal regions. Using NDVI layers ensured that all natural areas were considered, particularly in the areas where the vegetation is denser. Brightness values were applied to the temporary non-irrigated plain class lying in the bottom reaches of the eastern area.

The canal network begins in the topmost northern parts of the eastern section and has been classified using a digitised vector layer. The narrow canal structure is such that it is extremely difficult to classify using satellite imagery of 2.5 m.
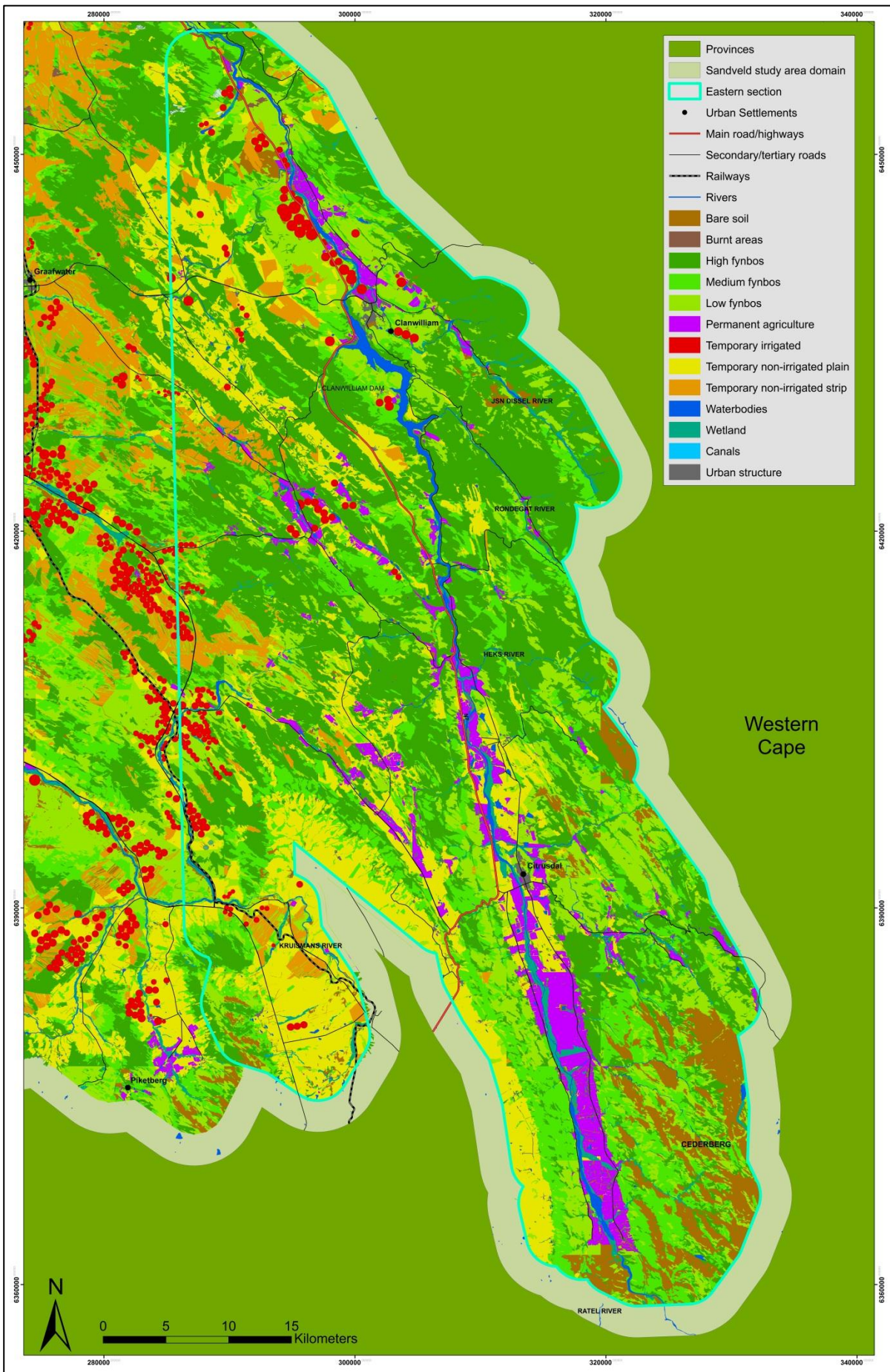
Figure 5.4 Land cover in the eastern section

Before further discussions of the classification, the accuracy of the results must be determined. In accuracy assessment each class is taken into consideration and accuracy calculated individually to determine the trustworthiness of the classification compared to the fieldwork findings. The following section gives an account of the processes involved to assess the accuracy of the results.

5.2   THE ACCURACY ASSESSMENT

The only way to measure the outcome of the classification is by determining the accuracy or correctness of the classified classes. Accuracy defines correctness: it measures the agreement between a standard assumed to be correct and a classified image of unknown quality. If the image classification corresponds closely with the standard, it is said to be accurate (Campbell 1996). In the following subsections the steps taken to complete the accuracy assessment are treated to eventually present the results of the classification in an error matrix. Once the accuracy of the results is known, the patterns of each class can be scrutinised to highlight the environmental concerns of the north-west Sandveld.

There are many methods with which to conduct an accuracy assessment, including the overall proportion of area; pixels or polygons classified correctly for the entire map; various forms of kappa (κ) coefficients of agreement; the τ coefficient, users and producers accuracy; and conditional κ (Stehman 1997). The kappa statistic measurement for determining accuracy has been used to calculate the accuracy of the results of studies to this one (Bock et al. 2005; Stehman 1997)

The goal of the field assessment is to determine the accuracy of the classification within a certain percentage and an error range within a certain confidence level (CL) which Thompson et al. (2001:40) described as the "probability of (x) number of pixels being correctly classified within a random sample (n), usually expressed as a percentage". This definition applies to pixel-based classification systems so that it would be used differently in an object-based classification.

5.2.1   Preparation and planning for field work

The first step in the accuracy-rating process is a thorough field survey throughout the study area. Every application of remote sensing must apply, if only implicitly, field observations in one form or another. Each analyst must define relationships between image data and conditions at corresponding points in reality (Campbell 1996). Accuracy assessments are a critical component of any land cover mapping exercise as they provide potential end-users with quantifiable measures of data accuracy and reliability, which collectively determine a map's fitness for use in a particular application

(Fairbanks & Thompson 1996). No map can be considered worthy for a particular cause until a concise accuracy assessment has been done. Accuracy assessments usually entail a field excursion that involves selecting sample or reference locations and comparing the circumstances at these reference points to the classifications provided by the land cover map (Stehman 1997). It is important that the methodology of an accuracy assessment is similar to others to ensure that a level of uniformity is maintained.

The first field outing and workshop mentioned in Section 1.7 was to give the researcher an overview of the study area. The final field work assessment was conducted to do the accuracy assessment. Thorough preparation and planning of the accuracy assessment was crucial to ensure that a stress-free field outing took place. The procedural steps conducted for the field work will be discussed below. This involved the steps reported in Sections 5.2.2 to 5.2.5.

5.2.2   Creating the required maps

The modus operandi of the fieldwork exercise was to drive through the study area, stopping at pre-assigned randomly calculated points, taking GPS readings noting at each point what class was seen on an accompanying photograph. A map showing the predetermined stopping points was a prerequisite. High-quality field data is essential for accurate land cover classification (Gamanya, De Maeyer & De Dapper 2009). Campbell (1996) cautions that one cannot simply assess accuracy from the appearance of a map, nor from past experience or from personal knowledge of an area. Rather, accuracy must be evaluated through a well-defined effort to assess the map in a manner that permits quantitative measurement of accuracy and comparisons with alternative images of the same area (Campbell 1996). A random distinction of sample points could easily be generated over the entire study area, but gaining access to them would be impractical. A random distribution of points accessible by suitable roads was the chosen alternative.

To create a map with pre-determined points located within a suitable distance to an accessible road, the ancillary data used in the classification was resorted to. The shapefiles include the study area boundary, urban areas and the roads layer. The roads layer required some manipulation to make it appropriate for generating random points. The road layer is defined as a 'line' layer so to allow for 300 randomly selected points to be on or near one of the roads, a buffer had to be created. Figure 5.5 shows the buffer of 80 m created on either side of the road layer and the random points generated within the buffer area. The road layer itself is 20 m wide and the buffer on either side of the road is 30 m, resulting in a buffer of 80 m.
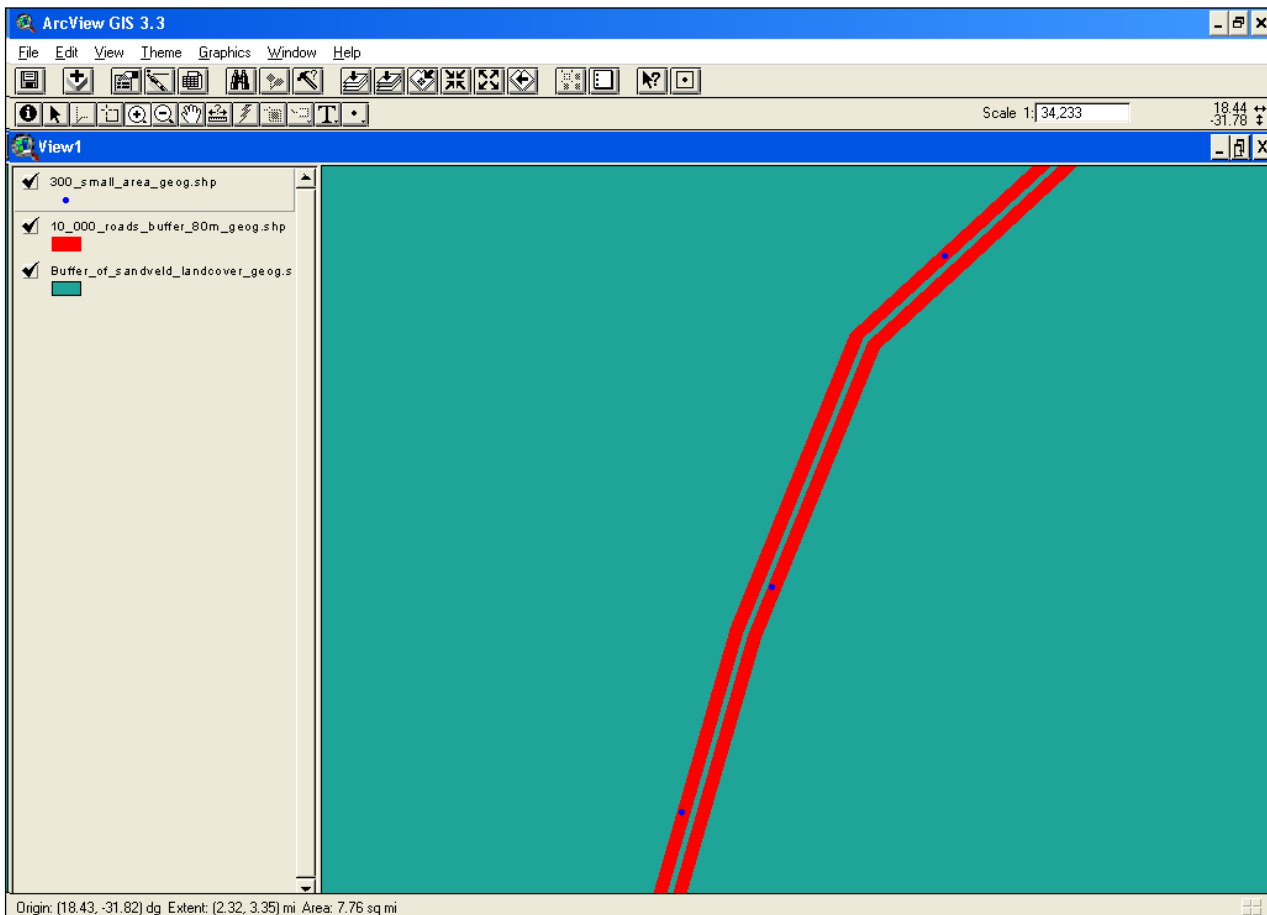
Figure 5.5 Shapefile of roads layer with 80m buffer with random points generated within it

The generation of the random points is explained in the following section to explain the steps taken to conduct the field work successfully.

5.2.3 Sample site selection

According to Thompson et al. (2001), the minimum number of sample points required during a field excursion conducted for accuracy assessments is 250. The number of points directly affects results of the accuracy assessment. If the number of points is too small the kappa index will give a weak result and if the number of points is great regarding practically visiting the points and calculating them, the exercise will be impractical and superfluous. To avoid a bias of sample site selection, a random selection of points was required that would automatically determine the points to be visited and their exact location. An extension known as 'random point generator' was downloaded from the ESRI website and into the extensions menu in ArcView (Jenness 2005). There are many scripts available in ArcView 3.0 that can be transferred to ArcMap 9.0 for better analysis. The random point generator script uses parameters set in the generator menu by the user to define the following factors: i) minimum distance that each point must be set from each other point; ii) the distance from the boundary of the polygon used; and iii) the number of points to be generated.

Once the points have been generated, the shapefile can then be projected and opened in ArcMap. Projecting the shapefile into the Geographic Co-ordinate System allows the points to be imported into the GPS. Each point is assigned an ID from 0-299. Figure 5.6 shows the distribution of the randomly selected points collected over the whole study area using the random point generator. In 'Step 3' of the generator there are three factors to be inserted. Point Tolerance is the maximum distance between each point in metres – a value of 1000 being given in this exercise. The second factor, 'Boundary Tolerance', is also measured in metres – and is the distance within the polygon used that is the road buffer layer. The value assigned of 30 means that the points will be placed a maximum of 30 m within the road buffer layer. The final value to insert is the number of points to generate, namely 300. Once these values are inserted, the random point generator can then be run in ArcView (Jenness 2005).

The 300 random points shown in Figures 5.6 and 5.7 are those to be visited on the accuracy assessment field excursion. Since all the points are within 30 m of a road they are accessible by car. Some points may lie in fields or fenced areas making access difficult to the exact point but the maximum of 30 m ensures that the nature of the points' area is clearly visible from a road as a vantage point. With the random points selected, route-planning can be done.
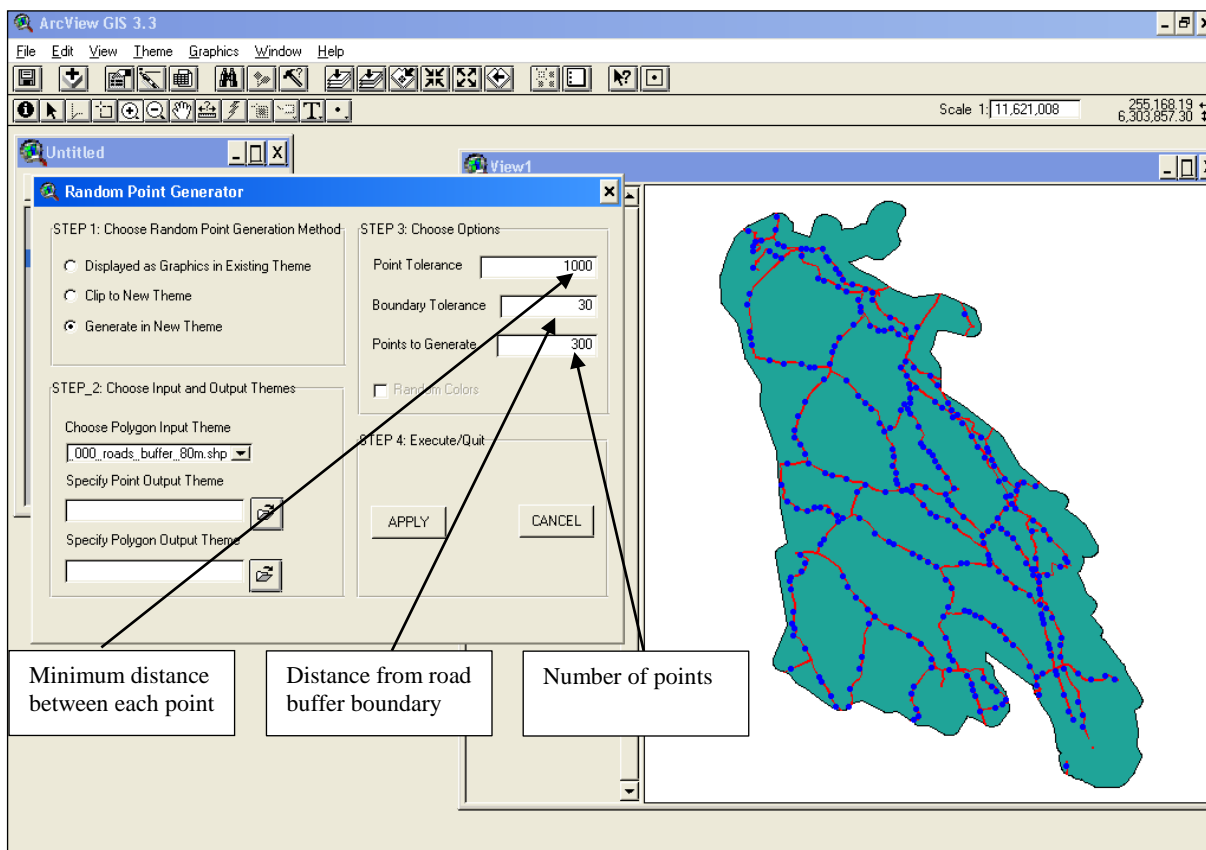
Figure 5.6 Generation of random points using downloaded extension in ArcView 3.3

5.2.4   Procedure for route planning

The first step to plan the route was to calculate the average speed to be travelled by car to reach each point, taking into consideration speed limits and the condition of the roads. All points were accessible via main or secondary roads. The poor condition of some roads made travelling between some points slower than others. Proper planning facilitated the reaching of the designated points for each day. Another controlling factor is the battery life of the GPS. The Dell palmtop used in conjunction with a Garmin GPS had a battery life of approximately six hours when fully charged and recovered its power at a rate of 5% per minute while re-charging. This meant that it could be recharged almost fully during a 45-minute lunch break. Petrol consumption of the car and location of petrol stations are other essential considerations as well as the location of accommodation places. Considering all these factors as well as aiming at visiting a minimum of 250 points during the entire trip, the route was planned for three days, working from sunrise to sunset and allowing approximately 10 hours per day during summer.

5.2.5   Visiting the points in the field

The goal for the three day excursion was to visit 100 points per day which meant that the points had to be visited with as little backtracking on roads as possible. Circular loops were driven so that all points in a certain area were visited and any remaining points were picked up on the way to the overnight accommodation. The itinerary was that the south east corner was covered on the first day, a total of 85 points being visited. The target number was missed because one of the excursion members arrived late from Stellenbosch that morning. The second day made up for the 15 points and covered the additional 100-point requirement. Effective route management of the eastern and northern sections was essential to ensure that the required number of points were visited. The final day allowed for all remaining areas to be visited in the western section. Figure 5.7 shows the location of all points visited and their respective ID codes.

The procedure carried out at each location was follows: the location of all points was uploaded onto the palm top and the car could be tracked along the route followed; each point had a radius of 100 m which would overlap into the road; once the car was in line with the point, the distance from the car to the point was measured using the ArcPad's scale bar; a note was taken as to what land cover type was present at the measured location of the point and a photograph taken of the area; using a printed table, shown as Table B1, the number of the photo taken, the GPS reading for the location of the car and a class description were written down. In-the-field decisions had to be taken whether or not it was possible to reach certain points due to road conditions.
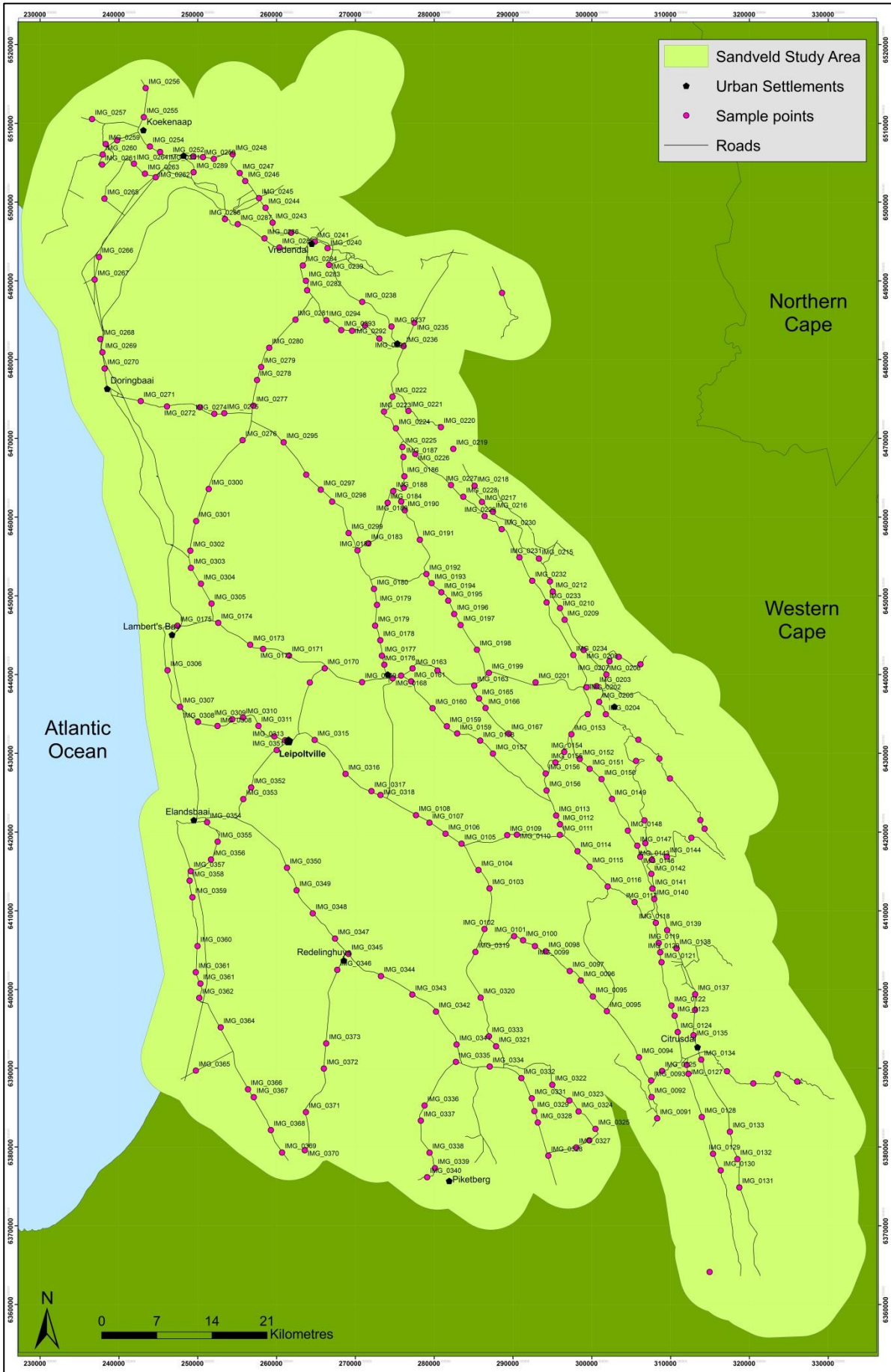
Figure 5.7 The study area with the location of the 300 randomly-selected points visited

There was a buffer of 50 points allowed in case some could not be visited and since only 19 points were not reached it was a deemed a successful survey. Table B1 in Appendix B lists all the points visited as well as those not visited.

5.3   ACCURACY OF THE RESULTS

The ultimate goal of an accuracy assessment is to determine how successful the technique was in recognising the real land cover types from digital image input and therefore how useful a classified map is to the user. This section explains the systematic approach followed to determine the accuracy of the Sandveld land cover classification. The field excursion served to collect the required information for the calculation of the overall accuracy, and augment knowledge of the study area. The information about the points visited had to be assimilated, digitised and analysed to calculate the overall accuracy of the automated classification.

5.3.1   Accuracy assessment methodology

Table 5.1 summarises the sample point results consolidated in an error matrix for the purpose of accuracy calculations. The field-observed land cover classification at each point was evaluated against the modelled classification at the same point. The column and row headings indicate the class names as they are cross-tabulated against each other. The diagonal cell row shows the number of sample points/cells that have been classified correctly for each land cover class. For example, the class 'Temporary non-irrigated plain' has been classified correctly in 27 sample cells, while being misclassified in seven as 'Permanent agriculture'. The total number of correctly classified cells was 195 out of 278 sampled (70.1%).

Using the cross tabulation in Table 5.1, the accuracy of each class as well as the overall accuracy of the classification become clear. The errors of commission and omission have also been calculated which determine if the errors have been evenly distributed for each class. According to Jensen (1996), the error of commission can be expressed in terms of the user's accuracy and error of omission as the producer's accuracy. In other words the user's accuracy is from the perspective of the end-user of the map and the producer's accuracy is from the perspective of the creator of the map. Overall accuracy calculations give an indication of how successful the map has been as a whole; however, in order to improve on the classification, the accuracy of each class must be calculated. The strengths and weaknesses of the model can then be identified rather than adjusting the entire model. With reference to Table 5.1, the user's accuracy would be the accuracy of each class per row. The producer's accuracy would be the accuracy of each class per column.

Table 5.1 Error matrix for kappa assessment

		MODEL DERIVED CLASSES																ROW TOTAL	USER'S ACCURACY %	Model Error (n)	Model Error (%)
		Temporary non-irrigated plain	Permanent agriculture	Bare soil	Low fynbos	Medium fynbos	High fynbos	Roads	Temporary non-irrigated strip	Railways	Canals	Rivers	Wetland	Water	Urban structure	Temporary irrigated	Burnt			n	%
OBSERVATION DERIVED CLASSES	Temporary non-irrigated plain	27	7		6	2			2							1		45	60	18	40
	Permanent agriculture	2	32	1	1													36	88.9	4	11.1
	Bare soil			7	1				1									9	77.8	2	22.2
	Low fynbos	3	1		39	2	6		2				2					55	70.9	16	29.1
	Medium fynbos				1	18			1									20	90	2	10
	High fynbos			2	5		25	1	3				2					38	65.8	13	34.2
	Roads		1		1		1	8					1					12	66.7	4	33.3
	Temporary non-irrigated strip	6	1	1		1	1		23									33	69.7	10	30.3
	Railways									1								1	100	0	0
	Canals				1						0							1	0	1	100
	Rivers											1						1	100	0	0
	Wetland		3				1						8					12	66.7	4	33.3
	Water													3				3	100	0	0
	Urban structure		1				1	1							3			6	50	3	50
	Temporary irrigated			1	1	2							1			0		5	0	5	100
	Burnt						1										0	1	0	1	100
COLUMN TOTAL		38	46	12	56	25	36	10	32	1	0	1	14	3	3	1	0	278*	70.1		
PRODUCERS ACCURACY (%)		28.9	30.4	41.7	30	28	31	20	28.1	0	0	0	43	0	0	100	0	23.8			
Model Error	n	14	5	17	7	11	2	9	0	0	0	6	0	0	1	0	14	83		83	
	%	28.9	30.4	41.7	30	28	31	20	28.1	0	0	0	43	0	0	100	0	29.9			29.9

*   Total number correct on the diagonal: 195 cells (70.1%); Incorrect: 83 cells (29.9%)

The definitions above are explained mathematically in the K calculations below:

$$\text{Pr}\,(\Omega) = \frac{diagonal\ total}{total\ samples}$$

$$\text{Pr}\,(\Psi) = \frac{diagonal\ total}{total\ samples}$$

$$= 0.7014$$

$$= \left[\frac{row\ total}{total\ samples} * \frac{column\ total}{total\ samples}\right]$$

$$= 0.126805$$

$$\text{K} = \frac{0.7014 - 0.126805}{1 - 0.126805}$$

$$\text{K} = 0.658$$

Landis & Koch (1977) tables the various levels of agreement between modeller and observer according to the calculated kappa values shown in Table 5.2.

Table 5.2 Interpretation of kappa

Kappa statistic	Strength of agreement
< 0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect

The calculated kappa index of 0.66 therefore reaches the 'substantial agreement" class fairly solidly, attesting to a good modelled result from this research.

5.3.2   Interpretation of classification accuracy

Conclusions regarding the accuracy of classification results are underpinned by Tables 5.1 and 5.3. A map's "fitness for use" for a particular application is determined by the quantifiable measures of data accuracy and reliability (Thompson et al. 2001). Thompson et al. (2001) also stated that although there are minimum mapping accuracy targets, there is no single universally accepted standard. While 100% accuracy should obviously be aimed for, realistic classification accuracy

targets range from 80% to 90% depending on the end-user's requirements. Anderson et al. (1976) however stated explicitly that an accuracy of 85% should be obtained in a given classification and this seems a realistic guideline. Hence, it was the aim of this study to reach an accuracy result of 85% bearing in mind various constraints and technical challenges. The accuracy assessment calculations in Section 5.3.1 gave a Kappa Index of 0.658 and total overall accuracy of 70.1% – only 14.9% off Anderson et al. (1976)'s benchmark. When each class is analysed, one can make the following conclusions: seven out of sixteen classes obtained an accuracy above 70%, five between 60% and 70% and four were at 50% or below – but, importantly, these were based on relatively low sample numbers. Reasons for the accuracy shortcomings were numerous. The pre-processing of the SPOT 5 imagery could be investigated where there may have been flaws resulting in image flaws. A different filter could have been applied that may have created more defined edges. Another factor to consider is the availability of hardware. Hardware that runs off large servers with adequate RAM may negate the need to apply a frost filter to the SPOT 5 imagery to reduce the dataset size. The imagery will therefore be of a higher resolution and the classification could be more accurate. The processing time would also be faster and more experimental parameters could be tested. Unfortunately this type of solution would be extremely expensive and not possible unless access to large financial resources was made available. In the coming paragraphs the classes are discussed according to their accuracy results and how their result can be improved on.

In Table 5.1 the two highest error classes are 'Bare soil' (41%) and 'Wetland' (43%). Regarding the former class, consider that the model does not classify land use, but specifically land cover. Therefore the spectral and textural characteristics will remain the same as for any relatively smooth-textured cover such as old fields. Hence the in-between strips of strip-cultivated rooibos, fallow irrigated fields or shadows in rocky mountainous areas can affect the model to classify cells as bare soil. Wetland boundaries are difficult to determine from spectral characteristics as their plant structure may yield NDVI values similar to other forms of natural vegetation. Wetland boundaries are notoriously evanescent along the edges where a wetland ends and where normal drier vegetation begins. Consequently, the classified polygons of either may overlap. Wetland areas may also be interspersed with notable expanses of river sand that affect the spectral signature of the polygons in which they occur. Both these classes are closely correlated since both contain interspersed natural vegetation and bare soil. To combat misclassification, "seed generation" using locational rules in relation to rivers for the 'wetland' class, for example, may help. This needs insurance that the 'river' class is correctly classified. Bare soil patches can occur in any area and remain a very difficult class to classify distinctly.

The second highest misclassified group (above 30% error) includes the 'Permanent agriculture', 'Low fynbos' and 'High fynbos' classes. The 'Permanent agriculture' class are mainly vineyards and orchards. Of the 30.4% misclassified polygons in the 'Permanent agriculture' class, most were classified as "Temporary non-irrigated plain'. The high percentage of this class owes to form characteristics of polygons. The fact that the plain-like structure of some fields may take on a similar "block"-like shape to the vineyards and orchards as well as the fact that some vineyards may be young with low stand density and thus give a similar spectral signature to the 'Temporary non-irrigated – plain' class. The 'Low fynbos' and 'High fynbos' class were both interchangeably confused by the model since there is by nature a very subtle or slight difference in the spectral signature between the various fynbos classes. Furthermore, even the observation based classification may have foundered in observer classification judgement on fynbos stands at or near the boundary densities decided upon. The spectral range for each fynbos level should be within more defined parameters with a large enough gap between them to ensure that there is no overlap. A possibility for a more refined classification would be to conduct another classification on only the natural classes and set very definitive rules for each class. This process would however require significantly more time and investment on a technical front.

The remaining misclassified classes have lower average error levels of about 25% and include 'Temporary non-irrigated – plain', 'Temporary non-irrigated – strip', 'Medium fynbos' and 'Roads'. The first two agricultural classes were both classified incorrectly (confused) in some instances as each other. The narrow linear structure of the strip class may be extremely faint on the SPOT imagery at this 2.5 m resolution. This is evident in the eastern section where Soutbos strips are used to separate rooibos strips particularly and cannot be clearly distinguished on the imagery. The 'medium fynbos' often has a spectral signature and NDVI value in the same parameter range as other classes including 'Temporary irrigated crops'. Additional experimentation to determine more exact spectral characteristics of the natural vegetation classes may help to improve classification accuracy. 'Roads' as a linear feature was misclassified as 'Urban structure' and 'High fynbos'. This may be due to the resolution of the imagery that can affect the classification of narrow linear features, or some 'mixing' of designation along the roads. Imagery with a higher resolution might compensate for the narrowness of linear features, but this solution for a large study area may not be practical due to the size of the resultant datasets and the practical insignificance of improved classification output.

To conclude, it is argued that an automated classification at the scale used throughout the research has been relatively successful but with some technical challenges. When classifying land cover of

an area where natural vegetation dominates, building a spectral signature "dictionary" could be the solution. Prior to classification, a considerable amount of time should be spent on investigating the exact values of varying types of vegetation according to their brightness, textural and NDVI values. Also, these need to be studied inter-seasonally since vegetation undergoes change through the course of a year. Such spectral signatures should also consider the range of agricultural vegetation in particular. In the following section the classes will be discussed according to their areas and their relationship with the errors of omission calculated earlier.

5.3.3 Calculated areas of land cover

The accuracy assessment determined how successful the modelled classification was as a whole and for each individual class. The level of agreement between the two 'observers' was calculated using Cohen's kappa index. The errors of omission show the percentage of error in each class and it is this error along with their total areas that will be discussed here.

Each polygon within a single tile that is exported into ArcGIS has attribute data associated with it shown in Figure 5.8. eCognition exports the map projection that the original imagery was in when it was loaded into the software. In the case of the Sandveld classification, the projection is WGS84. An area-preserving projection must be used from the beginning to ensure accuracy in all calculations. When each tile is exported, the area can be calculated for each polygon in the tile using the ArcGIS Field Calculator. Scripts are available in the ArcGIS desktop help files accessible to users (ESRI 2009). The area of each polygon can be calculated for each tile and, as shown in Figure 5.8, an additional field of 'Area' is put into the attribute table. For each tile an area is calculated for each polygon within it and these polygons have an assigned class. The script used for calculating area is:

Dim dblArea as double
Dim pArea as Area
Set pArea = [Shape]
dblArea = pArea area.

All tables have to be exported to Microsoft Excel and the areas for each tile totalled and then for each class in the study area. The classes have been sorted by area and include the error of omission (error percentage) for each.
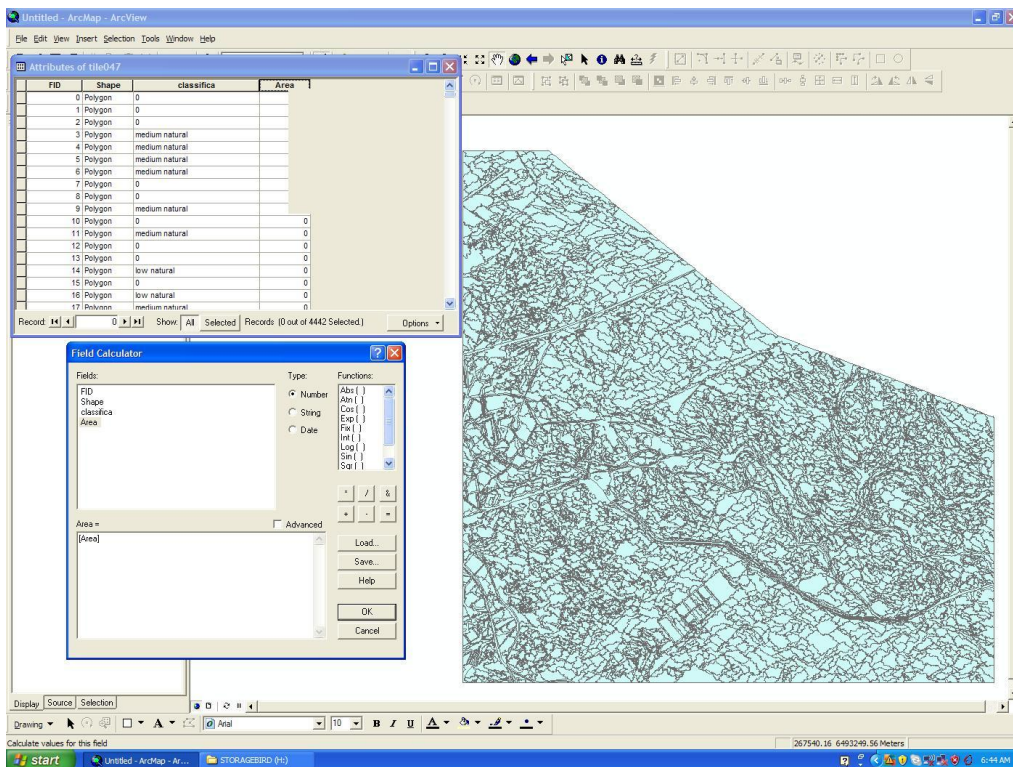
Figure 5.8 Exported polygons from eCognition into ArcGIS

The results for the total study area are shown in Table 5.3. The error of commission is calculated by taking the total incorrectly classified cells per column and dividing it by the total for the column. The percentage of the incorrectly classified classes can be calculated.

Table 5.3 Area of each land cover class

Class	Area (ha)	Area %	% Error
Low fynbos	183 168	22.3	30.4
High fynbos	181 665	22.1	30.6
Medium fynbos	136 192	16.6	28.0
Temporary non-irrigated strip	105 246	12.8	28.1
Temporary non-irrigated plain	64 144	7.8	28.9
Bare soil	43 367	5.3	41.7
Temporary irrigated	29 662	3.6	100.0
Permanent agriculture	26 058	3.2	30.4
Water	23 596	2.9	0.0
Wetland	11 920	1.5	42.9
Burnt area	7 785	0.9	0.0
Roads	3 944	0.5	20.0
Urban structure	3 878	0.5	0.0
Rivers	1 192	0.1	0.0
Canals	218	0.3	0.0
Railways	23	0.0028	0.0
Total	**822 058**	**100.0**	

Looking at Table 5.3 there are certain ramifications in terms of a class' error percentage according to the total area. The first three are the natural fynbos classes. Although the 'Low fynbos' and 'High fynbos' classes both have a 30% error, they were mainly misinterpreted as each other. Through refining of the model over time one can improve the results on the natural classes. The total area of the three fynbos classes would therefore not change severely and would not have a drastic impact on the overall classification.

As discussed earlier the class that posed the greatest challenges in terms of their areas' error calculations was the 'Bare soil' and the 'Wetland' classes. The latter class' misclassifications were mainly into one of the fynbos classes but makes up only 5111 ha. With ground based analyses of wetland boundaries the class' classification can be improved. The 'Bare soil' class as mentioned before was misclassified as agriculture since the model did not discriminate between land use and land cover. One could say that the model was not entirely wrong in that it classified what the rules defined, that being open bare patches of low to no vegetation cover. The classification would not be considerably affected since the classification still showed where natural vegetation has been removed, either through erosion or through ploughing new or existing farm lands.

The errors between the 'Temporary non-irrigated strip' and the 'Temporary non-irrigated plain' classes were predominantly amongst each other. As mentioned the defining strip-like structure can be difficult to distinguish on the SPOT 5 imagery. The implications of this are that one can get an inaccurate calculation on the total surface area of crops such as rooibos and grains. However if one is only looking at the encroachment of agricultural practises on the natural vegetation, the fact that both the above classes are not irrigated will mean their impacts will be similar.

The 'Temporary irrigated' class has an error of 100%. However the class was only found in one instance and one cannot make clear assumptions on this result. The 'Temporary irrigated' class was digitised using high resolution imagery as a reference and classification of the class was successful.

The 'Permanent agriculture' class has an error of 30.4% and can be mainly attributed to misclassifications of either wetlands or other agricultural classes. Improvement of the model for the 7921 ha that were misclassified would be required. The impact in terms the effects on removal of the natural would be negligible. The additional extraction of ground water and canal abstraction would need top measured but would be beyond the scopes of this study.

To conclude, the errors apparent in the classes are predominantly caused by misclassifications of classes in a similar group, such as another form of natural vegetation or agricultural class. Through the course of Section 5.3 the accuracy pitfalls and achievements have been detailed and one can make conclusions on where the strengths lie in using a model such as the one used to classify land cover of the Sandveld.

$$= (\frac{195}{278} * 100)$$

$$= 70.1\%$$

The overall accuracy has thus been calculated as 70.1% by taking the quotient of the total number of cells correctly classified by the model (195) against the total number of random sample cells (278). The overall accuracy gives an indication on the successfulness of the classification as a whole but does not take into account individual classes nor does it indicate the level of agreement between the two observers. The following sections will discuss the errors of commission and omission as well the kappa index. The interpretation of the accuracy assessment will be discussed in Section 5.3.6.

5.3.4   Errors of commission and omission

The error of omission is calculated as a percentage of the number of sample points that should have been classified into a particular class but were not (row cells). The error of commission is calculated as the percentage of sample points that were placed into a given class when the in fact they belong to another (column cells). Another way of expressing errors of commission and omission is in terms of user's accuracy and producer's accuracy. User's accuracy is shown as the likelihood that a given sample point will appear in reality (on the ground) as it was classified (percentage correct for each row divided by the total for that row). The producer's accuracy is represented as a percentage of each class on the map that is correctly classified (the percentage correct for each column divided by the total for that column) (Debrowski 2006).

The first class, 'Temporary non-irrigated plain' will be considered as an example of the errors of commission and omission. The error of commission is calculated as the total number of sample points correctly modelled as 'Temporary non-irrigated plain' (27) divided by the total number of times the class occurred in reality or the row total (45). The remaining 18 sample points out of the total of 45 were incorrectly excluded from 'Temporary non-irrigated plain' due to classification error. The class' error of commission is consequently 60.0% (user's accuracy). The column total

will be the accuracy of the map according to the person who created the map (producer's accuracy). The column total shows the total number of sample points (38). 27 out of 38 cells were correctly classified as 'Temporary non-irrigated plain' and 11 sample points or 28.9% were incorrectly included into classes into which they do not belong (Senseman et al 1995: 14).

5.3.5   Kappa calculation

Cohen's kappa index is used to measure the level of agreement between two raters in a given classification. The kappa value gives a score of how much consensus there is in the results given by the raters. In other words, is there an agreement between the two observers in terms of the results calculated? The measure of agreement based on Cohen's kappa has been taken from Landis & Koch (1997). Kappa (К) measures the agreement between two evaluations when both are classifying the same objects. In the case of the Sandveld land cover classification it will be the agreement between what was classified by the model against what was observed in reality. If К = 1 then the two observers are in complete agreement. If К = -1 then there is a perfect disagreement between the observers. К = 0 indicates that there is no relationship between the two evaluations and thus there are discrepancies in the data used. In-between there are the varying levels of agreement.

The calculation of Cohen's kappa agreement takes into account the agreement occurring by chance and is thus calculated using the tabled results. Cohen's kappa measures the agreement between two raters or evaluators, who classify N samples into C mutually exclusive classes. The equation to calculate kappa uses the formula:

$$К = \frac{Pr\,(\Omega) - Pr\,(\Psi)}{1 - Pr\,(\Psi)}$$

The starting point in calculating the accuracy of the classification is to conduct a basic overall accuracy assessment. This is calculated as:

$$\left(\frac{D}{N} * 100\right)$$

Where:

Pr (Ω)	Relative observed agreement among evaluators. Calculated by the sum of diagonal values in the error matrix divided by the total sample size
Pr (Ψ)	Probability that agreement is due to chance. Calculated by the sum of (product of row and column totals for each class) divided by the total sample size

5.3.6   Interpretation of classification accuracy

Conclusions regarding the accuracy of classification results are underpinned by Tables 5.1 and 5.2. A map's "fitness for use" for a particular application is determined by the quantifiable measures of data accuracy and reliability (Thompson et al. 2001). Thompson et al. (2001) also stated that although there are minimum mapping accuracy targets, there is no single universally accepted standard. Classification accuracy targets can range from 80% to 90% depending on the end-user's requirements. Anderson et al. (1976) however stated that an accuracy of 85% should be obtained in a given classification. It was the aim of this study to reach a accuracy result of 85% however this was not met due to varying constraints and technical challenges. The accuracy assessment calculations in Section 5.3.1 gave a Kappa Index of 0.658 and total overall accuracy of 70.1%. The core aim of this study has been to determine if the model's methodology was able to classify land cover at a fine scale. The results of the accuracy assessment have indicated that the final accuracy is 14.9% off Anderson et al. (1976)'s benchmark of 85%. When the classification is separated into each class, one can make the following conclusions: of the 16 land cover classes, seven obtained an accuracy of 70%, five between 60% and 70% and four were at 50% or below. In the coming paragraphs the classes are discussed according to their accuracy results and how their result can be improved on.

Firstly, classes with the largest number of incorrectly classified cells will be discussed, followed by those with the highest degree of classification accuracy – i.e. the least number of misclassifications. In Table 5.1 the two classes with the highest error percentage are 'Bare soil' (41%) and 'Wetland' (43%). Regarding the former class, consider that the model does not classify land use, but specifically land cover. Therefore the spectral and textural characteristics will remain the same as for any relatively smooth-textured cover such as old fields. Hence the in-between strips of strip-cultivated rooibos, fallow irrigated fields or shadows in rocky mountainous areas can affect the model to classify bare soil. Wetland boundaries are difficult to determine from spectral characteristics as their plant structure may yield NDVI values similar to other areas of natural vegetation. Wetland boundaries are notoriously evanescent along the edges where a wetland ends and where normal drier vegetation begins. Consequently, the classified polygons of either may overlap. Wetland areas may also be interspersed with notable expanses of river sand that affect the spectral signature of the polygons in which they occur. Both these classes are closely correlated since both contain interspersed natural vegetation and bare soil. To combat misclassification, "seed generation" using locational rules in relation to rivers for the 'wetland' class, for example, may

help. This needs insurance that the 'river' class is correctly classified. Bare soil patches can occur in any area and remain a very difficult class to classify distinctly.

The second highest misclassified group includes the 'Permanent agriculture', 'Low fynbos' and 'High fynbos' classes. The 'Permanent agriculture' class includes vineyards and orchards. Of the 30.4% misclassified polygons in the 'Permanent agriculture' class, most were classified as "Temporary non-irrigated plain'. The high percentage of this class owes to the fact that the plain-like structure of some fields may take on a similar "block" -like shape to the vineyards and orchards as well the fact that some vineyards may not be actively cultivated and thus give a similar spectral signature to the 'Temporary non-irrigated – plain' class. The 'Low fynbos' and 'High fynbos' class were both interchangeably confused by the model since there is by nature a very fine difference in the spectral signature between all the fynbos classes. The spectral range for each fynbos level should be within more defined parameters with a large enough gap between them to ensure that there is no overlap. A possibility for a more refined classification would be to conduct another classification on only the natural classes and set very definitive rules for each class. This process would however require significantly more time and investment on a technical front.

The remaining misclassified classes have an average error of 26.25% and include 'Temporary non-irrigated – plain', 'Temporary non-irrigated – strip', 'Medium fynbos' and 'Roads'. The first two agricultural classes were both classified incorrectly (confused) in some instances as each other. The narrow linear structure of the strip class may be extremely faint on the SPOT imagery at this 2.5 m resolution. This is evident in the eastern section where Soutbos strips are used to separate rooibos strips particularly and cannot be clearly distinguished on the imagery. The 'medium fynbos' often has a spectral signature and NDVI value in the same parameter range as other classes including 'Temporary irrigated crops'. Additional experimentation to determine more exact spectral characteristics of the natural vegetation classes may help to improve classification accuracy. 'Roads' as a linear feature was misclassified as 'Urban structure' and 'High fynbos'. This may be due to the resolution of the imagery that can affect the classification of narrow linear features, or some 'mixing' of designation along the roads. Imagery with a higher resolution might compensate for the narrowness of linear features, but this solution for a large study area may not be practical due to the size of the resultant datasets.

To conclude, it is argued that an automated classification at the scale used throughout the research has been relatively successful but with some technical challenges. When classifying land cover of an area where natural vegetation dominates, a spectral signature "dictionary" could be the solution.

Prior to classification, a considerable amount of time should be spent on investigating the exact values of varying types of vegetation according to their brightness, textural and NDVI values. Also, these need to be studied inter-seasonally since vegetation undergoes change through the course of a year. Such spectral signatures should also consider the range of agricultural vegetation in particular.

5.4   LAND COVER PATTERN ASSESSMENT

When studying the land cover of an area, the land cover patterns that have arisen as a result of human intervention must be identified. In some cases, fragmented natural areas have been preserved and remain in their natural state, but the long-term effects of containing natural fragments in smaller areas has no doubt affected its biodiversity. In this attempt to classify the north-west Sandveld's land cover the patterns and possible reasons for the patterns must be analysed and discussed. Assumptions on impacts on biodiversity can be made using a map of suitable accuracy and resolution.

5.4.1   Agriculture

Agricultural practices in the Sandveld have been the most detrimental human activity to the well-being of the natural biodiversity and they are regarded as the major agent in habitat transformation in the CFR (Rouget et al. 2003). The land cover map shows that the greater part of invasive agricultural practices have occurred on the flatter lowland areas. The varying impacts on the landscape of the various types of agriculture are treated below.

5.4.1.1   Temporary non-irrigated strip agriculture

According to the Sustainable Rooibos Initiative (Hansen 2006) approximately 36 000 ha of rooibos is currently planted in the Western Cape, most of which is in the Greater Cederberg Biodiversity Corridor (GCBC). But the total rooibos footprint is 60 000 ha, and includes fields not currently in production, which are rotated every two years (Hansen 2006). The Cape Nature report notes that due to environmental concerns, the footprint is expanding into the Redelinghuys area of the Sandveld. From Figure D1, it is evident that the majority rooibos plantings between Graafwater and the Olifants River. The map shows that temporary non-irrigated strip agriculture grown is predominant in the Redelinghuys area with most of the production occurring between Graafwater and Vredendal. The total area of strip cultivation calculated from the land cover is 105 246 ha (or 13% of the study area), an area considerably larger than that reported by Hansen 2006. The large difference can be ascribed to strip-cultivated areas not necessarily being rooibos tea plantations and that Hansen reviewed a smaller study area. There are many examples throughout the north-west

Sandveld study area of other crops being grown, including grains such as barley. Figure 5.9 shows an example of a grain cereal crop other than rooibos being grown in the strip-like structure.

Figure 5.9 Crops other than rooibos grown in a strip structure

Because rooibos is endemic to South Africa, the international demand for production of the beverage has resulted in a surge in the local areas under rooibos cultivation. In some instances strips of natural vegetation are left between the cultivated strips (see Figure 5.9 as example) and these can provide corridors to small pockets of natural areas. The linear corridors between patches improve connectedness and facilitate organism dispersal – in contrast to an inhospitable matrix of unsuitable land cover types such as heavily degraded and transformed land and physical barriers which inhibit organism dispersal (Griffiths & Eversham 2000). Conversely, what is often the case and shown in Figure 5.10 is wide strips of natural vegetation cleared to make way for large plantations of rooibos and separated only by narrow strips of planted or natural vegetation. The possibility of linking fragmented landscapes is slight in such cases. For example, invertebrate dispersal is more likely to occur in a landscape structure shown in Figure 5.9 than in Figure 5.10. Many insect species, including important pollinators of rare plants will not cross large agricultural fields, and others move seasonally between hills and flatlands along routes that still have natural vegetation where they can feed and find shelter (Knight, Conrad & Helme 2008). Another motivation for creating wider strips in fields is to promote the veld's recovery to its natural state should plantings be abandoned.

Figure 5.10 Rooibos cultivation showing narrow strips of planted or natural vegetation

It is likely that the global recession's toll on the world economy will cause rooibos production to decrease and this will be reflected in the area cultivated despite rooibos's gaining popularity due to its many health benefits. Threats to rooibos production include global warming (decreasing rainfall and increasing temperatures), strength of the Rand, increasing production costs, fluctuating demand and supply, high finance costs and lack of government support (subsidies) (Hansen 2006).

The way to ensure the existence of harmonious systems involving man and nature is through the active involvement of all role players. The best way to achieve satisfactory results is to design economic (and social) benefits to farmers who engage in conservation. Hansen (2006) has described a set of mitigation ideas for biodiversity guidelines. These include establishing a set of biodiversity guidelines; developing an incentive system for compliant 'champions'; encouraging values-driven marketing; promoting value addition in South Africa; and opening new markets through the sustainable production angle. A balance between the development of new plantations which increase the economic benefit and the well-being of biodiversity must be carefully managed. Fortunately, the possibility for the two to coexist in harmony is high.

5.4.1.2   Temporary irrigated agriculture

Centre-pivot irrigation agriculture that constitutes most of the temporary agricultural class, is an interesting and dynamic one because its growth has been so pronounced. There are various types of agricultural classes employing centre-pivot irrigation systems with a predominance of potato cultivation.

Potato production is the core economic activity in the Western Cape Sandveld (Knight, Conrad & Helme 2008). The industry has grown appreciably since 1990 and the attendant threats to the Sandveld region have become severe. The number of centre-pivot fields in the potato-production area of the Sandveld totals, according to Knight, Conrad & Helme (2008) 30 740 ha. The growing incidence of centre-pivot irrigated agriculture has placed a great deal of pressure on the natural biodiversity of the region and it is crucial that such rapid growth be slowed to limit the amount of damage done. Inspection of Figure 5.11 shows the expansiveness of the centre pivot class. The total calculated area is 29 662 ha, which corresponds closely with the figure given by Knight, Conrad & Helme (2008).

Source: Ranger (2010)

Figure 5.11 Aerial view of the Sandveld potato production

Most centre-pivot irrigation occurs in the western section of the study area, predominantly in the Verlorenvlei and Jakkals River areas as well as between the Elands Bay and Lamberts Bay areas. Historically increasing potato farming in the Sandveld area is attributable to many factors. A main driver of increased potato production in the Sandveld was the introduction of bulk electricity supplies by Eskom in the 1980s. The result was the ability to drive large centre-pivot irrigation systems, as well as to pump large volumes of groundwater for irrigation into the arid landscape (Lewarne 2009). Other factors that made the Sandveld an attractive place for potato farming are the conversion of the Lamberts Bay fish factory into a potato-processing plant and cannery, the good sandy soil, groundwater availability, and the limited disease potential of crops (Lewarne 2009).

To strike successful balance between the agricultural practices and the environmental concerns, the needs of the farmers, retailers, government and the conservation organisations have to be addressed. A best practise initiative, the Biodiversity Best Practice Guidelines for Potato Production in the

Sandveld, was designed to give examples and information to all those concerned about potato production with biodiversity-friendly practices. Although no financial incentives are currently being given, farmers are recognised as being a best practise producer at different levels depending on how they adopt biodiversity-friendly measures. The system has been proposed as an attempt to recognise good work (Knight, Conrad & Helme 2010).

To forcefully minimize the effects agriculture has on the environment, water extraction laws have been implemented. The minimum requirements have been set by legislation concerning water abstraction and ploughing and are not considered as best practice since full compliance is the law (Ranger 2010). Since one can enforce biodiversity practises by law, best practice guidelines are aids with which the attitudes of those affecting biodiversity are encouraged to preserve the country's natural heritage.

To reduce the over abstraction of water from natural sources, the National Water Act (South Africa 1998) has numerous regulations that are enforcing the unlawful use of water in catchment areas. These include the establishment of catchment management agencies (CMAs) and water user's associations (WUAs) who will be responsible for the monitoring and management of water issues on a catchment basis. Water, including ground water and water from dams, is no longer considered a 'bottomless' resource and is strictly controlled to limit over extraction for irrigation. The present ruling in the Sandveld is that no additional water may be abstracted unless a licence is obtained from Department of Water Affairs (DWAF) (Knight, Conrad & Helme 2008).

As pristine land is ploughed, the loss of biodiversity increases and this is the single most important activity leading to loss of biodiversity in the Sandveld (Knight, Conrad & Helme 2008). The clearing of new or virgin land is a listed activity under the National Environmental Management Act (NEMA) South Africa (1998), requiring a basic environmental assessment (BA) or scoping and environmental impact assessment (EIA). Activity 12 in Government Notice number R386 of 21 April 2006:11 reads as follows:

"*The transformation or removal of indigenous vegetation of 3 hectares or more or of any size where the transformation or removal would occur within a critically endangered or an endangered ecosystem listed in terms of section 52 of the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004):*
Areas <20 Ha – BA
Areas >20 Ha – EIA"

According to the class areas calculated for the study area, the centre-pivot irrigated agriculture only makes up 4% of the total area, but has the most disastrous effects. To mitigate damage already done and minimize the negative impacts of any new growth, very stringent regulations are needed. More importantly, they must be enforced to ensure full compliance. One such measure is to continue using remotely-sensed imagery to get a full perspective of the current structure of the landscape. Comparative studies with older images will show up farmers who have not complied with guidelines and stipulations. Using locally-derived information such as groundwater quality and levels as well as information gained from the stewardship programme from the GCBC, a detailed report can be compiled on a regular basis by CapeNature. From the evidence available those that choose to ignore the rules can be prosecuted and those that comply applauded or compensated.

5.4.1.3 Temporary non-irrigated plain agriculture

The 'non-irrigated' or field class comprises agriculture that does not require any irrigation. Most of the remaining areas that are no longer in their natural state have been converted to rain-fed agriculture. Predominantly under grains and cultivated grazing, these areas are highly transformed and have not been considered for conservation since they cannot be converted back to their natural states. The 'non-irrigated agriculture plain' class makes up 8% of the study area and covers an area of 64 144 ha. This type of land cover mainly occurs in the western section of the Sandveld area and is interspersed with strip and centre-pivot irrigated agriculture. It is noteworthy that although rain-fed agriculture is not a fast growing industry, there has been a trend by farmers to convert their land into centre-pivot irrigated fields. One can deduce this from examples where a centre- pivot irrigated field lies amidst a field for a rain fed crop that has been left fallow. Figure 5.12 shows the structure of the 'non-irrigated' agriculture class, with wheat being grown. The plain-like structure of the crop is spectrally different to the neighbouring natural areas in the background (top right).

Source: Job et al. (2008:58)

Figure 5.12 Typical wheat field classified as temporary plain agriculture with strips in the top left

Looking at the structure and size of these fields it is clear that although it may be possible to convert some areas back to their natural state, it is unlikely and the best possible solution is to limit any further expansion and ensure connectivity between the fragments of natural areas that remain.

5.4.1.4   Permanent agriculture

'Permanent agriculture' is the term used to classify the orchards and vineyards found in the northern and eastern sections of the study area. Vineyards predominantly occur along the Olifants River where a canal services the vineyard area and water pumped from the Olifants River adds water supplies to the region along its banks. In the Cederberg region around areas of Citrusdal, citrus orchards prevail. Most of the permanent agriculture occurs along the Olifants River banks where citrus, grapes and deciduous fruit are grown (Low, Mustart & Van Der Merwe 2004). To support these various types of agriculture a series of canals has been built to allow for adequate water distribution by 120 km of main canals and 60 km of distribution canals (Low, Mustart & Van Der Merwe 2004).

The total area classified as 'permanent agriculture' is 26 058 ha and making up 3% of the study area. Like the centre-pivot irrigated class, the permanent agriculture class does not account for a large proportion of the Sandveld land cover, but its impacts on biodiversity are considerable. The Olifants River flood plain has been severely reduced in extent due to the encroachment of agricultural activities, primarily the cultivation of vines, tomatoes and potatoes, often right up to the river's edge (Job et al. 2008). Vineyards and citrus orchards can be considered as permanent features with limited if any possibility of their being converted to a natural state. The main cause for concern is the increasing quantities of water being extracted from the Olifants and Doring Rivers and from the canal system.

Figure 5.13 shows the typical landscape structure along the Olifants River, stretching from Citrusdal through Clanwilliam and Vredendal up to the Olifants River mouth. The Olifants River flow rates fluctuate depending on rainfall. Orchards visible in the top right of Figure 5.13 are common in the Clanwilliam area while production of wine and table grapes mainly occur in the lower reaches of the Olifants River.

Source: Job et al. (2008:40)

Figure 5.13 Olifants River near Clanwilliam showing orchards on river banks

Since it is not possible to convert these areas to their natural states, their effects regarding water abstraction need to be closely monitored. Lack of water availabilty to natural species facilitates an increase in alien species growth and decreases in vigour of the natural species. The areas where the viticultivation exist are a semi-arid karoo type biome so great care must be taken to prevent degradation of the landscape into an arid ecosystem. Strict application of water abstraction laws is called for to prevent further negative impacts on the region.

5.4.2   Natural Vegetation

The 'natural vegetation' class has been subdivided into three subclasses according to the spectral values of brightness and their NDVIs. The three natural vegetation classes make up 61% of the study area land cover and this bodes well for conservation efforts. The total area of the natural vegetation classes is 501 025 ha. The areas in the eastern section have largely been preserved due to a bias in planning reserves in the past. However in the lower coastal areas of the western section, the natural areas are highly fragmented due to overzealous expansion of agricultural activities. Some areas that have been classified as natural vegetation are actually used for livestock grazing as shown in Figure 5.14. The satellite imagery shows natural patches of land cover whereas the land use is agriculture. These areas offer good opportunities for rehabilitation because over time alien invasive species can be reduced and natural grasses allowed to grow.

Figure 5.14 Natural vegetation with livestock grazing

The issue of the high level of fragmentation of the Sandveld area re-emerges. It is imperative to ascertain from the natural vegetation land cover class how severely fragmented the landscape is due to the increases in the various agricultural practices. The discussion of the landscape structure of the previous three agricultural classes, confirms a pressing need for the natural areas to be connected somehow to allow a connection of the biodiversity of the Sandveld. A biodiversity corridor is a mosaic of land uses connecting fragments of natural habitat across a landscape (Greater Cederberg Biodiversity Corridor Planning Phase Report s.a.). Corridors enable the gene flow between populations of an area ensuring the longevity of species. The conservation status for most parts of the CFR is low and urgent attention to preserve its natural biodiversity is required. Threats to habitat loss are high, with the Leipoldtville sand fynbos having at least half its area ploughed for agriculture (potatoes and rooibos) (Low, Mustart & Van Der Merwe 2004).

High fynbos areas in mountainous regions of the study area are in general, adequately conserved in the CFR (Low, Mustart & Van der Merwe 2004). The natural areas covering the Cederberg have mainly remained in pristine condition principally because of the rugged terrain and thanks to the area already being a protected reserve. The dominance of natural vegetation throughout the eastern section testifies to the area being well preserved. Inappropriate fire regimes, alien flora invasions and overgrazing in certain areas are current threats to the Sandveld (Low, Mustart & Van der Merwe 2004). Habitats that are relatively free of human activities or transformation are self-protected to a large extent by their harsh environmental characteristics (Rouget et al. 2003). Figure 5.15 shows the typical landscape structure of these areas. Rocky outcrops and steep slopes make for easy preservation of natural areas.

Source: Helme (2007:39)

Figure 5.15 The Cederberg area at the Piekenierskloof Pass

One can deduce from the final land cover map that the main areas where connectivity could take place are those where temporary non-irrigated strip cultivation exists. Although the surface area calculations show that temporary irrigated centre-pivot agriculture occupies a smaller area (13%) than many of the other classes, the detrimental effects that the class has is very severe in relation to impacts on biodiversity. These effects are amplified by the rate at which new centre-pivot circles are started and the growing volumes of groundwater they demand. The areas in the Leipoldtville region known as Leipoldtville sand fynbos have been heavily targeted for agriculture, as the deep, acid, sandy soils are ideal for rooibos and potato cultivation (Helme 2007).

In the northern section of the north-west Sandveld natural vegetation is still widespread with all the transformation having taken place along the Olifants River. Mining is common in the northern section and creates areas of bare soil. According to Helme (2007), mining is a threat to this area, along with overgrazing and strip ploughing. To prevent further transformation of natural areas, habitats that are susceptible to future transformation should be prioritised in conservation actions (Rouget et al. 2003). Thus areas in the northern part of the western section and those along river banks and wetlands not already transformed, must receive environmental protection.

5.4.3   Non-agricultural human activities

The non-agricultural activities in the north-west Sandveld are only a secondary focus of the study and are therefore overviewed briefly. The landscape structure has been severely impacted by agricultural activities through removal of the natural vegetation for agricultural fields. Urban areas

and other built-up zones have affected the environmental landscape structure to a lesser degree. Problems such as increasing poverty and swelling populations will no doubt play a role. Informal settlements can grow rapidly without effective planning resulting in surface run-off problems and waste-management issues. In areas where there is a severe lack of services, vegetation resources can be exploited by urban dwellers for firewood and building material thereby increasing the potential degradation of vegetation on or near urban boundaries. Elands Bay is a local example of how urban areas can affect both natural areas and wetland areas in a rural setting. Vredendal has an informal settlement that is encroaching on the natural areas. Utilities such as roads and railways have indirect negative impacts on the areas directly bordering them, particularly regarding veld fires. Cigarette butts thrown from cars easily set alight dry grass on road verges. Burning of natural vegetation plays an integral role in the fynbos biome. Too-frequent fires disrupt the delicate balance of the ecosystem, and also destroying invertebrates essential for pollinating, reptiles, small mammals and birds. Burnt areas make up 7 785 ha in the study area. Fire scar mapping is an essential tool for analysing ecosystem function. Litter will also affect the area especially as it can be ingested by animals; chemicals can run off into streams and degrades the aesthetic values of the area. Canals have been a very important driver in growth of agriculture in the upper reaches of the Olifants River. It is difficult to determine the non-agricultural impacts because the activities make up such a small proportion (1%) of the study area. One requires an in-depth ground survey coupled with a long archive of satellite imagery to determine their impacts on the surrounding areas.

Chapter 5 has been a very important one in analysing the model used in the classification to determine the environmental impacts on the Sandveld. The model was applied to three broad areas where a certain rule-base was applicable. The rules' successfulness could be determined by considering how they classified and misclassified all classes in each sub-section. Proceeding from the visual analysis, the accuracy assessment can be conducted. The overall accuracy of the classification was 70% with a kappa index of 0.658. Classification accuracy could be improved on by collecting a large archive of historical imagery combined with the current dataset to superimpose on one another. The boundary lines' changes over time can be extracted using an edge detection and reclassified.

In analysing the land cover patterns, it has been confirmed that there are three all-encompassing land cover types interacting with each other. Agriculture, natural vegetation and non-agricultural human activities are intertwined with each other to create the dynamic landscape of the Sandveld. It is through the course of Chapter 6 that these interactions will be analysed in terms of how they have

affected the landscape structure and how the effective model used has been in facilitating this analysis.

CHAPTER 6: MOVING FORWARD

The concluding remarks and discussion in Chapter 6 will examine the viability of the processing steps taken to classify land cover of the north-west Sandveld to use as a tool in determining the environmental impacts. The concluding remarks will be made about the possibility for further study using the results of the research.

To begin, the primary aim of the study is revisited, namely; to demonstrate that a semi-automated, fine-scale land cover classification using an object-oriented image analysis is applicable to a large local area to examine the environmental issues prevailing in the Sandveld is possible. Finally, this aim will be taken into account to determine whether the study's objectives have been reached.

6.1   THE DEVELOPMENT OF THE MODEL USED

For a study in which a very large area is to be analysed, the procedural steps taken need to be systematically planned and implemented to achieve an adequate result. The model or plan must be designed so that the application can be replicated. The first objective of the present study was to delineate the study area and to obtain the required satellite imagery. Obtaining and preparing the imagery required an appropriate level of remote sensing knowledge to determine the correct imagery to use and the relevant processing steps. The SPOT 5 imagery was selected on the grounds of the resolution offered by the satellite, the availability of the imagery and the costs to acquire the images. The study's results have demonstrated that the 2.5 m resolution of the imagery is adequate for a fine-scale analysis of the large area involved. Any finer resolution and the large datasets generated would exceed the capacity of available hardware; any coarser resolution and lower level of detail would be insufficient for a fine-scale analysis.

The second objective was to define the land cover classes for the intended classification. The differences between land use and land cover were emphasised to ensure an understanding of the distinction. Once the classes had been defined, the classification process could proceed. Achievement of the second objective was the departure point of the third objective which was to develop the model to classify land cover classes using a semi-automated model. Before the steps of eCognition could be implemented, many complimentary steps to produce layers for assisting the classification had to be executed. Border and frame are two important layers that assisted in producing reliable results after the segmentation. The border and frame layers enhanced the edges of areas where the edge was imperative in defining the classes. Eventually the classes that needed

enhanced edge detection were the temporary non-irrigated strip class and the permanent agriculture class that comprised vineyards and orchards.

The rationale for the classification being a semi-automated procedure is that to classify certain classes a manual intervention was needed. The manual intervention took the form of digitising linear classes as well as centre-pivot irrigated fields. The classes that were digitised were problematic regarding their contrast to neighbouring classes. Because the border and frame layers did not successfully extract the edges of these classes, they were digitised to ensure accuracy. An option for doing edge detections for these classes is presented later.

The fourth objective was to implement the model on the imagery to classify the land cover classes. An accuracy assessment testified that the classification was done successfully. Comparisons of the calculated areas with those given in the literature indicated that the use of an object-oriented methodology to classify land cover over a large local area is a fitting approach. Doubtless further developments in the field of object-oriented classification and continued education about its benefits will provide more opportunities for the method's application. In Section 6.2 a discourse on the environmental assessments will be done and to make conclusions on the classification of the north-west Sandveld.

6.2   MODEL ASSESSMENT

Two fronts characterise the evaluation of the Sandveld classification: One is the technical aspect of classifying land cover and the second is to assess the results that the classification has yielded. These two technical aspects are discussed before the environmental results are addressed.

The analytical results show that a semi-automated classification model can classify the landscape structure of an area using satellite imagery with a resolution of 2.5 m. In particular, the object-oriented classification technique in eCognition accomplished this task. The question should be asked, however, if this type of classification methodology would succeed over a very large local area, because it raises a host of technical issues. Large areas cover a variety of vegetation types, topography and gradients. These variances cause the spectral signatures to differ from one area to the next. Variations in climate and gradient also affect the types of agriculture practiced in different areas. Furthermore, the imagery itself, by its technical nature, affects the reflectance characteristics of every object. When acquiring imagery over a large area, it is likely that the imagery for different dates will be needed. Discrepancies between images taken on different days, will ultimately affect the classification rules. With so many differences across the entire landscape, there can be no one

set of rules that can define every class in all areas. The result is that rules need to be divided across the landscape to ensure that all classes are accounted for in the classification.

To consider whether the classification has been efficacious or not, one must look at the results and their errors to conclude if using an object-oriented methodology is effective or not. In Chapter 5 the accuracy was calculated and yielded a KIA of 0.658 and an overall accuracy value of 70.1%. One needs to ask: was this a valuable result? The answer lies in the knowledge gained through the course of the research. In Chapter 5 the results were shown in Table 5.1 indicating the correctly and incorrectly classified percentages for each class and they are summarised here.

The most incorrectly classified classes were 'Bare soil' and 'Wetland'. It is easy for the two to be confused with each other since they both possess the same salient features. Bare soil patches and low (wetland) vegetation show similar NDVI, brightness and textural characteristics. To combat problems of this nature, the locational aspects of objects, like height above sea level, could be used. Wetlands would, in general, lie in lower areas than other bare soil patches and digital elevation models could be employed for this purpose.

In the agricultural classes, the majority of the misclassifications were due to the model grouping the crop spectral signatures into the same category as natural vegetation. In many instances limited shape characteristics of crop units make it difficult for the model rules to distinguish between classes. Table 5.1 showed that the majority of the errors were due to the model confusing the three different types of fynbos class. These three natural classes ('Low fynbos' (30.4%), 'Medium fynbos' (28.0%) and 'High fynbos' (30.6%)) were very close in accuracy terms: proving that there is no systematic confusion between them. As discussed in Section 5.3.3, the best possible solution to ensuring that vegetation is grouped into the correct class is to identify their spectral signature range using a collection of data. The data can include seasonally averaged NDVI values, brightness values and colour ranges. It is crucially important that the values are averaged across all seasons since it is not possible to obtain imagery at the exact date required. In order to obtain an average one would require a large volume of satellite imagery over many years in order to obtain enough cloud and haze free imagery over all seasons.

Looking at the errors of the classification and taking into consideration that the overall accuracy of the results was 70.1%, it can be deduced that the classification results were a success. As with most research applications, the scope for improvement is evident but lies mainly in fine tuning the model

to suit the imagery available. Increased time and resources will ensure progression of the model and will undoubtedly enhance classification system results.

6.3 THE ENVIRONMENTAL ASSESSMENT

Following the determination of the accuracy of the classification, conclusions about the environmental impact can be drawn. The final land cover map exhibited an overall distribution of the north-west Sandveld's land cover, which can be used as a departure to determine the threats to the area. The map can be used to analyse the landscape structure and make necessary conclusions. A first feature to look at is the areas worst affected by the impacts of human activities in the Sandveld. Agricultural activities rank as the main culprits.

6.3.1 Agricultural impacts

Agricultural activities are the most studied aspects of the Sandveld's landscape largely because they have the most detrimental impacts on the area. Direct loss of habitat has resulted from removal of natural vegetation to make way for agriculture and indirect losses have resulted from overgrazing. The growth of the centre-pivot irrigated agriculture has been the most invasive land cover class with 5000 to 6000 ha of potatoes being planted in the Sandveld annually (Knight, Conrad & Helme 2008). The impacts of this class are largely due to the nature of potato cultivation. Potato production is the core economic activity and employer in the Sandveld region, producing an annual turnover of R400 million and employing 3250 people (Ranger 2010). The rotation cycles are a five-year pattern, to combat plant diseases in the soil. This means that farmers require an increased footprint for one crop of productive potato farming. Figure 6.1 shows an expanse of centre-pivot irrigated croplands with many lying fallow and some being cultivated (green crops). Between each circle the fragmentation of the natural vegetation is clearly visible.
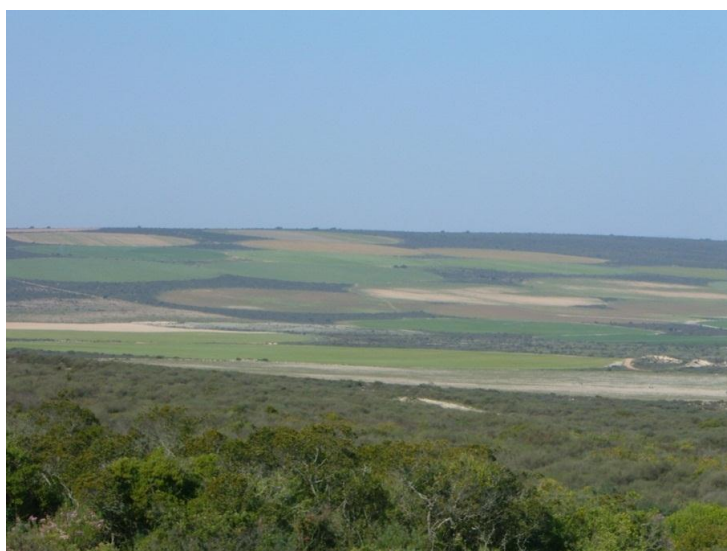
Figure 6.1 Sandveld centre-pivot irrigated agriculture

It is crucial to consider the economic activities of the area when making conservation decisions. The revenue created by potato production supports many people and beneficial causes in neither the economic front nor the environmental fronts will be promoted if job losses increase. Poverty, lack of education and poor attitudes of the Sandveld's inhabitants will only hinder efforts to conserve the natural biodiversity. Use of the map to locate the areas where environmental threats are severe due to invasive centre-pivot irrigated fields and advice on best-practice measures will help the Sandveld's inhabitants to understand the pressures the region is under. Once this understanding is gained by some innovative farmers, the ideas diffuse to other farmers, families and workers, thus promoting a progressive long-term attitude towards biodiversity and its preservation.

The second most invasive is temporary non-irrigated strip cultivation. The final land cover map shows that temporary non-irrigated strips make up the largest area agriculturally in the Sandveld. The main crop grown in strips is rooibos. Technically, the map shows that the protocol has successfully classified the land cover, with some misclassifications of the temporary non-irrigated strip class. Concerning its spectral characteristics, the class was clearly distinguishable with its light and dark alternating strips. The classification protocol was suitable for identifying strip farming and the only improvement would be to classify the temporary non-irrigated strip classes more accurately in mountainous areas.

Concerning the environmental impacts, the visual aspects are clear. Rooibos requires deep sandy well-drained soil hosting certain bacteria found only in the CFR (Pretorius 2008). Rooibos grows better at increased altitude, lower temperatures and soil mineral content (Pretorius 2008). As climate change is altering rainfall patterns and increasing average annual temperatures, along with increased global demand for rooibos products, rooibos cultivation has expanded to the Sandveld region. Evidence of this expansion is seen in the lower-lying coastal areas. Growth in the rooibos industry means more demands being placed on an already-sensitive ecosystem, and as the demand increases so will the pressures on and conflicts between farmers and those trying to conserve our natural biodiversity. As with potato farmers, legislation now forces rooibos farmers to comply with NEMA's and other prescriptions. There are also best-practice guidelines devised to encourage farmers to consider effects that farming will have on biodiversity. An adequate map that shows the extent of human activities and sustainable initiatives improves the possibility of fostering symbiotic relationships between the conflicting sectors. Figure 6.2 shows a typical rooibos strip plantation covering a large area. Dry-land agriculture fields occur in the background and there is evidence of fragmentation in between.

Source: C.A.P.E (2010)

Figure 6.2 Image of rooibos grown in strips

Vineyards as well as citrus and deciduous fruit orchards are a common feature along the Olifants River. These types of agriculture are considered to be permanent features since the option of rehabilitation is very limited. Although the footprint is well established, the overarching effects from water extraction and alien flora and fauna invasions have devastating effects on the biodiversity of the region. Buffer zones do not exist and as a result the surface run-off containing pesticides and fertilisers pollutes river systems. Two large in-stream dams (Clanwilliam and Bulshoek) act as barriers to fish migration, and rivers are over abstracted for irrigation and to fill hundreds of smaller farm dams (Darwall et al. 2009).

Concerning wine production, in November 1998, the Scheme for Integrated Production of Wine (IPW) was promulgated under the Act on Liquor Products 9 (Act No. 60 of 1989). Its aims are to produce quality fruit in an environment-friendly, sustainable manner (ARC 2010). The IPW is a voluntary scheme that gives producers the opportunity to market their products as being produced in an environment-friendly way. The Biodiversity and Wine Initiative (BWI) was set up to prevent further loss of habitat by co-opting the wine industry and the conservation sector. Wine producers have been encouraged to take part in sustainable wine production by adopting the IPW biodiversity guidelines set by the South African wine industry (Winter, Esler & Kidd 2005). Compounding human impacts on biodiversity is the effects urban dynamics have on negatively changing the landscape. This factor will be discussed next.

6.3.2   Urban Expansion

The extent of urban areas in the Sandveld is limited, since most of the towns in the north-west Sandveld study area are rural towns that support the area's agricultural activities. The main disturbances arising from urban dwellings are water abstraction, polluted run-off and loss of habitat through construction of new dwellings. Currently, the effects of agriculture far outweigh the effects of urban activities. It is the indirect impacts of urban activities that contribute to the loss of biodiversity, namely the potato-processing plant in Lamberts Bay and growth in industrial developments.

Not directly related to urban expansion is the illegal use of off-road vehicles through natural areas. It is important that a study be conducted to ascertain the extent and legality of these activities in the area (Low, Mustart & Van der Merwe 2004). Dunes are extremely sensitive to disturbances and vegetation is key to maintaining their stability. A study of this important activity to determine vegetation loss where this type of activity occurs is needed in which advanced edge detections can be applied to automatically identify and classify existing paths.

6.3.3   Natural prosperity

The rare natural vegetation of the Sandveld is the ultimate reason for extensive studies of the Sandveld. Sadly, the future of these areas hangs in the balance if adequate preservation measures are not implemented timeously. The Greater Cederberg Biodiversity Corridor project has been going to great lengths to preserve the natural biodiversity of the Sandveld by connecting areas of natural vegetation. The aim has been to create two contract nature reserves by the end of 2006 totalling 1569 hectares of the endangered Leipoldtville sand fynbos and the vulnerable Graafwater sandstone fynbos.

Figures 6.3 and 6.4 show the areas placed under some kind of conservation protection either through government or privately. The areas are limited in size and the proposed Cederberg Mega-Reserve will make a drastic improvement in the conservation status of the area by linking the smaller reserves. Scrutiny of both maps reveals that the possibility for reserves between Lamberts Bay and Vredendal is quite limited and ultimately the biodiversity of the area will remain under threat. The area, dominated by privately-owned farms, is already heavily fragmented. Consequently, there is only a limited opportunity for any kind of formal conservation status. Again, it is shifting attitudes of landowners that will assist conservationists in creating conservancies in the area.
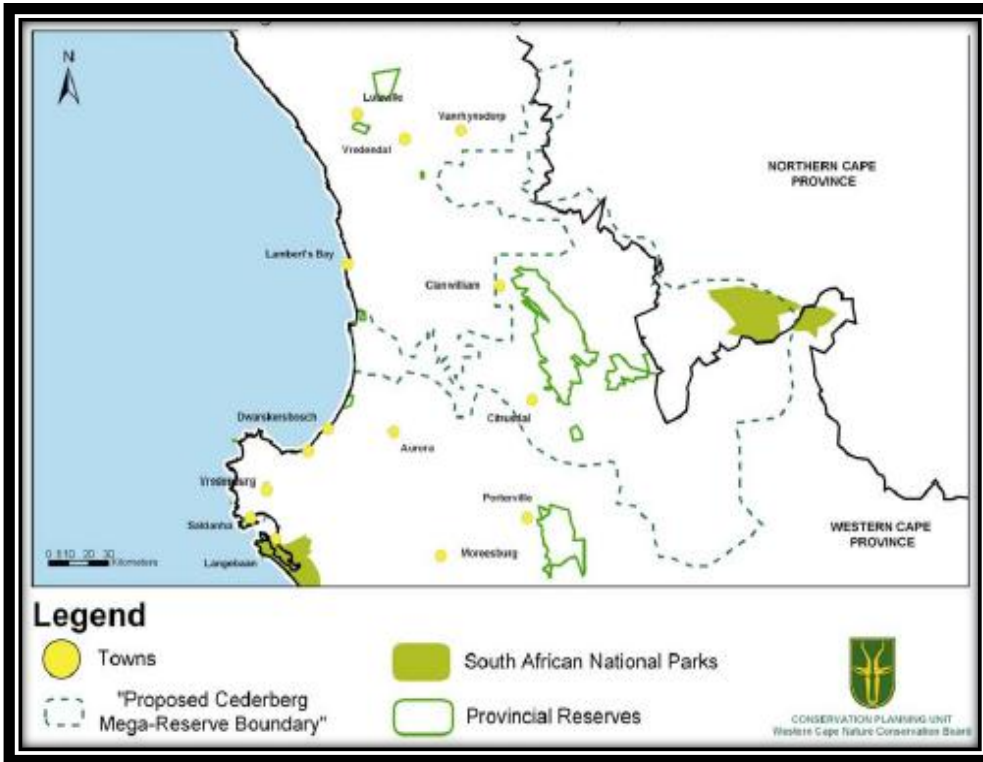
Source: Low, Mustart & Van Der Merwe (2004:58)

Figure 6.3 Greater Cederberg Biodiversity Corridor: Declared conservation areas
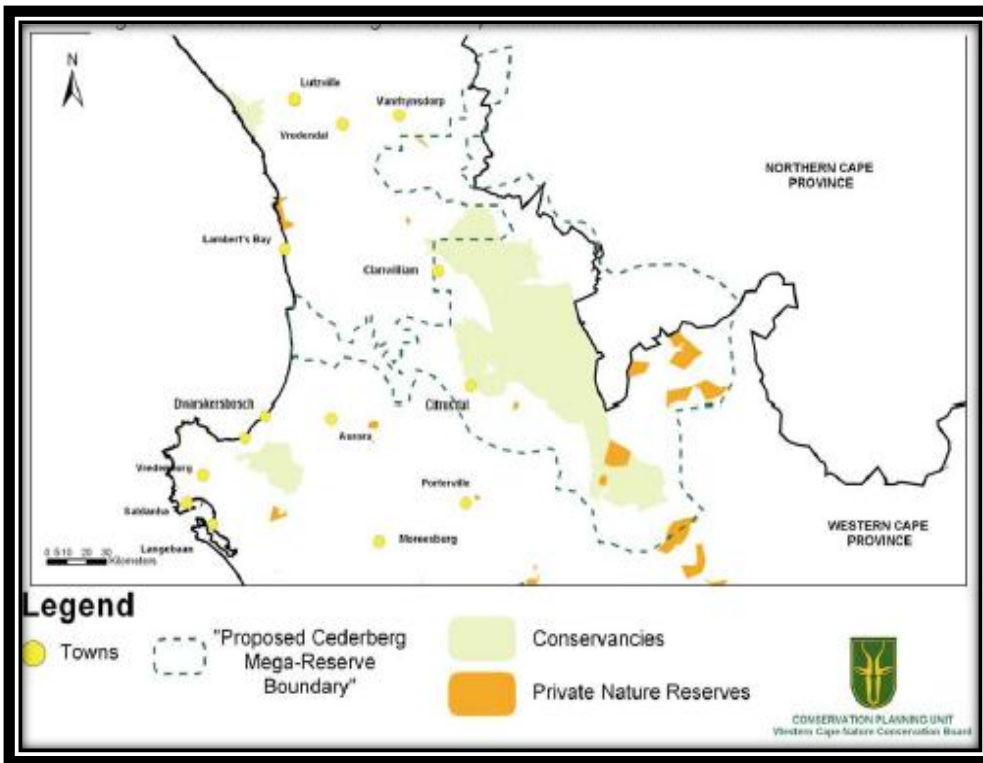
Source: Low, Mustart & Van Der Merwe (2004:59)

Figure 6.4 Private reserves and Conservancies in the Greater Cederberg Biodiversity Corridor

A limitation on the expansion of conserved areas is the effects of population dynamics. Poverty is a real threat to any conservation effort largely due to a lack of social structure and education. Efforts to involve local communities in conservation plans should be given a high priority. It makes no

sense to try to conserve natural areas if the people who live within it do not understand the accruing benefits. A possible solution to assist in preserving certain areas is to create conservancies in them. Conservancies can be rural natural areas, small spaces in an urban setting or industrial plots. Wherever land is managed according to sound environmental principles and best environmental practises, a conservancy may be registered (Conservancies 2011). A conservancy needs members that will ultimately drive the participation of all who reside within the area. In areas where formal conservation parks are not possible, the conservancies will assist in some preservation of the natural flora and fauna.

6.4   FOR FUTURE SCIENTISTS

Since many aspects of classifying the Sandveld's land cover were done on an experimental basis based on the assumption that an object-oriented classification can be done for a large area, the exercise evokes some suggestions for studies.

A first recommendation is to determine whether a fully-automated classification is possible without any user intervention for the number of classes handled here. A way to achieve this is to use satellite imagery for an extended period of time. The changes in agricultural areas from fallow to ploughed will facilitate suitable border extraction and edge detection within eCognition. The spectral and textural characteristics of the fields will change back and forth, allowing for their edges to be detected. The satellite images can be used in layers and weighted according to the requirements of the segmentation.

Second, the burnt area class offers an opportunity for a good time-series analysis. The CFR is a fire-driven system but the frequency of burning is important. Fires must occur in fynbos, but fires in the wrong season or too frequently eliminate species (Low & Rebelo 1996). Their importance to biodiversity richness is not fully understood. Mapping the extent of all burnt areas in a defined study area over a long-term period using archives of imagery will help to determine which areas have burnt and the frequency with which they have occurred. An historical overview of burning will give ecologists a good idea of how biodiversity is affected according to the number of burns over a given period. A botanical study coupled to a geographical one should yield volumes of useful information.

A third suggested study is to determine whether it is possible to extract linear features. Linear features include roads, rivers, railways, vineyard rows, strip cultivation and canals. The study should aim to get full edge detection in all classes. Linear extraction offers a range of possible

studies on both the technical and environmental fields. For example, the total surface area of vineyard rows can be determined for a given study area and from here the slope and aspect of the rows can be calculated as well the substrate type. Further, the surface run-off potential can be analysed and the effects on the surrounding areas determined.

The research possibilities are manifold in both the environmental and technical aspects, particularly in the South African context. There have been few studies conducted with proprietary software such as eCognition. Researchers should consider aspects such as time, available infrastructure and available educational resources before undertaking their studies.

6.5   FINAL REMARKS

The aim and objectives were set to accomplish an accurate classification of the north-west Sandveld's land cover to be used to analyse the environmental impacts of human activities. The steps taken to create a model and apply it to the study area have been discussed in detail. The model achieved results that show the landscape structure suitably enough to determine the impacts of human activities in the area.

The lack of sensitivity to the Cape Floral Kingdom, one of the world's most precious assets, has led to rapid and possibly devastating outcomes to the biodiversity of the Sandveld. Fortunately, this study's results have shown that in the north-west Sandveld, all is not lost given that 61% of the study area is still in its natural state in some way or another although some areas may be heavily over grazed or invaded severely with alien species. Continued conservation efforts will thus not be in vain. Through implementation of proper planning measures, the effects of human activities can be mitigated and over time the possibility of restoring a balance between man and nature is real.

The title of this final chapter; 'moving forward' means just that. We cannot stop progression and at the same time we cannot go back in time. Improper planning has led to the situation in which we currently find ourselves in, not only regarding biodiversity, but with the current environmental issue as a whole. This said, we human beings have recognized that the mistakes we made in the past can be slowly mitigated in the future. But, it will take time, it will call for effective planning measures and, most importantly it will demand the dedicated participation of all of us. If we all choose to make changes, however small, the rewards will be immense.

[36 050 words]

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APPENDIX A

Table A 1 Customised features for classification in eCognition

<u>Pan_BF</u>	**(Mean SPOT-pan)/((Mean Border) + (Mean Frame))**
	Disaggregates flat surfaces (low values)
	Distinguishes between dense tree stands and less dense tree stands (higher values)
Ratio_red	**(Mean SPOT-Red)/(Mean SPOT-Green)+(Mean SPOT-Red)+(Mean SPOT-NIR)+(Mean SPOT-SWIR)+(Mean SPOT-pan)**
	Distinguished between flat surfaces
	Forest also between natural forest (low) and plantations (higher)
	Clouds appear as high values
	Settlements appear as high values
Ratio_SWIR	**(Mean SPOT-SWIR)/((Mean SPOT-NIR)+(Mean SPOT-Green)+(Mean SPOT-pan)+(MeanSPOT-Red)+(Mean SPOT-SWIR))**
	Cloud shadows appear dark (low values)
	Pastureland appears light (high values)
	Water and roads appear dark (low values)
Norm_StdDev_Red	**(StdDev SPOT-Red)/(Area)$^{0.5}$**
	Bright areas are settlements and roads (occasional)
	Small defined plots appear bright
Zabut	**(((([Mean SPOT-Green]-[Mean SPOT-Red])^2) + (([Mean SPOT-red]-[Mean SPOT-NIR])^2 +(([Mean SPOT-NIR]-[Mean SPOT-SWIR]))^2))$^{(0.5)}$**
	Natural forests appear lighter
	Roads appear dark

Table A1 continued

NDVI	((Mean SPOT-SWIR)-(Mean SPOT-Red))/((Mean SPOT-Red)+(Mean SPOT-NIR))
	Clouds appear dark (low values)
	Bare soils appear dark
	Natural forest appears light
SDVI	((Mean SPOT-SWIR)-(Mean SPOT-NIR))/((Mean SPOT-SWIR)+(Mean SPOT-NIR))
	Bare soils appear light
	Natural forest appears dark
	Open veld appears light
Norm_StdDev_pan	$(StdDev\ SPOT\text{-}pan)/((area)^{(0.5)})$
	Built-up and roads appear bright
Norm_StdDev_NIR	$(StdDev\ SPOT\text{-}NIR)/((area)^{(0.5)})$
	Settlement areas appear mixed dark and bright
	Roads are differentiated as bright
Norm_StdDev_SWIR	$(StdDev\ SPOT\text{-}SWIR)/((area)^{(0.5)})$
	Areas with low differentiation appear dark i.e. open fields etc. mixed areas appear bright
Weighted_Bright	((Mean SPOT-Green)+(Mean SPOT-NIR)+(Mean SPOT-Pan)+(Mean SPOT- Red)+(Mean SPOT-SWIR))/5
	Dense forest stands appear dark
	Open spaces (vegetation) appear light
	Roads appear bright

Table A1 continued

ND_SWIR_NIR	**((Mean SPOT-SWIR)-(Mean SPOT-NIR))/((Mean SPOT-SWIR)+(Mean SPOT-NIR))**
	Dark patches represent natural forest areas
	Light areas are bare soil /open ground
	More dense forest stands appear lighter but difficult to differentiate Between natural forest
	Open ground appears light

APPENDIX B

Table B 1 Points visited with photo I.D code, class description and coordinates

ID	Photograph I.D	Class Description	X Coordinates	Y Coordinates
0	IMG_0340	DENSE NATURAL FYNBOS	18.64	-32.73
1	IMG_0347	FIELD	18.52	-32.45
2	IMG_0145	DENSE NATURAL FYNBOS	18.95	-32.35
3	IMG_0191	STRIP	18.65	-32.00
4	IMG_0167	ROOIBOS STRIP	18.76	-32.22
5	IMG_0179	DENSE NATURAL FYNBOS	18.59	-32.07
6	IMG_0283	WETLAND/AGRICULTURAL INFRASTRUCTURE	18.50	-31.70
7	IMG_0339	DENSE NATURAL FYNBOS	18.65	-32.72
8	IMG_0353	DENSE NATURAL FYNBOS	18.41	-32.29
9	IMG_0319	FIELD	18.71	-32.47
10	IMG_0172	PIVOT	18.44	-32.12
11	IMG_0298	NATURAL	18.54	-31.95
12	IMG_0111	ORCHARD	18.83	-32.34
13	IMG_0312	AGRICULTURAL INFRASTRUCTURE	18.45	-32.22
14	IMG_0175	DENSE NATURAL FYNBOS	18.32	-32.09
15	IMG_0266	LOW NATURAL FYNBOS	18.23	-31.67
16	IMG_0235	FIELD	18.65	-31.75
17	IMG_0291	VINYARD	18.58	-31.75
18	IMG_0304	DENSE NATURAL FYNBOS	18.36	32.04
19		NOT VISITED	18.94	-32.15
20		NOT VISITED	19.15	-32.63
21	IMG_0348	DEGRADED	18.50	-32.43
22	IMG_0193	STRIP ROOIBOS	18.67	-32.05
23	IMG_0135	URBAN – LOW-COST HOUSING	19.01	-32.57
24	IMG_0099	DENSE NATURAL FYNBOS	18.80	-32.47
25	IMG_0231	SANDY NATURAL	18.79	-32.02
26	IMG_0142	ORCHARD	18.95	-32.39
27	IMG_0133	FIELD	19.05	-32.69
28		NOT VISITED	19.09	-32.63
29	IMG_0146	DENSE NATURAL FYNBOS	18.94	-32.37
30	IMG_0103	DENSE NATURAL FYNBOS	18.74	-32.40
31	IMG_0129	DENSE NATURAL FYNBOS	19.03	-32.71
32	IMG_0102	DENSE NATURAL FYNBOS	18.73	-32.45
33	IMG_0251	LOW NATURAL	18.37	-31.56
34	IMG_0215	VEGETABLE FIELD	18.81	-32.02
35	IMG_0093	ROOIBOS FIELD DISPERSED	18.95	-32.62
36		NOT VISITED	18.94	-32.26
38	IMG_0158	ORCHARD	18.73	-32.23
39	IMG_0225	DEGRADED	18.63	-31.89
40	IMG_0098	ORCHARD	18.81	-32.47
41	IMG_0279	DISPERSED NATURAL	18.44	-31.80
42	IMG_0121	DENSE NATURAL WITH PORT JACKSON	18.97	-32.49
43	IMG_0119	ORCHARD	18.96	-32.47
44	IMG_0127	DENSE NATURAL WITH ALIENS	19.00	-32.62
45		NOT VISITED	19.02	-32.85
46	IMG_0299	NATURAL WITH SALINIZED IN BACKGROUND	18.56	-31.99

Continued overleaf

Table B1 continued

ID	Photograph I.D	Class Description	X Coordinates	Y Coordinates
47	IMG_0131	FIELD	19.06	-32.75
48	IMG_0177	DENSE NATURALWITH ALIENS	18.60	-32.13
49	IMG_0104	NATURAL	18.72	-32.38
50	IMG_0141	DENSE NATURAL FYNBOS	18.95	-32.41
51	IMG_0107	WETLAND	18.66	-32.32
52	IMG_0308	DISPERSED NATURAL	18.35	-32.20
53	IMG_0346	DENSE NATURAL FYNBOS	18.53	-32.49
54	IMG_0230	DENSE NATURAL FYNBOS	18.76	-31.99
55		NOT VISITED	18.92	-32.14
56	IMG_0168	STRIPS - SOUTBOS	18.61	-32.16
57	IMG_0240	VINYARD	18.54	-31.66
58	IMG_0278	STRIPS	18.44	-31.81
59	IMG_0226	NATURAL	18.65	-31.90
60	IMG_0192	NATURAL	18.66	-32.04
61	IMG_0288	VINEYARD	18.40	-31.63
62	IMG_0331	ROOIBOS FIELD	18.79	-32.64
63	IMG_0162	FIELD	18.62	-32.16
64	IMG_0196	ROOIBOS FIELD - POSSIBLY STRIPS	18.70	-32.09
65	IMG_0189	FIELD	18.63	-31.96
66	IMG_0179	STRIPS	18.59	-32.10
67	IMG_0202	WETLAND	18.87	-32.17
68	IMG_0281	STRIPS	18.49	-31.75
69	IMG_0272	LOW NATURAL	18.32	-31.84
70	IMG_0232	NATURAL	18.80	-32.05
71	IMG_0367	FIELD	18.41	-32.63
72	IMG_0253	LOW NATURAL WITH BARE SOIL	18.32	-31.55
73	IMG_0350	NATURAL	18.46	-32.37
74	IMG_0157	FIELD	18.74	-32.25
75	IMG_0311	ROAD/FIELD EDGE	18.43	-32.21
76	IMG_0176	FIELD	18.60	-32.14
77	IMG_0095	FIELD	18.89	-32.54
78	IMG_0150	NARROW FIELD	18.89	-32.28
79	IMG_0328	FIELD	18.79	-32.67
80	IMG_0159	SOUTBOS STRIP - NARROW	18.70	-32.22
82	IMG_0128	FIELD	19.02	-32.67
83	IMG_0114	ROOIBOS FIELD	18.86	-32.36
84	IMG_0136	FIELD/OLD FIELD	19.01	-32.55
85		NOT VISITED	19.12	-32.62
87	IMG_0198	NATURAL POSSIBLY DEGRADED	18.73	-32.13
88	IMG_0143	DENSE NATURAL FYNBOS	18.96	-32.37
89	IMG_0097	DENSE NATURAL FYNBOS	18.84	-32.50
90	IMG_0301	NATURAL	18.35	-31.97
91	IMG_0156	NATURAL	18.81	-32.27
92	IMG_0123	FIELD	18.98	-32.55
93	IMG_0262	LOW NATURAL WITH BARE PATCHES	18.31	-31.58
94	IMG_0227	VINEYARD - TABLE GRAPES	18.70	-31.94
95	IMG_0096	ORCHARD	18.86	-32.51
96	IMG_0365	STRIPS	18.33	-32.60
97	IMG_0126	FIELD/DEGRADED	19.00	-32.61
98	IMG_0336	DENSE NATURAL	18.64	-32.65

Table B1 continued

ID	Photograph I.D	Class Description	X Coordinates	Y Coordinates
99	IMG_0122	DEGRADED NATURAL	18.98	-32.54
100	IMG_0326	FORESTRY TALL EUCALYPTUS PATCH	18.86	-32.69
101	IMG_0222	WETLAND	18.62	-31.84
102	IMG_0280	ROAD	18.46	-31.78
103	IMG_0118	RIVER	18.96	-32.44
104	IMG_0335	FIELD	18.69	-32.60
105	\IMG_0144	WETLAND	18.98	-32.37
106	IMG_0315	FIELD	18.50	-32.23
107	IMG_0334	DENSE NATURAL	18.73	-32.61
108	IMG_0290	NATURAL	18.60	-31.77
109	IMG_0195	BURNT	18.69	-32.07
110	IMG_0185	ROOIBOS STRIP	18.63	-31.94
111	IMG_0343	WETLAND	18.63	-32.52
112	IMG_0354	NATURAL	18.36	-32.32
113	IMG_0303	SOUTBOS NATURAL	18.34	-32.03
114	IMG_0171	NATURAL	18.47	-32.13
115	IMG_0313	AGRICULTURAL INFRASTRUCTURE	18.46	-32.23
116	IMG_0197	FIELD	18.70	-32.10
117	IMG_0207	DEGRADED	18.90	-32.14
118	IMG_0273	STRIP	18.36	-31.84
119	IMG_0256	BARE NATURAL	18.30	-31.48
120	IMG_0190	FIELD	18.63	-31.97
121	IMG_0156	DENSE NATURAL FYNBOS	18.82	-32.29
122	IMG_0204	DENSE NATURAL FYNBOS	18.90	-32.20
123	IMG_0151	NARROW FIELD NEXT TO NATURAL	18.87	-32.27
124	IMG_0110	ROAD	18.77	-32.34
125		NOT VISITED	19.03	-32.34
126	IMG_0342	OLD FIELD	18.66	-32.54
127	IMG_0246	GRAVEL QUARRY	18.43	-31.59
128	IMG_0170	SHORT DENSE NATURAL	18.52	-32.15
129	IMG_0130	ORCHARDS NARROW	19.04	-32.73
130	IMG_0254	NATURAL	18.30	-31.54
131	IMG_0318	FIELD	18.59	-32.29
132	IMG_0184	RAILWAY NEXT TO NATURAL	18.61	-31.96
133	IMG_0203	ORCHARDS	18.89	-32.17
134		NOT VISITED	19.05	-32.62
135	IMG_0243	VINEYARD	18.46	-31.63
136	IMG_0220	ROAD	18.68	-31.87
137	IMG_0186	NATURAL	18.63	-31.93
138	IMG_0355	OLD FIELD	18.37	-32.34
139	IMG_0332	ROAD	18.77	-32.62
140	IMG_0239	RUGBY FIELD/SCHOOL/URBAN	18.54	-31.68
141	IMG_0357	SERVICE ROAD	18.33	-32.37
142	IMG_0327	FIELD	18.85	-32.70
143	IMG_0269	LOW NATURAL	18.23	-31.78
144	IMG_0108	PIVOT	18.64	-32.32
145	IMG_0277	STRIPS	18.43	-31.84
146	IMG_0317	SMALL PIVOT	18.58	-32.29
147	IMG_0287	VINEYARD	18.42	-31.63
148		NOT VISITED	18.50	-32.16

Table B1 continued

ID	Photograph I.D	Class Description	X Coordinates	Y Coordinates
149		NOT VISITED	18.98	-32.28
150	IMG_0320	FIELD/DEGRADED EDGE	18.72	-32.53
151	IMG_0154	ROCKY NATURAL	18.84	-32.25
152	IMG_0351	NATURAL	18.45	-32.24
153	IMG_0356	FIELD	18.36	-32.36
154	IMG_0117	ORCHARDS	18.93	-32.42
155	IMG_0224	CANAL/LOW VEG/VINEYARD	18.62	-31.87
156	IMG_0362	DENSE NATURAL FYNBOS	18.34	-32.52
157	IMG_0217	GRASS-COVERED DUNE	18.74	-31.96
158	IMG_0250	LOW NATURAL	18.39	-31.56
159	IMG_0242	DEGRADED	18.49	-31.65
160	IMG_0370	FIELD	18.48	-32.70
161	IMG_0095	FIELD	18.87	-32.53
162	IMG_0244	LOW NATURAL	18.46	-31.62
163	IMG_0229	NATURAL	18.74	-31.97
164	IMG_0092	DENSE NATURAL FYNBOS	18.95	-32.64
165	IMG_0297	SOUTBOS STRIPS	18.52	-31.94
166	IMG_0368	FIELD	18.43	-32.67
167	IMG_0236	ENGEN ONESTOP -URBAN	18.64	-31.78
168	IMG_0305	NATURAL WITH TRACK	18.37	-32.07
169		NOT VISITED	19.01	-32.35
170	IMG_0329	FIELD	18.79	-32.66
171	IMG_0258	WETLAND	18.26	-31.54
172	IMG_0238	LOW NATURAL	18.58	-31.73
173	IMG_0325	ROOIBOS FIELD	18.87	-32.68
174	IMG_0212	DEGRADED	18.83	-32.06
175	IMG_0209	VINEYARD - TABLE GRAPES	18.84	-32.10
176	IMG_0163	LOW NATURAL	18.72	-32.17
177		NOT VISITED	18.77	-31.72
178	IMG_0274	TALL TREES IN DEGRADED GRAVEL PIT	18.38	-31.85
179	IMG_0173	FIELD/NATURAL EDGE	18.42	-32.12
180	IMG_0178	STRIP/NATURAL	18.60	-32.11
181	IMG_0308	LOW NATURAL	18.37	-32.21
182	IMG_0338	FIELD	18.65	-32.70
183	IMG_0091	DEGRADED KRAALBOS	18.96	-32.67
184	IMG_0223	NATURAL	18.61	-31.85
185	IMG_0292	VINEYARD	18.57	-31.76
186	IMG_0284	VINEYARD	18.50	-31.68
187	IMG_0208	PATH	18.87	-32.13
188	IMG_0155	DENSE NATURAL FYNBOS	18.83	-32.26
189	IMG_0187	NATURAL/ROAD EDGE	18.63	-31.91
190	IMG_0275	DEGRADED STRIP	18.39	-31.85
191		NOT VISITED	18.94	-32.23
192	IMG_0210	VINYARD/PATH	18.84	-32.08
193	IMG_0233	ORCHARDS	18.82	-32.08
194	IMG_0294	VINEYARD	18.53	-31.75
195	IMG_0237	DEGRADED	18.62	-31.76
196	IMG_0112	ORCHARD	18.83	-32.33
197	IMG_0289	VEGETABLE PATCH	18.36	-31.57

Table B1 continued

ID	Photograph I.D	Class Description	X Coordinates	Y Coordinates
198	IMG_0116	DENSE NATURAL FYNBOS	18.89	-32.40
199	IMG_0361	COASTAL PRISTINE NATURAL	18.34	-32.49
200	IMG_0352	DENSE NATURAL FYNBOS	18.42	-32.28
201	IMG_0293	VINEYARD/WETLAND	18.55	-31.76
202	IMG_0166	NATURAL	18.74	-32.19
203	IMG_0364	FIELD	18.37	-32.55
204	IMG_0337	DENSE NATURAL FYNBOS	18.64	-32.67
205	IMG_0228	VINEYARD - WINE GRAPES	18.71	-31.95
206	IMG_0206	OLD FIELD	18.90	-32.16
207	IMG_0300	LOW NATURAL	18.37	-31.94
208	IMG_0282	VINYARD	18.51	-31.71
209	IMG_0234	NATURAL	18.85	-32.14
210	IMG_0160	STONEY STRIPS	18.66	-32.19
211	IMG_0148	DENSE NATURAL FYNBOS	18.92	-32.34
212	IMG_0125	ROAD	18.96	-32.61
213	IMG_0137	FIELD ON CONTOURS	19.01	-32.53
214	IMG_0149	OLD FIELD/NATURAL/WETLAND EDGE	18.90	-32.30
215	IMG_0115	ORCHARD	18.87	-32.38
216	IMG_0109	ROCKY NATURAL	18.76	-32.34
217	IMG_0268	LOW NATURAL	18.23	-31.76
218	IMG_0270	MINING TRENCH DEGRADED	18.23	-31.80
219	IMG_0369	FIELD	18.45	-32.70
220	IMG_0105	DEGRADED	18.70	-32.35
221	IMG_0349	FIELD	18.48	-32.40
222	IMG_0267	LOW SANDY NATURAL	18.22	-31.69
223	IMG_0261	VEGETABLE PATCH	18.24	-31.56
224	IMG_0134	VEGETABLE PATCH	19.02	-32.60
225	IMG_0316	FIELD	18.54	-32.27
226	IMG_0255	LOW NATURAL	18.30	-31.51
227	IMG_0358	NATURAL WITH DUNES	18.33	-32.38
228	IMG_0285	VINEYARD	18.47	-31.66
229	IMG_0147	ORCHARD NARROW	18.94	-32.36
230	IMG_0265	DEGRADED	18.24	-31.60
231	IMG_0306	PIVOT	18.31	-32.14
232	IMG_0182	SOUTBOS STRIP	18.57	-32.01
233	IMG_0106	NOT VISITED	18.68	-32.34
234	IMG_0120	DAM	18.96	-32.48
235	IMG_0094	FIELD	18.93	-32.60
236	IMG_0218	LOW NATURAL	18.73	-31.94
237	IMG_0276	STRIP	18.42	-31.88
238	IMG_0359	PIVOT	18.33	-32.40
239	IMG_0139	DAM	18.97	-32.45
240	IMG_0307	NATURAL	18.32	-32.19
244	IMG_0271	LOW NATURAL	18.28	-31.83
245	IMG_0180	DEGRADED	18.59	-32.06
246	IMG_0165	ROOIBOS STRIP	18.73	-32.18
247	IMG_0132	ORCHARD	19.06	-32.72
248	IMG_0302	LOW NATURAL	18.34	-32.01
249		NOT VISITED	18.97	-32.26

Table B1 continued

ID	Photograph I.D	Class Description	X Coordinates	Y Coordinates
250	IMG_0101	DENSE NATURAL FYNBOS	18.77	-32.46
251	IMG_0322	DENSE NATURAL FYNBOS	18.81	-32.63
252	IMG_0361	NATURAL	18.34	-32.50
253	IMG_0248	NATURAL	18.41	-31.55
254	IMG_0100	FIELD	18.78	-32.46
255	IMG_0188	FIELD	18.62	-31.94
256	IMG_0259	AGRICULTURAL INFRASTRUCTURE	18.24	-31.54
257	IMG_0333	DEGRADED NATURAL	18.73	-32.57
258	IMG_0216	NATURAL	18.75	-31.97
259	IMG_0295	NATURAL	18.47	-31.89
260	IMG_0124	FIELD	18.99	-32.57
261	IMG_0138	OLD FIELD	18.99	-32.47
262	IMG_0241	VINEYARD	18.52	-31.66
263	IMG_0183	ROOIBOS STRIP	18.58	-32.00
264		NOT VISITED	18.83	-32.05
265	IMG_0371	NATURAL	18.48	-32.65
266	IMG_0373	STRIP	18.51	-32.57
267	IMG_0328	FIELD	18.81	-32.71
268	IMG_0164	NATURAL	18.67	-32.15
269	IMG_0310	WETLAND ON EDGE SALT MARSH	18.41	-32.20
270	IMG_0245	NATURAL	18.45	-31.61
271	IMG_0221	PATH SEP IRRIGATED OLIVES AND GRAPES	18.64	-31.85
272	IMG_0163	NATURAL	18.64	-32.15
273	IMG_0159	SOUTBOS STRIP	18.68	-32.21
274	IMG_0260	LOW NATURAL	18.24	-31.55
275	IMG_0372	DENSE NATURAL FYNBOS	18.51	-32.60
276	IMG_0324	FIELD	18.85	-32.66
277	IMG_0257	NATURAL	18.23	-31.51
278	IMG_0161	SOUTBOS STRIP	18.64	-32.16
279		NOT VISITED	18.95	-32.33
280	IMG_0247	DEGRADED	18.42	-31.58
281	IMG_0321	DEGRADED WETLAND	18.74	-32.58
282	IMG_0174	NATURAL/FIELD EDGE	18.38	-32.09
283	IMG_0169	DEGRADED NTURAL/OLD STRIP	18.57	-32.16
284	IMG_0152	NATURAL	18.86	-32.26
285	IMG_0205	URBAN LAWN	18.89	-32.19
286	IMG_0219	LOW DENSE NATURAL	18.70	-31.90
287		DEGRADED	18.50	-31.92
288	IMG_0344	FIELD	18.59	-32.50
289		NOT VISITED	18.87	-32.20
290	IMG_0366	NATURAL	18.40	-32.62
291	IMG_0360	DENSE COASTAL	18.34	-32.46
292	IMG_0140	RIVERINE NATIRAL/SAND BANK/POSS RIVER	18.96	-32.42
293	IMG_0194	STRIP	18.68	-32.06
294	IMG_0113	DAM	18.83	-32.32
295	IMG_0341	LOW NATURAL POSS DEGRADED	18.69	-32.58
296	IMG_0199	NATURAL/ROAD EDGE	18.74	-32.15

Table B1 continued

ID	Photograph I.D	Class Description	X Coordinates	Y Coordinates
297	IMG_0323	ROOIBOS STRIP	18.84	-32.65
298	IMG_0286	VINEYARD	18.45	-31.65
299	IMG_0263	LOW NATURAL	18.30	-31.57
300	IMG_0200	OLD FIELD	18.74	-32.15
301	IMG_0201	FIELD	18.80	-32.17

APPENDIX C

Table C 1 Calculated accuracy per tile

Tile Name	Overall Accuracy	KIA value
tile001	0.83	0.50
tile002	0.88	0.75
tile003	0.72	0.56
tile004	0.73	0.53
tile005	0.92	0.51
tile014	1.00	undefined
tile015	0.58	0.47
tile018	1.00	1.00
tile019	0.99	0.96
tile028	0.97	0.95
tile029	0.76	0.68
tile030	0.60	0.50
tile031	0.89	0.86
tile032	0.89	0.86
tile033	0.50	0.47
tile042	0.38	0.19
tile043	0.54	0.47
tile044	0.85	0.80
tile045	0.98	0.97
tile046	0.78	0.71
tile047	0.80	0.76
tile048	0.88	0.85
tile049	0.98	0.97
tile056	0.85	0.78
tile057	0.57	0.47
tile058	0.75	0.68
tile059	1.00	1.00
tile060	0.83	0.78
tile061	0.71	0.63
tile062	0.77	0.70
tile093	0.90	0.87
tile073	0.81	0.69
tile075	0.85	0.81
tile076	0.79	0.73
tile085	0.67	0.54
tile086	0.69	0.50
tile090	0.79	0.74
tile100	0.74	0.64
tile101	0.77	0.66
tile102	0.87	0.77
tile103	0.70	0.61
tile105	0.73	0.70
tile113	0.75	0.65
tile114	0.89	0.86
tile115	0.80	0.68
tile116	0.82	0.73
tile117	0.71	0.57

Table C1continued

Tile	Overall Accuracy	KIA value
tile118	0.77	0.51
tile119	0.88	0.82
tile120	0.72	0.69
tile121	0.93	0.89
tile131	0.93	0.90
tile132	0.80	0.71
tile135	0.76	0.70
tile144	0.78	0.67
tile146	0.90	0.84
tile157	0.90	0.88
tile158	0.95	0.94
tile159	0.94	0.90
tile160	0.90	0.84
tile161	0.89	0.84
tile162	0.96	0.94
tile163	0.84	0.82
tile164	0.90	0.87
tile165	0.68	0.56
tile171	0.80	0.76
tile172	0.83	0.79
tile173	0.80	0.74
tile176	0.48	0.42
tile187	0.95	0.91
tile191	0.74	0.70
tile198	0.85	0.83
tile205	0.84	0.77
tile206	0.79	0.75
tile215	0.90	0.89
tile229	0.60	0.51
tile244	0.80	0.76
tile247	0.95	0.93
tile251	0.44	0.36
tile257	0.92	0.88
tile258	0.86	0.81
tile259	0.93	0.92
tile274	0.64	0.55
tile278	0.73	0.67
tile292	0.62	0.57
tile016	0.93	0.90
tile017	0.98	0.94
AVERAGE	**0.80**	**0.73**

APPENDIX D

Sandveld land cover classification map

Sandveld land cover classification

Legend:
- Provinces
- Sandveld study area domain
- Urban Settlements
- Main road/highways
- Secondary/tertiary roads
- Railways
- Rivers
- Bare soil
- Burnt areas
- High fynbos
- Medium fynbos
- Low fynbos
- Permanent agriculture
- Temporary irrigated
- Temporary non-irrigated plain
- Temporary non-irrigated strip
- Waterbodies
- Wetland
- Canals
- Urban structure

Atlantic Ocean

Western Cape

0 9 18 27 Kilometers