CHANGE DETECTION OF INVASIVE BRACKEN FERN (*PTERIDIUM AQUILINUM* [L.] KUHN) IN THE ROYAL NATAL NATIONAL PARK AND RUGGED GLEN NATURE RESERVE

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As the candidate's Supervisor I agree/do not agree to the submission of this dissertation

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Mr A.M Forbes Date
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DECLARATION 1 - PLAGIARISM

I, ………………………………………….………………………., declare that

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ABSTRACT

Bracken fern (*Pteridium aquilinum* [L.] Kuhn) is an indigenous invasive plant and it is known to have a negative impact on biodiversity. This research focuses on infestations of bracken fern in two areas within the uKhahlamba Drakensberg Park World Heritage Site; the Royal Natal National Park and the Rugged Glen Nature Reserve.

Prior change detection research on bracken fern were constrained due to the low resolution satellite imagery and the inability of hard classification techniques to account for the mixtures of land cover types that occur within pixels of low resolution imagery. To overcome these constraints this research applied the fuzzy image classification technique to multispectral digital aerial imagery of 0.5 m spatial resolution. Multi date imagery used for image classification was captured in the mid-winter of 2009 and mid-spring of 2011. Thereafter post-classification change detection analysis was conducted using the fuzzy classified images.

The classified images were verified using ground truth surveys. The 2009 and 2011 fuzzy classified images produced overall accuracies of 81.4% and 94.4*%* with Kappa coefficients of 0.63 and 0.89 respectively. This research found that the distinct seasonal development pattern of bracken fern and the time of year imagery were captured were significant factors in its detection. As bracken fern was found to be more spectrally distinct in spring as compared to winter, due to the plant growth of bracken fern, grass and other shrubbery.

These classified images were used in post-classification change detection analysis which revealed that the bracken fern infestation in the Royal Natal National Park and Rugged Glen Nature Reserve had increased at a rate of 24 % and 27 % per annum respectively. This showed that bracken fern is spreading in the Royal Natal National Park and Rugged Glen Nature Reserve, as expected. Fire regimes, slope and aspect were found as factors that could be promoting the spread of bracken fern, 67.5 % and 75 % of the bracken fern infestation in the Park and Reserve respectively, occurred in areas that were burnt by fire regimes and have gentle to moderately gentle slopes facing east, south east and south.

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ACRONYMS

CIR	Colour infrared
DEM	Digital Elevation Model
DRDLR	Department of Rural Development and Land Reform
EC	Error of commission
EKZNW	Ezemvelo KwaZulu-Natal Wildlife
EO	Error of omission
GIS	Geographic Information Systems
GPS	Global Positioning System
IMP	Integrated Management Plan
IPCA	In-Process Classification Assessment
ISODATA	Iterative Self-organizing Data Analysis Technique Algorithm
ISRIC	International Soil Reference and Information Centre
Kc	Kappa coefficient
m	Metre
mm	Millimetre
ML	Maximum Likelihood
NDVI	Normalised Difference Vegetation Index
NEMBA	National Environmental Management: Biodiversity Act
NIR	Near-infrared
OA	Overall Accuracy
RGB	Red, Green and Blue
PA	Producers Accuracy
SOTER	Soil and Terrain
ssp	Subspecies
UDP	uKhahlamba Drakensberg Park
UA	Users Accuracy
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre
WHS	World Heritage Site

Chapter 1 : Introduction

1.1 Background

The National Environmental Management: Biodiversity Act (NEMBA, Act 10 of 2004) provides a definition of an invasive species. This definition is used in this dissertation when referring to invasive plant species.

> "any species whose establishment and spread outside of its natural distribution range (a) threatens ecosystems, habitats or other species or has demonstrable potential to threaten ecosystems, habitats or other species; and (b) may result in economic or environmental harm or harm to human health"
>
> (NEMBA, Act 10 of 2004)

Expansion of an invasive plant can negatively impact the biodiversity of an ecosystem it infests (Goodall and Naudé, 1998). The management of invasive plant species growing in the uKhahlamba Drakensberg Park (UDP), which is a World Heritage Site (UNESCO, 2001; UNEO-WCMC, 2011) is considered a challenge (UDP WHS- IMP, 2011).

There is a significant level of alien and invasive species in the UDP (UDP WHS- IMP, 201). The exact physical extent of one such invasive plant species, bracken fern is not known in the Royal Natal National Park (will now be referred to as the Park) and Rugged Glen Nature Reserve (will now be referred to as the Reserve). Bracken fern is of concern due to its potential to invade and spread in areas of high biological importance (Holland and Aplin, 2013). Knowledge of the bracken fern infestation extent and its change in growth over a period of time would serve as a vital tool in deriving management plans for the control or eradication of bracken fern within the UDP.

The UDP has been used as a case study with particular focus on the Park and Reserve. This research aims to provide an assessment of the extent of bracken fern infestation and changes in its extent within the UDP through application of remote sensing and GIS analysis.

1.1.1 Remote Sensing and invasive plant management

Internationally remote sensing has become a high priority resource for the classification, mapping and research of invasive plant species (Shaw, 2005; Slonecker et al, 2009). Remote sensing products such as classification maps facilitate the management, monitoring and identification of changes of the spread of invasive species (Shaw, 2005; Slonecker et al, 2009). Remote sensing is the only practical method to identify and monitor of invasive plants over large areas (Holland and Aplin, 2013). Remote sensing can provide data within a short time frame that allows for quick management reaction to plant invasions which could then reduce the adverse ecological and economic impacts of invasive plant species (Shaw, 2005).

1.1.2 Invasive plant management

Before any action can be taken against invasive species in the UDP a management plan needs to be created. A management plan needs to comprise of certain relevant pieces of information as outlined in the NEMBA Regulations, 2008, section 11, subsection 1.

> “(a) A detailed list and description of any listed invasive species occurring on the relevant land; (b) a description of the parts of that land that are infested with such listed invasive species; (c) an assessment of the extent of such infestation; (d) a status report on the efficacy of previous control and eradication measures; (e) the current measures to monitor, control and eradicate such invasive species, as appropriate; and (f) measurable indicators of progress and success, and indications of when the control plan is to be completed”
>
> (NEMBA Regulations, 2008)

Requirement (a) can be attained by conducting a review of previous research conducted on the physical characteristics of bracken fern along with ground truth surveys of the research areas. Requirement (b) and (c) can be attained by using remote sensing and Geographic Information Systems (GIS) techniques of image classification and change detection analysis to create of classification maps and change detection maps.

1.1.3 What is change detection

Change detection is a process that involves the qualitative analysis of multi-temporal data sets to determine the temporal effects on a phenomenon (Singh, 1989; Lu et al, 2004; Lu and Weng, 2007). Change detection is an active field of study given the importance of monitoring land cover features (Lu et al, 2004). It has a multitude of applications that include; land use and land change (LULC), vegetation change, forest mortality, damage assessment, wetland change and crop monitoring (Lillesand et al, 2008; Lu et al, 2004).

1.2 Research Motivation

The motivating factors for this research were the potentially severe economic, ecological impacts of invasive plant species on the environment as well as the role remote sensing can play in the management of invasive plant.

1.2.1 Economic impacts

Ghorbani et al (2006) stated that land management and economic problems can be caused by bracken fern. As invasive plant species can increase the management costs associated with maintaining the ecological constitution of national parks (Goodall and Naudé, 1998). Schneider (2006) also states that combating the spread of bracken fern is often a costly exercise in terms of labour costs.

The Working for Water Programme focuses on the removal of invasive plants in South Africa spent about R 30 million per annum using methods of physical removal and herbicides to control invasive plant species (Turpie, 2004). Working for Water also spent R 880 million from 2000 to 2010 on the removal of invasive Silver and Black Wattle (Wilgen et al, 2011). In 2002, Working for Water estimated that it would take about R 650 million per annum over a further twenty years to control and prevent re-invasion of invasive plant species (Turpie, 2004).

1.2.2 Ecological impacts

The ecological threat of bracken fern relates to the biodiversity of the grasslands in the Park and Reserve. The UDP is a hotspot of plant biodiversity (UDP WHS- IMP, 2011); it contains 37% of endemic and near-endemic angiosperm (flowering plants) unique to Southern Africa of which 13% unique to the UDP (UDP WHS- IMP, 2011). This biodiversity could be threatened as bracken fern is also known to interrupt the ecosystem functions and land-cover patterns of an ecosystem.

Marrs et al (2000), Eastman (2003), Schneider (2004), Schneider (2006) and Bond et al (2007) state that bracken fern is known to secrete allelopathic substances which changes soil composition. This change in soil composition in its immediate surrounding either limits or totally inhibits the growth of other vegetation. This allows bracken fern to spread uncontrollably and produce a monoculture that crowds out other vegetation (Schneider, 2006; Schneider and Fernando, 2010). Thereafter bracken fern replaces secondary vegetation it then dominates areas (Schneider and Fernando, 2010). The dense thickets that bracken can form prevent the regeneration of other plants in the ecosystem (Schneider, 2006; Bond et al, 2007).

Given the above it is imperative to detect bracken fern in order to gain an understanding of the extent, change of its extent and the factors responsible for its increase in extent as soon as possible before the infestation becomes unmanageable.

1.3 Research Problem

The Park and Reserve have significant infestations of bracken fern that can exert significant negative ecological impacts on the environment. Also, there is currently no management plan for the control or eradication of bracken fern in the Park and Reserve. Thus there are no classification maps delineating; the parts of Park and Reserve that are infested with bracken fern. Given the above combination of factors it is important that classification and change detection maps be created for bracken fern infesting the Park and Reserve.

1.4 Research Question

Given the above motivations for this research and relevant issues raised above, the research question was developed as follows: is it possible to determine the factors contributing to the spread of bracken fern in the Park and Reserve with the application of change detection analysis?

1.5 Research Aims and Objectives

The aims and objectives are based on investigating the spread of bracken fern in the Park and Reserve using remote sensing and GIS analysis.

1.5.1 Research Aim

This research aims to produce a detail description of areas affected by the bracken fern infestation, the extent of the bracken fern infestation and investigate the changes of bracken fern infestation in the Park and Reserve by creating classification and change detection maps of bracken fern infesting the Park and Reserve.

1.5.2 Research Objectives

1. Find and apply a suitable image classification technique that would accurately and reliably classify bracken fern on the Park and Reserve, by carrying out a pilot study comparing supervised and fuzzy classification.
2. Provide a detailed description of bracken fern infesting the Park and Reserve, by carrying out image classification to determine the areas affected by the bracken fern infestation and their extent.
3. Determine changes and the factors responsible for those changes in the bracken fern infestation in the Park and Reserve, by conducting change detection analysis.

1.6 Study Area

The UDP is situated in the province of KwaZulu-Natal of the Republic of South Africa bordering the Kingdom of Lesotho on its western boundary and is a 2428.13 Km^2 protected area (Kruger et al, 2011; UNEO-WCMC, 2011). The Park and Reserve are a part of the UDP and have an area of 80.94 km^2 and of 7.62 km^2 respectively (UNEO-WCMC, 2011). The Reserve is adjacent to the Park.

The UDP is under the control the provincial conservation organisation, Ezemvelo KwaZulu-Natal Wildlife (EKZNW) (Kruger et al, 2011; UDP WHS- IMP, 2011). The altitude of UDP ranges from 1280 – 3446 m above sea level (UNEO-WCMC, 2011) and falls within the afromontane region, where grassland is the dominate land cover type (UDP WHS- IMP, 2011). A locality map of the Park and Reserve in the UDP is shown in figure 1.1.

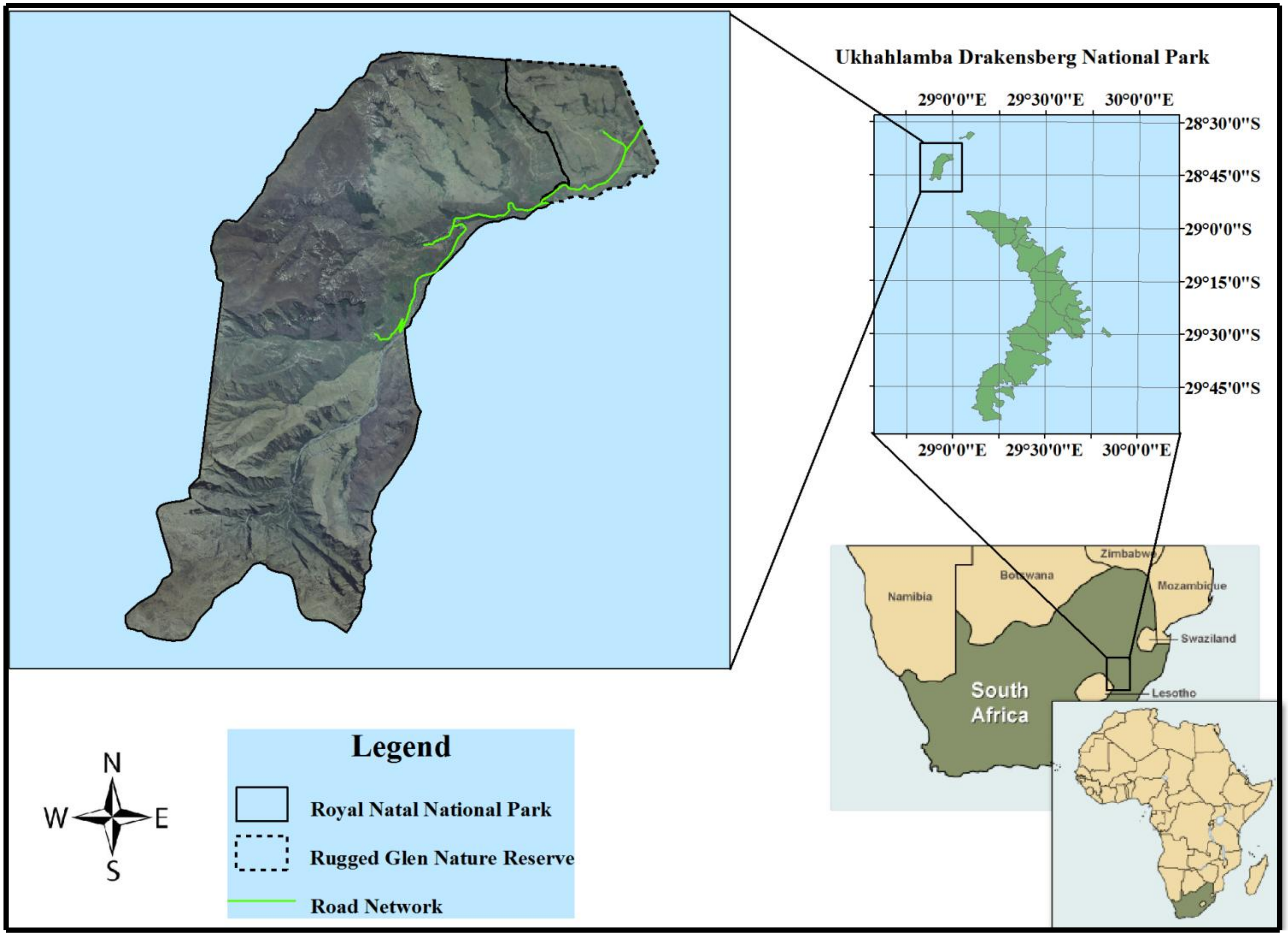

Figure 1.1 : Park and Reserve

1.7 Thesis Organisation

Chapter 1 has provided the context in which this research was undertaken. The content of the other chapters of this thesis expands on the points outlined in this chapter and seek to achieve the aim and provide an answer to the research question.

Chapter 2 is the literature review and is contained in two parts. The first part of the literature review that outlines previous research and the associated advantages and disadvantages of possible image classification techniques. The second part of the literature review contains a description of bracken fern and its characteristics.

Chapter 3 outlines the methodology used in this research. This was based on the previous research and techniques outlined in Chapter 2.

Chapter 4 presents the results obtained from the ground truth surveys, image orthorectification, image analysis and change detection analysis.

In chapter 5 the results of the ground truth surveys, pilot study, image analysis and post-classification change detection are discussed.

Chapter 6 reflects on the project results, aim and objectives. Also recommendations for further research into the study of invasive bracken fern are outlined.

Chapter 2 : Literature review

This chapter consider previous research to determine a change detection process that outlines; classification based change detection techniques, mixed pixels, image classification techniques, classification decision rule, remotely sensed imagery, image orthorectification, accuracy assessment and comparison of classified images. Also a detailed description of bracken fern is included at the end of this chapter.

2.1 Change detection

There are a variety of change detection techniques and applicability of a technique varies with the intended application and thus there is no universal change detection technique (Coppin et al, 2004; Lu et al, 2004; Lu and Weng, 2007). Before change detection analysis can be undertaken there are general conditions that must be satisfied. Lu et al (2004) lists these conditions as being; the precise registration between multi-temporal imagery, precise radiometric and atmospheric or normalisation between multi-temporal imagery, selection of the same spatial and spectral resolution imagery.

Change detection can provide; area change, a rate of change and the spatial distribution of land cover types (Lu et al, 2004; Lu and Weng, 2007). The accuracy of the change detection analysis is dependent on eight factors. These factors in that include; precise geometric registration of multi-temporal imagery (Singh, 1989; Coppin et al, 2004), availability of quality ground truth data, complexity of the landscape, change detection method used, classification technique applied, analyst skill and experience, knowledge of the study area and, time and cost restrictions (Lu et al, 2004; Lu and Weng, 2007).

There are four important factors to consider when applying change detection to natural land cover types. These factors are; detecting if a change has occurred, identifying the nature of the change, measuring the extent of the change and, assessing the spatial pattern of the change (Singh, 1989; Lu et al, 2004).

The change detection process is broadly comprised of four steps (Lu et al, 2004). These steps include; any image pre-processing required to the data sets, selection of suitable image classification techniques, accuracy assessment of the classification and the comparison between two or more classified images to determine change (Lu et al, 2004).

2.2 Classification based change detection techniques

Mas (1999), Lu et al (2004) and Lu and Weng (2007) state that classification based change detection techniques are commonly used in remote sensing. Classification based change detection techniques include; post- classification comparison, spectral-temporal combined analysis, expected maximization (EM) detection, unsupervised change detection, hybrid change detection and artificial neural networks (ANN) (Lu et al, 2004; Lu and Weng, 2007). In classification based change detection if corresponding pixels across the different epochs are categorized by the same land cover type, then no change has taken place (Lu and Weng, 2007; Sheoqing and Lu, 2008). Singh (1989) suggests that the overall accuracy (OA) of the classified based change detection can be determined by multiplying the OA of the individual classified images.

2.3 Previous research on change detection

Mas (1999) applied direct multi-date unsupervised classification, post-classification change differencing, combination of image enhancement and, post-classification comparison to change detection of vegetation land cover types. Mas (1999) found that post-classification analysis obtained the highest accuracies of all the techniques that were applied for change detection analysis.

While Schneider and Fernando (2010) applied a linear mixture model (LMM) for image classification before carrying out post-classification comparison in their change detection research on bracken fern. However Schneider and Fernando (2010) attained relatively low Kappa index of agreement (KIA) of 0.4079 for 1989 and 0.5254 for 2000. Their results could be attributed to the low spatial resolution (30m x 30m) of the Thematic Mapper (TM) LANDSAT 5 and Enhanced Thematic Mapper (TM) Landsat 7 imagery. However their research highlighted that post-classification comparison could be used to detect changes in bracken fern infestation however higher resolution imagery must be used in order to attain better results.

2.3.1 Post-classification comparison

The most common classification based approach in change detection is post-classification comparison popular because it is simple to apply (Singh, 1989; Lu et al, 2004; Lu and Weng, 2007, Sheoqing and Lu, 2008). Post-classification change detection technique involves the comparative analysis of independently produced spectral classifications for two or more epochs (Coppin et al, 2004; Lu et al, 2004). This technique can produce a matrix of change information as well as reduce the impact of atmospheric and environmental differences between the multi-temporal images (Singh, 1989; Coppin et al, 2004; Lu et al, 2004; Lu and Weng, 2007).

This method is also dependent on large amounts of training sample data (Lu et al, 2004; Lu and Weng, 2007). When high-quality training sample data are not available it prevents the classification from attaining high accuracies and this leads to unsatisfactory change detection results (Lu et al, 2004; Lu and Weng, 2007). The accuracy of the change map created is dependent on the accuracy of the independent classified images (Mas, 1999; Coppin et al, 2004).

Post-classification comparison change detection technique does not require; *á priori* class probabilities as needed in expected maximization (EM) detection technique, the identification and labelling of change trajectories as required by unsupervised change detection, or the thresholds as required for the hybrid change detection technique (Lu et al, 2004).

Post-classification change detection may be more favourable than spectral temporal combined analysis, if using multi-date imagery that was captured in different seasons. Considering the difference in the reflectance values of the land cover types caused by a seasonal growth pattern (Pakeman et al, 1996). A land cover type could possess different spectral reflectance patterns in different seasons which may negatively affect image classification results (Pakeman et al, 1996).

The difficulty of identifying and labelling of change trajectories (Lu et al, 2004) and the unavailable *á priori* class probabilities and thresholds rules out the maximization (EM) detection technique, unsupervised change detection and hybrid change detection technique for application in this research. Also considering that the available remotely sensed imagery has been captured in different seasons that rules out spectral temporal combined analysis. Thus post-classification change detection is the most favourable technique to apply given the data available for this research. Table 2.1 shows each of the techniques, characteristics, advantages, disadvantages and key factors that affect change detection analysis.

Table 2.1: Classification change detection techniques (extracted and modified from Table 1 of Lu et al [2004])

	Techniques	Characteristic	Advantages	Disadvantages	Key factor
1	Post-classification comparison	Separately classifies multi-temporal images into thematic maps and then implements comparison of the classified images, pixel by pixel.	Minimizes impacts of atmospheric, sensor and environmental differences between multi-temporal images and provides a complete matrix of change information.	Requires a great amount of time and expertise to create classification products. The final accuracy depends on the quality of the classified image of each date.	Selects sufficient training sample data for classification.
2	Spectral temporal combined analysis	Puts multi-temporal data into a single file, then classifies the combined dataset and identifies and labels the changes.	Simple and timesaving in classification.	Difficult to identify and label the change classes and this cannot provide a complete matrix of change information	Labels of the change classes.
3	Expected maximization (EM) detection	The EM detection is a classification-based method using an expectation-maximization (EM) algorithm to estimate the a priori joint class probabilities at two times. These probabilities are estimated directly from the images under analysis.	This method was reported to provide higher change detection accuracy than other change detection methods.	Requires estimating the a priori joint class probability.	Estimates the a priori joint class probability.

Table 2.1 (Continued)

4	Unsupervised change detection hybrid change detection	Selects spectrally similar groups of pixels and clusters date 1 image into primary clusters, then labels spectrally similar groups in date 2 image into primary clusters in date 2 image, and finally detects and identifies changes and outputs results.	This method makes use of the unsupervised nature and automation of the change analysis process.	Difficulty in identifying and labelling change trajectories.	Identifies the spectrally similar or relatively homogeneous units.
5	Hybrid change detection	Uses an overlay enhancement from a selected image to isolate changed pixels, and then uses supervised classification. A binary change mask is constructed from the classification results. This change mask sieves out the changed themes from the LULC maps produced for each date.	This method excludes unchanged pixels from classification to reduce classification errors.	Requires selection of thresholds to implement classification; somewhat complicated to identify change trajectories.	Selects suitable thresholds to identify the change and non-change areas and develops accurate classification results.

Table 2.1 (Continued)

6	Artificial neural networks (ANN)	The input used to train the neural network is the spectral data of the period of change. A back propagation algorithm is often used to train the multi-layer perceptron neural network model.	ANN is a nonparametric supervised method and has the ability to estimate the properties of data based on the training samples.	The nature of hidden layers is poorly known; a long training time is required. ANN is often sensitive to the amount of training data used. ANN functions are not common in image processing software.	The architecture used such as the number of hidden layers, and training samples.

2.4 Previous image classification of invasive plants

In the image classification of bracken fern Holland and Aplin (2013) used supervised classification and attained the higher accuracies and reliability with the use of IKONOS imagery of 4 m spatial resolution [4 visible bands and near infrared (NIR)] as compared to Landsat 5 and 7 imagery of 30 m resolution [6 visible, NIR and short wavelength infrared (SWIR)]. This highlighted that a hard classifier used with low spatial resolution remotely sensed imagery will not result in the most accurate and reliable image classification of bracken fern possible.

In the image classification of other invasive plant species Fletcher et al (2011) and De Castro et al (2012) showed that supervised classification with multispectral high spatial resolution [red, green, blue (RGB) and colour infrared (CIR)] imagery can produce high levels of accuracy and reliability. Fletcher et al (2011) used digital aerial imagery of 0.46 – 1.36 m spatial resolution and obtained an overall accuracy (O.A) of 84% - 86% and a Kappa coefficient (Kc) of 0.7840 - 0.8145. While De Castro et al (2012) used digital aerial imagery of even higher spatial resolution (0.25 m) and obtained an O.A of 83.4% - 99.9% and a Kc of 0.7 - 0.9. This highlighted the importance of high spatial resolution and the spectral resolution remotely sensed imagery for the image classification of invasive plants.

However even with high resolution imagery the results obtained with hard classifiers can be improved with the use of fuzzy classification (Laba et al, 2008). This is because hard classification techniques that require unambiguous data that is referred to crisp or hard data sets (Mather, 2001) cannot address the problem of mixed pixels which can cause significant errors in image classification (Pakeman et al, 1996). A mixed pixel or mixel is a picture element that represents an area covered by two or more categories, classes or land cover types (Gebbinck, 1998). Mixed pixels can often be misclassified into one of the pure categories that that are part of their composition (Campbell, 2007).

Fuzzy classification on the other hand does take mixed pixels into consideration (Mather, 2001; Campbell, 2007; Lillesand et al, 2008). Image classification carried out by Laba et al (2008) used both fuzzy and supervised classification with high resolution RGB and CIR imagery (0.61 - 2.4 m). According to their findings fuzzy classified image attained an OA of 75% - 83% compared to the super classification image that attained an OA of 64.9% - 73.6%. Laba et al (2008) showed that fuzzy classification produced a more accurate and reliable classified image than the supervised classification.

Schmook et al (2011) used (RGB and NIR) Landsat ETM+ 2000 (30 m) and a soft classifier In-Process Classification Assessment (IPCA) to classify bracken fern and other vegetation. Their classified image attained an OA of 90 % for bracken fern. This highlights the importance of a soft classifier for the image classification of bracken fern.

Boyd and Foody (2010) suggest two ways in which the problem of mixels can be reduced which include; the use of remotely sensed imagery that has the finest spatial resolution that is possible and employ algorithms that focus on spectral unmixing analysis (sub-pixel classifiers) that are also referred to as soft classifiers. Thus the use of a soft classifier together with high resolution imagery would reduce the impact of mixed pixels on the classified imagery and could be the most suitable method for image classification of invasive bracken fern.

Firstly, it is likely that mixed pixels will be a common occurrence and will have to be considered in the image classification process. Secondly, the imagery available for this research is 0.5 m and not 0.25 m as with the imagery used by De Castro et al (2012). Thirdly, fuzzy classification has been shown to produce better results than supervised classification with imagery of high spatial resolution. Therefore it would be favourable to use fuzzy classification with high resolution RGB and CIR imagery for this research.

Table 2.2 includes previous research on image classification of invasive plant species under the following categories; researchers, species, remote sensor, image analysis techniques, results, research area and software used for the image classification process.

Table 2.2: Previous research of image classification of invasive plants

	Reference	**Species**	**Remote Sensor**	**Image analysis techniques**	**Research Area**	**Software**
1	Holland and Aplin (2013)	Bracken Fern (*Pteridium aquilinum*)	LANDSAT 5 TM, LANDSAT 7 ETM+ IKONOS	1.Supervised classification with the Maximum likelihood classifier	Lake District National Park, United Kingdom	Unspecified
2	Schmook et al (2011)	Bracken Fern (*Pteridium aquilum*) and other vegetation	LANDSAT ETM+ 2000	Supervised classification with the Maximum likelihood classifier and In-Process Classification Assessment (IPCA).	Southern Yucatán, Mexico	Prototype IDRISI with IPCA
3	Fletcher et al (2011)	*Schinus terebinthfolius* (Brazilian pepper)	Digital mapping camera	Supervised classification with the Maximum likelihood classifier.	South Texas	Erdas Imagine Software version 9.3
4	Laba et al (2008)	*Trapa natans* (Water chestnut), *Phragmites australis* (Common reed), *Lythrum salicaria* (Purple loosestrife)	Quickbird satellite	1.Supervised Classification 2.Fuzzy Classification	Tivoli Bays, Stockport Flats, Piermont and Iona Island	ERDAS 8.7

Table 2.2 (Continued)

5	De Castro et al (2012)	*Diplotaxis* spp. (Wallrocket) and *Sinapis* spp. (White mustard)	Digital mapping camera	Supervised classification with the Maximum likelihood classifier.	Córdoba and Seville, southern Spain	ENVI 4.4

A system of image classification steps based upon previous research includes; obtaining remotely sensed imagery with spatial, spectral and temporal resolution required for a particular application, applying image pre-processing to correct for radiometric and geometric distorts in the imagery, identifying which land cover features will be involved in the image classification, selection of an image classification technique taking into consideration the imagery available and the feature that will be classified, selecting a classifier that will assist the classy pixels representing each feature, selecting the location and quantity of training sites to train the classifier, create and error matrix and Kappa coefficient to assessment the accuracy of a classified image. Image classification is an iterative process that repeats if the accuracy assessment of the classification image is poor. This system is illustrated in Figure 2.1.

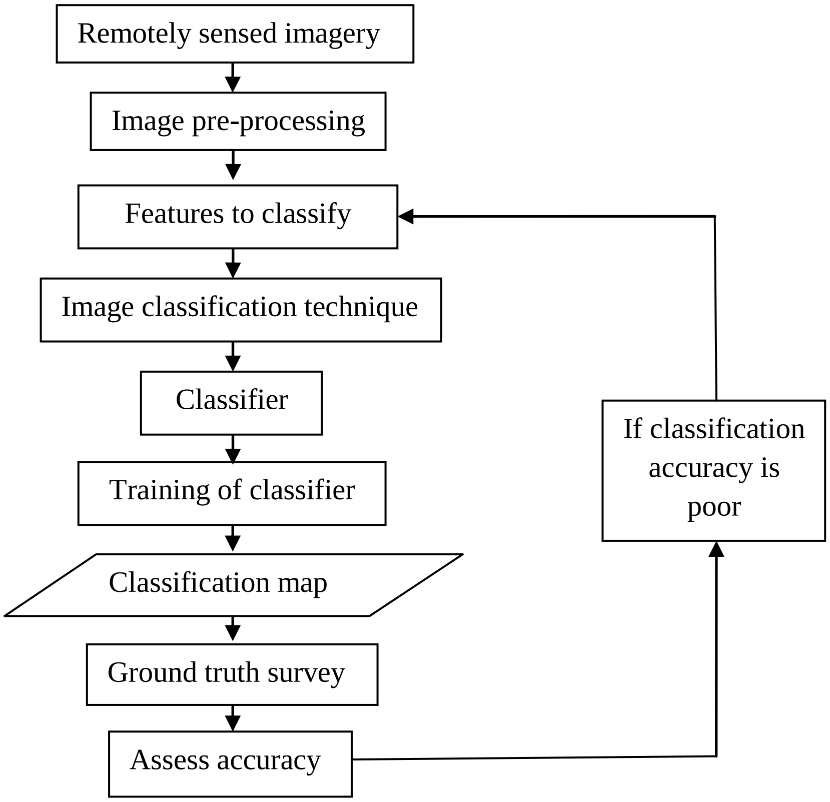

Figure 2.1: Brief outline of the image classification process

2.5 Image pre-processing: radiometric and geometric corrections

Image pre-processing is essential to improve positional accuracy and the integrity of the radiance values of the imagery and usually entails a series of sequential operations (Campbell, 2007; Lu and Weng, 2007). Image pre-processing resolves major discrepancies that could diminish the quality of information that could be extracted from processed imagery (Campbell, 2007; Lu and Weng, 2007; Schowengerdt, 2007).

Radiometric correction is necessary to remove distortion that cause variability of surface reflectance values in raw digital images (Campbell, 2007). Geometric correction is necessary to remove terrain distortions in digital remote sensing imagery (Mather, 2001; Gil et al, 2011).

These operations result in converting raw digital remote sensing imagery into a usable data set (Campbell, 2007; Lu and Weng, 2007). These corrections facilitate accurate spatial analysis from digital multispectral remotely sensed imagery (Mather, 2001; Jensen, 2005; Lu and Weng, 2007).

2.6 Remotely sensed imagery

The unique spectral characteristics of a feature or scene are captured by remote sensing sensors (Campbell, 2007). The unique characteristics of features or objects allow for their identification in remotely sensed imagery (Campbell, 2007). The use of remotely sensed imagery in change detection analysis is based on the premise that changes in the objects of interest will result from changes in reflectance or local textures (Lu et al, 2004).

Remotely sensed data can be reliable and cost effective though cost varies with the remote sensor (Campbell, 2007; Jensen, 2005; Lillesand et al, 2008; Schowengerdt, 2007). The temporal, spectral, radiometric, and spatial resolution of remote sensed imagery plays a significant role in image classification and subsequent change detection analysis (Coppin et al, 2004; Lu et al, 2004).

Colour infrared (CIR) imagery can better distinguish various vegetation types in a scene than red, green and blue (RGB) imagery (Campbell, 2007; Ihse, 2007). This is because the greater degree of plant matter reflectance that occurs in the near-infrared (NIR) as compared to RGB portion of the electromagnetic spectrum (Campbell, 2007; Ihse, 2007). This highlights the importance of spectral resolution of remotely sensed imagery.

2.7 Image orthorectification

Image classification can be applied to remotely sensed imagery after it has to be orthorectification (Gil et al, 2011). Image orthorectification removes terrain distortions and changes the image projection that results in the production of an orthoimage (Campbell, 2007; Schowengerdt, 2007; Lillesand et al, 2008). An Orthoimage shows the same level of detail as the original aerial image (Campbell, 2007; Schowengerdt, 2007).

In the orthorectification process, the image has to be resampled. Bilinear interpolation is a resampling technique used in image orthorectification (Slonecker et al, 2009). The smoothing that takes place with bilinear interpolation may be avoided by using cubic convolution (Schowengerdt, 2007). However cubic convolution results in digital number (DN) overshoots which are undesirable because it reduces radiometric accuracy which is an important factor for classification of remotely sensed imagery (Schowengerdt, 2007). Bilinear interpolation would produce the least displacement of pixels form the original imagery (Schowengerdt, 2007). Thus bilinear interpolation is more favourable technique than cubic convolution for the orthorectification of aerial imagery used in this research. Equation 2.1 (Erdas field guide, 2010) shows the calculation used in the bilinear resampling of a pixel value r (V_r) with coordinates (xr, yr).

$$\text{Bilinear Interpolation} = \sum_{i=1}^{4} \frac{\left(D - \Delta x_i\right)\left(D - \Delta y_i\right)}{D^2} \times V_i \qquad \textbf{Equation 2.1}$$

Δxi - Change in X direction between (xr,yr) and the data file coordinate of pixel i

Δyi - Change in Y direction between (xr,yr) and the data file coordinate of pixel i

Vi - Data file value for pixel i

D - Distance between pixels (in X or Y) in the source coordinate system.

2.8 Image classification techniques

The objective of image classification is to extract various classes or themes of land cover and automatically categorise pixels into one land cover type found in remotely sensed imagery (Mather, 2001; Jensen, 2005; Campbell, 2007; Lillesand et al, 2008). In addition to the traditional methods of unsupervised and supervised classification, other methods such as fuzzy classification and artificial neural networks (ANN) can be used to conduct image classification (Jensen, 2005; Campbell, 2007; Lillesand et al, 2008).

In image classification Schmook et al (2011) and Mather (2001) suggests that there should be a minimum of 30 training sites per a land cover class is sufficient for reliable statistical analysis to be performed. Supervised and fuzzy classifications are image classification techniques (Campbell, 2007; Lillesand et al, 2008) that have been successful applied to the classification of invasive plant species. The characteristics that made the supervised and fuzzy classification methods suitable for image classification are explored.

2.8.1 Supervised classification

Supervised classification offers the analyst complete control on the land cover classes created (Campbell, 2007). The analyst decides on which land cover types are of interest and that those will appear in the final classified image (Campbell, 2007). This method is dependent on the prior knowledge possessed by an analyst of a research area (Jensen, 2005; Campbell, 2007; Schowengerdt, 2007; Lillesand et al, 2008).

The general stages in the supervised classification procedure are the training stage and classification stages (Mather, 2001; Jensen, 2005; Campbell, 2007; Schowengerdt, 2007; Lillesand et al, 2008). In the training stage of supervised classification uses pixel information derived from analyst pre-defined pixel data sets and statistical techniques to develop the numeric description of spectral attributes for each land cover type (Mather, 2001; Jensen, 2005; Campbell, 2007).

That then informs the classification system in the classification stage to select pixels that have similar characteristics into established classes and reject pixels with different characteristics from established classes (Mather, 2001; Jensen, 2005; Campbell, 2007). A pixel is not categorised into a land cover class, due to it being insufficiently similar to any training class it is labelled as unknown (Mather, 2001; Jensen, 2005; Campbell, 2007; Lillesand et al, 2008).

2.8.2 Fuzzy classification

Fuzzy classification is an alternative approach to hard classification techniques for image classification and has become well known (Holland and Alpin, 2013). Fuzzy classification offers the analyst complete control on the land cover classes created (Benz et al, 2003; Mather, 2001; Jensen, 2005; Schowengerdt, 2007; Erdas field guide, 2010). Fuzzy classification provides information about the overall reliability, stability and class mixture whereas hard classification will only provide information on the highest class membership degree (Benz et al, 2003).

In order to carry out a fuzzy classification a complete fuzzy system is required (Benz et al, 2003). This system consists of input values and, logic combinations of fuzzy sets (grouping of input values), a modification of membership values and the defuzzification of classification results (Benz et al, 2003; Chaira and Ray, 2010).

2.8.2.1 Fuzzification and defuzzification

Fuzzification is a process of converting a crisp system into a fuzzy system (Benz et al, 2003). The fuzzy system creates fuzzy sets and represents the land cover feature classes (Benz et al, 2003). Feature classes are defined using membership functions (Benz et al, 2003; Chaira and Ray, 2010). Fuzzy classification utilises a membership function that signifies which class a particular pixel value most belongs (Mather, 2001; Jensen, 2005; Chaira and Ray, 2010).

Fuzzy classification uses fuzzy logic which is a multi-valued logic system that uses a continuous range of values from 0 – 1 to quantify the uncertainty of relational aspects (Benz et al, 2003; Chaira and Ray, 2010). Fuzzy logic avoids using arbitrary sharp thresholds and can be used to approximate the real world (Benz et al, 2003). This makes fuzzy classification suited to manage the uncertainties in image processing and analysis (Benz et al, 2003; Chaira and Ray, 2010).

Thereafter Defuzzification is required to obtain a classified image (Benz et al, 2003). The defuzzification process converts fuzzy results into crisp values by applying the maximum membership degree of the fuzzy classification (Benz et al, 2003). However if the minimum membership value degree does not meet the threshold value, no classification will take place .This ensures the minimum reliability of the classification (Benz et al, 2003).

2.9 Classification decision rule

A decision rule used in image classification techniques allocates pixels into clusters or classes (Mather, 2001; Jensen, 2005; Campbell, 2007; Schowengerdt, 2007; Lillesand et al, 2008). Decision rules are either parametric or non-parametric. Parametric decision rules are based parametric signatures, based upon the mean vector and covariance matrix values of pixels, created from user defined training data used to define land cover class (Erdas field guide, 2010). The maximum likelihood classifier (MLC) is a parametric decision rule (Mather, 2001; Jensen, 2005; Lillesand et al, 2008).

2.10 Gaussian Maximum Likelihood Classifier

This classification decision rule assumes that pixel values of a land cover type follow a normal distribution (Mather, 2001; Jensen, 2005; Campbell, 2007; Lillesand et al, 2008). The MLC examines the probability of a pixel in relation to each defined land cover class and the mean reflectance of each land cover class. Pixels are assigned to classes based on the highest posterior probability (Mather, 2001; Jensen, 2005; Campbell, 2007; Lillesand et al, 2008). Equation 2.2 (Campbell, 2007) shows the calculation of the MLC.

$$D = \text{In}\left(a_c\right) - \left[0.5\ \text{In}\left(\left|\ \text{Cov}_c\ \right|\right)\right] - \left[0.5\left(X - M_c\right)^T\left(\ \text{Cov}_c^{\ -1}\ \right)\left(X - M_c\ \right)\right] \qquad \textbf{Equation 2.2}$$

D - Maximum likelihood distance
c - Class
X - Measurement vector of the candidate pixel
M_c - Mean vector of the sample of class c
a_c - Probability a candidate pixel is a member of class c (defaults to 1)
Cov_c - Covariance matrix of the pixels in the sample of class c
$|Cov_c|$ - Determinant of covariance matrix of the pixels in the sample of class c
Cov_c^{-1} - Inverse of covariance matrix of the pixels in the sample of class c
ln - Natural logarithm function
T - Transposition function

2.11 Accuracy assessment

Gil et al (2011), states that an orthorectified image can be used in GIS and image classification. After image classification the accuracy assessment of the classified images takes place (Mather, 2001; Jensen, 2005; Lillesand et al, 2008).Schmook et al (2011) and Fletcher et al (2011) have all used the ground truth surveys, error matrix and Kappa coefficient (Kc) to assess the accuracy of classified images.

A Classified image is assessed to determine the accuracy to which it reflects the real world (Lillesand et al, 2008). Ground truth surveys along with error matrices and Kappa coefficients (Kc) are techniques used to assess the accuracy of classified images (Mather, 2001; Jensen, 2005; Campbell, 2007; Lillesand et al, 2008). The data that can be extracted classified images can assist in the management of invasive plants (Shaw, 2005).

2.11.1 Ground truth verification

Ground truth surveys are used in the verification of the image classification results (Hu et al, 2001; Campbell, 2007; Navulur, 2007). Random, systematic random and stratified random samplings are sampling methods used to determine which sites to visit to verify classified images (Mather, 2001; Lu and Weng, 2007; Lillesand et al, 2008).

Ground truth surveys provide information needed for statistical analysis. The difficult terrain and general inaccessibility of infested areas of the UDP (UDP WHS- IMP, 2011) could make the ground truth survey needed to verify the classified images unfeasible.

2.11.2 Error matrix

The error matrix uses the overall accuracy (OA), user's accuracy (UA) and producer's accuracy (PA) to determine the fitness of derived land cover classes considering reference data (Campbell, 2007; Lillesand et al, 2008). The overall accuracy refers to the proportion of pixels correctly classified (Holland and Aplin, 2013).The user accuracy refers to the percentage of pixels that are correctly classified in relation to the number of classified pixels (Campbell, 2007; Lillesand et al, 2008; Holland and Aplin, 2013). The producer's accuracy refers to percentage of pixels that are correctly classified in relation to the number of reference pixels (Campbell, 2007; Lillesand et al, 2008; Holland and Aplin, 2013).

An error of commission occurs when a pixel is classified into a particular land cover class that it does not truly represent. An error of omission occurs when a pixel is not classified into a particular land cover class that it truly represents (Campbell, 2007; Navulur, 2007; Lillesand et al, 2008).

2.11.3 Kappa coefficient

The kappa statistic is a multi-variant technique used to test the error matrix classification accuracy (Erdas field guide, 2010). The kappa statistic results in an unbiased outcome because it considers the entire error matrix and not just the producers or overall accuracy (Navulur, 2007; Erdas field guide, 2010; Fletcher et al, 2011).

The kappa measures the degree to which each class differs, compared to a random classification of reference data, it uses the observed agreement and chance agreement (Navulur, 2007; Fletcher et al, 2011). Table 2.3 shows the ratings given to different ranges of Kappa values.

Table 2.3: Kappa value ratings

Kappa values	Rating
below 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

Navulur (2007) stated that since overall accuracy overlooks the amount of random dataset agreements it over estimates the classification accuracy. Foody (2002) on the other hand states that use of the kappa coefficient can result in an under estimation of the classification accuracy. Equation 2.3 (Lillesand et al, 2008) shows the calculation of the Kappa coefficient.

$$k = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+} x_{+i}}{N^2 - \sum_{i=1}^{r} x_{i+} x_{+i}} \qquad \textbf{Equation 2.3}$$

k	-	Kappa coefficient
r	-	Number of rows in the error matrix
Xii	-	Number of observations in row i and column i in the major diagonal
Xi+	-	Total number of observations in row i
X+i	-	Total number of observations in column i
N	-	Total number of observation included in matrix

Accuracy assessment of classified images ends the process of image classification. Thereafter classification maps can be used in applications such as GIS.

2.12 Geographical Information Systems

GIS facilitates the collection, organisation, manipulation, interpretation, display, and data base storage of geographic information. It is an effective tool for spatial data and analysis (With, 2002; Campbell, 2007). These attributes make GIS valuable for the purposes of monitoring, mapping and managing the distribution and spread of invasive plant species have led to its wide use in invasive plant research (With, 2002; Campbell, 2007). Thus GIS can be applied to the monitoring of invasive bracken fern in the Park and Reserve.

2.13 Bracken fern

Bracken fern is indigenous to South Africa, but has become a weed as a result of it taking over repeated burned grassland (Crouch et al, 2011). Bracken fern is also considered an invasive plant species in Mexico, Canada, New Zealand, Australia, United Kingdom and United States of America (Crane, 1990; Marrs et al, 2000; Schneider, 2004; Schneider, 2006; Bond et al, 2007; Schneider and Fernando, 2010). Figure 2.2 shows a large clump of bracken fern in the Park.

Figure 2.2: Bracken fern clump in the Park

2.14 Taxonomy

Bracken fern in the Park and Reserve are of the family: *Dennstaedtiaceae*, genus: *Pteridium*, species: *aquilinum* and subspecies: *capense* (Seebacher, 2003; Crouch et al, 2011) and is regarded as widely spread in sub-Saharan Africa (Thomson et al, 2005).

2.15 Description

Bracken fern has a woody fern stalk that can grow up to 500 mm long (Eastman, 2003; Crouch et al, 2011). The stalk has a swollen underground portion that is covered with brown, short, fine hairs (Crouch et al, 2011). Bracken fern has triangular fronds that are erect, stiff and hard (Crane, 1990; Crouch et al, 2011). The fronds can range from 0.5 – 1.75 m (Crane, 1990; Eastman, 2003; Crouch et al, 2011) that are divided into 2 pinnate blades (Eastman, 2003). Fronds are produced from short braches that grow from the rhizome (Crane, 1990; Bond et al, 2007). Bracken fern has a type of root system called a rhizome that can reach depths over a meter (Crane, 1990; Eastman, 2003; Bond et al, 2007), and can also be up to 5-10 mm in diameter and creeps widely (Crane, 1990; Eastman, 2003; Crouch et al, 2011).

2.16 Habitat

Bracken fern can also be found in many parts of the world, from grasslands to woodlands, except desert and Polar Regions (Hirono and Yamada, 1987; Crane, 1990; Eastman, 2003; Seebacher, 2003; Schneider, 2004; Schneider, 2006; Crouch et al, 2011). Bracken fern can occur in water-shedding areas (Seebacher, 2003).

Bracken fern prefers neutral to acidic, sandy, well drained, damp soils (Crane, 1990; Seebacher, 2003; Bond et al, 2007) and is rarely found in soil that contains calcium carbonate (Bond et al, 2007). Waterlogged soil inhibits the growth of young rhizomes (Crane, 1990; Schneider, 2006; Bond et al, 2007) and rhizome growth stops altogether in marsh land areas (Crane, 1990; Bond et al, 2007).

Bracken fern can also survive long dry periods and is resistant to disease (Crane, 1990; Schneider, 2006). Bracken fern can survive and thrive in a variety of conditions and many different biological environments due to its remarkable adaptability (Crane, 1990; Eastman, 2003; Schneider, 2004; Schneider, 2006; Bond et al, 2007; Schneider and Fernando, 2010). Bracken fern can be found along roadsides (Seebacher, 2003)

2.17 Growth pattern

Bracken fern produces fronds in spring (Crane, 1990; Bond et al, 2007). Only fronds that develop early become fertile (Bond et al, 2007). Bracken fern produce spores which ripen throughout summer (Crane, 1990; Eastman, 2003; Bond et al, 2007). These spores are shed in from late summer to mid-autumn (Eastman, 2003; Seebacher, 2003; Bond et al, 2007). Frond defoliation occurs periodically in late spring to mid-summer (Crane, 1990; Bond et al, 2007). Frost in winter destroys emerging fronds (Eastman, 2003; Bond et al, 2007).

The development of spore into new bracken fern plants is facilitated by soils that have constant moisture and are frost free (Bond et al, 2007). Soil minerals such as nitrogen, phosphorous, calcium and potassium are important for the establishment of young bracken fern plants (Bond et al, 2007). Nitrogen and potassium stimulate its growth in the later stages of its development (Bond et al, 2007). In nutrient rich soils young bracken fern plants could develop very rapidly (Bond et al, 2007).

Warmer climates allow bracken fern to grow at a consistent rate (Bond et al, 2007). However, a cold climate will bring a halt to any growth altogether and emerging fronds (Crane, 1990; Bond et al, 2007). So bracken fern experience consistent growth during the spring and summer months and a decrease or even a halt in growth in the autumn and winter months (Crane, 1990; Bond et al, 2007).

Bracken fern is known to be aggressive, opportunistic and long-lived (Cooper-Driver, 1990; Crane, 1990; Eastman, 2003). Bracken fern has a fast growth rate that can be difficult to control (Bond et al, 2007). The depths that can be reached by bracken fern rhizomes into the soil are the most significant factor that contributes to its expansion (Schneider, 2004; Schneider, 2006). The persistent underground rhizome growth pattern and dispersal mechanisms of bracken fern make it difficult to eradicate (Schneider, 2004; Schneider, 2006).

2.18 Fire regimes

Repeated burning of large areas over a long period of time constitutes a fire regime (Brooks, 2008). Fire regimes are carried out by EKZNW in late winter from July to August (UDP-WHS IMP, 2011) which disturbs the area. Seebacher (2003) states that bracken fern can be found in fire disturbed areas. Lu et al (2004) states that change in land cover type can be influenced by alterations in land cover induced by humans.

When fires burn bracken fern plants above ground its underground rhizome remains unscathed (Crane, 1990; Marrs et al, 2000; Eastman, 2003). This allows for the rapid re-growth of bracken fern and its domination of areas that have been cleared by fire (Crane, 1990; Seebacher, 2003; Thomson et al, 2005; Schneider, 2006; Bond et al, 2007; Schneider and Fernando, 2010).

2.19 Toxicity

The fronds of bracken fern are poisonous and can be harmful to livestock (Eastman, 2003; Bond et al, 2007). Young bracken fern fronds are and cause ulceration and blood loss, leucopoenia, thrombocytopenia and haemorrhagic syndrome in cattle (Hirono and Yamada, 1987; Bond et al, 2007). Bracken fern also causes a thiamine deficiency in horses that can result in anorexia, stagger and a loss of coordination (Hirono and Yamada, 1987; Bond et al, 2007). In sheep it is known to cause night- blindness and tumours on live stock (Hirono and Yamada, 1987; Cooper-Driver, 1990). It also creates an environment suitable for the transmission of Lyme disease via sheep ticks (Eastman, 2003; Bond et al, 2007).

2.20 Chapter 2 summary

This chapter the image classification process was outlined together with hard and soft image classification techniques as well as a change detection technique, post-classification comparison. The image classification process outlined provides the back bone of this research. Also the physical description of bracken fern and its seasonal growth pattern were outlined. This knowledge together with the review of previous research done on the image classification of species suggests that both soft and hard classification techniques could be undertaken with high resolution aerial imagery. However fuzzy classification can produce more accurate and reliable results than supervised classification.

Chapter 3 : Materials and Methods

This chapter covers the methodology decided upon for this research. First an overview of the research methodology is outlined. Thereafter a detailed methodology diagram is outlined at each stage of the methodology. A pilot study was undertaken to decide between applying hard or soft classification techniques to image classify bracken fern.

3.1 Overview of research methodology

This research methodology was broken down into eight stages. Stage 1 comprised of determining the resources and data required for this research and how that data would be acquired. Stage 2 comprised of GPS surveys and observations of the land cover types in the research areas. In stage 3 reference data was created from observations made and location information gathered in the research areas that were used in data training of the classifier. Stage 4 involved the image orthorectification of multispectral aerial imagery. Stage 5 comprised of a pilot study that was used to determine whether the supervised or fuzzy classification technique was the most suitable for this research. In stage 6 the fuzzy classification technique was applied to the orthoimagery of the research areas. In stage 7 the classified images produced were verified by a ground truth survey. Thereafter the accuracy and reliability of the classified images were determined using error matrices and Kc. In stage 8 the classification maps were produced and then change detection analysis was carried out using post-classification analysis. The overview of the project methodology is illustrated in Figure 3.1.

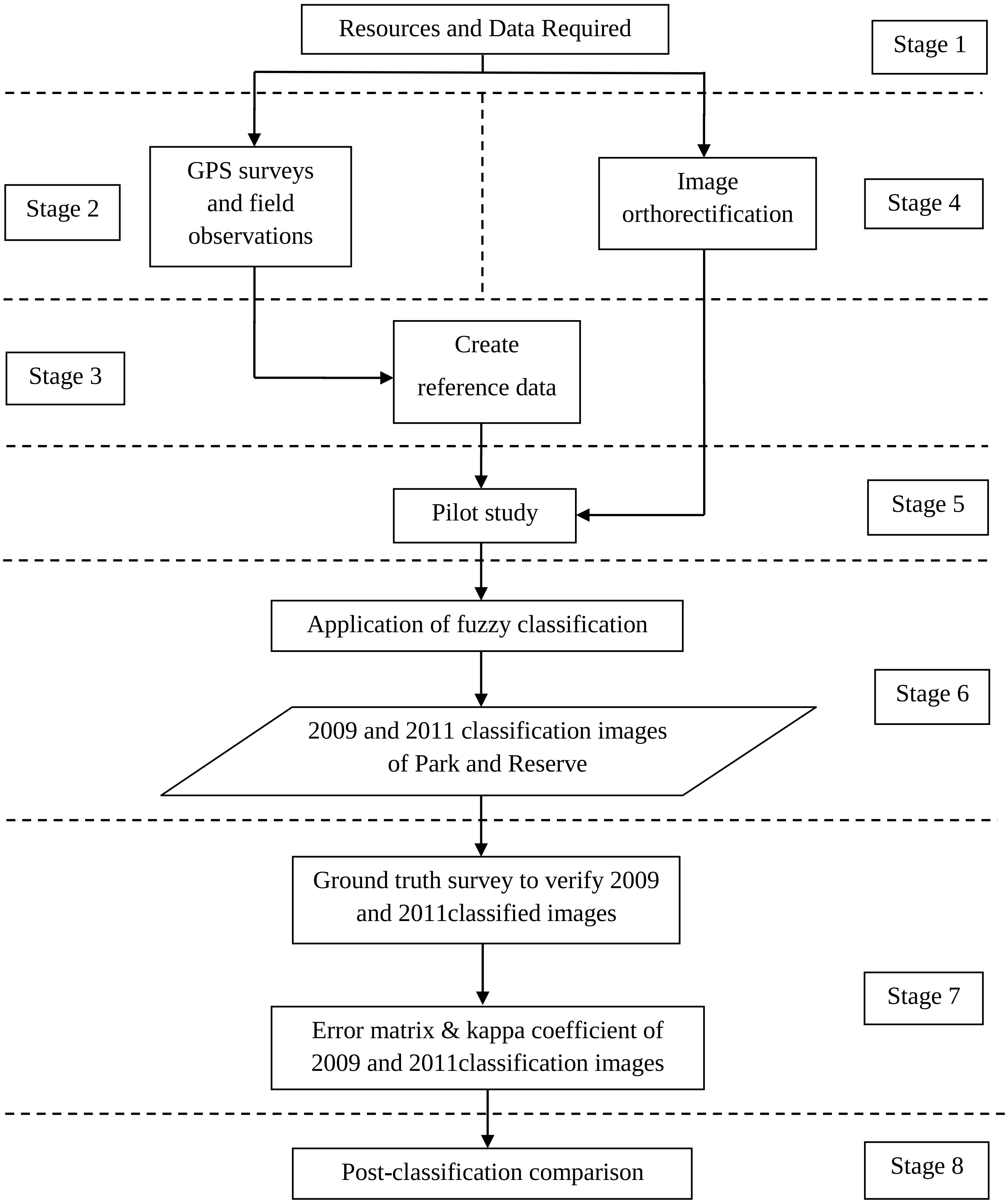

Figure 3.1: Overview of research methodology

3.2 Stage 1: Resources and Data Required

A Global positioning system (GPS) to collect data during the ground truth surveys, software packages that had image orthorectification and image classification functionality and a computer capable of running a software package as well as the amount data that would be processed was required for this research.

Primary data in the form of GPS coordinates are required to create reference data for image classification and secondary data in the form of remotely sensed imagery are required to carry out image classification and GIS layers of the Park and Reserve boundary required to create the classification maps. Figure 3.2 shows the data required for this research.

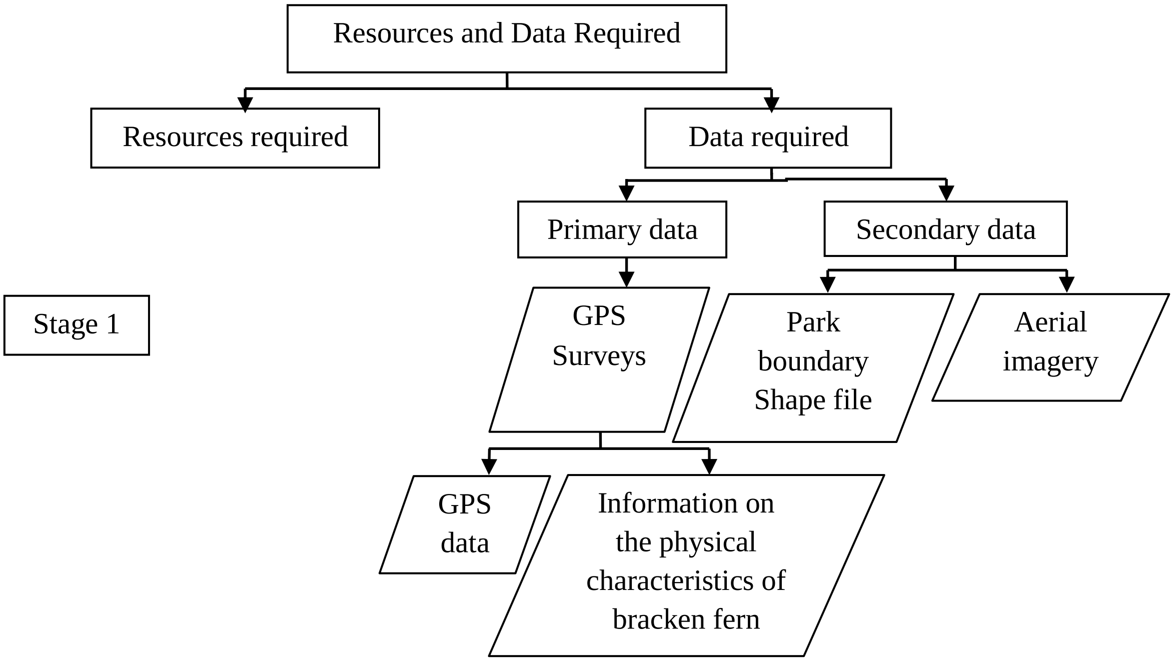

Figure 3.2: Data required for this research

3.2.1 Software

The choice of software used in this project was informed by the choice of previous research (refer back to Table 2.3) and availability of software. ArcEditor Version 9.2, Erdas 2011 and Leica Photogrammetry Suite (LPS) were used in this research. ArcEditor Version 9.2 was be used to create reference data. It was also used to determine the area infested with bracken fern Park and Reserve. LPS was used to orthorectify the multispectral aerial imagery. Erdas 2011 was used to carry out image classification as it had the supervised and fuzzy classification methods. Erdas 2011 was used to assess the accuracy of the classified images of the pilot study.

3.2.2 GPS surveys

The primary qualitative and quantitative data set was attained from GPS surveys. The qualitative data was the GPS coordinates of land cover features such as bracken fern and grassland, while the quantitative data consisted of the general; clump sizes, spatial distribution, condition, homogeneity, and vegetation comprising the landscape. A Garmin Etrex and Trimble Geo TX were used to collect GPS coordinates of land cover types.

3.2.3 Aerial Imagery

Multispectral aerial imagery was obtained from the Chief Directorate: National Geospatial Information (CD: NGI) free of charge. The imagery was captured on two epochs on 2009/07/13, in mid-winter, and 2011/10/08, in mid-spring with a Z/I Imaging Digital Mapping Camera (DMC) from a light aircraft. The DMC has a focal length of 12 cm, pixel size of 12 microns and an image size of 13824 x 7680 pixels. These figures were stated after camera calibration.

The average flying height is 5525 m and 5730 m above mean sea level for the 2009 and 2011 imagery respectively. The distance between exposure stations was 1500 m for both epochs. All the imagery has a spatial resolution of 0.5 m.

RGB and CIR imagery received covered all of the research areas and was cloud free. The aerial imagery received was re-quantized by the CD: NGI, from 12 bit to 8 bit but not re-sampled. The imagery had been corrected for radiometric and geometric distortions by the CD: NGI. The imagery was geo-referenced but not orthorectified.

3.3 Stage 2: GPS surveys of the Park and Reserve

Two GPS surveys were conducted in the research areas. The first survey was conducted, during early autumn, from 26 to 30 March 2012 and the second GPS survey was conducted, during early winter, from 18 to 22 June. During each survey accessible areas of the Park and Reserve were visited.

The first GPS survey was carried out using a Garmin Etrex GPS. The Etrex GPS settings were set to the following; projection system was set to Transverse Mercator, the datum was set to Haartebeeshoek 94 and units set to meters. The accuracy limit of the GPS in the field was 4 m^2 and

GPS coordinates were taken as close the centre as possible to compensate for low accuracy Etrex. Due to this factor only bracken clumps larger than 4 m^2 were surveyed. Determination of the clump sizes in the research areas was done visually and one GPS point represented the centre of one clump of bracken fern.

In the pilot study, it was noticed that the boundaries of bracken fern and grassland was not sufficiently indicated by one GPS point coordinate to facilitate data training for the image classification. Also there was a concern to due to the positional error that could be caused by using GPS coordinates that were recorded on a lower accuracy than the spatial resolution of the aerial imagery. Thus a second GPS survey was conducted using a higher accuracy the Trimble R8 GPS.

Base stations were setup and the rover was carried into the Park and Reserve to collect GPS coordinates in real time kinematic (RTK). It was quoted to have an accuracy of +/- 1 cm + 1ppm RMS for horizontal and +/- 2 cm + 1ppm RMS for vertical measurements. The GPS coordinates of each land cover type were taken around its perimeter to form a polygon of GPS coordinates to represent each land cover type.

3.4 Stage 3: Create reference data

In order to create reference data for this project a geodatabase was created in ArcEditor, within that geodatabase feature classes and features were created. Those features were imported in ArcMap and were edited to form polygon layers that represented the bracken fern and grassland using the GPS coordinates. The GPS data used to create the reference polygons are listed in Appendix A. The methodology used to create the reference data illustrated in Figure 3.3.

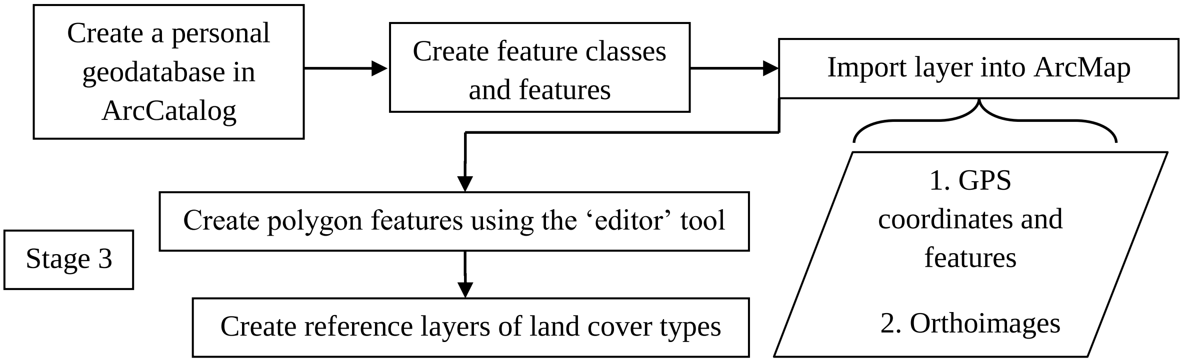

Figure 3.3: GIS analysis using ArcEditor

3.5 Stage 4: Image orthorectification

In order to orthorectify the imagery a project was created in LPS Project Manager. Camera, orientation information and imagery were entered manually. Automatic tie point collection and aerial triangulation was performed. A Digital elevation model (DEM) was created for the area covered in the imagery. The ortho resampling was performed and the orthorectified images or orthoimages were produced.

After the image orthorectification the RGB orthoimages were joined together to form a RGB mosaic of the research areas and the same was done for the CIR orthoimages. The RGB and CIR mosaics were stacked to create three 6-band orthoimages; one covering the pilot study test area and two covering the entire research areas from 2009 and 2011 aerial imagery. The repeated red and green bands in the 6-band stacked orthoimages would not decrease the accuracy of the classified images and the increase in time taken for image processing would be negligible, thus were not removed.

The Park and Reserve are adjacent which facilitated the creation of one orthoimage containing both the research areas. This saved time by avoiding the need to conduct separate image orthorectification of imagery for the Park and Reserve. The methodology to be used to create the orthoimages is illustrated in Figure 3.4.

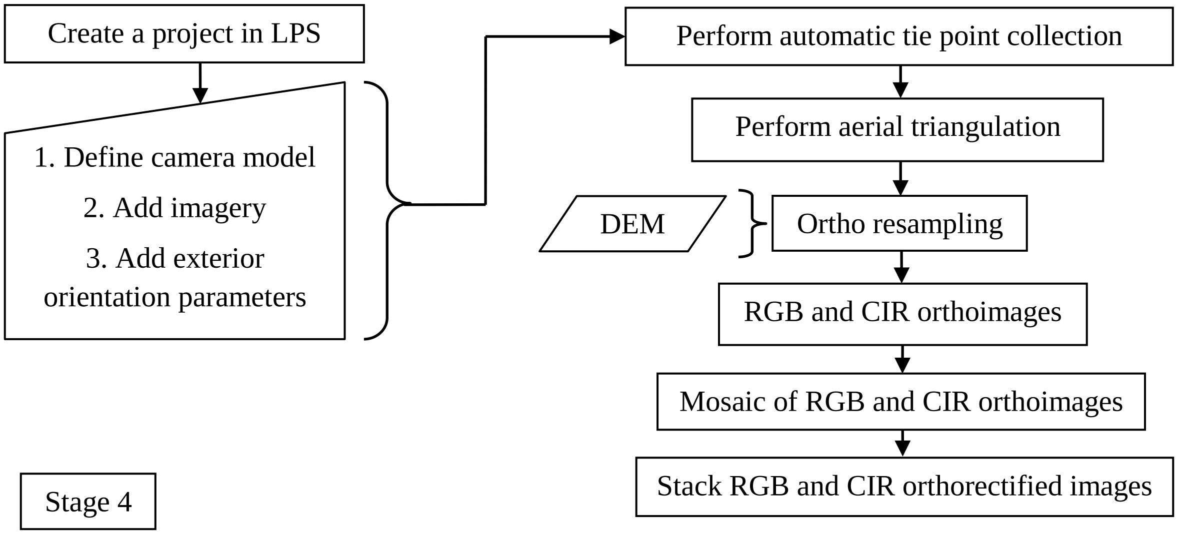

Figure 3.4: Image orthorectification using LPS Project Manager

3.6 Stage 5: Pilot study

Supervised and fuzzy classification techniques were chosen because of three factors. Firstly the GPS surveys provided large amounts of reference data which would facilitate sufficient training the classifiers. Secondly the experience from the GPS surveys would create an understanding of the land cover classes that occurred in the research areas which would facilitate accurate training for image classification. Thirdly these techniques gave full control of which land cover classes were classified. The combination of these factors would lead to the creation of classified images that would be easily understood.

The pilot study was carried out using a stacked orthoimage of the 2011 aerial imagery covering a portion of the research area, which was used as the test area. In the pilot study supervised and fuzzy classification techniques were conducted on the same stacked orthoimage. The spectral signature of bracken fern was not investigated in the pilot study. The pilot study methodology is illustrated in Figure 3.5.

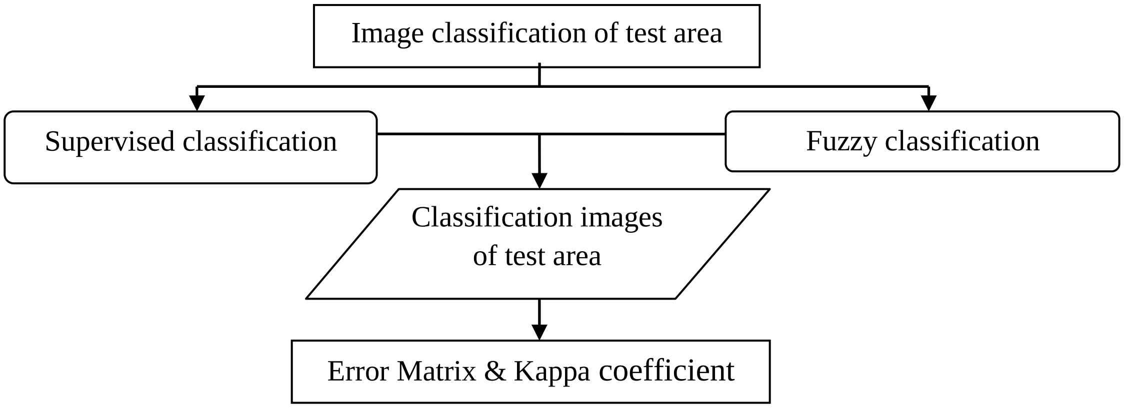

Figure 3.5: Methodology of pilot study

The land cover classes were initially informed by observation from the GPS field surveys. However during data training stage of image classification, mixtures of land cover types were identified. These mixtures of land cover types occurred in areas that were inaccessible and thus were not identified in the ground truth survey. These land cover mixtures were considered in the image classification. Vegetation cover types were selected for classification because they may produce similar spectral characteristics bracken and may lead to misclassifications in the classified image.

The principal focus of this research was to classify the bracken fern. Thus a two land cover class classification system was employed. The land cover types were grouped into two classes; bracken fern was one class and the other seven land cover types were grouped together into the non-bracken fern class. Table 3.1 shows he land cover classes classified in the pilot study.

Table 3.1: Land cover classes of included in the image classification

Class no.	Class Name	Class Description
1	**Bracken Fern**	Bracken fern on the plains and hills.
2	**Forest Land**	Forest of mixed trees types.
3	**Grassland**	Different types of grasses on the plains, hillsides and hilltops.
4	**Vegetation Type 1**	Areas of mixed vegetation growing on the hillsides.
5	**Vegetation Type 2**	Areas of sparse vegetation growing on the hilltops.
6	**Vegetation Type 3**	Areas of dense mixed vegetation on the top of hills on the western side of the Park.
7	**Vegetation Type 4**	Areas of mixed vegetation growing on hilltops on the northern side of the Park and Reserve.
8	**Maintained Areas**	Maintained lawns and vegetation around reception area and chalets.

3.6.1 Classification approach 1: Supervised classification

The test area stacked orthoimage was imported into Erdas 2011 then ‘Signature Editor’, ‘Area of Interest’ (AOI) polygon drawing tool and reference data polygon layers were used to define the training data for each class.

All samples of training data was selected from within the boundaries of the reference polygons for each land cover type. This was done to prevent the training of pixels in the incorrect land cover class. Seventy sites were used to train the classifiers, 35 for each land cover class.

The frequency distribution histograms for each land cover class were inspected using to determine the fitness of the training data. Land cover classes whose frequency distributions did not have a normal distribution curve were re-trained. Some land cover types were spilt to produce two or more land cover classes that had a normal Gaussian frequency distribution. A trial and error approach was used to select the optimum training data for each class.

Thereafter classification was run; zero values were not classified, using the MLC. The supervised classification produced a single layer image of the land cover types. The methodology of the supervised classification is shown in Figure 3.6.

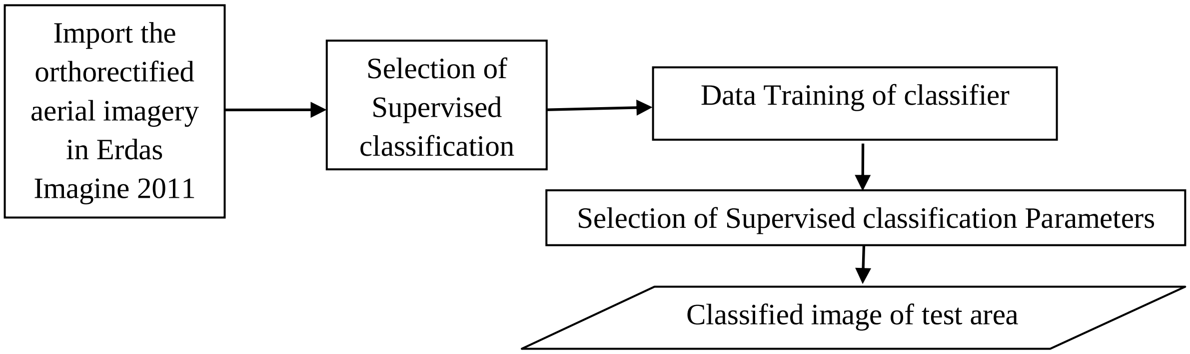

Figure 3.6: Supervised classification methodology

3.6.2 Classification approach 2: Fuzzy classification

The fuzzy classification process in Erdas 2011 was made up of two steps. The first step was ‘fuzzy classification’ and the second step was ‘fuzzy convolution’. Three equations show the calculations used in the fuzzy classification process. Equation 3.1 (Erdas field guide, 2010) shows the calculation of the centre pixel, Equation 3.2 (Erdas field guide, 2010) shows the calculation of the fuzzy mean, and Equation 3.3 (Erdas field guide, 2010) shows the calculation of the fuzzy covariance matrix.

$$T[k] = \sum_{i=0}^{s} \sum_{j=0}^{s} \sum_{l=0}^{s} \frac{W_{ij}}{D_{ijl}[k]}$$ **Equation 3.1**

$T[k]$ - Total weighted distance of window for class *k*

i - Row index of window

l - Layer index of fuzzy set

n - Number of fuzzy layers used

W - Weight table for window

j - Column index of window

k - Class value

s - Size of window (3, 5, or 7)

$D[k]$ - Distance file value for class k

$$u_c = \frac{\sum_{i=1}^{n} f_c(x_i)\, x_i}{\sum_{i=1}^{n} f_c(x_i)}$$ **Equation 3.2**

u_c - Fuzzy mean

n - Sample of pixel measurement vectors

f_c - Membership function of class c

x_i - Sample pixel measurement vector

$$V_c = \frac{\sum_{i=1}^{n} f_c(x_i)(x_i - u_c)(x_i - u_c)^T}{\sum_{i=1}^{n} f_c(x_i)}$$ **Equation 3.3**

V_c - Fuzzy covariance matrix

n - Sample of pixel measurement vectors

f_c - Membership function of class c

x_i - Sample pixel measurement vector

In order to perform a fuzzy classification, each class must be defined by a membership function (Erdas field guide, 2010). The following fuzzy classification is based on the MLC. Here the fuzzy mean (u^*) and fuzzy covariance matrix (V^*) replace the conventional mean and covariance matrix. Equation 3.4 (Jenson, 2005) is the representation of the fuzzy classification using based on the MLC and Equation 3.5 (Jenson, 2005) shows the variable involved in a fuzzy classification based on the MLC membership function for class c.

$$f_c(x) = \frac{P_c^*(x)}{\sum_{i=1}^{m} P_i^*(x)}$$

Equation 3.4

Where,

$$P_i^*(x) = \frac{1}{(2\Pi)^{\frac{N}{2}} \left| V_1^* \right|^{\frac{1}{2}}} \times \exp\left[-0.5 \left(x - u_i^* \right)^T \left(V_i^* \right)^{-1} \left(x - u_i^* \right) \right]$$

Equation 3.5

N - Dimension of pixel vectors
m - Number of classes
P_i* - MLC algorithm with the fuzzy mean and covariance matrix
u* - Fuzzy mean
V* - Fuzzy covariance matrix
$1 \leq i \geq m$

3.6.2.1 Fuzzy classification step

The ‘fuzzy classification’ step used the same training data procedure as supervised classification. The fuzzy classification box was carried out using; the 2 ‘best classes for a pixel’, an orthorectified image, and signature file, MLC and a distance file selected to be created along with the ‘fuzzy classification’ image. After the ‘fuzzy classification’ image was produced the ‘fuzzy convolve’ procedure was selected.

3.6.2.2 Fuzzy convolution step

The ‘fuzzy convolve’ step used the ‘fuzzy classification’ image and a distance file created in the ‘fuzzy classification’ step. The following parameters were selected for this step: a 3x3window size, neighbourhood weighting by distance, the default neighbourhood weighting factor of 0.5, all 6 layers of the orthoimage was selected because the increase in processing time was negligible. A single classification layer was created by the fuzzy convolution operation. This image was then assessed to determine its accuracy. The methodology of the supervised fuzzy classification is shown in Figure 3.7.

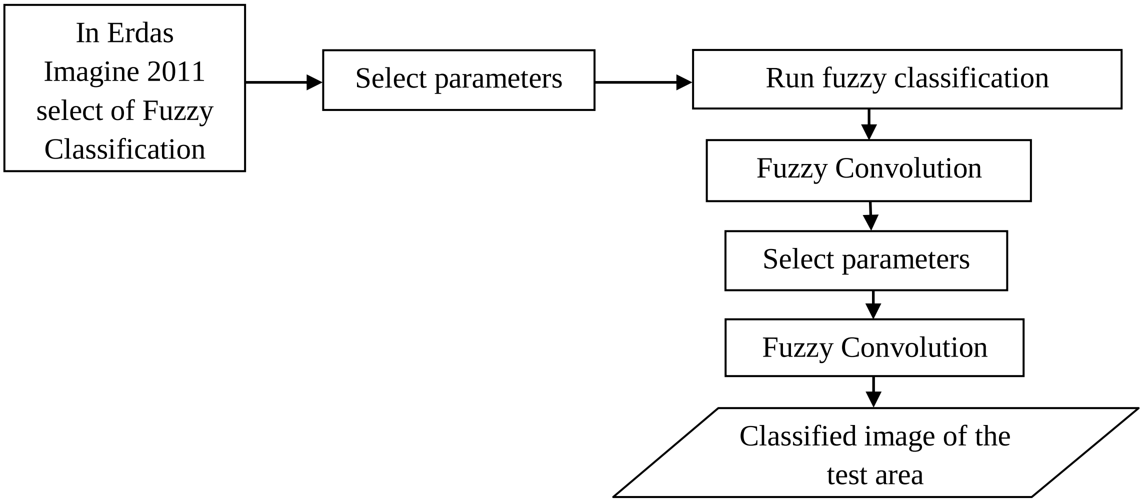

Figure 3.7: Fuzzy classification methodology

3.6.3 Accuracy assessment of pilot study

The accuracy assessment tool in Erdas 2011 was used to assess the supervised and fuzzy classified images. The Erdas assessment tool required entering of user defined points and 35 points for each land cover class were used in the assessment. Then an error matrix and Kc were produced automatically. A visual inspection was conducted on each classified images. The OA, Kc and visual inspection were used to select an image classification technique for this research.

3.7 Stage 6: Fuzzy classification

Since the multi-date imagery used in the image classification was captured in different seasons, due to the seasonal growth pattern of vegetation in the Park and Reserve, land cover types possessed a different spectral reflectance pattern at different parts of the year. Thus independent fuzzy classifications using the 2009 and 2011 stacked orthoimages.

The 2009 and 2011 fuzzy classifications were trained using the same training areas of bracken fern. In the 2009 orthoimage nine land cover types grouped to form two land cover classes, bracken fern and non-bracken fern. Non-Bracken fern comprise of the other eight land cover types. The land cover classes that were considered for the 2009 and 2011 fuzzy classifications are show in Table

3.2 and Table 3.1 respectively. The methodology used for the fuzzy supervised classification was the same as outlined in Figure 3.7.

Table 3.2: land cover classes considered for the 2009 image classification

Class no.	**Class Name**	**Class Description**
1	**Bracken Fern**	Bracken fern on the plains, hillsides and hilltops.
2	**Forest Land**	Forest of trees.
3	**Grassland**	Different types of grasses on the plains, hillsides and.
4	**Vegetation Type 1**	Areas of mixed vegetation growing on the hillsides.
5	**Vegetation Type 2**	Areas of sparse vegetation growing on the hilltops.
6	**Vegetation Type 3**	Areas of dense mixed vegetation on the top of hills on the western side of the Park.
7	**Vegetation Type 4**	Areas of mixed vegetation growing on hilltops on the northern side of the Park and Reserve.
8	**Maintained Areas**	Maintained lawns and vegetation around reception area and chalets.
9	**Burnt Area**	Burnt grassland, hillsides and hilltops.

3.8 Stage 7: Accuracy assessment

The accuracy of the 2009 and 2011 fuzzy classified images of the Park and Reserve were evaluated using a ground truth survey, error matrix and Kc. The third ground truth survey was used to verify the classifications of both epochs.

In the ground truth survey 70 sites were used to validate the 2009 classified image and 90 sites were used to validate the 2011 classified image. The 2009 and 2011 fuzzy classified images were validated using equal number of sites for the two classes. The ground truth sites used in the validation process are listed in Appendix B.

The difficult terrain made it unfeasible to travel to all parts of the research areas. Thus the sampling was restricted to the accessible grasslands, hillsides and hilltops. However this restriction did not introduce bias into the accuracy assessment because 2009 and 2011 fuzzy classified images identified bracken fern in the research areas growing on grasslands, hillsides and on hilltops of varying altitude and degree of slope. The Figure 3.8 shows the methodology of accuracy assessment of the 2009 and 2011 fuzzy classified images.

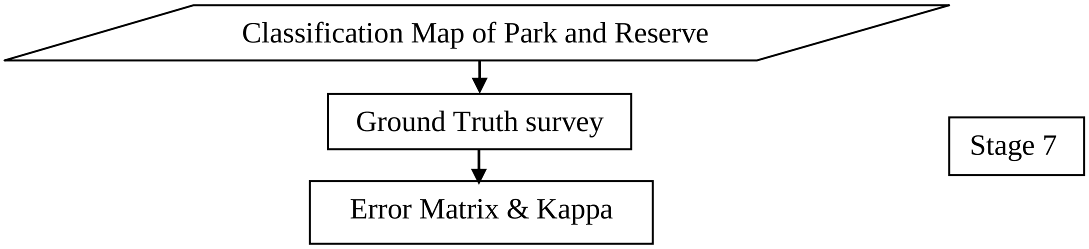

Figure 3.8: Accuracy assessment methodology

Figure 3.9 and 3.10 shows the ground truth sites that were used in the validation process of the 2009 and 2011 fuzzy classified images respectively.

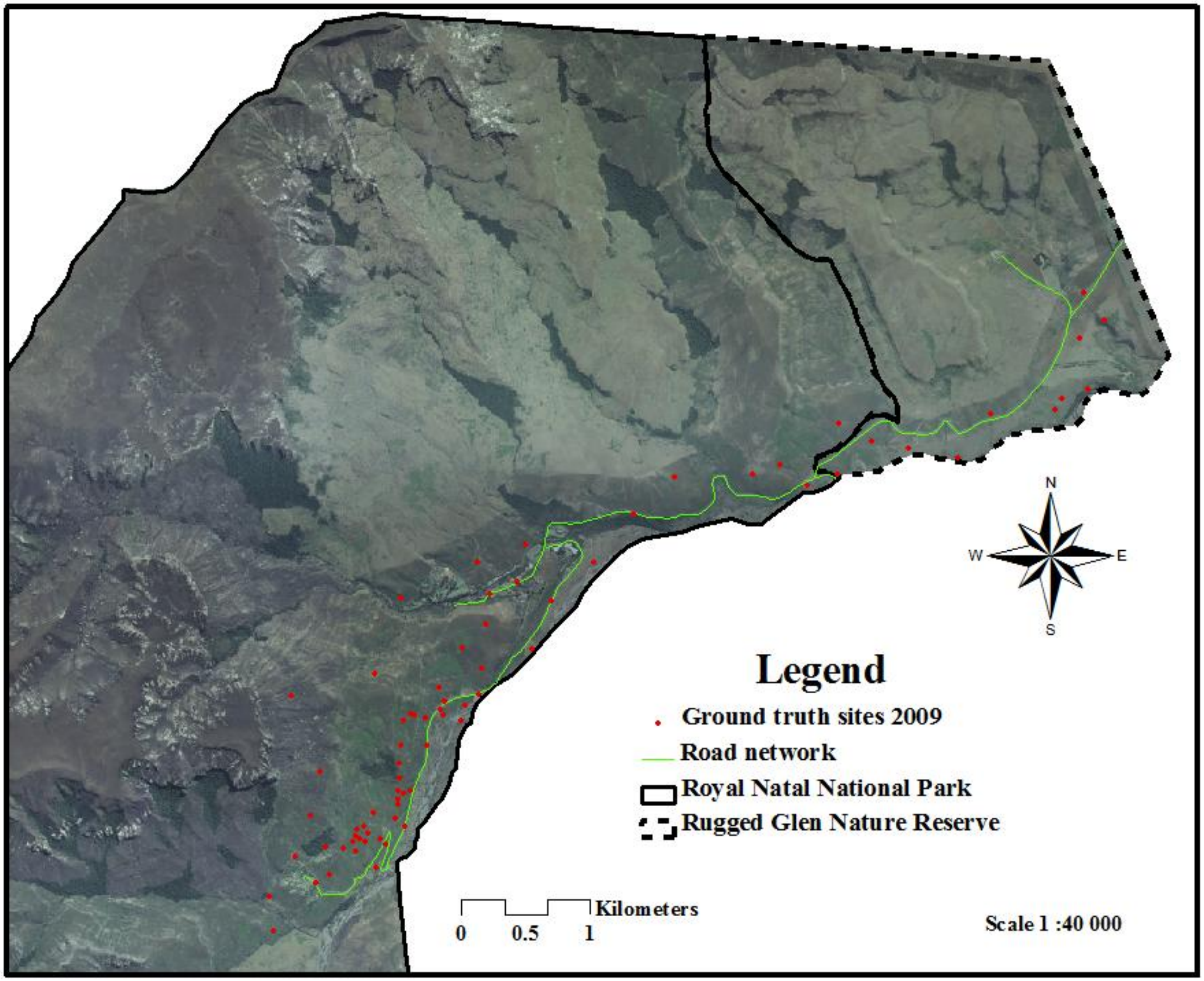

Figure 3.9: Ground truth survey sites of 2009 classified image

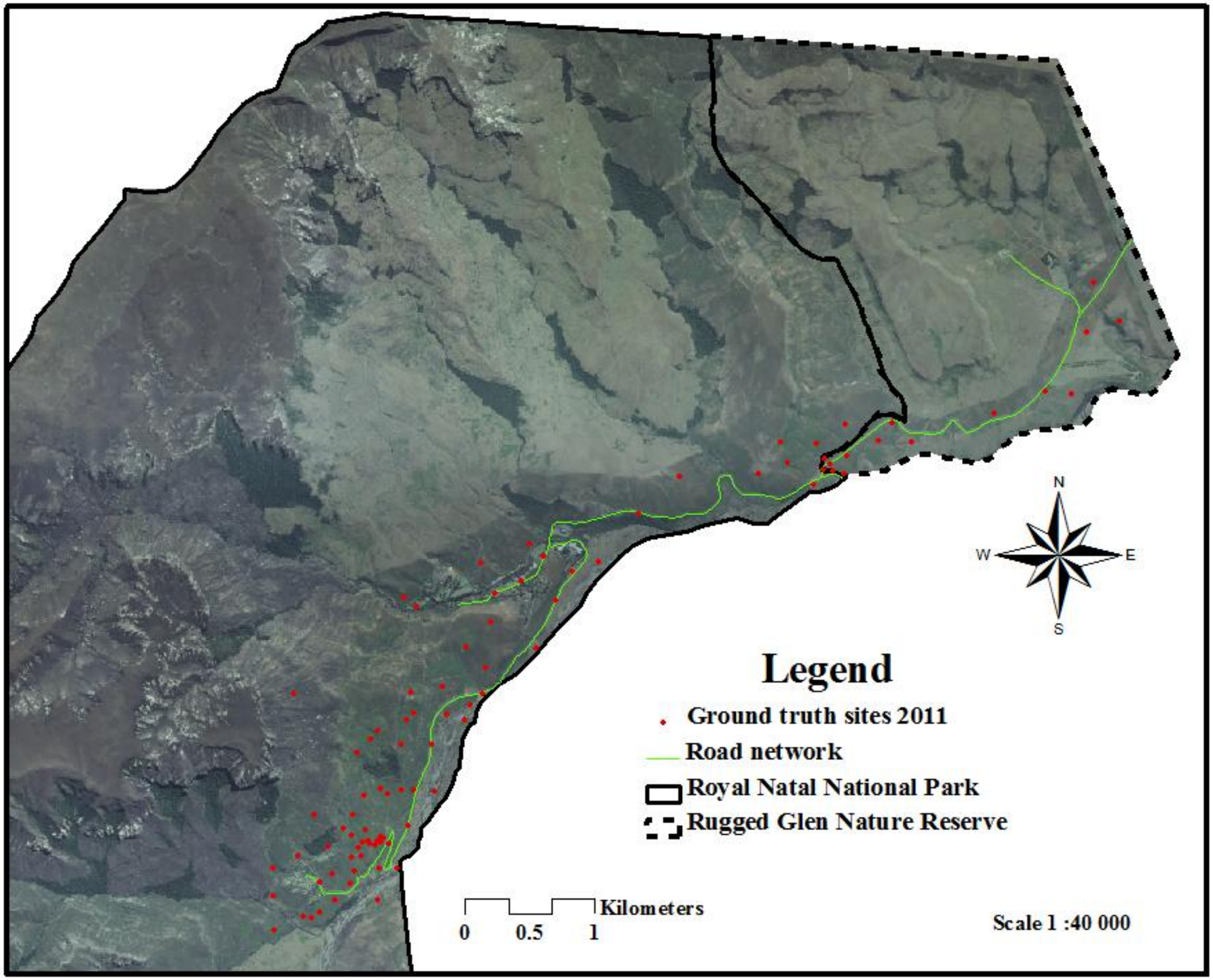

Figure 3.10: Ground truth survey sites of 2011 classified image

3.9 Stage 8: Post-classification comparison

Since independent fuzzy classifications were conducted, this ruled out the application of spectral temporal combined analysis as a change detection technique. Thus post-classification change detection technique was the only change detection technique that could be applied to determine any change in the bracken fern infestation in the Park and Reserve from 2009 to 2011 using independent classified images.

The ‘measure’ tool in ArcMap was used to determine the area that was infested by bracken fern in 2009 and 2011. This area amount obtained was divided by the total area for each research area to determine the percentage of area in the Park and Reserve was infested. Equation 3.6 was used to determine the percentage of area in the Park and Reserve that was infested.

$$\text{Percentage of infestation} = \frac{\text{Area covered by bracken fern in the Park or Reserve}}{\text{Area of the Park or Reserve}} \times 100$$

Equation 3.6

The percentage change of bracken fern infestation in the Park and Reserve was based on the difference of the total area infested by bracken fern in 2009 and 2011 divided by the area infested by bracken fern in 2009. Equation 3.7 was used to determine this percentage change of bracken fern infestation in the Park and Reserve.

$$\text{Percentage change} = \frac{\text{Area infested in 2011} - \text{Area infested in 2009}}{\text{Area covered by bracken fern in 2009}} \times 100$$

Equation 3.7

3.10 Chapter 3 summary

The methodology outlined was the image classification process adapted for this research given the data available and data required. GPS field surveys were needed to obtain information about bracken fern and the land cover types that occurred in the research areas. This information was used as reference data to the training of the classifiers. The possibility that mixed pixels in the classified image could produce unsatisfactory results was the reasons why fuzzy and supervised classifications were compared pilot study. Also, given that the 2009 and 2011 imagery were captured in different seasons only independent classifications could be undertaken. This then left post-classification comparison as the only change detection technique that could be applied given the data available.

Chapter 4 : Results

The results for this research include; the observations of the GPS surveys, pilot study, image orthorectification, fuzzy classification and post-classification comparison. The results of the pilot study affected the choice of image classification technique used in this research. These results are then discussed in the next chapter.

4.1 Observations of GPS surveys

The GPS surveys revealed that the clumps bracken fern were growing across grasslands, on hillsides and hilltops in the Park and Reserve. Also the area covered by bracken fern clumps varied greatly. Using the 'Area tool' in Arc Editor it was found that bracken fern clumps vary from 5 m^2 to over 500 m^2. Bracken fern was found to be growing in mostly homogenous clumps with other vegetation such as grass, shrubbery and small trees growing on the periphery of clumps. Also American bramble was found to be growing in some areas within the clumps of bracken fern. Bracken fern was seen growing in open grasslands that were fully exposed to sunlight. Large tracts of bracken fern were found to occur along the roadside in the Park and Reserve.

The first GPS survey of the Park and Reserve was during early autumn. Clumps of bracken fern consisted of plants that were in different life cycle stages and exhibited different physical states. The clumps comprised of healthy green, decaying brown plant and dead grey bracken fern plants. This gave the bracken fern clumps a dark green-brown colour. Figure 4.1 shows the physical condition of bracken fern in autumn.

Figure 4.1: Bracken fern in early autumn in the Park

The second GPS survey of the Park and Reserve was during early winter. Clumps of bracken fern contained plants that were in the same life cycle stage and exhibited the same physical state. The clumps comprised of dead, brown bracken fern. This gave the clumps of bracken fern a brown colour. Figure 4.2 shows the physical condition of bracken fern in early winter.

Figure 4.2: Bracken fern in early winter in the Reserve

Also it was observed that areas that had been infested with bracken fern during the first GPS survey were burned. Figure 4.3 shows the burnt areas of the Park.

Figure 4.3: burnt landscape in Park

The third GPS survey in the Park and Reserve was carried out during early spring. The clumps comprised of new bracken fern sprouting from the bed of decayed bracken fern in areas that had not been burnt. This gave the clumps of bracken fern a bright green-brown colour. Figure 4.4

shows the physical condition of bracken fern in an area that was not burnt in winter by the fire regimes.

Figure 4.4: Bracken fern in early spring in an area that was not burnt of the Reserve

While in areas that were burned during spring bracken fern clumps comprised of young, bright green plants. Figure 4.5 shows the physical condition of bracken fern in an area that was burnt in winter by the fire regimes.

Figure 4.5: Bracken fern in early spring in a burnt area of the Reserve

It was observed that bracken fern reappeared in areas it occupied earlier in the year prior to the burnings. In addition a greater growth of bracken fern were observed in areas it reappeared in after the burnings.

4.2 Results of image orthorectification

The orthoimage of the Park and Reserve consisted of RGB and CIR digital multi-spectral aerial imagery. The reference system for image orthorectification was WGS 84 ellipsoid and the coordinate system was Haartebeeshoek 94, and the projection system was the Transverse Mercator with the 29˚ as the central meridian. Bilinear resampling was used to resample the imagery. The spatial resolution of the orthoimage was kept at 0.5 m. The root mean square error (rmse) of the orthoimage for the triangulation was 1.4352 and 1.0027 microns for the 2009 and 2011 imagery respectively. There are 12 microns that made up an image pixel, so the rmse represented about 1/12th of a pixel and thus was considered acceptable for image classification.

4.3 Result of pilot study

The supervised classification considered bracken fern and Non-Bracken fern as land cover classes. The supervised classification attained an OA of 97 % and Kc of 0.96. The results of the supervised classification done in the pilot study are shown in Table 4.1. These high accuracies attained by the supervised classification may be misleading because sites used to verify the classifier were selected in the middle of land cover clumps and do not reflect areas where combinations of land cover classes occurred in a pixel.

Table 4.1: Supervised classification results of the pilot study

	Classification	Class	OA (%)	Kc (%)	PA (%)	UA (%)	EO (%)	EC (%)
1	Supervised classification	Bracken Fern	97	0.96	95.92	94.29	4.08	5.71
		Non-Bracken Fern			94.29	95.92	5.71	4.08

In Figure 4.6 the fuzzy classified image is overlaid with the supervised classified image. It shows that there was a significant difference in the areas classified as bracken fern in the fuzzy and supervised classified images. There were a significant omission of areas classified as bracken fern in the fuzzy classified image that are not reflected as bracken fern on the supervised classified image. This was the major factor taken into account when selecting fuzzy classification as the classification technique to be used in the research.

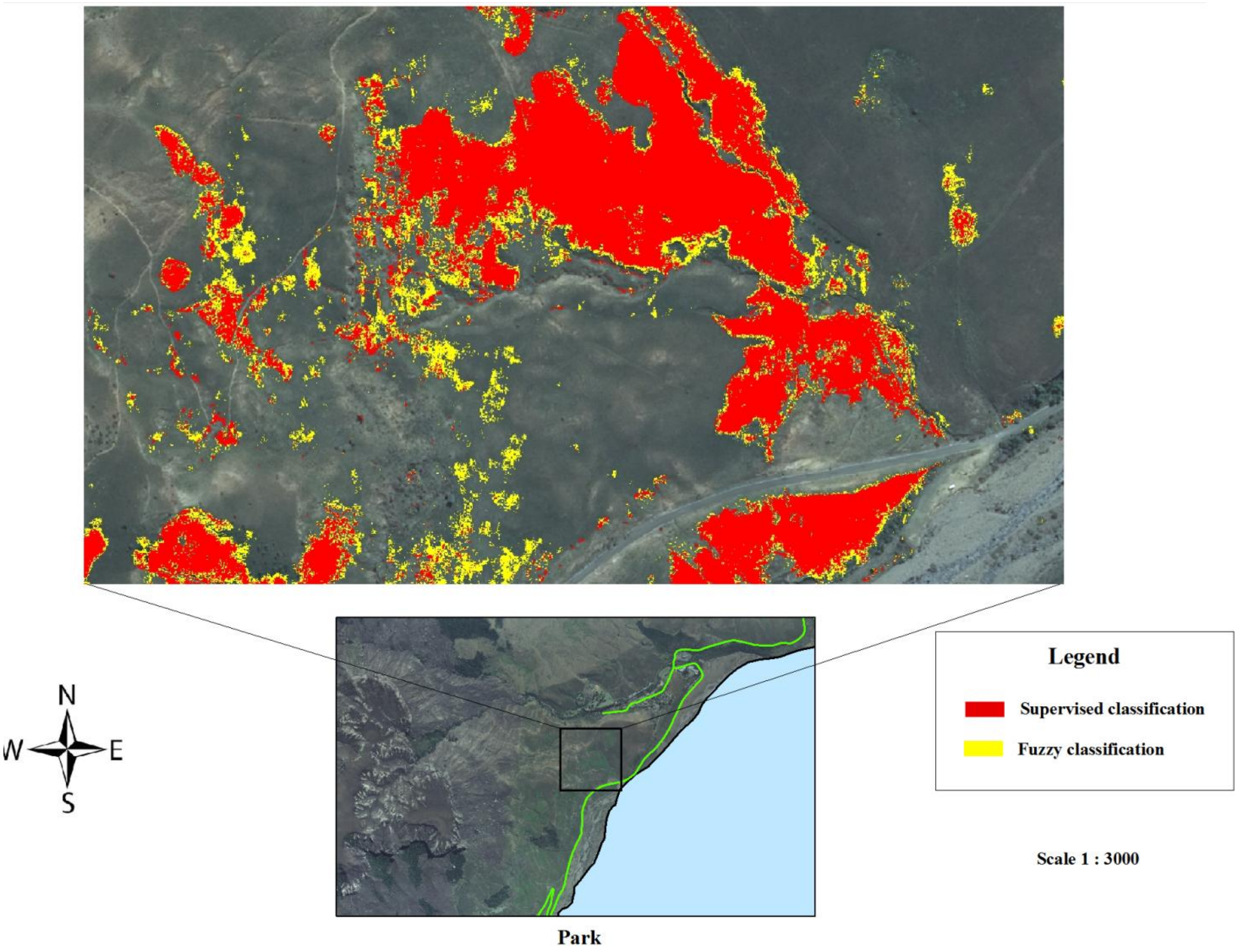

Figure 4.6: Bracken fern in a portion of the fuzzy and supervised classification image of the Park

4.4 Result of fuzzy classification

A ground truth survey was conducted from the 3rd -7th September 2012, to validate the 2009 and 2011 fuzzy classified images of the Park and Reserve. Equation 2.3 was used to calculate the Kc for both classified images. The coordinates of the sites surveyed to verify the classified image can be found in Appendix B.

The 2009 fuzzy classification obtained an OA of 81.43% and Kc of 0.63. Table 4.2 shows the error matrix for the 2009 fuzzy classified image. The calculations are shown thereafter.

Table 4.2: Results of the 2009 fuzzy classification of the Park and Reserve

Nos.	**Classes**	**Reference Data**				
		Bracken fern	**Non-Bracken fern**	**TOTALS**	**UA**	**EC**
1	**Bracken fern**	24	11	35	68.6%	31.4%
2	**Non-Bracken fern**	2	33	35	94.2%	5.7%
TOTALS		26	44	70		
PA		92.3%	75%			
EO		7.7%	15%			

Overall Accuracy (OA) = (24+33/ 70) x 100

= **81.4%**

Kappa Coefficient (Kc):

N = 70

$\sum_{i=1}^{r} X_{i+} X_{+i}$ = (26 x 35) + (44 x 35)

= 2450

Kc = 70(57) – 2450 / $(57)^2$ – 2450

= **0.63**

The 2011 fuzzy classification obtained an OA of 94.44% and Kc of 0.89. Table 4.3 shows the error matrix for the accuracy assessment of the 2011 image classification. Thereafter calculations are shown.

Table 4.3: Results of the 2011 fuzzy classification of the Park and Reserve

Nos.	**Classes**	**Reference Data**				
		Bracken fern	**Non-Bracken fern**	**TOTALS**	**UA**	**EC**
1	**Bracken fern**	41	4	45	91.1%	8.9%
2	**Non-Bracken fern**	1	44	45	97.8%	2.2%
TOTALS		42	48	90		
PA		97.6%	91.7%			
EO		2.4%	8.3%			

Overall Accuracy (OA) = (41+ 44/ 90) x 100

= **94.4%**

Kappa Coefficient (Kc):

N = 90

$\sum_{i=1}^{r} X_{i+}X_{+i}$ = (42 x 45) + (48 x 45)

= 4050

Kc = 90(85) – 4050 / $(90)^2$ – 4050

= **0.89**

The 2009 and 2011 fuzzy classified images depict areas where bracken fern occurs in the Park and Reserve and are shown in Figure 4.7 and 4.8 respectively.

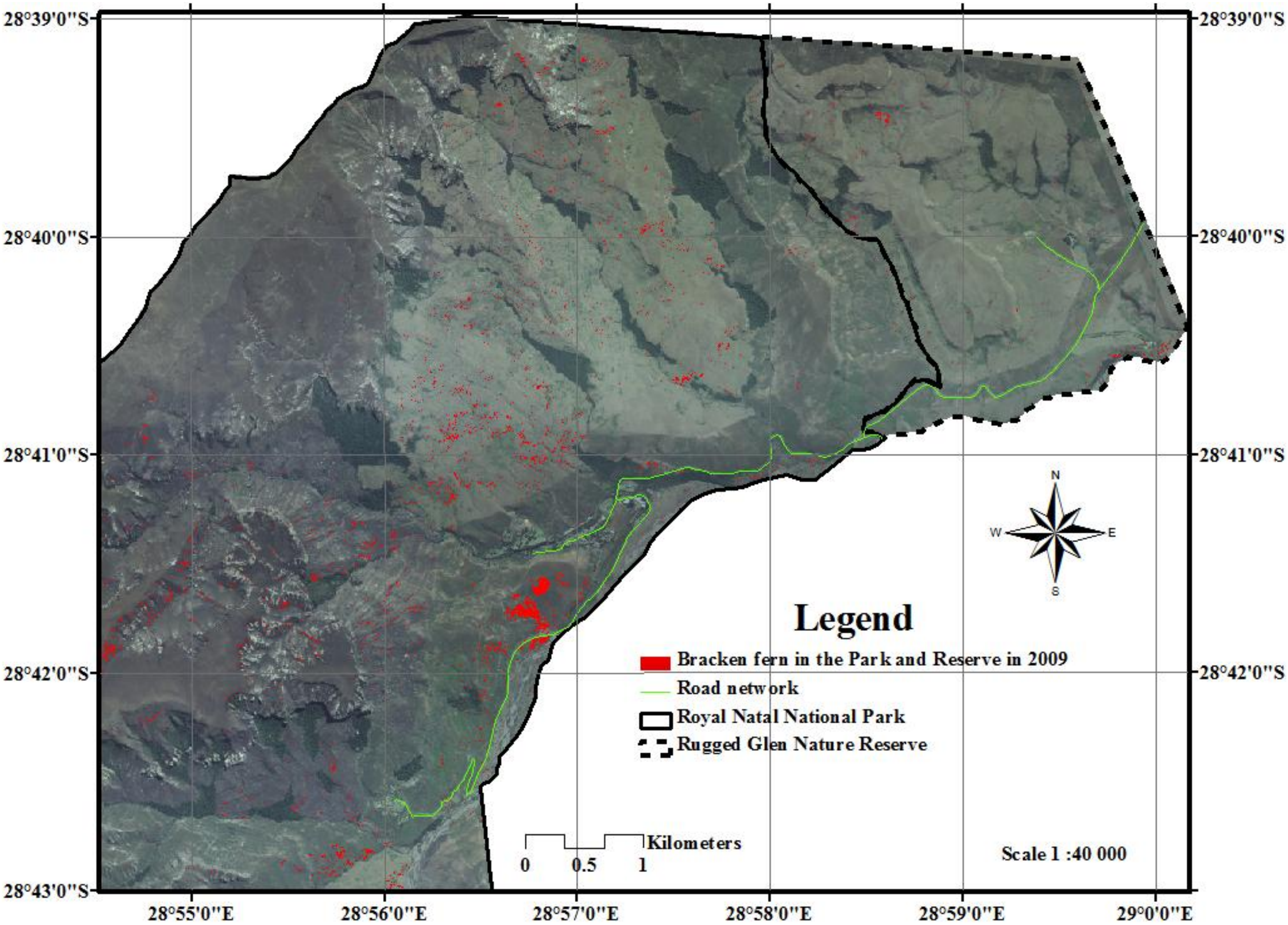

Figure 4.7: Classification map of Bracken fern in the Park and Reserve in 2009

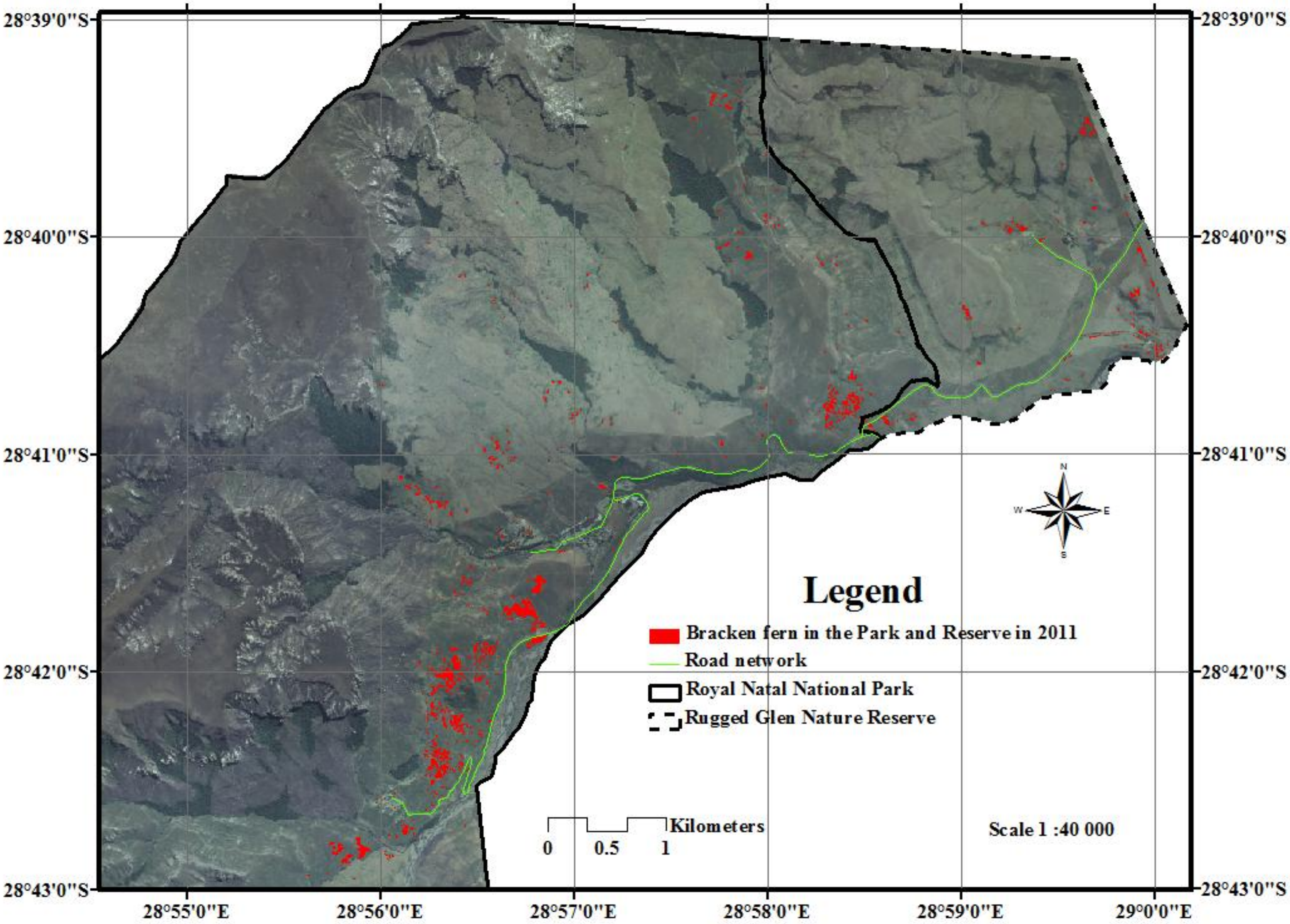

Figure 4.8: Classification map of Bracken fern in the Park and Reserve in 2011

4.5 Results of post-classification analysis

The classification maps were compared to determine the area infested in both epochs as well as the change in area infested by bracken fern. Equation 3.6 was used to calculate the percentage change of bracken fern in the Park and Reserve from 2009 to 2011. Table 4.4 contains the area covered by bracken fern and the percentage of change in the Park and Reserve from 2009 to 2011.

Table 4.4: Percentage change in the Park and Reserve across 2009 and 2011

Research areas	Bracken fern in 2009	Bracken fern in 2011	Area change	Percentage change
Park	185495 m^2	275753 m^2	90259 m^2	**+ 49 %**
Reserve	27327 m^2	41995 m^2	14668 m^2	**+ 54 %**
Total	212822 m^2	317748 m^2	104926 m^2	**-**

Equation 3.7 was used to calculate the percentage of the Park and Reserve that were infested with bracken fern in 2009 and 2011. Table 4.5 shows the percentage of the Park and Reserve that has been infested with bracken fern in 2009 and 2011. Thereafter the change of bracken fern distribution in the Park and Reserve is shown on the change detection map in Figure 4.9.

Table 4.5: Percentage of the infestation in the Park and Reserve across both epochs

Epochs	Park infested with Bracken fern	Reserve infested with Bracken fern
2009	0.2 %	0.4%
2011	0.3 %	0.6 %

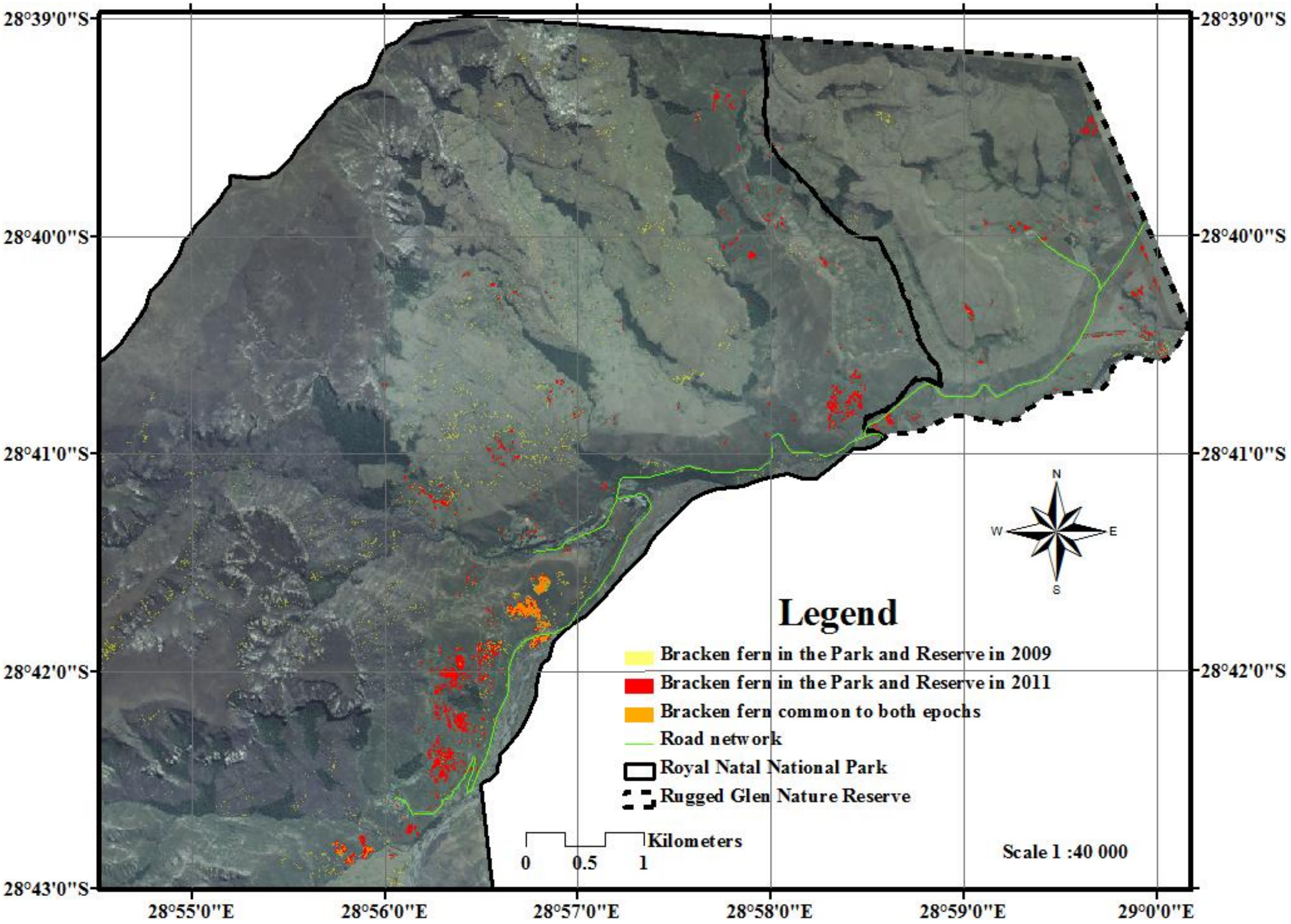

Figure 4.9: Change map of Bracken fern in the Park and Reserve from 2009 to 2011

During the visual inspection of change map seemed to show a trend in the distribution of the Bracken fern infestation. Two observations were made; the first was a reduction of bracken fern in the western and northern areas of the Park and the northern areas of the Reserve from 2009 to 2011; the second observation was that was an increase of bracken fern growth in the eastern and central areas in the Park from 2009 to 2011 and the eastern, central and southern areas in the Reserve from 2009 to 2011.

A reference change percentage of bracken fern growth had to be created to compare to areas of significant infestation seen in 2011 fuzzy classified image. Two areas were selected as reference sites (referred to as site 1 and site 2) and their change percentage of bracken fern growth were calculated. These sites consisted of large clumps of bracken fern that occurred in both epochs. The reference change percentage of bracken fern of sites 1 and 2 were compared with the change percentage of bracken fern growth in another two sites of significant infestation (referred to as site 3 and site 4).

Equation 4.1 was used to determine the percentage change of bracken fern growth in sites 1 – 4. The percentage change of bracken fern growth from 2009 to 2011 for sites 1 – 4 are shown in Table 4.6. Thereafter Figure 4.10 shows the reference site 1 to 4 in the Park and Reserve and Figure 4.11 shows a zoomed in view to site 1 – 4.

$$\text{Percentage change} = \frac{\text{Bracken fern in a site (2011)} - \text{Bracken fern in a site (2009)}}{\text{Bracken fern in a site (2009)}} \times 100$$

Equation 4.1

Table 4.6 : Area and percentage change of bracken fern growth in sites 1 – 4

Sites	Bracken fern in 2009	Bracken fern in 2011	Area change from 2009 to 2011	Percentage change from 2009 to 2011
1	35429 m^2	47836 m^2	12407 m^2	**+ 35 %**
2	9610 m^2	18678 m^2	9068 m^2	**+ 94 %**
3	3730 m^2	35966m^2	35593 m^2	**+ 954 %**
4	14445 m^2	112783 m^2	98338 m^2	**+ 681 %**

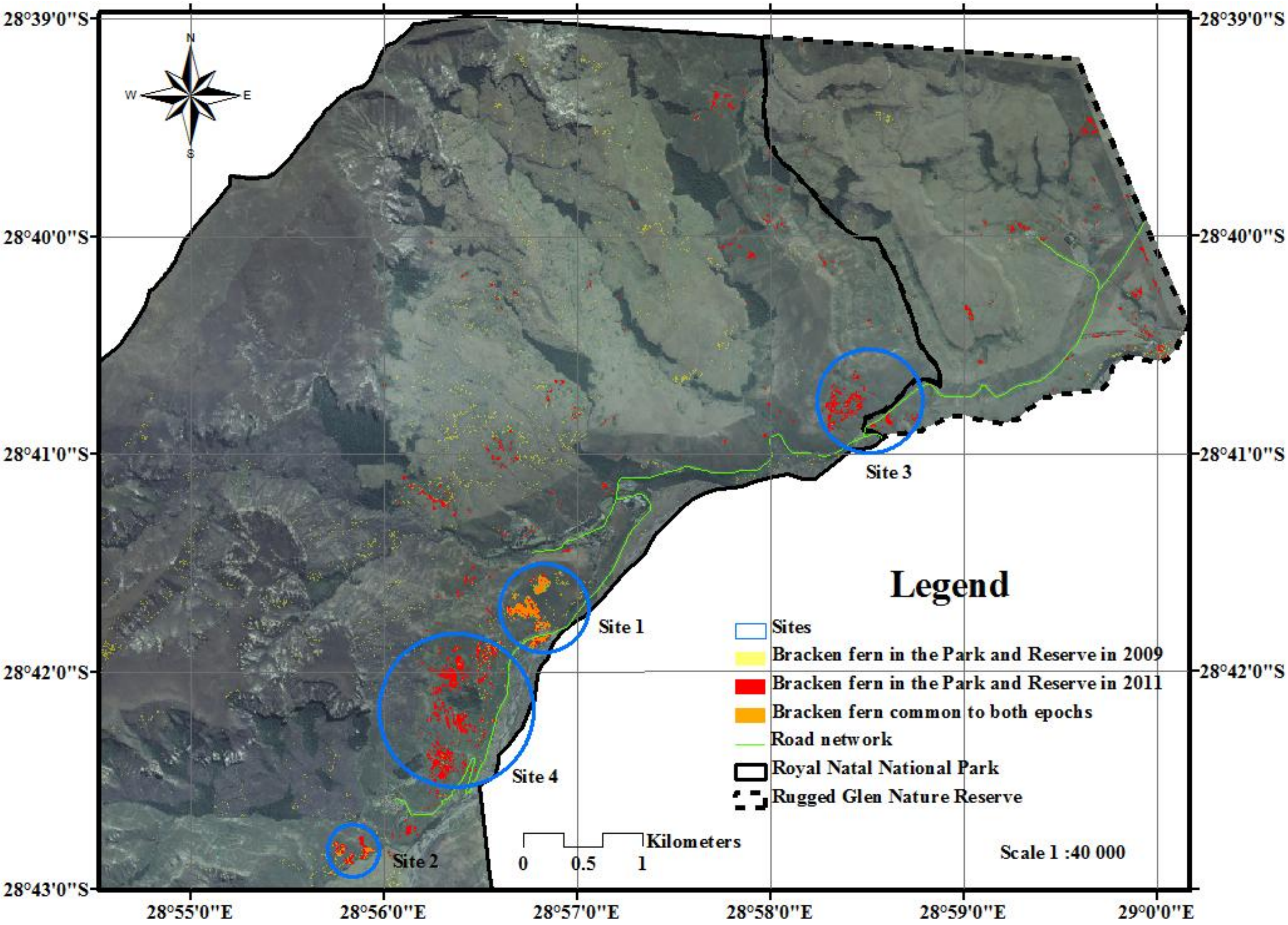

Figure 4.10: Sites of Bracken fern growth

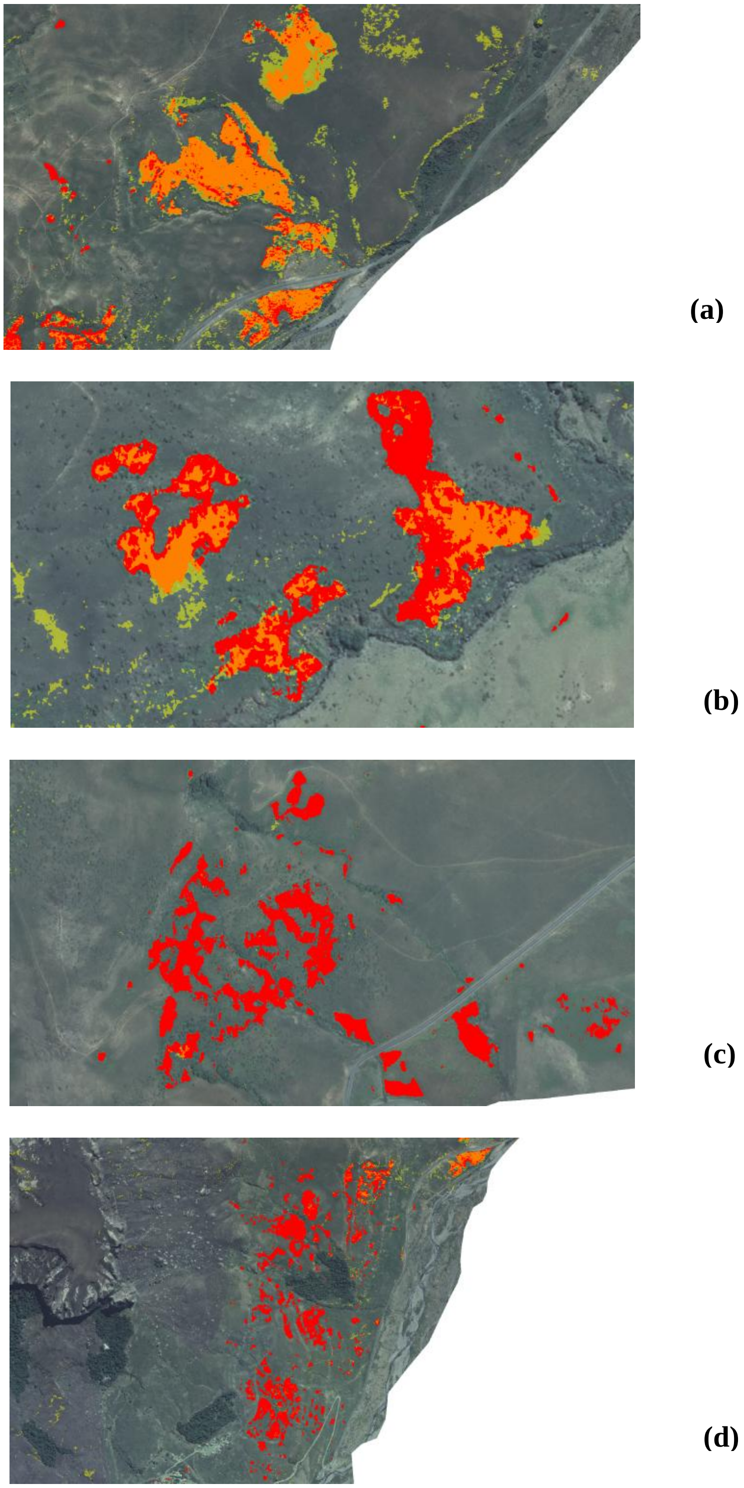

Figure 4.11: Sites where there is an increase of bracken fern from 2009 to 2011; (a) site 1, (b) site 2, (c) site 3 and (d) site 4

4.6 Chapter 4 summary

Bracken fern displayed a distinct seasonal growth pattern which affected its physical appearance that would cause its spectral pattern to change according to the season. The pilot study results that there were significant misclassification of bracken fern in the supervised classified image as compared to the fuzzy classification. Thus fuzzy classicisation was employed for the image classification. Two independent image classifications were conducted. The fuzzy classified images produced were of high accuracy and reliability. The change detection analysis of the fuzzy classified images showed a decrease in bracken fern certain parts of the research area as well as a dramatic increase in other parts. However overall the area infested by bracken increased from 2009 to 2011.

Chapter 5 Discussion of results

This chapter explains the results of analysis conducted and explains the possible reasons for the results obtained. This discussion covers the findings of the; GPS surveys, pilot study, fuzzy classification and change detection analysis.

5.1 Discussion of GPS survey observations

The homogenous clumps of bracken clumps found in the Park and Reserve could be due to Bracken fern inhibiting the growth of other vegetation in the immediate vicinity as stated by Marrs et al (2000), Schneider (2004), Schneider (2006) and Bond et al (2007). This characteristic of Bracken fern allows bracken fern to take over vast areas in an ecosystem (Schneider, 2004; Schneider, 2006; Schneider and Fernando, 2010). This observation demonstrated the possible risk Bracken fern could pose to the biodiversity of the Park and Reserve.

New bracken fern growth of the Park and Reserve in areas where it did not occur prior to the fire regimes was observed in subsequent GPS surveys and was unsurprising as Bracken fern was known to occur in fire disturbed areas (Schneider, 2004; Schneider, 2006; and Schneider and Fernando, 2010) and the road side (Seebacher, 2003). This suggested that there may be a link between the fire regimes carried out in the Park and Reserve and the spread of bracken fern.

Bracken fern was seen growing in open grasslands that were fully exposed to sunlight. This was also unsurprising given such areas are favoured by bracken fern (Crane, 1990). Finding bracken fern growing along the road is a common sight according to Seebacher (2003).

The physical state of bracken fern found in the Park and Reserve changed with the season. Thus bracken fern would have a different spectral reflectance pattern for each season. This was expected given the seasonal growth pattern of bracken fern.

5.2 Discussion of pilot study

A visual inspection of the supervised and fuzzy classified images was carried out. It was observed that the fuzzy classification image noticeably classified more area as bracken fern than the supervised classification image.

The supervised classification classified less area as bracken fern due misclassification of bracken fern as grassland and mixed vegetation land cover types in the Park and Reserve. It was expected that misclassifications would occur in the supervised classification at areas along the periphery of the bracken fern clumps, where mixtures of land cover types occurred. These areas on the periphery of bracken clumps could have a reflectance characteristic that is similar to other land cover types (Schneider and Fernando, 2010). The misclassification that occurred in the supervised classification could under estimate the area occupied by the bracken fern infestation (Schneider and Fernando, 2010).

However such an omission of area the supervised classification as compared to the fuzzy classification was not expected given the high resolution imagery used for the image classification. This highlighted that taking mixed pixels into account was very important because mixtures of land cover types such as; bracken fern, grass, and vegetation types occurred across the Park and Reserve.

Fuzzy classification could produce a more accurate and reliable classified image than supervised classification as it is sensitive in identifying areas that do not contain pure bracken fern. Therefore fuzzy classification was selected as the most suitable image classification technique for this research.

5.3 Discussion of fuzzy classification

This discussion covers the contributing factors to the image classification results of the 2009 and 2011 fuzzy supervised classified images and the comparison of the results to that of previous research.

There were five factors that attributed to the results. These factors were; the spatial resolution of the multispectral imagery, spectral resolution, temporal aspect of the capture of imagery, classification technique, and homogeneous clumps of bracken fern.

The high spatial resolution of the aerial imagery together with the fuzzy classification technique proved as sufficient to identify clumps of bracken fern while reducing the impact of mixed pixels on the classification accuracy. This negates the need to apply un-mixing analysis. The homogeneity of the bracken fern clumps and the NIR portion of the imagery allowed for the fine calibration of the classifier to detect Bracken fern in a heterogeneous environment.

The season in which the aerial imagery was captured were significant to the classification results as the OA and Kc results suggest that mid-spring is more favourable for the capture of aerial imagery than winter, for the purposes of image classification of bracken fern, due to the spectral distinction of bracken fern from to other land cover types in the Park and Reserve.

During spring bracken fern consist of bright green plants with their fronds fully unfurled (Bond et al, 2007). Its growth in spring contrasted with other land cover types and it exhibited a unique spectral reflectance pattern. The physical state of bracken fern was the reason why it exhibited a single unique reflectance pattern in spring and not so in winter.

The physical state of bracken fern clumps in winter consisted of dead and decaying plants and was similar to grassland and vegetation type 3 and 4 in the western and northern areas of the Park and the northern areas of the Reserve. Thus it was not surprising that the spectral confusion resulted in a higher EC in the 2009 fuzzy classified image as compared to the 2011 fuzzy classified image. These areas were classified as containing bracken fern in the 2009 classified image but do not appear in the 2011 fuzzy classified image.

The research carried out by Holland and Aplin (2013) also highlighted that the distinct seasonal pattern bracken fern development and the time of year imagery was captured are significant factors in its detection. Holland and Aplin (2013) found that bracken fern was more spectrally distinct in winter as compared to summer, due to the die back of bracken fern which formed dead plant matter which contrasted markedly with other vegetation.

However this finding by Holland and Aplin (2013) is contrary to the findings of this research, which found that bracken fern was more spectrally distinct in spring as compared to winter. The difference in findings could be due to the different locations of research areas as Holland and Aplin (2013) was located in Lake District National Park, England; different climatic conditions; and different seasonal growth patterns of vegetation species occurring within each research area.

Other differences include the spatial resolution of the multispectral remotely sensed imagery and the classification techniques. Holland and Aplin (2013) used low spatial resolution Landsat imagery of 30 m and IKONOS imagery of 4 m spatial resolution. Holland and Aplin (2013) also used supervised classification together MLC.

This research is also comparable to research done by Schmook et al (2011). Schmook et al (2011) used an un-mixing analysis together with MLC in the image classification process and the classified images also obtained high accuracies for bracken fern with a PA and UA of 90%. Schmook et al (2011) used IPCA which is an un-mixing analysis.

Other differences include the research areas and the spatial resolution of the multispectral remotely sensed imagery. The research area for was in the Southern Yucatán, Mexico and Schmook et al (2011) used low resolution Landsat ETM+ 2000 imagery of 30 m spatial resolution.

5.4 Discussion of the post-classification comparison

This discussion covers the results of the change detected of bracken fern in the Park and Reserve from 2009 to 2011. Then the possible reasons responsible for the results obtained are discussed. Thereafter the results are compared to that of previous research.

The change detection analysis showed that in a two year period there was a 49% and 54% increase in the area infested with bracken fern in the Park and Reserve respectively. This is rate of spread of the infestation could have been 24% and 27% per annum in the Park and Reserve respectively. However these rates are not verified because there was no third epoch of imagery to classify and to compare with the results of the 2009 and 2011 classified images.

Post-classification comparison also revealed that the Park does have a higher area infested of bracken fern then the Reserve across both epochs. However the percentage of infestation in the Reserve infested was slightly higher than the Park.

As Schneider (2006) stated that bracken fern can spread out of control and produce a monoculture across large tracts of land which could pose a direct threat to biodiversity. Thus if bracken fern within the Park and Reserve is left to spread unhindered it might emerge as the dominant land cover type. Biodiversity is also part of the reason why the Park and Reserve received their WHS status. Biodiversity is also a tourist attraction of the Park, Reserve and the UDP.

The 2009 Tourism KwaZulu-Natal Occasional Paper No. 68, outlines conservative estimates from local and international tourism revenue received by the UDP. It estimated revenues from R 63 million to R126 million from local tourism and R 208 million from international tourism. Therefore the tourism revenue of the UDP could be negative impacted if there was major degradation of protected ecosystems. Thus the environmental impacts of the bracken fern infestation could ultimately reduce much needed revenue for the UDP.

The change detection map offered more insight into the distribution of the bracken fern in the Park and Reserve in 2009 and 2011. There was a reduction of bracken fern in the western and northern areas of the Park and the northern areas of the Reserve from 2009 to 2011. This reduction could have possibly been caused by the high EC of the 2009 fuzzy classified image as compared to the 2011 fuzzy classified. The relatively high EC of 2009 fuzzy classified image likely led to an over estimation of the area occupied by bracken fern in the western and northern areas of the Park and the northern areas of the Reserve in 2009.

There was also an increase in bracken fern growth in the eastern and southern areas in the Park from 2009 to 2011 in sites 3 and 4 as well as other areas of the Reserve where Bracken fern was not seen in 2009. The change of bracken fern growth in sites 3 and 4 was 954 % and 681% respectively which were dramatically higher than the 34 % and 94 % base line increase of reference sites 1 and 2 respectively. However classification maps indicated that bracken fern did not infest all areas of the Park and Reserve. Therefore there had to be a set of factors responsible for the increase in bracken fern growth seen in sites 1 – 4 and the Reserve in 2011.

The first factor that could be contributing to bracken fern growth is fire regimes. Crouch et al (2011) stated that the repeated burning of grassland has led to the spread of bracken fern. Fire regimes change the soil properties of the burnt areas (Schneider, 2004; Bond et al, 2007; Schneider and Fernando, 2010; UDP WHS- IMP, 2011). The pH and carbon to nitrogen ration properties change (Fynn et al, 2003; UDP WHS- IMP, 2011). Also the burning of plant matter during burning regimes returns valuable nutrients to the soil (Bond et al, 2007; UDP WHS- IMP, 2011). Bond et al (2007) stated that nutrient rich soils can lead to the rapid development of bracken fern. Schneider (2004), Bond et al (2007) and Schneider and Fernando (2010) state that the change of soil conditions brought about by fire regimes facilitate the rapid growth and spread of bracken fern.

Soil maps by Fey (2010) show that a combination of humic (30 – 60 %), lithic (7 – 15 %), cumulic (7 – 15 %) and gleyic (7 – 15 %) soil groups may occur in the Park and Reserve. It may be possible that bracken fern in the Park and Reserve could be growing in areas with a combination of these soil groups. The fire regimes carried out regularly by EKZN Wildlife (UDP WHS- IMP, 2011) could result in creating nutrient rich soil, due to the burning of the frond foliage litter. Thus the fire regimes could be a factor contributing to the spread of bracken fern by rhizome growth and spore dispersal in the Park and Reserve.

Site 1 was burnt in 2009 and 2011, site 2 was burnt in 2011, site 3 was burnt in 2009, 2010 and 2011 site 4 was burnt in 2009 and 2011 and almost all of the Reserve was burnt in 2009 and 2010. Figure 5.1 shows the areas burnt in the Park and Reserve by the 2009, 2010 and 2011 fire regimes.

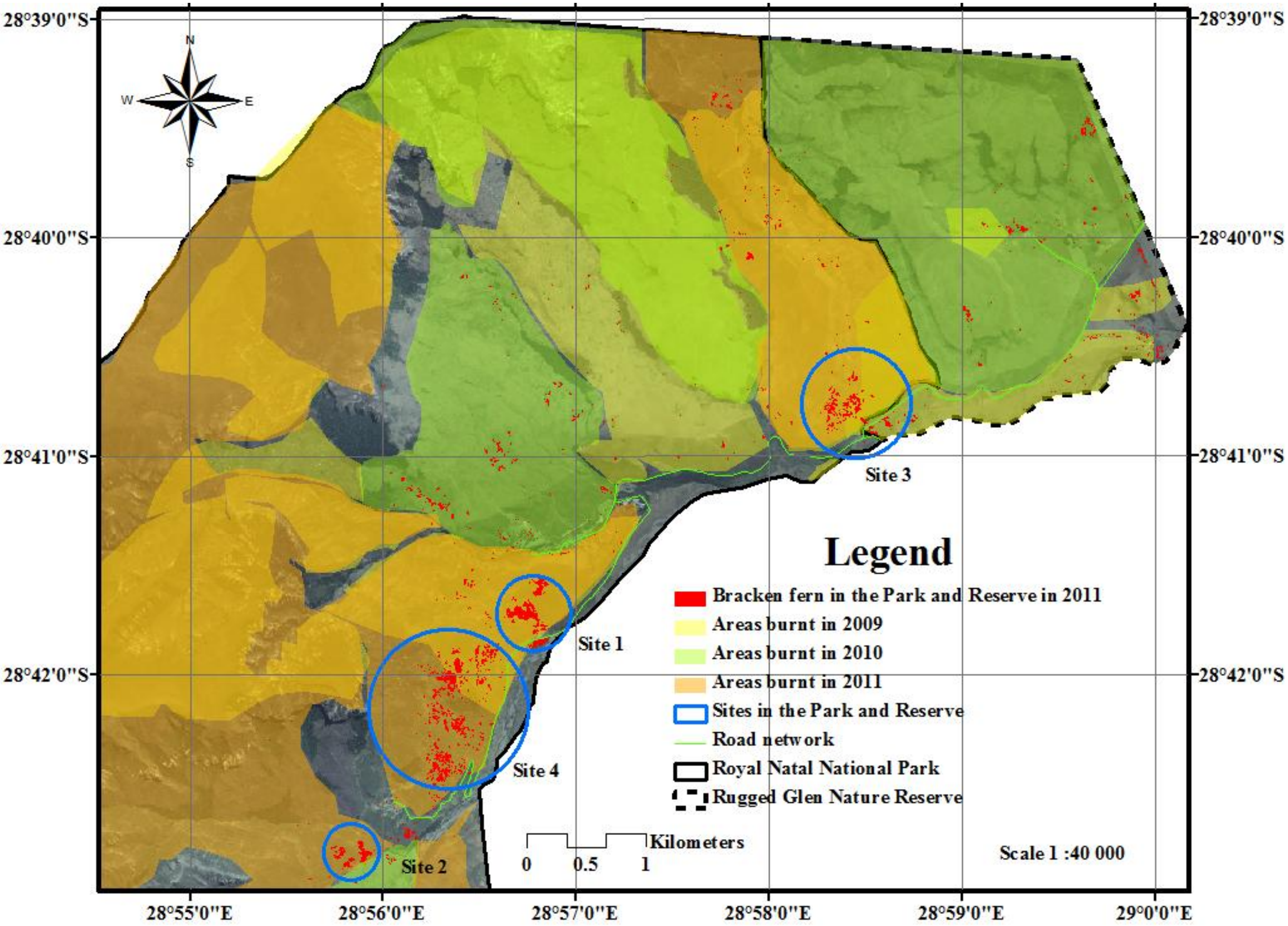

Figure 5.1: Areas burnt in the 2009, 2010 and 2011 fire regimes

However large areas of the Park and Reserve were burnt and only certain areas were infested with bracken fern. This suggests that that the fire regimes alone may not be responsible for the increase of bracken fern. Other factors in conjunction with the fire regimes could be responsible for the increased growth that occurred in sites 1 – 4 and in the Reserve. This led to the investigation of the type of slope as a second contributing factor to the spread of bracken fern. A slope map was created of the Park and Reserve. The scaling used to categories the slopes was a modified version as those used by Sarma and Barik (2010). Slopes were categorised into six categories; gentle (0 – 8˚), moderately gentle (8 – 15˚), moderate (15 – 24˚), moderately steep (24 – 35˚), steep (35 – 45˚) and extremely steep (> 45˚).

The aspect map revealed that; 27.6 % of bracken fern occurred on gentle slopes, 42 % occurred on moderately gentle slopes, 20.4 % occurred on moderate slopes, 10 % occurred on moderately steep slopes, no occurred on steep slopes and extremely steep slopes in the Park. In the Park bracken fern that occur in a 0 – 35˚ range and predominately on moderately low slopes. While in the Reserve 86.4 % of bracken fern occurred on gentle slopes, 11.1 % occurred on moderately gentle slopes, 2% occurred on moderate slopes, 0.5% occurred on moderately steep slopes, no occurred on high slopes and extremely steep slopes. In the Reserve bracken fern that occur in a 0 – 35˚ range and predominately on low slopes.

UDP receives high rain fall and its annual precipitation in the UDP varies from 1000 mm on the foot hills and 1800 mm on the escarpment, of which 70 % occurs in the summer months (UDP WHS- IMP, 2011). This coincides with the growing season of bracken fern which is from spring to summer. Rain fall run off from high and extremely slopes may collect on the gentle, moderately gentle, moderate and moderately steep slopes. Also Seebacher (2003) stated that bracken fern occurs in water-shedding areas. This may be why bracken fern predominately occurred on gentle to moderately gentle slopes as compared to moderate and moderately steep slopes and does not occur on steep and extremely steep slopes.

Bracken fern could possibly grow in the combination of humic, lithic, cumulic and gleyic soil, on low to moderately low slopes because of the potential for water accumulation of gleyic soil (Fey, 2010) may keep the soil damp, given only a small quantity is present, and the free draining humic soil (Fey, 2010) may prevent the soil from becoming waterlogged. This combination of soil types may result in a soil that is damp and drains well, which is favourable for bracken fern growth (Crane, 1990; Seebacher, 2003; Bond et al, 2007). The slope map in Figure 5.2 shows that the bracken fern in the Park and Reserve occurs on gentle to moderately steep slopes.

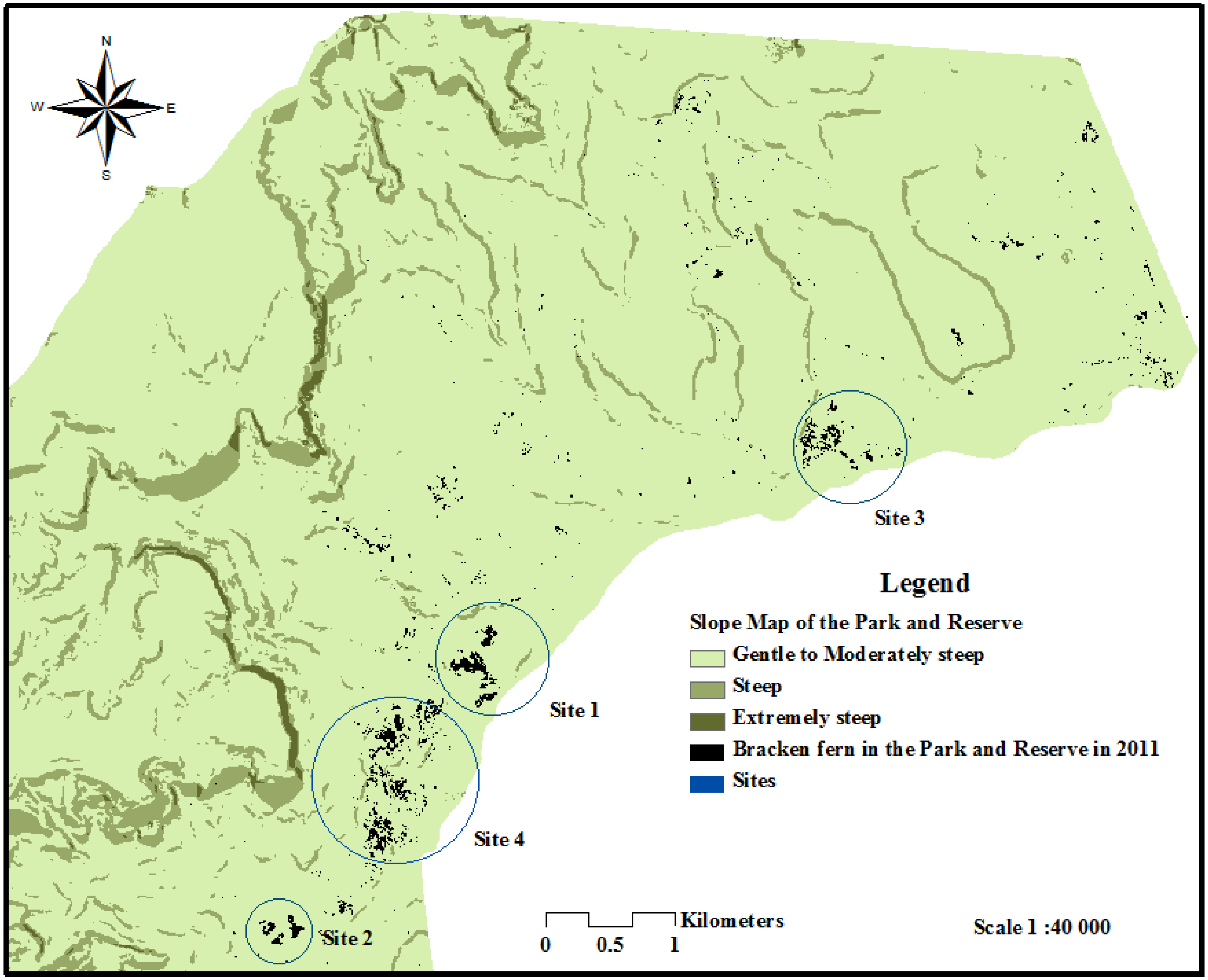

Figure 5.2: Slope map of the Park and Reserve

Through visual inspection of the classification maps it was noticed that not all gentle, moderately gentle, moderate and moderately steep slopes occurred in the Park and Reserve was infested by bracken fern. To further investigate this phenomenon an aspect map was created of the Park and Reserve. An aspect map showed the direction of slopes in the Park and Reserve.

The aspect map showed that in the Park, 97 % of bracken fern occurred on east, south east and south facing slopes and 3 % occurring on west, north east and north facing slopes. In the Reserve 77 % of bracken fern occurred on east, south east and south facing slopes and 23 % occurring on west and north east facing slopes.

These percentages highlighted that bracken fern growth predominately occurred on slopes facing east, south east and south. The east, south east and south facing slopes may provide the optimal sun exposure as bracken fern is known to grow in areas exposed to full sunlight (Crane, 1990; Eastman, 2003). The aspect map in Figure 5.3 shows that the majority of Bracken fern occurs on east, south east and south facing slopes. The slope and aspect image was not included in the image classification process.

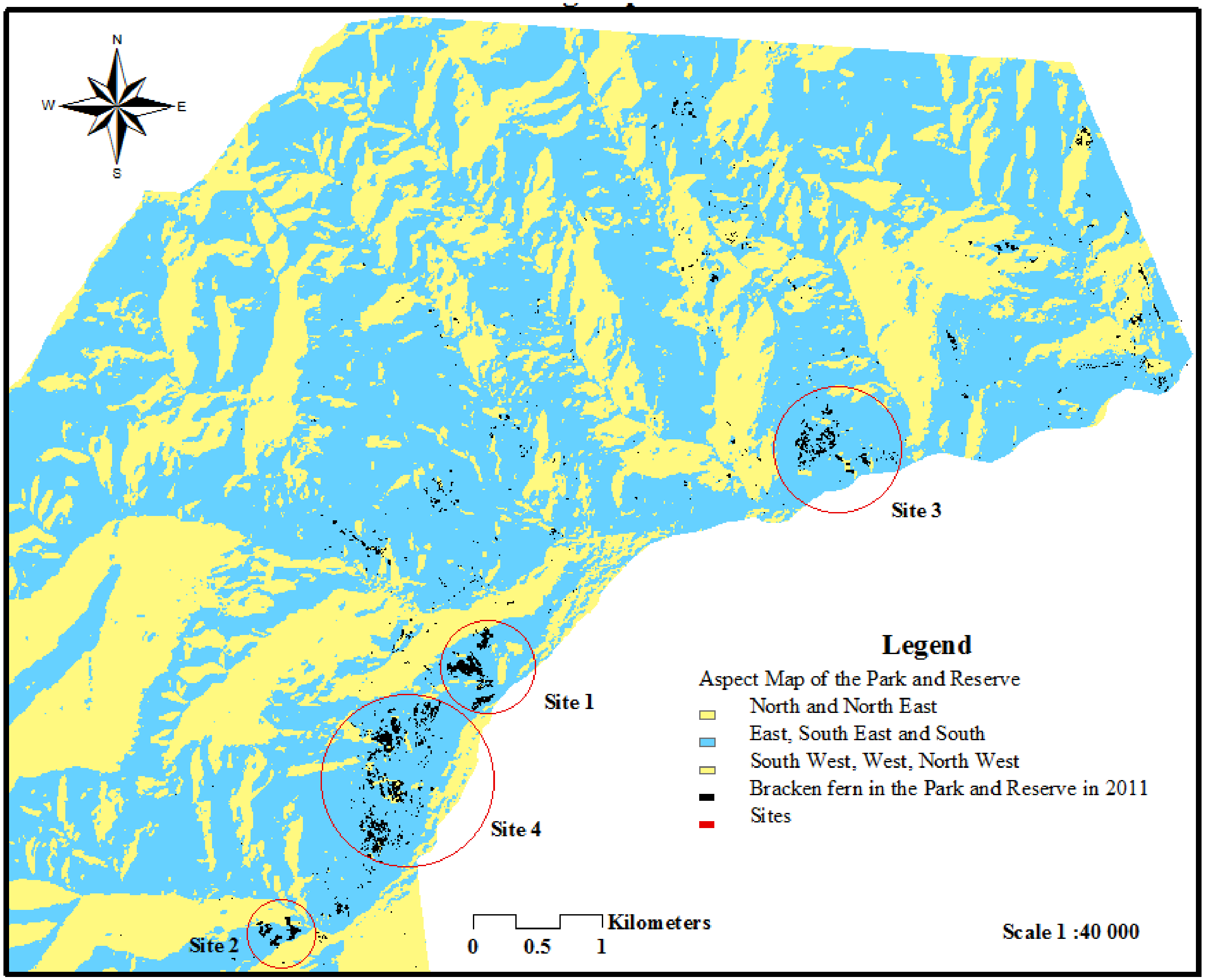

Figure 5.3: Aspect map of the Park and Reserve

In the Park 67.5 % of bracken fern occurred in areas that had been burnt by fire regimes on slopes that range from gentle to moderately gentle slopes facing east, south east and south facing slopes and in the Reserve 75 % of bracken fern occurred under the same conditions. These three factors were common to sites 1 – 4 and areas of new bracken fern growth in the Reserve seen in 2011. These three factors could be contributing to the spread of bracken fern in the Park and Reserve. Site 4 seems to be the area where these three factors come together to produce optimal conditions for bracken fern growth. This would explain the higher increase in bracken fern infestation in site 4 as compared to sites 1 – 3.

A predictive map of areas that could be at risk of bracken fern infestation was created using a multi-criteria analysis of the fire, slope and aspect maps. The risk map highlights areas that have the same combination of factors that could be responsible for the increased growth and spread of bracken fern in sites 1 – 4. This includes areas that have been burnt in the fire regime, have a slope that ranges from 0 – 35 ° and an aspect of east, south east, south, west and north east directions only. Areas that met all these three criteria were included in the risk map. Areas of the Park and Reserve beyond the sites infested in 2011 were identified as potentially at risk of infestation by bracken fern and are shown in Figure 5.4.

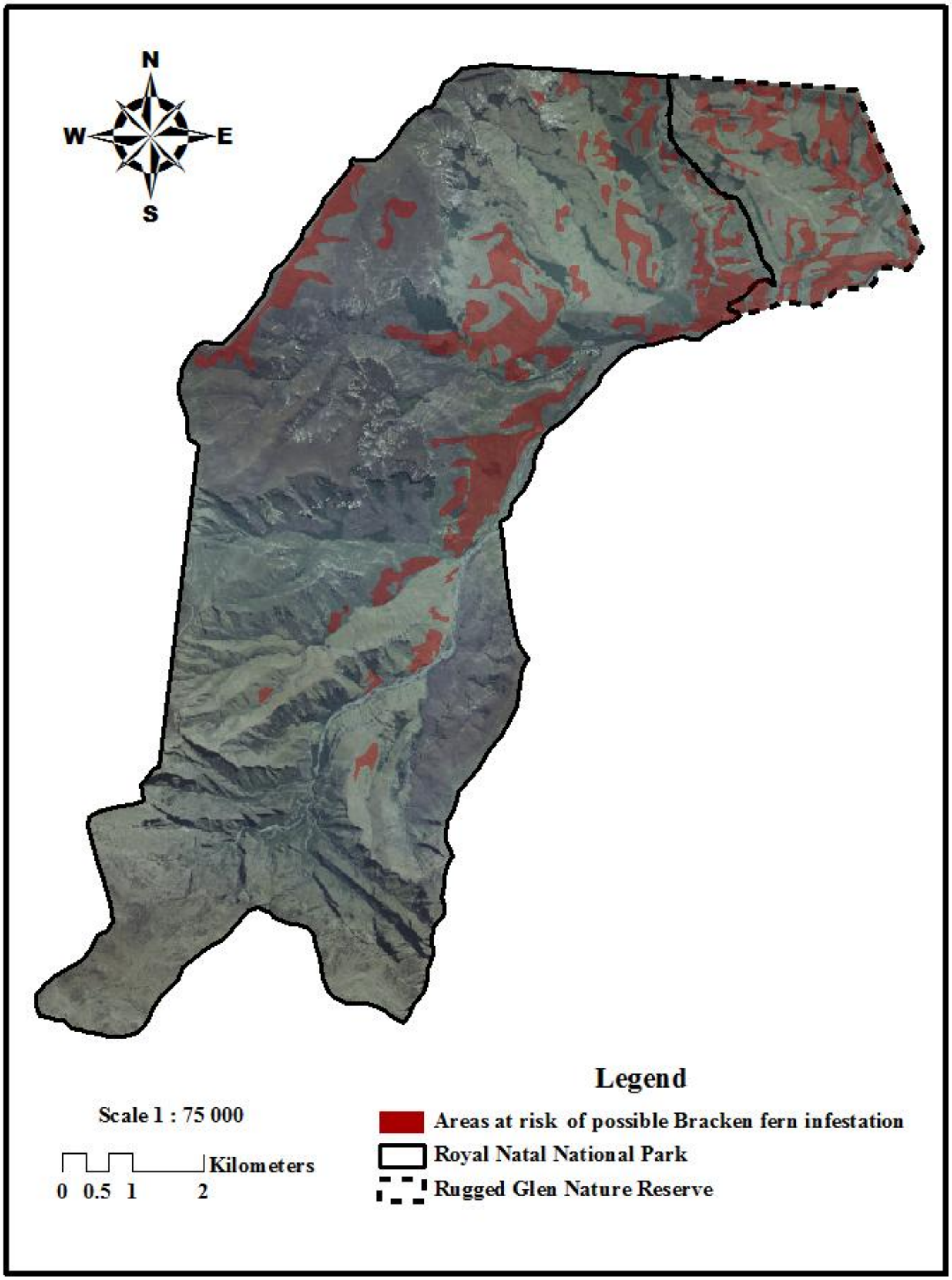

Figure 5.4: Risk map of possible Bracken fern invasion

An area of 6, 479, 222 m^2 in the Park and 2, 453, 439 m^2 in the Reserve could be at risk of possible bracken fern infestation. Areas in potential risk of bracken fern infestation in the Park mostly occurred in its eastern and central areas. While areas in a potential risk of Bracken fern infestation were distributed all across the Reserve.

These areas of potential risk to infestation accumulate to 8 % of the Park and 32.2 % of the Reserve. These percentages are much higher than the 0.3 % of the Park and 0.6 % of the Reserve was infested by bracken fern in 2011. This suggests that there is a strong possibility that bracken fern could spread further and infest a greater area within the Park and Reserve. Further expansion of the bracken fern invasion brings with it a higher risk to biodiversity in the Park and Reserve.

5.5 Chapter 5 summary

The field observations of bracken fern increasing in the Park and Reserve supported the results obtained from the classified images. Increases of bracken fern were initially seen in areas that were burnt as part of the burning regimes carried out in the research areas. The fire regimes, along with slope and aspect could be the factors responsible for the increase of bracken fern in the research areas from 2009 to 2011. Also, the decrease of bracken fern in some areas were due the large EO in the 2009 fuzzy classified image as compared to the 2011 classified image.

Chapter 6 : Conclusion and Recommendations

This chapter reflects on the results of this research to determine the following; whether the research aim and objectives have been accomplished, whether the research question was answered, examine results and make recommendations for further study.

6.1 Review of objectives

Objective 1: Find and apply a suitable image classification technique that will accurately and reliably classify bracken fern on the Park and Reserve.

Recent previous image classification research of invasive plant species used high resolution imagery together with hard classification. This method was supposed to reduce the impact of mixed pixels in the classification. However the results of the pilot study highlighted that this was not a suitable option for the image classification of bracken fern in the Park and Reserve because it did not reduce the misclassification of pixels that were caused by mixed pixels.

The combination of fuzzy classification and high resolution aerial imagery on the other hand did show that it could reduce the misclassification of mixed pixels could cause in image classification as compared to supervised classification. The 2009 fuzzy classification classified image attained a PA of 92.3 % and UA of 68.6 % for bracken fern with an OA of 81.4 % and Kc of 0.63. The 2009 fuzzy classification classified image attained a PA of 97.6 % and UA of 91.1% for bracken fern with an OA of 94.4 % and Kc of 0.89. Thus fuzzy classification was chosen as a suitable for the image classification of bracken fern and objective two was achieved.

The accuracy results also showed that the 2011 fuzzy classified image was more accurate and more reliable as compared to the 2009 fuzzy classified image. The aerial imagery captured in spring may produce a more accurate and reliable classified image than imagery captured in winter. This may highlight the importance of seasonal growth pattern of bracken fern and the temporal aspect of image capture in the image classification process. However, the length of time that had elapsed since the 2009 imagery was captured and the ground truth survey could also contribute to the unreliability of the 2009 fuzzy classification.

Objective 2: Provide a detailed description of bracken fern infesting the Park and Reserve.

The classified images were used to produce classification maps that highlighted areas infested with bracken fern in the Park and Reserve in 2009 and 2011. The classification maps also allowed for the determination of the infestation extent in the Park and Reserve in 2009 and 2011. In the Park 185,495 m^2 was infested in 2009 and 275,753 m^2 was infested in 2011. In the Reserve 27,327 m^2 was infested in 2009 and 41,995 $m^2$was infested in 2011. In 2011 bracken fern infested 0.3 % of the Park and 0.6 % of the Reserve. These statistics together with the classification maps objective two was achieved.

Objective 3: Determine changes and the factors responsible for those changes in the bracken fern infestation in the Park and Reserve.

Post-classification change detection analysis of the classified images determined the changes in the bracken fern distribution from 2009 to 2011. The bracken fern infestation was found to be increasing in both the Park and Reserve from 2009 to 2011 at 24 % and 27 % per annum respectively. There were four sites were there was a noticeable increase in the bracken fern infestation from 2009 to 2011.

Further investigation of the infested areas revealed that the majority of bracken fern growth, 67.5 % in the Park and 75 % in the Reserve, occurred on slopes that ranged from gentle to moderately gentle slopes facing east, south east or south and burnt by fire regimes. These three factors could be responsible for the increased spread seen in the Park and Reserve in 2011.

These three factors were used to predict areas that were at possible risk of bracken fern in the Park and Reserve. This highlighted an area of 6, 479, 222 m^2 which is 8 % of the Park and 2, 453, 439 m^2 which is 32.2 % of the Reserve could be at risk of possible bracken fern infestation. Thus the distribution characteristics were identified and objective four was achieved.

6.2 Review of aim

All four objectives of this research were accomplished. That facilitated the answering research question. This research has determined it is possible to determine the factors contributing to the spread of bracken fern in the Park and Reserve with the application of change detection analysis.

The same four factors were determined to be the major drivers of the spread of bracken fern in the Park and Reserve. Two of these factors; the slope and aspect, are natural and the third factor, the fire regimes, was man-made. This leaves possibility for the omission of areas in the Park and Reserve that have large infestations of bracken fern from being burnt in the fire regimes.

6.3 Limitation to research

The limiting factor was the imagery available for this research was that aerial was captured in different seasons. This affected the reliability of the 2009 fuzzy classification. In winter grass and other vegetation mixtures exhibit a similar spectral reflectance pattern to that of bracken fern. This caused a high error of commission for bracken fern of 31.4 % in the 2009 classified image as compared to 8.9 % in the 2011 classified image. This resulted in an over estimation of the area infested by bracken fern in 2009. This error of commission in turn led to an under estimation of the change in bracken fern growth in the Park and Reserve from 2009 to 2011.

6.4 Recommendations for further research

The recommendations for future research could provide EKZNW with an understanding of the severity of bracken fern infestation, its spread characteristics and which areas to focus its resources. Further could help facilitate the creation of a management plan to control or eliminate the spread of bracken fern.

It is recommended that research of bracken fern in other locations be conducted to determine whether bracken fern is invasive elsewhere or if this was an isolated occurrence. If bracken fern was found to be spreading multiple areas it would become an increasingly serious problem. Also further research in other areas where bracken fern is spreading could determine whether the factors facilitating bracken fern growth are the same or different in different regions.

Further research could determine whether a spectral signature of bracken fern developed in one region could accurately and reliably classify bracken fern in another region. Such research could determine whether bracken fern exhibits similar or different reflectance characteristics in different regions. If bracken fern is invasive the other areas and found to exhibit similar reflectance characteristics in different areas, that could facilitate the application of a standard classification technique to image classify bracken fern, such as fuzzy supervised classification along with high resolution imagery.

It is recommended that change detection analysis is conducted using a minimum of three epochs of imagery which could provide a rate of spread for the bracken fern infestation. A rate for the spread for bracken fern growth would increase the understanding of how serious the spread of bracken fern in areas in which it infests.

Further study of the factors that play a role in increasing the spread of bracken is recommended. Knowledge of those factors together with a rate of spread may even be used to model its spread in an area such as the Park and Reserve. If a system that models the spread of bracken fern could be created, it would serve a valuable tool for the monitoring and control of its spread.

6.5 Concluding Remarks

The bracken fern infestation is increasing in the Park and Reserve and as it increases it will pose a greater and greater threat to the biodiversity. The results of this research showed that fire regimes slope and aspect could be factors contributing to the bracken fern spread in the Park and Reserve. Also monitoring of bracken fern using remote sensing and GIS is possible and could be used to manage the bracken fern infestation.

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Appendix A

GPS Coordinates

These coordinates represent the centre of bracken fern clumps in the Park and Reserve.

Ground truth survey 1

Park and Reserve

Nos.	Y	X	Name
1	28.95852076	-28.68435340	Bracken fern 1
2	28.95848103-	28.68428324	Bracken fern 2
3	28.95950513	-28.68431333	Bracken fern 3
4	28.95950278	-28.68394621	Bracken fern 4
5	28.95923054	-28.68366466	Bracken fern 5
6	28.9592297	-28.683817130	Bracken fern 6
7	28.9591596	3-28.68390899	Bracken fern 7
8	28.96430327	-28.68447678	Bracken fern 8
9	28.96474826	-28.68437905	Bracken fern 9
10	28.96531932	-28.68458566	Bracken fern 10
11	28.96924021	-28.68321765	Bracken fern 11

Theses coordinates represent the perimeter of bracken fern clumps in the Park and Reserve.

Ground Truth Survey 2

Park and Reserve (Set up 1)

Nos.	Y	X	Z	Name
1	4131.493	3174276.026	1434.491	Bracken fern
2	4132.348	3174276.268	1434.473	Bracken fern
3	4129.53	43174277.031	1434.195	Bracken fern
4	4127.439	3174275.652	1434.724	Bracken fern
5	4129.028	3174274.081	1435.281	Bracken fern
6	4131.300	3174274.256	1435.191	Bracken fern
7	4132.053	3174271.585	1435.985	Bracken fern
8	4132.417	3174269.143	1436.869	Bracken fern
9	4135.308	3174268.054	1436.988	Bracken fern
10	4137.899	3174269.532	1436.289	Bracken fern
11	4138.188	3174272.563	1435.252	Bracken fern
12	4139.250	3174274.182	1434.266	Bracken fern

13	4141.890	3174272.730	1434.965	Bracken fern
14	4146.245	3174270.846	1435.379	Bracken fern
15	4149.484	3174272.642	1434.280	Bracken fern
16	4150.131	3174275.672	1433.408	Bracken fern
17	4146.529	3174275.020	1433.875	Bracken fern
18	4143.156	3174274.801	1434.151	Bracken fern
19	4140.723	3174276.930	1433.340	Bracken fern
20	4138.950	3174279.740	1432.672	Bracken fern
21	4137.244	3174281.944	1431.892	Bracken fern
22	4131.856	3174282.916	1432.166	Bracken fern
23	4127.677	3174282.590	1432.690	Bracken fern
24	4126.920	3174279.890	1433.497	Bracken fern
25	4096.283	3174273.592	1436.740	Bracken fern
26	4096.377	3174275.627	1436.363	Bracken fern
27	4098.843	3174280.057	1435.483	Bracken fern
28	4101.765	3174284.901	1434.413	Bracken fern
29	4103.615	3174289.645	1433.466	Bracken fern
30	4102.337	3174298.165	1432.260	Bracken fern
31	4105.831	3174302.024	1431.624	Bracken fern
32	4106.803	3174305.955	1431.369	Bracken fern
33	4103.793	3174305.900	1431.778	Bracken fern
34	4098.833	3174306.818	1430.300	Bracken fern
35	4094.517	3174306.019	1430.200	Bracken fern
36	4090.088	3174304.564	1430.419	Bracken fern
37	4085.278	3174303.508	1430.596	Bracken fern
38	4078.223	3174301.132	1430.930	Bracken fern
39	4075.730	3174297.822	1431.646	Bracken fern
40	4071.336	3174298.924	1431.459	Bracken fern
41	4065.672	3174299.285	1431.602	Bracken fern
42	4062.989	3174293.912	1432.391	Bracken fern
43	4068.496	3174293.829	1432.369	Bracken fern
44	4068.058	3174286.631	1433.290	Bracken fern
45	4076.225	3174283.207	1433.802	Bracken fern
46	4082.594	3174280.874	1434.215	Bracken fern
47	4091.595	3174278.246	1434.812	Bracken fern

48	4097.957	3174280.445	1434.483	Bracken fern
49	4101.277	3174284.339	1433.556	Bracken fern
50	4170.888	3174255.660	1433.907	Bracken fern
51	4170.711	3174261.114	1433.356	Bracken fern
52	4170.475	3174266.398	1433.083	Bracken fern
53	4170.311	3174271.109	1432.570	Bracken fern
54	4170.754	3174275.356	1431.823	Bracken fern
55	4173.126	3174275.400	1431.558	Bracken fern
56	4171.675	3174280.014	1431.286	Bracken fern
57	4171.434	3174284.221	1430.713	Bracken fern
58	4168.843	3174290.113	1429.825	Bracken fern
59	4170.253	174297.411	1429.311	Bracken fern
60	4167.089	3174304.302	1427.749	Bracken fern
61	4167.042	3174309.172	1427.261	Bracken fern
62	4166.944	3174315.512	1426.506	Bracken fern
63	4171.050	3174311.531	1427.302	Bracken fern
64	4169.639	3174304.453	1428.458	Bracken fern
65	4171.878	3174294.644	1429.634	Bracken fern
66	4176.419	3174277.268	1430.267	Bracken fern
67	4175.089	3174272.107	1431.418	Bracken fern
68	4173.259	3174266.760	1432.239	Bracken fern
69	4174.883	3174257.394	1432.034	Bracken fern
70	4177.462	3174254.169	1431.579	Bracken fern
71	4178.321	3174249.823	1432.435	Bracken fern
72	4180.444	3174244.702	1432.965	Bracken fern
73	4183.926	3174245.466	1433.858	Bracken fern
74	4188.901	3174245.508	1434.767	Bracken fern
75	4198.582	3174246.590	1436.320	Bracken fern
76	4203.078	3174250.286	1436.861	Bracken fern
77	4208.280	3174251.701	1437.768	Bracken fern
78	4212.756	3174251.500	1438.822	Bracken fern
79	4213.254	3174256.749	1438.193	Bracken fern
80	4209.100	3174261.019	1436.730	Bracken fern
81	4214.980	3174262.007	1437.884	Bracken fern
82	4219.319	3174260.510	1439.134	Bracken fern

83	4218.284	3174266.053	1438.145	Bracken fern
84	4222.178	3174268.849	1438.717	Bracken fern
85	4215.331	3174273.202	1436.350	Bracken fern
86	4214.014	3174277.065	1435.545	Bracken fern
87	4207.624	3174280.702	1433.857	Bracken fern
88	4206.198	3174285.898	1432.887	Bracken fern
89	4204.095	3174292.044	1431.921	Bracken fern
90	4210.020	3174294.704	1432.760	Bracken fern
91	4214.021	3174296.604	1433.226	Bracken fern
92	4218.227	3174291.453	1434.995	Bracken fern
93	4220.839	3174298.357	1434.486	Bracken fern
94	4227.755	3174297.483	1436.154	Bracken fern
95	4227.590	3174304.187	1434.709	Bracken fern
96	4223.548	3174307.434	1433.306	Bracken fern
97	4219.274	3174301.006	1433.737	Bracken fern
98	4211.603	3174309.761	1431.054	Bracken fern
99	4205.179	3174314.334	1429.812	Bracken fern
100	4198.323	3174314.884	1428.686	Bracken fern
101	4205.200	3174304.662	1430.870	Bracken fern
102	4208.964	3174296.345	1432.391	Bracken fern
103	4200.108	3174293.370	1431.158	Bracken fern
104	4191. 829	3174299.396	1429.412	Bracken fern
105	4183.447	3174303.239	1428.218	Bracken fern
106	4180.703	3174294.677	1428.553	Bracken fern
107	4182.513	3174288.125	1429.228	Bracken fern
108	4190.471	3174284.448	1430.745	Bracken fern
109	4188.396	3174278.737	1430.706	Bracken fern
110	4226.604	3174268.795	1440.037	Bracken fern
111	4227.795	3174273.629	1440.039	Bracken fern
112	4229.413	3174277.917	1439.925	Bracken fern
113	4234.511	3174279.389	1441.227	Bracken fern
114	4239.550	3174274.492	1443.877	Bracken fern
115	4247.305	3174273.221	1447.233	Bracken fern
116	4246.131	3174268.567	1447.853	Bracken fern
117	4247.382	3174261.272	1449.983	Bracken fern

118	4242.797	3174257.663	1448.410	Bracken fern
119	4238.806	3174252.005	1447.328	Bracken fern
120	4234.377	3174253.338	1445.252	Bracken fern
121	4227.311	3174249.732	1443.265	Bracken fern
122	4222.156	3174247.194	1442.006	Bracken fern
123	4228.616	3174227.281	1446.383	Grass
124	4222.449	3174233.420	1443.905	Grass
125	4212.879	3174235.597	1440.692	Grass
126	4210.825	3174225.174	1441.315	Grass
127	4194.085	3174224.553	1437.503	Grass
128	4191.813	3174237.785	1435.964	Grass
129	4166.182	3174243.868	1437.470	Grass
130	4160.004	3174242.851	1438.791	Grass
131	4160.854	3174250.897	1437.299	Grass
132	4151.871	3174250.512	1439.179	Grass
133	4143.135	3174248.203	1441.010	Grass
134	4137.907	3174250.770	1441.139	Grass
135	4141.753	3174253.435	1439.925	Grass
136	4152.261	3174259.253	1436.656	Grass
137	4158.700	3174261.166	1435.107	Grass
138	4163.637	3174265.136	1433.779	Grass
139	4160.424	3174269.730	1432.911	Grass
140	4167.525	3174274.063	1431.947	Grass
141	4165.827	3174283.470	1430.263	Grass
B1	4132.655	3174333.873	1428.394	Base

Park and Reserve (Set up 2)

Nos.	Y	X	Z	Name
1	5112.065	3175714.006	1438.268	Bracken fern
2	5111.063	3175710.888	1438.181	Bracken fern
3	5107.973	3175708.742	1437.917	Bracken fern
4	5105.854	3175706.409	1437.797	Bracken fern
5	5106.095	3175704.916	1438.803	Bracken fern
6	5108.835	3175705.102	1439.619	Bracken fern

7	5113.983	3175706.543	1441.171	Bracken fern
8	5121.548	3175710.234	1443.339	Bracken fern
9	5127.163	3175713.624	1444.049	Bracken fern
10	5130.749	3175714.019	1444.929	Bracken fern
11	5141.526	3175716.489	1445.695	Bracken fern
12	5146.427	3175721.966	1445.941	Bracken fern
13	5146.553	3175721.182	1446.300	Bracken fern
14	5151.083	3175717.136	1446.909	Bracken fern
15	5161.048	3175722.492	1448.217	Bracken fern
16	5168.306	3175722.147	1449.301	Bracken fern
17	5176.043	3175725.177	1450.332	Bracken fern
18	5180.726	3175723.589	1451.093	Bracken fern
19	5195.332	3175725.344	1452.131	Bracken fern
20	5205.236	3175721.934	1453.068	Bracken fern
21	5217.995	3175724.244	1454.619	Bracken fern
22	5227.792	3175728.446	1455.422	Bracken fern
23	5241.493	3175732.104	1457.205	Bracken fern
24	5250.329	3175734.495	1458.802	Bracken fern
25	5256.437	3175739.363	1459.918	Bracken fern
26	5260.719	3175739.070	1460.724	Bracken fern
27	5269.612	3175745.031	1461.328	Bracken fern
28	5278.232	3175748.177	1461.835	Bracken fern
29	5286.750	3175754.059	1462.149	Bracken fern
30	5303.658	3175762.887	1465.293	Bracken fern
31	5300.793	3175768.492	1463.881	Bracken fern
32	5287.017	3175794.338	1459.195	Bracken fern
33	5282.751	3175799.385	1456.816	Bracken fern
34	5299.297	3175813.797	1459.731	Bracken fern
35	5299.494	3175818.329	1458.379	Bracken fern
36	5294.877	3175822.405	1456.417	Bracken fern
37	5285.534	3175823.252	1454.962	Bracken fern
38	5279.919	3175827.479	1452.766	Bracken fern
39	5285.528	3175835.934	1452.566	Bracken fern
40	5276.307	3175840.642	1449.987	Bracken fern
41	5284.213	3175846.818	1450.249	Bracken fern

42	5288.893	3175851.494	1450.434	Bracken fern
43	5291.281	3175857.836	1449.181	Bracken fern
44	5275.115	3175851.426	1444.172	Bracken fern
45	5264.475	3175844.809	1442.867	Bracken fern
46	5254.254	3175837.146	1442.111	Bracken fern
47	5241.103	3175825.409	1441.384	Bracken fern
48	5227.689	3175812.608	1441.245	Bracken fern
49	5216.964	3175811.198	1439.949	Bracken fern
50	5208.079	3175806.406	1439.268	Bracken fern
51	5180.076	3175789.020	1438.435	Bracken fern
52	5154.804	3175775.367	1436.273	Bracken fern
53	5144.241	3175767.322	1435.612	Bracken fern
54	5115.849	3175724.876	1434.917	Bracken fern
55	5109.758	3175719.916	1434.391	Bracken fern
56	5104.984	3175688.950	1438.535	Grass
57	5108.002	3175683.812	1439.463	Grass
58	5112.305	3175679.084	1440.164	Grass
59	5116.541	3175672.806	1440.472	Grass
60	5123.350	3175672.459	1441.925	Grass
61	5128.102	3175676.979	1443.294	Grass
62	5136.427	3175681.161	1444.617	Grass
63	5147.589	3175677.170	1446.213	Grass
64	5156.082	3175673.893	1447.200	Grass
65	5161.870	3175680.508	1447.073	Grass
66	5166.394	3175683.634	1447.621	Grass
67	5172.205	3175688.732	1448.211	Grass
68	5175.470	3175696.801	1448.702	Grass
69	5173.972	3175704.493	1448.561	Grass
70	5140. 676	3175656.312	1445.953	Bracken fern
71	5146.817	3175653.720	1446.847	Bracken fern
72	5151.298	3175647.659	1447.427	Bracken fern
73	5157.739	3175650.009	1448.534	Bracken fern
74	5164.306	3175653.300	1449.391	Bracken fern
75	5170.472	3175652.320	1450.435	Bracken fern
76	5169.968	3175642.597	1450.438	Bracken fern

77	5169.315	3175637.101	1450.114	Bracken fern
78	5163.824	3175628.432	1449.357	Bracken fern
79	5162.645	3175619.468	1449.457	Bracken fern
80	5163.032	3175612.448	1449.634	Bracken fern
81	5167.771	3175611.994	1450.576	Bracken fern
82	5172.167	3175611.547	1450.767	Bracken fern
83	5181.639	3175610.071	1451.788	Bracken fern
84	5189.209	3175609.129	1452.430	Bracken fern
85	5198.911	3175613.698	1453.451	Bracken fern
86	5210.006	3175618.445	1454.945	Bracken fern
87	5215.374	3175627.031	1455.194	Bracken fern
88	5217.493	3175641.161	1455.999	Bracken fern
89	5206.242	3175648.780	1454.584	Bracken fern
90	5206.557	3175661.534	1455.481	Bracken fern
91	5219.107	3175685.470	1457.375	Bracken fern
92	5243.168	3175688.204	1459.270	Bracken fern
93	5249.141	3175683.750	1459.681	Bracken fern
94	5256.222	3175676.033	1460.189	Bracken fern
95	5250.189	3175663.967	1458.755	Bracken fern
96	5245.754	3175647.913	1457.695	Bracken fern
97	5233.246	3175633.731	1456.158	Bracken fern
98	5236.796	3175624.646	1456.526	Bracken fern
99	5226.148	3175617.853	1455.136	Bracken fern
100	5248.689	3175611.326	1457.019	Bracken fern
101	5256.266	3175603.362	1456.879	Bracken fern
102	5244.296	3175604.210	1455.715	Bracken fern
103	5233.451	3175602.940	1454.875	Bracken fern
104	5232.200	3175598.255	1454.640	Bracken fern
105	5236.403	3175594.176	1455.315	Bracken fern
106	5232.957	3175587.214	1455.477	Bracken fern
107	5227.346	3175582.444	1454.240	Bracken fern
108	5225.520	3175572.670	1452.225	Bracken fern
109	5230.920	3175569.835	1452.613	Bracken fern
110	5239.504	3175563.465	1454.956	Bracken fern
111	5238.627	3175559.782	1456.260	Bracken fern

112	5242.741	3175556.915	1457.085	Bracken fern
113	5248.760	3175554.072	1457.731	Bracken fern
114	5248.872	3175550.360	1458.335	Bracken fern
115	5247.910	3175545.549	1458.874	Bracken fern
116	5247.780	3175538.774	1459.497	Bracken fern
117	5259.360	3175536.342	1460.733	Bracken fern
118	5259.160	3175547.209	1458.407	Bracken fern
119	5266.143	3175553.143	1457.490	Bracken fern
120	5273.168	3175553.425	1458.302	Bracken fern
121	5278.214	3175550.749	1459.609	Bracken fern
122	5282.219	3175549.535	1460.705	Bracken fern
130	5290.022	3175547.203	1463.420	Bracken fern
131	5286.426	3175530.944	1465.575	Bracken fern
132	5277.276	3175524.047	1464.573	Bracken fern
133	5273.210	3175521.309	1464.282	Bracken fern
134	5267.390	3175523.226	1462.990	Bracken fern
135	5260.057	3175521.106	1462.209	Bracken fern
136	5249.760	3175518.620	1461.021	Bracken fern
137	5240.690	3175514.413	1459.712	Bracken fern
138	5228.171	3175519.375	1458.124	Bracken fern
139	5214.549	3175525.472	1456.484	Bracken fern
140	5205.880	3175534.510	1455.030	Bracken fern
141	5204.483	3175542.378	1453.925	Bracken fern
142	5206.341	3175552.755	1453.055	Bracken fern
143	5197.634	3175565.987	1451.876	Bracken fern
144	5197.578	3175576.834	1451.738	Bracken fern
145	5195.112	3175581.866	1451.355	Bracken fern
146	5191.996	3175600.001	1451.148	Bracken fern
147	5169.739	3175598.615	1449.226	Bracken fern
148	5153.876	3175605.708	1447.280	Bracken fern
149	5142.734	3175616.074	1445.881	Bracken fern
150	5114.393	3175672.672	1439.334	Grass
151	5114.183	3175679.180	1439.456	Grass
152	5109.928	3175680.653	1438.743	Grass
153	5113.110	3175684.101	1439.546	Grass

154	5115.058	3175685.573	1439.430	Grass
155	5113.163	3175690.133	1438.879	Grass
156	5104.895	3175686.984	1437.768	Grass
157	5100.523	3175733.424	1433.128	Boulders
158	5094.258	3175727.980	1433.028	Boulders
159	5083.695	3175719.418	1432.751	Boulders
B2	5099.671	3175726.893	1434.066	Base

Appendix B

Sites visited in the Ground truth survey to verify the 2009 fuzzy classified image

Nos.	Longitude (E)	Latitude (S)	Name
1	28°59'45.81"E	28°40'8.914"S	Non-Bracken fern
2	28°59'51.546"E	28°40'15.855"S	Bracken fern
3	28°59'44.476"E	28°40'20.444"S	Non-Bracken fern
4	28°59'46.877"E	28°40'32.914"S	Bracken fern
5	28°59'39.54"E	28°40'35.502"S	Non-Bracken fern
6	28°59'37.805"E	28°40'38.208"S	Bracken fern
7	28°59'19.262"E	28°40'39.265"S	Non-Bracken fern
8	28°59'9.789"E	28°40'50.323"S	Bracken fern
9	28°58'55.782"E	28°40'47.851"S	Non-Bracken fern
10	28°58'45.11"E	28°40'45.967"S	Non-Bracken fern
11	28°58'35.773"E	28°40'41.966"S	Non-Bracken fern
12	28°58'35.503"E	28°40'54.436"S	Non-Bracken fern
13	28°58'26.875"E	28°40'56.97"S	Non-Bracken fern
14	28°58'18.996"E	28°40'51.784"S	Bracken fern
15	28°58'11.365"E	28°40'54.099"S	Non-Bracken fern
16	28°57'49.099"E	28°40'55.196"S	Non-Bracken fern
17	28°57'37.212"E	28°41'4.239"S	Non-Bracken fern
18	28°57'25.995"E	28°41'16.59"S	Non-Bracken fern
19	28°57'6.67"E	28°41'11.95"S	Non-Bracken fern
20	28°57'13.981"E	28°41'26.183"S	Non-Bracken fern
21	28°57'4.038"E	28°41'21.216"S	Non-Bracken fern
22	28°56'52.875"E	28°41'16.496"S	Non-Bracken fern
23	28°56'56.437"E	28°41'24.357"S	Non-Bracken fern
24	28°57'8.346"E	28°41'38.177"S	Non-Bracken fern
25	28°56'55.214"E	28°41'31.719"S	Non-Bracken fern
26	28°56'54.176"E	28°41'43.053"S	Non-Bracken fern
27	28°56'53.234"E	28°41'49.672"S	Non-Bracken fern
28	28°56'49.386"E	28°41'52.069"S	Non-Bracken fern
29	28°56'48.258"E	28°41'55.792"S	Non-Bracken fern
30	28°56'43.098"E	28°41'54.466"S	Non-Bracken fern
31	28°56'48.643"E	28°41'37.756"S	Bracken fern

32	28°56'41.929"E	28°41'47.721"S	Non-Bracken fern
33	28°56'38.634"E	28°42'2.388"S	Non-Bracken fern
34	28°56'30.945"E	28°41'25.338"S	Non-Bracken fern
35	28°56'43.431"E	28°41'51.306"S	Bracken fern
36	28°56'42.528"E	28°41'53.265"S	Bracken fern
37	28°56'38.237"E	28°41'55.318"S	Bracken fern
38	28°56'34.853"E	28°41'54.619"S	Bracken fern
39	28°56'33.645"E	28°41'54.347"S	Bracken fern
40	28°56'31.82"E	28°41'56.129"S	Bracken fern
41	28°56'31.003"E	28°42'2.193"S	Bracken fern
42	28°56'23.674"E	28°41'44.229"S	Non-Bracken fern
43	28°56'31.023"E	28°42'2.218"S	Bracken fern
44	28°56'30.691"E	28°42'6.829"S	Bracken fern
45	28°56'33.852"E	28°42'13.611"S	Bracken fern
46	28°56'30.314"E	28°42'13.435"S	Bracken fern
47	28°56'31.72"E	28°42'14.192"S	Bracken fern
48	28°56'30.225"E	28°42'15.605"S	Bracken fern
49	28°56'30.422"E	28°42'17.097"S	Bracken fern
50	28°56'32.177"E	28°42'22.659"S	Non-Bracken fern
51	28°56'29.321"E	28°42'20.604"S	Bracken fern
52	28°56'23.3"E	28°42'19.284"S	Bracken fern
53	28°56'20.398"E	28°42'22.498"S	Bracken fern
54	28°56'8.012"E	28°42'8.698"S	Non-Bracken fern
55	28°56'5.412"E	28°42'19.934"S	Non-Bracken fern
56	28°56'18.485"E	28°42'23.273"S	Bracken fern
57	28°56'21.583"E	28°42'24.146"S	Bracken fern
58	28°56'25.143"E	28°42'25.581"S	Bracken fern
59	28°56'26.79"E	28°42'27.171"S	Bracken fern
60	28°56'18.133"E	28°42'24.784"S	Bracken fern
61	28°56'19.451"E	28°42'25.792"S	Bracken fern
62	28°56'20.725"E	28°42'26.257"S	Bracken fern
63	28°56'17.385"E	28°42'26.333"S	Bracken fern
64	28°56'14.681"E	28°42'28.192"S	Bracken fern
65	28°56'18.021"E	28°42'28.852"S	Non-Bracken fern
66	28°56'23.864"E	28°42'32.982"S	Non-Bracken fern

67	28°56'10.699"E	28°42'34.584"S	Non-Bracken fern
68	28°56'9.582"E	28°42'27.647"S	Non-Bracken fern
69	28°56'1.076"E	28°42'30.143"S	Non-Bracken fern
70	28°55'53.641"E	28°42'40.214"S	Non-Bracken fern

Sites visited in the Ground truth survey to verify the 2011 fuzzy classified image

Nos.	Longitude (E)	Latitude (S)	Name
1	28°40'46.211"S	28°58'44.927"E	Non-Bracken fern
2	28°40'41.906"S	28°58'35.742"E	Non-Bracken fern
3	28°40'49.88"S	28°58'36.027"E	Bracken fern
4	28°40'54.564"S	28°58'35.165"E	Non-Bracken fern
5	28°40'53.798"S	28°58'32.554"E	Bracken fern
6	28°40'52.052"S	28°58'31.763"E	Bracken fern
7	28°40'50.699"S	28°58'29.982"E	Bracken fern
8	28°40'47.046"S	28°58'27.899"E	Bracken fern
9	28°40'57.298"S	28°58'26.892"E	Non-Bracken fern
10	28°40'54.503"S	28°58'11.383"E	Bracken fern
11	28°40'55.173"S	28°57'49.31"E	Non-Bracken fern
12	28°41'16.431"S	28°57'25.825"E	Non-Bracken fern
13	28°41'18.809"S	28°57'18.582"E	Non-Bracken fern
14	28°41'15.177"S	28°57'10.258"E	Non-Bracken fern
15	28°41'26.149"S	28°57'14.081"E	Non-Bracken fern
16	28°41'21.167"S	28°57'4.131"E	Non-Bracken fern
17	28°41'16.69"S	28°56'52.936"E	Non-Bracken fern
18	28°41'24.371"S	28°56'56.665"E	Non-Bracken fern
19	28°41'38.045"S	28°57'8.525"E	Non-Bracken fern
20	28°41'31.712"S	28°56'55.513"E	Non-Bracken fern
21	28°41'42.934"S	28°56'54.072"E	Non-Bracken fern
22	28°41'37.7"S	28°56'48.428"E	Bracken fern
23	28°41'49.601"S	28°56'53.112"E	Non-Bracken fern
24	28°41'52.299"S	28°56'49.473"E	Non-Bracken fern
25	28°41'55.928"S	28°56'48.132"E	Non-Bracken fern
26	28°41'54.491"S	28°56'43.156"E	Non-Bracken fern
27	28°41'47.74"S	28°56'42.011"E	Non-Bracken fern

28	28°42'2.253"S	28°56'38.653"E	Non-Bracken fern
29	28°41'27.822"S	28°56'34.556"E	Non-Bracken fern
30	28°41'25.204"S	28°56'31.017"E	Non-Bracken fern
31	28°41'4.275"S	28°56'26.818"E	Non-Bracken fern
32	28°41'11.863"S	28°56'13.895"E	Bracken fern
33	28°42'14.151"S	28°56'39.795"E	Non-Bracken fern
34	28°41'49.223"S	28°56'33.147"E	Non-Bracken fern
35	28°41'54.307"S	28°56'33.598"E	Bracken fern
36	28°41'56.085"S	28°56'31.78"E	Bracken fern
37	28°42'2.092"S	28°56'30.414"E	Bracken fern
38	28°41'58.831"S	28°56'23.723"E	Bracken fern
39	28°42'0.833"S	28°42'0.833"S	Bracken fern
40	28°42'4.196"S	28°56'17.876"E	Bracken fern
41	28°41'49.587"S	28°55'59.984"E	Non-Bracken fern
42	28°42'13.67"S	28°56'33.86"E	Bracken fern
43	28°42'13.428"S	28°56'30.287"E	Bracken fern
44	28°42'14.735"S	28°56'26.44"E	Bracken fern
45	28°42'13.292"S	28°56'24.26"E	Bracken fern
46	28°42'14.972"S	28°56'19.838"E	Bracken fern
47	28°42'22.64"S	28°56'32.19"E	Non-Bracken fern
48	28°42'33.319"S	28°56'29.185"E	Bracken fern
49	28°42'27.23"S	28°56'26.827"E	Bracken fern
50	28°42'25.548"S	28°56'25.162"E	Bracken fern
51	28°42'25.307"S	28°56'24.344"E	Bracken fern
52	28°42'23.623"S	28°56'20.045"E	Bracken fern
53	28°42'19.937"S	28°56'16.655"E	Bracken fern
54	28°42'19.905"S	28°56'5.48"E	Non-Bracken fern
55	28°42'23.193"S	28°56'13.958"E	Bracken fern
56	28°42'25.09"S	28°56'16.258"E	Bracken fern
57	28°42'26.775"S	28°56'24.283"E	Bracken fern
58	28°42'26.371"S	28°56'23.435"E	Bracken fern
59	28°42'27.439"S	28°56'22.859"E	Bracken fern
60	28°42'26.958"S	28°56'21.466"E	Bracken fern
61	28°42'26.263"S	28°56'20.77"E	Bracken fern
62	28°42'26.636"S	28°56'19.286"E	Bracken fern

63	28°42'28.184"S	28°56'18.104"E	Bracken fern
64	28°42'30.187"S	28°56'18.739"E	Bracken fern
65	28°42'30.346"S	28°56'16.164"E	Bracken fern
66	28°42'33.073"S	28°56'23.886"E	Bracken fern
67	28°42'33.871"S	28°56'17.101"E	Bracken fern
68	28°42'36.941"S	28°56'15.979"E	Bracken fern
69	28°42'34.696"S	28°56'10.68"E	Non-Bracken fern
70	28°42'27.727"S	28°56'9.624"E	Non-Bracken fern
71	28°42'30.179"S	28°56'1.083"E	Non-Bracken fern
72	28°42'36.723"S	28°56'7.075"E	Non-Bracken fern
73	28°42'41.131"S	28°56'11.373"E	Non-Bracken fern
74	28°42'44.36"S	28°56'7.07"E	Bracken fern
75	28°42'45.533"S	28°56'4.768"E	Bracken fern
76	28°42'45.158"S	28°56'2.618"E	Bracken fern
77	28°42'40.215"S	28°55'53.808"E	Non-Bracken fern
78	28°42'33.273"S	28°55'53.903"E	Non-Bracken fern
79	28°42'48.424"S	28°55'27.453"E	Non-Bracken fern
80	28°40'53.451"S	28°58'29.864"E	Bracken fern
81	28°40'51.803"S	28°58'19.386"E	Bracken fern
82	28°40'46.36"S	28°58'17.593"E	Bracken fern
83	28°40'41.619"S	28°58'49.315"E	Bracken fern
84	28°40'33.776"S	28°59'32.304"E	Bracken fern
85	28°40'16.308"S	28°59'53.475"E	Non-Bracken fern
86	28°40'46.556"S	28°58'54.697"E	Non-Bracken fern
87	28°40'39.281"S	28°59'18.237"E	Non-Bracken fern
88	28°40'34.599"S	28°59'39.624"E	Non-Bracken fern
89	28°40'18.903"S	28°59'44.074"E	Non-Bracken fern
90	28°40'6.752"S	28°59'46.155"E	Non-Bracken fern