CARBON SEQUESTRATION AND TRADING POTENTIAL IN SEMI-ARID SOUTH AFRICA: A KAROO CASE STUDY

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Arts in the Faculty of Arts and Social Sciences at Stellenbosch University.

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December 2014

DECLARATION

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ABSTRACT

The succulent thicket plant community of South Africa, particularly *Portulacaria afra* (in this study referred to as spekboom), occurring in the Thicket Biome, sequestrates an exceptional amount of carbon dioxide (due to its photosynthetic properties), particularly for a warm, semi-arid region and in this capacity is more akin to forest ecosystems. Spekboom has additional favourable characteristics over forested systems regarding carbon trading (CT), namely: economic water use; potential for combating desertification and poverty in arid environments; and ability to withstand stand-replacing fire (spekboom doesn't burn) which improves its attraction as a commodity in CT and the payments for ecosystem services (PES) industry.

Landowners interested in using the capacity of their land for carbon sequestration (CS) are challenged to calculate their plant communities' sequestration ability and biodiversity potential and therefore to quantify the carbon credits to be sold. The aim of the study was to quantify the CS ability of a selected property unit by vegetation area and to establish the carbon credits value that can be sold in the carbon market. It commenced by highlighting the problem of global warming and its effect on climate change in South Africa. CS is described as a process and a solution to decrease high and rising atmospheric CO_2 levels, and its use in the carbon market to attain a monetary value to promote the growing of vegetation or to protect and conserve biodiversity that will enhance carbon stocks.

The study site is Bosch Luys Kloof Private Nature Reserve (BLK PNR) in the semi-arid Karoo. Because CS potential is known to follow a rainfall gradient, one expects the semi-arid Karoo to have a low CS potential. However, this area contains spekboom, an extraordinary thicket type that sequestrates carbon at similar rates to forest ecosystems and should therefore reap the benefits of CT. Yet, accurate mapping of this vegetation is critical for accurate carbon stocks assessment. The CS potential of all vegetation communities in the study area had to be established to estimate the carbon stocks in the whole property unit.

ArcGIS was used to map the vegetation communities (sub biomes) and eCognition to refine mapping of the Gamka Thicket (containing spekboom) through an object-orientated approach to automated vegetation mapping. For accuracy assessment a heads-up digitized map was created for comparison. The true surface area was calculated for the vegetation classification to ensure accurate area accounting on the mountainous terrain and this calculated area of the mapped vegetation was used to convert area to carbon sequestration potential. By examining the different markets and

trading mechanisms for trading in the carbon market, using CS, a marketing strategy for the land units was advised.

Results show that due to BLK PNR's history of overstocking, spekboom remains degraded on the study site. This creates an opportunity to restore the vegetation with funding through CT. The sequestration potential of spekboom on BLK PNR was determined through a regional differentiation comparison. The regional differentiation comparison identified that rainfall amount and carbon accumulation are inversely proportional, therefore more arid conditions (<200mm a year, or a dry season longer than seven and a half months) cause spekboom to switch to Crassulacean acid metabolism (CAM) due to water stress, so increasing the rate of carbon accumulation. In wetter environments, where spekboom is not under water stress, it continues in carbon fixation of 3-phosphoglycerate (C3) having a lower carbon accumulation. This is a remarkable finding as CS is known to follow a rainfall gradient: in this instance spekboom is an exception to the norm.

Mapped results showed that eCognition classified spekboom poorly, yielding between 64% and 69% correspondence to the accurate manually classified map. As expected three-dimensional area comparative results show that the true surface area on complex terrains was 10% higher than the original (and surveyed) land area of the estate.

Results indicate that there are substantial carbon stocks for CT on BLK PNR. This study recommended the most practised form of CT (restoration) for BLK PNR. Over a period of 30 years of restoration on BLK PNR about 46 000 tons of carbon could be sequestrated. At the current price of carbon credits this could accumulate over R3.7 million over the 30-year restoration period. Combining restoration with conservation strategies into one project type has additional favourable characteristics as it takes into account the CS potential of all vegetation communities on the land unit and the ecosystem services it promotes. Conservation of BLK PNR would yield 758 000 tons of carbon. Calculated through emission abandonment, this could be valued at R8-10 million. The economic importance of the vegetation community’s biodiversity on BLK PNR and significant differences between biomes were recorded and implies a total intrinsic value in excess of R830 000 per annum.

To date, pilot projects elsewhere have successfully acquired carbon credits for avoided deforestation through the climate, community and biodiversity alliance (CCBA). However, owing to the pilot stage status there is little literature that substantiates the calculation of the monetary value of conservation. This is a fertile area for further research.

OPSOMMING

Die sukkulent-struikplantgemeenskap van Suid-Afrika, in besonder *Portulacaria afra* (waarna in hierdie studie as Spekboom verwys word), wat in die Struikgewasbioom voorkom, neem ‘n uitsonderlike hoeveelheid koolstofdioksied op (weens die fotosintetiese eienskappe daarvan), veral vir ‘n warm, semi-ariede streek en is in hierdie kapasiteit meer verwant aan woud-ekosisteme. Spekboom het, met betrekking tot koolstofuitruiling (KU) of koolstofhandel, addisionele gunstige eienskappe bo dié van woudsisteme, naamlik lae waterbenutting; potensiaal vir die bestryding van woestynvorming en armoede in ariede omgewings; en die vermoë om brand te weerstaan (Spekboom brand nie), wat sy aantreklikheid as ‘n kommoditeit in KU verhoog, en die betaling vir dienste in die ekosisteem-industrie (BED) verbeter.

Grondeienaars wat geïnteresseerd is in die benutting van hul grond vir koolstofopname (KO), word uitgedaag om hul plantgemeenskappe se opnamevermoë en potensiaal vir biodiversiteit te bereken, en gevolglik die hoeveelheid koolstofkrediete wat verkoop kan word, te kwantifiseer. Die doel van die studie was om die KO-vermoë van ‘n geselekteerde eiendomseenheid volgens die oppervlakte onder plantegroei te kwantifiseer en om die waarde van koolstofkrediete wat in die koolstofmark verkoop kan word, vas te stel. Ten aanvang is die probleem van aardverwarming en die uitwerking daarvan op klimaatsverandering in Suid-Afrika uitgelig. KO word beskryf as ‘n proses en oplossing om die hoë en stygende atmosferiese CO_2-vlakke te verminder, en die gebruik daarvan in die koolstofmark, om ‘n monetêre waarde te verkry om plantbedekking te bevorder of om biodiversiteit, wat koolstofvoorraad sal vermeerder, te beskerm en te bewaar.

Die studieperseel is Bosch Luys Kloof Privaat Natuurreservaat (BLK PNR) in die semi-ariede Karoo. Omrede KO-potensiaal bekend is daarvoor om ‘n reënvalgradiënt te volg, verwag mens dat die semi-ariede Karoo ‘n lae KO-potensiaal sal hê. Hierdie gebied bevat egter Spekboom, ‘n buitengewone struiksoort wat koolstof teen soortgelyke tempo’s as woud-ekosisteme opneem, en behoort daarom voordeel uit KU te trek. Akkurate kartering van hierdie plantegroei is kritiek vir akkurate assessering van koolstofvoorraad. Die KO-potensiaal van alle plantgemeenskappe in die studiegebied is derhalwe vasgestel om die koolstofvoorrade in die totale eiendomseenheid te skat.

ArcGIS is gebruik om die plantgemeenskappe (sub-biome) te karteer en eCognition is gebruik om die kartering van die Gamkaruigte (wat Spekboom bevat) deur ‘n objek-georiënteerde benadering tot geoutomatiseerde plantegroeikartering te verfyn. Vir akkuraatheidsassessering is ‘n vergelykbare plantegroeikaart per hand versyfer. Die werklike oppervlakte van die gebied is vir die

plantegroeiklassifikasie bereken om akkurate oppervlakberekening van die bergagtige terrein te verseker, en hierdie berekende oppervlakte van die gekarteerde plantegroei is gebruik om oppervlakte na koolstofopname-potensiaal te herlei. Advies oor ‘n bemarkingstrategie vir die grondeenhede is gegee, deur die verskillende markte en uitruilings- of handelsmeganismes vir handel in die koolstofmark te ondersoek.

Resultate toon dat weens die BLK PNR se geskiedenis van oorbeweiding, Spekboom op die studieperseel gedegradeer het. Dit skep ‘n geleentheid om die plantegroei met befondsing deur KU te herstel. Die opname-potensiaal van Spekboom op BLK PNR is deur ‘n streeksdifferensiasie-vergelyking bepaal. Die streeksdifferensiasie-vergelyking toon dat hoeveelheid reënval en koolstofakkumulasie omgekeerd eweredig of proporsioneel is, en gevolglik veroorsaak meer ariede omstandighede (<200 mm/jaar, of ‘n droë seisoen van langer as sewe en ‘n half maande) dat Spekboom weens waterstres na Crassulacea-suurmetabolisme (CSM) oorskakel, en sodoende die tempo van koolstofakkumulasie verhoog. In natter omgewings, waar Spekboom nie aan waterstres onderwerp word nie, gaan dit voort met koolstofbinding van 3-fosfogliseraat (C3) en het ‘n laer koolstofakkumulasie. Dit is ‘n merkwaardige bevinding aangesien KO daarvoor bekend is dat dit ‘n reënvalgradiënt volg: in hierdie geval is Spekboom ‘n uitsondering op die reël.

eCognition het Spekboom swak onderskei, en slegs ‘n ooreenstemming van tussen 64% en 69% met die akkurate hand-geklassifiseerde gehad. Soos verwag, toon vergelykende resultate van driedimensionele oppervlakte dat die werklike oppervlakte byna 10% hoër is as die oorspronklike (en gemete) grondoppervlak van die eiendom.

Resultate dui aan dat daar aansienlike koolstofvoorrade vir KU op BLK PNR is. Hierdie studie beveel die mees gebruikte praktyke van KU (herstelproses) vir BLK PNR aan. Oor ‘n hersteltydperk van 30 jaar op BLK PNR kan ongeveer 46 000 ton koolstof opgeneem word. Teen die huidige prys van koolstofkrediete kan dit meer as R3.7 miljoen oor die hersteltydperk van 30 jaar akkumuleer. Die kombinasie van herstelprosesse en bewaringstrategieë in een tipe projek, hou addisionele voordeel in, omdat dit die KO-potensiaal van alle plantgemeenskappe op die grondeenheid en die ekosisteem-dienste in berekening bring. Bewaring van BLK PNR sal 757 913 ton koolstof lewer. As dit in terme van die staking van uitlatings bereken word, kan dit teen R8-10 miljoen gewaardeer word. Die ekonomiese belangrikheid van die ekosisteem en plantgemeenskap-biodiversiteit op BLK PNR impliseer ‘n totale intrinsieke waarde van meer as R800 000 per jaar.

Loodsprojekte elders was suksesvol in die verkryging van koolstofkrediete vir die vermyding van ontbossing deur die klimaat-, gemeenskap- en biodiversiteitsalliansie (KGBA). Vanweë die loodsprojekstatus, is daar egter min literatuur beskikbaar wat die berekening van die monetêre waarde van bewaring staaf. Dit laat ruimte vir verdere navorsing.

ACKNOWLEDGEMENTS

I thank the following people and institutions that assisted me in some way or another during the course of this research project:

- The academic staff of the Department of Geography and Environmental Studies, Stellenbosch University, for helpful comments.
- Prof Hannes van der Merwe my supervisor, for facilitating numerous sessions of academic discussions, fieldwork assessment and his enthusiasm about my research.
- Jeff Jenness for providing the DEM extension tool.
- The owner of Bosch Luys Kloof Private Nature Reserve, Mr Gerhard Rademeyer, for letting me use his property as the case study.
- Garth Stevens from the CGA for providing all the data and satellite images, and his advice in the use of eCognition.
- My family, for greatly appreciated support.
- The editor of my text Dr PH de Necker

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ACRONYMS AND ABBREVIATION

3D	three-dimensional
ANOVA	Analysis of variance
BLK PNR	Bosch Luys Kloof Private Nature Reserve
C	carbon
C_3	carbon fixation of 3-phosphoglycerate
CCN	carbon credit notes
CAM	Crassulacean acid metabolism
CART	classification regression trees
CCB	climate, community and biodiversity
CCBS	community, climate and biodiversity standard
CGA	Centre for Geographical Analysis
CCBA	climate, community and biodiversity alliance
CDM	clean development mechanism
CER	certified emissions reductions
CFR	Cape Floristic Region
CS	carbon sequestration
CT	carbon trading
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
COP13	13th United Nations Framework Convention on Climate Change
COP16	16th United Nations Framework Convention on Climate Change
DEAT	Department of Environmental Affairs and Tourism
DEM	digital elevation model
DNA	designated nation authority
DME	Department of Minerals and Energy
DWAF	Department of Water Affairs and Forestry

ERU	emissions reduction units
ERO	emissions reduction option
FCPF	forest carbon partnership facility
FSC	Forest Stewardship Council
GHG	greenhouse gases
GIS	geographic information system
GLCM	grey- level co-occurrence matrices
GMO	genetically modified organism
Gt	Giga tonnes
HCL	hydrochloric acid
HCV	high conservation values
IPCC	International Panel on Climate Change
IPES	international payment for ecosystem services
IET	international emissions trading
JSE	Johannesburg Stock Exchange
LSU	large stock unit
LULUCF	land use, land-use change and forestry
LUCs	land use changes
PDD	project design document
PES	payment for ecosystem services
REDD	reduced emissions from deforestation and degradation
REDD+	reduced emissions from deforestation and degradation- plus
SANBI	South African National Biodiversity Institute
STU	small stock unit
SOC	soil organic carbon
[SOC]	concentration of soil organic carbon
Soil C	soil carbon
SPOT	Système Pour l'Observation de la Terre (French remote sensing satellite)

STEP	subtropical thicket ecosystem planning
STRP	subtropical thicket restoration projects
tC	tons of carbon
TBGC	total below-ground carbon
TAGC	total above-ground carbon
TCS	total carbon stocks
TIN	triangular irregular network
TOC	total organic carbon
TSC	total soil carbon
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
VCS	voluntary carbon standard
VER	verified emission reduction
WTP	willingness to pay
WWF	World Wildlife Fund

CHAPTER 1 CARBON SEQUESTRATION POTENTIAL IN THE KAROO

This chapter briefly introduces carbon trading (CT) and carbon sequestration (CS) as research challenges in the semi-arid Karoo as a case study and presents the formal research problem, aim and objectives and methodology.

1.1 CARBON SEQUESTRATION AND CARBON TRADING POTENTIAL

The cumulative effect of excessive carbon release into the atmosphere threatens world ecological systems and this threat is proposed to be offset by global management measures discussed in this section, such as CT. The section identifies the need for such a study and concludes with a consideration of the problem and its possible resolution in South Africa.

1.1.1 Atmospheric carbon accumulation as a global challenge

Work by Powell, Mills & Marais (2008) reports that the current level of global atmospheric carbon dioxide (CO_2) is higher than it has been for the past 420 000 years. This high concentration of atmospheric CO_2 is directly affecting climate through the so-called greenhouse effect. The latter concept states that atmospheric CO_2 creates an effect similar to a greenhouse that allows light energy in but doesn't allow all of the heat energy out, hence acting as a blanket which consequently warms the atmosphere. This warming of the atmosphere is changing weather patterns which are directly impacting on the environment. A well-known popular magazine contends that the earth's environment is reaching a crisis point where glaciers are melting, sea levels are rising, biomes are drying and wildlife is struggling to keep pace with the change (National Geographic 2012). Society continues to release toxic carbon emissions (CO_2 gases) and to harvest the forests needed to biologically sequester (reduce) these high carbon levels. For our planet to be conserved and sustained for future generations, drastic action must be taken to minimize current CO_2 levels. One mechanism is by sequestering or storing excess carbon.

1.1.2 Carbon sequestration and trading as a global solution

CS is the term used to describe the action of photosynthesis, where plants consume CO2 and produce oxygen (O2). Lal (2004: 1) defines CS as "a process of transferring atmospheric CO2 into long lived carbon pools and storing it securely so it is not immediately re-emitted"; and adds that "carbon sequestration has the potential to offset fossil-fuel emissions by 0.4 to 1.2 Gigatons of carbon per year, or 5 to 15% of the global fossil-fuel emissions" which could account for a substantial reduction in atmospheric CO_2. CS could therefore be used as a mechanism to actively reduce CO_2 levels. According to Sedjo & Marland (2003) the possibility of using CS in the terrestrial biosphere (which refers to the part of the Earth's surface and atmosphere that contains all terrestrial or land ecosystems) has been recognized as a potentially powerful, yet relatively low-cost tool to offset carbon emissions. This would be achieved by maintaining existing and adding new stores of growing vegetation materials worldwide to absorb excess CO_2.

The use of CS projects in the CT industry is documented in the literature as a powerful tool to attain a monetary value for the conservation and protection of ecosystems. Both the voluntary carbon market and the compliance carbon market have been quick to put CS into policy and practise. The Green Guide (2009) identifies CT as the world's next biggest market with the value of a carbon credit equal to one ton of CO_2 or CO_2 equivalent and it rates the value of one credit at between US$10 and US$15. In the context of how much one can gain for the preservation of various biomes, this has significant monetary value.

1.1.3 Carbon trading potential in South Africa

South Africa has a large amount of undeveloped land which includes: conservation areas, open farming and grazing areas and forested areas. Landowners could potentially gain extra monetary value from their land depending on the vegetation's CS ability. By developing a mechanism to calculate the sequestration ability of various plant communities growing in these areas, land in its natural state can become a commodity that owners could sell in the form of carbon credits. One of these plant communities, the spekboom (*Portulacaria afra*) (shown in Figure 1.1), has the potential to sequester carbon and restore the functioning of the ecosystem at an average rate of 4.1 tons/ha/annum (Powell 2009), in a semi-arid area. This is an exceptionally large amount of carbon for a warm semi-arid region, given that it is well known that water scarcity in warm, semi-arid landscapes limits accumulation of biomass because water demand increases with an increase in biomass. While this is true, spekboom in the arid Karoo is an exception, due to its efficient photosynthetic properties. Therefore due to the CS potential of spekboom (which is at a level similar to forest ecosystems) it has the potential to be used in the CT industry in the same way that forests are used, with additional advantages in arid environments, namely economic water use; potential for combating desertification; alleviation of human poverty; and ability to withstand damaging fires (spekboom doesn't burn) (Kerley, Knight & De Kock 1995; Vlok, Euston-Brown & Cowling 2003). These properties further increase spekboom's market potential. A technical challenge in this regard

Figure 1.1 Spekboom, new hope for carbon farming in South Africa's arid environments

is how to identify and calculate the market potential of any given property unit. Vegetation has to be accurately mapped and classified for identification of its carbon biomass. This is not an easy task in mountainous terrains having large, complexly shaped features.

Furthermore, manual mapping of vegetation through heads-up digitizing from remotely sensed imagery is a time-consuming and rather complicated task. Therefore, the use of automated image analysis for mapping individual vegetation stands as a possible solution to provide sufficiently accurate results calls for investigation. The situation is further complicated by the difficult task of calculating true surface area of vegetation communities and areas of high soil carbon content. The calculation of true surface area from planimetric boundaries draped over eccentrically shaped landscapes pose unique technical challenges.

There is thus an expectation that by harnessing the pronounced sequestration ability of some plant communities in South Africa, precise values can be attached to currently undeveloped land through trading in the carbon market, while contributing to reduction of currently rising global CO_2 levels. While landowners have become generally aware of this potential market, its operational mechanisms are poorly understood and the means to accurately calculate the sequestration potential, hence the trading value of various natural vegetation communities on individual properties, is unclear and seemingly complex.

1.2 PARTICULAR RESEARCH QUESTIONS

The concept of CS and the principles and practises involved in trading in the values accruing to sequestration (as a globally new economic commodity and evolving developing market opportunity) are generally poorly understood. These aspects need to be explored and coherent guidelines for its use in the setting of natural land-cover ownership in South Africa has to be formulated. One has to build an argument for CS in a semi-arid area because CS is usually associated with moist forested areas and not arid environments. What makes spekboom so special that it can accumulate so much carbon? While certain plant species have been studied in greater detail, the sequestration potential of specific South African natural vegetation communities occurring in semi-arid areas has not been analysed, particularly at a landscape-identifiable scale. A number of problems and complications face attempts to analyse sequestration potential.

A first complication is the lack of knowledge about the CS potential of the vegetation in particular regions in South Africa. Calculating this CS potential will require identification of the different types of vegetation occurring in various biomes, for example the eight biomes identified by SANBI (2007) in the southern Karoo and the identification of their sequestration potential from literature. A related problem is how to calculate the CS potential of the same vegetation community (spekboom in this case) occurring in widely differing regional settings. For instance, it is well documented that carbon accumulation is determined by the rainfall gradient so that one expects spekboom to grow more readily and become prolific in the humid Eastern Cape, while sequestration values should diminish in the westerly and arid environments. Is this the case with spekboom?

A second problem is how to document and map the occurrence of given communities (like spekboom) at regional landscape and local scales. Manually mapping the vegetation is tedious, time consuming and complicated, therefore automated mapping mechanisms need to be explored and experiments done with various parameters. Could an object-orientated analytical platform like eCognition serve this purpose? A further methodological complication is the difficult task of accurately calculating vegetation community sequestration values based on area coverage over complicated three-dimensional (3D) terrains. By what order does planimetric area differ from true surface area? Another complication is how to convert CS into carbon credits that can be sold in the carbon market. And how does one value biodiversity for conservation? A final challenge is posed by the intricacies of organized CT: What routes are to be followed? What documentation is to be obtained? How is the project design documentation to be completed for application for CT? Finally, owners of agricultural land, while broadly aware of some market potential inherent in some of their land-cover normally considered to have limited productive capacity, lack the basic knowledge and capacity to exploit the sequestration marketing potential inherent in their land. These questions are addressed by the present research.

1.3 RESEARCH AIM AND OBJECTIVES

The research aims to document and explain the concepts, principles and practises involved in international and national CT opportunities using CS and to place these in a local context. It develops a South African case study, in a semi-arid area, which involves mapping the actual surface boundaries and calculating the aerial extent of all vegetation communities on an individual property unit in the Great Karoo. CS and CT potentials are quantified. The research concludes by suggesting a possible trading strategy for the land-owner.

The aim is achieved through sequentially addressing seven research objectives:

1. Examine the concepts of global warming, conservation and the carbon sink cycle.
2. Review the principles, policy and practise involved in CS and CT calculations internationally and in South Africa.
3. Establish the CS capacity of the identified plant communities (biomes) in the case study area.
4. Use GIS to map the officially (SANBI 2007) recognized vegetation communities occurring in the study area and refine the vegetation boundaries of spekboom.
5. Apply GIS to three-dimensional areas to establish the real surface area per vegetation.
6. Calculate the CS potential and biodiversity considerations for the total property unit.
7. Give advice on the different carbon markets relevant to the study area and calculate the property unit's CT potential.

Solving the research aim and objectives will determine the feasibility of carbon farming as an option on the study sight and its location in general.

1.4 THE STUDY AREA: BOSCH LUYS KLOOF PRIVATE NATURE RESERVE

The study area is the Bosch Luys Kloof Private Nature Reserve (BLK PNR) located between Laingsburg and Prince Albert on the southern edge of the Great Karoo and on the northern footslopes of the Great Swartberg in the Western Cape province of South Africa (see Figure 1.2). The reserve covers 15513.04 ha (planimetric area established in ArcGIS from the mapped cadastral boundaries overlain on satellite imagery). This area is characterized by considerable natural beauty (recognized through the high influx of tourists) and the wide interest shown in its geology, botanical

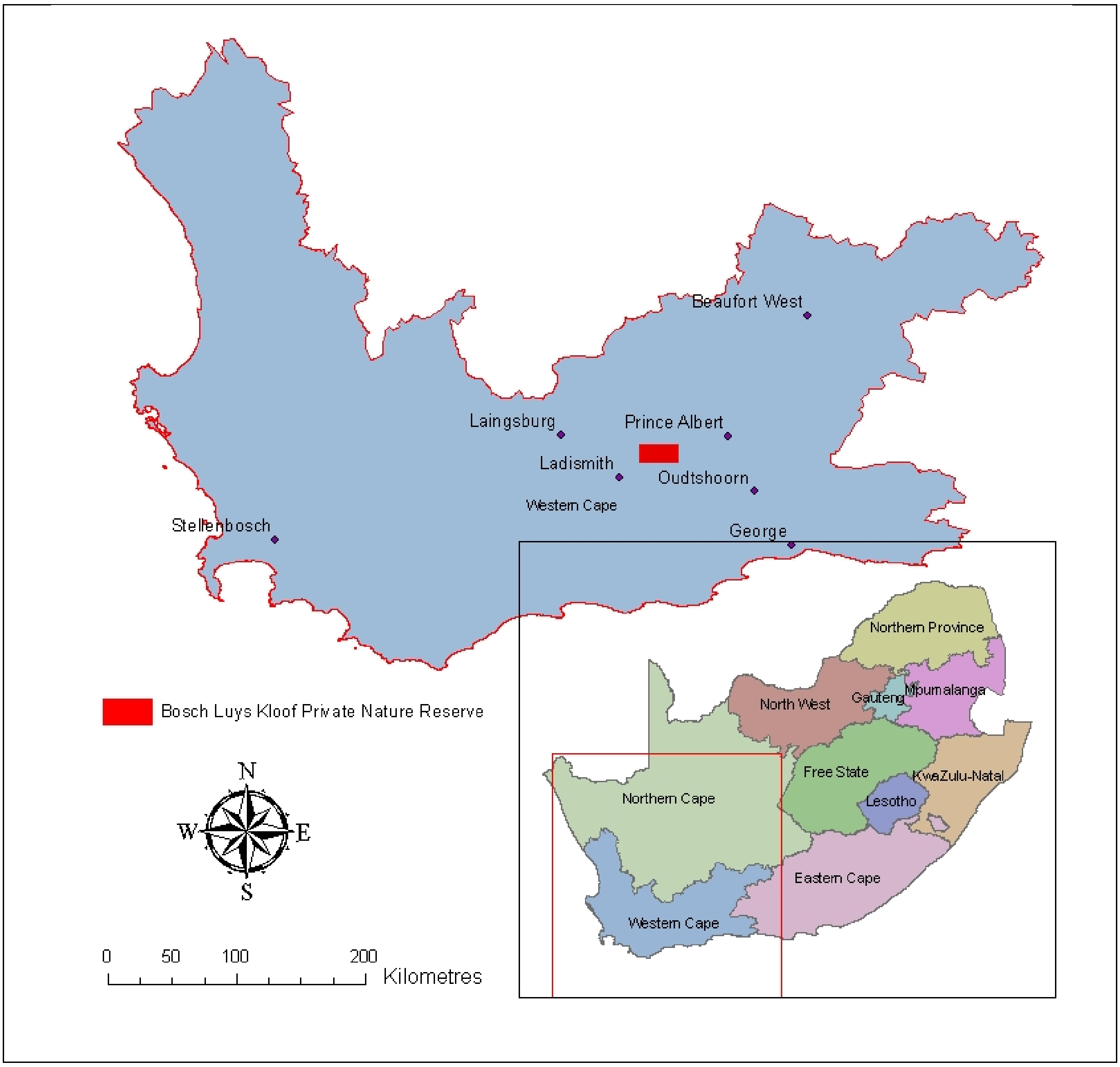


Figure 1.2 The study area location in the Western Cape

wealth and occurrence of fossils. The rest of this section elaborates on the background climate, geology, natural vegetation and biome status of various communities relevant to the research. The reserve's settlement history is explored to identify why parts of the reserve are severely degraded and current land-use practises are described.

1.4.1 Physical setting: Climate and geology

Depending on the source used, the average rainfall for the area is very low and reported as 230 mm per year (South African Rain Atlas 2006) or falling in the mapped range between 101 mm and 200 mm per year (Schulze & Maharaj 2006), with most occurring during mid-summer. The rainfall is higher towards the high Swartberg which receives winter precipitation in the form of rain and snow. The lowest monthly rainfall is in December (0-9 mm) and the highest rainfall is in March (22-30 mm) (South African Rain Atlas 2006; SA Explorer 2008). The monthly distribution of average daily maximum temperatures ranges from 16.5°C in July to 30°C in January. The region is coldest in July when the temperature drops to 3.2°C on average during the night (SA Explorer 2008).

The area is topographically fairly high above sea level and altitudes range between 500m and about 1400m (derived from the 20m DEM for the study area) at the highest point which characterizes the hilly and mountainous landscape of the reserve. The landscape is defined by the east-west stretching fold mountain ranges of the Great Swartberg consisting of Table Mountain sandstone and reaching 1880 m in the south and the northern Elandsberg (1400 m) composed of Witteberg sandstone. The interspersed hill-and-valley configuration was carved from the underlying Bokkeveld shale formation with pronounced and steeply sloping north- and south-facing aspects. A west-east trending river valley some 300m wide bisects the unit to decant into the Gamka dam. In the narrower part of the valley there are dense stands of *Acacia karroo* with fairly large individual trees. Lower down the river course the stream becomes braided and the valley floor broadens.

1.4.2 Natural vegetation communities

According to the SANBI (2007) classification scheme mapped in Figure 1.3, the BLK PNR study area spans three biomes, namely Fynbos, Succulent Karoo and Albany Thicket as well as the important azonal vegetation group Southern Karoo Riviere along the river course. The seven diverse vegetation communities described in Table 1.1 are distinguished for mapping and demarcation purposes. The original SANBI map did not capture the Southern Karoo Riviere sector because the linear and areal mapping tolerances were set too coarsely to allow its incorporation at the original national mapping scale of 1:1 500 000. Regarding biomass its noteworthy that the Southern Karoo Riviere group features fairly dense stands of *Acacia karroo* (or sweet thorn) trees that are landscape defining (seen along the northern boundary of the Gamka Thicket in Figure 1.3), important sequestors of carbon and easy to map from aerial imagery. This vegetation class had to be added to the final map by heads-up digitizing from the available aerial photography, so allowing it to be very accurately recorded. Contrarily, all the other vegetation classes were rather coarsely mapped given the scale resolution. Consequently, these vegetation boundaries were refined later. The east-west banded nature of the vegetation pattern demonstrates the well-known deterministic

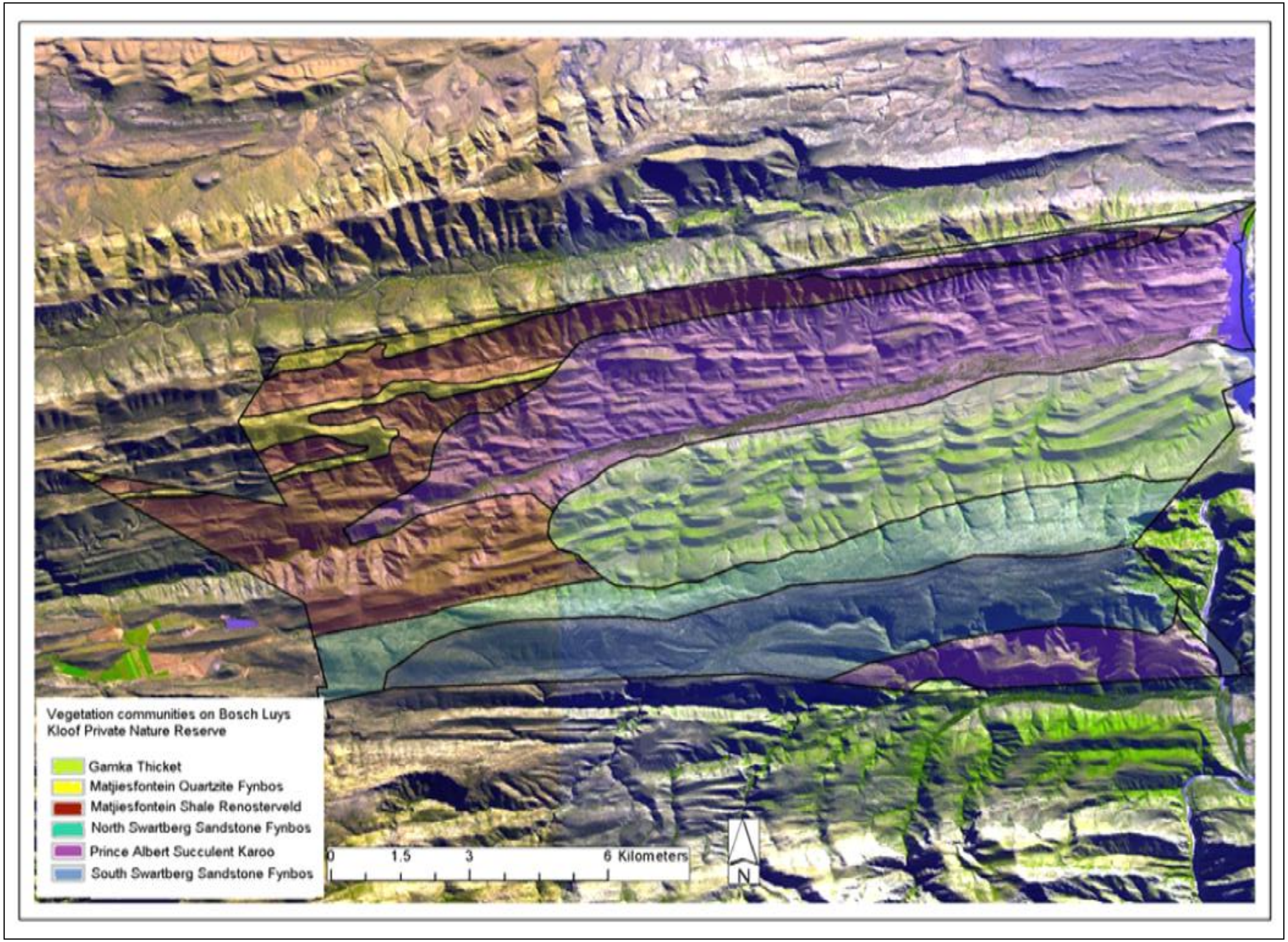


Figure 1.3 SANBI vegetation communities on BLK PNR

relationship between geology and vegetation types (clearly depicted in Figure 1.3 running west to east) and the topographical description provided above. The most important group is the Gamka Thicket (member of the Albany Thicket biome) in which the all-important spekboom (*Portulacaria afra*) dominates. Table 1.1 provides further vegetation description.

Table 1.1 SANBI biomes, vegetation units and groups on BLK PNR

Biome	Unit	Group(code)	Description
Fynbos	Sandstone fynbos	South Swartberg Sandstone Fynbos(FFs24)	Medium-tall shrubland and heathland. Proteoid and restioid fynbos dominate, with ericaceous fynbos at higher altitudes and shrub fynbos at lower altitudes.
		North Swartberg Sandstone Fynbos (FFs23)	Structurally, mainly asteraceous (vegetation dominated by members of the daisy family), proteoid (fynbos shrublands dominated by the family Proteaceae) and restioid (vegetation dominated by restios) fynbos.
	Quartzite fynbos	Matjiesfontein Quartzite Fynbos (FFq3)	Consists of narrow, linear bands surrounded by Matjiesfontein Quartzite Fynbos and Succulent Karoo vegetation. A medium-dense, medium-tall shrubland, structurally classified mainly as asteraceous and proteoid fynbos, although restioid fynbos is also present. The lower northern slopes in the east, where there is a rain-shadow effect due to the Swartberg range, support Succulent Karoo vegetation.
	Shale renosterveld	Matjiesfontein Shale Renosterveld (FRs6)	Open to medium-dense, leptophyllous shrubland with a medium-dense matrix of short, divaricate shrubs, dominated by renosterbos. Heuweltjies present at low densities in places.
Albany thicket		Gamka Thicket (AT2)	Spekboom (*Portulacaria afra*) occur, often with *Euclea unduata*, *Gloveria integrifolia*, *Pappea capensis* and *Rhus glauca*. Shrubs are also abundant, stem-and-leaf succulents are often prominent, and the grass component is poorly developed, with *Cenchrus ciliaris*, *Ehrharta calycina*, *Eragrosis plana and Sporobolus fimbriatus* occasionally abundant after good rain.
Succulent Karoo	Rainshadow valley Karoo	Prince Albert Succulent Karoo (SKv13)	Low shrub where leaf succulent vygies and small-leaved Karoo shrubs share dominance. Heuweltjies an important feature as they occur at a density of about two per hectare, supporting succulent and salt-tolerant plant assemblages.
Azonal vegetation	Inland saline vegetation	Southern Karoo Riviere (AZi6)	*Acacia karroo* or *Tamarix usneoides* thicket (up to 5 m tall) and fringed by tall *Salsola*-dominated shrubland (up to 1.5 m tall). In sandy drainage lines *Stipagrostis namaquensis* may occasionally dominate. Mesic thicket forms in the far eastern part of this region may contain *Leucosidea serices*, *Rhamnus prinoides* and *Ehrharta erecta*.

Source: Compiled from Mucina & Rutherford (2006)

In essence the Gamka Thicket occurs along the central eastern valley side. Broadly speaking, the two vegetation units not belonging to the Fynbos biome are sandwiched along the central eastern ranges, with the fynbos related to the sandstones and shale of the Cape Super group framing them in the south, north and west. Later vegetation-related discussions will recall Figure 1.3 and Table 1.1 to anchor various research steps.

1.4.3 Land ownership and settlement history

According to the resident estate manager and conservationist (Muller 2011, Pers com) who has compiled substantial information on the historical background of BLK, a fairly accurate indication could be obtained of how the farm was stocked during the earlier decades. Actively settled by white stock farmers since the middle 1800s until 1996, different parts of the reserve were extensively and heavily used for commercial stock farming. The intensity of grazing led to large areas of the property becoming degraded, signs of which remain. An understanding of the level of degradation demands a look at the farm’s actual stocking rate compared to the recommended stocking rate by the Department of Agriculture. The recommended stocking rate is the number of hectares of land that can support one large stock unit (LSU). The LSU differs from area to area, and the Department of Agriculture's 1993 grazing capacity map indicates the stock carrying capacity values for the area as: Prince Albert 42 ha/LSU and Ladismith 66 ha/LSU for veld in good condition (Avenant 2012, Pers com). According to Muller (2011, Pers com) the Department of Agriculture recommends a stocking rate of 60 ha per LSU for BLK PNR. The conversion factor from LSU into small stock units (SSU) is 1:6, thus 10 ha/SSU (Avenant 2012, Pers com) on BLK PNR. According to this recommended stocking rate the number of SSU that can be supported sustainably on BLK PNR is only 1550 head of small stock (sheep, goats, most small game animals).

Between the middle 1800s and 1966 the land was actively stock farmed, yet there is no data on the type or number of animals being grazed. However, between 1966 and 1976 records show that more than a thousand merino ewes (note that this does not include rams or replacement lambs equivalent to about a third of total stock, plus annual lamb production ideally reaching 100%) were farmed on the area on a full-time basis. This stocking rate is estimated to be about 2500 at times, far exceeded the suggested carrying capacity recommended by the Department of Agriculture. The next owner (1976-1980) farmed goats (boerbok) and according to local farmers the owner exploited the land ruthlessly. The exact stocking rate maintained is unfortunately not known, but considering that the owner occupied the property on a Land Bank loan and simply absconded with the proceeds from the sale of all stock when the bond (loan) was finally called in, it is safe to assume that exploitation of the land by excessive livestock numbers far above the ideal stocking rate was severe. The next owner (1981-1996) farmed more rationally with 1458 goat (boerbok) ewes (total stock above 3000) thus also representing double the SSU equivalent recommended as carrying capacity for the land. It is also likely that the more accessible vegetation along valley bottoms and the more palatable species like spekboom would have been severely grazed. Obviously, the BLK property has been systematically and consistently overexploited for a century or more through stock farming and this has generated certain signs of extensive land and vegetation degradation as evidenced by the patchiness of the vegetation conspicuous in low-lying spekboom stands.

Since 1996 the reserve has been under the current management. During this tenure the property has been allowed to revert to natural veld since its proclamation as a nature reserve. At present it carries about 500 (mostly) game animals, although some 30 head of Nguni cattle roam the *Acacia karroo*-covered river banks. Black-backed jackal, caracal, leopard and genet are some of the carnivores that occur naturally in the reserve. A number of large troops of Cape baboon inhabit the reserve, vervet monkeys, honey badgers and leguans are regularly observed. Fortunately, these animals have very little damaging effect on the vegetation. The game population comprises naturally occurring migrant kudu, various small game and re-introduced eland, zebra, oryx, red hartebeest, springbok and ostrich. Consequently, the natural vegetation appears to have slowly recovered toward a largely intact state with long-lasting degradation evident in the Gamka Thicket only. It is likely that without purposive manual restoration, these areas will remain degraded.

1.5 RESEARCH METHODOLOGY

This research is exploratory in nature, as it employed various methods and techniques to analyse the various problems and to reach its objectives. Various instruments were used for quantifying the CS potential of vegetation, overcoming specific earth observation challenges like automating the identification and delineation of patchy land-cover features from moderate-to-high resolution multispectral earth observation imagery, calculating the three-dimensional area of patches on complex mountainous terrains (planimetric area vs true surface area) and for uncovering CT opportunities and strategies to pursue. This methodology section justifies the choice of the research approach, records the various research instruments and methods used and declares the nature of the types and sources of data used.

1.5.1 Qualitative and a quantitative approach

The research deployed qualitative and quantitative methodologies. Empirical data (satellite images and field observations) were used to carry out quantitative or instrument-based measurements and experiments. Literature was analysed and interviews conducted to gather qualitative information. The quantitative approach involved mapping various vegetation types in manual and automated modes and calculating the areal extents of vegetation. True three-dimensional area was calculated via a GIS platform and CS potential was quantified by a regionally differentiated comparison of experimental figures obtained from peer-reviewed publications and related literature. The qualitative approach mostly involved finding current and relevant literature and information regarding evidence of the nature of current and future global warming scenarios in South Africa; CS as one means by which to locally reduce atmospheric CO_2; the CS potential of South African vegetation types; CT potential locally and internationally; CT mechanisms and implementation; and carbon accounting.

1.5.2 Research instruments and methods

Various instruments and methods were used to address the research problems. ArcGIS and eCognition were the geographical information system (GIS) platforms used for automated and manual vegetation mapping. Experimentation with various automated mapping software systems, namely eCognition, and experimentation with different parameters (scale, spectral attributes, classification rule-sets and parameters and samples) in the eCognition application were conducted to identify and map spekboom stands. This identification was helped by the knowledge and observations that spekboom mainly grows on north-facing, sun-bathed slopes. A manually classified map was created for accuracy assessment of the automated map. *Acacia karroo* was mapped in GIS through heads-up digitizing as it does not appear on the SANBI vegetation map. Jenness and TIN data structures were used in GIS to calculate true surface area of the mountainous terrain of the study area, as described in Section 3.8.

The CS potentials of the identified biomes (except for the Gamka Thicket Biome) were obtained from literature and relevant local case studies to determine the average CS potential. The CS potential for the spekboom was established through a process of regional differentiation comparison. The comparison was based on the mean annual rainfall (data provided by Schulze & Maharaj (2006) and other literature sources) and soil and climatic factors (gleaned from the literature). The CT potential was explored in the current literature and relevant local case studies. The project design documentation was used to determine the baseline data needed in valuing and accounting for CS. The study area was investigated through field assessment and interviews with the conservationist (Muller 2011, Pers com) working on BLK PNR regarding farming history, vegetation classification mapping and groundtruthing. Groundtruthing consisted of waypoint digitizing by handheld GPS recorder to demarcate individual spekboom stands and other vegetation, together with direct observation and normal photography to perform accuracy assessments of the automated vegetation classifications.

1.5.3 Data types and sources

Data was digitized, processed and analysed using ArcGIS and ArcMap. All the data was obtained from the Centre for Geographical Analysis, University of Stellenbosch. The data sources were:

- two SPOT true colour mosaic tiles for the study area, from summer 2008 at a spatial resolution of 2.5 m (pixel size);
- a series of 50 colour aerial photographs (3321BC_01_498_608_06_0128 to 3321BC_25_498_608_10_0257 and 3321AD_01_498_607_06_0082 to 3321AD_25_498_607_10_0044 for the area dated September 2006, at a spatial resolution of 0.75 m;
- a 20 m digital elevation model (DEM) for the study area obtained from the CGA (Van Niekerk 2012);
- A farm boundary data set to establish the case study's boundary was obtained from the Chief Surveyor General’s office. This data was in accordance with the deeds diagrams held by the property owner, hence it is considered to be an accurate and dependable source; SANBI (2007) vegetation classification data set were used to map the vegetation communities on BLK PNR. SANBI mapped each vegetation community throughout South Africa and the document contains information on 13 attributes, namely list name and code, biome, biome region, vegetation type identification, bioregion code, group, group code, protection status, conservation status, % conserved, % protected and % remaining. SANBI, the national institute for biodiversity monitoring, is regarded as the most reliable source on vegetation mapping; and
- Schulze & Maharaj (2006) provided rainfall data for South Africa. This was used to identify potential carbon accumulation along a rainfall gradient evident in the country's rainfall patterns.

1.6 RESEARCH AGENDA

The research agenda describes the sequence in which research was undertaken and is summarized in Figure 1.4. The research began with a thorough literature survey to gain an understanding of a number of theoretical constructs, namely:

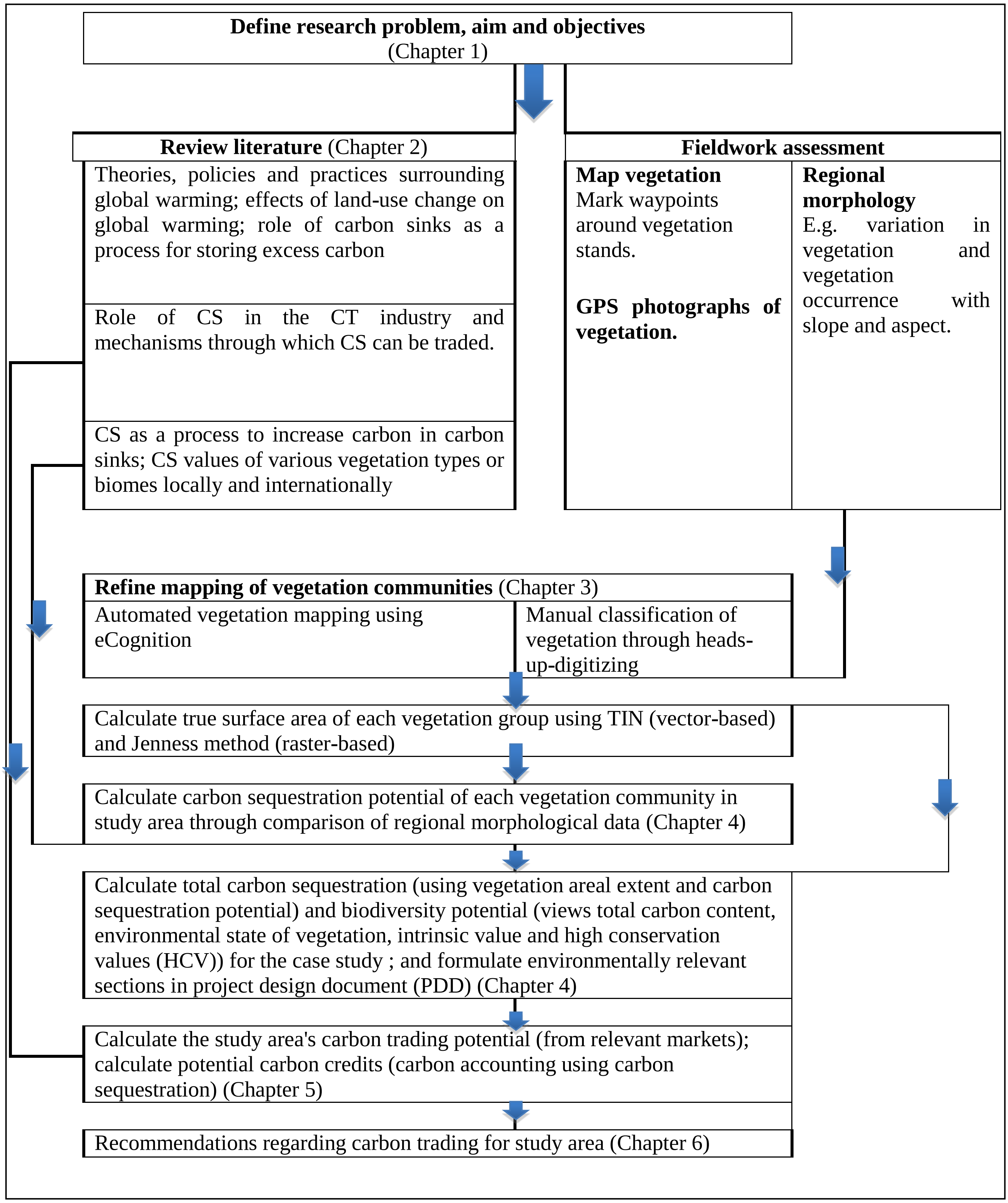


Figure 1.4 The research design for establishing carbon sequestration and trading potential of spekboom in the Karoo

- the theories, policies and practices surrounding global warming and the effect of land-use change on global warming;
- the role of carbon sinks as a process for storing excess carbon;
- CS as a process to increase carbon in carbon sinks;
- the different CS values of various vegetation types or biomes locally and internationally; and
- the role of CS in the CT industry and the different mechanisms through which CS can be traded.

A fieldwork assessment was conducted to attain mapping data and regional morphological data for later use in the study. The next step entailed mapping the vegetation communities in the study area. This was done manually and automatically. A literature survey of automated mapping techniques helped to decide on the best mechanism to map vegetation at a landscape level. The chosen mapping mechanism, eCognition, was used to experiment with various parameters to find the most suitable methodology for mapping spekboom. A map of manually classified data was created in GIS using aerial photographs and mapping data collected in a fieldwork assessment in BLK PNR. Various terrestrial photographs were taken of vegetation, and GPS location coordinates were added together with marked waypoints around spekboom stands. This was done to assess the accuracy of the automated mapping. Once mapped, the three-dimensional area of the vegetation areas was calculated using two measuring processes for accuracy assessment, namely TIN and the Jenness method. Next, the regional differentiation comparison of carbon storage values for spekboom along a west-east trajectory was made. This entailed the acquisition of spatial data from the literature about five separate sites along a west-easterly trajectory characterized by varying mean annual rainfall, size and height of spekboom plants, density of vegetation, soil and climatic factors and CS potential. This was done to gain an understanding of the distribution of carbon content in South Africa for the same vegetation type. Regional morphological data (planting density, height and size of plants, specific genotype, variation of vegetation and vegetation occurrence with slope aspect) was collected through field survey at BLK PNR. The third objective required the determination of the relationship between rainfall and spekboom carbon accumulation in South Africa so as to accurately estimate the CS potential in BLK PNR. This is useful for estimating the carbon content of spekboom distributions in South Africa found in areas with various precipitation regimes. The mapped and calculated three-dimensional areas of various biomes in the study area, along with the regional differentiation comparison, were used to calculate CS potential for each vegetation community. The CS potential of each vegetation community was used to calculate the potential CT credits based on the information acquired from the literature. The final step entailed the formulation of a viable strategy for conducting CS and CT at BLK PNR. This is recorded in a project design document (PDD).

1.7 THE REPORT STRUCTURE

The report was structured in six chapters. Chapter 1 commenced with a brief introduction to the concepts carbon cycle, carbon trading (CT) and carbon sequestration (CS) as research challenges, particularly in the semi-arid Karoo. This was followed by the statement of the research problem, aim and objectives and overviews of the methodology and data types and sources.

Chapter 2 discusses the relevant literature concerned. The concepts and theories concerning global warming and the role of ecosystem services in reducing the rate of global warming, especially using CS as a tool to store excess ground carbon in carbon sinks, are explored. The high CS potential of the thicket biome is considered and the latter's vulnerability to degradation is treated. The opportunities to trade in the carbon market and to obtain funding through carbon credits are highlighted, these carbon markets are explored and their applicability to spekboom farming is reviewed.

Chapter 3 describes the processes and results of the various mapping procedures to create an accurately classified vegetation map. The concepts of automated vegetation classification are discussed, followed by their application to the study area's vegetation. The creation of a manual vegetation classification map for accuracy assessment by comparison with an automated map is described. *Acacia karroo* was mapped by heads-up digitizing. The chapter ends by reporting the calculation of the true surface area of the classified vegetation groups.

Chapter 4 concentrates on determining the CS and biodiversity potential of BLK PNR. It starts by specifying the requirements for the calculation of accurate CS potential. This is followed by accounts of measuring CS at a landscape level and the differing CS values worldwide. The examination of biodiversity potential in BLK PNR is set out next and the chapter ends with a description of the calculation of the CS potential of BLK PNR.

Chapter 5 examines the CT potential of using BLK PNR, suggests relevant carbon markets and estimates the potential carbon credits.

Chapter 6 revisits the study's aim and objectives, draws conclusions and makes suggestions for future research.

CHAPTER 2 GLOBAL WARMING, CARBON SEQUESTRATION AND CARBON TRADING: A CONCEPTUAL APPROACH

This chapter discusses concepts and theories relating to global warming and explores the role of ecosystem services in reducing the rate of global warming, especially the use of CS as a tool to store excess ground carbon in carbon sinks that can be accounted and traded on the carbon market. These carbon markets are explored and applied to spekboom farming. Carbon accounting using CS is examined to determine how carbon credits are allocated. The global concepts are applied locally.

2.1 GLOBAL WARMING AS AN ENVIRONMENTAL PROBLEM

An account is given in this section of the concepts concerning global warming and consideration is given to the role of ecosystem services in storing excess carbon in carbon pools to decrease atmospheric CO_2 levels, so decreasing the rate of global warming. The effects of global warming on South Africa's biomes are explored to identify ways to reduce and manage these impacts.

2.1.1 Mechanisms of global warming

Powell, Mills & Marais (2008: 1) have noted that "the level of atmospheric carbon dioxide (CO_2) exceeds levels not reached for the past 420 000 years" so emphasizing the urgency of the concern over this issue. Watson (2000) and Prentice et al. (2001) maintain that the chief factor driving the increase in atmospheric CO_2 levels is anthropogenic activities, mainly the burning of fossil-fuels and land-use change. The current high concentration of atmospheric CO_2 is having directly impacting on climate through the greenhouse effect that leads to increases in average global temperatures. The greenhouse effect is the natural process by which the atmosphere traps some of the sun's energy, warming the earth enough to support life. The greenhouse effect entails that CO_2 acts like a greenhouse allowing light energy in but like a blanket prevents all of the heat energy from escaping, consequently warming the atmosphere. This warming of the atmosphere is changing climate and weather patterns (Houghton et al. 2001) which further impact on the environment by altering the composition, structure and function of ecosystems, that are vital to the survival of humanity (Palmer, Bernhardt & Chornesky 2004). Global warming is resulting in glaciers melting, sea-level rising, biomes drying and wildlife struggling to keep up with the pace of change.

According to the IPCC (2000: 4):

> From 1850 to 1998, approximately 270 (±30) Gt carbon has been emitted as carbon dioxide (CO_2) into the atmosphere from fossil-fuel burning and cement production. About 136 (±55) Gt carbon has been emitted as a result of land-use change,

> predominantly from forest ecosystems. This has led to an increase in the atmospheric content of carbon dioxide of 176 (±10) Gt C. Atmospheric concentrations increased from about 285 to 366 ppm (i.e., by ~28%), and about 43% of the total emissions over this time have been retained in the atmosphere. The remainder, about 230 (±60) Gt C, is estimated to have been taken up in approximately equal amounts in the oceans and the terrestrial ecosystems.

The essence of these numbers is that, by reducing the rate of land-use change and by protecting vegetation (especially forests) that contain high carbon stocks, the rate of CO_2 emitted into the atmosphere can be significantly reduced.

2.1.2 Ecosystem services for global warming reduction

Ecosystem services are ecological functions that maintain and enhance human life. There are a number of ecosystem services that provide the earth with a wide range of services, from reliable clean water flows to productive soil and carbon sequestration**.** People, companies and societies rely daily on these services for many raw material inputs, production processes and climate stability, therefore their protection is of the utmost importance. A recent classification of ecosystem services by the Millennium Ecosystem Assessment (2003) and Kremen & Ostfeld (2005) divides them into four categories namely provisioning services, regulating services, supporting services and cultural services. Provisioning services supply goods like food, fuel and timber. Regulating services include climate and flood control. Supporting services involve pollination, population control, soil formation and other basic ecological properties (like sequestered carbon) upon which biodiversity and other ecosystem functions or services depend. Cultural services provide humans with recreational, spiritual and aesthetic value. These services support and depend on biodiversity, yet our ecological understanding of most ecosystem services remains basic, so impeding progress in identifying targets for conservation and management (Palmer, Bernhardt, Chornesky 2004). Many ecosystems and the services they provide are under pressure from human activities. A comprehensive study by the Millennium Ecosystem Assessment (2003) team of over 1300 scientists concluded that more than 60% of the world's ecosystems are being used in ways that cannot be sustained. This alarming statistic underlines the need for conserving our ecosystems, especially those that have many regulating and supporting services critical to stabilizing atmospheric CO_2 if a reduction of climate change is our concern.

This study aims to explore CS as a mechanism that will promote the biodiversity and conservation of an arid biome (mainly Gamka Thicket) currently subjected to strain and undergoing degradation. These arid ecosystems provide many provisioning services, supporting services, cultural services and most importantly have a high potential for regulating services given their high CS potential. Regarding South Africa (SANBI 2007: 18) has predicted that

> the value of the final consumption of ecosystems as well as the value added by ecosystems in the production of biological resources at R27 billion per annum for the whole of South Africa. This is the equivalent to an average value of R20 000 per terrestrial km^2.

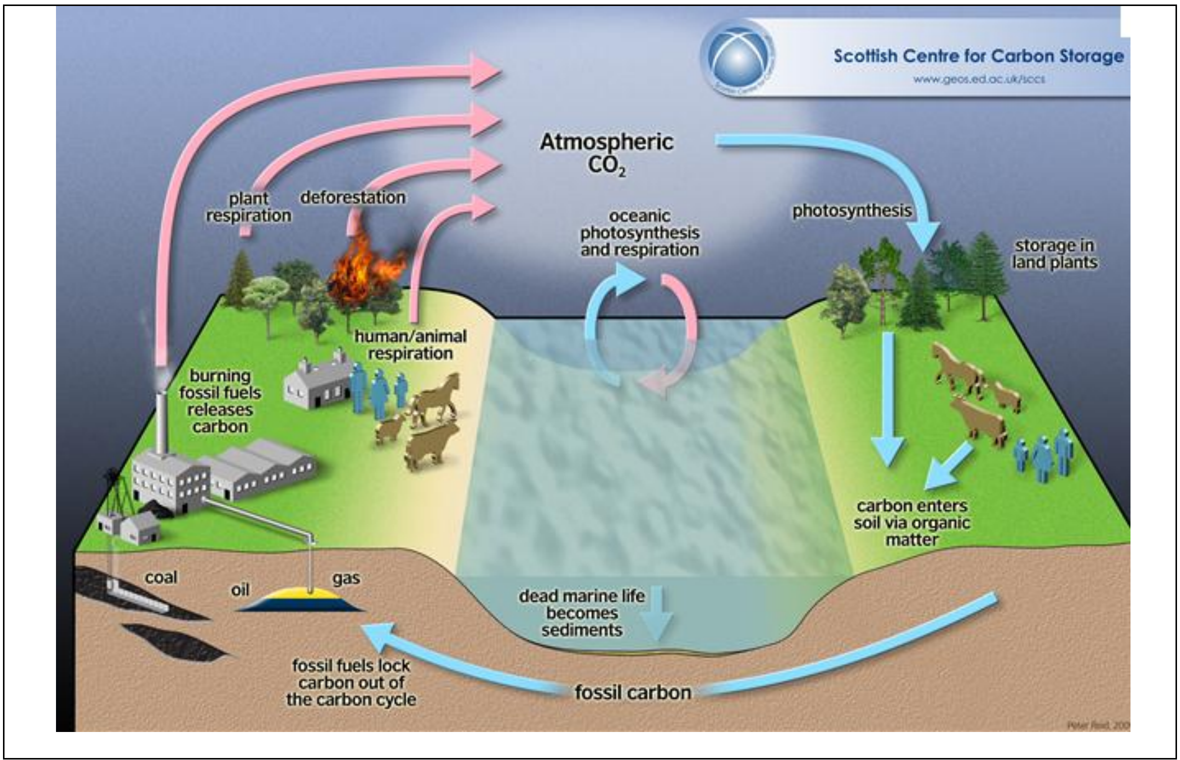
Such large earnings from ecosystem services could realize profits that could be spent on the protection and enhancement of ecosystems with ultimate positive secondary impacts.

To minimize the effects of global warming, destruction of ecosystems and land-use change, society has to manage land-use change, reduce the rate of carbon emissions (or increase the rate of carbon uptake) and protect and conserve all ecosystems. To manage and protect carbon pools effectively, we need to understand the global carbon cycle and know where high carbon pools exist.

2.1.3 The global carbon cycle

The dynamics of global ecosystems depend on interactions between a number of biogeochemical cycles, particularly the carbon cycle, nutrient cycles and the hydrological cycle, all of which may be modified by human actions. The IPCC (2000: 3) note that "terrestrial ecological systems, in which carbon is retained in live biomass, decomposing organic matter, and soil, play an essential role in the global carbon cycle." Carbon is exchanged naturally between these systems and the atmosphere through photosynthesis, respiration, decomposition and combustion. Every day human activities interact and change carbon stocks in these sinks, which release the stored carbon into the atmosphere, leading to an aberrantly high level of atmospheric CO_2. Most of this exchange of carbon from carbon sinks into the atmosphere is through land use, land-use change and forestry, among other activities (IPCC 2000). To reduce the increasing levels of CO_2, nations have to decrease the amount of CO_2 emitted or increase the capacity of ecosystems to absorb these greenhouse gases (GHG).

The global carbon cycle is an important naturally occurring process that produces the atmosphere life on earth needs to survive. Figure 2.1 illustrates the processes that add and reduce carbon in the carbon sink. Energy usage practises (mostly human induced) and respiration release carbon which enters the global cycle through vegetation-driven natural processes. The importance of carbon pools, otherwise referred to as soil organic carbon (SOC), in the global carbon cycle cannot be overemphasized. It represents a major source or sinks for atmospheric CO_2 depending on land use and soil management (Lal 2008). Post & Kwon (2000) and Jones (2008) have identified various sinks on land that contain carbon. These sinks contain plant, animal and microbial residues in all



Source: Scottish Carbon Capture & Storage (2009: 1)

Figure 2.1 The earth's carbon cycle

stages of decomposition, detritus, soil, black carbon residue from fires, harvested products and many others. Post & Kwon (2000), Myneni et al. (2001) and Lal (2004) have explained the nature of carbon sinks in detail. According to them there is a total global carbon pool of 2500 Gigatons (Gt) of SOC (Lal 2004). A Gigaton or Gt is 10^9 or ten thousand million tons. Between two and four Gt of SOC a year is estimated to be sequestered in pools on land (Myneni et al. 2001). These ground sinks represent 15% to 30% of annual global emissions of carbon from fossil-fuels and industrial activities. In terrestrial ecosystems the amount of carbon in soil is usually larger than the amount in living vegetation. This is central to understanding the dynamics of soil carbon as well as its function in the terrestrial ecosystem carbon balance and the global carbon cycle (Post & Kwon 2000). Changes in land use increase the release of carbon from the carbon sink.

2.1.4 Land-use change and global warming

The conversion of natural to agricultural ecosystems depletes the SOC pool. Land-use change and agricultural activities play an important role in the emission of radioactive gases. The emissions of CO_2, methane and nitrous oxide together account for approximately one fifth of the annual increase in radioactive forcing of climatic change (Lal 2004). When land-use changes involving biomass burning and soil degradation are included, the overall radioactive forcing amounts to one-third of the anthropogenic impact (Lal 2001). Globally, soils have lost as much as 20 to 80 tons of C/ha, mostly emitted into the atmosphere (Lal 2004).

The Albany Thicket Biome of South Africa, where the succulent shrub spekboom is the dominant cover, has been severely degraded by injudicious pastoralism, reducing the unusually high (200 t/ha) carbon stocks in the biome by more than 50% in areas, that is up to 60 tC/ha (Marais et al. 2009). The release of ground carbon stocks increases the rate of global warming and impacts on the surrounding ecosystems, but this affect can be effectively reduced through sound management systems. Post & Kwon (2000), Watson (2001), Niles et al. (2002) and Lal (2004) explain several strategies of increasing the soil carbon pool, namely soil restoration; woodland and vegetation regeneration; adopting zero- or minimum-tillage farming; improving rangeland management; cover crop cultivation; nutrient management; green manuring; sludge application; improved or reduced grazing; water conservation and harvesting; efficient irrigation; agroforestry practises; and growing energy crops on auxiliary lands. In arid areas, rangeland and grazing management are relevant strategies. The effect of land-use change on the carbon sink can be effectively managed through conservation and management practises, and in some instances can attain a monetary value through CT if the mitigated (sequestered) carbon can be accounted for.

2.1.5 Global warming impacts on biodiversity in South Africa

Evidence for climate change due to the high and rising levels of GHGs is well documented in the literature and substantiated by rises in mean global air and ocean temperatures, rising sea levels, melting glaciers, melting permafrost and melting ice caps, as well as abnormal climatic events (IPCC 2007). South Africa is a biologically diverse country, containing seven major terrestrial biomes: Forest, Fynbos, Grassland, Nama-Karoo, Savanna, Succulent Karoo and Thicket (containing an eighth category, Azonal vegetation, scattered throughout the main biomes). Of these, the Fynbos Biome is prominent due to its species richness and levels of endemism and rarity (Turpie 2003). The Fynbos Biome is the dominant component of the Cape Floristic Region (CFR), and it occurs nowhere else in the world, yet it is one of the world's "hottest biodiversity hotspots" (Myers 1990). The Fynbos Biome is located mostly in the Western Cape province and "is the smallest, richest and most threatened of the world's six floral kingdoms" (SANBI 2007: 1). It is home to 9000 plant species, or 38% of the country's plant species, of which 1850 (over 20%) are threatened with extinction (DEAT 2006). Reference to Figure 1.3 confirms that this Fynbos Biome covers the majority of the study area and impacts on this biome are therefore highly relevant. Much of BLK PNR is covered by the Gamka member of the Albany Thicket Biome that stretches intermittently into the Western Cape from the Eastern Cape where the succulent spekboom is the dominant species in the biome. This biome has an exceptionally high CS potential for a species in such an arid landscape. The *Acacia karroo* (dominant in the Southern Karoo Riviere) stands in arid areas offer similarly high CS potential, but are confined to narrow lines hugging river courses.

Van Jaarsveld & Chown (2001) have predicted that the impact of global temperature change on South Africa could have dire consequences for our biodiversity and agriculture due to a major shift in rainfall distribution and intensity that is associated with climate change, bringing about related implications most likely in the form of species reductions and species compositional changes, including extinctions. The boundaries of South Africa's biomes are predicted to shift radically and there is a possibility that the entire Succulent Karoo Biome could potentially be lost (Van Jaarsveld & Chown 2001). The Fynbos Biome could potentially have a 51% to 65% loss of surface area by 2050, resulting in a sudden extinction of 10% of the endemic Proteaceae group (Midgley et al. 2002). Therefore it is of the utmost importance that rising atmospheric CO_2 levels are checked. This study explores the potential of a strategy known as CS that has been identified as a powerful tool to offset carbon emissions. This is achieved by maintaining and protecting existing high carbon stocks and adding new stores of growing vegetation materials that have high CS potentials worldwide.

2.2 CARBON SEQUESTRATION POTENTIAL

CS is a potential mechanism to offset high and rising carbon emissions. This section overviews the CS process. The areas where high carbon stocks exist, including the Thicket Biome in South Africa, are discussed and the mechanisms which release these high carbon stocks are explored to identify which and how various biomes should be protected and enhanced.

2.2.1 Carbon sequestration processes

CS is involved in the photosynthesis process, where plants use sunlight to convert CO_2, water, and nutrients into sugars and carbohydrates which build up in leaves, twigs, stems and roots. Plants also release CO_2 during respiration. Plants ultimately die, quickly releasing their stored carbon to the atmosphere or slowly to the soil where the plants decompose and increase soil carbon levels. CS is thus a vital mechanism in the global carbon cycle. According to UNFCCC (1998) the principle that sequestration of carbon in the terrestrial biosphere can be used to offset emissions of carbon from fossil-fuel combustion, is supported to reduce climate change proposed by the Kyoto Protocol (UNFCCC 2001). In addition, the IPCCC special report on land use found that roughly 10% of the total amount of carbon currently accumulated in the atmosphere (one third of a trillion tons of CO_2) could be sequestered (absorbed and stored) by 2050 by restoring degraded and fragmented natural ecosystems, by protecting threatened wilderness areas, by protecting intact natural ecosystems from being destroyed, and by adopting best practises in the agriculture and forest products sectors that minimize the effect of land-use change (UNESCO-MAB & Pro-Natura 2006). These are vital and necessary actions to help achieve atmospheric stabilization of low GHG concentration targets consistent with minimizing impacts on biodiversity.

There is a large variation in the rates and the length of time that carbon accumulates in soil. These are related to the productivity of the recovering vegetation, rate of CS, physical and biological conditions in the soil and the past history of soil organic carbon inputs and physical disturbance (Post & Kwon 2000). Post & Kwon (2000), Mills & Cowling (2006) and Jones (2008) explain the factors that influence the CS rate. These include management practises, climate, elevated CO_2, soil type and quality, browsing by herbivores, past and current land-use changes, agricultural management, horizontal transfer of hay, silage and manure, and non-linear kinetics. Lal (2001: 148) has noted that

> soils in their natural or undisturbed state contain large SOC pools, the size of which depends on temperature (higher in cool than in warm climates), moisture (higher in wetter and poorly-drained soils than in drier climates and well-drained soils), soil texture (more in fine than coarse-textured soils), and structure (more in well-aggregated than in poorly-aggregated soils).

These factors cause worldwide differences in CS potential in similar vegetation.

2.2.2 Global differences in carbon sequestration potential

According to the rules of the first commitment period of the Kyoto Protocol CS quantities of CO_2 emissions and emission reductions are stipulated in tC/ha/year in soil, litter and living biomass (UNFCCC 2001). Estimates of the total potential of CS in world soils vary widely from a low of 0.4-0.6 Gt C/year to a high of 0.6-1.2 GtC/year (Lal 2004). Woodward (1987) notes that ecologists are accustomed to a pattern of increasing biomass (and therefore carbon accumulation) along a rainfall gradient from deserts to forests. Table 2.1 clearly shows this phenomenon, namely that wetlands have the highest carbon stocks and deserts have the lowest. Although the Boreal and Temperate forests have the highest carbon accumulation, they are severely threatened by deforestation and wildfires. South Africa has very few wetlands (which sequestrate the most carbon of all), no tropical forests, little temperate forest and heavy use of grasslands, consequently the country has limited potential for CS. The Thicket Biome (containing spekboom) is noteworthy because it stretches from the more humid Eastern Cape to the BLK PNR study area which experiences desert-like climate conditions, yet this biome can accumulate as much as 244 tC/ha or three times the amount for similar arid systems elsewhere.

Table 2.1 Average carbon stocks held by various biomes

Biome	Plants	Soil	Total (t/acre)	Total (t/ha)*
Tropical forests	54	55	109	269
Temperate forests	25	43	68	168
Boreal forests	29	153	182	450
Tundra	3	57	60	148
Croplands	1	36	37	91
Tropical savannahs	13	52	65	161
Temperate grasslands	3	105	108	267
Desert/ semi desert	1	19	20	49
Wetlands	19	287	306	756

*Tons per hectare (Originally reported in tons per acre)

Source: IPCC 2000: 4

Thus, spekboom's CS potential and services to its ecosystem are comparable to forest ecosystems and so should be eligible for the benefits these forests can attain through CT. An additional beneficial condition spekboom shares with temperate forests is a favourable water balance (Mills, O'connor et al. 2005) along with its potential for combating desertification and alleviating poverty in dry areas (Van Cotthem 2010). An important difference between the forest ecosystems and spekboom regarding CS is that forests are likely to experience periodic fires which replace stands (Bond & Van Wilgen 1996), whereas spekboom does not burn (Kerley, Knight & De Kock 1995; Vlok, Euston-Brown & Cowling 2003). This is largely due to the incombustibility of the evergreen succulent vegetation and can thus be considered safe from fire (Kerley, Knight & De Kock 1995). Spekboom will very likely play a key role in the accumulation of ecosystem carbon as fire suppression in fire-prone ecosystems results in substantial gains in carbon storage (Tilman, Reich & Phillips 2000). In order to make CS a prominent factor in reducing the rate of global warming, land use change needs to be identified and reduced.

2.2.3 Global vegetation degradation, deforestation and land-use change

Global forest covers around 30% (nearly four billion hectares) of the earth's land surface (UNFCCC 2011). These forests provide priceless ecosystem services and goods which supply habitat for a wide range of flora and fauna and hold a significant standing stock of global carbon (UNFCCC 2011). The total carbon content of forests has been estimated in 2005 at 638 Gt which exceeds the amount of carbon in the entire atmosphere (UNFCCC 2011). Emissions from deforestation and forest degradation account for 20% to 25% of the overall annual emissions of GHGs (IPCC 2007): This is more carbon output than is generated by all transportation sources worldwide (Boucher 2010). This is a distressing situation considering that forests are the mechanism in which this excess carbon is absorbed: Should forests be destroyed, the stored carbon will be released. However, there is no natural mechanism to absorb this excess carbon and the whole carbon cycle is deranged. Worldwide deforestation, mainly conversion of forests for agricultural activities, has been estimated to occur at the alarming rate of 13 million hectares per year (in the period 1990-2005) (IPCC 2007). To reduce this high rate of land-use change it is important to identify areas that accommodate high carbon content, so as to protect and conserve them as reserves. It is also necessary to identify areas of extreme degradation and the possibility of restoring such degraded areas. The IPCC declared in its Fourth Assessment Report that the reduction and/or prevention of deforestation and land-use change are the mitigation options with the largest and most immediate impact on carbon stock in the short term (UNFCCC 2011). In South Africa the Thicket Biome sequestrates am exceptional amount of CO_2 for such an arid region, yet it is under severe strain due to overgrazing.

2.2.4 Carbon sequestration potential in the Thicket Biome of South Africa

Recently, there has been a notable influx of information on spekboom as a plant having a high CS potential. The plant's aforementioned favourable characteristics over forest systems have boosted its attractiveness. This section first overviews reasons why spekboom has such a high CS potential, specifically in such an arid environment as prevailing in BLK PNR. The high level of degradation of this plant species in South Africa offers an opportunity for CT through restoration in the current Kyoto Protocol's compliance market.

2.2.4.1 Spekboom sequestration potential

Among South Africa's diverse biomes, one of the most significant is the Thicket Biome containing spekboom (*Portulacaria afra*) as a dominant species. The species plays a crucial role in both above-ground and below-ground carbon stock storage (Powell, Mills & Marais 2008). Vlok, Euston-Brown & Cowling (2003), Mills et al. (2003; 2005b), Mills & Cowling (2006), Marais et al. (2009) and Sproutingforth (2008) all conclude that the vegetation of the Thicket Biome of South Africa's southern coastal belt comprises a closed scrubland that exhibits rainforest-like functioning, despite the region's semi-arid (climatic regions that receive annual precipitation below 250 mm) climate. Spekboom has the potential to sequester carbon and restore the functioning of the ecosystem at a surprisingly fast rate of 4.1 tons/ha/annum in a semi-arid area (Powell 2009). This is an exceptional amount of carbon for a warm, semi-arid region and is similar to the carbon content values of forest ecosystems (Mills, O'connor et al. 2005). In the Eastern Cape province of South Africa, subtropical thicket can store around 200 tC/ha or 84 tC/acre (Mills et al. 2003; 2005a;

Powell, Mills & Marais 2008) and "...up to 245 tC/ha or 99.15 tC/acre in some instances" (Tennigkeit & Wilkes 2008: 21).

Portulacaria afra is referred to in this study as spekboom (literally "fat pork tree"), but it is also known as Elephant's Food, Elephant Bush, Elephant Grass, Elephant-plant, Olifantskos, Purslane tree, Dwarf or Tiny Leaf Jade. The common name spekboom originates from the succulent nature of the plant's leaves and its stout trunk. Spekboom is dominant in most of the semi-arid (200-350 mm/yr) thicket. Spekboom's exceptional potential to sequester carbon and restore the functioning of an ecosystem noted above is attributable to the plants high photosynthetic properties.

Maxwell Griffiths & Young (1994), Huerta & Ting (1998), Marais (2008), Powell, Mills & Marais et al. (2009) and Mills & Cowling (2010) have empirically determined how spekboom has such high carbon-storing abilities. Spekboom performs a type of photosynthesis, called Crassulacean acid metabolism (CAM), which is exhibited by some succulent plants. This photosynthetic mechanism allows carbon dioxide to be taken up and stored during the night to allow the stomata to remain closed during the day so decreasing water loss. These plants fix CO_2 during the night, storing it as the four-carbon acidmalate which increases efficiency. Being able to keep stomata closed during the hottest and driest part of the day reduces loss of water through evapotranspiration, allowing CAM plants to grow in environments that would otherwise be far too dry. This high sequestration ability of the plant opens various ways for trade in the carbon market. Spekboom's exceptional CS ability can produce some 160 tons of dry mass per hectare which is higher than the values for certain forests and 50 to 100 times higher than in other semi-desert ecosystems (including the Karoo Biome) (Mills et al. 2009). Mills et al. (2009: 9) elucidate the reasons as:

> … firstly, it produces inordinately large amounts of leaf litter – some 4.6 tons of litter per hectare per year which is comparable to wet forest ecosystems and five to 35 times higher than that of other semi-arid ecosystems; secondly, the dense canopy maintains a microclimate of cool and dry conditions, conducive to the slow decomposition of leaf matter on the thicket floor and in the soil; and thirdly, spekboom-rich thicket is fire-resistant. This allows large amounts of organic carbon to accumulate, dramatically improving the soil's fertility.

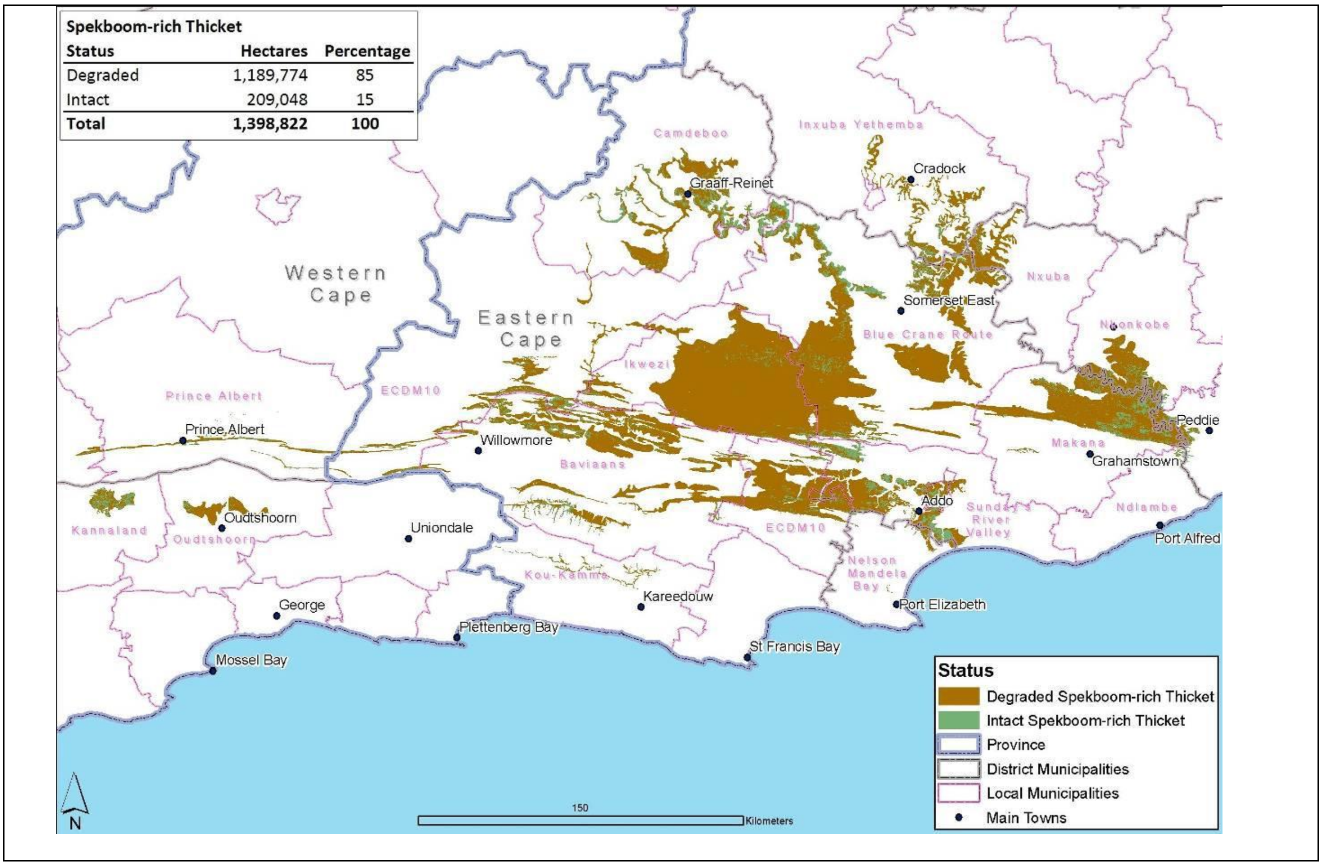
But they (Mills et al. 2009: 9) note further that:

> Spekboom is highly palatable to animals, and resilient to the pattern of browsing by indigenous animals such as elephant. However, it is vulnerable to browsing by goats and sheep, especially if poorly managed. Over-stocking leads to a rapid breakdown of the protective "skirt" of branches, and within a short period, dense thicket degrades to open vegetation resembling Karoo veld.

It has been estimated that approximately 4 million ha of subtropical thicket in South Africa have been degraded, 1.3 million ha moderately so and 2.7 million ha severely (Lloyd, Van den Berg & Palmer 2002). A significant component of this degradation is the loss of carbon from various pools which is attributable to overgrazing, incorrect ploughing techniques, overcropping and soil erosion (Mills, Cowling et al. 2005).

2.2.4.2 Spekboom degradation

Degradation of spekboom has decreased the species richness and unique biodiversity in the Western Cape and Eastern Cape regions. In the Eastern Cape spekboom covers approximately 17% of the surface area (4 000 000 hectares) (Powell, Mills & Marais 2008) of which nearly 50% has been severely degraded due to overgrazing and land-use change (Lloyd, Van den Berg & Palmer 2002; Marais et al.2009). Mills (2009) reckons that the situation is far worse contending that up to 85% has been degraded. Of the four million hectares of uninterrupted canopy thicket, 46% has been heavily impacted by domestic herbivores, 1.8% by cropping and 0.5% by urbanization (Mills & Cowling 2010). Figure 2.2 illustrates the spread of spekboom-rich thicket and the areal extent to which it has been degraded in South Africa. Clearly, the majority of thicket occurrences, especially in the central regions of the Eastern Cape, have been seriously degraded and there are only small isolated patches of intact thicket remaining. The majority of spekboom occurs north of Addo Elephant National Park and north of Grahamstown in the Eastern Cape. It is only along sinuous, deeply incised river valleys and in mountainous terrain rimming these basin-like landscapes that isolated stands of intact spekboom have been maintained. The thin bands and small islands of spekboom stretching westwards beyond Prince Albert and Oudtshoorn (toward the study area) represent a small proportion of the biome, but it is similarly degraded as elsewhere to the east. In the west the biome representation is clinging precariously to the north-facing slopes and foothills of the lofty and fynbos-dominated fold mountain ranges of the Swartberg. Fortunately, the general contention is that almost the entire degraded thicket is potentially restorable (Mills 2009). Empirical research by Mills & Cowling (2006) found that heavy browsing by goats (boerbok and angora) transformed the majority of thicket to an open savannah, resulting in carbon losses greater



Source: Mills (2009: 8)

Figure 2.2 The status of spekboom-rich thicket occurrence and its degradation in South Africa

than 8.5 tC/ha. The reason for this goat-caused high degradation rate in spekboom is that goats graze the shrub from the bottom up, therefore destroying the plant's ability to reproduce and revegetate. Game animals browse the top branches of the shrub only, thus having no effect on the plant's reproduction or survival rate. At times game can encourage revegetation when branches are broken off when they pass through the vegetation. This happens freely with grazing elephants. Many Eastern Cape farmers, following a century (1900s) of intensive goat farming, are now left with degraded spekboom in the form of the open, bare lands spectacularly displayed in Figure 2.3 as desert-like landscapes. The degraded thicket results in loss of biodiversity, large losses of ecosystem carbon, a reduction in soil quality and a reduction in plant productivity, and hence herbivore carrying capacity (Mills & Cowling 2010). Mills et al. (2003) have noted that a significant feature of degraded thicket is a net loss of biomass, greater than 89 tC/ha and a concomitant loss of biodiversity, often resulting in a pseudo-savannah with a strong karroid component. According to the United Nations definition, areas under desertification risk are so-called susceptible dry lands (Hoffman et al. 1999). In South Africa nearly 91% of the national surface is classified as arid, semi-arid or dry sub-humid and falls broadly within the United Nations

Source: Mills (2009: 5,7)

Figure 2.3 Fence-line contrasts showing intact and degraded spekboom in the Eastern Cape

Convention to Combat Desertification (UNCCD) definition of affected dry lands (Hoffman et al. 1999). These are dry areas where the rainfall is low and potential evaporation is high. Dry-land systems are often very sensitive to change and therefore need to be managed carefully to avoid land degradation (Stocking & Murnaghan 2000).

In summary, spekboom thickets have experienced extensive degradation resulting in losses of:

- phytomass (Lechmere-Oertel, Kerley & Cowling 2005; Mills, O'connor et al. 2005);
- species diversity (Sigwela et al. 2003; Lechmere-Oertel, Kerley & Cowling 2005);
- soil carbon (Mills & Fey 2004a; 2004b; Mills, O'connor et al. 2005);
- soil fertility (Mills & Fey 2004a; Lechmere-Oertel, Kerley & Cowling 2005);
- water penetration (Kerley, Knight & De Kock 1995 Mills & Fey 2004a); and
- litter production (Lechmere-Oertel 2003; Lechmere-Oertel et al. 2008).

It is highly probable that there has also been a loss of diversity of invertebrate species in spekboom thicket in the extreme cases of desertification. Similar to those reported in the adjacent Succulent Karoo Biome (Seymour & Dean 1999). Once this change has occurred and the vegetation becomes degraded, it is very difficult to reverse the status, even by restoration actions (Turpie 2003).

2.2.4.3 Spekboom restoration

Powell (2009: 61) has alerted that "it is well recognized that once semi-arid subtropical thickets are degraded, they remain degraded, with seedlings being rare, even in intact vegetation." Intact subtropical thickets have a thick litter layer (~10 cm) (Lechmere-Oertel et al. 2008) which is vital for seedling establishment (Sigwela et al. 2003), but it is lost in the degraded state due to the absence of leaf-litter production. This litter loss also crucially affects water infiltration rates, hence sediment transportation (Stuart-Hill 1999). Litter must therefore play a key role in spekboom truncheon survivorship regarding restoration plantings in degraded landscapes.

Spekboom reproduces both sexually and asexually, but with poor seed rain (deposition of seeds spread by bird, wind, humans, and animals), it exhibits low levels of seed dormancy (Von Maltitz 1991) and insignificant seed banks exist (Powell 2009). Because seedlings are rare, restoration requires active replanting. When spekboom branches are broken off or touch the ground they begin to develop roots as evident in Figure 2.4.

Figure 2.4 Skirt branches developing roots in spekboom on BLK PNR

Despite spekboom having remarkable abilities to produce roots from cuttings, it does not recolonize degraded areas due to the lack of skirt branches (Stuart-Hill 1999). Fortunately, manual planting of the species can recoup a significant proportion of lost or degraded communities.

Spekboom carbon farming is only suitable in areas where natural spekboom-rich thicket once occurred, namely in its original natural habitat. The criteria for selecting a degraded site suitable for restoration are fourfold: 1) ensure that it was previously covered in spekboom-rich thicket; 2) the restoration site should preferably be near an abundant source of spekboom for cuttings, not only to reduce transport costs but also to ensure that the appropriate plant variety or genotype for the area is replanted; 3) it should be easily accessible by road; and 4) it is advantageous to be near a water source (Cowling et al. 2011). Nevertheless, water is not a necessity for root development (i.e. cuttings can be planted in the ground without any prepropagation).

Since 2004 studies by the Department of Agriculture, based on farmers' experience, and by Sub-tropical thicket restoration projects (STRP) suggest that the following requirements, procedures and methods pertain to successful restoration:

> The spekboom cuttings must be 25-30 millimetres in diameter at the base and about 800-1000 mm in length. Once harvested, the stems must be stored in the shade for two

> days before planting. The cuttings must be planted 150-200 mm deep in the ground, at a density of about 1.5-2 m intervals. If the ground is hard and stony, koevoets and picks are often a necessity, but the recent testing of a mechanical auger or drill (similar to a chainsaw) has improved planting time dramatically. Using this, a team of 12 members, can plant up to 26 hectares over a 20 day contract period (Cowling et al. 2011: 7).

Careful costing by Mills et al. (2009: 20) reveal "that the cost of sequestering one tone of carbon dioxide decreases from approximately R85 in a 500 hectare project in a steeply sloping landscape to R30 in a 64,000 hectare project in a gently sloping landscape." Therefore, ideal land for restoration should not have steep slopes and the amount of project land to be transformed should be maximized.

In conclusion, global warming is a grim problem that needs to be addressed to reduce CO_2 levels. In South Africa, spekboom is a significant plant due to the fact that it reduces atmospheric CO_2 at similar rates to forest ecosystems with additional favourable characteristics. Due to over grazing this plant has been severely degraded which creates an opportunity to restore the vegetation with funding through carbon trading. Its potential in the carbon market is explored next.

2.3 CARBON SEQUESTRATION TRADING POTENTIAL

The trading potential of CS is realized in two ways, namely through payments for the regulation of ecosystem service maintenance and through active trading on the carbon market. These two avenues for realizing market potential in theory and practise are explored in the following subsections in a format intended to guide would-be traders in the international market.

2.3.1 The principle of payments for ecosystem services

In principle, payment for ecosystem services (PES) or international PES (IPES) amounts to "environmental policies that can be used to address the market failures resulting from the exclusion of ecosystem services from the market, and is especially adapted for addressing the global public goods nature of biodiversity conservation" (Peterson et al. 2007: 2). Gutman (2003), on the other hand, explains IPES as a transaction whereby a well-defined ecosystem service, or a landuse likely to secure that service, is being 'bought' by at least one buyer from at least one provider if, and only if, the provider secures the provision of the service in which the beneficiaries of ecosystem services pay suppliers of these services for their conservation and maintenance. Howsoever defined, the mechanism offers an increasingly popular means for generating funding and securing a sustainable supply of these valuable environmental services (Robertson & Wunder 2005; Peterson et al. 2007).

Payments for ecosystem services are a means of protecting the valuable ecosystems that provide the planet with a wide range of services, from reliable clean water flows to productive soil and CS.

Many people, companies and societies daily rely on these services for raw material inputs, production processes and climate stability. Therefore, their protection is of the utmost importance. The problem is one of responsibility of payment to protect and conserve these valuable ecosystems. Peterson et al. (2007: 3) recognizes that the "IPES is currently being developed to address the financing of ecosystem services at the international level, notably in terms of matching providers and beneficiaries that reside in different countries." The most developed and practised form of IPES is for CS projects. This is mainly because the demand for CS has been significantly boosted by the Kyoto Protocol's Clean Development Mechanism (which is one form of IPES) under which only CS through afforestation or reforestation projects can be traded on the Kyoto compliance markets. All other IPES activities have to be traded in the voluntary market. In contrast to IPES, international payments for biodiversity conservation are less common (Peterson et al. 2007). In the past, the conservation of biodiversity has been practised mainly through the national designation of protected areas. Payments for biodiversity conservation, while growing, remain largely a minor occurrence, instituted through forest and fisheries certification, hunting concessions, ecotourism, markets for biodiversity offsets and niche markets for products with high agricultural biodiversity value (Gutman 2003; Peterson et al. 2007). There is a need to value the ecosystems other than those that we can directly use, so improving biodiversity.

There are many other opportunities to attain carbon credits through sustainable land management (Niles et al. 2002). As yet it is not possible to trade by using avoided land-use change activities through the Kyoto Protocol compliance market. However, Peterson et al. (2007) point out that IPES does offer opportunities to 'bundle' payments for reduced emissions with payments for biodiversity, conservation and possibly other ecosystem services which could be purchased on the voluntary market.

The most important part of any CS project is long-term sustainability. This requires a long-term commitment by the landowner to continue managing the land to guarantee that carbon is stored on a permanent basis. By sequestering substantial amounts of carbon, landowners can be granted carbon credits which are sold for cash payments on a carbon exchange.

2.3.2 Carbon market trading: Definitions and mechanisms

Understanding CT in principle requires definition of the term per se, the use of carbon offsets as a tool for that purpose and an introduction to some practical experiences with the instrument, especially concerning spekboom. An apt definition for CT is provided by the Australian Foundation for Science (2008: 1) as:

> A market-based mechanism for helping mitigate the increase of CO_2 in the atmosphere by providing economic incentives for achieving reductions in the emissions of pollutants, and CT markets are developing that bring buyers and sellers of carbon credits together with standardized rules of trade.

The instrument is operationalized by formulating so-called carbon offsets. According to Taiyab (2006: 3) a "carbon offset 'counteracts' or 'neutralizes' a ton of CO_2e (carbon dioxide equivalent) produced in one place by avoiding the release of a ton of CO_2e elsewhere or absorbing/sequestering a ton of CO_2e that would have otherwise remained in the atmosphere." Sedjo & Marland (2003), as well as Tietenberg (2006), state the purpose of carbon emissions credits (a generic term meaning that a value has been assigned to a reduction or offset of GHG–usually 1 ton of CO_2 equivalent) is to get rid of the liability associated with a firm's (or country's) release of carbon into the atmosphere and it is a regulatory programme that allows pollution emitters significant flexibility through financial payments. Carbon offsetting is an increasingly popular mechanism for decreasing current rising CO_2 levels that are increasing the rate of global warming. The purchaser of carbon offset credits pays someone else to reduce GHG emissions elsewhere, thus aiming to compensate for or offset their own emissions. Individuals or companies seek to offset their emissions (either through compliance or voluntarily) to become 'climate neutral' or 'carbon neutral' by buying large quantities of carbon offsets to 'neutralize' their carbon footprint or that of their products.

There are a number of carbon offset mechanisms that produce carbon credits. They range from installing improved technologies to active vegetation replanting projects, but the focus in this study is on forestry-based projects. Offsets considered are restoration, avoided deforestation and landuse change and avoided land degradation. Restoration involves active replanting of indigenous vegetation in areas where it previously occurred. Avoided deforestation or landuse change includes protecting or conserving forest-like systems in their natural state from being destroyed for timber, farming or other practices. Avoided land degradation includes protecting land from extreme degradation through actively adopting good farming and management practices.

Depending on the price of carbon credits and the complexities of accreditation and verification, CS as a land-use and farming practise could rival or surpass the profitability of pastoral farming (Mills, O'connor et al. 2005). For instance, even at the current carbon prices, it has been established that Cameroonians will find it more profitable to refrain from crop farming and receive compensation from reduced emissions from deforestation and degradation (REDD) carbon credits (Bellassen & Gitz 2008). As an indication of the market potential for trading carbon credits consider that at least 65 million tons of carbon credits were already transacted in 2007, a 165% increase over 2006 and a near 200% increase for the over-the-counter market alone, with a total market value of

US$331 million (Taiyab 2006). An organization called Ecosystem Marketplace and the Carbon Finance Group (http://www.carbon-financeonline.com/) has valued the international voluntary market at US$258 million in 2007. Together with the compliance market, which was valued at US$72 million, the global voluntary market was worth an estimated US$331 million in 2007. This more than tripled the 2006 market value of US$97 million (Global Green-houseWarming.com 2011).

Although many scientific investigations have been conducted to determine the CS potential of spekboom, little research on its potential market value has been concluded, especially with reference to the voluntary market. Consequently, very few projects have actually fully participated in CT to date, although studies have shown that using CT as a source of funding for landscape-scale restoration is economically viable at current carbon prices (Marais, Cowling & Powell 2009).

2.3.3 Carbon trading in practise

Trading in the carbon market requires the prior identification of the way in which carbon credits can be verified and sold. The two market mechanisms; namely the voluntary carbon market and the compliance market, are compared in Table 2.2. The main difference between them reside within their names – the one is voluntary, driven by institutions themselves, while the compulsory markets are driven by international obligations that leave institutions no choice. They also differ according to CS mechanisms applicable, the format in which carbon credits are recorded, and the activities that are deemed eligible. The two alternatives are discussed next, and in the case of compliance markets, future trends in its application are considered.

2.3.3.1 Voluntary carbon markets

A voluntary carbon market functions outside the compliance market, enabling companies and individuals to purchase carbon offsets on a voluntary basis. This market is mainly driven by public concern about climate change and corporate social responsibility and it is employed by either environmentally-conscious people wanting to play their part in tackling the issue of global warming or businesses wanting to use it as a mechanism for advertising and marketing themselves as ‘green’ or ‘carbon neutral’. Such claims hold significant marketing advantages in modern societies. Carbon credits that are sold in the voluntary carbon market are known as verified emission reduction (VER).

Most retailers of carbon credit usually sell to the voluntary market because the projects in which they invest do subsequently not have a local overseeing authority, as is the case with the clean

Table 2.2 Comparison of the voluntary carbon market and the Kyoto Protocol compliance market

	MARKET OPTION	
	Voluntary carbon market	***Kyoto compliance market***
Carbon sequestration mechanisms	Variety IPES (international payments for ecosystem services), REDD (reduced emissions from deforestation and degradation), REDD+ (reduced emissions from deforestation and degradation plus)	Clean development mechanism (afforestation/reforestation)
Carbon credit format	Verified emission reduction (VER)	Certified emission reduction (CER)
Eligible activities	Restore soil carbon, practise agroforestry, avoid deforestation, nature conservation, PES	Vegetation restoration/reforestation
Comparison	• Market opened to experiments • Quality of VERs differ • Generally lower capacity requirements than CDM • Mostly focus on environmental and social co-benefits	• High technical and bureaucratic capacity requirements • Very few projects registered • Strict requirements, high transactional costs • Environmental and social co-benefits neglected

Source: Compiled from: Taiyab (2006); Peterson et al. (2007); Peterson et al. (2012)

development mechanism (CDM) under the compliance market. It is clearly beneficial to traders in voluntary markets that;

> free from the stringent guidelines, lengthy paperwork, and high transaction costs, project developers have more freedom to invest in small-scale community-based projects. The co-benefits of these projects, in terms of, for example, local economic development or biodiversity, are often a key selling point (Taiyab 2006: 1).

It must be noted that in South Africa such projects are required to comply with applicable South African legislation and regulations.

Peterson et al. (2007: 7) have noted that “voluntary markets provided the first financing for forest conservation as a means of reducing GHG emissions.” The Nature Conservancy (US charitable environmental organization that works to preserve the lands and waters on which all life depends) and Conservation International (a nonprofit environmental with the mission to protect nature, and its biodiversity, for the benefit of humanity) have been predominantly active in reducing GHG emissions through forest conservation strategies which aim at conserving and protecting the natural ecosystem and its services. Currently, aside from a retail market with small project-based emissions reductions not used for compliance or trading, the international markets for selling voluntary carbon credits include a number of prominent players. They are:

- the United Kingdom Emissions Trading Scheme (UK ETS) which allows companies the option to enter into an available scheme and receive financial incentives for doing so; and
- the Chicago Climate Exchange, a voluntary trading scheme in the US.

In South Africa, options for trading have opened. Nedbank has developed the first local carbon market known as the Nedbank Carbon Finance Unit. This includes Nedbank Capital's carbon asset management which focuses on: devising a carbon strategy and policy (sustainability); carbon advisory and foot printing services; identification and development of CDM projects; and the identification and development of energy efficiency projects. It also offers a platform for trading CERs and VERs and providing client brokerage services to monetise carbon benefits or to obtaining carbon neutrality (Nedbank Capital 2013). The Johannesburg Stock Exchange (JSE) is formulating proposals for and implementing a scheme for the introduction of a voluntary carbon credit trading programme to which companies on its listing may subscribe. The JSE offers "Carbon Credit Notes (CCN) that provide holders with the opportunity to gain exposure to Carbon Credits that are generated from carbon dioxide emission reducing projects, through holding a listed tradable security" (JSE 2012a: 1). In fact, a scorecard for performance in this regard is becoming a major evaluation criterion for listed companies through the Socially Responsible Investment Index which assesses JSE-listed companies' environmental, social and economic sustainability practises and corporate governance (JSE 2012b). With more than €20 billion already traded in 2006 (Capoor & Ambrosi 2007), voluntary carbon markets are a considerable economic force and will likely expand substantially over the coming years (Taiyab 2006).

2.3.3.2 Current compliance market practises

The Kyoto Protocol was established as an international agreement to address the challenge of global climate change. As part of an effort to reduce global emissions of GHGs that contribute to a significant warming of the earth's climate, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was signed in Kyoto, Japan in December 1997 (Lambrou & Piana 2006). Its objective was to establish a legally binding international agreement whereby all the participating nations must commit themselves to tackling the issue of global warming and GHG emissions. In developing the Kyoto Protocol, the parties to the UNFCCC took into consideration the need to promote sustainable development by implementing policies and measures to enhance energy efficiency, protect and enhance sinks and reservoirs of GHGs, promote sustainable forms of agriculture, increase the use of new and renewable forms of energy and of advanced and innovative practises and technologically sound practises (Lambrou & Piana 2006). The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European Union for reducing GHG emissions. This amounts to an average of five per cent against 1990 levels over the five-year period 2008-2012. The main distinction between the Kyoto Protocol and the Convention is that, while the Convention supports and encourages industrialized countries to stabilize GHG emissions, the Kyoto Protocol commits signatories to do so. Recognizing that developed countries are predominantly responsible for the current high levels of GHG released into the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of 'common but differentiated responsibilities'.

The UNFCCC (1998) stipulates a principle that sequestration of carbon in the terrestrial biosphere can be used to offset emissions of carbon from fossil-fuel combustion (Articles 3.3 and 3.4) and introduces three processes to combat climate change. These three processes are Joint Implementation (Article 6), the Clean Development Mechanism (Article 12) and International Emissions Trading (Article 17). McKibbin et al. (2000) and The Green Guide (2009) explain the three mechanisms.

Under Joint Implementation a developed country with relatively high costs of domestic greenhouse reduction could set up a project in another developed country. The emissions reduction units (ERUs) generated from such a project can be used by the former to meet its emission reduction target. Any project under Article 6 aimed at enhancing anthropogenic removals by sinks must conform to definitions, accounting rules, modalities and guidelines under Article 3, paragraphs three and four, of the Kyoto Protocol (UNFCCC 2009).

Under the Clean Development Mechanism (CDM) a developed country can 'sponsor' a greenhouse gas reduction project in a developing country where the cost of GHG reduction project activities is usually much lower, but the atmospheric effect is globally equivalent. The developed country would be given credits for meeting its emission reduction targets, while the developing country would receive the capital investment and clean technology or beneficial change in land use such as funding for afforestation, reforestation and restoration activities. The CDM mechanism has already registered more than 1000 projects internationally and is anticipated to produce certified emission reductions (CERs) amounting to more than 2.7 billion tons of CO_2 equivalent in the first commitment period of the Kyoto Protocol from 2008 to 2012 (UNFCCC 2010).

Under International Emissions Trading (IET) countries can trade in the international carbon credit market to cover their shortfall in allowances. Countries with surplus credits can sell them to countries with capped emission commitments. South Africa has joined this initiative by setting up the appropriate institutional structure. However, the forestry-based CDM in South Africa is complicated and requires intergovernmental cooperation. Designated national authority (DNA) is being developed under the Department of Minerals and Energy (DME) for this purpose. Although the Department of Environmental Affairs and Tourism (DEAT) is the leading institution in climate change response in South Africa, the Department of Water Affairs and Forestry (DWAF) plays an essential role in forestry-based CS projects.

The UNFCCC has already set up mechanisms to deal with specific projects such as REDD the mechanism that falls under the CDM and allows afforestation and reforestation projects in the current period (until 2012). In December 2009 the international climate negotiations in Copenhagen made important progress in establishing a REDD+ which includes carbon-sequestering forest activities such as avoided deforestation, avoided land-use change, ecosystem conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (Boucher 2010). This mechanism, however, will only be implemented in the era of post-Kyoto Protocol 2012.

2.3.3.3 Future compliance market practices

Future trading in mandatory markets will be determined by moving beyond REDD to REDD+. The Kyoto Protocol currently only mandates REDD-afforestation and -reforestation projects. With the second phase of the Kyoto Protocol coming into effect in 2012 and with the establishment of REDD+ through UNFCCC workshops (in Rome (2006), Cairns (2007) and Cancun (2010)) reduced carbon emissions in developing countries is encouraged through avoided deforestation and degradation. These workshops established the potential and preparations for avoided deforestation and land-use change in the post-Kyoto Agreement.

REDD+ is the main topic of debate for CS projects as it is an emission abatement mechanism whereby GHG emissions are reduced by decreasing deforestation and land degradation. REDD+ represents a more detailed type of land use, land-use change and forestry (LULUCF) GHG reduction method, other than the current afforestation and reforestation projects. REDD+ focuses specifically on wider environmental management activities, poverty reduction and other public services (Peterson et al. 2012). The centre of attention in this study is the conservation of existing carbon stocks in biomass in contrast to REDD which only includes afforestation and reforestation which aim to sequester carbon from the atmosphere through tree planting and growth (Peterson et al. 2007). REDD+ promotes forest conservation, the sustainable management of forests and the enhancement of forest carbon stocks.

Although REDD+ activities were eventually excluded from the first commitment period of the Kyoto Protocol, trading on the compliance market was not possible, they have re-emerged as a topic for debate preceding the second round of negotiations for REDD+. As a result, the inclusion of REDD+ has become a priority for discussions concerning the post-2012 commitment period for the Protocol and it was a prominent issue at the 13th United Nations Framework Convention on Climate Change (COP13) in December 2007 (UNFCCC 2006). At the 16th United Nations Framework Convention on Climate Change (COP16) the Subsidiary Body for Scientific and Technology Advice was requested to develop a programme to identify land-use change activities in developing counties, identify the associated methodological issues to estimate emission removals and develop, as necessary, modalities for measuring, reporting and verifying anthropogenic forest-related emissions by source and removals by sinks resulting from implementation of REDD+ activities (Henry 2011).

How does this relate to the South African situation and spekboom in particular? The loss of more than 85 tons of carbon per hectare could be avoided by preventing degradation of spekboom. Incentive schemes such as those promised by REDD+ are needed to safeguard intact thickets (Mills 2009).

The main problem with REDD+ activities is the implementation, management and accounting surrounding these activities in the voluntary market. Peterson et al (2012) suggest having a non-profit organization as the implementing agency which would act as a coordinating agency collect contributions from willing investors, while making no additional contribution themselves. The World Bank's BioCarbon Fund is an example of this non-site-specific investment in REDD.

The World Bank administered a public-private initiative in 2007 of Tranche Two of its BioCarbon fund to demonstrate projects that sequester or conserve carbon in forest and agro-ecosystems (World Bank Carbon Finance Unit 2012). The fund has also been prominent in spearheading REDD+ initiatives through the launch "…with the clear aim of investing in REDD and REDD+" (Peterson et al. 2007: 8). This portion of the fund plans to collect over US$50 million from the public and private sectors and direct these investments toward REDD+ projects with positive linkages between reduced emissions, biodiversity and development (Peterson et al. 2007). The World Bank has also recently launched the Forest Carbon Partnership Facility (FCPF) which aims to supply US$250 million to projects in developing countries to implement REDD+ initiatives. During the Oslo Climate and Forest Conference in May 2010, several developed nations jointly pledged US$4 billion to support REDD+ policies and measures (Henry 2011). These commitments indicate that there is a large potential for CT using REDD+.

Peterson et al. (2007: 8) notes that with the "development of new methodologies in carbon accounting, measuring leakage and establishing baselines, REDD+ has the potential to become an increasingly attractive emissions reduction option (ERO) for VER". Although still in a pilot phase, ongoing REDD+ projects are helping to strengthen REDD+ credibility as a viable offsetting mechanism (Peterson et al. 2012). In addition to credibility, the cost of REDD+ is an important dimension that will influence its popularity among investors.

Factors that influence price include opportunity cost (amount/ha), administrative costs (amount/ha), and estimates of the amount of carbon sequestered in biomass (tC/ha). These mandatory markets have currently excluded REDD+ as an offset possibility. Exclusion from mandatory carbon markets has seriously restricted the REDD+ potential for reducing GHG emissions, making voluntary markets and non-market funding the main option for delivering REDD+ activities. Having established the different markets for CT, an understanding of the carbon accounting process for the mitigated carbon is called for in the next section.

2.4 CARBON ACCOUNTING FOR SEQUESTRATIONTRADING

Allocating carbon credits is a complex task for a carbon trading projects. The potential is established by exploring the principles of carbon accounting standards, the relevant carbon standards and the accounting methods to calculate carbon content and CS potential. The section concludes with a roadmap of the project design phase, its structure and required documentation.

2.4.1 Principles of carbon accounting standards

To improve specifications and measures for future commitment periods of the Kyoto Protocol or related international agreements aimed at reducing GHG in the atmosphere, policy makers need more clarity on the accounting process (Rokityanskiy et al. 2007). It relates to the measurement and accounting issues regarding IPES measures and the effects of policies designed to induce landowners to sequester carbon or to reduce emissions from land-use change (LUC), especially to avoid loss of vegetation through, for instance, deforestation.

A number of standards have been developed to address the potential shortcomings of carbon offset projects and to strengthen their creditability (ability to have values calculated). A report commissioned by WWF (Germany) compared 10 different voluntary carbon offset standards and noted that

> no such one standard has yet established itself as the uncontested single industry standard, and that each standard has a slightly different focus. Some closely mirror compliance market standards, while others take a more lenient approach in order to lessen the administrative burden and enable as many credits as possible to enter the market. Certain standards are limited to particular project types, while others exclude some project types in order to focus on the social benefits of carbon projects (WWF 2008: 5).

Therefore, a comprehensive standard is needed that can validate a project's integrity and sustainability, and ensure that it ultimately will make a contribution to reducing atmospheric CO_2 levels. A good standard for carbon offset projects must adhere to the eight criteria specified in Box 2.1. These criteria were incorporated in the project design phase of this study. Moreover,

Box 2.1 Criteria for determining a good carbon offset standard.

The standard must employ methodologies that screen a carbon offset project for:

Additionality: GHG emission reductions generated by a carbon offset project exceed what would have occurred in the absence of the project.

Leakage: Increase in GHG emissions occur outside the boundary as a possible result of displacement by the project. Difficult to judge in ‘stand-alone' projects: Projects for REDD in countries where leakage is reduced by national baselines are preferable.

Permanence: The risk of temporary GHG reductions only – i.e. future release of the stored or sequestered carbon. This will include assessments on discounting, insurance and temporary credits. Permanence is a particular concern in forest carbon projects, due to the risk of the trees succumbing to disease, fire or unsustainable logging. Commonly addressed through mechanisms such as risk pooling and 'banking' a certain percentage of credits as risk insurance.

Sustainable development: The extent of contribution toward sustainable development of the host country, and adherence to rigorous social and environmental safeguards.

Stakeholder consultation: Incorporation of meaningful stakeholder consultation into project design to ensure that adverse social or environmental impacts are properly identified. This is particularly important in countries where environmental and social regulations are absent or weakly enforced.

Validation and certification: Enforcement of strict accreditation requirements for potential validators and certifiers to ensure that they have sufficient expertise and competencies to fulfil their tasks. The standard should separate the certification and approval procedures to avoid conflicts of interest between the certifiers and the project developers.

Avoidance of double counting: Double counting can occur when implemented in a country that has committed to emission reductions under the Kyoto Protocol (Annex 1 countries) and both the offsets purchaser and the host country claim emissions reductions. The standard should therefore have clear and unambiguous registration procedures.

Issuance and tracking: The standard should issue carbon credits and track them in a single registry.

Source: Adapted from WWF (2008)

additionality, leakage, permanence and sustainable development are used to asses and classify carbon credits. Stakeholder consultation, validation and certification and avoidance of double accounting are used in the accounting process. These principals of carbon accounting are applied to the various carbon accounting standards next.

2.4.2 Applied carbon accounting standards

The four carbon offset standards regarding forestry now used in carbon accounting are listed in Table 2.3 and outlined in this section. The standard requirements for these project types were summarized from a number of sources (Lambrou & Piana 2006; WWF 2008; UNFCCC 2009) and matched with the various applicable standards.

Table 2.3 Eligible project types for the different carbon trading standards

Eligible forest project types	**Standards**			
	Clean Development Mechanism (CDM)	Voluntary carbon standards (VCS)	Climate, community and biodiversity standard (CCB)	Forest Stewardship Council certification (FSC)
Afforestation and reforestation	X	X	X	X
Improved forest management		X	X	
Forest protection		X	X	

- The Clean Development Mechanism (CDM) compliance standard was developed by the UNFCCC in the current Kyoto Protocol, specifically under the Clean Development Mechanism. This standard applies only to reforestation and afforestation in the current Kyoto Protocol phase. However, following discussions for the post Kyoto Protocol (REDD+) this standard should eventually include the conservation of existing carbon stocks.
- The voluntary carbon standard (VCS) is a global benchmark standard for project-based voluntary GHG emission reductions and removals. The VCS has been developed by The Climate Group, the International Emissions Trading Association (IETA), the World Business Council for Sustainable Development (WBCSD) and a range of business, governmental and non-governmental organizations. The VCS covers all major land-use activities including agriculture and forestry.
- The climate, community and biodiversity (CCB) standard project design standards have been developed by the Climate, Community and Biodiversity Alliance, a partnership of research

institutions, corporations and NGOs. These standards evaluate land-based carbon mitigation projects in the early stages of development against a set of criteria to assess the extent to which the projects are simultaneously addressing climate change, supporting local communities and conserving biodiversity. The CCB standards apply to all land-based carbon offsets (including reforestation, afforestation, reducing emissions from deforestation and forest degradation, agroforestry and agriculture) for the voluntary or regulatory markets with no geographical restriction.

- Forest Stewardship Council (FSC) certification was established by a diverse grouping of forest enterprises, indigenous forest communities, timber retailers and environmental NGOs (including WWF). FSC certification is one of several such systems for inspecting forest management and tracking timber and paper through a 'chain of custody' to ensure that the products have come from sustainably managed forests. The FSC certification system is currently the only one that meets all of WWF's criteria for environmental, social and economic sustainability as listed in Box 2.1. Although not designed for forest carbon projects per se, the FSC certification system for production forests is included here as it is the most widely applied and credible system for ensuring responsible forest management.

2.4.3 Carbon accounting methods

Most of the accounting methods for CS projects identified in the literature follow one of three approaches, namely payment for carbon growth, payment for the stock of carbon, or payment for land conversion (Caparros et al. 2010). In this study carbon stocks and the changes in carbon stocks apply.

In principle payments for *carbon growth* would include projects such as restoration of vegetation stands. Accounting methods for this activity include the carbon flow method, an accounting mechanism assuming that "the land-owner gets paid when CS takes place and has to pay when carbon is released" (Caparros et al. 2010: 3). CS is then calculated as the change in carbon stocks over a given time. This change in carbon stocks constitutes the creditable portion of the activity. According to the rules of the Kyoto Protocol, one ton of carbon sequestrated equals one carbon credit. The amount paid is equal to the value of the carbon credit on the international market at the time.

Payment principles for the *stock of carbon*, in this study, payment for avoided deforestation or degradation, is less developed in the literature as it was not included in the current Kyoto Protocol. Santilli et al. (2005) propose the concept of 'compensated reductions' to pay for the reduction in deforestation and degradation. This includes the concept of opportunity costs as an indication of what must be sacrificed to obtain some other goal. In the environmental context, it is a measure of the value of whatever must be sacrificed to prevent or reduce the chances of a negative environmental impact.

Payment for *land conversion*, in this instance the conversion of land into conservation areas, is still in the pilot stage so there is no specific accounting method. The project design document (PDD) for the climate, community and biodiversity standard (CCBS) takes into account biodiversity information and carbon stock information. Valuing biodiversity is a complicated process given the vast extent and variation of ecosystems, but general indicators include species richness, protection status, endangered species and endemic species.

2.4.4 Project design

The project design phase of the marketing process for planning and accounting for carbon mitigation project and for realising CS payments requires the completion of six general steps (WWF 2008). These steps, together with the various accounting and standards issues relevant to each step, are listed in Table 2.4. This study is limited to the first two steps which entail the development of

Table 2.4 Carbon sequestration project design process

Phase	***Accounting issues***	***Key standards issues***
Step 1	Carbon accounting	Base line indicators: additionality; leakage; permanence; carbon stock calculations
Step 2	Social and environmental impacts	• Stakeholder consultation, grievance mechanism and transparency • Identification of high conservation values (HCV's) • Assessment of social and environmental impacts • Long-term viability • Legal compliance
Step 3	Validation and registration process	• Validation of anticipated emissions reductions • Validation of project proposals against applicable project design standards • Accreditation of bodies for validation • Registration requirements for the project design
Step 4	Social and environmental performance	• Maintenance of HCV's • Adherence to social and environmental performance standards • Legal compliance of operations
Step 5	Verification	• Verification of achieved GHG benefits • Verification of social and environmental performance • Accreditation of bodies for verification of GHG benefits and for verification of social and environmental performance
Step 6	Registration and issuance of carbon credits	• Registration of carbon credits • Efficient procedures for handling of carbon credits

Source: WWF (2008)

PDD and the identification of the market potential. An application to BLK PNR is detailed in the next chapter.The last four steps are beyond the scope of this application. The first step of carbon accounting requires attention to a number of standards factors and criteria and involves a full assessment of additionality, leakage, permanence as well as baseline calculations of carbon stocks. These baseline indicators include the calculation of carbon stocks, CS, area of vegetation cover, rate of deforestation and degradation, and opportunity costs. The second step, social and environmental impact evaluation, entails a literature survey to identify HCVs and the assessment of social and environmental impacts for the study area and project setting.

This project design phase will help complete the PDD that is used to apply for CT.

2.4.5 Project design documentation

For entry into the CT market and to qualify for active trading, a prescribed PDD must be completed. Irrespective of which market an applicant wants to trade in, the PDD must include a baseline calculation and monitoring plan. Baseline indicator measurement and monitoring should either be based on existing methodology or new methodology must be submitted for approval. To determine the market potential of a project the various steps in measuring and accounting CS must follow regulated guidelines. There are three well recognized PDDs or project design standards each with its own documentation particulars as outlined below.

- CDM PDD – A self-explanatory copy is provided as Appendix A and is not discussed further.
- The voluntary carbon standard (VCS) – It follows the format of CDM but does not require authorization by the host country, so greatly reducing transaction costs.
- The community, climate and biodiversity standard (CCBS) is used as a template in Table 2.5 to show what information is needed to complete the documentation and what aspects this study addresses to complete it for BLK PNR. Its use ensures that benefits accrue to communities, that biodiversity is considered, and that the role of ecosystems (over and above the carbon stored) is recognized. This instrument can be linked with the CDM and VCS and verified accordingly.

All three PPDs must include documentation of the following rubrics or elements:

- General description of project activity;
- Application of a baseline and monitoring methodology;
- Duration of the project activity or crediting period;
- Listing of possible environmental impacts;
- Stakeholders’ comments; and
- Biodiversity information and community impacts – this rubric applies to CCBS only.

Table 2.5 outlines the prescribed sections to be completed in the CCBA PDD, and identifies the 22 of a possible 66 aspects organized in 16 thematically distinct sections, all of which are addressed

Table 2.5 CCBA project design documentation and relevance to BLK PNR

Prescribed sections to be completed	**BLK PNR aspects addressed (Relevant section in thesis)**
G1. ORIGINAL CONDITIONS IN THE PROJECT AREA	
1. General Information	Section 1.4
2. Climate Information	Section 1.4
3. Community Information	Not addressed
4. Biodiversity Information	Section 1.4
G2. BASELINE PROJECTIONS	
1. Land Use without Project	Section 5.1.1
2. Carbon Stock Exchanges without Project	Section 5.1.1
3. Local Communities without Project	Not addressed
4. Biodiversity without Project	Section 5.1.1
G3. PROJECT DESIGN and GOALS	
1. Scope and Project Goals	Not addressed
2. Major Activities	Section 5.1.1
3. Project Location	Section 1.4
4. Project Time frame	Not addressed
5. Risks to Climate, Community and Biodiversity Benefits	Sections 2.1, 5.1.1 and 5.1.2
6. Enhancement of Climate, Community and Biodiversity Benefits	Sections5.1.2 and 4.2
7. Stakeholder Identification and Involvement	Not addressed
8. Project Transparency	Not addressed
9. Financial Mechanisms and Project Implementation	Not addressed
G4. MANAGEMENT CAPACITY and BEST PRACTISES	
1. Roles and Responsibilities of Project Proponents	Not addressed
2. Key Technical Skills and Staff	Not addressed
3. Orientation and Training	Not addressed
4. Community Involvement	Not addressed
5. Relevant Laws and Regulations	Not addressed
6. Worker Safety Assurance	Not addressed
7. Financial Status of Organizations	Not addressed
G5. LEGAL STATUS and PROPERTY RIGHTS	
1. Compliance with Laws	Sections 2.3.2 and 2.4.1
2. Approval from Appropriate Authorities	Not addressed
3. Non-Involuntary Relocation	Not addressed
4. Identification of Illegal Activities and Mitigation Strategy	Not addressed
5. Property Rights and Carbon Rights	Not addressed
CL1. NET POSITIVE CLIMATE IMPACTS	
1. Estimation of Net Changes in Carbon Stocks	Sections 4.1.5, 5.2 and 5.3
2. Other non-CO2 Greenhouse Gases	Not addressed
3. Project Activities' GHG Emissions	Sections5.2 and 5.3
4. Net Climate Impact	Not addressed
5. Avoidance of Double Counting	Sections 2.4.1, 5.2 and 5.3
CL2. OFFSITE CLIMATE IMPACTS ('LEAKAGE')	

Continued overleaf

Table 2.5 continued

Prescribed sections to be completed	**BLK PNR aspects addressed (Relevant section in thesis)**
1. Types of Leakage	Not addressed
2. Mitigation of Leakage	Not addressed
3. Subtraction of Unmitigated Negative Offsite Climate Impacts	Not addressed
CL3. CLIMATE IMPACT MONITORING	
1. Initial Monitoring Plan	Not addressed
2. Full Monitoring Plan	Not addressed
CM1. NET POSITIVE COMMUNITY IMPACTS	
1. Community Impacts	Not addressed
2. Impact on High Conservation Values	Section 4.2.4
CM2. OFFSITE STAKEHOLDER IMPACTS	
1. Potential Negative Offsite Stakeholder Impacts	Not addressed
2. Mitigation Plans	Not addressed
3. Net Effect of Project on Stakeholders	Not addressed
CM3. COMMUNITY IMPACT MONITORING	
1. Initial Community Monitoring Plan	Not addressed
2. Initial High Conservation Values Plan	Not addressed
3. Full Monitoring Plan	Not addressed
B1. NET POSITIVE BIODIVERSITY IMPACTS	
1. Biodiversity Impacts	Sections 2.2.3 and 4.2
2. Impact on High Conservation Values	Section 4.2.4
3. Identify All Species to be used by the Project	Section 1.4.2
4. Possible Adverse Effects of Non-Native Species	Not addressed
5. Non-Use of GMOs	Not addressed
B2. OFFSITE BIODIVERSITY IMPACTS	
1. Potential Negative Offsite Biodiversity Impacts	Not addressed
2. Mitigation Plans	Not addressed
3. Net Effect of Project on Biodiversity	Not addressed
B3. BIODIVERSITY IMPACT MONITORING	
1. Initial Biodiversity Monitoring Plan	Not addressed
2. Initial High Conservation Values Plan	Not addressed
3. Full Monitoring Plan	Not addressed
GL1. CLIMATE CHANGE ADAPTATION BENEFITS	
1. Climate Variability Scenarios and Impacts	Sections 2.1.4 and 5.1.1
2. Climate Variability Risks to Project Benefits	Not addressed
3. Climate Changes Impact on Communities and Biodiversity	Sections 2.1.4 and 5.1.1
4. Project's Adaptation Activities for Community and Biodiversity	Section 4.2
GL2. EXCEPTIONAL COMMUNITY BENEFITS	
1. Project Zone and Socio-Economic Status	Not addressed
2. Involvement of Poorest Community Members	Not addressed
3. Community Impact Monitoring	Not addressed
GL3. EXCEPTIONAL BIODIVERSITY BENEFITS	
1. Project Zone's High Biodiversity Conservation Priority	Section 4.2

Source: Adapted from CCBA (2013)

Some rubrics (G1, G2, CL1, B1, GL1) which largely cover baseline and biodiversity aspects are covered fairly well by the research. Remaining rubrics on community, participatory and impacts and benefits were not addressed by this research. Having addressed the principles and practise for carbon accounting for CT, its potential in South Africa is examined.

2.5 ORGANIZED CARBON TRADING IN SOUTH AFRICA

The South African Government ratified the UNFCCC in August 1997 and the Kyoto Protocol on 31 March 2002. Regulations in terms of the National Environmental Management Act were published in December 2004 in South Africa to give effect to the Kyoto Protocol. A designated national authority (DNA) was established under the Department of Minerals and Energy to consider and approve applications for CDM projects (Tucker & Gore 2008). Note that Article 12 of the Kyoto Protocol makes allowance for the reforestation of forest areas degraded prior to 1990. In a report to the South African deputy presidency, Blignaut et al. (2009) concluded that the estimated market for ecosystem services in South Africa is worth R17 billion with livelihood opportunities for as many as 350 000 people on offer. Indeed, the protection of ecosystems through avoided devegetation or degradation generates an opportunity to define a ‘bundle’ of ecosystem services from a given area, including those enabled by CS and biodiversity conservation.

Even though spekboomveld is not forest according to the definition of forests in the Marrakesh Accords (UNFCCC 2001), by its exceptionally high CS potential its reforestation is eligible for trading. In principle then, the carbon economy can provide funding for large-scale restoration of semi-arid subtropical thickets in South Africa. The conservation of ecosystems, and of spekboomveld in particular, is a means of ensuring environmental benefits under climate mitigation and biodiversity preservation. Tucker & Gore (2008) note that in 2008 some 54 CDM projects were submitted to the DNA, 13 PDDs were registered with the UNFCCC as CDM projects and seven were at the validation stage. The projects cover biofuels production, energy efficiency development, waste management, cogeneration (the joint generation of electricity and useful heat), fuel switching (change from one fuel to one more sustainable) and hydropower development for the manufacturing, mining, agriculture, energy and housing sectors. However, only three CDMs had had their CERs certified by 2008, the first CERs being issued on the Lawley Switch Fuel CDM Project (Tucker & Gore 2008).

There are three large protected areas in the Eastern Cape relevant to this research: the Baviaanskloof Nature Reserve, Addo Elephant National Park and the Fish River Reserve, all of which are covered by thousands of hectares of spekboom-rich thicket. Overgrazing has severely degraded this vegetation over the past century. The emergence of the international carbon market has created a solid prospect for funding large-scale thicket restoration, and the South African government has been quick to capitalize on this opportunity. In 2003, the then Department of Water Affairs and Forestry decided to invest in the research and development of large-scale restoration projects that focus on CS and generation of carbon credits. The rationale behind this investment was that carbon credits would be generated and ultimately provide a reasonable financial return. As a result of this investment decision, the Working for Woodlands Programme is undertaking large-scale planting operations in all of the above protected areas. In 2009 “a total of 430 hectares were planted in these reserves” (Mills 2009: 8).

Various groups of experts have been building baseline surveys for CS projects in the Thicket Biome, namely the Subtropical Thicket Ecosystem Project (STEP) (Powell, Mills & Marais 2008; Powell 2009; Mills 2009; Cowling et al. 2011), the Subtropical Thicket Restoration Projects (STRP) team (Mills 2009; Powell 2009; Cowling et al 2011), the Restoration Research Group (R3G) (Marais et al 2009; Mills 2009; Cowling et al. 2011) and AfriCarbon (Mills 2009; AfriCarbon 2010). Their work has covered the spatial distribution of thickets, the levels of degradation and the cost-effective baseline methodologies for calculating carbon stocks and CS potentials. Sasol has planned a project using spekboom to make their state-of-the-art coal-to-liquids venture in Limpopo environmentally sustainable. Sasol’s initial studies suggest that the carbon emissions from the 80 000 barrels produced a day at Mafutha plant could possibly be offset by planting 100 000 ha of spekboom (Creamer 2008). This testifies that spekboom has the potential to cover carbon offset on a local scale. The ongoing discussion about the inclusion of existing forests or forest-like systems, such as spekboom Thicket into international climate mitigation frameworks represents a significant opportunity for alleviating earth warming and conservation efforts. However, to date only restoration of spekboom projects have been investigated so that the possibility of using REDD and REDD+ as viable emissions abatement mechanisms offers an appropriate platform for developing IPES beyond CS by taking into account the other benefits of protecting and conserving important ecosystems (Peterson et al. 2007).

The concepts and theories relating to global warming have now been identified, the role of ecosystem services (especially the use of CS) in reducing the rate of global warming was identified as a powerful tool to reduce atmospheric CO_2. CS was identified as a process that stores excess carbon in carbon sinks that can be accounted and traded on the carbon market. Three carbon markets identified for spekboom farming included restoration through the CDM on the voluntary and compliance market and REDD (reduced emissions from deforestation and degradation) and

REDD + (conservation of carbon stocks) through the CCBA on the voluntary carbon market. Carbon accounting using CS was examined and the allocation of carbon credits was investigated. The global concepts applied to South Africa to determine its market potential locally were explored. In planning the carbon trading project, the PDD requires an accurate carbon stocks assessment of study site. The carbon content is derived in the next chapter by empirically identifying and mapping the vegetation communities for the cases tudy.

CHAPTER 3 TARGETED VEGETATION MAPPING

A project design document for carbon trading needs to be populated by, inter alia, specific physical site research material and information such as various natural area identifications and demarcations, vegetation classifications, area calculations and mapped carbon storage capacity. These aspects and their technical execution at BLK PNR are covered in this chapter. It begins by outlining the different mapping procedures performed to ensure accurate vegetation mapping and classification. The challenges regarding automated vegetation classifications are discussed and certain procedures are applied. The automated classification's accuracy is assessed by comparing it with a map manually classified. The *Acacia karroo* is mapped by heads-up digitizing, the degraded spekboom on BLK is mapped and the area suitable for restoration is identified for CT purposes. The chapter concludes with the calculation of true surface areas of the various vegetation classes.

3.1 VEGETATION MAPPING STRATEGY

To improve the accuracy of mapping, and for carbon accounting purposes, the mapping of vegetation with high carbon content must be completed to allow its CS value to be traded on the carbon market. In this research, vegetation mapping entailed the refining of the demarcation of some vegetation classes appearing only broadly on the SANBI base maps and additions of another class not appearing at all, namely the *Acacia karroo*. Dense stands of spekboom were demarcated and *Acacia karroo* stands were mapped from scratch to identify areas suitable for restoration.

Vegetation mapping commenced with the importation of the SANBI (2007) vegetation map overlays into ArcMap onto the georeferenced satellite image and by cutting the project extent according to similarly imported cadastral information. Since the SANBI vegetation boundaries were mapped at 1:1 250 000 scale, the real vegetation boundaries had to be refined and their accuracy checked during several field visits. The vegetation community descriptions and demarcations by Mucina & Rutherford (2006) were instrumental in these tasks and the mapped results were displayed as Figure 1.3. It was ascertained through the accuracy assessment that the sinuous, yet clearly significant stands of *Acacia karroo*, had been excluded from the SANBI (2007) vegetation map. *Acacia karroo* is clearly identifiable and grows in a narrow belt along the riverbed between the Gamka Thicket and Prince Albert Succulent Karoo. This vegetation community was therefore mapped manually by heads-up digitizing as described in Section 3.4. The refined mapping of spekboom vegetation stands in the Gamka Thicket was crucial for an accurate assessment of the carbon content of this specific sub-biome (the other biomes were not mapped in detail as their vegetation was deemed to be homogeneous and continuous). Spekboom, however, does not grow very homogeneously or continuously in this vicinity because of its preference for north-facing slopes and its inherent growth pattern distinguished by bandedness and patchiness of stands. For CT purposes the individual stands had to be accurately mapped.

Concerning slope aspect, spekboom grows almost exclusively and more prolifically on sunbathed north-facing slopes, whereas it is almost absent from the shaded south-facing slopes of the west-east stretching mountainous terrain of the study area. This phenomenon is clear from the photographs in Figure 3.1 where the lighter yellowish-green spekboom stands can be easily recognized. While some vegetation types, like the ghwarrie (small darker green trees), grow equally densely on both aspects, the valley drainage line, as aspect separator, forms a formidable barrier to spekboom propagation.

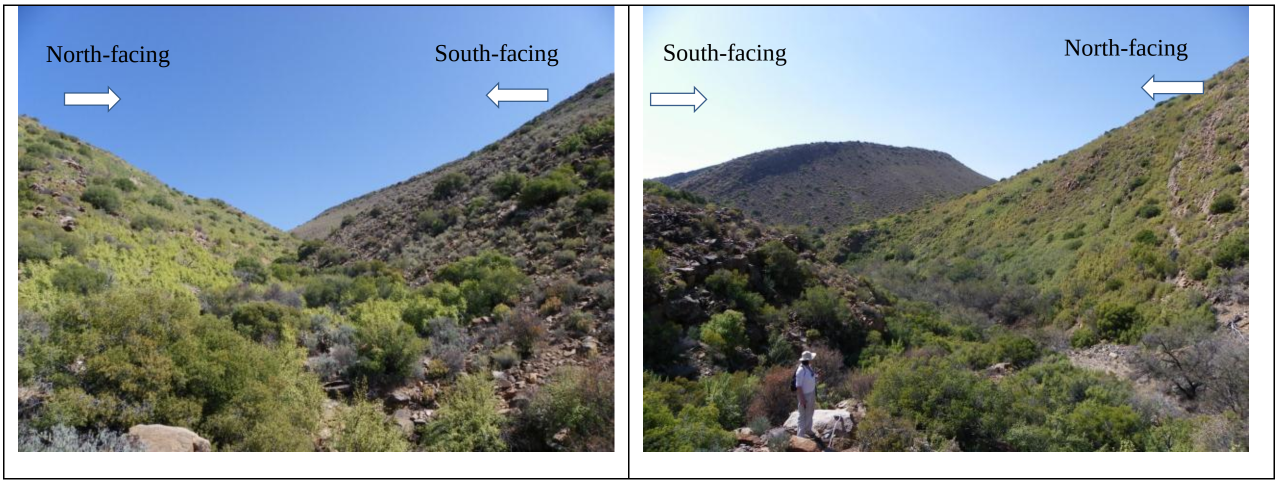


Figure 3.1 Westerly and easterly views of spekboom preference for north-facing slopes on BLK PNR

Concerning the growth pattern determinant, the two displays in Figure 3.2 show a certain upslope bandedness that may be attributed to the grazing pattern of stock (remnant) and game. However, the patchiness is undeniably clear and seems to be related to slope and terrain form, as well as the degrading effect of grazing. Often large bare patches seem to denote areas that earlier may have been covered by spekboom. Given the property's past history as a farm exposed to overstocking, the degradation of spekboom on certain north-facing slopes now not covered by these plants is evident. Mapping spekboom as accurately as possible was unnegotiable given that its high CT potential, for creditable purposes, had to be determined. Both automated image analysis and manually classified maps were produced.

In the final instance, and to comply with the regulations under the CDM which requires that all areas historically covered by the target vegetation (spekboom in this case) have to be indicated,

Figure 3.2 Patchiness of spekboom occurring on BLK PNR

areas most suitable for potential restoration were identified and mapped through heads-up digitizing. Such areas had to meet the requirements of being in close proximity to spekboom for cuttings, had to be accessible by road and water had to be available.

Because this vegetation is not continuous, it must be accurately mapped. Manually mapping vegetation of this extent is a time consuming practice, therefore an automated approach to vegetation mapping is suggested.

3.2 AUTOMATED VEGETATION MAPPING

To map an extensive area through heads-up digitizing is time consuming because of the large size of area and the accuracy with which it needs to be mapped. To build baseline mapping data for spekboom distribution, a more accurate and automated mode of mapping had to be established. Various methods of vegetation mapping are explored. They follow a multispectral image analysis technique to create objects. This paradigm entails the segmentation of images into similar objects and subsequent object classification. Various methods for automatically mapping vegetation cover were examined, including the use of eCognition. The concepts and application of segmentation and classification as automated mechanisms to map vegetation are encountered next, followed by descriptions of the relevant method and their application to the study area.

3.2.1 Object-orientated image analysis for vegetation mapping

Segmentation and classification of high-resolution imagery is a challenging problem as computer-aided image analysis is faced with the vast task of mimicking the human interpretation process and associated complex interpretation rules, advanced pattern recognition and knowledge retrieval mechanisms (Navulur 2007). In addition, Burnett & Blaschke (2003) noted that with all observation of reality, remotely sensed images capture patterns imperfectly, which themselves mirror ecosystem processes imperfectly. However, image analysis conducted by human analysts is quickly becoming less viable given the quantity and currency requirements of data being managed in modern GIS. Due to the multitude and high resolution of satellite imagery, classification using standard per-pixel approaches is often too complex (Benz et al. 2004; Mohan, Nayak & Hogg 2006; MacMillan et al. 2009; Rizvi I & Mohan K 2010) for the high volume of data, as well as high spatial variability within the objects (Maxwell 2005). Maxwell (2005: i) claims that “object-orientated classification methodology is better able to deal with this highly textured data.” Innovation in this direction is to segment the image into a collection of regions based on various criteria, and then to classify the regions using spectral, textural and shape attributes to form objects. Navulur (2007: 10) defined an object as “a grouping of pixels of similar spectral and spatial properties.” Thus, applying the object-orientated paradigm to image analysis refers to analysing the image as an object space rather than pixel space, and objects can be used as the ‘modern mechanism’ for image classification rather than pixels (Benz et al. 2004; Cochran & Chen 2005; Navulur 2007). Image segmentation is the primary technique used to convert an image (aerial photographs of vegetation) into multiple objects (vegetation types). An object, compared to a pixel, has in addition to spectral values, numerous other attributes, including shape, texture and morphology which can be used in image analysis (Benz et al. 2004; Mohan, Nayak & Hogg 2006; Navulur 2007).

Object-orientated image analysis represents a paradigm shift from the traditional pixel-based approach. Object-orientated image classification was developed for classifying image features into user-defined classes (Blaschke et al. 2000). To map spekboom vegetation, the (aerial photograph) imagery had to be segmented into areas of definitive spekboom cover and areas without spekboom cover to distinguish the areas of high carbon soil content. The segmented polygons were then classified to either spekboom (high soil carbon content) or everything else (lower soil carbon content).

3.2.2 Image segmentation techniques

Image segmentation is a popular technique for creating objects. Segmenting a vegetation map involves dividing the image into regions or objects that have common features and properties, in this example dividing the image into areas of target vegetation cover and areas without target vegetation cover. According to Navulur (2007: 19) image segmentation techniques generally involve one of two processes: “region merging according to some measure of homogeneity and separation of objects by finding edges using gradients of digital numbers between neighbouring pixels.” In this study merging according to homogeneity of land-cover was used as areas of homogeneous land-cover had to be found. According to Maxwell (2005) and Navulur (2007) region-merging approaches can be divided into region growing and region split, and merging approaches. Navulur (2007: 19) explains the two processes as:

> …firstly region-growing techniques involve pixel aggregation and start with a set of seed points, from these seed pixels, the regions are grown by merging neighbouring pixels that have similar properties. The second approach includes the region-splitting and merging approach and includes subdividing an image initially into a set of arbitrary, disjointed regions and then merging and/or splitting the regions based on the similarity rules for object creation.

Regardless of the approach, many segmentation algorithms rely on user-selected parameters to perform the segmentation (Maxwell 2005). Maxwell adds that the appropriate selection of these parameters (thresholds) is very important and has a decisive influence on the segmentation results.

Thresholding is the simplest method of image segmentation. Thresholding can be used to create binary images (cells holding values of 0 or 1 only) (Shapiro & Stockman 2001). This region-merging technique is useful for discriminating objects from their background (Navulur 2007). Most thresholding techniques indirectly use the shape information contained within the image histogram.

There are many software options available in the public domain for image segmentation and most of them are distributed by academic institutions. However, of the many approaches that have been developed and employ the multiscale methodology, few are available commercially and fewer provide convincing results. Studies by Benz et al. (2004), Maxwell (2005), Navulur (2007) and Sullivan (2008) have reported that the use of eCognition in image segmentation yields the best and most accurate results compared to a number of other segmentation schemes tested on a variety of terrain types.

3.2.3 Segmentation principles in eCognition

eCognition, a product of Definiens Imaging GmbH, follows an object-orientation approach to image analysis and provides a bundle of innovative features and techniques for fast image analysis. According to Navulur (2007) and the eCognition User Guide 4 (2012), eCognition creates patented segmentation (images) using four thresholds: scale, colour, smoothness and compactness. By combining these criteria in numerous ways, varying output results can be obtained for homogeneous image object extraction in any desired resolution.

In eCognition scale is the parameter set in order to distinguish the object from the background. Benz et al. (2004: 241) notes the important difference between scale and resolution "as resolution commonly expresses the average area dimensions, a pixel covers the ground; scale describes the magnitude or the level of aggregation (and abstraction) on which certain phenomena can be defined." According to Maxwell (2005), one of the major limitations to image segmentation is the concept of optimal scales. The scale parameter determines the maximum allowed heterogeneity within an object (Benz et al. 2004; Navulur 2007). It determines the number of objects in a class, as the same object appears differently at different scales. Benz et al. (2004) highlight that scale is a crucial aspect of image understanding. The concept of scale then becomes central to an analysis and understanding of terrains. Scale represents the 'window of perception', the filter or measuring tool with which a system is viewed and quantified: Consequently, real-world objects only exist as meaningful entities over a specific range of scales (Hay et al. 2002).

Landscape ecologists define scale as having grain and extent, where grain refers to the smallest intervals in an observation set and extent refers to the range over which observations at a specific grain are made (O'Neill & King 1998). In remote sensing, grain is equivalent to the spatial, spectral and temporal resolutions of the image pixels, whereas extent represents the geographic area, combined spectral bandwidths and temporal duration covered by an image as a whole (Hay et al. 2001). For a given scale parameter, heterogeneous regions in an image will result in fewer objects than in homogeneous regions.

Although there is no direct relationship between the scale parameter and the number of pixels per object, heterogeneity at a given scale parameter is linearly dependent on object size. For example, to detect changes in vegetation cover an analysis at different resolution levels (50,100,150) will identify which scale is best to detect spekboom cover. Navulur (2007) notes that object homogeneity is defined by the homogeneity criterion and is represented by three criteria, namely colour, smoothness and compactness.

These attributes optimize the objects' spectral homogeneity and spatial complexity. Understanding the effects of these criteria is necessary to perform effective segmentation. The colour parameter defines the overall contribution of spectral values to define homogeneity. The shape factor is defined by two parameters: smoothness and compactness. The smoothness factor optimizes image objects for smoother borders and compactness optimizes image for compactness. These criteria is explained in the eCognition user's manual (eCognition User Guide 4 2012).

3.2.4 Feature classification techniques

Once the segmented map has been created, each segment has to be classified according to its feature type. Numerous mechanisms can be used in object classification, but Navulur (2007) suggests using one of four (some of which are probed further in the rest of the subsection), that is:

- unsupervized and supervized classification;
- rule-based classification approaches;

- neural net and fuzzy logic classification; and
- classification regression trees (CART) and decision trees.

Unsupervised classification is a technique to group pixels with similar multispectral responses in various spectral bands into clusters or classes that are statistically distinguishable. The software does most of the processing, generally resulting in more use categories than the user is interested in (Banman 2002).

In *supervised* classification, the user processing the imagery guides the image processing software to determine how particular features are classified. This is done by the use of a vector layer containing training polygons for which the class type had been established beforehand. Supervised classification is a technique in which the user must select training or sample sites and the statistical analysis is performed on the multiband data for each class. Instead of clusters in unsupervised classification, this approach uses pixels in the training sets to develop appropriate discriminate functions that distinguish each class.

Rule-based classification employs the principle that a given occurrence can be explained by a set of rules and occurrence instances. Each instance results in a decision and the associated rule set comprises a series of logical steps that are built on an existing set of variables to explain the occurrence.

Tree-based modelling is an exploratory data mining technique for uncovering structure in large data sets and not deemed relevant here.

This study employed supervised land classification since the classes were simplified binary types and had been predefined with training or sample sites. eCognition was the software of choice for performing these analyses.

3.2.5 Classification principles in eCognition

eCognition features a set of interfaces which make information about objects, features and classification transparent and accessible. The classification process is based on a nearest neighbour classifier on a fuzzy logic basis. This allows the integration of different object features, such as spectral values, shape, texture or local contrast. As the resolution of objects can easily be adapted to represent specific texture structures, object-orientated texture analysis with eCognition is a powerful tool. Combining these features allows image analysis to be performed in a variety of ways. Individual image objects are marked as typical representatives of a class, and then the rest of the scene is classified according to samples. After classification, samples can be added or removed to improve accuracy without having to restart the project.

The concepts and application of segmentation and classification as automated mechanisms to map vegetation were identified. Their application to the study area will be completed next.

3.3 APPLICATION OF IMAGE ANALYSIS

eCognition was used in this study for image segmentation and the classification of spekboom veld. This method is explained in this section, the thresholds or parameters used are declared and the segmentation of the aerial photographs is described, followed by an account of the rule-based nearest neighbour method for defining classes segmented from the vegetation map.

The imagery used for mapping included two SPOT true-colour mosaic tiles for the area dated 2008 at a 2.5 m resolution, a colour aerial photograph mosaic for the area dated 2006 at a 0.75 m resolution and 195 normal horizontal photographs, taken with GPS co-ordinates recorded, used for accuracy assessment and groundtruthing. While the aerial photographs and the SPOT 5 image were first analysed experimentally, the aerial photographs were eventually preferred for two reasons; that is for their higher spatial resolution and the consequent higher accuracy of the results and because the SPOT 5 image proved unable to correctly classify spekboom on southerly aspects. Three aerial photographs covered the area where Gamka Thicket occurs. Each image was experimentally analysed following the rule-based classification method. The following subsections outline the methods and their application to segmentation and classification.

3.3.1 Methods and application of object segmentation in eCognition

The methods of segmentation and classification are outlined separately before discussing their application to spekboom.

3.3.1.1 Segmentation

Image segmentation follows a four-step process during which various parameters are applied experimentally to search for the most effective outcomes. As a first step, the spatial data sources must be prepared for use in eCognition. Each aerial photograph, obtained in .jpg format, has to be imported into ArcGIS and subsequently exported to eCognition as an image in .img format. The second step entails experimenting with attributes to render features on the image more identifiable. Experiments with various tools in colour image layer mixing can be conducted to make the target vegetation (spekboom) more easily recognizable. For instance, in the edit layer mixing option, band combinations can be reassigned to enhance the image display by activating various options. The last step involves defining the appropriate scale at which to segment the image. Recall that the larger the scale, the fewer the number of objects that will be identified (i.e. more aggregation of image objects). Substantial experimentation is required to determine the optimal scale at which objects will appear at the desired level of distinction accuracy. Also, in the final step a rule set is defined in which the parameters are set for ultimate recognition. This step includes choosing different algorithms, such as multiresolution segmentation or spectral difference segmentation.

3.3.1.2 Application of segmentation for spekboom identification

The application of the methods outlined above followed the steps to import data successfully and proceeded to the second step where experiments were done with various tools. The tools used various colour image layer mixing through three options while simultaneously changing the colour band weights, namely

- histogram-equalizing;
- three-layer mixing; and
- deviation stretch.

These enhancing algorithms have different effects on visual display of the image and were effective visualization tools for identifying target features before commencing with the project. In Figures 3.3, 3.4 and 3.5 the different results from changing the layer mixing on the same image

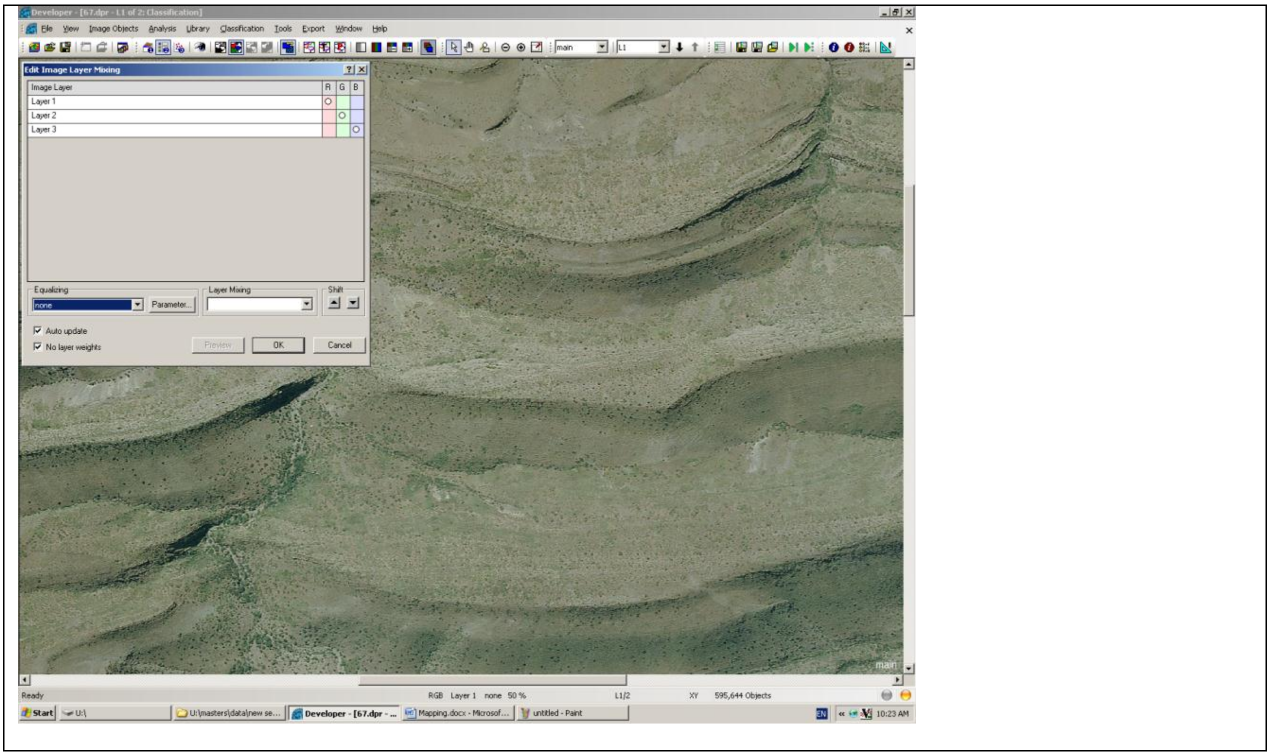


Figure 3.3 Landscape depiction of an application with layer weights of (1,1,1) in BLK PNR

are demonstrated. Note how the visible landscape features are augmented or suppressed – an effect that carries through to the segmentation performed on the resultant image. Figures 3.4 and 3.5

clearly show much sharper definition of vegetation stands, especially spekboom Figure 3.4, giving a preferred superior depiction.

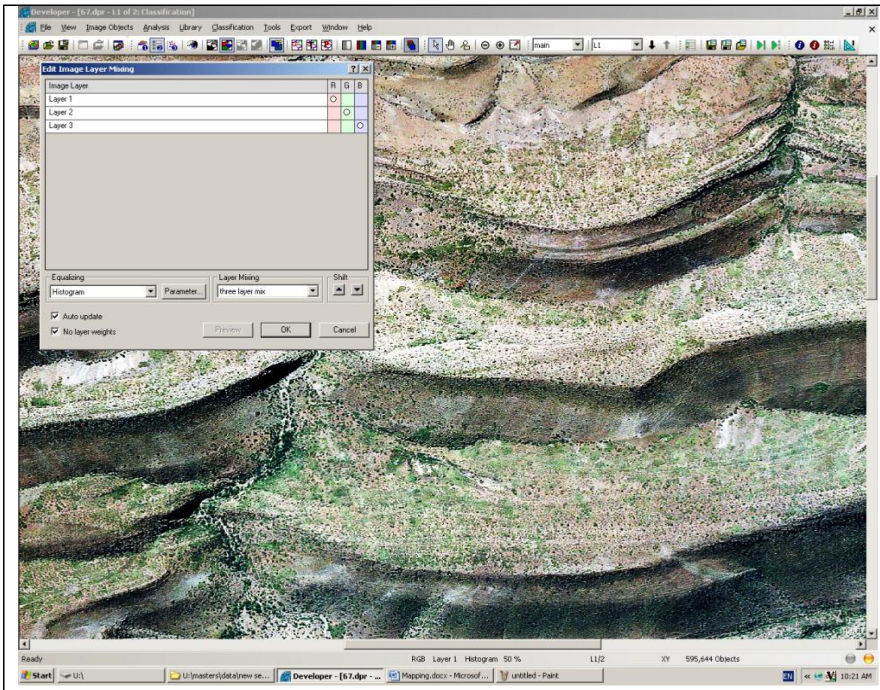


Figure 3.4 Landscape depiction of histogram function with three-layer mixing (1,1,1) in BLK PNR

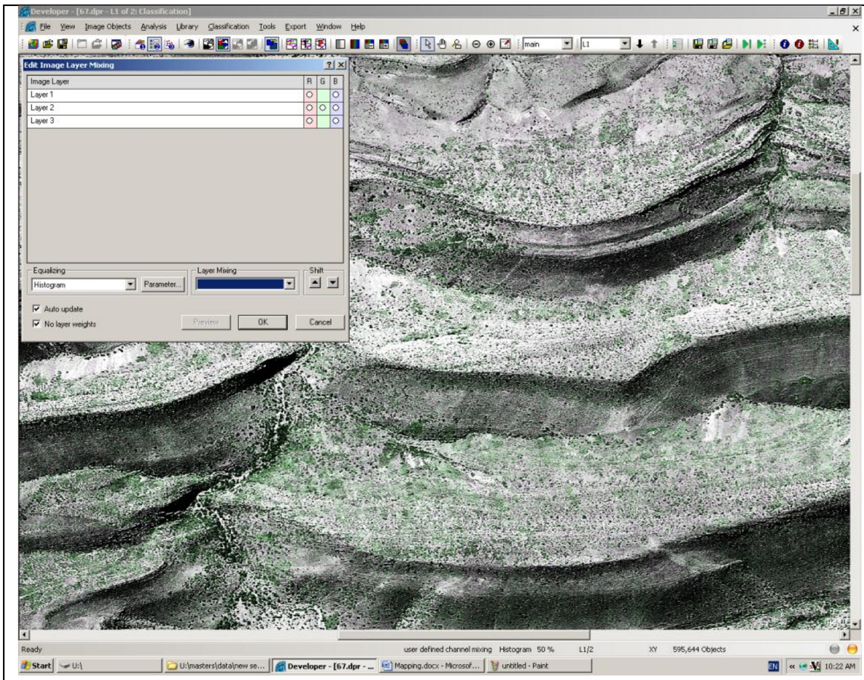


Figure 3.5 Landscape depiction of histogram function with three-layer mixing (3,1,3) in BLK PNR

Three-layer mixing using histogram-equalizing (shown in Figure 3.4) worked best for identifying spekboom. Spekboom occurring on slightly different slope aspects reflects completely dissimilar spectral values. In Figure 3.4, the spekboom on the first northerly slope appears greenishbrown, whereas on more southerly slope sit appears bright green. These differences are only acceptable for segmentation, but are problematic for classification because in the classification process the algorithm clusters only pixels with similar spectral values.

The third step of segmentation was choosing an optimal scale to segment the image. Experimentation was done with various scales in the segmentation process to determine which scale identified spekboom best on both layers. Experimental scale values of 25, 50, 100 and 200 (25 being a fine scale and 200 being a coarse scale) were implemented and the results are displayed in Figure 3.6. The legend item Spek50 refers to the segmentation level of the spekboom vegetation (at a scale of 50). Close study of the segmented imagery reveals how finer or coarser the scale is, the more over- or undersegmented the images. The figures provide evidence that the larger scales (100 and 200) grouped spekboom into larger and more generalized clusters, too coarse to make distinctions and the consequent low degree of accuracy grouped spekboom patches with the bare in-between land so leading to overestimations of spekboom areas. Smaller scales effectively identified the single stands which is essential for accounting purposes. Scale 50 emerged as the best choice for use in segmentation, because it clinically identified all stands and patches of vegetation. To further justify this choice, the enlarged imagery in Figure 3.7 shows how individual, contiguous patches of spekboom occur in the landscape (top image), and how segmentation at a scale of 50 (the bottom image) picks out these patches for classification. eCognition is efficacious for patch segmentation of vegetation stands that are fairly contiguous and stands out or rise on the landscape.

The final processing step entailed the definition of the rule set for segmentation. It executed two algorithms for the segmentation. First, the multiresolution segmentation rule set, shown in its programming command screen format in Figure 3.8, was used to segment the images at a scale of 50, with a shape value of 0.1, a compactness value setting of 0.5 and each image layer weighting had a value of 1. Figure 3.9 illustrates the multiresolution segmentation settings in an eCognition screenshot. Second, the algorithm for spectral difference segmentation was executed and the parameter settings for spectral difference (3) and layer weightings (1,1,1) are illustrated in Figure 5.10.

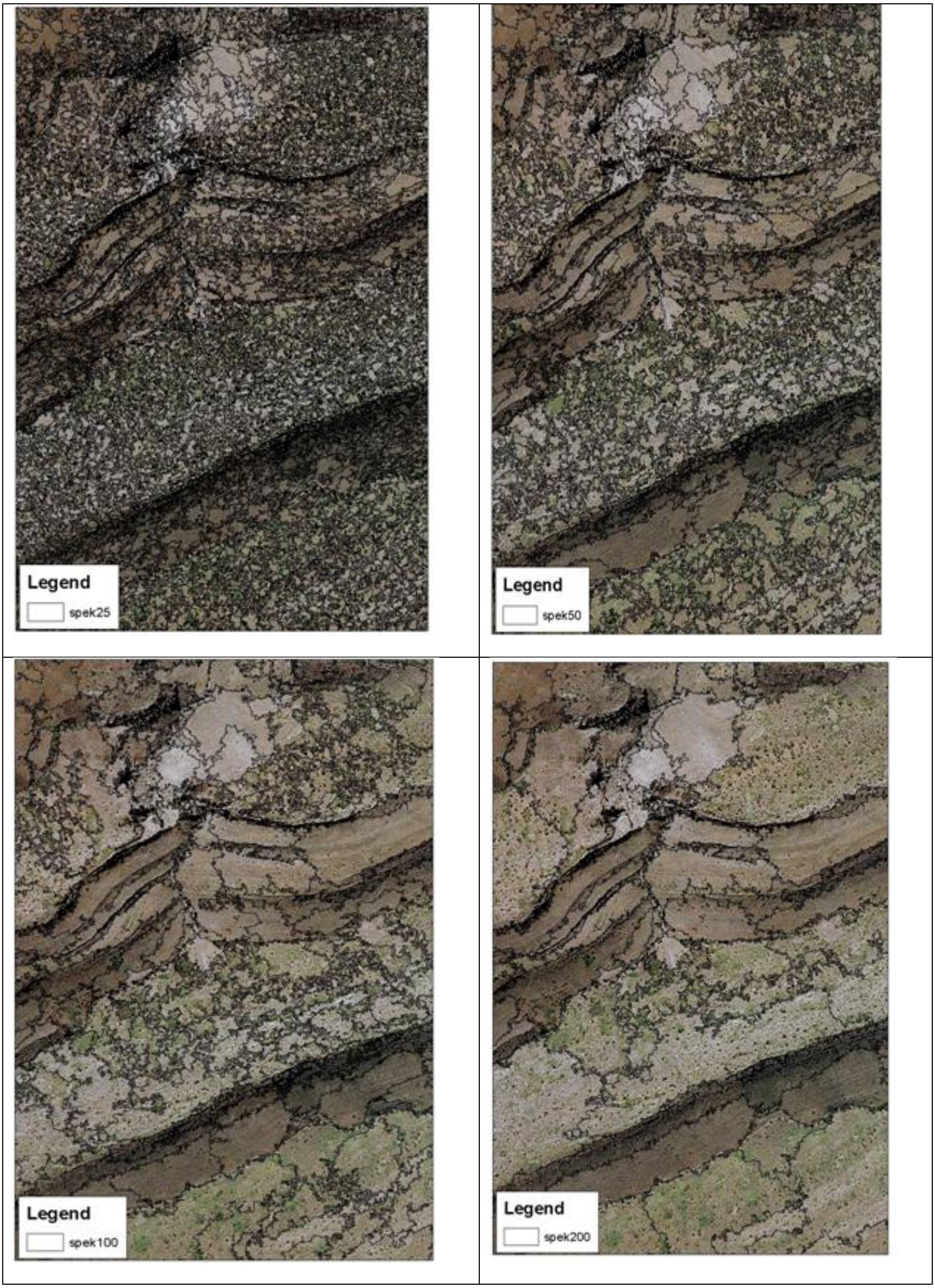


Figure 3.6 Results of segmentation experimentation at scales of 200,100,50,25 in BLK PNR

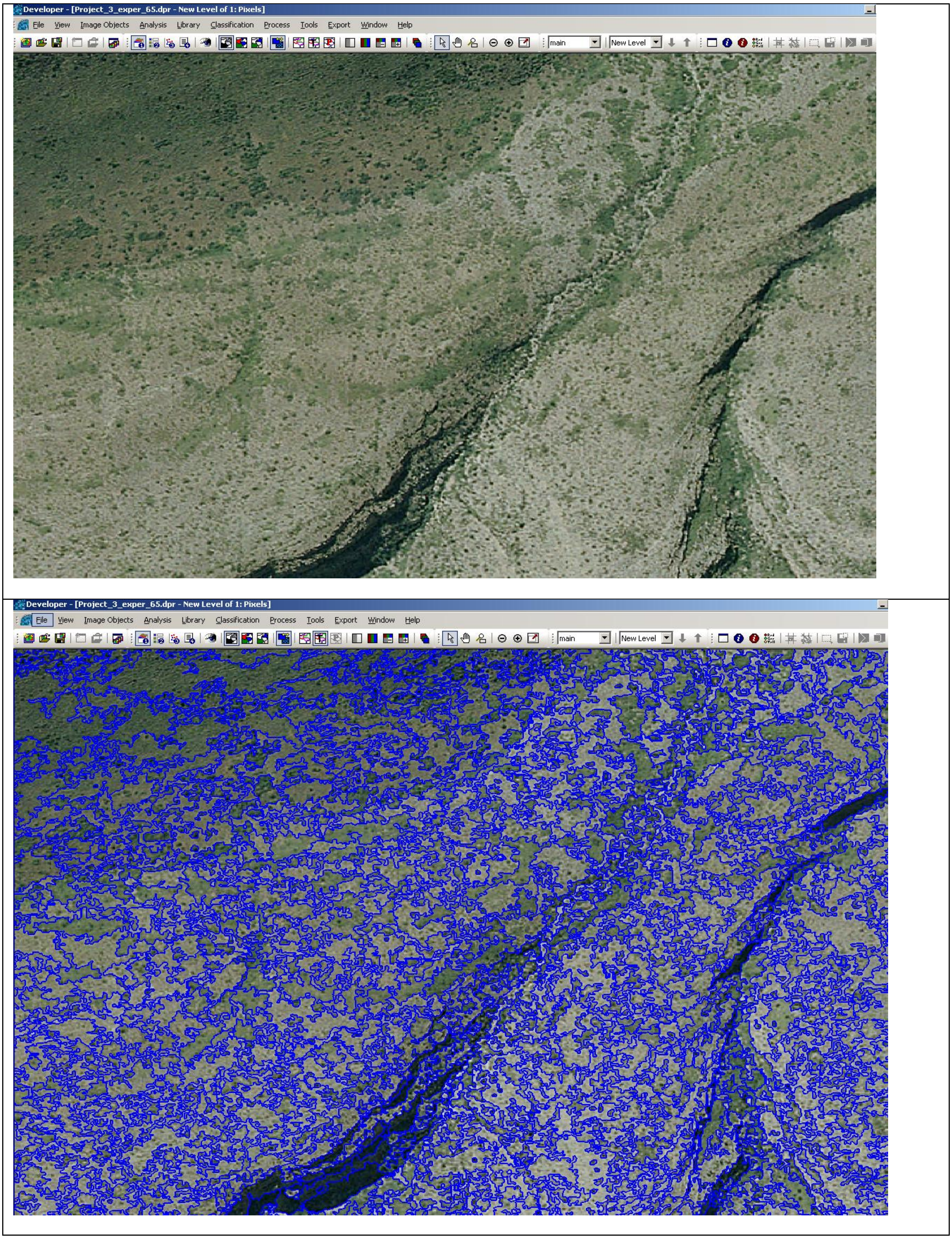


Figure 3.7 Patches of spekboom on BLK, then outlined through segmentation at a scale of 50

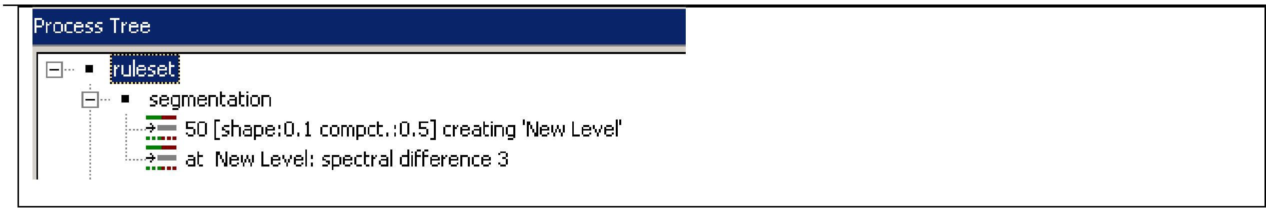


Figure 3.8 Command screen for setting a defined multiresolution segmentation rule set

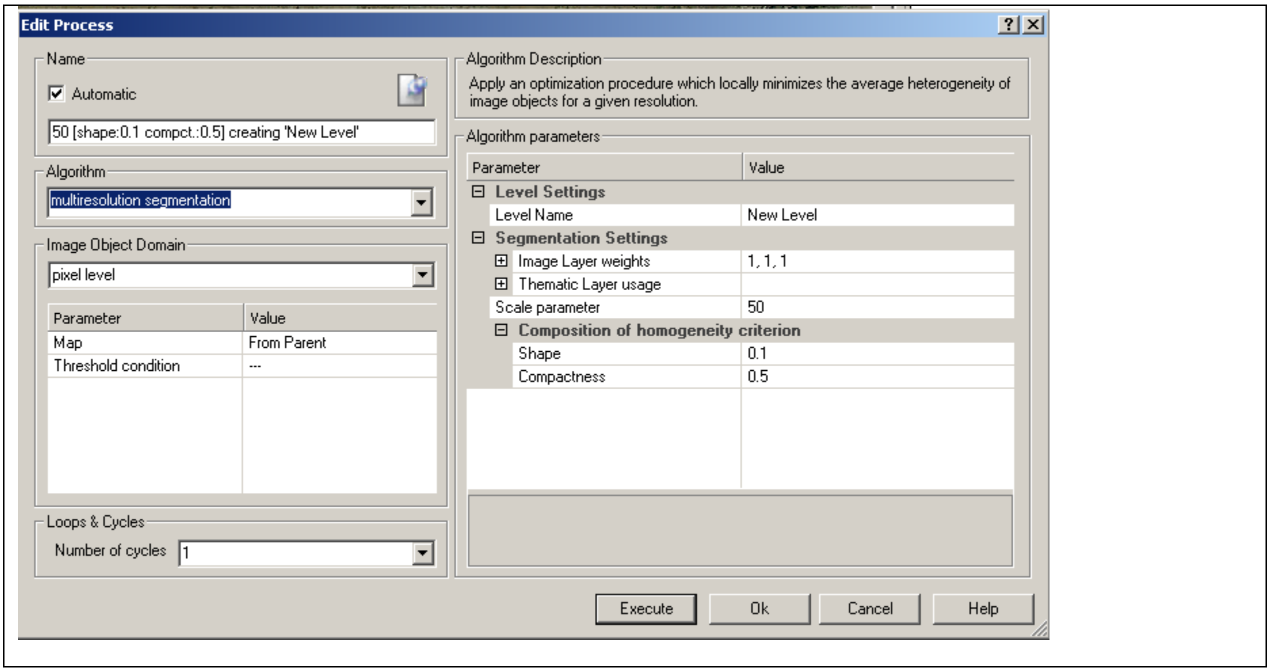


Figure 3.9 Settings for eCognition multiresolution segmentation

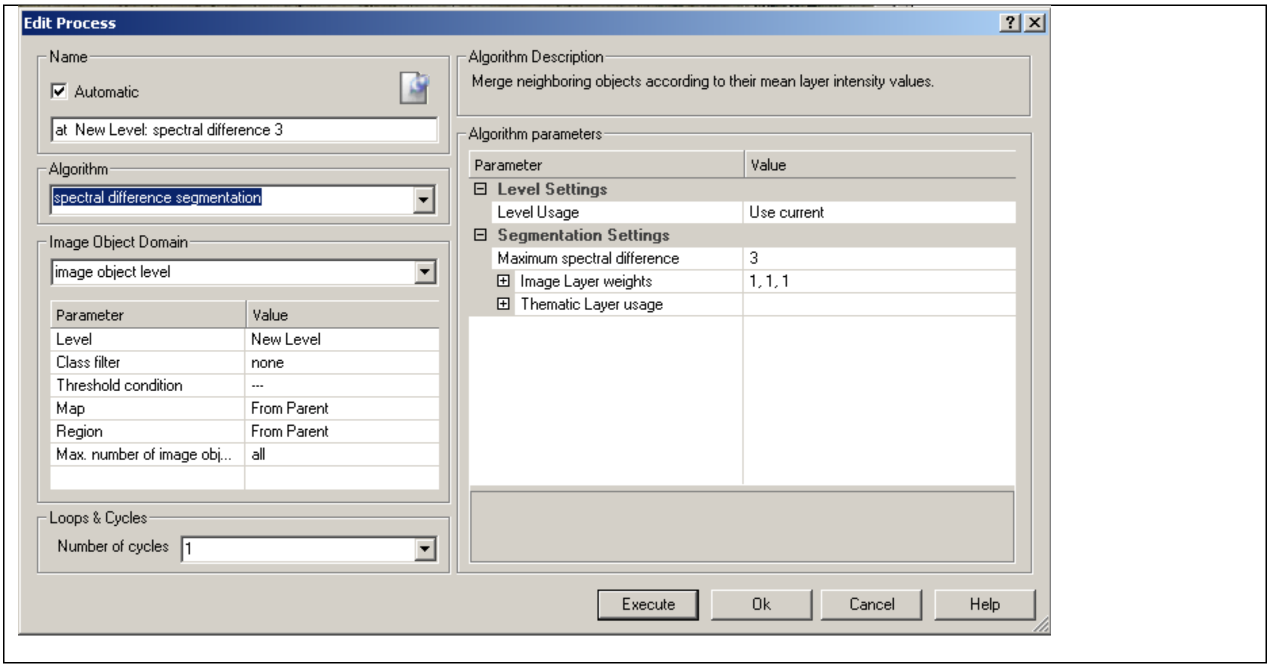


Figure 3.10 eCognition program settings for spectral difference segmentation

3.3.2 Application of object classification in eCognition

The algorithm for object classification was executed with a value of three set for maximum spectral difference. This setting has been shown to be useful for the extraction of impervious surfaces and it merges neighbouring objects according to their layer mean intensities. Neighbouring image objects are merged in the process if the difference between their layer mean intensities is below the value given by the maximum spectral difference, in this instance three. This algorithm is designed to refine existing segmentation results by merging spectrally similar image objects produced by previous segmentations. The classification method is outlined next, followed by its application.

3.3.2.1 Classification method

For classification of a segmented map, five steps are executed as described here.

- First, the classes for classification must be created. The necessary sequential actions are: activate the classification sequence on the top toolbar: dropdown icon/classification/class hierarchy right click/add classes to be classified.
- Second, the standard nearest neighbour classification rule is applied. In the nearest neighbour drop-down icon, activate apply standard nearest neighbour to classes/select classes to be classified.
- Third, the feature space for nearest neighbour classification is created. In the classification drop down icon, activate edit standard nearest neighbour feature space.
- Fourth, the classification rule set is defined. The rule set for the classification is established in the process tree dropdown icon. The aim is to identify the active classes for classification and the level at which the classification is to take place.
- Fifth, before beginning the classification, training samples must be created for each class. In the classification drop down icon, activate select samples; to select samples, hold down shift and select samples for each active class; 50 samples should be collected for each class;

The final execution step is to run the classification procedure in eCognition by activating the process tree, right-clicking the rule set and clicking the execute command.

3.3.2.2 Application of classification method

The first of the five application steps required the creation of classes for classifying the vegetation in the study area. In this case there was only one class, namely spekboom which had to be defined. The nearest neighbour classification was run on 60 samples. This decision led to certain south-facing slopes and *Acacia karroo* along the riverbed being erroneously classified as spekboom. Six different cover classes were then defined to instruct the software which features to recognize as *not* being spekboom. The classes were *Acacia*, bare rock, non-vegetated soil (no vegetation), spekboom, south-sloping land (i.e. all vegetation occurring on south-facing slopes) and other (all other vegetation that was not spekboom). These classes are listed in Figure 3.11. At this point the

Figure 3.11 Defined classes in eCognition

concern was not about the accuracy of eCognition's classification of these added communities, rather the accuracy of spekboom classification as this was the only objective that had to be reached.

The second step in applying the standard nearest neighbour classification rule was to select classes for applying the nearest neighbour rule. This selection tool is depicted in Figure 3.12.

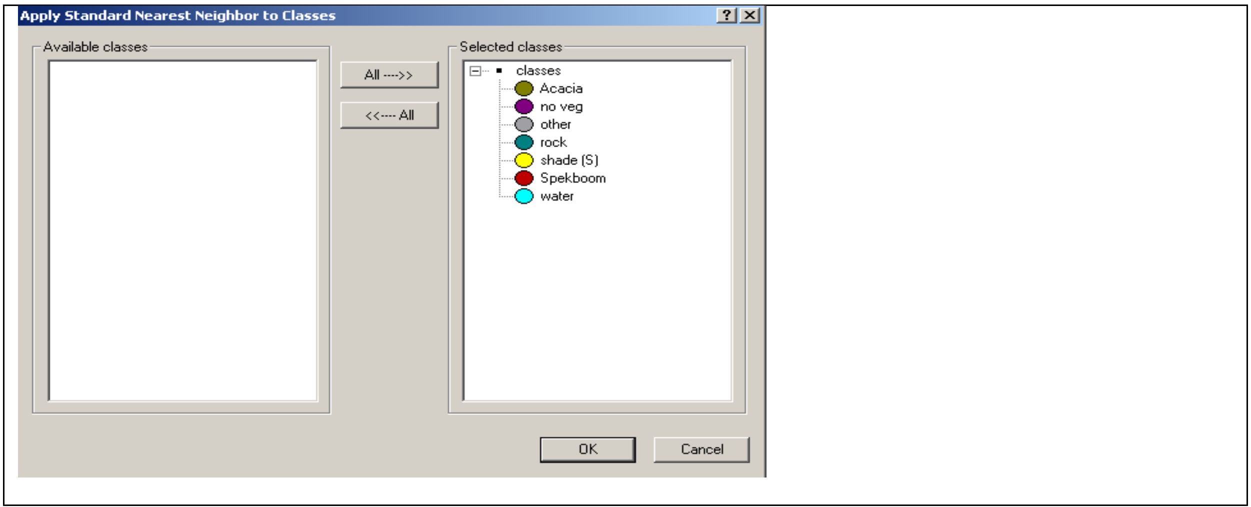


Figure 3.12 Classes selected for the nearest neighbour classification

The third step entailed the creation of the feature space for nearest neighbour classification and this was done by experimentation with various options using texture. This involved setting parameters for texture after Haralick (an option in eCognition which uses texture to discriminate among objects) by using the gray-level co-occurrence matrices (GLCM) homogeneity and mean which worked well as a tool to discriminate texture features. The layer values in which the mean value for brightness and the maximum difference for each layer specified were added. The selection tool is shown in Figure 3.13.

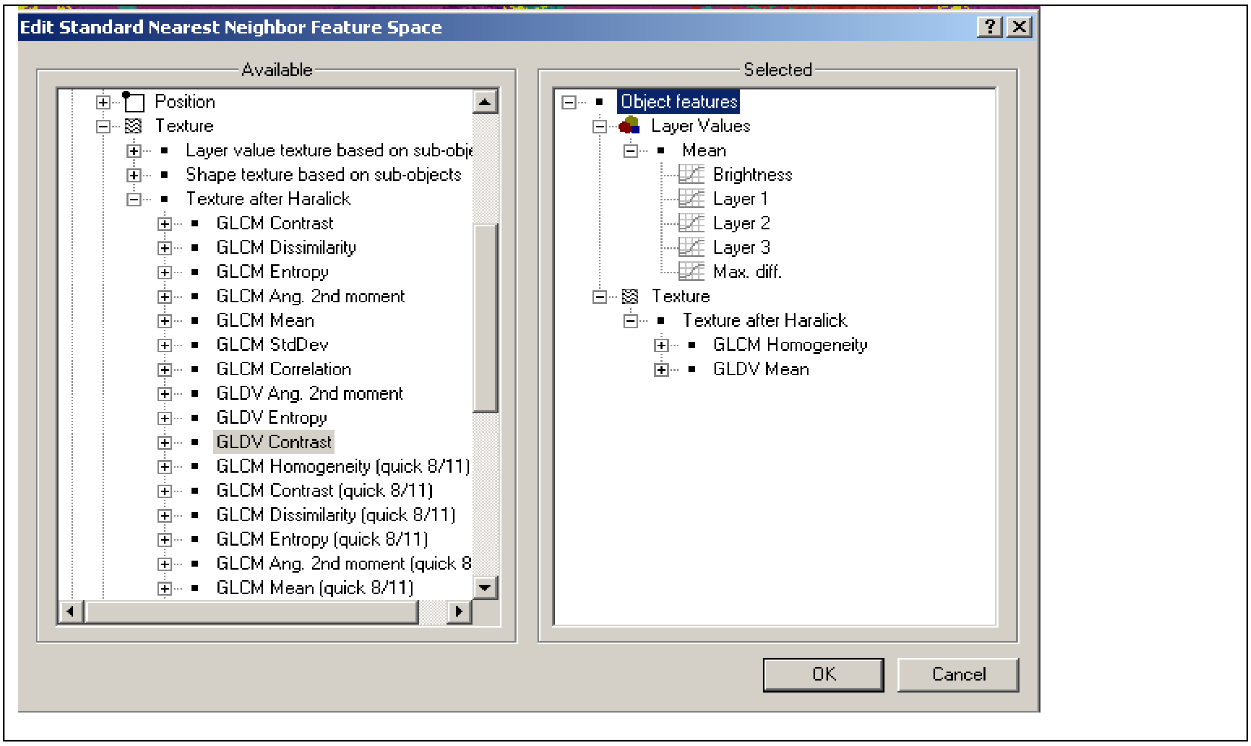


Figure 3.13 Object features selected for the nearest neighbour classification

Fourth, the rule set for the classification was established in the process tree. Here the user had to identify the active classes for classification and the level at which the classification had to take place. Figure 3.14 shows the command screen menu that was activated in eCognition.

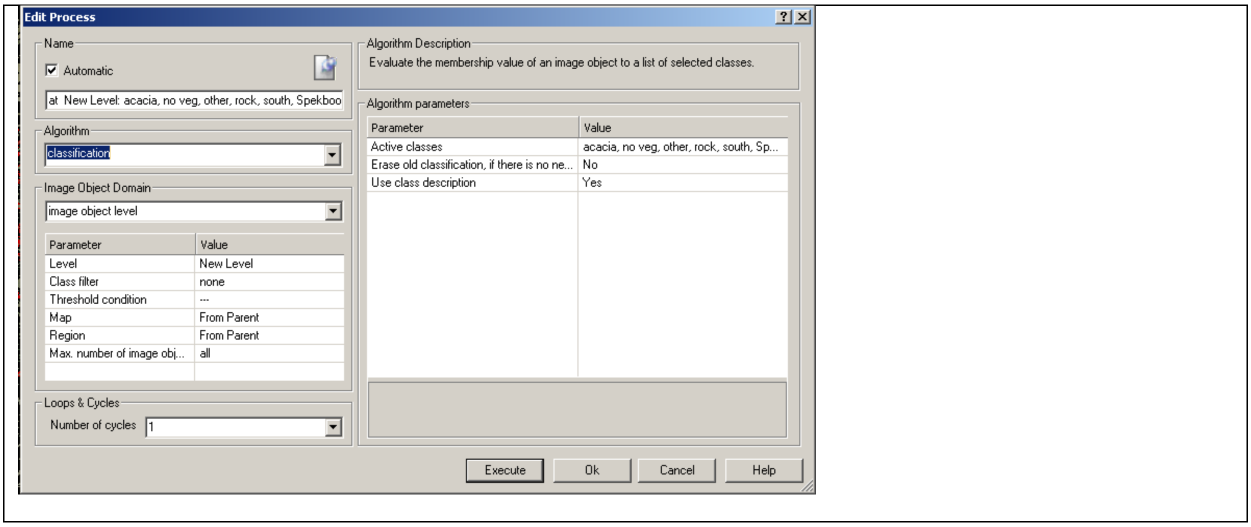


Figure 3.14 Identification of active classes and level classification

In the fifth step following the establishment of the rule set, training sites or samples for the actively defined classes were demarcated. In creating training samples for each class, the need for a variety of spekboom samples became clear, especially those which spekboom occurred at different densities and with segments with different colour tones. A minimum of 50 spekboom samples were used in each image to accurately identify all the various ways it occurs based on the slightly different spectral attributes. Figure 3.15 shows the location of some of the samples that were selected.

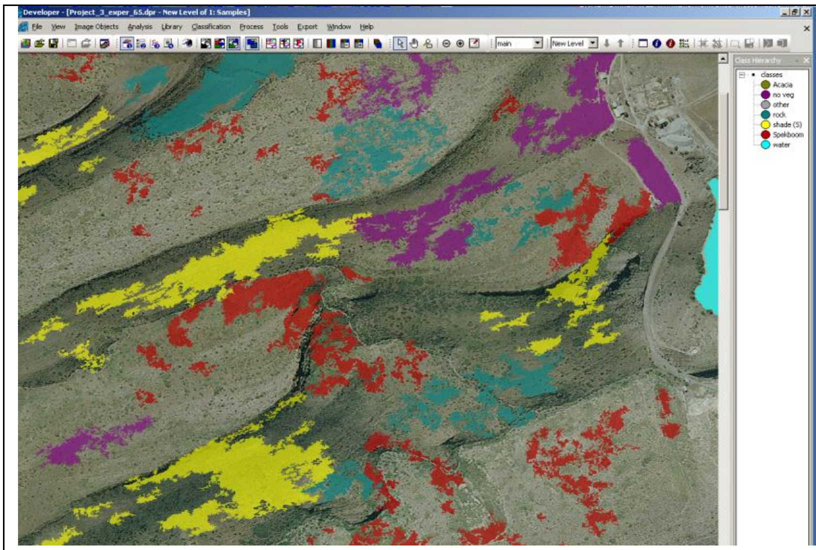


Figure 3.15 Location of a variety of class samples chosen for classification in BLK PNR

The classification results based on the chosen samples in Figure 3.15 are displayed in Figure 3.16.

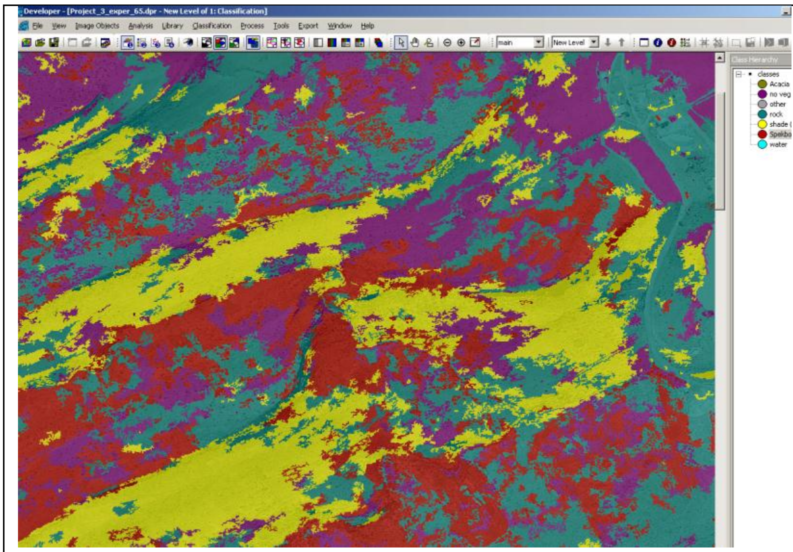


Figure 3.16 Results of the nearest neighbour classification from identified samples in BLK PNR

It was evident that the algorithm accurately extrapolated from samples to the classification. Especially important is that the location of spekboom occurrences has been accurately classified as spekboom. This result is statistically demonstrated by comparing the identified (green) patches of spekboom growing on the mountainside in Figure 3.17 with the classified patches (red) in the image of Figure 3.18.

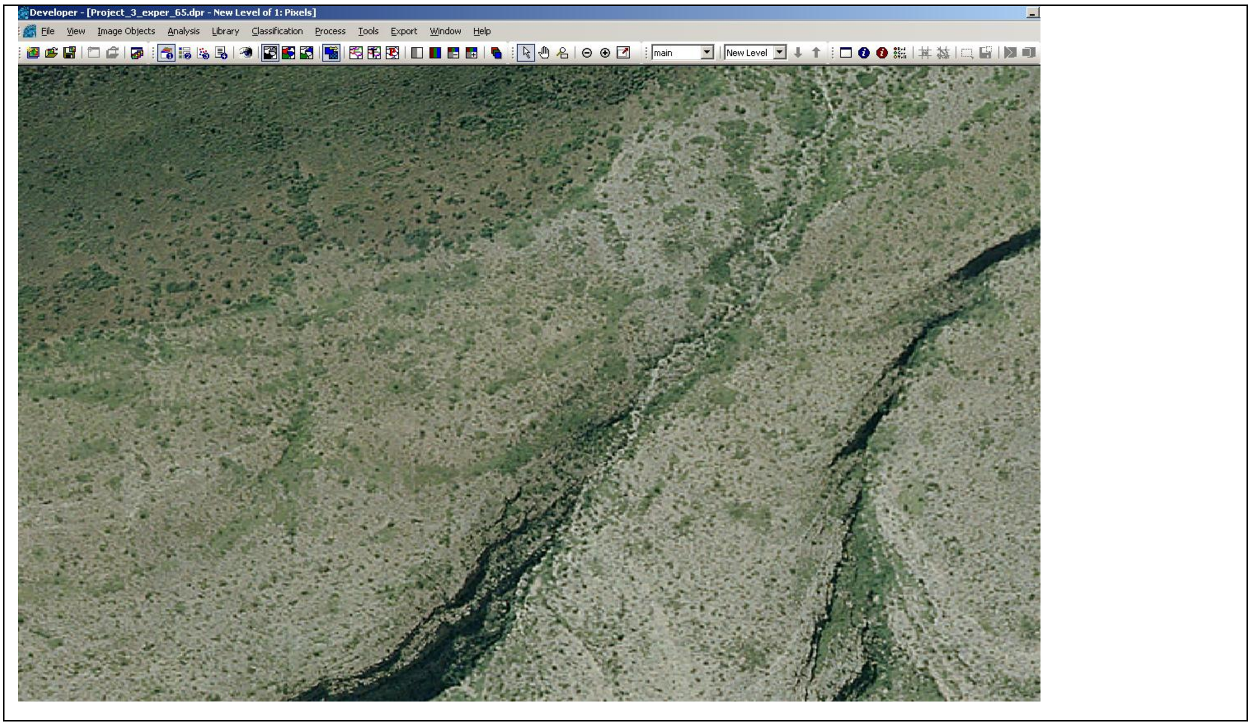


Figure 3.17 Spekboom growing in patches on the mountainside in BLK PNR

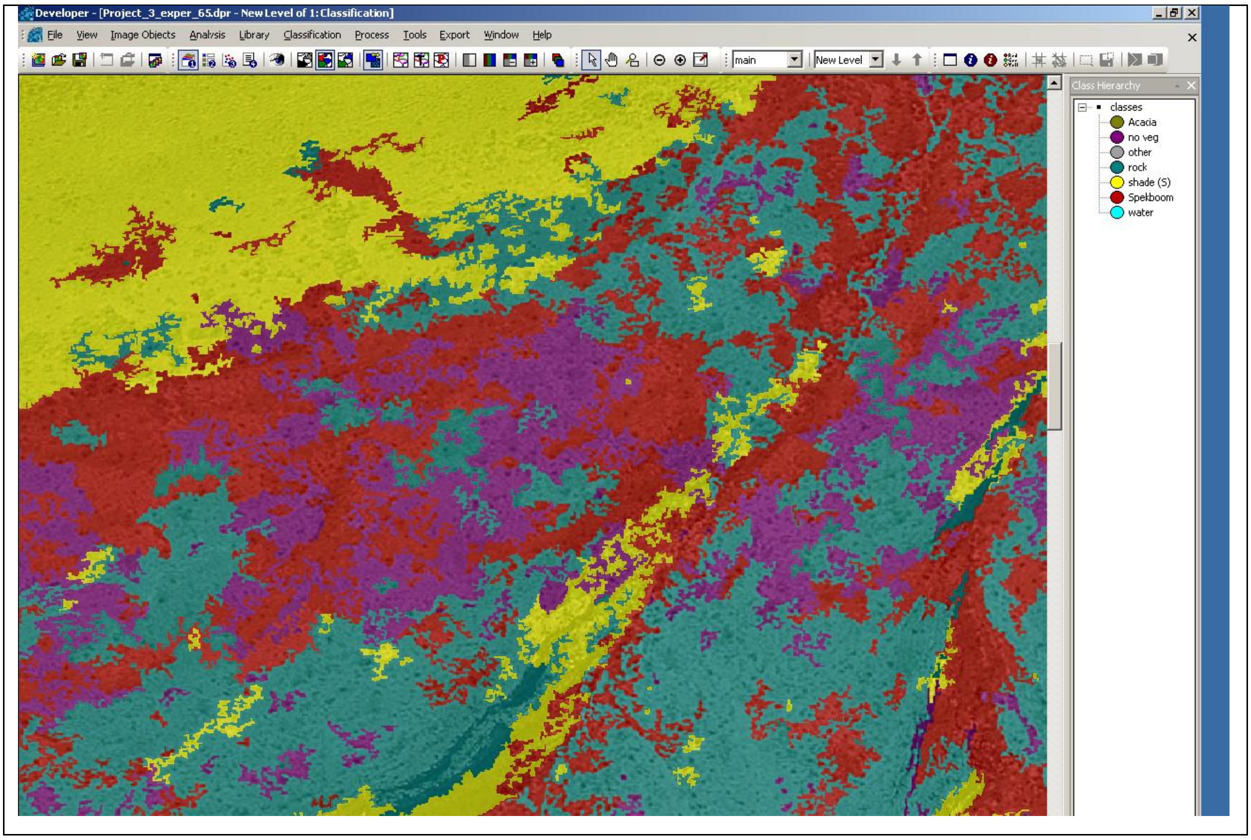


Figure 3.18 Spekboom patches classified in eCognition (nearest neighbour) in BLK PNR

Finally the classified image containing only the classified spekboom polygons was exported in shape-file format to the ArcGIS platform. Unfortunately, due to the similar colour range displayed by *Acacia* stands, some were mapped as spekboom. Because *Acacia* occurs along the riverbed in a distinctive, non-overlapping band, it was easy to select and delete such polygons using the editor tool in ArcGIS.

Despite the problems and frustration (slow and freezing) of using eCognition, the vegetation in the Gamka Thicket was identified using segmentation at a scale of 50 and classified using the nearest neighbour rule, the accuracy of this classification will be dealt with next.

3.4 ACCURACY ASSESSMENT THROUGH MANUAL CLASSIFICATION

A manually classified map was created for comparing the accuracy of the automated segmented and classified map in eCognition. In the first approach the vegetation was demarcated and mapped through onscreen heads-up digitizing. Heads-up digitizing entailed mouse-clicking the cursor around the visible edges of vegetation patches and fully tracing their extent. With so many individual stands of spekboom and the large size of the study area, this exercise was time consuming and for this reason the strategy is inefficient for large tasks. The second approach used the already segmented map (at a scale of 50) draped over the image and the editor toolbar in ArcGIS was used to manually select the polygons (segments) that contained spekboom. By displaying the polygons as hollow without outline, visual identification of the vegetation was made easier with the naked eye. To highlight the desired segments to be classified as spekboom, the shift/click action allowed fast selection of polygons with spekboom occurrences. When a substantial number of segments had been selected, they were classified in the attribute table.

In areas of uncertain spekboom occurrence, a number of tools aided the identification and selection process. First Jenness's (2010) method was used to create an aspect layer for the terrain from the DEM. Earlier, the strict preference was pointed for spekboom growth on sunbathed north-facing slopes and on those with easterly and westerly tending aspects, where they receive sunlight on winter mornings and afternoons. Consequently, this aspect map allowed the user to determine whether vegetation in doubt adhered to the right spectrum of aspect criterion values to be defined as spekboom or not.

Second, physical fieldwork mapping was undertaken. This entailed traversing the west-east stretching Gamka Thicket vegetation occurrence in the landscape along three north-south observation spokes. These spokes followed major drainage lines and spekboom stands were photographed in the field at locations recorded by hand-held GPS co-ordinates as waypoints. Photographs were taken in various directions at these locations to form a visual reference database of the target vegetation to help identify it during image analysis. This data set was structured to represent all the various aspect directions, slope and height occurrences of spekboom in the mountainous terrain. The waypoints were loaded into ArcGIS (depicted in Figure 3.19) where they were used in conjunction with the photographs to help identify uncertain patches of vegetation. For

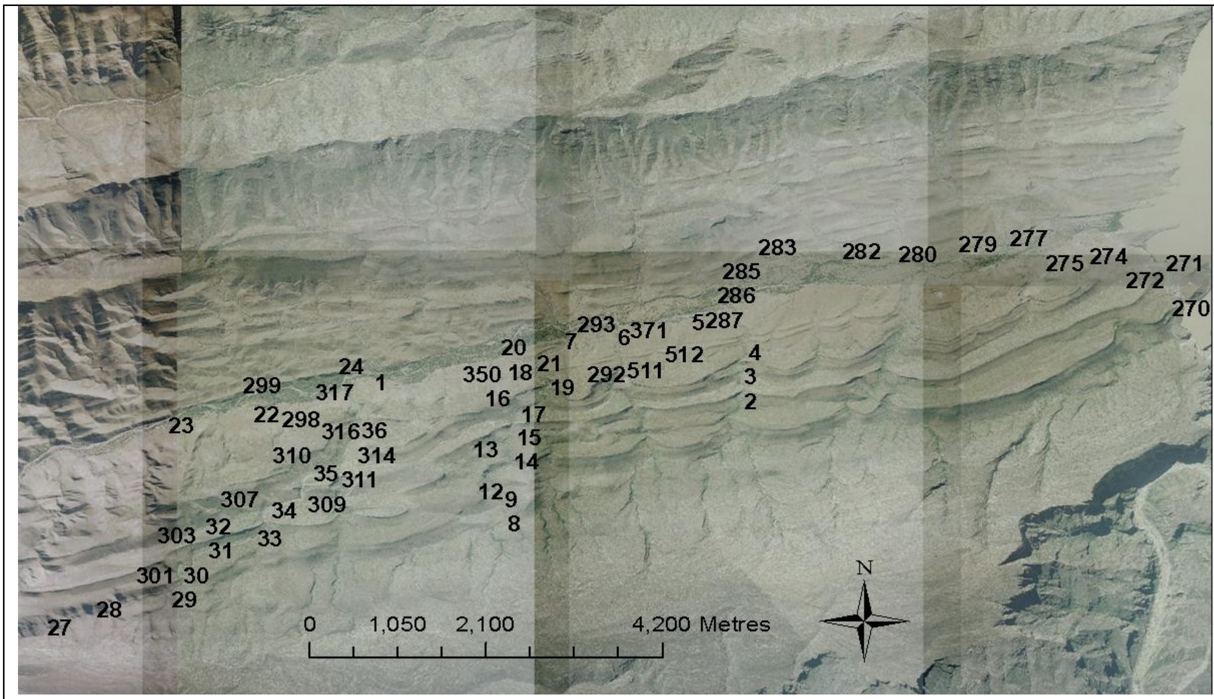


Figure 3.19 Waypoint sets along traverses for accuracy assessment of spekboom stands in BLK PNR

example, Figure 3.20 shows the landscape location of waypoints 273 and 274. From these vantage points the green patches photographed in Figures 3.21 and 3.22 were unmistakably confirmed as spekboom capping the mountain ridge.

The Jenness (2010) DEM extension allowed the creation of an aspect layer, as shown in Figure 3.23, for the area shown in Figure 3.20 and in which waypoints 273 and 274 are indicated for orientation. The mapped aspect classes each represent an aspect direction of 45 degrees centred on the eight major compass directions. In Figure 3.23 the vegetation clearly occurs on the north-facing sunbathed slopes and the type is plainly identifiable in Figure 3.22.

The third method of accuracy assessment entailed field demarcation of very distinctive spekboom stands by GPS-delimited waypoints. Stands were manually delimited by GPS waypoints at 5-m intervals around stands to create polygons importable to ArcGIS. These waypoint polygons were superposed on the imagery for verification of stand appearances on the imagery with other

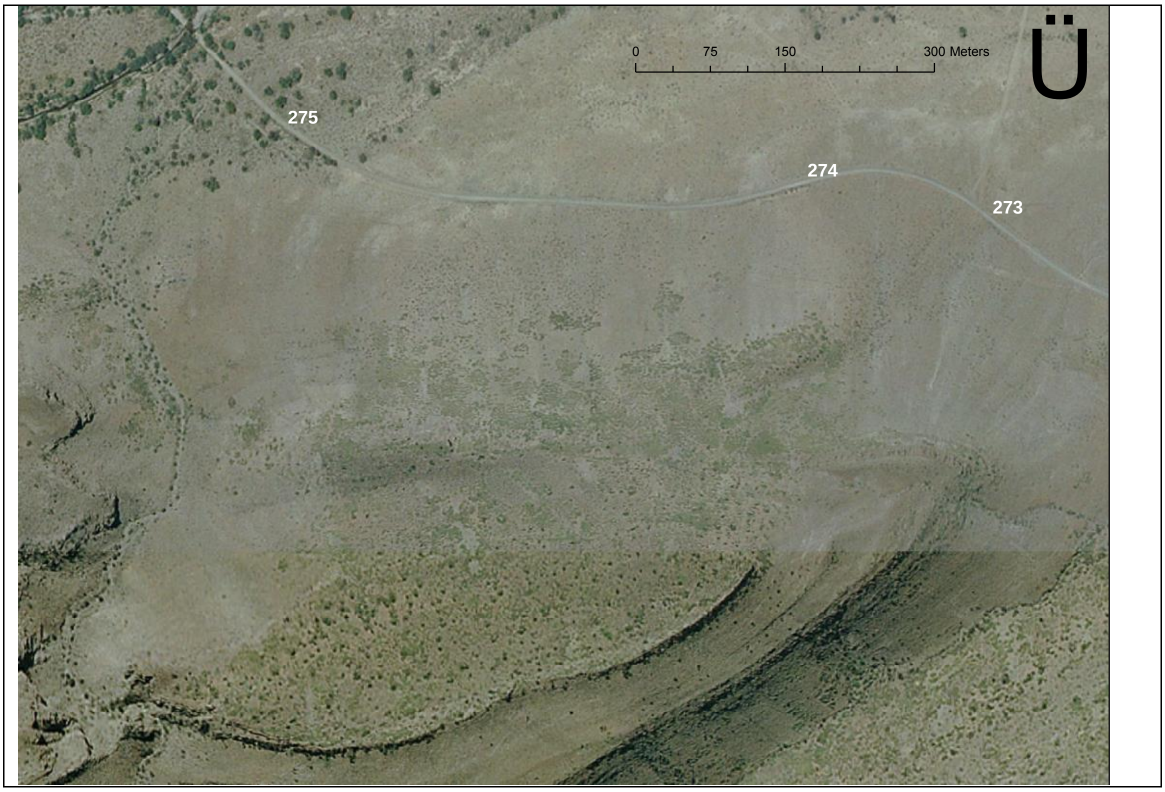


Figure 3.20 Landscape location of waypoints 273 and 274 for accuracy assessment of vegetation about which uncertainty existed in BLK PNR

Figure 3.21 View of spekboom stands in a southerly direction from waypoint 273 in BKL PNR

Figure 3.22 View of spekboom stands in a south-south-westerly direction from waypoint 274 in BLK PNR

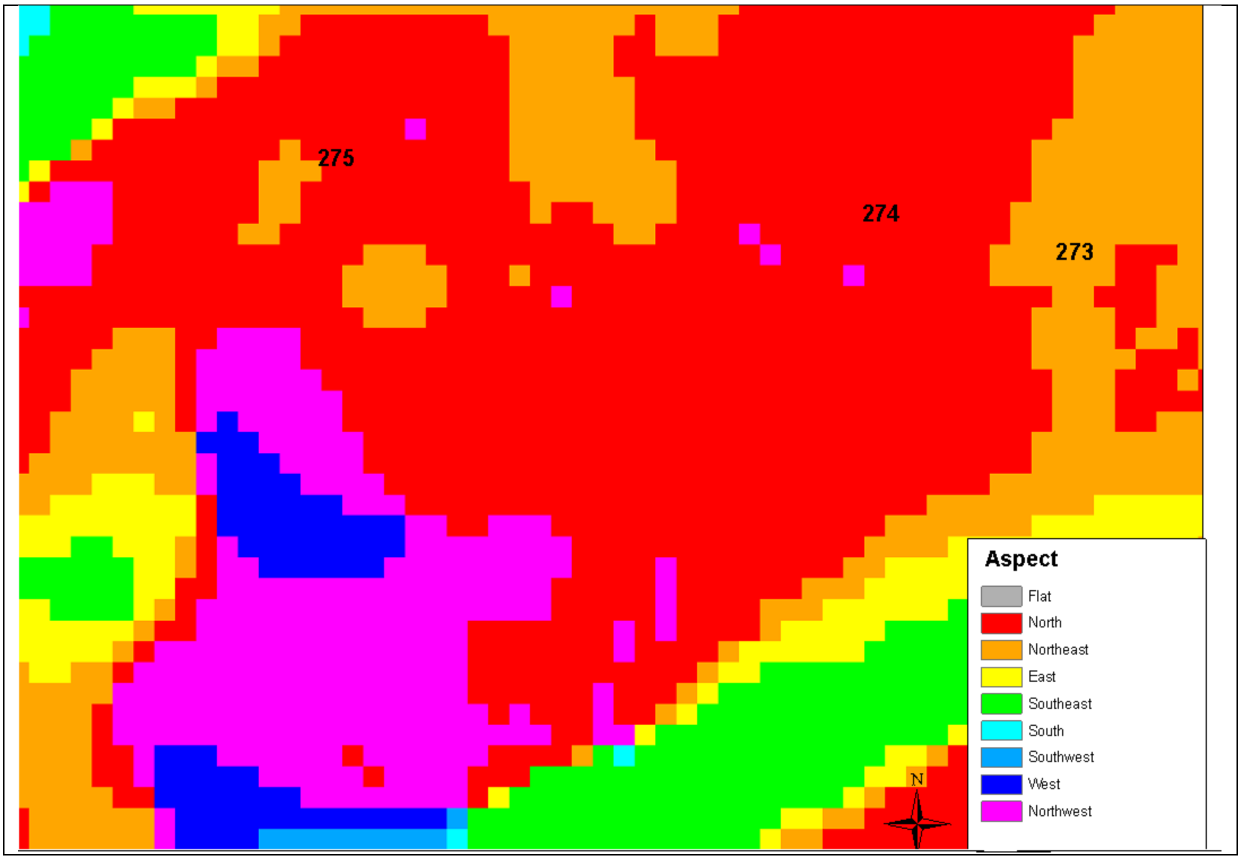


Figure 3.23 Aspect map used to identify spekboom growing on north-facing slopes in BLK PNR

stands and with the photographs to facilitate the accurate inclusion of uncertain patches of spekboom vegetation. Figure 3.24 shows the patch of spekboom that was manually delineated with waypoints and subsequently plotted on the image in Figure 3.25.

Figure 3.24 Example of a spekboom stand manually delineated by waypoint series in BLK PNR

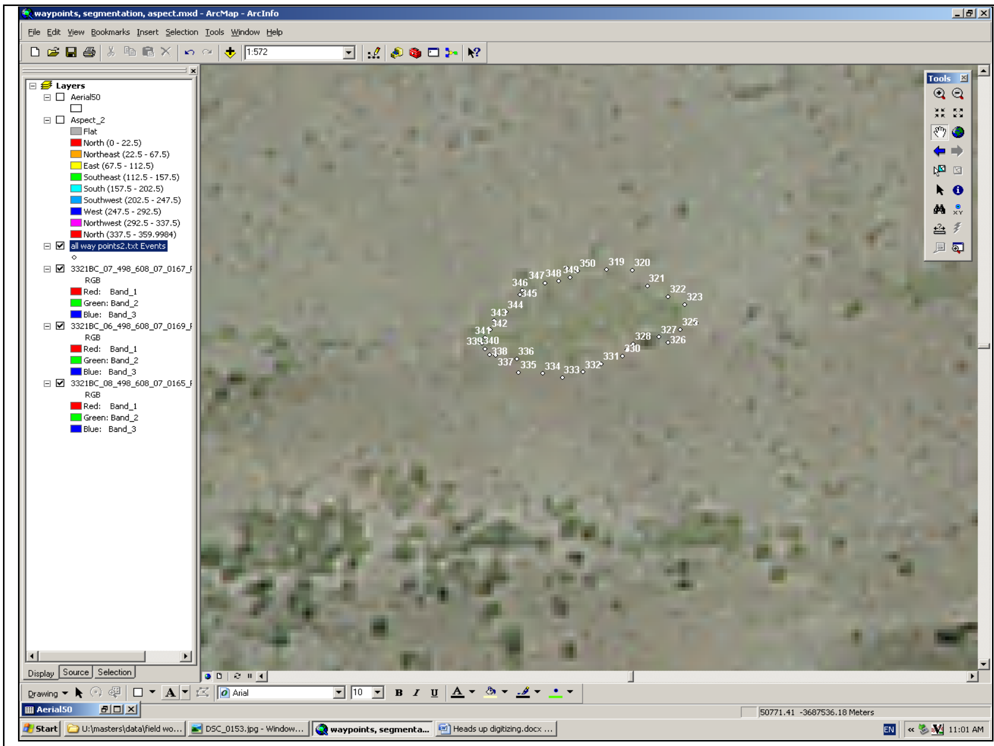


Figure 3.25 Spekboom stand shown in Figure 3.24 plotted on satellite image

When superposed on the segmented image (Figure 3.26), the high level of accuracy with which the combination of methods succeeded in identifying and delimiting spekboom stands in the study area is illustrated, although a measure of generalization is also evident.

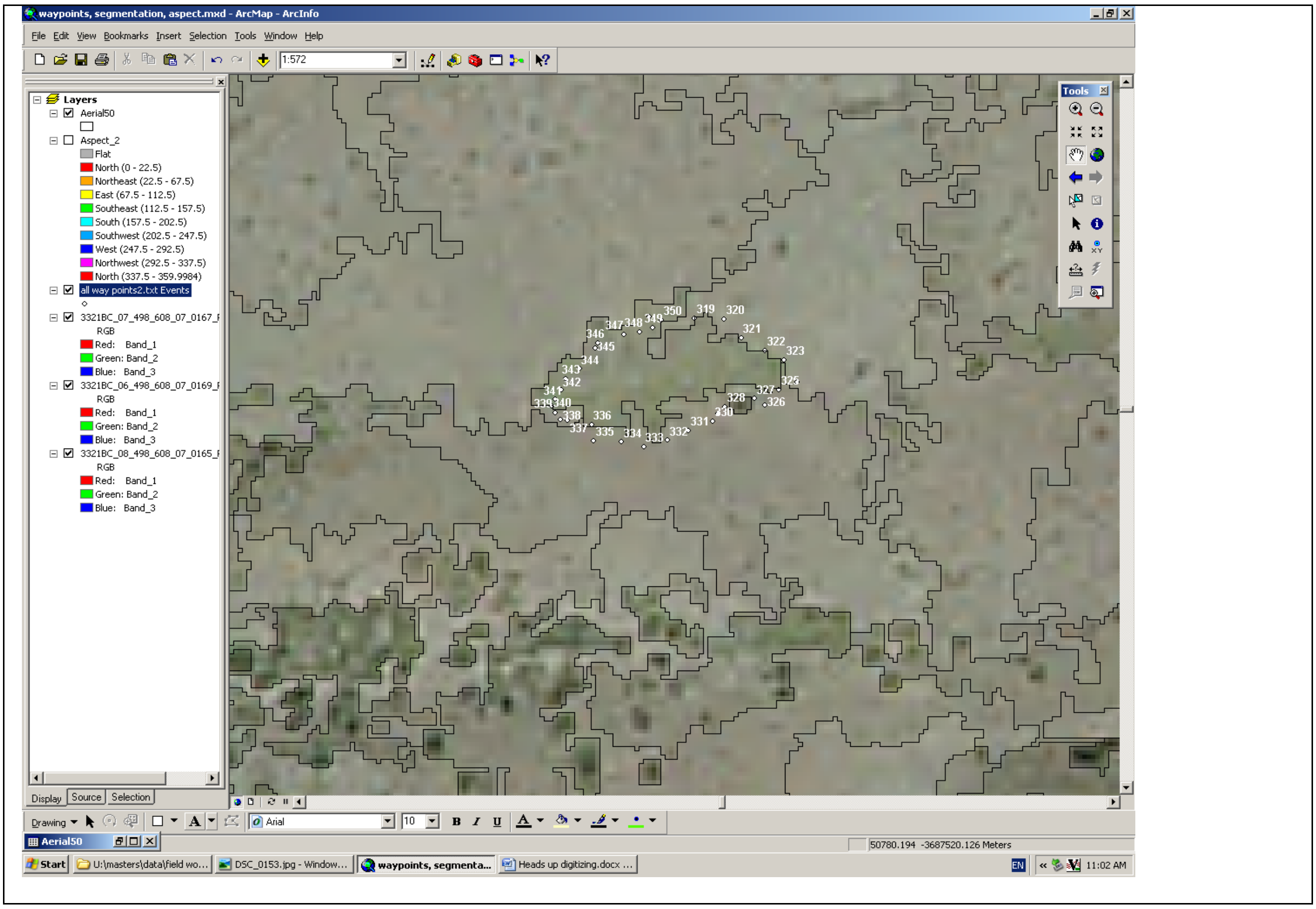


Figure 3.26 Superposed waypoint demarcation of spekboom on segmented stand image in BLK PNR

The final manually classified map for the larger part of the study area is shown in Figure 3.27 and its accuracy is compared to that of the automated classification in the next section.Note in Figure 3.27 the unexpected occurrence of smaller isolated stands of spekboom on some north facing slopes in the northerly part of the Gamka Thicket. A noteworthy feature is the sharp transition boundaries between spekboom and other vegetation types – due mainly to the deterministic role of landscape form and terrain aspect. Significantly, the area of spekboom demarcated by this manual method showed that about 900 ha are covered by this vegetation type – almost 25% of the total area demarcated as Gamka Thicket in the SANBI map.

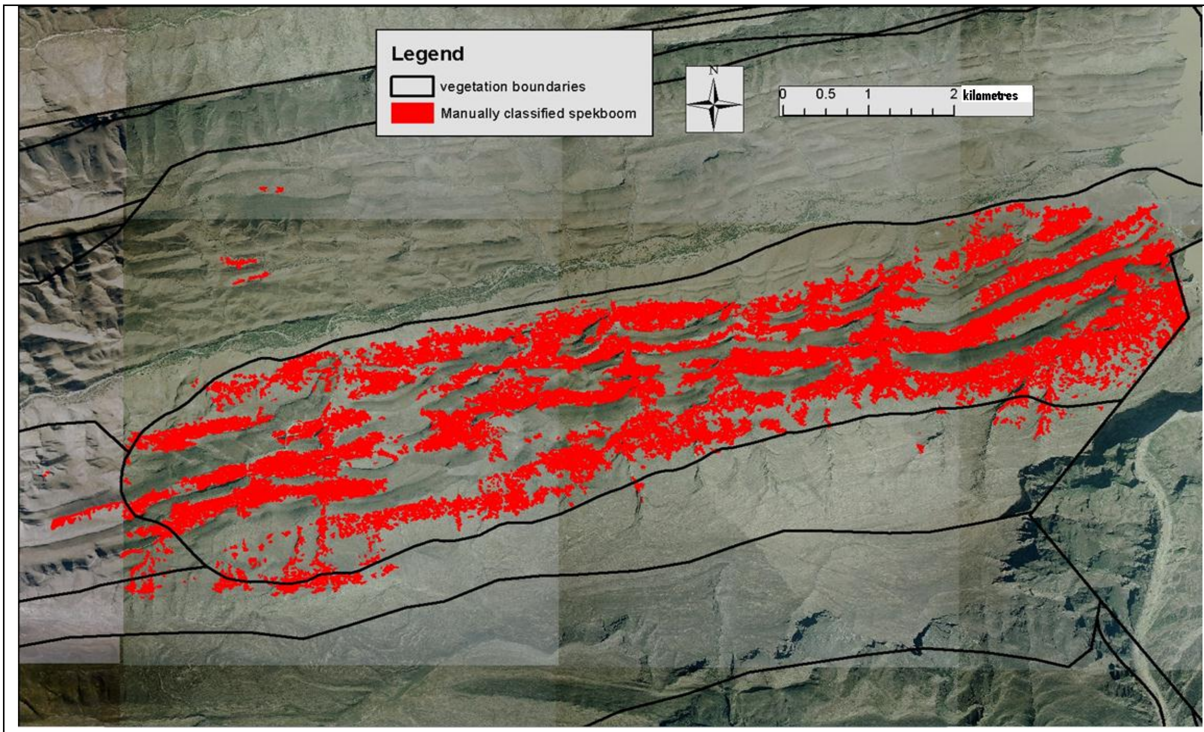


Figure 3.27 Final manually classified spekboom stand demarcated in the Gamka Thicket in BLK PNR

The automatically classified vegetation map (created in Section 3.3) and the manually classified vegetation map (created in this section) will be used in the accuracy assessment in Section 3.9. The *Acacia karroo* will be mapped next.

3.5 MAPPING *ACACIA KARROO* ON BLK PRN

The significant *Acacia karroo* stands (as a representation of Southern Karoo Riviere azonal vegetation) on BLK PNR were not distinguished as such in Mucina & Rutherford's (2006) map of South Africa's vegetation. This vegetation type is a vital landscape and biological element because it represents a Karoo natural forest that provides much needed shade and grazing to a range of fauna in the arid environment. Figure 3.28 shows the appearance of these stands. Importantly, in the context of this thesis *Acacia karroo* stands contribute appreciably to ground carbon stocks. Because this study aims to determine CS potential on the whole property unit, this vegetation type had to be accurately mapped and accounted for. The *Acacia karroo* stand extends both sides of the river valley, at places some 300m wide. In the narrower part of the valley the stands are dense and the individual trees are large. Lower down the river course where the stream becomes braided and the valley floor broadens, the stands become less dense and individual trees tend to be smaller. Toward the eastern edge of the study site, some stands are dense, others less dense and they hug the river bed. This vegetation type was mapped and classified using heads-up digitizing using the editor

Figure 3.28 Prominent *Acacia karroo* stand on BLK PNR

toolbar in ArcGIS to create a polygon around the vegetation occurrence – a suitable method because it clearly distinguishes between *Acacia karroo* stands and all the other surrounding vegetation types. *Acacia karroo* is visibly depicted in the zoomed-in frame in Figure 3.29. This vegetation type covers a planimetric area of 513.52 ha, so constituting a substantial vegetation presence on the BLK PNR property.

This mapped *Acacia karroo* were used at a later stage in the carbon accounting for the study site. To further add to this carbon accounting the degraded spekboom had to be mapped.

3.6 MAPPING DEGRADED SPEKBOOM ON BLK PNR

Degraded spekboom areas in BLK PNR had to be mapped for the carbon accounting process and to determine which land in BLK PNR qualified for restoration. It was highlighted in Chapter 1 that BLK PNR went through a period of intensive stock farming that left large portions of the farm degraded. It was pointed out earlier that spekboom dominates sunbathed north-facing slopes and those with easterly and westerly aspects where they receive sunlight on winter mornings

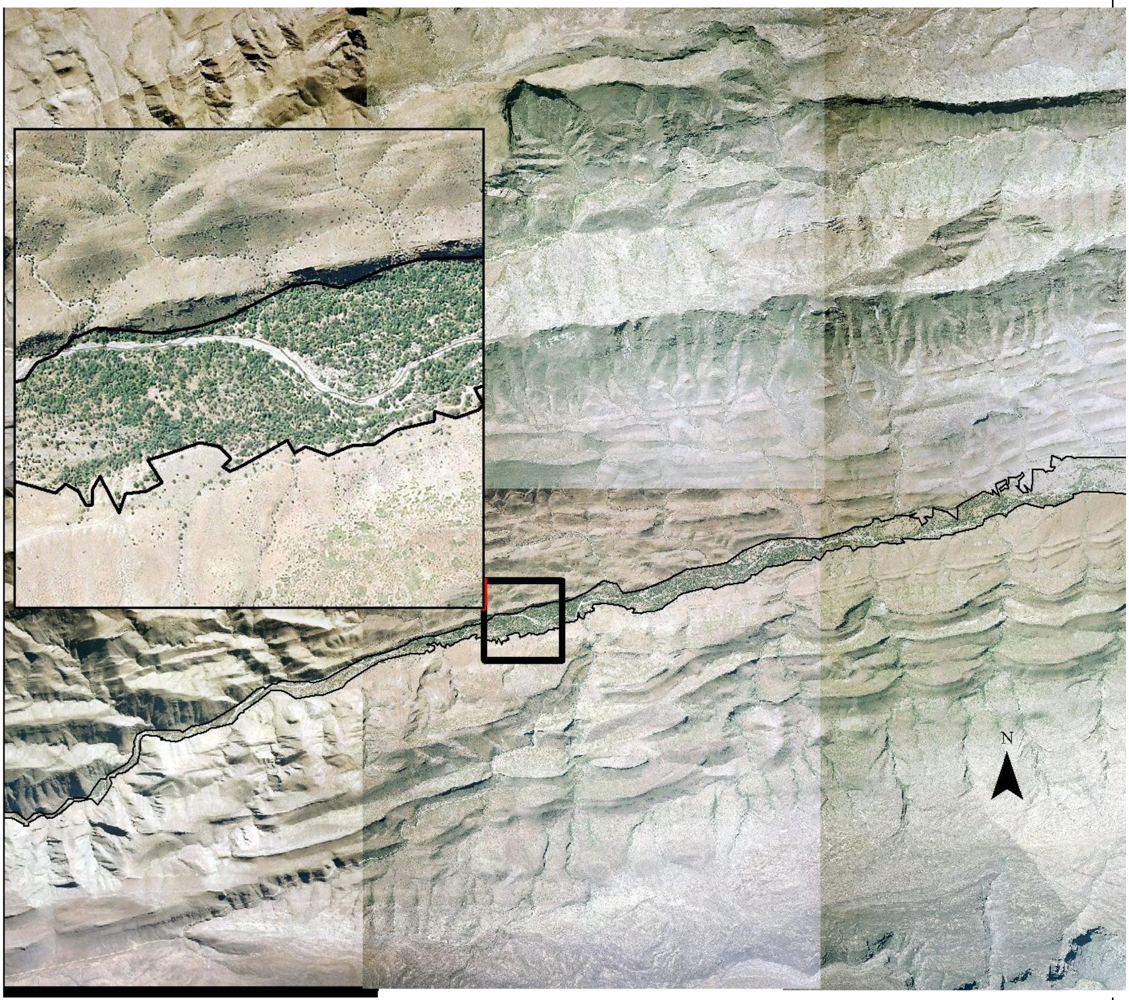


Figure 3.29 Enlarged *Acacia karroo* stand in BLK PNR

and afternoons opposed to the shaded south-facing slopes. This is easily seen in Figure 3.30 where the manually classified spekboom stands (depicted in green) dominate all aspects except for the southerly slopes (depicted in red). Consequently, the value of this aspect map (Figure 3.30) is that in GIS one can select all the aspects that spekboom should potentially dominate (depicted in blue) and where spekboom should not potentially dominate (depicted in red) and then calculate the area of the aspects that spekboom should dominate.

The mapping of intact spekboom was reported in Section 3.3 (recall Figure 3.18). Using the calculated area that spekboom should dominate and the calculated area of where spekboom does actually dominate, the degraded area can be established. This was calculated once an appropriate method was chosen to calculate true surface area, the results of which were presented in Table 4.3.

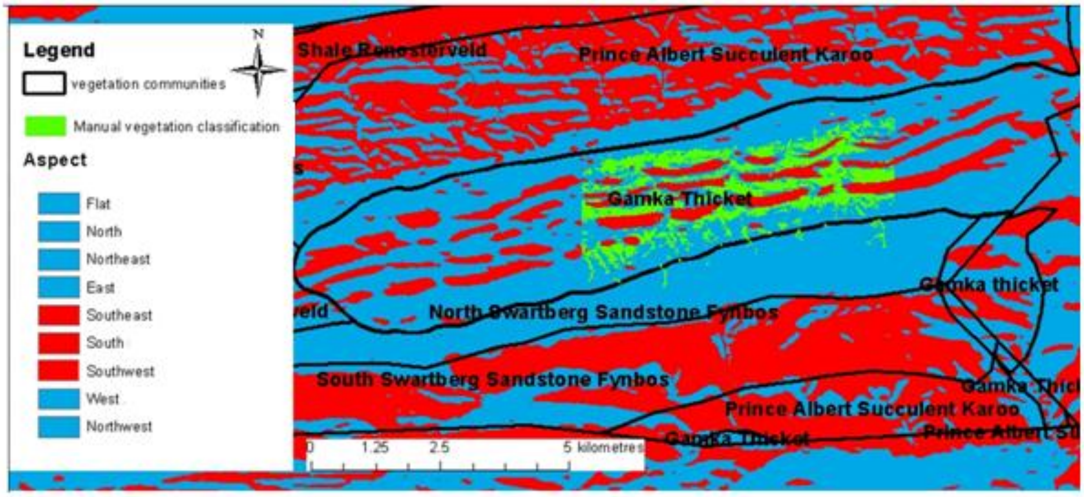


Figure 3.30 Aspects where spekboom dominates in BLK PNR

The site identified for spekboom restoration was mapped next.

3.7 MAPPING A SPEKBOOM RESTORATION SITE ON BLK PNR

Heads-up digitizing involves the tracing of geographic features directly on top of aerial imagery. Restoration using spekboom is accredited only in areas where spekboom thicket formerly occurred, namely in its original natural habitat. To map areas suitable for restoration, the basic criteria for selecting degraded sites suitable for restoration are: ensure that it was previously covered in spekboom-rich thicket; the restoration site must preferably be near an abundant source of spekboom for cuttings, not only to reduce transport costs but also to ensure that the appropriate plant variety or genotype for the area is replanted; sites should be easily accessible by road; and it is advantageous to be near a water source. It is not a necessity to propagate spekboom cuttings (Cowling et al. 2011). Without an on-site soil sample one cannot conclude that an area identified for restoration was previously covered in spekboom. Even so, by analysing findings of the manual mapping in BLK PNR, it can be safely concluded that spekboom occurred naturally on most aspects, except on shaded southerly slopes. This conclusion taken with the history of intensive goat farming in the area (a proven cause of extreme degradation that does not recoup naturally) leads on to reasonably assume that this area used to be covered in spekboom, but historical overstocking degraded it. Given all the applicable criteria and requirements, the most suitable restoration area lies along the old Prince Albert road as demarcated in Figure 3.31. Mills & Cowling (2010) have reported that the cost of sequestering one ton of CO_2 decreases from approximately R85 in a 500-hectare project in steeply sloping terrain to R30 in a 64 000-hectare project in a gently sloping terrain. Therefore, although the area suitable for restoration shown in Figure 3.31 is not extremely large, a smaller

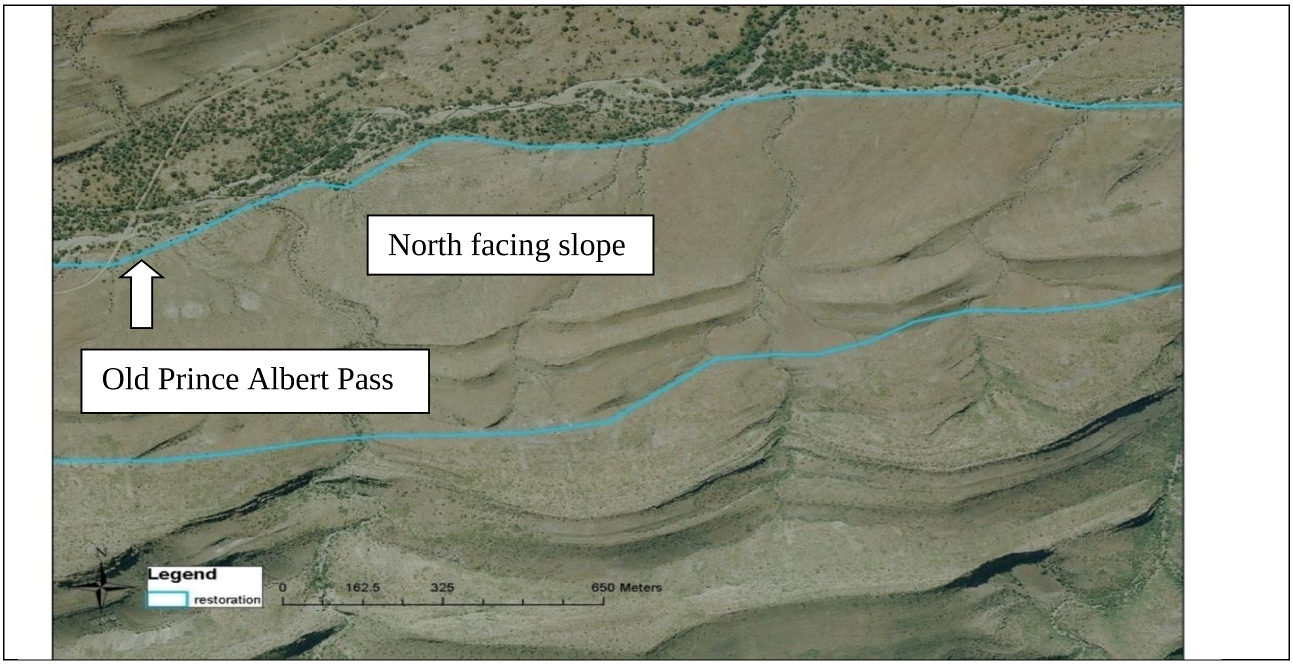


Figure 3.31 Suitable area for restoration for spekboom in BLK PNR

portion with gently sloping terrain is preferable where restoration will be easier and cheaper. Such an area was identified for restoration as mapped in Figure 3.32. The planimetrically calculated area of the proposed restoration site is 365.52 ha. This is an approximately sized and suitable area for

Figure 3.32 Gently sloping terrain suitable for a spekboom restoration project in BLK PNR

restoration. From this, BLK PNR shows potential for restoration, due to substantial degraded areas and its site suitability for active restoration. The true surface area of all the mapped features in this chapter was calculated next.

3.8 CALCULATION OF BLK'S SURFACE AREA IN A COMPLEX LANDSCAPE

Once the vegetation map had been classified, the crucial question concerning the accurate calculation of the relevant areas and volumes of tradable vegetation for CT arose: What is the true surface area of the territories of high soil carbon content and the area of each biome? Given the mountainous terrain of BLK PNR (see Figure 3.33) this question is pertinent to BLK PNR and presents a complicated task even in less rugged environments. This section treats the calculation of true surface area as opposed to planimetrically calculated area. The application of two methods to accurately calculate three-dimensional area, namely the Jenness extension and TIN data structures, is considered in separate sections. The advantages of three-dimensional (3D) data structures for measuring true surface area and recommendations for their use are specified and the section is concluded with an explanation of calculating the real area of the relevant sites in BLK PNR.

Figure 3.33 The precipitous terrain of the mountainous BLK PNR

3.8.1 Mechanical concepts

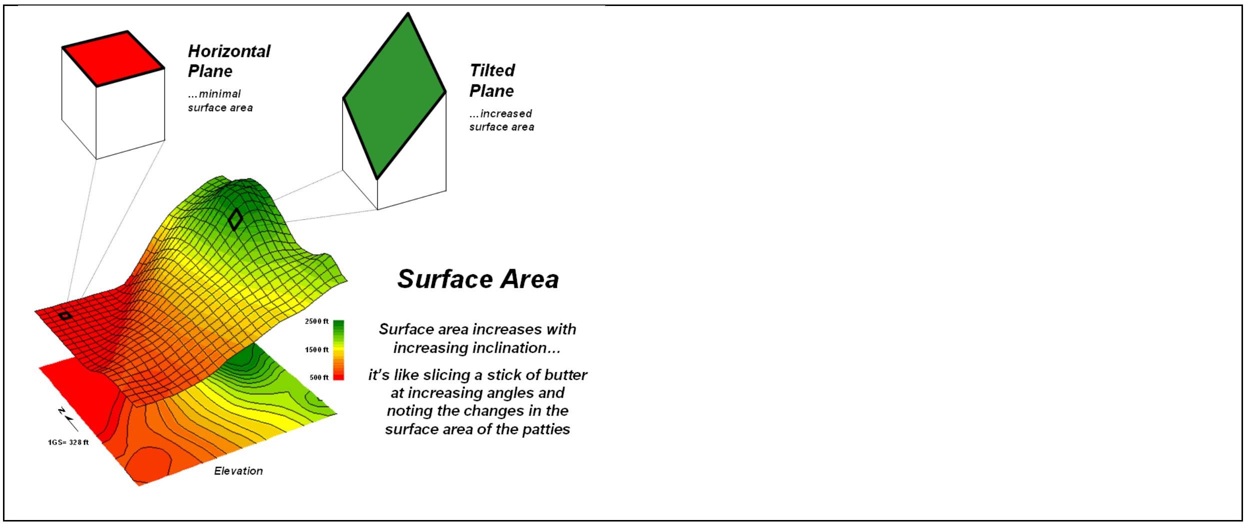
The principle of 3D area calculation is expounded first, followed by the application of two methods to calculate true surface area, namely the Jenness extension and TIN.

3.8.1.1 The principle of three-dimensional area calculation

Terrain area is almost always presented as planimetric area, shown as the 'horizontal plane' in Figure 3.34. Two-dimensional area is usually calculated simply as length multiplied by breadth. Most software (including GIS) calculates the planimetric area of map features which is basically the bird's-eye view of an area derived from coordinate points referenced to horizontal space anchored to latitude and longitude. For example, a square kilometre planimetrically calculated in the Swartberg range with its crags and ravines represents the same area of land as a square kilometre in the flat Karoo plains. Of course, the real surface area of the former is larger, since it reflects tilted planes. Calculating the total planimetric area of grid based systems is simply done by multiplying the number of regular-sized grid cells by the planimetric area of an individual grid cell on a horizontal plane, that is

(cell length x cell breadth) x number of grid cells.

However, planimetric area represents only the horizontal dimensions of features. When calculating the true surface area, in this study the area that spekboom covers on steep slopes (compare Figure 3.33), the larger vertical aspect or tilted plane of the terrain has to be accounted for as surface area increases with inclination in a grid cell. Figure 3.33 graphically demonstrates this dilemma in aerial representation and calculation, while Figure 3.34 demonstrates the graphical principles involved.



Source: Lopez & Berry (2003: 1)

Figure 3.34 Increasing surface area with inclination in a grid cell

By using a digital elevation model (DEM) of the relevant area, the slope of each grid cell is calculated and then used to adjust planimetric area to surface area. Lopez & Berry (2003) and GeoWorld (2002) provide the formula for surface area calculation as:

Surface area = Planimetric area ÷ Cosine (Slope angle)

where, surface area is the area of the tilted plane (in the shape of a parallelogram) on the terrain surface corresponding to a rectangle on the planimetric reference grid;

planimetric area is the area of the rectangle on the planimetric reference grid; and

slope angle is the inclination of the tilted plane with respect to the horizontal reference grid.

A DEM is a regularly spaced grid of elevation points that can be represented as a raster (a grid of squares, also known as a height map). Within DEMs, each cell value reflects the elevation above some reference point – usually sea level – in metres at the central point in that cell. Figure 3.35 is an expression of topography based on shading a 20m resolution DEM for the larger region within which the BLK PNR study terrain is located. The Figure shows the rugged and uneven topography of the area.

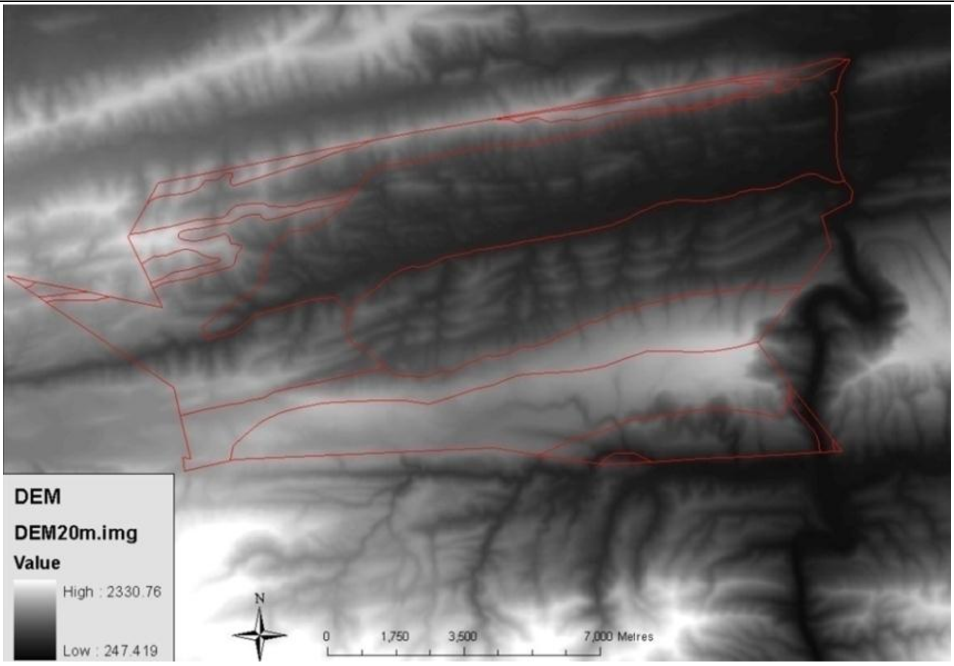


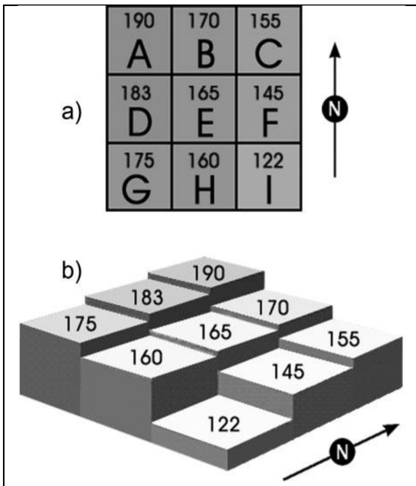
Figure 3.35 Topography showing elevation for BLK PNR created from a 20m DEM

A triangular irregular network (TIN) and a variety of slope-aspect, surface area and land-curvature values can be created from the DEM to calculate true surface area. For this study, the surface area was calculated using an extension provided by Jenness (2010) that creates a surface area layer and a TIN model, both in ArcGIS. The two methods are similar in their calculations (they both calculate three-dimensional area and planemetric area). However, they differ slightly in that one is vector-based and the other raster-based. The differences are discussed below. Comparisons of the two methods should inform the choices other users of the methods will need to make.

3.8.1.2 Three-dimensional area calculation via the Jenness extension

The Jenness (2010) extension makes it possible to generate surface area and surface ratio grids from an existing elevation grid or DEM. The cell values for these grids reflect the surface area and (surface area) ÷ (planimetric area) ratio for the land area contained within that cell’s boundaries.

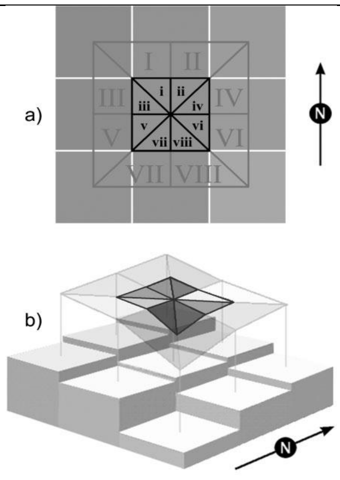
The 'surface area tool' creates a raster with cell values reflecting the surface area within each cell to calculate total true surface area. Jenness (2010) explains more fully how the tool works. Encapsulated, the Jenness tool uses the DEM to generate eight 3D triangles around each cell centre by connecting each cell centre point with the centre points of the eight surrounding cells, then calculates and sums the area of the portions of each triangle that fall within the cell boundary to determine the true surface area of the grid. For example, in Figure 3.36a, which is a 3x3 sample elevation grid, the tool calculates the surface area for the central cell with elevation value 165 based on the elevation values of that cell plus the eight surrounding cells. In Figure 3.36 the central cell and its surrounding cells are pictured in 3D space as a set of adjacent columns, each rising as high as its specified elevation value. Further in Figure 3.36b, the central cell with height value 165 to the centres of the surrounding cells, and the lengths between adjacent surrounding cells, yield the edge lengths for the triangles I–VIII in Figure 3.37a. These triangles form a continuous surface over the nine cells shown in Figure 3.37a. The surface area within the target cell should, however, only reflect the areas of triangles I–VIII in Figure 3.37a.



The centre cell (165) plus 8 adjacent cells are used

Source: Jenness (2010: 831)

Figure 3.36 Sample grid system to calculate true surface area



The distances between adjacent surrounding cells are used to calculate true surface area

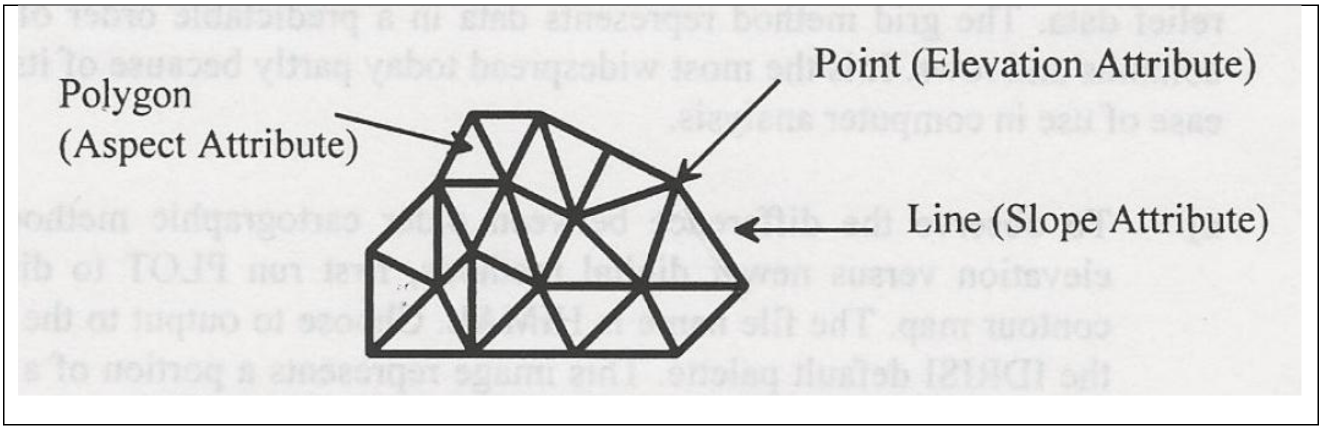
Source: Jenness (2010: 831)

Figure 3.37 Cell distance principle used to calculate tilted surface area

Therefore, the extension trims the triangles to the cell boundaries in Figure 3.37b by dividing all the triangle side lengths by two.

3.8.1.3 Three-dimensional area calculation via TIN data structures

The second method, the triangulated irregular network (TIN), is a surface model by which elevation, slope and aspect are captured in vector-based GIS data-base format as illustrated in Figure 3.38. The TIN data model is a conception of point-measured elevation connected by lines

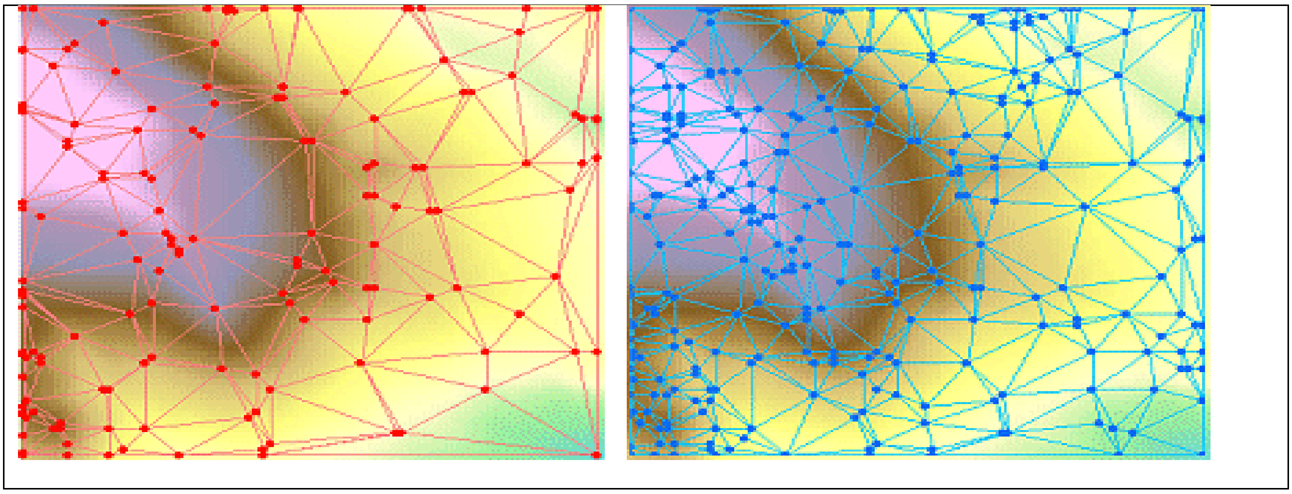


Source: Schneider & Robbins 2009: 22

Figure 3.38 Topographic information in a TIN

and planes. By connecting all these elevation points (vertices) with their neighbours, a network of contiguous, non-overlapping Delaunay triangles is formed. The number of points selected by the command is a function of the specified z-tolerance and the smoothness of the input raster. A TIN surface may differ from the cell centre heights of the input raster. A low number results in a

TIN that preserves more of the detail of the raster surface (ArcGIS 2009). A larger number results in a more generalized representation of the surface. Figure 3.39 displays the effect of different tolerances. In the figure on the left the background raster has been converted to the foreground TIN



Source: NMT 2008: 21

Figure 3.39 Display of different Z tolerance using a z-tolerance of 50 units. The output TIN has 169 nodes and 269 triangles. (Only nodes and edges are symbolized.) The figure on the right was the same raster but is converted using a z-tolerance of 25 units. Unlike DEMs, these TINs are continuous vector surfaces and can therefore be precisely measured and clipped (Jenness 2004). By using 'interpolate polygon to multipatch' (command in GIS), one can create surface-conforming aerial features by extracting those portions of a surface that fall within the extent of input polygons as multipatches (ArcGIS 2009). Area is then displayed in planimetric and true surface area in the attribute table. The principle of 3D area having been examined is now applied to the study area.

3.8.2 Practical application

The two methods discussed above are applied to the case study of BLK PNR and the area of vegetation and mapped features is calculated.

3.8.2.1 Activating the Jenness method and TIN

Both methods were used in ArcGIS to calculate the true surface area of polygons of the case study area. Both use a DEM to determine surface area data, however they differ slightly in their calculation method and results output. The TIN is a vector-based calculation and the Jenness is raster-based. The experiments with the two methods should inform prospective users in their choice of method. The results and their suitability for determining true surface area in mountainous landscapes were compared because the methods are not always equally accessible depending on the availability of various GIS platforms (software programs).

Activating the Jenness method entailed five steps, namely:

1. Download Jenness extension from: http://www.Jennessnt.com/ArcGIS/surface_area.htm.
2. Activate the Jenness extension in ArcGIS (follow instructions provided by extension).
3. Open ArcGIS and add DEM data for study area (add data).
4. Create surface area or surface ratios in the DEM tools extension (DEM tools extension/create surface area).
5. Activate the ArcGIS tool 'Zonal Statistics' as Table (the command sequence is: ArcToolbox/Spatial Analyst Tools/Zonal/Zonal Statistics as Table). This procedure calculates the sum of all the real three-dimensional surface area raster cells contained inside the target polygons as explained in Section 3.8.1.2.

Activating the TIN method requires the creation of a TIN data structure from the available DEM and the carrying out of the following five analytical steps:

1. Open ArcGIS and add DEM data for study area.

2. Activate the tabs Tools/Extensions and turn 3D Analyst on.
3. Convert the DEM (raster) to a TIN.
4. Run the actions interpolate polygon/multipatch tool in 3D Analyst.
5. Open the attribute table of the output data set to access the calculated planimetric and surface area figures.

3.8.2.2 Calculation of areas of vegetation and mapped features in BLK PNR

The application of the Jenness extension resulted in the production of a raster image similar to an ordinary 3D topographical DEM, but each 10x10m cell carried an area and not a height value. This area value was colour coded for display purposes so that larger areas appear darker in Figure 3.40. The topographical height display in Figure 3.40 shows darker coloured cells (larger surface area indicative of steeper slope) along valley and mountain sides, thereby mimicking the topographical displays. Experimentation was conducted using different tolerances for creating a TIN. The first TIN database created for this study area using a tolerance suggested by the software did not allow a similarly fine-scaled image to be created. As seen in Figure 3.41, the Delaunay triangles created are much more coarsely delimited, some triangles are clearly over 5 km long, but this should be more finely delimited as a 10-m DEM was used. A second TIN database was created (seen in Figure 3.42) using a z tolerance of .05 and a z unit of 1. This data set was far more comparable to the data

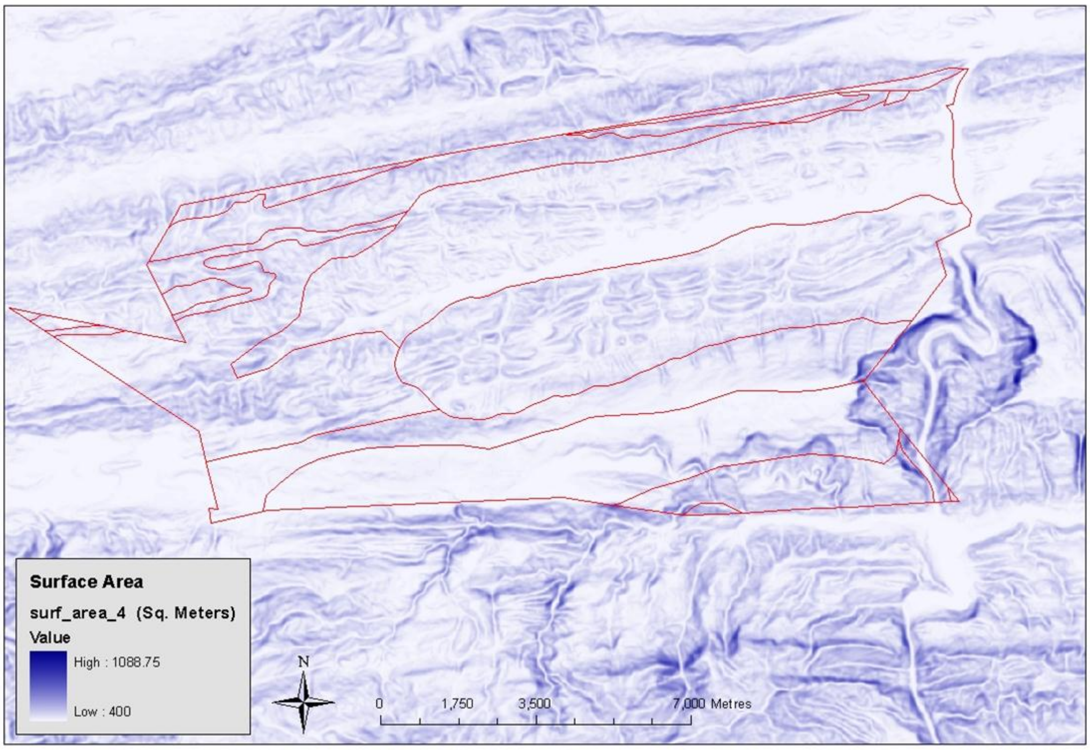


Figure 3.40 Raster-based surface area display for BLK PNR from Jenness extension application

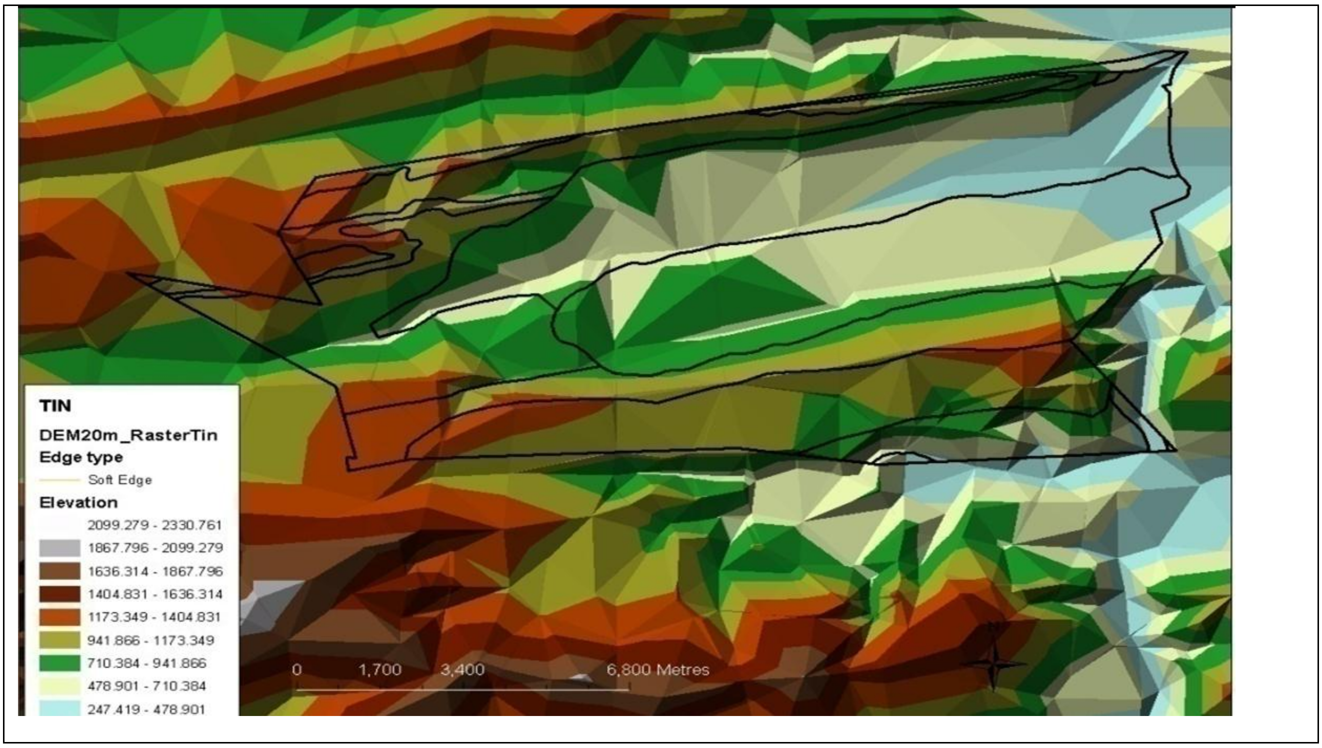


Figure 3.41 TIN model for BLK PNR with z tolerance equal to the default suggested by the software

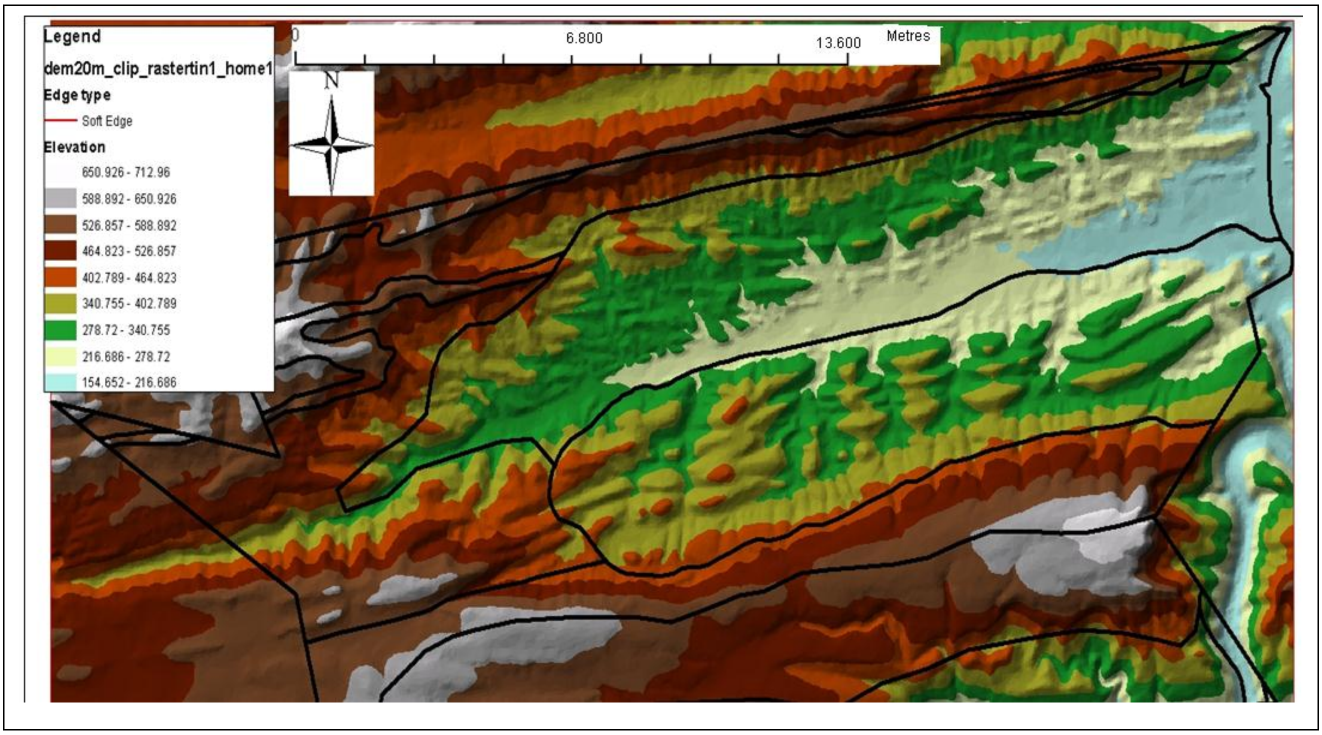


Figure 3.42 TIN model for BLK PNR with z tolerance of 0.5

set created by using the Jenness extension and to the 10-m DEM which was used to create it. In ArcGIS the relevant vegetation polygons inside the BLK PNR study area were clipped from this TIN and surface area grid and the areas calculated by vegetation type.

Comparison of the two methods led to several useful conclusions, both concerning the difference in results and the strategic considerations relevant when deciding which method to employ. The results marshalled in Table 3.1 show that the refined calculations improved area by almost 10%

Table 3.1 Area covered by different biomes in BLK PNR

Vegetation community	Planimetric area in ha (%)[1]	TIN area in ha (%)[2]	Jenness area in ha (%)[2]
North Swartberg Sandstone Fynbos	1432.7 (100)	1586.7 (110.7)	1545.6 (107.9)
South Swartberg Sandstone Fynbos	2039.9 (100)	2160.4 (105.9)	2163.2 (106.0)
Matjiesfontein Quartzite Fynbos	472.2 (100)	490.2 (103.8)	529.8 (112.2)
Matjiesfontein Shale Renosterveld	2914.7 (100)	3086.9 (105.9)	3241.6 (111.2)
Prince Albert Succulent Karoo	4541.9 (100)	4737.2 (104.3)	4900.4 (107.9)
Gamka Thicket: SANBI map	3598.1 (100)	3813.5 (106.0)	4008.6 (111.4)
Total	**15513.0 (100)**	**16392.7 (105.7)**	**16909.9 (109.0)**
Spekboom: Automated classification	1017.9 (100)	1073.2 (105.4)	1044.8 (102.6)
Spekboom: Manual classification	900.1 (100)	951.0 (105.7	918.8 (102.1)
Southern Karoo Riviere	513.5 (100)	517.9 (100.9)	520.6 (101.4)

[1] The planimetric dimension as originally mapped is taken as the benchmark calculation (100%).
[2] The three-dimensional calculated area figures expressed as a percentage of the benchmark planimetric original.

(larger) on average in the case of the more accurate Jenness method, versus 6% for TIN. The total area of BLK PNR was calculated as just smaller than 17 000 ha – almost 1500 ha more than the planimetric total. For the Gamka Thicket alone the same calculation is more than 11% up on the original – although this is greatly reduced when calculated for the more patchy manual demarcation of spekboom alone. Note how significant the more accurate demarcation of spekboom alone is for CT calculation (it covers only 25% of the Gamka Thicket Biome under which it falls). Both methods show little difference between automated and manual classification of the area for spekboom. The differences between the area calculation methods are clearly related to the type of terrain – as can be expected the Southern Karoo Riviere which occupies the near-flat river valley yields an almost 100% correspondence with planimetric values. Contrariwise, vegetation groups occurring on the steep mountain sides, yield up to 10% greater areas than the planimetric measurement.

3.8.3 Advantages of 3D data structures to measure true surface area and recommendations for their use

The results of the two sets of area calculations are quite similar. The similarities and differences are highlighted below to help decide which process best suits the purpose of measuring true surface area.

First, regarding the use of TINs to generate 3D areas. TINs are continuous surface-based DEM elevation values. They can be precisely clipped to polygon boundaries and measured. There are many advantages of using vector-based data sets such as TINs. These include the following: they are not affected be edge-effect problems; they are more reliable and accurate over areas with low cell counts; they take up less space on hard drives; and they are more aesthetically pleasing to display.

Second, regarding surface area grids for generating 3D areas. Some advantages of using raster-based data sets are: they are useful for measuring topographic roughness or ruggedness; they good for neighbourhood analysis (values of a region) which is good over multiple scales; they have a much faster processing speed over TINs which take much longer; and they have more consistent and comparable output.

TINs are often generated according to a specified accuracy tolerance in which the surface must come within a specific vertical distance of each elevation point, meaning that a TIN surface rarely goes exactly through all the base elevation points on the landscape. Two TINs may have been generated with different tolerances, making surface statistics derived from those TINs incomparable. This is especially problematic when the TINs are derived using whatever default accuracy is suggested by the software, and this generally varies from analysis to analysis based on the range of elevation values in the DEM.

The Jenness method, however, always produces a surface-area grid that takes full advantage of all the elevation points in the DEM. Surface-area statistics derived from any region may then be justifiably compared with any other region. Surface area grids have more accurate extents and proportions of resources within a particular region, especially those associated with particularly steep or flat regions. Strategically, the Jenness extension calculates surface areas much faster than 3D Analyst (TIN), and with similar accuracy. It is much easier to calculate final areas from the Jenness extension because it clusters the same classified polygons with identical field ID values and provides statistics representing the combined areas, such that each record in the statistics table represents a unique zone or group. The TIN, contrariwise, calculates the area of each polygon and offers statistics on each polygon separately regardless of whether they have identical field ID values. In this study accuracy and precision increased rapidly with increasing cell counts and the calculated surface-area value was consistently close to the TIN-based area value at cell counts above 250.

The application of the TIN data structure and the true surface area data structures (Jenness method) on BLK PNR led to some recommendations. This research concentrates on calculating area and is unconcerned with downstream modelling so that the raster route is suggested. If area calculation starting from fine resolution is the point of departure, choice of method is immaterial. Scrutiny of the values calculated in the previous subsection shows that there is little difference in the results of calculating true surface area. For CT purposes the Jenness method's more accurate map is preferable. The surface areas reported in this chapter were used in the accounting process to calculate the amount of potential carbon credits that could be accumulated from each type of vegetation. Next the automatically classified vegetation map was compared to the manually classified vegetation map (deemed 100% correct) to determine its accuracy.

3.9 ACCURACY ASSESSMENT OF THE AUTOMATED MODE OF SEGMENTATION AND CLASSIFICATION

Accuracy assessment was done by comparing the manually classified map with the automated object-recognized map. The aim of the accuracy assessment was to determine how successful automated classification was at identifying and classifying stands of spekboom. Errors of commission and omission were expressed as percentages and it was assumed that the manually classified map is 100% correct, the accuracy of the automated classified map being compared against this benchmark. The two maps were overlaid to conduct a pixel-by-pixel comparison in GIS using the union analysis tool. Concerning errors of omission and commission, Lotz (2012: 87) has noted that:

> the error of omission is calculated as a per cent of the number of sample points that should have been classified into a particular class but were not. The error of commission is calculated as the per cent of sample points that were placed into a given class when in fact they belong to another.

In this study errors of omission were taken to be the polygons classified in the manual classification but not in the automated classification, errors of commission deemed what is classified in the automated classification but not in the manual classification.

To conduct the accuracy assessment the automated classification and the manual classification polygons were imported into GIS. Using the union analysis tool the two sets of data were compared. The output of the comparison was presented in an attribute table. Where polygons were correctly classified a value of 1 was given and where the classification was incorrect a value of 0. Three fields were created in the attribute table, that is 'correct', 'omission' and 'commission'. Each group was defined by using the select by attributes tool. The 'correct' field was defined as all values manually classified=1 and automated classified=1; 'omission' was specified as manually classified=1 and automated≠1; and 'commission' was fixed as manually classified≠1 and automated classified=1. Field calculator was used to summarize the results into the sum of the areas.

The incidence of omission and commission was relatively high which suggests that eCognition's classification was not as successful as hoped. By adding all the values and dividing the total by the correct value the percentage degree of accuracy was determined. Multiple runs produced accuracy values between 64% and 69% agreement between the automated classification and the manually classified map which was considered 100% correct.

The manually classified vegetation map and the automated classified map of BLK PNR are depicted in Figure 3.43 (automated demarcation of spekboom) and Figure 3.44 (manual demarcation of spekboom). Visually, these images are quite similar although close inspection reveals some faults which are attributable to a number of reasons. Regarding commission errors eCognition misclassified some polygons with similar spectral values as spekboom. This is apparent in Figure 3.43 at the bottom of the image where many single spots were classified by the automated method but not in the manual map. The automated map generally classified more spekboom than the manual map. This is most likely due to the spectral similarity of spekboom and other occurrences of vegetation. In the automated map, spekboom was classified on southerly slopes

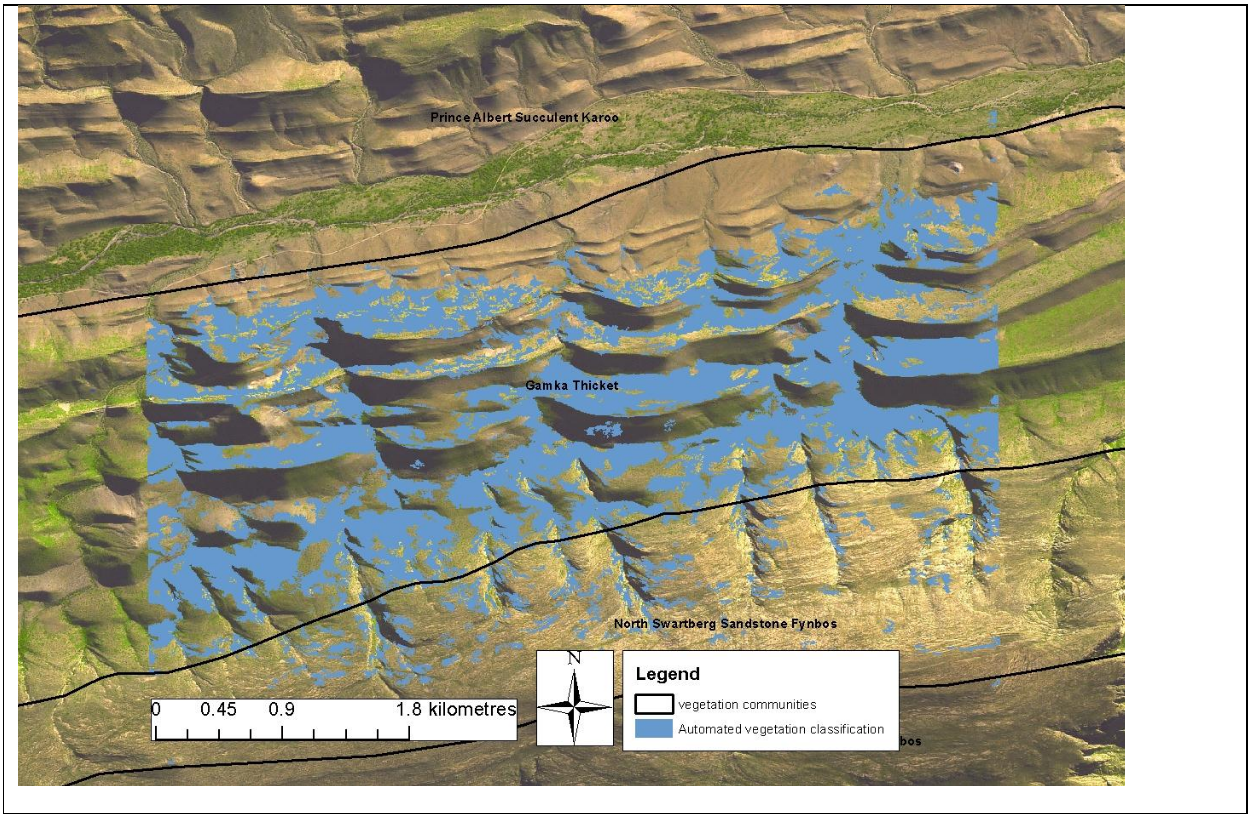


Figure 3.43 Automated demarcation of spekboom

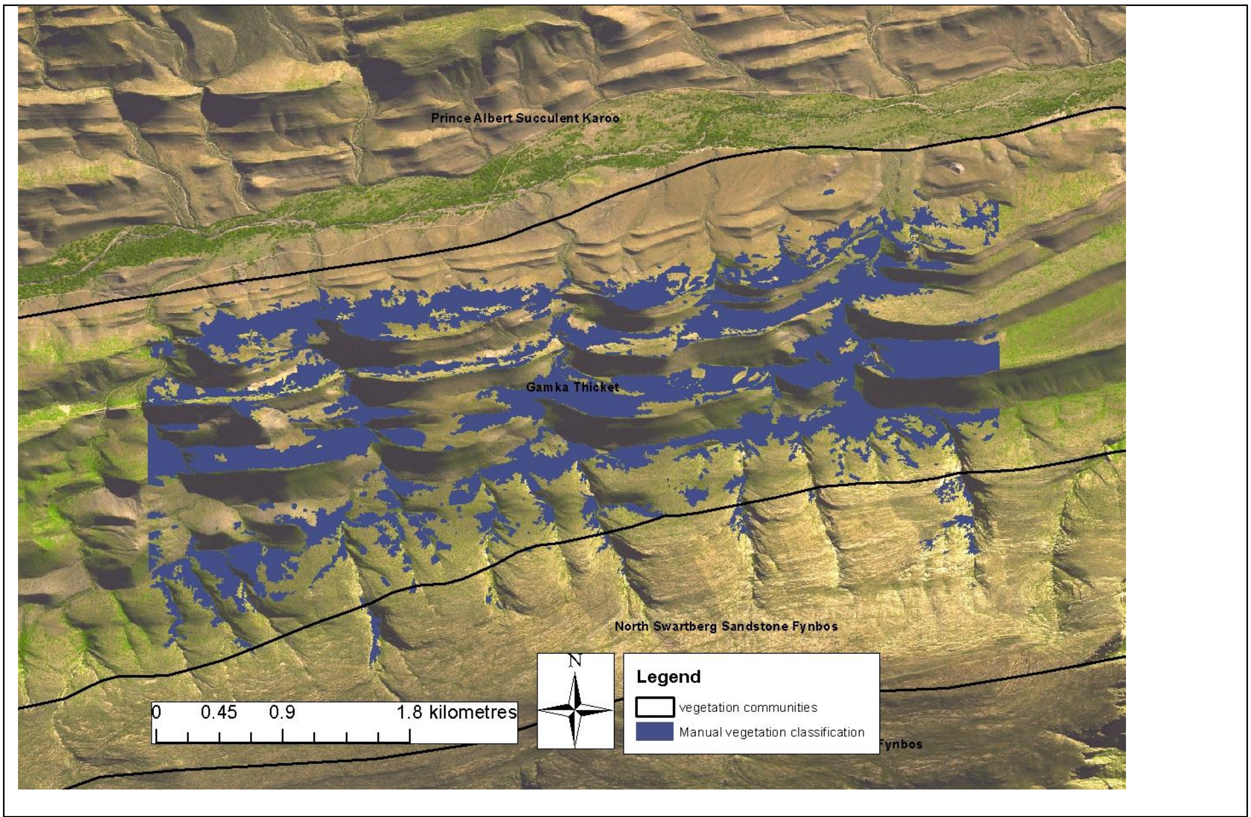


Figure 3.44 Manual demarcation of spekboom

where it does not occur. Because of shadow on the southerly slopes its spectral similarity to spekboom no doubt accounts for this misclassification. Misclassification also occurred north of the stands of *Acacia karroo* where the Matjiesfontein Shale Renosterveld and the Prince Albert Succulent Karoo occur on a north facing shaded slope. In the case of omission errors, the classification could have missed spekboom on steeper slopes where its spectrum is slightly different. Also, spekboom occurs in less dense patches (due to degradation) on the northern slope so eCognition failed to identify this as spekboom. By increasing the scale for segmenting the image this fault would probably have been avoided. Accuracy will be improved by segmenting at a finer scale to classify smaller stands. This would be especially beneficial in areas where spekboom is degraded and occurs in patches or single stands. Accuracy could be further improved by choosing more samples of each class, where they occur on all aspects. More experimentation could have been conducted using more aspects in feature space, such as texture. The eCognition program tended to crash and freeze regularly when dealing with high-resolution imagery. This caused frustration and time-wasting in the experimentation. What helped (but did not entirely solve the problem) was to clip the image into smaller sections and run each section separately.

Even though eCognition's results were disappointing, it provided a platform for automated vegetation mapping. All the mapped and calculated true surface areas of features from this section was used in the final carbon accounting process to determine carbon content in the study area, as shown for BLK PNR in the next chapter.

CHAPTER 4 CARBON SEQUESTRATION POTENTIAL AND BIODIVERSITY CONSIDERATIONS ON BLK PNR

This chapter gives an account of the CS potential of BLK PNR for use in the carbon accounting process. The CS potential of each vegetation type mapped in BLK PNR was calculated based on areas worked out in the previous chapter. The chapter commences by determining the universal and spekboom-specific requirements for accurately calculating CS potential and concludes with a biodiversity valuation of BLK PNR. The CS potential and the biodiversity considerations are used in Chapter 5 to calculate BLK PNR's CT potential.

4.1 DETERMINING CARBON SEQUESTRATION POTENTIAL

The feasibility of restoring subtropical thicket and avoided deforestation for trading in carbon markets is largely a function of the thicket's CS potential and total soil carbon (TSC). To trade through CS, baseline carbon content measurements must be conducted on-site for each project. In this section the principle of CS measurement is outlined, following which the methods for measuring the constituent elements of carbon storage, namely soil carbon, above-ground biomass and root carbon to establish total carbon content are described. Given the high CS potential of spekboom, attention will be placed on this vegetation type. The regional variations in spekboom CS potential are identified and the reasons for the disparities are examined to determine spekboom CS equivalency for BLK PNR. CS values for the other vegetation groups in the study area are derived from the literature as averages per biome. These deviations had to be done when faced with the relevant research results concerning the South African vegetation.

4.1.1 The principles of carbon sequestration measurement

To measure the rate at which carbon is taken from the atmosphere through photosynthesis (i.e. CS) is a complicated and time consuming procedure. Accurate measurement of CS is critical as changes in carbon stocks constitute the 'creditable' portion of a CS project. Accurate measurement and monitoring methods are available, however most are labour intensive and require large numbers of sample plots (Pro Natura 2008). Consequently, there is a need for rapid, feasible and cost-effective methods and tools for measuring baseline soil carbon, modelling carbon offsets, and monitoring land management systems that contribute to CS across all biomes (Perez et al. 2007).

According to the rules of the Kyoto Protocol for the first commitment period, CS is expressed as tC/ha/year in soil, litter and living biomass and CO_2 emission reductions in tC/ha/year (UNFCCC

2001). For any offset project, the total organic carbon (TOC) of target organisms must be measured as well as the rate of CS.

The total carbon content of a specific plant is calculated as the sum of the components as in:

Total organic carbon (TOC) = total below-ground carbon (TBGC, i.e., root carbon + soil C) + total above-ground carbon (TAGC = herb carbon + litter carbon + woody C).

To measure the rate of CS, the rate of TOC return to soil must be analysed. Mills & Cowling (2006) calculated the rate of CS for a spekboom restoration project by dividing the difference of total carbon components (soil, biomass, root carbon) of the transformed block (degraded) and the restored blocks (revegetated) by the number of years of restoration. This process is repeated over 30 sample plots to make an accurate estimation. The calculation gives the change in carbon storage over time, so the rate of carbon return to the soil during CS.

4.1.2 Carbon sequestration measurement in practice

Most approaches for assessing soil carbon at a field scale follow the protocol outlined by Lal (2000) which includes soil mapping, soil sampling, measuring soil-bulk density, preparation and analysis. While rapid assessment methods for point measures continue to advance, there is no standard method for scaling up soil carbon from point measurements to regional scales (Lal 2005).

To measure soil carbon, a minimum of 30 plants must be sampled to get a mean CS value for a species. Mills & Cowling (2010), Powell (2009), Powell, Mills & Marais (2008) and Mills & Cowling (2006) served to compile baseline measurements of the TOC of spekboom, while Emmer (2009) provided useful comments on the methods of CS measurement. The fundamentals of measuring soil carbon, above-ground carbon, soil carbon and the total carbon content are elucidated next.

4.1.2.1 Measuring soil carbon

The volume of soil carbon storage is calculated from the soil carbon content, the bulk density of soil and the volume of stones at each depth interval. Soil carbon is usually measured by destructive soil and vegetation sampling and by determining the mass of organic matter or carbon in a sample. Emmer (2009) has provided a formula for calculating soil organic carbon (SOC):

SOC=[SOC] Bulk density* Volume (1-Coarse fragments)*, where

SOC= soil carbon stock (Mg C/ha)

[SOC]= concentration of soil carbon (g C/kg)

Bulk density = (Mg/m^3)

Coarse fragments= volume of stones at each depth interval or layer, subtracted from each depth layer to provide an estimate of soil volume in each layer (Emmer 2009).

Mills & Cowling (2006) prescribe the following sequential steps to calculate soil organic carbon:

- Remove 1 m^3 sample material from a pit 1 m deep under the plant canopy or as deep as the plant root system extends.
- Measure bulk density first. The bulk density of soil under spekboom is estimated by excavating samples 100-150 mm into the soil pit wall for the following depth intervals: 0-100, 101-500, 501-1000 mm. The dimensions of each excavation for each sample are recorded to determine the soil volume. After air-drying (by contact with unheated air) the samples are weighed and sieved to remove roots and stones larger than 2 mm. Stones are weighed and the volume of stones is determined by water displacement. Bulk density is calculated by dividing the mass of soil by the volume of soil (both excluding stones >2 mm).
- Two methods for determining total soil carbon (TSC) of the removed sample material are available.

▪ First, Mills & Cowling (2010) analysed TSC by complete combustion of the sampled material and thus all the carbon content, using a EuroVector Elemental Analyzer. Procedures entail air-drying of samples and sieving to 2 mm diameter to remove small rocks, and then milling with a ball mill to a fine powder before analysis. Calcrete (i.e. calcium carbonate) is sometimes evident at the bottom of pits, consequently inorganic carbon contributes to the total soil carbon of some samples. Samples with inorganic carbon can be identified as those that effervesced after addition of 3M HCl[1] (diluted hydrochloric acid). The inorganic carbon content of these samples is determined and described by the U.S. Salinity Laboratory Staff (1954) which entails gravimetric measurement of the loss of CO_2 after reaction of the sample with 3M HCl. Inorganic carbon should be subtracted from total carbon to determine the organic carbon content.

▪ Second, Powell (2009) suggests using the Walkley-Black method as summarized in De Vos et al. (2007) as concentrated H_2SO_4 (sulphuric acid) added to a mixture of soil and aqueous $K_2Cr_2O_7$ (potassium dichromate, a common inorganic chemical reagent used as an oxidizing agent). The heat of dilution raises the temperature sufficiently to induce a

[1] 3M HCl: add 3mol/12M = 250 ml conc. HCl to 1L of water or 25 ml to 100ml

substantial, but not complete, oxidation by the acidified dichromate. Residual dichromate is back titrated using ferrous sulphate. The difference in added $FeSO_4$ (iron sulfate or ferrous sulfate) compared with a blank titration determines the amount of easy oxidizable organic carbon.

With soil carbon determined, above-ground carbon becomes the next element to measure.

4.1.2.2 Measuring above-ground carbon biomass

Aerial plant carbon is estimated using allometric equations derived from destructive harvesting. The method entails the following procedures:

- Before harvesting, record the measurements of stem numbers, plant height and mean canopy diameter; systematically separate into leaves, branches, thorns, flowers, fruit and main stem for carbon partitioning estimates; weigh the wet material listed above.
- Dry sub-samples using a modified fruit-drying oven at 60ºC to constant weight; the species-specific and component-specific (leaves, thorns, etc.) dry:wet ratios (which are different for each species) serve to convert the remainder of the wet biomass to dry biomass.
- Powell (2009) has proposed a dry mass to carbon conversion ratio for spekboom of 1:0.48. Mills & Cowling (2006) specify a ratio of 1:0.32 for stems thicker than 30 mm and 1:0.23 for stems less than 30 mm in diameter. The carbon content of biomass is calculated by multiplying dry matter mass by 0.48 (Lamlom & Savidge 2003; Powell 2009).

With above-ground carbon measurement determined, root carbon measurement was attended to next.

4.1.2.3 Measuring root carbon

Roots are extracted by wet sieving from the same samples used for determining biomass. The extracted roots are dried in an oven at 60°C. The carbon content of the roots can be assumed to be 50% of the dry root mass (Birdsey 1996; Mills & Cowling 2010). Lechmere-Oertel (2003) reported a comparison of above- and below-ground biomass, the results indicating that for all perennials excluding canopy trees, the above-ground biomass was approximately twice that of below-ground mass.

Having determined how to measure root carbon, preceded by above-ground and soil carbon, it remained to calculate total carbon content.

4.1.2.4 Measuring total carbon content

The total carbon content of a specific plant is calculated as the sum of the components discussed above, or:

Total carbon stocks (TCS) = Total below-ground carbon (TBGC, i.e., root carbon + soil C) + Total above-ground carbon (TAGC = herb carbon + litter carbon + woody C).

Normality (being within certain limits that define the range of normal functioning) can be tested using the Shapiro-Wilks test, homogeneity of variances using Levenes test and subsequently differences can be tested using a Kruskal-Wallis analysis of variation (ANOVA) (Powell 2009).

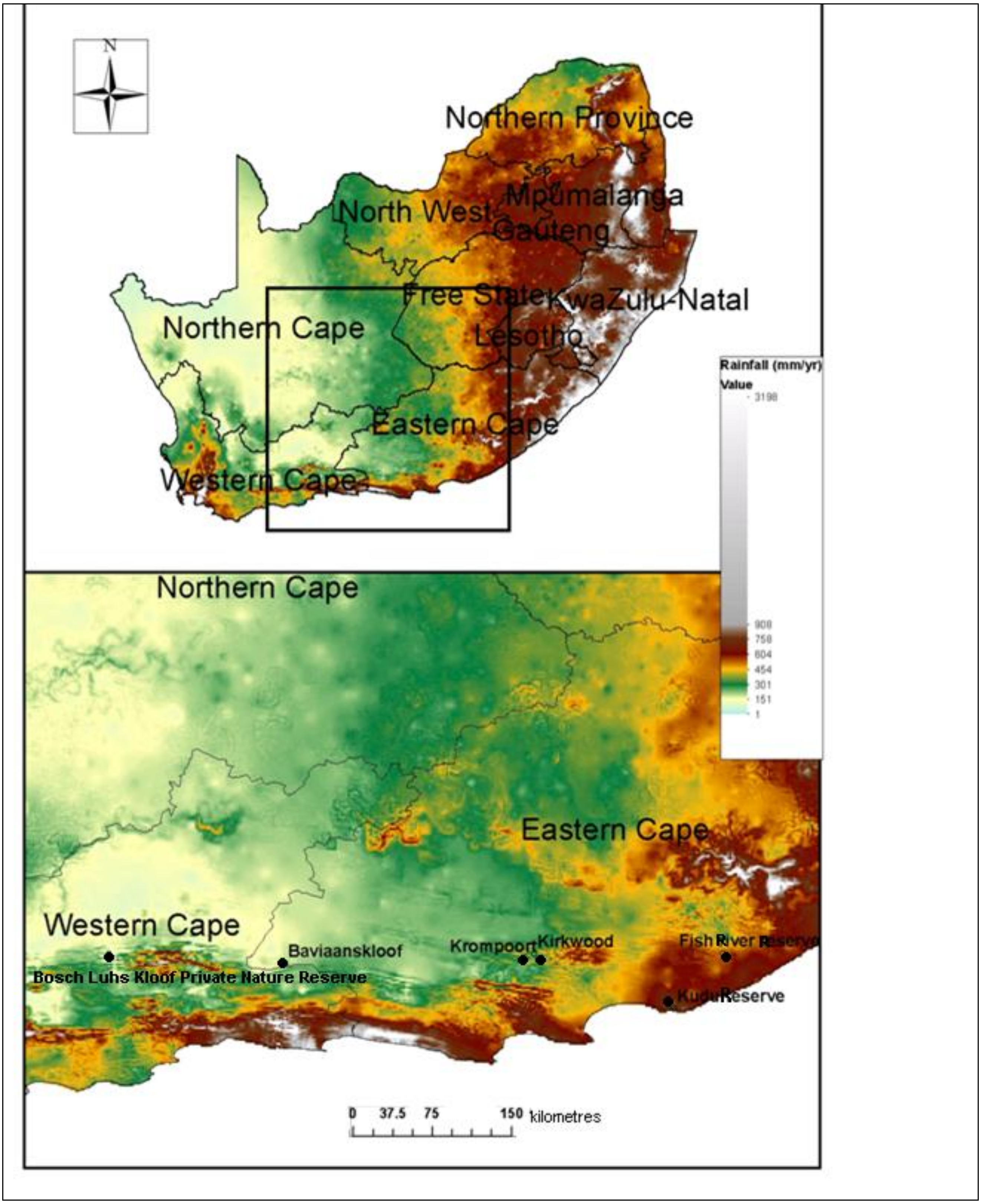
The high carbon content of spekboom is attributed to its high vegetative mass, consisting of living biomass, a surface litter layer build-up in intact thicket (160 t of dry matter per ha) (Mills, O'connor et al. 2005) and this is further increased with associated slow decomposition rates (Mills & Fey 2004a). On-site soil analysis using the above carbon measurement process from a variety of case studies (Birch 2000; Mills et al. 2003; Lechmere-Oertel 2003; Winston et al. 2004; Mills, Cowling et al. 2005; Mills & Cowling 2006; Powell, Mills & Marais 2008; Powell 2009; Mills & Cowling 2010; Mills et al.2011) was used to determine CS potential of BLK PNR.

4.1.3 Variations in the potential of spekboom carbon sequestration

It is problematic to establish useable CS potential numbers for vegetation species in different geographical settings subjected to variant geographical conditions (soils, climate etc.). This is especially so concerning spekboom which occurs along a sub-escarpment belt stretching from the Eastern Cape to the western reaches of the Swartberg range in the Western Cape. This section reports on extrapolating CS values from different study sites to equivalent values for use in BLK PNR. A variety of study sites (where empirical studies for CS have been conducted) was investigated to identify the distribution of carbon content across the Thicket Biome. Conclusions had to be drawn from insights into the discrepancies between values for various experimental sites.

Diverse study sites have been investigated by researchers to prepare for trade in the carbon market for spekboom. Five studies have used the procedures expounded above to distinguish variations in spekboom carbon content at locations in the Eastern Cape (Figure 4.1) which represents diminishing rainfall profiles from east to west.

The approach followed here was to establish measured carbon content at these locations, relate these values to the geographical factors rainfall, geology and soil type and then to extrapolate the known numbers to the study region at BLK PNR. These factors affect CS and TSC and subsequently CS and TSC potential. Relevant attributes from the five experimental sites and from



Source: Adapted from Schulze & Maharaj (2006)

Figure 4.1 Location of case studies in the Eastern and Western Cape relevant to the rainfall profile reliable spatial climate information (Schulze & Maharaj 2006) are summarized in Table 4.1 together with the source references. By comparing study site location and rainfall regimes, equivalent CS

Table 4.1 Comparison of experimentally established spekboom CS potential and related geographical attributes

Case study	**Source reference**	**Landscape, geology and soil**	**Average rainfall** (mm)	**Measured CS potential (** tC/ha/yr)	**Total carbon storage (** tC/ha)
Fish River Reserve	(Birch 2000; Winston et al. 2004; Powell 2009; Mills et al. 2011)	Steep river valleys with inter-basin ridges. The river valleys contain the nutrient-rich mudstones, which are extremely susceptible to erosion, while the more resistant sandstones occur on the interbasin ridges. Predominantly grey/red mudstone and sandstone of the Middleton Formation (Adelaide Subgroup: Karoo Supergroup), with sandstone dominating the formation.	451	4.4	127
Kudu Reserve	(Mills & Cowling 2006)	Beaufort Group shale of the Adelaide Formation and Ecca Group shale of the Fort Brown Formation.	400-450	1.2	65
Kirkwood	(Lechmere-Oertel 2003; Mills, Cowling et al. 2005)	Relatively flat areas with overlying Uitenhage Group sediments that give rise to fine-textured soils, often overlying a calcrete layer.	250-350	8	209
Krompoort	(Mills & Cowling 2006; Powell 2009)	Valley between Groot Winterhoek mountain range and Klein Winterhoekberge. Table Mountain Group quartzite sandstones (Nardouw Formation and Peninsula Formation, Bokkeveld shales, siltstones of the Ceres and Traka Subgroups)	250-350	4.1	110
Baviaanskloof Nature Reserve	(Mills et al. 2003; Mills & Cowling 2006; Powell, Mills & Marais 2008; Powell 2009; Mills& Cowling 2010)	Restricted to the valley slopes between the parallel ranges of the Kouga and Baviaanskloof mountains. Table Mountain quartzites (nutrient-poor soils) – Peninsula, Skurweberg, Goudini Formations and Bokkeveld shales (nutrient-rich soils) in valleys.	250	4.1	93 ± 7 (110 cm) (Mills & Cowling 2010) 87.73±6.51 (25 cm) (Powell 2009)

and total carbon estimates for BLK PNR were based on the experimental numbers obtained from the case studies. Preferably, total carbon measurement should be made to the same depth for all experimental case studies, but both root carbon and soil carbon diminish rapidly with increasing soil depths (Mills & Fey 2004a; Mills & Cowling 2006) so that measurement to different depths should not affect comparisons significantly. The two Baviaanskloof experiments measured to a depth of 25cm and 110cm respectively, compared to standard depths of 30cm for the other studies. At Baviaanskloof, Mills & Cowling (2010) registered spekboom carbon content of 93± tC/ha to a depth of 110cm and Powell (2009) measured to a depth of 25 cm finding 87.73 ± 6.51 tC/ha. So, a study pit more than four times deeper yielded less than 5% difference in carbon, because almost all the soil carbon is stored in the first 25cm of soil. These depths support the logic of regional comparison with 30-cm pits at the other study sites.

A comparison of carbon potentials and carbon storage figures of the sites in Table 4.1 shows no clear and consistent relationship between regional location, landscape type and rainfall differentials moving from east to west. Consequently, other explanations must account for the discrepancies between carbon content values so as to inform a sound choice of an equivalency value for BLK PNR spekboom based on these experimental results. These factors are considered next.

4.1.4 Accounting for carbon sequestration differences between sample points

According to Marais et al. (2009) sequestration rates vary according to climate, plant density, herbivory intensity and soil type. Because rainfall is the major factor accounting for CS differentials it is discussed in detail, followed by comments on other factors that are likely to contribute to differences. In conclusion, the selection of a study site for approximating spekboom's CS potential in BLK PNR is justified.

4.1.4.1 Rainfall variation as main difference

Average rainfall figures at case study sites were obtained from the sources reporting the case studies and from Schulze & Maharaj (2006) (see Table 4.2).

Table 4.2 Mean annual rainfall of selected study sites

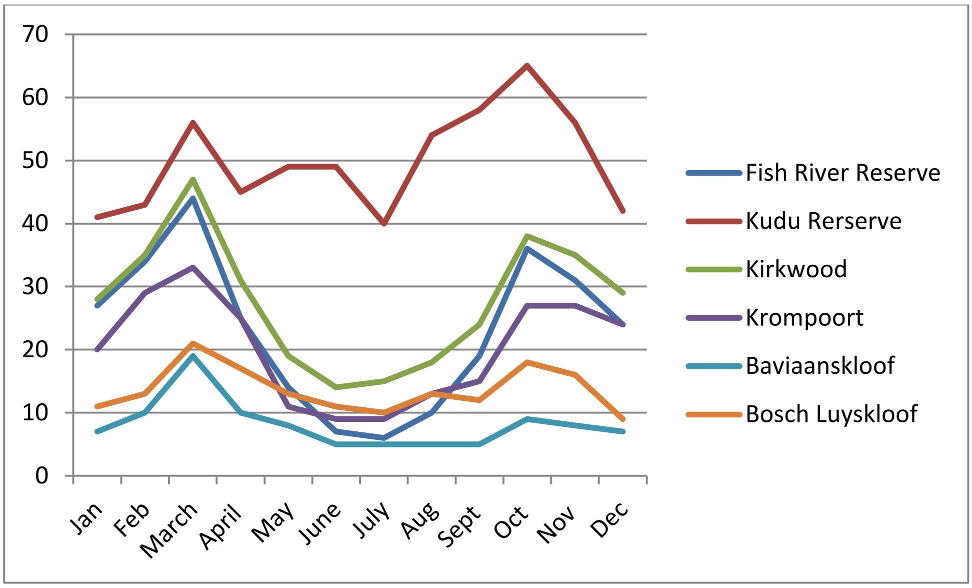
Case study	*Rainfall (mm)*
Fish River Reserve	450
Kudu Reserve	400-450
Kirkwood	250-350
Krompoort	250-350
Baviaanskloof Nature Reserve	250
Bosch Luys Kloof Private Nature Reserve	230

Compiled from: Schulze & Maharaj (2006); Mills & Cowling (2006); Powell (2009)

BLK PNR rainfall matches that of Kirkwood, Krompoort and the Baviaanskloof Nature Reserve approximately, but is closest to the latter site, thus allowing some claim to equivalency for BLK PNR CS potential vis-à-vis these three case studies. Powell (2009) ascribes the difference in total organic carbon (TOC) of spekboom between the Fish River Reserve and the Baviaanskloof Nature Reserve spekboom (see Table 4.1) thickets to a higher annual rainfall.

Ecologists readily assume a positive linear relationship between biomass volume and rainfall (lower in deserts and higher in forests) (Woodward 1987). It is assumed that low water availability in warm, semi-arid landscapes limits accumulation of biomass because water demand increases with increased biomass. While true, exceptions to this rule occur in semi-arid and arid lands where water is not the primary limiting factor to CS (Mills, O'connor et al. 2005). Physiological decoupling from water limitation can also occur where Crassulacean acid metabolism (CAM) systems allow highly efficient use of water and thus relatively high productivity and biomass in areas with very low rainfall (Guralnick & Ting 1986; Maxwell, Griffiths & Young 1994; Mills & Cowling 2006). Lechmere-Oertel (2003) and Lechmere-Oertel et al. (2008) note that increasing aridity favours the percentage cover of spekboom which is a copious litter producer. To what can one attribute this anomaly, this deviation from the standard assumption that carbon accumulation is positively correlated with a rainfall gradient?

An explanation for the phenomenon is that spekboom cyclically seasonally shifts its photosynthetic pathway from CAM during summer to carbon fixation of 3-phosphoglycerate (C3) in the winter and spring (Guralnick & Ting 1986). Most plants experience their main vegetative period using the C3 photosynthetic pathway when rainfall is plentiful, as is the case with spekboom during winter (when most rainfalls if in a winter-rainfall area). However, during the drier months when most plant growth slows or stops, spekboom switches its photosynthetic pathway to CAM, continuing in the vegetative stage. By being in the vegetative stage all year round, spekboom's high leaf and litter production, hence its high carbon storage potential, is accounted for. During winter and spring the rapid response of spekboom to rewatering and its lower water loss, favour additional carbon gain as a C3 plant (Guralnick & Ting 1986). So, does a rainfall regime tending toward more winter rain as one moves westward point to the more accurate appraisal of CS values for BLK PNR? Figure 4.2 displays the rainfall regimes of the studied sites. The graphs show that the two western-most locations (BLK PNR and Baviaanskloof Nature Reserve) have the following features: 1) they are the most arid; 2) they have the lowest summer peaks, i.e. tend toward an all-year rainfall pattern with more gentle summer peaks; and 3) rain falls more often in winter when it is more effective. This suggests a relationship between rainfall regime and CS potential for spekboom,



Source: Calculated from Schulze & Maharaj (2006) data

Figure 4.2 Median monthly rainfall for study sites

especially given its ability to switch its storage mechanism. Because BLK PNR's rainfall regime is very similar to that of Baviaanskloof the latter's CS characteristics seem more applicable to adopt for the BLK PNR, than those of the case studies further east. An arid environment encourages the switch from C3 to CAM which increases carbon accumulation. More frequent rainfall (low water stress) encourages spekboom to switch back to C3 and lower carbon accumulation. Therefore, most carbon accumulation occurs in areas where the CAM pathway is used, while at the same time sufficient rainfall occurs to maximize carbon accumulation. Guralnick & Ting (1986) have noted that after seven-and-a-half-months of drought spekboom completely eliminates exogenous CO_2 uptake, therefore even if increasing aridity favours spekboom coverage, there is a limit to the level of aridity it can withstand. Yet, Borland et al. (2009) showed that CAM plants can survive several years without rainfall. They also concluded that the highest values of daily net CO_2 uptake reported for CAM species exceed those of nearly all productive C3 and C4 crops and occurred under rain-fed as well as dry conditions when moderate day and night temperatures prevailed.

More research is needed into this switching point, the conditions under which CS is maximized, and the rate of carbon accumulation by spekboom in conjunction with precipitation. It seems justifiable to assume that spekboom in the relatively arid BLK PNR may offer higher CS yields than intuitively expected.

4.1.4.2 Other factors causing CS differences

According to Mills & Cowling (2010) soil samples, planting density and soil quality all affect the rate of CS in spekboom occurrences. These factors are discussed in turn.

i. Concerning differences in *soil sampling* and analysis techniques, Mills & Cowling (2010) ascribe discrepancies between values to: 1) not including rock volume in some calculations, 2) differentials in soil nutrient status between sites, 3) differences in soil sampling depth and 4) not factoring in soil bulk density. Differences in the method of analysis possibly contribute to the recorded differences in soil carbon stocks. For example, (i) soil bulk density in Baviaanskloof was relatively low (0.76-0.08 g/cm^3, 0-3 cm deep in intact thicket under canopy) suggesting that by calculating bulk density from texture, as done in Kirkwood (range of 1.21–1.35 g/cm^3) soil carbon stocks were overestimated; (ii) stone volumes in Baviaanskloof Nature Reserve were relatively high (e.g. 22% at 0-25 cm deep under canopy in intact thicket) and were not accounted for in the Kirkwood study; and (iii) the Kirkwood study sampled to a depth of 30 cm in contrast to the 25 cm of the Baviaanskloof study. Notwithstanding the above issues and the large amount of soil carbon in the Kirkwood case, the soil carbon stocks recorded in Baviaanskloof Nature Reserve, Krompoort and the Fish River Reserve are exceptionally large relative to other semi-arid regions (Mills, O'connor et al. 2005). Slower sequestration in the Kudu Reserve was ascribed to browsing by black rhinoceros and other herbivores, shallower soil and greater stone volumes (Mills & Cowling 2006).

ii. Mills & Cowling (2006: 3) aver that "*Planting density* [own emphasis] and spekboom genotype appeared to affect sequestration at Krompoort. Closely-packed spekboom planting may create positive feedback through increased infiltration of rainwater." While there are areas of degraded spekboom on BLK PNR, the intact state of dense and tall (up to 2 m) spekboom stands (illustrated in Figure 4.3) supports an argument that different planting densities should not be a factor in assigning CS values to occurrences of spekboom in BLK PNR.

iii. Furthermore, regarding *soil quality* Mills & Cowling (2010: 98) have observed that: (a) "nutrients play a role in stabilizing organic carbon in the soil; (b) soil organic matter strongly influences nutrient holding capacity; and (c) other factors, such as site productivity, govern both soil nutrient and carbon stocks". However, Mills et al. (2011) investigated the relationship between spekboom cover and soil properties and concluded that in the thicket biome, landscapes are dominated by spekboom veld or Spekboom Thicket (Vlok, Euston-Brown & Cowling 2003) across an exceptionally wide range of climatic and soil conditions. These range between approximately 200-800 mm mean annual rainfall regimes, nutrient-rich, alkaline, shale-derived soils as well as nutrient-poor, acidic sandstone-derived soils, all

Figure 4.3 Areas densely vegetated with spekboom in BLK PNR

suggesting that spekboom tolerates a wide range of soil conditions and is unlikely to be directly constrained by soil properties.

If rainfall and rainfall regime are governing factors in carbon accumulation, spekboom in BLK PNR (230mm rain a year) (South African Rain Atlas 2006) should possess similar carbon accumulation potential to Baviaanskloof's spekboom. The Baviaanskloof reserve is also a suitable benchmark since soil sampling and analysis techniques employed there precluded overestimation of carbon stocks and spekboom there appears similar in physical characteristics (see in Figure 4.4).

Source: Powell (2009: 35)

Figure 4.4 Spekboom in Baviaanskloof Nature Reserve

It therefore seems justifiable to adopt the CS potential values derived experimentally at Baviaanskloof for use in the CS equivalency for BLK PNR in the next section.

4.1.5 Carbon sequestration equivalency values for BLK PNR

Because spekboom has such a high CS potential, it is the primary type of vegetation investigated in this study. The CS potential values determined in the Baviaanskloof Nature Reserve are used for the BLK PNR spekboom calculations, given the similar rainfall, geological and related physical landscape characteristics of the two environments, as well as the sampling conditions (rock volumes) applicable, so preventing serious over-estimation of carbon stocks in the latter reserve.

An effort was also made to calculate CS values for the other vegetation communities mapped in BLK PNR – also based on values reported for other places. Currently, no reports exist that give CS potential values for specific vegetation families or plant species identified by Mucina & Rutherford

(2006) on BLK PNR (other than spekboom). Fortunately, generalized CS potential values for the broad vegetation biomes in BLK PNR were traced.

Regarding the Thicket Biome, the spekboom stands on BLK PNR were assigned a conservative CS value of 87 tC/ha (determined by Powell (2009) for Baviaanskloof Nature Reserve – see Table 4.1) for intact thicket and a value of 30.5 tC/ha for degraded thicket. The value for degraded spekboom is useful for determining potential carbon loss through vegetation degradation or the CS loss in confirmed historically degraded areas. The CS potential values for the other vegetation biomes on BLK PNR were taken over from results reported by Mills & Fey (2004b), Mills, O'connor et al. (2005), Jindal, Swollow & Kerr (2008) and Powell (2009) and arranged in Table 4.3.

Table 4.3 Carbon content reported at biome level

Biome		***C content (tC/ha)***	***Source***
Fynbos		42-81.0	Mills, O'connor et al. (2005)
		34-65.0	Mills & Fey (2004b)
Thicket	Intact	87.0	Powell (2009)
	Degraded	30.5	Powell (2009)
Karoo		21-50.0	Mills & Fey (2004b)
		30.0	Mills, O'connor et al. (2005)
		30.3 (Acacia)	Jindal, Swollow & Kerr (2008)
Old lands		28.7±1.95	Powell (2009)
Grasslands		97-164.0	Mills & Fey (2004b)

These reported values were used to calculate averages for each biome and vegetation group as presented in Table 4.4. The value of 55 given to the four fynbos communities present in BLK PNR approximates the two value ranges for fynbos by Mills and co-authors in Table 4.3 and the 32 for Succulent Karoo derives from the same authors. The Gamka Thicket was differentiated into intact

Table 4.4 Carbon content at the level of vegetation groups

Vegatation community		***Biome***	***Total carbon content tC/ha***
South Swartberg Sandstone Fynbos		Fynbos	55.0
North Swartberg Sandstone Fynbos			
Matjiesfontein Quartzite Fynbos			
Matjiesfontein Shale Renosterveld			
Gamka Thicket	Intact spekboom	Albany Thicket	87.0
	Degraded spekboom		30.5
	No spekboom (southern slopes)		28.6
Prince Albert Succulent Karoo		Karoo	32.0
Southern Karoo Riviere			30.3

thicket, degraded thicket and no thicket (typically the south-facing shaded slopes without spekboom). The latter slopes are given a value of about 29 tC/ha which is the CS value for old lands. The entire Gamka Thicket has the highest expected carbon content but the Fynbos and Karoo Biomes are not insignificant contributors, given the arid regional surroundings where they occur. Southern Karoo Riviere normally occurs in dense, narrow riverine strips ignored in regional mapping exercises, but in this research the community was accurately mapped and an approximate value for carbon content was attributed to it. A value of 30.3 t C/ha was assigned to *Acacia karroo* based on results from Jindal, Swollow & Kerr (2008) who assessed the CS potential for Acacia community plantations in Niger. Intuitively, this value is much too low but in the absence of other information on the species it had to suffice until other carbon content calculations have been made for *Acacia karroo*.

Thus far CT valuation has only been considered on CS, but richness and maintenance of biodiversity is another means for valuing CT. This valuation principle requires attention here and is addressed in the next section.

4.2 BIODIVERSITY VALUATION ON BOSCH LUYS KLOOF PRIVATE NATURE RESERVE

The valuing of ecosystem protection is more complex than merely considering the monetary value of sequestered carbon in selected vegetation. Biodiversity valuation encompasses the entire natural system. CCBA project design (see Table 2.5) requires that a section on biodiversity impacts be completed to identify the benefits a proposed CT project will have on applicable ecosystems. Biodiversity indicators examine the diversity of species and ecosystems within biomes, and evaluate the threats to them. Four methods of valuing biodiversity were used in this study to indicate the importance of ecosystems and biodiversity. First, the total carbon content resident in vegetation across BLK PNR was calculated to determine the carbon stock for conservation. Second, the SANBI (2007) rating of the environmental state for each vegetation group investigated was considered. Third, the economic importance of the ecosystem was calculated according to Turpie (2003). Fourth, some additional indicators and high conservation activities were identified from the CCBA. The following four sections report on these topics.

4.2.1 Conserved carbon content across Bosch Luys Kloof Private Nature Reserve

The per-area CS potential values listed in Table 4.4 were used to calculate the amount of carbon sequestered on the BLK PNR landholding by multiplying each vegetation community's area by its CS value. Table 4.5 presents the results.

Table 4.5 Calculated area and carbon content for each vegetation type in BLK PNR

<table>
<tr><th colspan="2">Vegetation community</th><th>Biome</th><th>Carbon content (tC/ha)</th><th>Area (ha)</th><th>% Area</th><th>Total carbon content (t)</th><th>% C contribution</th></tr>
<tr><td colspan="2">South Swartberg Sandstone Fynbos</td><td rowspan="4">Fynbos</td><td rowspan="4">55.0</td><td>2163</td><td>12.8</td><td>118 965</td><td>15.7</td></tr>
<tr><td colspan="2">North Swartberg Sandstone Fynbos</td><td>1 546</td><td>9.1</td><td>85 030</td><td>11.2</td></tr>
<tr><td colspan="2">Matjiesfontein Quartzite Fynbos</td><td>530</td><td>3.1</td><td>29 150</td><td>3.9</td></tr>
<tr><td colspan="2">Matjiesfontein Shale Renosterveld</td><td>3 242</td><td>19.2</td><td>178 310</td><td>23.5</td></tr>
<tr><td rowspan="3">Gamka Thicket</td><td>Intact</td><td rowspan="3">Thicket</td><td>87.0</td><td>918</td><td>5.4</td><td>79 866</td><td>10.5</td></tr>
<tr><td>Degraded</td><td>30.5</td><td>2 964</td><td>17.5</td><td>90 402</td><td>11.9</td></tr>
<tr><td>No spekboom (southern slopes)</td><td>28.6</td><td>126</td><td>0.8</td><td>3 604</td><td>0.5</td></tr>
<tr><td colspan="2">Prince Albert Succulent Karoo</td><td rowspan="2">Karoo</td><td>32.0</td><td>4 900</td><td>29.0</td><td>156 800</td><td>20.7</td></tr>
<tr><td colspan="2">Southern Karoo Riviere</td><td>30.3</td><td>521</td><td>3.1</td><td>15 786</td><td>2.1</td></tr>
<tr><td colspan="2">Total</td><td></td><td></td><td>16910</td><td>100</td><td>757 913</td><td>100</td></tr>
</table>

The total carbon content for the case study area (16 910 ha) approaches 758 000 tons (53.2 t/ha). This is a large amount of carbon given the arid climate of the area – especially when considering the possibility of CT. The major contributors of carbon in BLK PNR are the Matjiesfontein Shale Renosterveld (23.5%) and the Prince Albert Succulent Karoo (20.7%), but mainly due to the large areas covered by these vegetation types. The contribution by the intact Gamka Thicket (10.5%), mainly spekboom, proves its value beyond its relatively small areal coverage (5.4%).

The next section considers the environmental state of the vegetation in the study area.

4.2.2 Environmental state of vegetation on BLK PNR

The state of the various biomes gives an indication of the need for conservation and helps to identify specific areas on which to focus actions. Normally, an ecologist has to do an on-site field analyses to determine the state of each biome. In the absence of such localized particulars, the conservation status values in Table 4.6 which reflect the national state of each vegetation type can be extrapolated to the respective local conditions. The Sandstone Fynbos communities are generally well protected – formally either through nature reservation or through mountain catchment protection. Large proportions consequently remain intact in their natural state. All the other communities are rather poorly protected, but still have fairly large proportions remaining intact. The condition of Matjiesfontein Shale Renosterveld, Gamka Thicket and Southern Karoo Riviere is

Table 4.6 Conservation status of the BLK PNR vegetation communities

Vegetation community	***Status: % Formally protected (% Private)***	***% Intact***	***Proportion transformed***
South Swartberg Sandstone Fynbos	47% (+35%); Well protected	99.8%	Small portion transformed
North Swartberg Sandstone Fynbos	69.5% (+5.1%); Well protected	98.2%	2% transformed
Matjiesfontein Quartzite Fynbos	5% (+2.8%); Poorly protected	85%	15% transformed
Matjiesfontein Shale Renosterveld	7%; Poorly protected	90.8%	9%; Erosion moderate-high in places
Gamka Thicket	8.8% (+1.8%); Poorly protected	96.4%	Only 4% transformed, however, up to 50% of remaining thicket is degraded.
Prince Albert Succulent Karoo	3% (+0.6%); Poorly protected	98.5%	Low to moderate erosion
Southern Karoo Riviere	1.5%; Poorly protected	88%	12% transformed

Source*:* Mucina & Rutherford (2006)

cause for concern because of substantial and growing extent of transformation. The Gamka Thicket is exceptionally vulnerable and prone to degradation – mainly through overgrazing. Vegetation in arid environments is often very sensitive to change and therefore needs to be managed carefully to avoid land degradation (Stocking & Murnaghan 2000). Once change has occurred and the vegetation becomes degraded, it is very difficult to reverse (Turpie 2003). Given the low protection status and high proportions of remaining vegetation, the vegetation in the study area should be carefully conserved because of its high potential for irreversible changes due to transformation.

4.2.3 Economic evaluation of vegetation on BLK PNR

The calculation of a monetary value for biodiversity in biomes requires an innovative approach. Turpie (2003) have established the price people were willing to pay (WTP) to protect the various biomes. The estimates recorded in Table 4.7 are the only estimates available for South African biomes. These figures distinguish the estimated intrinsic value of the biomes in 2003, according to how much people were willing to pay to have particular biomes protected. In view of the high growth rate of the carbon market and likely changed perceptions of people since 2003, the current value is no doubt greater. For example, SANBI (2007) values the Karoo ecosystem at R5500/km^2/yr. This value does not include a consistent valuation of non-use values of biodiversity, thus it is only a partial economic valuation of the country's biodiversity. The values do, however, emphasize the importance of price or value variances between biomes. The Albany Thicket Biome

Table 4.7 Potential market value of various biomes

Biome	***Percentage allocation (%)***	***US$ per ha per year***
Fynbos	39	0.46
Marine	19	0.64
Forest/ Spekboom	15	22.27
Succulent Karoo	7	0.07
Nama Karoo	7	0.02
Grassland	7	0.02
Savanna	6	0.01

Source: Turpie (2003: 210)

which was not directly measured by Turpie (2003), was rated equal to the forest value because the vegetation has similar carbon storage potential, potential to decrease soil erosion and high carrying capacity for naturally occurring herbivores. The accurate assessmentof ecosystem and biodiversity potential in South Africa requires rapid and accurate procedures for valuing ecosystems individually. By extrapolation of these estimates, the WTP values for the three main vegetation types on BLK PNR were derived as listed in Table 4.8.

Table 4.8 Intrinsic value given to each biome on BLK PNR

<table>
<tr><th rowspan="2">Vegetation community</th><th rowspan="2">Biom</th><th rowspan="2">Area (ha)</th><th colspan="2">Value in 2003 US$ per year</th><th colspan="2">Value in 2003 Rand per year</th><th rowspan="2">%</th></tr>
<tr><th>Total</th><th>US$ ha/yr</th><th>Total</th><th>R/ha/yr</th></tr>
<tr><td>Matjiesfontein Shale Renosterveld
North Swartberg Sandstone Fynbos
Matjiesfontein Quartzite Fynbos
South Swartberg Sandstone Fynbos</td><td>Fynbos</td><td>7480</td><td>3440.9</td><td>0.46</td><td>30 624</td><td>4.09</td><td>3.7</td></tr>
<tr><td>Gamka Thicket</td><td>Thicket</td><td>4009</td><td>89 272.6</td><td>22.27</td><td>794 526</td><td>198.24</td><td>95.9</td></tr>
<tr><td>Southern Karoo Riviere
Prince Albert Succulent Karoo</td><td>Karoo</td><td>5421</td><td>379.5</td><td>0.07</td><td>3 378</td><td>0.62</td><td>0.4</td></tr>
<tr><td colspan="2">Total</td><td>16910</td><td>93 094</td><td>5.51</td><td>828 528</td><td></td><td>100</td></tr>
</table>

The value in US$ was converted to Rands at an exchange rate of US$1 = R8.90 (Rainbow nation 2012). The Gamka Thicket has the highest intrinsic value (contributing 95.9 %), as expected given its high CS potential, its positive effects on soil maintenance and its efficient water usage. The Thicket Biome contributes inordinately to the value of the biomes in BLK PNR. The table indicates the substantial intrinsic value of the vegetation communities in BLK PNR characterized by significant differences between Thicket biome and the other two.

4.2.4 High conservation values for BLK PNR

A status of high conservation values (HCV) can be applied from the WWF to give recognition to the outstanding value of unique vegetation types. The WWF Green Carbon Guide Book (2008) nominates the HCV that can be applied for in the CCBA scheme. The concept involves focusing on areas where ecosystem services can be considered to have 'outstanding significance or critical importance' to maintain natural processes and species or to sustain the livelihoods of local people. The HCV rating classes are presented in Box 4.1.

Box 4.1 Climate, community and biodiversity alliance (CCBA) valuation scheme for high conservation values (HCV)

HCV1. Globally, regionally or nationally significant concentrations of biodiversity values.

- *E.g., the presence of several globally threatened bird species within a Kenyan montane forest.*

HCV2. Globally, regionally or nationally significant large landscape-level forests.

- *E.g., a large tract of Mesoamerican lowland rainforest with healthy populations of jaguars, tapirs, harpy eagles and caiman as well as most smaller species.*

HCV3. Forest areas that are in or contain rare, threatened or endangered ecosystems.

- *E.g., patches of a regionally rare type of freshwater swamp forest in an Australian coastal district.*

HCV4. Forest areas that provide basic services of nature in critical situations (e.g. watershed protection, erosion control).

- *E.g., forest on steep slopes with avalanche risk above a town in the European Alps.*

HCV5. Forest areas fundamental to meeting the basic needs of local communities.

- *E.g., key hunting or foraging areas for communities living at subsistence level in a Cambodian lowland forest mosaic.*

HCV6. Forest areas critical to local communities' traditional cultural identity.

- *E.g., sacred burial grounds within a forest management area in Canada.*

Source: WWF Green carbon guidebook (2008: 9)

The features of the various BLK PNR biomes were examined to establish their potential HCV ratings and the results are presented and explained in Box 4.2. BLK PNR contains significant HCV and it is advisable that management conserve these highly important ecosystems. Not only will the high carbon stocks be protected but many other secondary benefits will accrue. For example, increased life spans will result for dams from reduced silt loads (Powell 2009)– an important aspect for BLK PNR as the mountainous areas drain into the Gamkapoort Dam. Thicket landscapes will also give higher yields during drought years. There will be retention of biodiversity, continuous

Box 4.2 Examination of BLK PNR biomes for high conservation value (HCV) rating

HCV2. BLK PNR contains some 16 000 ha of naturally occurring vegetation supporting a wide range of naturally occurring wildlife such as migrant kudu, various small game and re-introduced eland, zebra, oryx, red hartebeest, springbok, ostrich black-backed jackal, caracal, leopard, genet, vervet monkeys, honey badgers, leguans and a number of large troops of Cape baboon also inhabit the reserve. Recently, a study identified 12 species of butterflies (Bosch Luys Kloof 2009). The vast extent of the reserve and the indigenous animals found in it create a locally significant environment that warrants approval for HCV2.

HCV3 and HCV4. The BLK PNR terrain can be termed ‘susceptible dry lands’. If these dry-lands are not managed carefully severe degradation can occur in a short time causing loss of biodiversity and species diversity (Sigwela et al. 2003; Lechmere-Oertel, Kerley & Cowling 2005), large losses of ecosystem carbon (Mills & Fey 2004a, 2004b; Mills, Cowling et al. 2005), a reduction in soil quality and soil fertility (Mills & Fey 2004a; Lechmere-Oertel, Kerley & Cowling 2005), lower water infiltration rates, hence increased sediment yield (Mills & Fey 2004a; Kerley, Knight & De Kock et al. 1995; Scheltema as cited in Stuart-Hill 1999), and a reduction in plant productivity, hence herbivore carrying capacity (Mills & Cowling 2010). It is highly probable that there has also been a loss of diversity of invertebrate species in the extreme cases of desertification, similar to that reported in the adjacent Succulent Karoo Biome (Seymour & Dean 1999). Additionally, the Fynbos Biome is the dominant component of the Cape Floristic Region and occurs nowhere else in the world and is one of the world’s ‘hottest biodiversity hotspots’ (Myers 1990). The Fynbos Biome is “the smallest, richest and most threatened of the world’s six floral kingdoms” (SANBI 2007: 1). It is home to 9000 plant species, or 38% of the country’s plant species of which 1 850 (over 20%) are threatened with extinction (Rouget et al. 2004; DEAT 2006). These factors recognize that this ecosystem provides basic services of nature in critical situations and can quickly become threatened. HCV3 and HCV4 can confidently be applied for.

HCV6. Bosch Luys Kloof (2009) claims that BLK was included in the historical fossil collecting trip of Atherstone and Bain in the 1870s, during the pioneering years of documenting South Africa's geology. The site also contains some caves with San rock paintings from previous centuries. These factors are important to local communities’ traditional cultural identity. BLK PNR is therefore worthy of HCV6 status.

Source: Derived from WWF Green carbon guidebook (2008: 9)

large increases of ecosystem carbon sequestering and an improvement in soil quality. Intact thicket will provide more natural forage for naturally occurring game.

BLK PNR shows significant potential for CT due the high carbon content (mainly from intact thicket and high concentration of fynbos) and biodiversity considerations (vegetation has a low protected status with high proportions remaining, but high potential for irreversible changes due to transformation add potential to apply for HCV). Now, with CS values determined for BLK PNR and the biodiversity potential examined, the trading mechanisms can be explored and applied to BLK PNR. This is expounded in the next chapter.

CHAPTER 5 APPLICATION OF CARBON TRADING PRINCIPLES AND PRACTICE TO BOSCH LUYS KLOOF PRIVATE NATURE RESERVE

To be eligible for trading CS credits there are various steps to follow in the measuring and accounting of CS. This chapter first explores the CT market options for BLK PNR, then identifies the principle of carbon accounting and applies it to the CT market options to calculate the potential carbon credits for each. The chapter concludes with a summary of pointers for using spekboom and other arid vegetation types for CT in similar South African settings.

5.1 Exploring carbon trading market options for BLK PNR

Section 1.4.3 noted the extent to which BLK PNR underwent periods of intensive stock farming which caused severe degradation of spekboom, still evident today. This situation offers an opportunity for restoration through the clean development mechanism (CDM) to restore the land where spekboom formally occurred. In Chapter 3 the intact spekboom on BLK PNR was mapped. Protection of this intact spekboom can support a credible application for CT in terms of avoided deforestation through REDD+ on the voluntary market. Section 4.2 identified the biodiversity considerations which can be used to apply for CT through conservation using the CCBA on the voluntary market. These three carbon market options are developed in this chapter. Their baseline projections are explored to determine the potential for various CT projects and the benefits of each project are identified.

5.1.1 Baseline projection of hypothetical carbon trading projects

A baseline projection is a description of all expected environmental conditions in a CT project zone in the absence of project activities (such as restoration or conservation). The project impacts are measured against these projections. The three market options (restoration, conservation, avoided land-use change) are considered to determine the baseline scenarios on BLK PNR. These baseline scenarios are analysed independently. However, they can be combined to propose one single project that takes into account more than one baseline scenario. The three scenarios explored are: restoration within the CDM on the compliance market; REDD+ as a possible scenario of avoided deforestation in the Post-Kyoto protocol; and conservation through the voluntary carbon market. Each option is briefly described to consider its relevance.

Restoration through the CDM is an option because spekboom has a low natural recovery rate from degradation and without restoration the land previously degraded (identified in Section 2.2.4.2) will not naturally restore (Mills et al.2005a). Degraded spekboom has many negative impacts such as loss of biodiversity, large losses of ecosystem carbon, a reduction in soil quality, a reduction in plant productivity (Mills & Cowling 2010) and reduced herbivore carrying capacity. Without active restoration the land will remain degraded, resulting in a lack of phytomass, litter production, soil carbon, soil fertility, water penetration and species diversity (Kerley, Knight & De Kock 1995; Lechmere-Oertel 2003; Sigwela et al. 2003; Mills & Fey 2004a, 2004b; Lechmere-Oertel, Kerley & Cowling 2005; Mills, O'connor et al. 2005; Lechmere-Oertel et al. 2008).

In a *REDD+ (Reduced Deforestation and Degradation)* scenario BLK PNR will resume pastoral goat farming, even though the land has not been stock farmed commercially since the middle-1990s. The land-owner believes a substantial income can be derived from sheep and goat farming, given that the vegetation and grazing are in a good state following its natural restoration period. The high concentration of spekboom in the Gamka Thicket can provide substantial forage for goat farming. Resumed goat farming in the area would generate carbon losses into the atmosphere at a rate of 96.5 tC/ha (adding a substantial amount of carbon into the atmosphere) and transform the thicket to open savannah in less than a decade (Mills et al. 2003) with many attendant negative impacts. Withholding farming activities will preserve the vegetation and promote CS, thereby decreasing current CO^2 levels.

In an *international payments for ecosystem services (IPES) (conservation)* scenario the land-owner attains value for the land through conservation. If land-use change and unsustainable farming practises were to occur they would release the high stored carbon stocks, which could result in up to 87 t/ha of carbon being released into the atmosphere (Mills & Cowling 2006). This would substantially impact on all the ecosystems (habitat destruction, soil erosion, lower carrying capacity) in all the biomes of the case study area. This scenario is similar to REDD+ except that it takes into account all vegetation communities, therefore bundling the TC content and biodiversity protection of all vegetation communities in BLK PNR. The project benefits of each of these scenarios are explored next as they are essential parts of the project design document (PDD).

5.1.2 Benefits of the proposed carbon trading projects

The benefits of each proposed CT mechanism are distinguished as incentives for investments in the proposed projects; namely restoration, REDD+ and conservation benefits in BLK PNR.

Restoration of degraded spekboom will sequester carbon and restore the functioning of the ecosystem at a rate surprisingly fast for a semi-arid area. Degraded sites restored with spekboom can, over a 30-year period, capture some 15.4 tons of additional carbon dioxide per hectare per year (Mills 2009). Planting spekboom is labour intensive and consequently carbon farmers would typically employ many locals in the depressed rural economy of the region.

REDD+ involves sustainable land management of the intact Spekboom Thicket that will result in mean annual saving of 87 tC/ha. Many potential secondary benefits such as an increase in natural herbivore carrying capacity; a thriving of naturally occurring game on the vegetation; landscapes with greater yields during drought years; increases in biodiversity; an increase of ecosystem carbon of 4.1 tC/ha/yr (Powell 2009); and improved soil quality are all in the offing from reduced degradation.

Through *Conservation* land-use change and degradation will be avoided, so preserving these highly important ecosystems. Not only will the high carbon stocks be protected (up to 87 tC/ha), but there are also many secondary benefits such as increased lifespans of dams as a result of reduced silt loads (Powell 2009); the thicket landscapes producing higher yields during drought years; limited biodiversity losses; continuous large increases of ecosystem carbon; improvement in soil quality; and intact thicket that provides the natural forage for naturally occurring game. Moreover, as new carbon stocks are added to the sink through restoration, jobs would be created for unemployed locals. The PDD for the CCBA requires additional information about cultural heritage, effects on local communities and biodiversity indicators.

Next the different mechanisms to account for the mitigated carbon were identified.

5.2 Carbon accounting

This section identifies ways in which carbon can be accounted for each project activity identified in the previous section, namely restoration, REDD+ (conservation of spekboom) and conservation of the entire landholding. These accounting methods are taken from literature and applied to the BLK PNR case study. The three activities are discussed in turn.

To establish whether or not the area is feasible for *restoration (CDM)*, the CS potential of the vegetation, the area of the vegetation cover and the number of years the project is committed to run for, must be taken into account. The equation used for this purpose (Mills & Cowling 2006) is:

$$Restoration = CS \times Area \times T$$

Where:

CS=carbon sequestrated (tC/ha/yr);

Area= area identified for restoration (ha); and

T= time of project's commitment (number of years).

For restoration projects which are currently able to trade within the CDM of the Kyoto Protocol, Mills & Cowling (2006) calculated the CS potential by dividing the difference of total carbon components of the transformed block (degraded) and the restored blocks (revegetated) by the number of years of restoration. Results reported Section 4.1.5 (regional differentiation comparison) showed that the restored spekboom at BLK PNR has the potential to sequester 4.1 tC/ha/yr (Powell 2009) (Table 4.1). The calculation for potential CS through restoration on BLK PNR is:

If carbon sequestration = 4.1 tC/ha/yr,

Area = 365.5 ha (Note: Calculated in Section 3.7)

Years of restoration=30.

Using these variables the restoration of degraded area would result in 46 063.5 tons of carbon being sequestrated over 30 years or an average of 1535.5 tC/ha/yr.

In the case of *REDD+ (CCBA)* the indicators for determining the potential for avoided degradation and deforestation must be taken into account, that is the amount of stored carbon, the amount of carbon that would be released through degradation and, according to Brown (2002), the project's opportunity costs (US$/ha). For REDD+ to provide a meaningful incentive, the payments the sellers receive must be equivalent to the opportunity costs of foregoing alternative land-use practises (minimum payment), in this instance goat farming. Opportunity costs are the value of foregone opportunities or alternatives because of the diversion of time or money toward some other option (Powell 2009).

On BLK PNR the area covered by intact thicket (918 ha) currently containing around 79 866 tC, could potentially lose 96.5 tC/ha (Mills et al. 2003), or a total of 88 587 tons of carbon emitted into the atmosphere if goat farming was resumed in this area. To give an idea of opportunity cost or net profit, the profit from goat farming in the Lepelle-Nkumpi Local Municipality averaged R196 875 a year (off 1700 farmed stock) (Kayamandi Development Services 2007). To be a viable trading mechanism, the carbon credits would have to exceed opportunity costs of this magnitude.

There is a paucity of literature on accounting for *conservation (CCBA)* credits. Most projects combine multiple ecosystem services into one credit type, for example selling carbon and biodiversity values together from the same area of land. According to Clements (2009) the advantages of bundling services include increased value of the credits, increased attraction to buyers and multiple ecosystem services targeting, rather than single targeting.

The CCBA PDD requires descriptions of current climate, biodiversity and surrounding communities to be completed to help determine the allocation of carbon credits. Currently, there are pilot projects underway to establish these crediting mechanisms, one pilot project being the Prairie Pothole Region in the USA which is a good example of how conservation can generate profits (Ducks Unlimited 2007). Their priority is protecting the grasslands of the Prairie Pothole Region from development encroachment through conservation easements. When landowners agree to an easement that prohibits ploughing that land, they are also ensuring that the carbon in that soil will not be released.

To establish the potential market for the case study area, its climate potential and its biodiversity potential was valued in Section 4.2 based on a literature analysis. For validation, a full on-site biodiversity and community assessment has to be conducted. Now that the carbon has been accounted for, the potential carbon credits can be estimated next.

5.3 Calculating potential carbon credits

Carbon credits are allocated in the final stage of the project design phase, after implementation. The allocator of carbon credits investigates a number of factors which may influence the final product when allocating credits such as avoidance of double counting, additionality, leakage and permanence. Even so, income from the carbon credits must cover transaction costs, as well as planting and maintenance costs. Consequently, it is very difficult to determine the exact amount of carbon credits a proposed project will receive, yet there are examples in the literature that suggest methods for identifying market potential.

Carbon accounting methods are based on assessing scores for the criteria of the chosen standard. Each standard (specified in Section 2.4.1) has certain factors that count towards the final estimation of carbon credits. Some standards merely take into account carbon stocks, such as the CDM standard, where others such as the CCBA standard take into account biodiversity factors and community factors when allocating carbon credits. It is beneficial to use a specific standard when a project has criteria that suit that standard. For example, restoration credit (which generally falls under the CDM) can also be applied for under the CCBA. This is preferable if there are social and biodiversity benefits which could further increase the value of the carbon credit over CS.

The UNFCCC (2001) calculates CS in tC/ha/year in soil, litter and living biomass, and CO_2 emission reductions in tC/ha/year. Generally, for one ton of CO_2 accounted for one carbon credit is allocated. Based on a carbon credit selling price of US$10 or R75 (Powell 2009; Green Guide 2010), the market potential for each potential project was calculated.

Over a period of 30 years of *restoration*, 46 060 tons of carbon could be sequestrated. This would accumulate R3 707 350 over the 30-year period.

Regarding *REDD*, if goat farming was to resume as an alternative, a total of 88 587 tons of carbon could be emitted into the atmosphere. The benchmark opportunity cost for goat farming is R196 875 a year for 1700 STU (Kayamandi Development Services 2007), so the STU of 1548 recommended for BLK PNR translates to R179 270 a year or approximately R5.4 million over a 30-

year period. To cover the opportunity costs the credits must exceed R5 million over the 30-year period. In addition, by preventing degradation, a further R6 644 025 could be accumulated through carbon credits by emission abandonment mechanisms. If the vegetation is protected it will sequestrate more carbon. However, more research is needed to establish the rate or change in carbon storage over time in older vegetation.

The total carbon content for the case study area (16 910 ha) is 757 913 tons of carbon. Through *conservation* of this area, this tonnage of carbon would be considered. Calculated according to emission abandonment mechanisms, this would amount to R8-10 million. The ecosystem market potential (calculated from 2003 statistics reported by Turpie (2003)) for the case study area would be R67 480 500 a year. Because the post-Kyoto protocol is in a pilot stage, little literature could be found to aid calculation of the monetary value of conservation. This is an area for fruitful research.

5.4 Conclusions on using spekboom and other arid vegetation communities for carbon trading

Because spekboom has similar CS potential to forest ecosystems it should be able to reap similar benefits from CT as forests. Importantly, spekboom has additional favourable characteristics over forested systems regarding CT, namely more economical water use; the potential for combating desertification and poverty in arid environments, and the ability to tolerate stand-replacing fires (spekboom is not combustible) (Kerley, Knight & De Kock 1995; Vlok, Euston-Brown & Cowling 2003) which all increase spekboom's market potential. The other vegetation communities occurring in the arid landscape of BLK PNR also show CS potential, and importantly, they embrace biodiversity and ecosystem service delivery, especially true of the Fynbos Biome. Thus, they should also reap the benefits forests do through conservation with the CCBA as instrument.

To date, the best and most practised form of CT is restoration through the CDM. Many studies have shown that spekboom planting is an exceptionally cost-effective means of restoring degraded landscapes because, unlike most plants, it does not require nursery cultivation. Furthermore, because of spekboom’s remarkably fast growth rate, the rate of carbon capture can rival that of tropical forests. The result is that one ton of CO_2 can be captured for less than one tenth of the cost of restoration projects in temperate or tropical forests (AFRI CARBON 2010). The various sites where farmers have successfully restored spekboom by planting cuttings have demonstrated that this method of restoration is indeed feasible (Mills 2009).

REDD+ and conservation projects are not yet well developed as management instruments, but it is evident that there is much potential for their employment in the voluntary market. To date, projects have successfully acquired carbon credits for avoided deforestation through the CCBA. Denman Island applied for avoided conversion of forest land and the Purus project in Brazil attained carbon credits for forest conservation. The Prairie Pothole Region conservation project has shown that conservation can generate profits (Ducks Unlimited 2007).

The REDD+ mechanism demonstrates that when credible carbon accounting and monitoring methodologies are successfully employed, REDD+ has the potential to be a competitive emissions reduction option (ERO) in carbon markets, especially for spekboomveld which, on average, has relatively high biomass values and relatively low opportunity costs. Carbon credits for REDD+ projects may soon become a reality, thus creating the need for accurate accounting of carbon stocks for all biomes in South Africa. Even if countries decide not to sign the Post-Kyoto Protocol and if its policies are discontinued, CT will always be a necessity for controlling CO_2 emissions to reduce the rate of CO_2 emissions, climate change and global warming.

The concluding chapter will be expounded next. It summarizes all findings and makes conclusions and recommendations on the objectives set out in the first chapter.

CHAPTER 6 SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter concludes the examination of the viability of spekboom and other vegetation occurring in a semi-arid area through using the carbon market, with special reference to an application in Bosch Luys Kloof Nature Reserve (BLK PNR). First the aim of the study is recalled, then the objectives are revisited and the findings of each are summarized. Recommendations are made and suggestions for further research are put forward.

6.1 ACHIEVING THE RESEARCH AIM

The research set out to document and explain the concepts, principles and practises involved in international and national carbon trading (CT) opportunities using carbon sequestration (CS) and to place these in the local context of BLK PNR. The aim was pursued through a South African case study in a semi-arid area, where the surface boundaries of vegetation communities were mapped and areal extent was calculated. Relevant CS and CT potential values were derived from published literature and used to quantify CS values. The research concluded by outlining the existing international trading formats and specifying the South African side to set out a possible trading strategy for individual landowners. The aim was achieved by sequentially realizing the research objectives which are revisited in the next section where the results are summarized.

6.2 THE RESEARCH OBJECTIVES: SUMMARY OF RESULTS

The salient findings of the seven objectives, namely a conceptual overview; an overview of the principles, policy and practices of CS; establish the capacity of CS in plant communities in the study area; map plant communities, particularly spekboom, in BLK PNR; determine the real surface area of vegetation; calculate CS potentials of plant communities; and make recommendations on relevant carbon markets are summarized in the following subsections.

6.2.1 Conceptual overview of global warming, conservation and the carbon sink cycle

In reaching the first objective a conceptual overview of the literature on global warming, conservation and the carbon sink cycle was given in the first sections of Chapter 2. It was stressed that South Africa contains a variety of diverse biomes that provide important ecological services such as food, fuel, timber, climate and flood control, pollination, population control, soil formation and other basic ecological properties upon which biodiversity and other ecosystem functions or services depend. The biomes also have recreational, spiritual and aesthetic value for people. The necessity for protecting these naturally occurring services in South Africa was emphasized and special reference was made to the valuable Fynbos Biome in which the study region is situated. The research demonstrated how the cost of conservation might be covered by giving a value to these ecosystems through carbon storage and biodiversity which can be carbon credited and sold on the carbon market.

6.2.2 Overview of the principles, policy and practise involved in CS calculations internationally and in South Africa

The second objective was sought in the remainder of Chapter 2 where the technicalities of CS and the variations among global biomes were described and the dangers of biome degradation were highlighted. The focus narrowed to the Thicket Biome in South Africa and its signal species, spekboom. Findings of previous empirical studies indicated that spekboom can produce some 160 tons of dry mass per hectare which is greater than the values for certain forests and 50 to 100 times better than in other semi-desert ecosystems. Extensive and worrying evidence of degradation in this biome was documented and the chapter concluded with an introduction to the challenges and potentials of conserving and restoring this valuable natural resource.

The objective was pursued further by showing which mechanisms exist internationally and in South Africa to actually trade commercially in carbon credits derived from these potentially valuable biomes. The principle of attaching a monetary value to ecosystem services such as CS through the Kyoto Protocol's clean development mechanism (CDM) was confirmed and the formats of various markets were described. These included voluntary market formats in carbon offsets to neutralize or counteract given volumes of CO_2. The workings of the Kyoto Protocol were detailed and the realizable global dollar revenues (more than US$300 million by 2007) were emphasized.

Inherent to this process were the discussions in Section 2.4 on how to formally account for CT – including the methods by which this is to be obtained. Various standards have been agreed on. A six-step CS project design process (summarized in Table 2.4) was suggested and an elaborate listing of project design documentation relevant to BLK PNR was provided in Table 2.5 for reference purposes. Discussion of how spekboom trading in South Africa fits into the constellation of international CT practice and value chain (estimated at more than R17 billion for ecosystem services in South Africa alone) concluded the chapter and the realization of the second objective.

6.2.3 Mapping the vegetation communities, including spekboom

Chapter 3 aimed at realizing the third and fourth objectives and commenced by describing the accurate mapping of the officially (SANBI 2007) recognized vegetation groups occurring in the study area. Given the focus on spekboom as the target species, its boundaries were finely determined by using a geographical information system (GIS) and doing satellite image analysis. Object-orientated image segmentation was used for mapping spekboom as a vegetation class because it occurs in patches, bands and on north-facing slopes recognizable as spatial objects. These objects were determined by selecting an optimal scale to segment the satellite image, in this case 50. This segmentation resolution was effective in identifying relatively small patches of vegetation and unique vegetation stands. The more samples and defined classes chosen, the greater was the effectiveness of nearest neighbour classification in eCognition software. Mapping the vegetation on BLK PNR using eCognition was disappointingly ineffective, yielding between 64% and 69% correspondence with the accurate manually digitized mapping performed for accuracy assessment (reported in Section 3.9). eCognition's object-orientated method of classification is useful, but the resulting misclassification of polygons with similar spectral values as spekboom stands must be compensated for manually. Misclassification is due to spectral similarity between spekboom and other thicket-like Karoid vegetation. In the automated classification, spekboom was indicated on some southerly slopes where groundtruthing proved it did not occur, probably due to the shadow effect on south-sloping landforms that produced spectral similarity. Misclassification also occurred north of the *Acacia karroo* stands where the Matjiesfontein Shale Renosterveld and the Prince Albert Succulent Karoo occurred on a north-facing shaded slope. Classification could have missed spekboom on steeper slopes where its spectrum is slightly different. Another explanation is that spekboom currently occurs in less dense patches (presumably due to earlier degradation) on the low-lying, valley-side northern slope, where eCognition failed to recognize spekboom accurately. By increasing the image segmentation scale better results may compensate for this weakness.

To improve mapping accuracy, segmentation at a finer scale is suggested as a solution because smaller stands might become recognizable. Such classifications would be beneficial in areas where spekboom is degraded and occurring in patches or single stands. More samples of each class could be chosen where they occur on all aspects and more experimentation could be conducted using more landscape aspects, such as texture, in feature space. The particular version of the eCognition software employed tended to crash and freeze fairly regularly when dealing with high-resolution imagery and the concomitant large file sizes. This was a frustrating and time-consuming practice and precluded further experimentation. What did help (but didn't resolve the problem altogether) was to clip the image into smaller sections and run each section separately – of necessity an exercise wasteful of time and effort.

The area identified for spekboom restoration fitted all the optimal criteria, namely accessibility, closeness to existing spekboom stands as source for cuttings, flat landscape character (logically more effective for restoration than rocky mountain sides) and a closeness to a water source. The editor toolbar in GIS was effective in mapping the spekboom area for restoration as well as *Acacia karroo* as a separate vegetation community (see Section 3.5) not mapped by SANBI (Mucina & Rutherford 2006).

6.2.4 The real surface area of vegetation types

The fourth objective was also aimed at in Chapter 3, especially in Section 3.8. There, the calculation of three-dimensional (3D) areas to establish the real areal extent of each vegetation group (as tradable CS commodities) was performed. Following an initial detailed description and explanation of the intricacies involved in converting planar areal designations in GIS to its actual surface area in topographically complex landscapes (like that pertaining in BLK PNR) the real areas were calculated. The true surface area of classified objects was calculated using two mechanisms, namely a calculation tool provided by Jenness (2010) and the vector-based triangular irregular network (TIN) function in GIS. Both were done by means of a 20 m digital elevation model (DEM) obtained for the case study. Because the research focused on calculating area and was not concerned with downstream modelling, it was suggested that the raster option in the Jenness method be implemented. Area calculation based on a fine-resolution raster is effective, the results differing very little from areas derived by the more tedious vector method. Comparative results show that true surface area is clearly related to the type of terrain. The Southern Karoo Riviere that occupies the near-flat river valley registered an almost 100% correspondence to planimetric values. Contrarily, vegetation groups occurring on the steep mountain sides yielded, as expected, up to 10% higher values than the planimetric values. The areal yield for the total landholding was almost 10% higher than the original (and surveyed) land area of the estate. Furthermore, these elevated areas responsible for the greater areal extent pertain to the more valuable vegetation types occurring on the sloping and topographically complex parts of the unit.

6.2.5 The CS capacity values for identified plant communities

Having established the areal extent of the various vegetation communities accurately, the challenge was then to obtain acceptable CS values for each. This difficult fifth objective was reached in the initial main section of Chapter 4. The carbon storage of various vegetation types was investigated through literature survey and the effects of released stored carbon were identified for effective management. A detailed description of how to measure CS experimentally was provided, followed by a summary of experimental values obtained for spekboom. CS values for each vegetation type were not readily available so that average values for representative biomes were identified and used. It was concluded that the Albany Thicket which contains spekboom (dealt with individually due to its high CS potential and its active participation potential in the carbon market) possesses similar CS potential to forest ecosystems currently trading actively in the carbon market. An additional beneficial similarity between spekboom and forests is its favourable water balance, its potential for combating desertification and its usefulness for grazing which can contribute to poverty alleviation in arid environments. An important difference between these two ecosystems with respect to CS is that forests are likely to experience periodic stand-replacing fires, whereas the spekboom Thicket Biome does not burn.

Real CS values for spekboom were only obtainable from reported empirical experiments – albeit in the more hospitable and favourable regions to the east. The regional differentiation comparison in Chapter 4 determined that the experimental values obtained in the Baviaanskloof Nature Reserve are transferable to the BLK PNR site. These values are reported in Table 4.5 and show an estimated CS potential for the spekboom in BLK PNR of nearly 90 tons per hectare. Of course, to be verified for carbon credits, an on-site soil analysis must still be completed. The comparison concluded that rainfall is an important factor in carbon accumulation mainly because spekboom switches to Crassulean acid metabolism (CAM) during water stress which increases the rate and efficiency of photosynthesis. Table 4.3 shows spekboom has the highest expected carbon content but the Fynbos and Karoo Biomes are not insignificant carbon-content contributors, given the arid climate where they occur.

Southern Karoo Riviere that normally occurs in dense, narrow riverine strips was ignored in regional mapping exercises. In this research the community was accurately mapped through heads-up digitizing, but required an approximate CS value to be attributed to it. A value of 30 t/C/ha was assigned to *Acacia karroo* based on results from studies of Acacia community plantations in Niger. This tonnage seems intuitively too low, but it was accepted in the absence of other figures for the species. Future applications for *Acacia karroo* carbon calculations should reconsider which value to use. These high CS potentials in such an arid environment, the favourable conditions over forests and given that almost 50% of spekboom in South Africa has been severely degraded through overgrazing create an opportunity to attain carbon credits. These values can be applied to the accurately mapped vegetation classes.

6.2.6 The calculated CS potential inherent to vegetation on BLK PNR

The final subsection of Chapter 4 applied the assigned sequestration values to the vegetation areas in BLK PNR to reach the sixth objective. As alternative bases for valuing environmental goods in BLK PNR, biodiversity indicators examined the diversity of species and ecosystems within biomes, and evaluated the threats to it. Four methods of valuing biodiversity were applied to indicate the importance of the ecosystems and biodiversity in BLK PNR. First, the total carbon content resident in vegetation across BLK PNR was calculated to determine the carbon stock for conservation. The total carbon content for the case study area of 16 910 ha was shown to approach 758 000 tons. This is a large amount of carbon stock given the arid climate of the area and especially in the view of the possibility of CT. Surprisingly the major contributors of carbon to this final estimated value are the Matjiesfontein Shale Renosterveld and the Prince Albert Succulent Karoo, but this is mainly attributable to the large area covered by these vegetation types. The substantial contribution of the Gamka Thicket Biome (mainly spekboom) confirms its value vis-à-vis its relatively small areal coverage.

Second, SANBI (2007) specifies the environmental state of each vegetation type in the considered ecosystems as it pertains to the whole of the Cape Floral Region. The Sandstone Fynbos groups appear to be generally well protected, either through nature reservation or through protection of mountain catchments. Large portions consequently remain intact in their natural state. All the other groups represented in BLK PNR are nationally rather poorly protected overall, but still have fairly large proportions remaining intact. Matjiesfontein Shale Renosterveld, Gamka Thicket and Southern Karoo Riviere cause most concern because of the substantial and growing extent of transformation. The Gamka Thicket is exceptionally vulnerable and prone to degradation, mainly through overgrazing. Transformation of vegetation in arid environments is often very sensitive to change and therefore needs to be managed carefully to avoid land degradation. Once change has occurred and the vegetation becomes degraded, it is very difficult to reverse. Having a low protected status, a high percentage of intact vegetation and its high potential for irreversible changes due to transformation, makes the vegetation in the study area a resource that must be carefully conserved.

Third, the economic importance of the ecosystem, as calculated by Turpie (2003), was related to the case study area. The Gamka Thicket had the highest intrinsic value as expected given its high CS potential, its positive effects on soil maintenance and its efficient water usage. The results indicate a substantial intrinsict value of the biodiversity of the vegetation community in BLK PNR as well as significant differences between biomes. It was calculated that the vegetation in BLK PNR has a total intrinsic biodiversity value of nearly R830 000 per annum.

Fourth, some additional indicators and high conservation activities (HCV) were identified from the Climate, community and biodiversity alliance (CCBA), namely the statuses of HCV2 (due to indigenous animals and naturally occurring vegetation that are found within it), HCV3 and HCV4 (due to it being a susceptible dry land and containing fynbos from the Cape Floristic Region, which occurs nowhere else in the world and is one of the world's hottest biodiversity hotspots. These factors recognize that this ecosystem provides basic services of nature in critical situations and can quickly become threatened, therefore HCV3 and HCV4 can also be applied for) and HCV6 (due to presence of fossils and some caves with San rock paintings from previous centuries). These factors are important to local communities' traditional cultural identity and therefore HCV6 could also be applied. These factors contribute to the generation of an economic value for BLK PNR.

6.2.7 Recommendations for prototype project design

The final objective to give advice on the carbon markets relevant to BLK PNR was addressed in the final section of Chapter 4. Spekboom restoration is currently the most practised method of spekboom farming, and restoration projects in South Africa have already gained the ability to trade within the clean development mechanism (CDM) and on the voluntary market. Studies have shown that spekboom planting is an exceptionally cost-effective means of restoring degraded landscapes because, unlike most plants, it does not require nursery cultivation. Furthermore, because of spekboom's remarkable growth rate, its rate of carbon capture can rival that of tropical forests. The result is that one ton of CO_2 can be captured for less than one tenth of the cost of restoration projects in temperate or tropical forests. The various sites where farmers have successfully restored by planting spekboom cuttings have demonstrated that this method of restoration is indeed feasible. These restoration projects have shown that active restoration leads to reduced erosion; increased biodiversity; enhanced tourism potential; increased wildlife carrying capacity; provision of browse for livestock; reduced silt in dams; and restoration further boosts its skills and job development for local inhabitants. Restoration of the degraded spekboom in BLK PNR could potentially bring in an additional R3.7 million over the 30-year period or about R123 600 a year if restoration is carried out. To date, the best and most practised form of CT is restoration through the CDM.

BLK PNR can also potentially trade in the voluntary market using the CCBA as opposed to the compliance market which has stringent guidelines, lengthy paper work and high transaction costs. Market project developers in the voluntary carbon field have more freedom to invest in small-scale community-based projects such as spekboom farming. The co-benefits of these projects, regarding local economic development or biodiversity, for example, are often key selling points (Taiyab 2006).

The CT potential determined using the CCBA on voluntary market is not clear as the document requires indicators in which the verifier allocates carbon credits. However, the literature shows that there is a large market potential for biodiversity in South Africa. Our endemic and important ecosystems which are very susceptible to change (and climate change) encourage the use of this mechanism.

Using the reduced emissions from deforestation and degradation plus (REDD+) mechanism is currently not an option for BLK PNR. However, in the post-Kyoto Protocol (after 2012) this may be an attractive option. The ideal route is to combine conservation with restoration into one bundle using the CCBA standard. This will have the most benefit for the ecosystems by protecting intact systems and restoring degraded systems. Socio-economically, restoration would also, through manual planting of spekboom in high unemployment areas like the nearby Zoar and Amalienstein, provide jobs.

6.3 LIMITATIONS OF THE STUDY AND RECOMMENDATIONS FOR FUTURE RESEARCH

Increasing aridity favours spekboom percentage cover, which is a copious litter producer (Lechmere-Oertel 2003; Lechmere-Oertel, Kerley & Cowling 2008). This statement opposes the general observation of carbon accumulation following a rainfall gradient (the more rainfall the more carbon accumulation). Research is needed to investigate spekboom's carbon accumulation in relation to rainfall. Which level of precipitation causes maximum carbon accrual? And does seasonal rainfall play a role in this? These questions beg further research.

Concerning CS potential in BLK PNR, there is a need to accurately calculate and map the carbon contents of the seven biomes as well as their sub-biomes for the potential to trade within REDD+ in the future. Spekboom's carbon accumulation regarding rainfall and carbon accumulation requires attention to get a better picture of spekboom's changing CS potential from west to east. The CS of older spekboom plants (+30 years) must be established along with the question whether this vegetation has a constant CS potential throughout its life. For example, do older (larger) plants have a higher CS rate due to increased leaf production and leaf litter? Or does soil reach a carbon equilibrium in which values decline with age, and if so at what point in their life cycle?

The results of the automated approach were not as accurate as hoped. To improve the results of electronic automated mapping in eCognition, more experimentation is needed on the different feature spaces used in standard nearest neighbour classification. This study used 'Texture after Haralick' (using the grey-level co-occurrence matrix (GLCM) homogeneity and mean) and the layer values (mean brightness, max difference) to help in the classification. Experimentation using more texture and attributes could improve the accuracy of object classification and mapping using eCognition. By choosing more classification groups and samples for each, accuracy could further increase.

For accurate calculation of ecosystem and biodiversity potential in South Africa, there is a need for rapid and accurate methodology for valuing individual ecosystems in South Africa. This evaluation must account for baseline carbon storage for all plant communities, average CS for all plant communities, ecosystem richness in all biomes, threats to that biodiversity, threatened or rare ecosystems, and areas that provide critical ecosystem services. This will contribute to making application with the CCBA much easier and consistent for all vegetation communities.

Finally, it will be beneficial if a South African CT platform such as the Nedbank Carbon Finance Unit along with the Working for Woodlands Programme of the Department of Water Affairs (DWA) and the Working for Water Programme of the Department of Water Affairs (DWA) were to develop the accounting system and methodology for mechanisms in which vegetation in South Africa can be given a monetary value. Currently, many farmers in the depressed economy would greatly benefit if they could attain additional money for the CS that exists or could be developed on their property. Unfortunately, they lack the knowledge to determine whether such action is feasible or possible. The availability of accounting methodology and CT mechanisms might educate and encourage participation in carbon farming in South Africa. This is important because South Africa is a signatory to the Kyoto Protocol and we have accepted the responsibility to reduce the effects of climate change. This can be done internally with benefits staying in South Africa. Companies operating and people living in South Africa would have access to offset projects in the country, enjoying the benefits of improved ecosystem services on their door step and have the potential to actively monitor their investments.

Word count: 42 255

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PERSONAL COMMUNICATIONS

Avenant P 2012. Agricultural scientist, specialist in natural resources inventories & assessments. Directorate for land use and soils management at the Department of Agriculture, Forestry & Fisheries. Email (PaulaA@daff.gov.za to15098605@sun.ac.za) on 12 July 2012 about LSU for study area.

Muller H 2011. MA student at Stellenbosch University and conservationist at Bosch Luys Kloof Private Nature Reserve. Email (halcyon.m@gmail.com to 15098605@sun.ac.za) on 24 October 2011 about case study's historical background.

APPENDIX

APPENDIX A
CLEAN DEVELOPMENT MECHANISM
PROJECT DESIGN DOCUMENT FORM for SMALL-SCALE afforestation and reforestation project activities (CDM-SSC-AR-PDD)
(VERSION 02)
CONTENTS

Annexes

SECTION A. General description of the proposed small-scale A/R CDM project activity:

A.1 Title of the proposed small-scale A/R CDM project activity:
>>

A.2 Description of the proposed small-scale A/R CDM project activity:
>>

A.3 Project participants:
>>
Please list project participants and Party(ies) involved and provide contact information in Annex 1. Information shall be indicated using the following tabular format.

Name of Party involved (*) ((host) indicates a host Party)	Private and/or public entity(ies) project participants (*) (as applicable)	Indicate if the Party involved wishes to be considered as a project participant (Yes/No)
Name A (host)	Private entity A Public entity A …	No
Name B	None	Yes
Name C	None	No
…	…	…

(*) At the time of making the CDM-SSC-AR-PDD public at the stage of validation, a Party involved may or may not have provided its approval. At the time of requesting registration, the approval by the Party(ies) involved is required.

A.4 Description of location and boundary of the small-scale A/R CDM project activity:
>>

A.4.1Location of the proposed small-scale A/R CDM project activity:

A.4.1.1 HostParty(ies):
>>

A.4.1.2Region/State/Province etc.:
>>

A.4.1.3City/Town/Community etc.:
>>

A.4.2 Detail of geographical location and project boundary, including information allowing the unique identification(s) of the proposed small-scale A/R CDM project activity:
>>

A.5 Technical description of the small-scale A/R CDM project activity:

A.5.1Type(s) of small-scale A/R CDM project activity:
>>

A.5.2A concise description of present environmental conditions of the area, which include information on climate, soils, main watershed, ecosystems, and the possible presence of rare or endangered species and their habitats:
>>

A.5.3Species and varieties selected:
>>

A.5.4Technology to be employed by the proposed small-scale A/R CDM project activity:
>>

A.5.5Transfer of technology/know-how, if applicable:
>>

A.5.6Proposed measures to be implemented to minimize potential leakage as applicable:
>>

A.6 A description of legal title to the land, current land tenure and land use and rights to tCERs / lCERs issued:
>>

A.7 Assessment of the eligibility of land:
>>

A.8 Approach for addressing non-permanence:
>>
Please select between:
☐Issuance of tCERs

☐Issuance of lCERs

A.9 Duration of the proposed small-scale A/R CDM project activity / Crediting period:
>>

A.9.1 Starting date of the proposed small-scale A/R CDM project activity and of the (first) crediting period, including a justification:
>>

A.9.2 Expected operational lifetime of the proposed small-scale A/R CDM project activity:
>>

A.9.3 Choice of crediting period and related information:
>>
Please select one of the following:

1. Renewable crediting period ☐

2. Fixed Crediting period ☐

A.9.3.1Duration of the first crediting period (in years and months), if a renewable crediting period is selected:
>>

A.9.3.2 Duration of the fixed crediting period (in years and months), if selected:
>>

A.10 Estimated amount of net anthropogenic GHG removals by sinks over the chosen crediting period:
>>
Please provide the total estimation of net anthropogenic GHG removals by sinks as well as annual estimates for the chosen crediting period. Information on the net anthropogenic GHG removals by sinks shall be indicated using the following tabular format.

Years	Annual estimation of net anthropogenic GHG removals by sinks in tonnes of CO_2e
Year A	
Year B	
Year C	
Year …	
Total estimated net anthropogenic GHG removals by sinks(tonnes of CO_2 e)	
Total number of crediting years	
Annual average over the crediting period of estimated net anthropogenic GHG removals by sinks (tonnes of CO_2e)	

A.11 Public funding of the proposed small-scale A/R CDM project activity:
>>

A.12 Confirmation that the small-scale A/R CDM project activity is not a debundled component of a larger project activity:
>>

SECTION B. Application of a baseline and monitoring methodology :

B.1 Title and reference of the approved baseline and monitoring methodology applied to the proposed small-scale A/R CDM project activity:
>>

B. 2. Justification of the applicability of the baseline and monitoring methodology to the proposed small-scale A/R CDM project activity:
>>

B.3 Specification of the greenhouse gases (GHG) whose emissions will be part of the proposed small-scale A/R CDM project activity:
>>

B.4 Carbon pools selected:

In calculating the baseline net GHG removals by sinks and/or actual net GHG removals by sinks, project participants may choose not to account for one or more carbon pools, and/or emissions of GHGs measured in units of CO_2 equivalents, while avoiding double counting.

Select the carbon pools that are considered in determining actual net GHG removals by sinks and baseline net GHG removals by sinks in the Table below in accordance with the proposed new/ approved methodology used. Note that the same carbon pools should be considered in the actual net GHG removals by sinks and the baseline net GHG removals by sinks.

Carbon pools	Selected (answer with yes or no)
Above ground	
Below ground	
Dead wood	
Litter	
Soil organic carbon	

B.5 Description of strata applied for ex ante estimations:
>>

B.6 Application of baseline methodology to the proposed small-scale A/R CDM project activity:
>>

B.7 Description of how the actual net GHG removals by sinks are increased above those that would have occurred in the absence of the registered small-scale A/R CDM project activity:
>>

B.8 Application of monitoring methodology and monitoring plan to the small-scale A/R CDM project activity:
>>

B.8.1 Data to be monitored: Monitoring of the actual net GHG removals by sinks and leakage.
>>

B.8.1.1 Actual net GHG removals by sinks data:
>>

B.8.1.1.1Data to be collected or used in order to monitor the verifiable changes in carbon stock in the carbon pools within the project boundary resulting from the proposed small-scale A/R CDM project activity, and how this data will be archived:
>>

Data variable	Source of data	Data unit	Measured (m), calculated (c) or estimated (e)	Recording frequency	Proportion of data to be monitored	How will the data be archived? (electronic / paper)	Comment

B.8.1.2Data for monitoring of leakage (if applicable)
>>

B.8.1.2.1If applicable, please describe the data and information that will be collected in order to monitor leakage of the proposed small-scale A/R CDM project activity
>>

Data variable	Source of data	Data unit	Measured (m), calculated (c) or estimated (e)	Recording frequency	Proportion of data to be monitored	How will the data be archived? (electronic / paper)	Comment

B.8.2Describe briefly the proposed quality control (QC) and quality assurance (QA) procedures that will be applied to monitor actual GHG removals by sinks:
>>

B.8.3Please describe briefly the operational and management structure(s) that the project operator will implement in order to monitor actual GHG removals by sinks by the proposed small-scale A/R CDM project activity:
>>

B.9 Date of completion of the baseline study and the name of person(s)/entity(ies) determining the baseline and the monitoring methodology:
>>

SECTION C. Estimation of ex ante net anthropogenic GHG removals by sinks:

C. 1. Estimated baseline net GHG removals by sinks:
>>

C. 2. Estimate of the actual net GHG removals by sinks:
>>

C. 3. Estimated leakage:
>>

C. 4. The sum of C. 2.minus C.1.minusC.3.representing the net anthropogenic GHG removals by sinks of the proposed small-scale A/R CDM project activity:
>>

C. 5. Table providing values obtained when applying equations from the approved methodology:

The result of the application of equations from approved methodology above shall be indicated using the following tabular format:

Year	Estimation of baseline net GHG removals by sinks(tonnes of CO_2 e)	Estimation of actual net GHG removals by sinks (tonnes of CO_2 e)	Estimation of leakage (tonnes of CO_2 e)	Estimation of net anthropogenic GHG removals by sinks (tonnes of CO_2 e)
Year A				
Year B				
Year C				
Year …				
Total (tonnes of CO_2 e)				

SECTION D. Environmental impacts of the proposed small-scale A/R CDM project activity:

D.1 Provide analysis of the environmental impacts, including trans boundary impacts (if any):
>>

D.2 If any negative impact is considered significant by the project participants or the host Party, a statement that project participants have undertaken an environmental impact assessment, in accordance with the procedures required by the host Party, including conclusions and all references to support documentation:
>>

D.3 Description of planned monitoring and remedial measures to address significant impacts referred to in section D.2. above:
>>

SECTION E. Socio-economic impacts of the proposed small-scale A/R CDM project activity:

E.1 Provide analysis of the socio-economic impacts, including transboundary impacts (if any):
>>

E.2If any negative impact is considered significant by the project participants or the host Party, a statement that project participants have undertaken a socio-economic impact assessment, in accordance with the procedures required by the host Party, including conclusions and all references to support documentation:
>>

E.3 Description of planned monitoring and remedial measures to address significant impacts referred to in section E.2. above:
>>

SECTION F. Stakeholders’ comments:

F. 1.Brief description of how comments by local stakeholders have been invited and compiled:
>>

F. 2.Summary of the comments received:
>>

F. 3.Report on how due account was taken of any comments received:
>

Annex 1

CONTACT INFORMATION ON PARTICIPANTS IN THE PROPOSED SMALL-SCALE A/R CDM PROJECT ACTIVITY

Organization:	
Street/P.O.Box:	
Building:	
City:	
State/Region:	
Postfix/ZIP:	
Country:	
Telephone:	
FAX:	
E-Mail:	
URL:	
Represented by:	
Title:	
Salutation:	
Last Name:	
Middle Name:	
First Name:	
Department:	
Mobile:	
Direct FAX:	
Direct tel:	
Personal E-Mail:	

Annex 2

INFORMATION REGARDING PUBLIC FUNDING

Annex 3

DECLARATION ON LOW-INCOME COMMUNITIES

Please provide a written declaration that the proposed small-scale afforestation or reforestation project activity under the CDM is developed or implemented by low-income communities and individuals as determined by the host Party.

- - - - -

History of the document

Version	Date	Nature of revision
02	EB35, Annex 22 19 October 2007	Sections A and B were restructured; Requirement to repeat equations has been removed from section C; Sections D and E have been aligned with the requirements of the Modalities and Procedures.
01	EB 23, Annex 16(a) and 16(b) 24 February 2006	Initial adoption