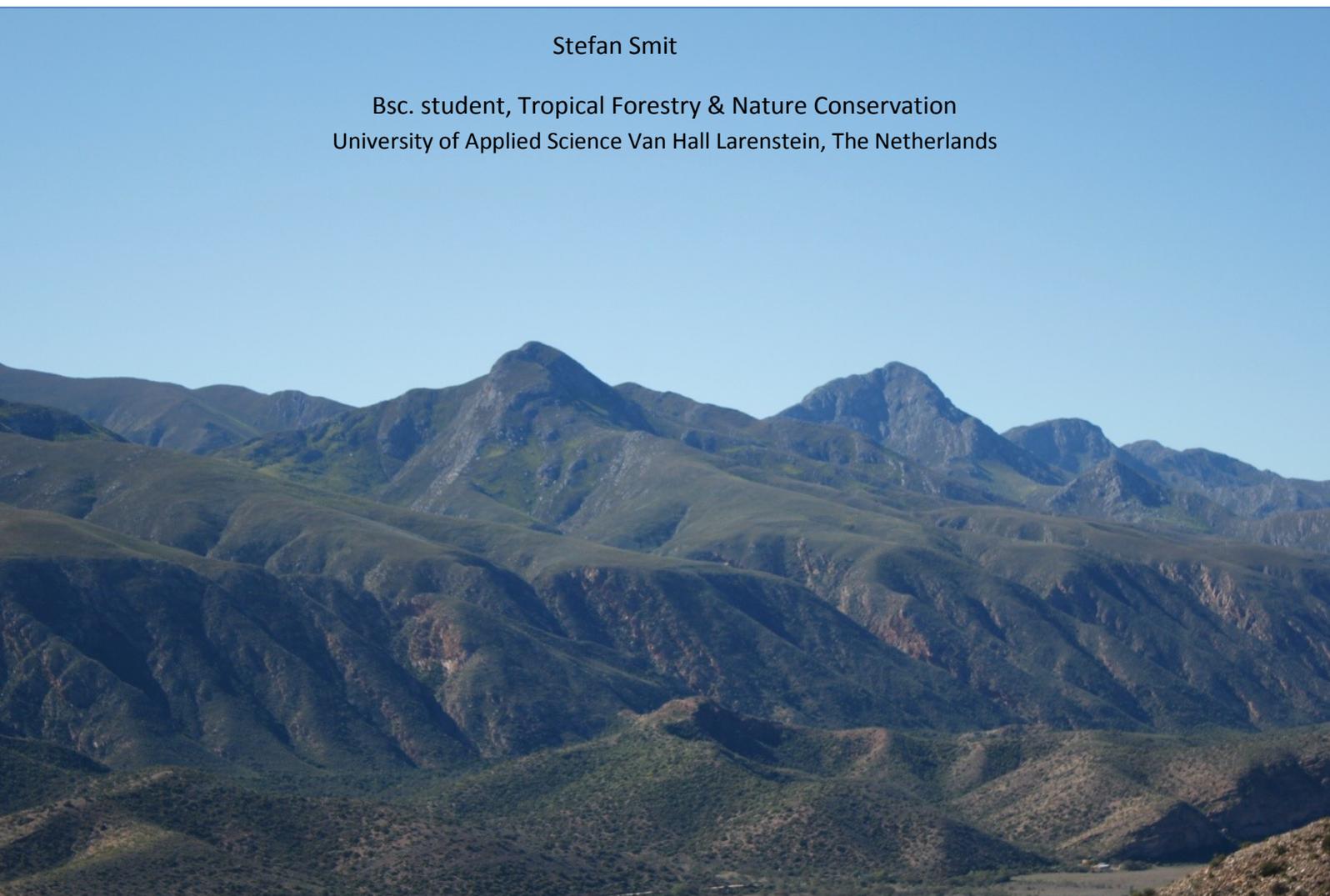


Observation of the change in vegetation density in degraded areas, of the Baviaanskloof catchment. Based on remote sensing techniques that estimate the relation between vegetation density and NDVI (Normalized Difference Vegetation Index).

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Abstract

The goal of this study is, to observe change of vegetation density in previously degraded areas of the Baviaanskloof catchment, South-Africa. The vegetation in the area has been severely degraded in the last century. But over the last two decades land use change and efforts to restore the area could have started a regeneration of vegetation cover. By using Remote Sensing techniques, I will be able to observe whether this assumption of regeneration in degraded areas is true.

Remote Sensing techniques used in this study include, generating NDVI (Normalized Difference Vegetation Index) maps from several Landsat Images of different acquisition dates. Field data of the vegetation density is used to "Ground Truth" assumptions based on an understanding how the NDVI reflects vegetation density. This would be found in statistical relations between the NDVI and vegetation density and between the NDVI and Leaf Area Index (LAI). NDVI maps have been reclassified, to be able to observe vegetation densities in 2013, 2001, 1992 and 1987. Furthermore differences in vegetation density between these years have been determined by using a change detection technique. Change was detected in severely degraded areas.

The study indicated a strong relation between the NDVI and vegetation density was found during the study ($R^2=0.8725$). In Addition, the NDVI appeared to have a strong relation between the vegetation density of different biomes (*Thicket*; $R^2= 0.8989$ *Doringsveld*; $R^2=0.7688$ and *Renosterveld*; $R^2=0.9891$). A indication that it is possible to determine spectral signatures for different biomes. Furthermore, a strong relation between the NDVI and the LAI was found ($R^2=0.7437$), which was used as reference material during the classification process of NDVI rasters.

This study shows that we can observe changes in vegetation densities, based on a combination of canopy cover, shrub cover and grass/herb cover. Observed was that some degraded areas the majority of the vegetation density increased by 20%. Furthermore the study shows what impact land use change and restoration works have had on the vegetation density. Before the restoration started, no major increase of vegetation density in any of the degraded areas was observed. However, increase of vegetation density was observed in the time period of 2001 to 2013, during which restoration works had been conducted. In conclusion, this study sets the bar for further investigation in the regeneration of degraded areas and the effect on vegetation by positive human interaction.

[Taglines: Remote Sensing, NDVI, LAI, degradation, vegetation density, Ground Truth, Landsat, Change Detection]

Foreword

During the courses of Tropical Forestry and Nature Conservation, I became fascinated with the possibilities of ArcGIS and satellite imagery. I learned that it was possible to detect changes by using Vegetation Indices such as the Normalized Difference Vegetation Index. When choosing my thesis placement options I actively searched for the possibility of working with ArcGIS. I would not have dared to dream, that I would have been able to do what is described in this report.

Thanks to Living Lands, I was able to conduct my thesis in their program called PRESENCE. They provided me with the option to estimate canopy cover changes by using aerial photography. I opted for a different approach, namely observing vegetation density change in degraded areas using Landsat imagery. The choice was made very easily for me because, it was what I wanted to do and what I wanted to develop into a skill.

I would like to thank everyone we has had some part in the realisation of this report. I would like to say special thanks to both Erika van Duijll and Julia Glenday for their guidance during this study. I would like to thank Tony Palmer for his willingness to come to the Baviaanskloof and provide his expertise and equipment for measuring the Leaf Area Index. I would like to thank Mike Powell for providing me with additional data. Which has, unfortunately, not been used. Last best, I would like to say special and warm thanks to Jael for his help during the collection of field data on vegetation density.

Due to the necessity to present maps, I have chosen to provide the maps in a separated appendix. Which is supplemented with this report, in digital form and in paper form. The digital form has been added to provide possibility to enlarge specific areas where necessary.

Arnhem, January 2014

Stefan Smit

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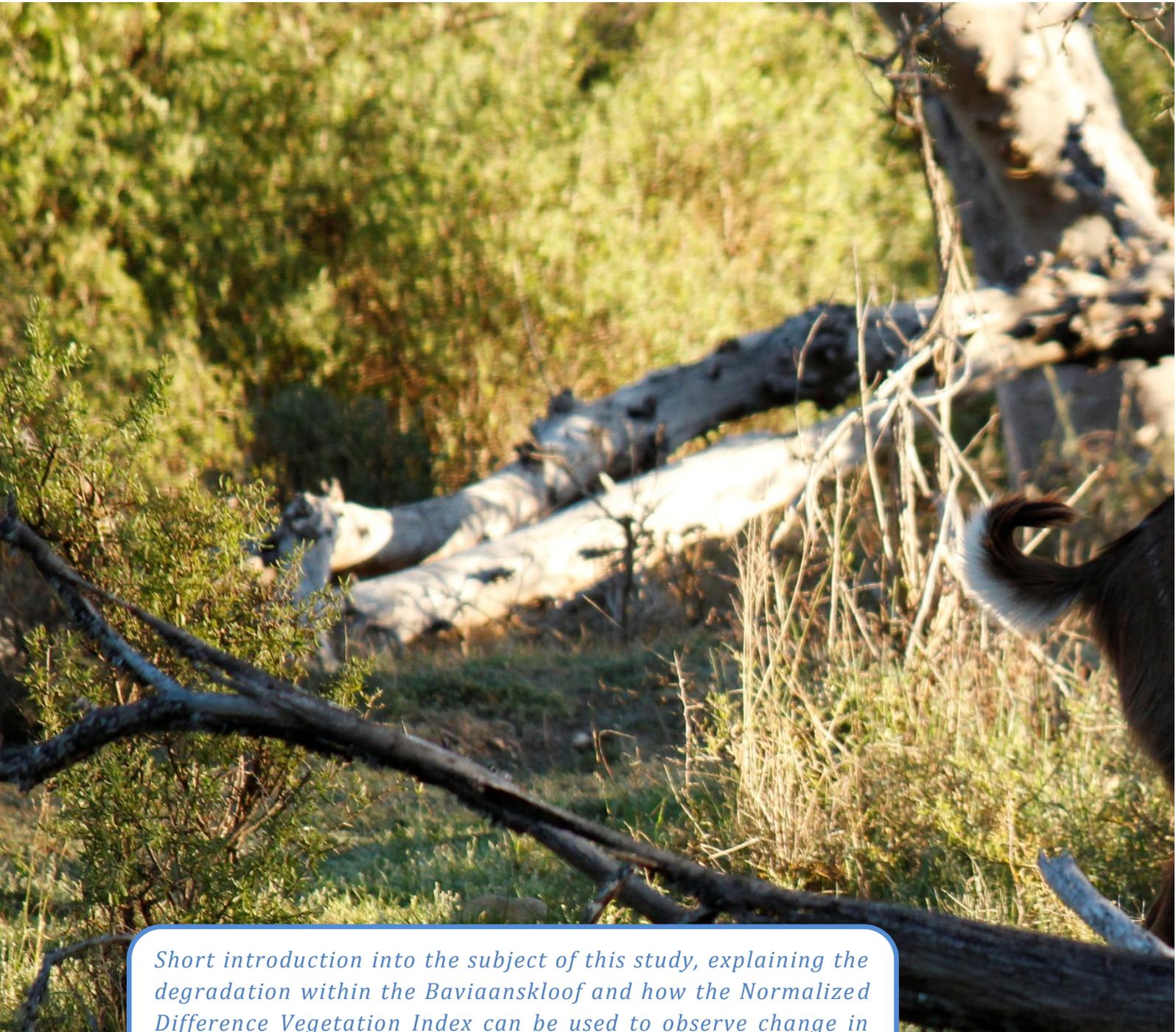
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List of Acronyms

ECP	-	Eastern Cape Parks
ETM	-	Enhanced Thematic Mapper
fAPAR	-	fractional Absorption of Photosynthetic Active Radiation
GIB	-	Gamtoos Irrigation Board
GIS	-	Geographical Information System
LAI	-	Leaf Area Index
NDVI	-	Normalized Difference Vegetation Index
NIR	-	The Near Infra Red spectrum
RED	-	The red spectrum
TM	-	Thematic Mapper



Short introduction into the subject of this study, explaining the degradation within the Baviaanskloof and how the Normalized Difference Vegetation Index can be used to observe change in vegetation density. Concluding with the objective and the research question posed in this study.

Chapter 1

Introduction



1.1 Introduction

This study is a combination of two goals which can be summed up in one sentence; "Observing change of vegetation density in degraded biomes". With the first problem being degradation and the second observing change. To understand the extent of the degradation we most look at how it came to be. Understanding the degradation, its extent and history, when understood, can be observed directly in the field. But observing change especially with vegetation requires a certain period of time. In a large area it even requires certain tools to be able to determine such observation over a large spatial scale. Remote Sensing of satellite images has become a valuable tool in forestry and nature conservation. It can be used to provide fast analysis of large spatial areas. Remote Sensing is in essence the ability to determine assumptions to be true from a distance.

Remote Sensing techniques used in this report are a combination of tools which are generally used. A strong emphasis has been laid on the use of the Normalized Difference Vegetation Index (NDVI). This NDVI can be obtained from processing satellite imagery, Landsat 5, 7 and 8 in this case. This can be done with using several Geographical Information Systems (GIS), in this case ArcGIS 10 was used. The NDVI is a conversion of the cell values from the raster that makes out a satellite image. This converted raster can be used to identify vegetation density and the Leaf Area Index (LAI). However to limit error and justify assumption the NDVI needs to have an input of field data. That process is called ground truth, by means of classifying the NDVI to a new raster which shows the approximate vegetation density or LAI for each cell value. The above described processes can be done for different images of different moments in time, which will enable a comparison. That comparison can be used to observe change of vegetation density in degraded biomes.

The study has been conducted in the Baviaanskloof, located on the Eastern Cape of South Africa. It is a water catchment area of approximately 1.243 ha. which has seen severe degradation during the 1970's and the 1980's. However the destructive land use practices of that time have been largely abandoned. The current situation, shows a efforts of restoring the area and assisting/encouraging the regeneration of degraded areas.

This study shall try to show that it is possible to observe change by using remote sensing techniques. It will do so by observing the change in vegetation density of degraded areas of the Baviaanskloof.

1.2 Problem statement

Large parts of the Baviaanskloof catchment have been degraded, some to a greater extent than others. Since the last two decades the human influenced disturbance has receded. Restoration of the catchment began in the last decade. Observing satellite images, a technique categorised as Remote Sensing, can provide answers about the regeneration of vegetation in degraded areas. A comparison between years could provide an observation and an answer to whether vegetation is indeed regenerating.

1.2.a Degradation in the Baviaanskloof

The areas of the Baviaanskloof that are degraded to some extent make out a significant portion of the total land surface. Almost all of the biomes found in the Baviaanskloof have been degraded, of which thicket has been degraded the most. Fynbos another biome has been degraded the least. The reason that thicket has been more degraded than fynbos, lies in the land use of the past.

During the 1970's and the 1980's farmers in the area, stocked large numbers of Mohair goats. During that period of time, the international wool price was favourable as well as the governmental subsidies on farming. The goats were able to roam, almost freely, throughout the catchment. The succulent thicket biome provide nourishment for the goats. Due to the high number of animals and thus the intensive grazing, areas which contained thicket were degraded to severe extents.

However, fynbos was not reached by the browsing goats. This is because of the geographic distribution of the two biomes. Where thicket grows around the floodplain and on the slopes, fynbos grows on the higher elevations. These high elevations were out of reach for the mohair goats, thus leaving the fynbos almost intact and the thicket easy accessible to be browsed. Later, during the late 1980's and the beginning of the 1990's, livestock numbers dropped dramatically since the wool price decreased and governmental subsidies ended. Farmers are now interested in restoring their lands.

With good reason, after three decades the effects of degradation are ongoing. Steep slopes have become susceptible of erosion. The main forms of erosion in the catchment are sheet erosion, gullies and incision in the river bed. Draajer (2010) mentioned that due to the degradation of thicket, overland flow and surface runoff have accelerated. Furthermore, he states that the valley has become more susceptible to drought because of the reduction in soil moisture holding capacity. Restoration programs have started since 2007, involving stakeholders within and outside the catchment in actively restoring the Thicket vegetation. Several efforts, in restoring the land, that have already been done in collaboration with Living Lands, Eastern Cape Parks (ECP), Gamtoos Irrigation Board (GIB) and the national initiative; Working For Water. Efforts to build capacity are now being made to plant Spekboom on degraded sites. Now, 65% of the catchment (Blanksma 2011) is part of a reserve, the Baviaanskloof Mega Reserve (marked as a UNESCO World Heritage Site). All these efforts to conserve and manage the Baviaanskloof, promotes a chance for the vegetation to restore.

1.2.b Observing change

To observe the change of vegetation density in degraded areas over a period of time, remote sensing techniques can provide assistance. Differences in vegetation density can be monitored by remote sensing Landsat imagery. By generating the Normalized Difference Vegetation Index (NDVI) from images of different years, it is possible to assess the current and past vegetation densities in an area. The NDVI is a combination of RED and NIR spectra derived from the spectral imagery (such as Landsat), which can be related to vegetation density and Leaf Area Index (LAI). To be able to categorise vegetation density, the NDVI needs to be converted or reclassified according to vegetation density. This can be done by gathering field data on vegetation densities and correlate data to the NDVI, providing a statistical relation between NDVI and vegetation density. The same can be done for LAI, although requiring special measuring devices.

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

Figure 1 NDVI Equation as used during the study

The NDVI is processed as follows. Each raster cell that makes out a satellite image is converted to NDVI. This conversion results that each raster cell now contains a value in the range between 1 and -1. Within this range, vegetation is represented between 0.2 and 0.8 . Several studies (Huang et al. 2000; Crouse 2001; Glenn et al. 2008; Suriyaprasit et al. 2008; Aziza et al. 2008; Blanksma 2011; Philpot 2011; Asner 2012) have been conducted in relating NDVI to forest canopy structure, vegetation dispersion and LAI. Strong correlations between the NDVI values and these forest characteristic, ranging between R 0.7 and 0.9 have been found in previous studies (Huang et al. 2000; Crouse 2001; Suriyaprasit et al. 2008; Aziza et al. 2008). LAI is an index that classes vegetation between 1 and 15 based on the foliage to ground cover ratio. NDVI has problems in detecting differences above an LAI of 2.0, saturation of the NDVI is the main problem in those cases. Furthermore, noise from the background, incl. atmospherically particles (aerosols), soil, litter among others influence the valuing of the NDVI. As LAI distribution seems to be more difficult to observe from the NDVI due to saturation, it has been selected in this study as cross reference material. However, by gathering field data on vegetation density and LAI, GIS software, such as ArcGIS 10, allows us to class the NDVI based on aforementioned field data.

Annual rainfall might impact the results of the study, as wet and dry periods will have direct influence on the vegetation cover, and therefore on the observed change in degraded areas. Therefore, the years that will be compared to each other need to be carefully selected. As LAI can be hard to differentiate in the NDVI, as stated before, it will be used as a reference. It will be used to validate the observed change and the distribution of vegetation density.

None of the studies have described a clear method on how to proceed in collecting field data for the specific goal. Most of the studies have used field data from inventories, done prior the mentioned studies, to use as ground truth source material. This study makes use of a "clump intercept method", of which its validity as field method for remote sensing, will be determined as true or false. Relations between vegetation density and NDVI need to be found based on the data of the clump intercept method. Furthermore, relations between NDVI and the different biomes should be sought after. This to be able to class each biome according to its own spectral signature.

1.3. Objective & Research Questions

Observe, vegetation density changes in degraded areas. Using remote sensing techniques in ArcGIS 10, based on the relation between the NDVI and field data on vegetation density and LAI.

Main questions

- Have degraded areas, regenerated in the period between 1987 - 2013?

Sub questions

- Do rainfall patterns have an strong influence on the major changes of vegetation cover density, in degraded areas?
- Can we see differences in vegetation density in different periods of time(1987-1992 1992-2001 and 2001 to 2013)?
- Can we discriminate spectral signatures based on biome?
 - Are spectral differences of the NDVI reflected by spectral signature differences per biome?
 - How can we discriminate the spectral signatures of each biome?
- Which degraded areas are observed to have regenerated the most?
- Is the regeneration rate of one biome to another observable by using NDVI?
- Do restoration projects have an influence on the regeneration of degraded areas?



Within this chapter, the study area is summarized, the local biomes reviewed and degradation localized.

Chapter 2

Study Area



2.1 Study Area

The Baviaanskloof catchment is located in the Eastern Cape, South Africa (approximate coordinates; E 24°3' S-33°7' and E 23°5' S-33°4'). The name Baviaanskloof, which means the "Valley of the Baboons" is related to the large amount of baboons in the valley of the catchment. Situated between the northern Baviaans mountains and the Southern Kouga mountains. Several initiatives have a resembling name, Baviaanskloof national reserve and the Baviaanskloof Mega Reserve, founded by UNESCO as a world heritage site. To clarify, the area discussed in this report is the Baviaanskloof catchment area, which is part of the national reserve which is in its turn part of the UNSECO Mega Reserve.

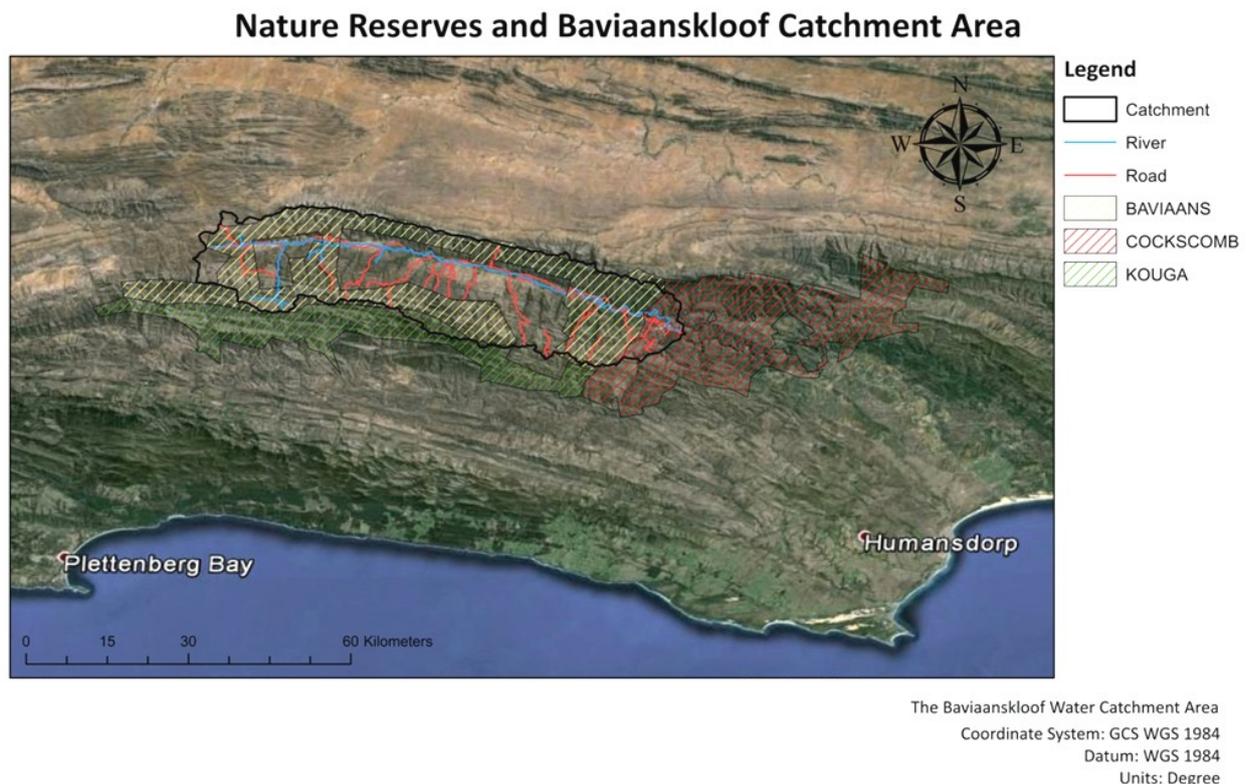


Figure 2: Location of the Baviaanskloof catchment and the reserve sections that form the UNESCO Mega Reserve.

The catchment covers an area around 1.234 ha, with many tributaries moving from the mountain reaches towards the main river down in the flood plain. The Baviaanskloof river joins the Kouga river, both contribute to the Kougadam reservoir. The Baviaanskloof can be characterised as a rift valley. With a flat flood plain and steep slopes, which can be observed on figure 8. Many smaller streams have formed gulches, giving the area a rough but divers terrain. On the flood plain several large hold farms have been established and have been in the area for several generations. Although some farms still consist of large pieces of land, other farms have been divided amongst shareholders. The farm areas are outside the boundaries of national reserve, which comprises 65% of the total catchment area.

As can be seen on the above map, most of the National Park is on the edges of the catchment area. Whereas the interior is primarily privately owned. Farmers in the area, have had a significant impact on the vegetation within the catchment. During the 1970's to the late 1980's wool prices

internationally caused farmers to increase stock of Mohair goats, which was at that time the main agricultural practices in the kloof. These goats were left the roam free over large stretches of land, causing severe degradation of flora and soil structures.

From data collected in the catchment, it can be observed that generally there is a peak in rainfall around March. A short dry period from June to September and a second rain season during October and November. Annual rainfall may differ from less than 100 mm to more than 500 mm per year. The last two decades show that dry years are followed up wet years. Although the amount of consecutive wet and dry years differ, the number of rainfall received remain the relatively the same, whether it was a dry or a wet year.

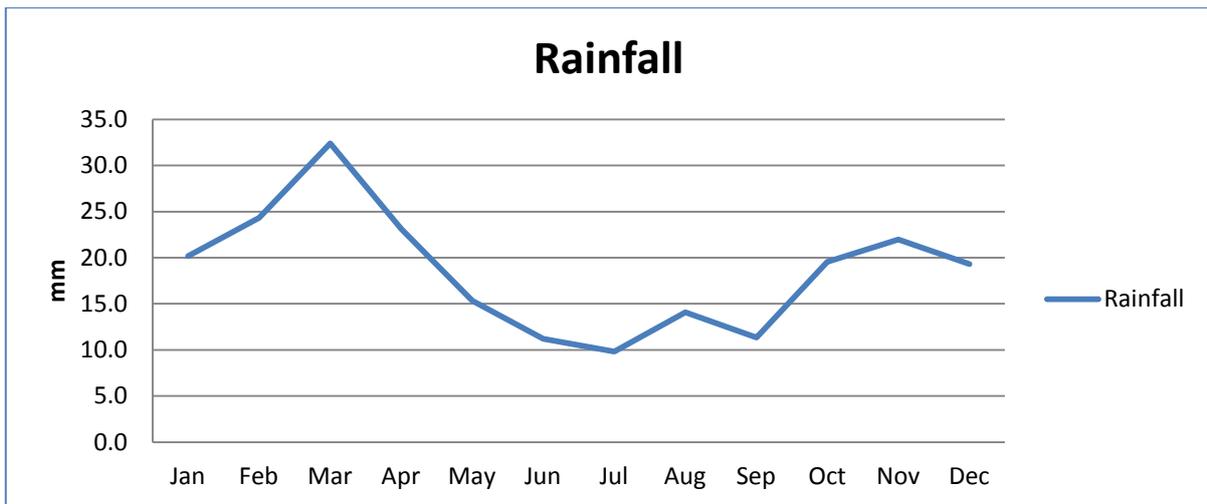


Figure 3: Chart show the distribution of rainfall per annum. Figures are based on data from ARC collected between 1900 and 2012

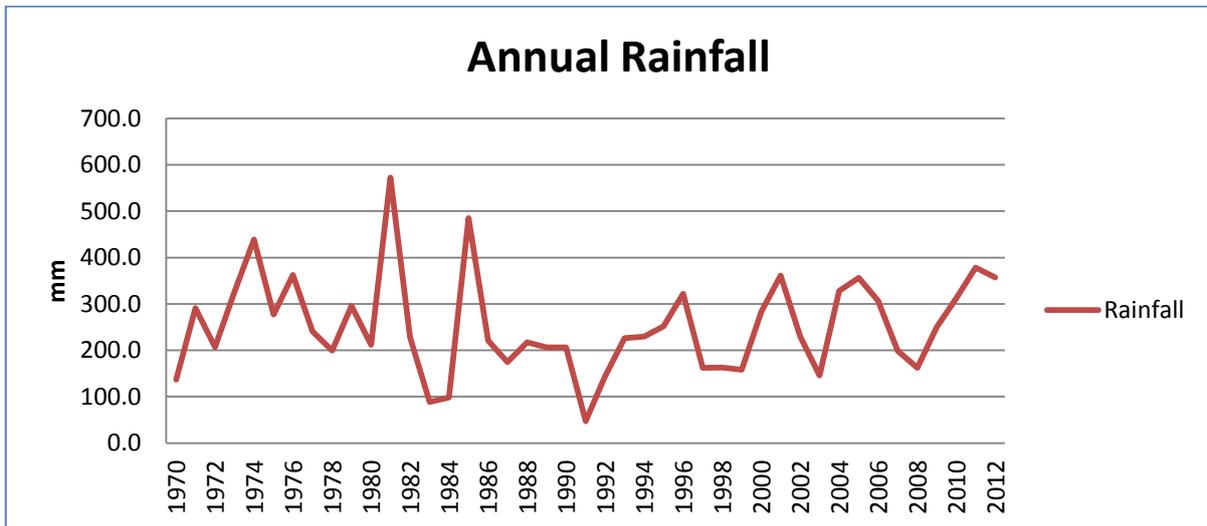


Figure 4: Chart show rainfall patterns, per annum. Selection was made from 1970 to 2012, which was relevant for this study. Data for 2013 was not available at the time. Figures are provided by ARC

2.2 Biome and degradation

Vegetation within the Baviaanskloof can be summed up to five biomes: Thicket, Fynbos, Forest Grassland and Savannah (Brown 2006).

Fynbos is predominantly found on the hill tops of the Kouga mountains and the Baviaans mountains at an elevation of 650m to 900m above sea level. Fynbos can be described as Heather, as the species found with Fynbos have similar physical traits. Fire is a major disturbance regime for the Fynbos biome.

Thicket-vegetation can be found on hill slopes ranging between 450m and 650 m above sea level. Thicket is dominated by a succulent locally known as Spekboom (*Portulacaria afra*). This species is being replanted throughout the catchment. The flood plain consist of different biomes, of Grassland and Savannah. These two biomes are characterised by shrub vegetation and small trees (*Acacia spec.*), locally know as doringsveld or thornfield. *Forests* are only found in areas where water is available

throughout the year and therefore will only be found in the smaller canyons which provide continuously water to the flood plain.

Transveld elevation causes a change in species composition, transveld can be distinguished into several subcategories. These subcategories are mosaiques of other biomes, such as thicket and fynbos. Other compositions such as a large number dense shrubs are classified as



Figure 5: Showing the landscape of the Baviaanskloof, with the floodplain containing grasslands and savannah. the sloops thicket and the mountaintops fynbos.



Figure 6: Showing a degraded area of thicket.

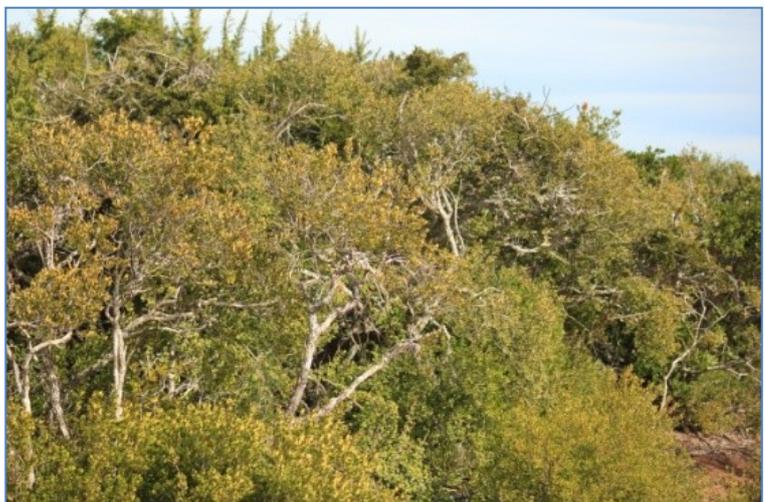


Figure 7: Close- up of spekboom (*Portulacaria afra*)

Biome Distribution in Comparison with Elevation

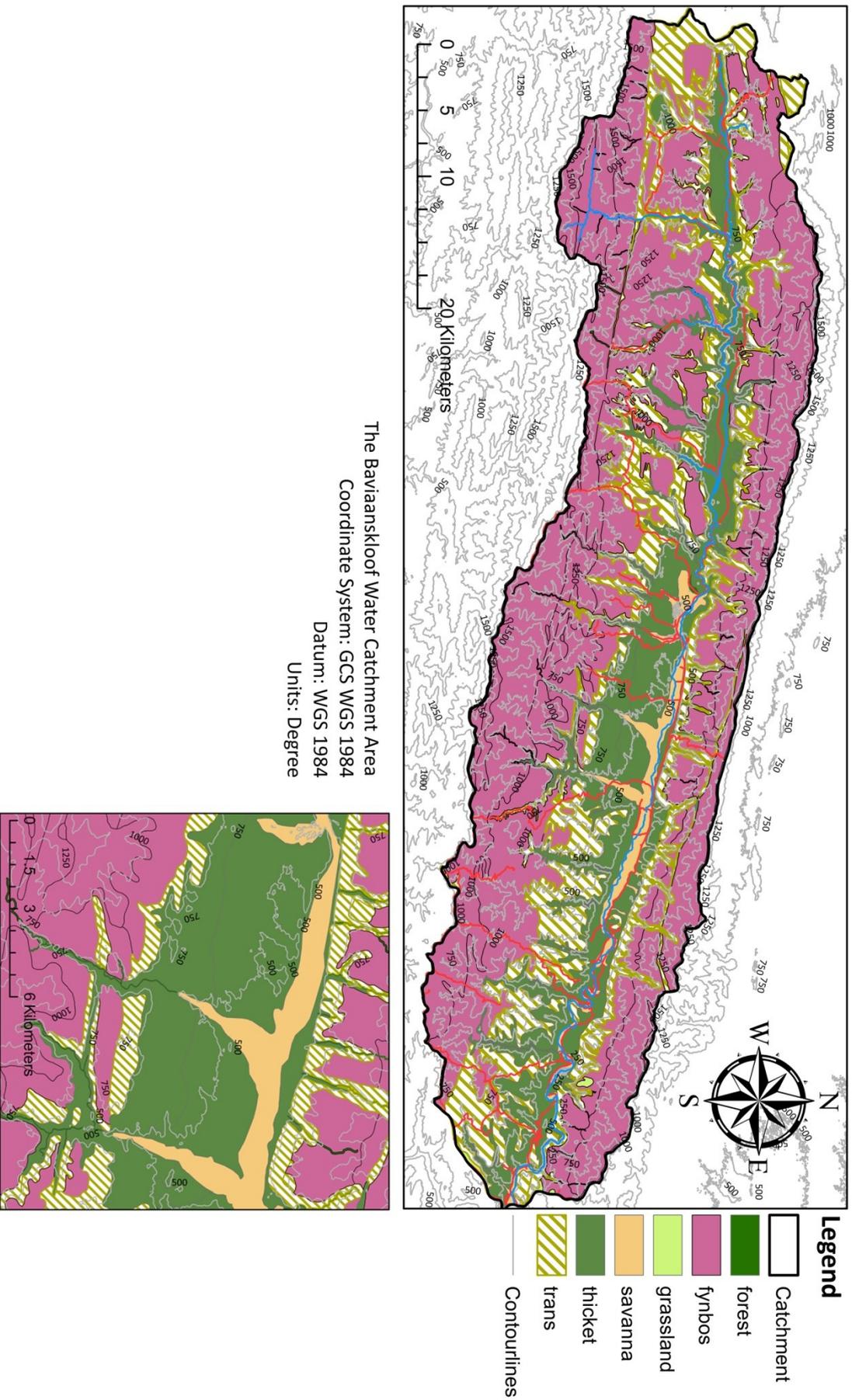


Figure 8: Biome distribution in comparison with Elevation.

Figure 8, shows the spatial distribution of each biome within the catchment. Within the cross section it is shown in detail how the biomes change as elevation increases. On the tops of the mountains we find fynbos, the largest portion of the area. As elevation becomes lower, the fynbos gradually changes in species composition. It is classified as transveld where different species slowly take over a dominant position in the landscape. Depending on the composition of species, transveld can be subdivided in different sub biomes, such as renosterveld. On even lower elevation, the thicket biome dominated by succulents is found. On the floodplain, where there is sufficient water, we find savanna and grassland biomes. Within the crevasses we find forests, due to the abundance of water available in those crevasses.

It is the lower elevations where farm lands area located which are degraded the most. As can be seen in figure 9, all the biomes have been degraded to some extent. Depending on the location, in some cases the severe extents. It can be seen that the floodplain is most degraded. Most notable two areas of thicket which are severely degraded. All along the floodplain savanna, grassland and the thicket biomes are degraded. The higher elevations, are little to not degraded, most notable, the Baviaans mountains and the eastern parts of the Kouga mountains, where we find the fynbos biomes.

Degradation levels

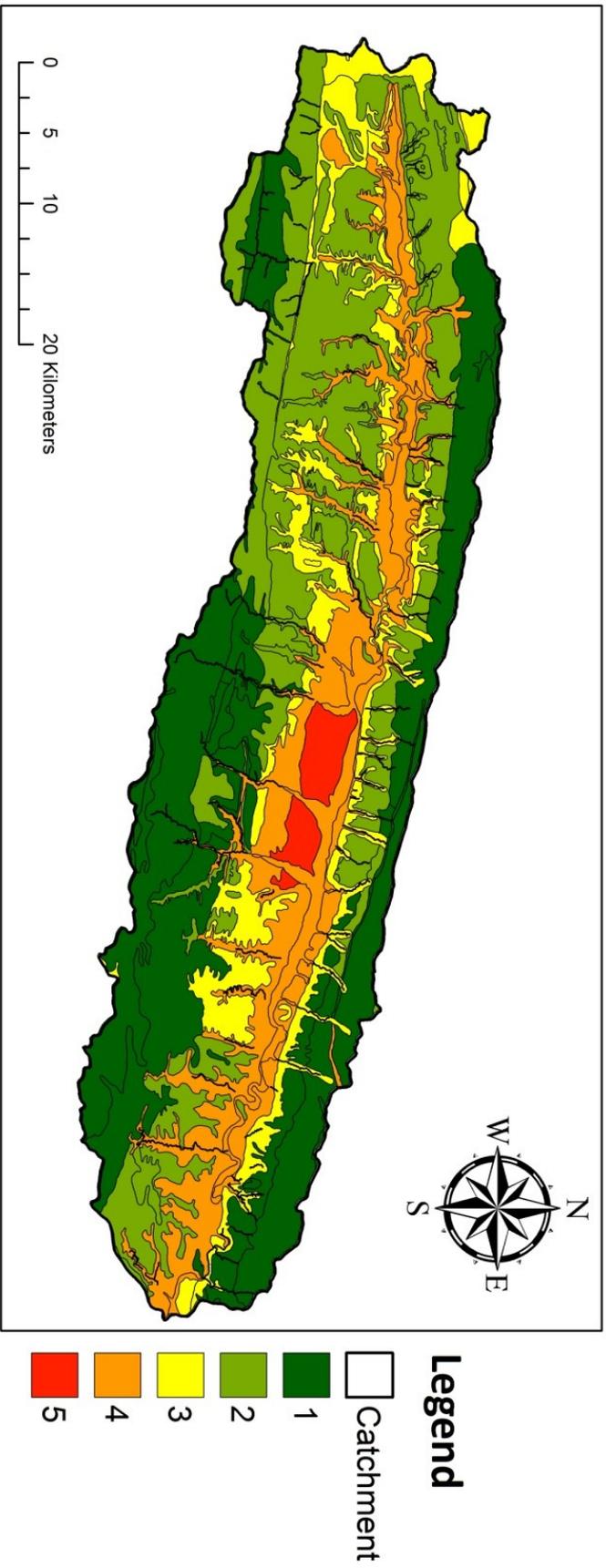
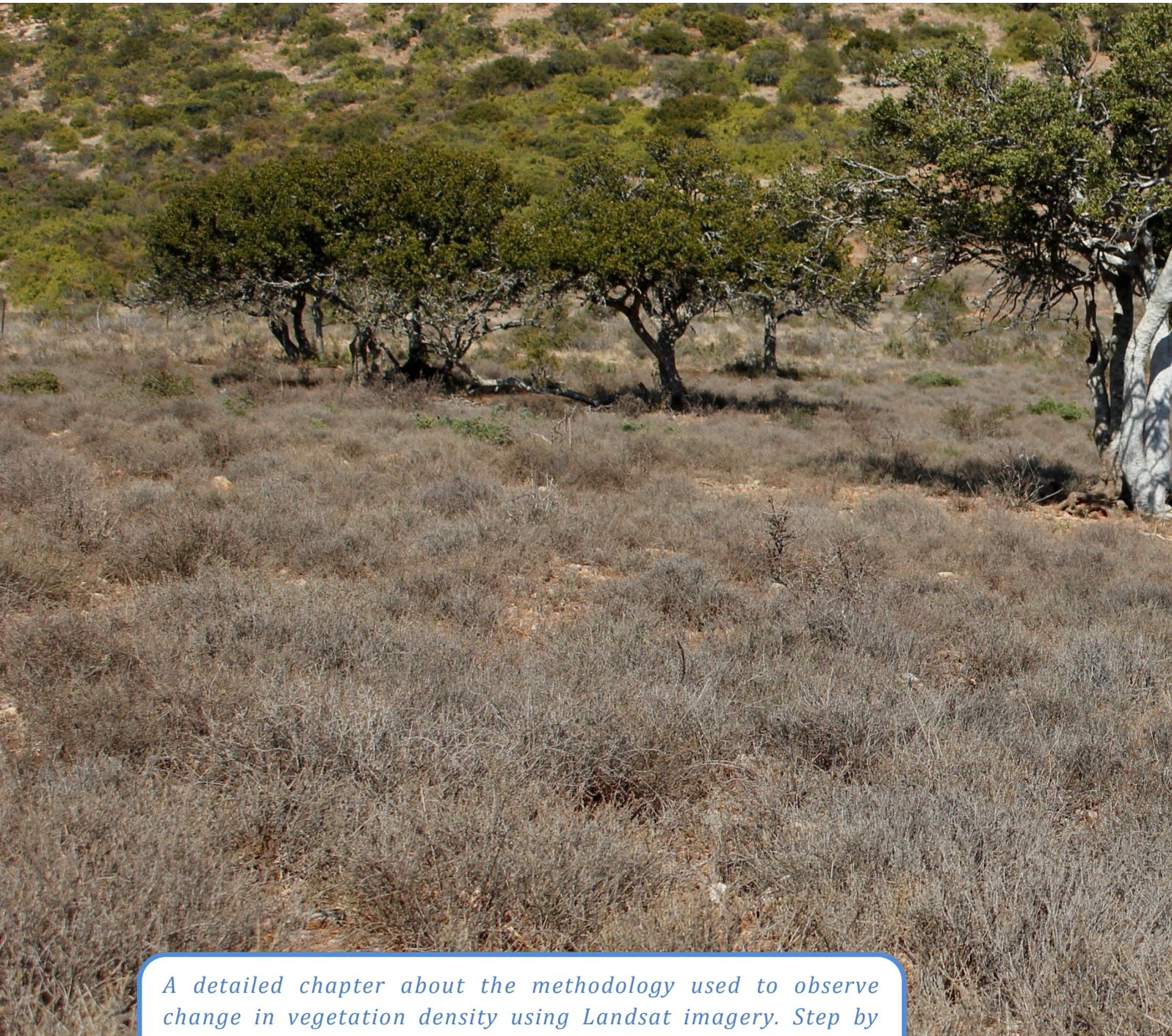


Figure 9: Degradation levels



A detailed chapter about the methodology used to observe change in vegetation density using Landsat imagery. Step by step, each part of the method is used to remote sense degradation and the vegetation density.

Methodology



The following chapter discusses what methods were used during this study. Methods that are closely related combined in subchapters. At first it was needed to gather data, the collection of Landsat Imagery and field data. This data was processed, to be able to determine a relation between the field data and the NDVI. That relation was in its turn used in ArcGIS to reclassify the NDVI rasters, on which finally it was able to observe the change of vegetation density.

3.1 Collecting data

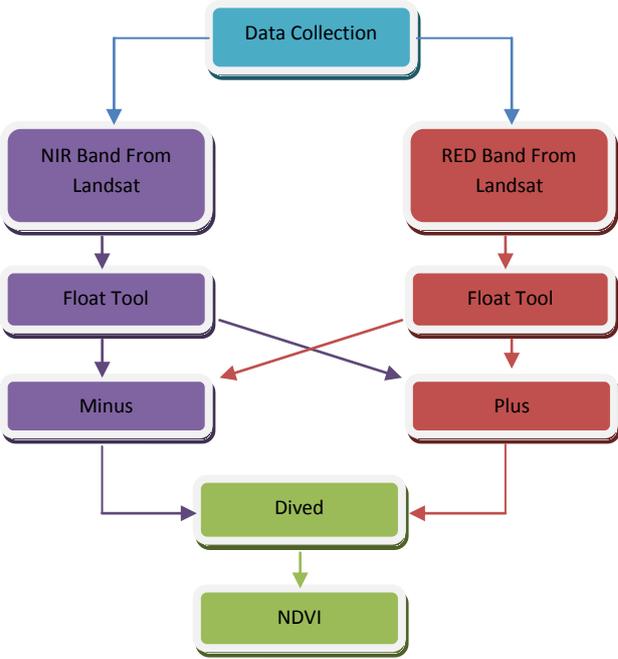
3.1.a Landsat data

Data collection of Landsat Images was done first, by using Earthexplorer from the USGS. Earthexplorer is an online database which has a free online geographic library. Images were retrieved from the following Landsat sensors, 5TM, 7ETM+ and 8LDCM. Selection criteria were based on cloud cover and month: May, June and July.

The reason for the selection of these months, is that the field data on vegetation density and LAI for this study were collected during that same period. This allows for a correct relation between field data and the spectral reflection of the NDVI.

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

Figure 10: NDVI equation as used during processing



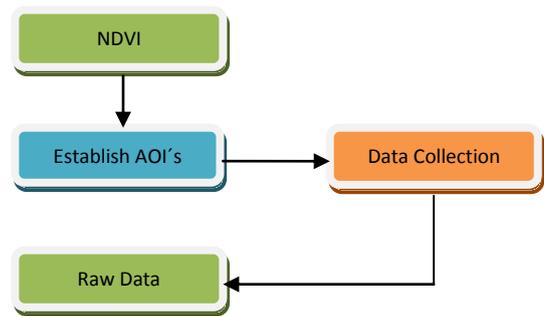
Schematic 1: Landsat Image to NDVI process

The images were processed to show the Normalized Difference Vegetation Index, which has been done by using "model builder" in ArcGIS 10.0. For this the raster formats of the NIR and RED Bands have to be float converted, in order to generate a raster depicting the NDVI within the range of 1 to -1. Within "model builder" the tools to subtract, add and divide were then used to generate the NDVI raster.

The "Float" tool, is part of ArcGIS, it allows converting a raster, so that it can be used to generate the NDVI. The "Float" tool, converts the integer values of a raster to floating point values on a cell-by-cell basis.

3.1.b Vegetation density data

The most recent NDVI raster of 2013 is then used to identify Areas of Interest (AOI'S). These AOI's are based on the relative values of the NDVI raster. AOI's are clumps of cells with similar values but also clumps of cells with a wide variety of values. The result of using these two types of AOI's is to gather sufficient data on differences in vegetation cover density. This will later result to having a large data base on spectral signatures for each cover density class. Furthermore, shapefiles provided by Living Lands, are to be used to identify the location to be part of a specific Biome group and the relative degradation.



Schematic 2: Data Collection process

Field data on vegetation density was collected by using transects of one hundred meters long. The starting locations were determined in the AOI's, of which the coordinates were entered in a GPS. Data collection focused on collecting density data of canopy, shrub and grass/herb. Criteria for each parameter is; Canopy, woody vegetation larger than 1.70m, shrub woody vegetation smaller than 1.70 m and greater than 1 m, grass/herbs all non woody vegetation and smaller than 1 m.

AOI (Areas of Interest) were selected on the following criteria: vegetation type, degradation level and NDVI value. Within those criteria starting locations for the transects are established.

Raw Data, total amount of unique values corresponding the geographic location within the Baviaanskloof. Gathered either in the field (cover densities)

The density of those three parameters are noted each ten meters. Following the "clump method", whenever one of the parameters intersect with transect line, counting starts when the intersection stops counting ends (counts are based on single centimetres). This results in thirty unique values for one transect, which are written down in centimetres.

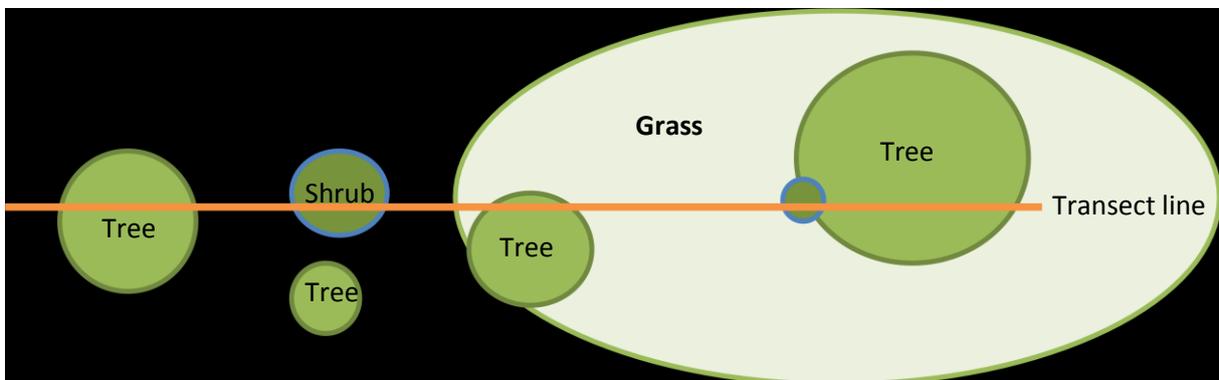
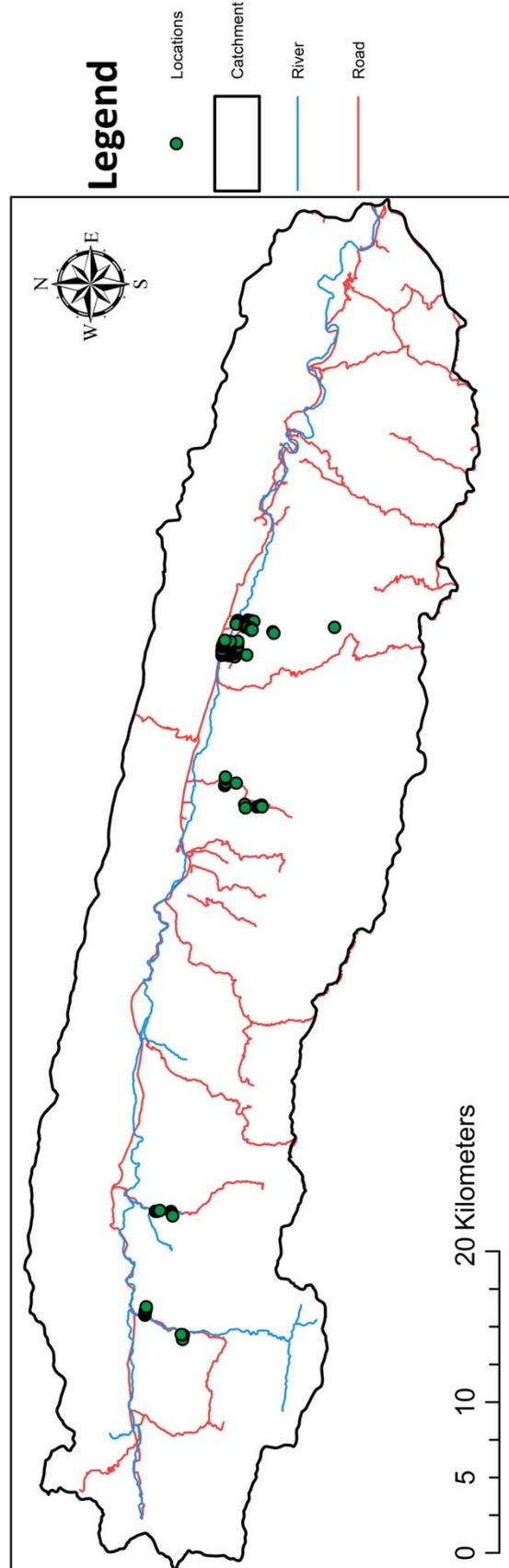


Figure 11 transect line overview

Transect Locations



The Bavianskloof Water Catchment Area
Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree

Figure 12: Transect Locations, final version, of all the transects that were visited during the study.

The end of the first transect line, marks an one hundred meter interval, the end of this interval marks the start of the second transect line. This continues for a thousand meters, making up five transect lines and gathers one-thousand and five-hundred unique values.

Note: this method was abandoned after fifteen plots. It proved to be time consuming, to implement the one hundred meter interval. Therefore it was chosen to run transect lines continuously, without interval. This was also favoured as some locations did not allow for an interval due to natural obstructions.

Data was stored in an Excel database, storing; location X and Y, transect ID and density to position along transect (ten meter interval). The data was be converted from centimetres to percentage, with the 100 percentage being 100 meter. Which was identified as the vegetation density in percentage along one hundred meter.

To clarify, when along a 100 meter transect line, Shrub and Grass/Herb cover perceived, there would be two strata. Meaning that Grass/Herb Cover would be divided by two, since Grass/Herb cover would also occur underneath shrubs. When Tree Canopy Cover would also be along a transect line, there are three strata. Then Shrub would be divided by two and Grass/Herb divided by three. As Grass/Herb and Shrubs can all grow underneath a Tree Canopy.

The MEAN Vegetation Cover and MEAN NDVI were used to generate classes. Each individual Sample Data was gathered into the representing cover class. The NDVI fitting to the Sample Data was also put into that Cover Class. For each Cover Class a MEAN for all the corresponding data was generated. Ending with two cover ranges, 10% interval and 5% interval, each with a MEAN of Cover from the Sample Data and a MEAN of NDVI for the same Sample location. The linear Regression between the Sample Data and NDVI was used to determine the exact NDVI value for Cover Classes with an interval of 10%.

3.1.c LAI

The selection of points to measure the LAI were based on a selection of different values of the NDVI. These points were entered into a GPS unit in order to find the location in the field. A close proximity to the road was required, to be able to take readings fast. The reason for this is that the instrument used a Septometer, can only be used during periods of direct sunlight. The time period was between 10:00 to 15:00. The instrument works by first taking a reading of fAPAR in direct sunlight, after that a reading under a canopy (tree, shrub, herb and grass). The instrument then uses these readings to calculate the LAI. When direct sunlight fAPAR reading was between 750nm to 1200nm, a second reading was taken underneath the canopy, to calculate the LAI. The areas for assessing the LAI were located in the Eastern part of the catchment. The LAI will be used to cross-reference the re-classed NDVI raster, processing of the LAI will follow the same steps as the field data on vegetation cover densities.



Figure 13: Septometer (Source: decagon)

3.1.d. NDVI collection

Collecting the NDVI requires geographical positions, which can be located using ArcGIS 10. Starting and end positions of the transect lines used to gather the vegetation density and the LAI plot locations are to determine these geographical positions. LAI plot locations, predetermined in ArcGIS, provide a single value of NDVI corresponding to the MEAN LAI collected in the field.

To determine the NDVI values corresponding to the transects, a line must be drawn in ArcGIS. This line is drawn between the start and end of each transect. The line will intersect several cells containing a single NDVI value. Using the "measuring tape" function in ArcGIS, we can determine the exact NDVI value for each ten meters along the transect line that was established in the field. After collection data will be entered into a Excel database, where the data will be stored based on determined position along transect line (ten meter interval) and transect ID.



Figure 14: Shows how the NDVI was collected using a line between transect points.

LAI plot Locations

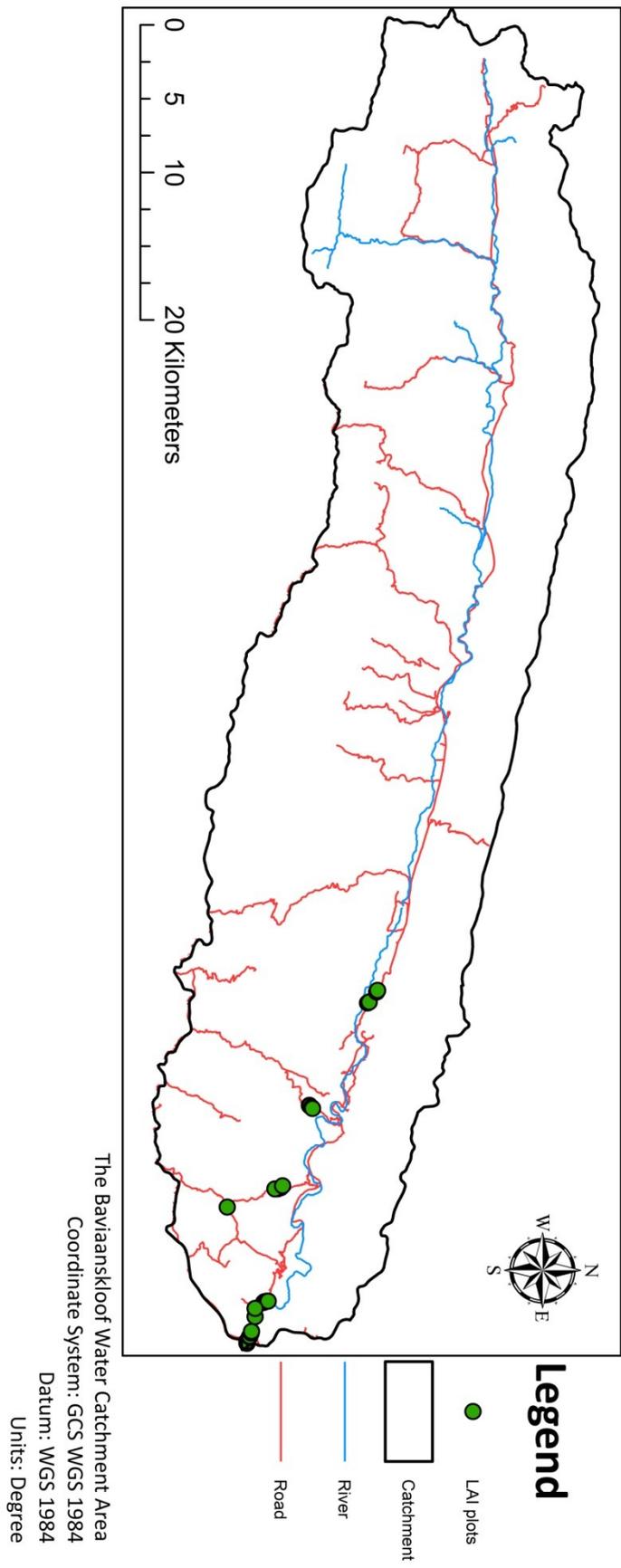


Figure 15: LAI plot locations, initial plot locations for the LAI collection. The cluster of plots to the west were not visited.

3.2 Cover Class Creation

The raw field data on vegetation density first needed to be converted before the data was compressed. Data conversion was done based on strata. As the total density, of the combined vegetation parameters (canopy, shrub and grass/herb) can be more than 100%. Because the shrubs and grasses/herbs might grow underneath a canopy. Since the NDVI is based on the horizontal reflectance of vegetation this conversion needs to be executed. This conversion is done in Excel and follows the following equation.

$$\left(\frac{G}{n}\right) + \left(\frac{S}{(n-1)}\right) + C$$

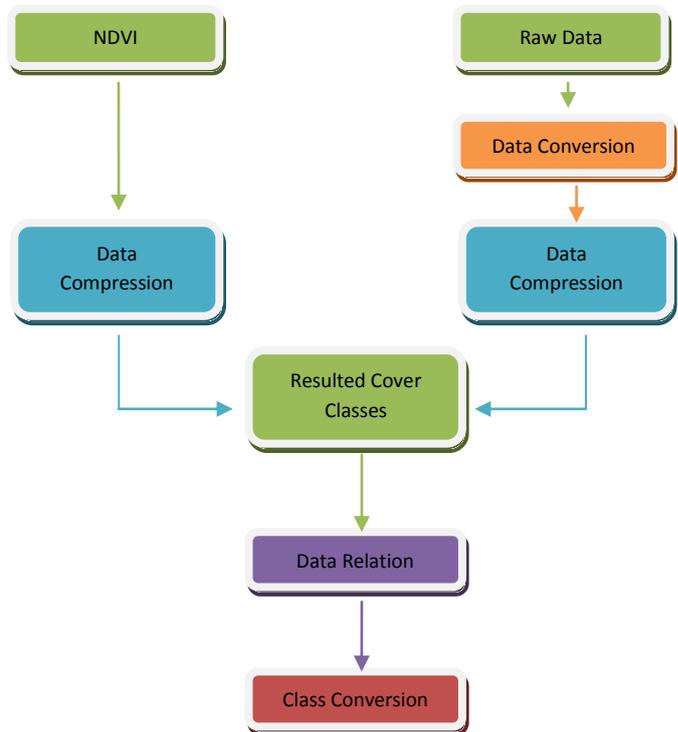
Figure 16: Stara conversion equation.

N is number of strata, G is grass/herbs, S is shrub and C is canopy.

After conversion, data was compressed to represent the MEAN in vegetation density and the MEAN in NDVI on which the first relation is based. The relation between NDVI and vegetation density was based on biome differences and indiscriminate towards biome differences. Meaning, one relation based on all the field data, and relations based on the biome in which the field data was collected.

The related data was converted to classes, were each MEAN value from a transect will be categorised within a density class table. This density class table has ten percent interval. It was used to combine the field data and NDVI values into separate classes, resulting in a second relation. This was needed to enter ranges of NDVI values into ArcGIS in order to reclass the NDVI raster.

To create the NDVI to LAI relations, no conversion or compression was needed. As all data is already represented in single values that can be related directly. The relation allows a LAI class table, in which the NDVI range for LAI values is determined, ranging from 1 to 8, with interval of 1.



Schematic 3: Schematic of the process to create cover classes from the collected data.

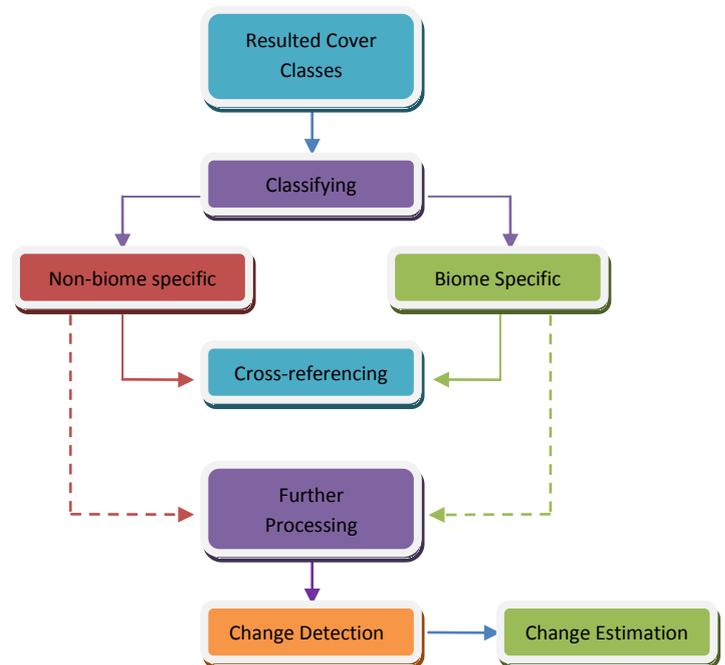
Data Compression, all unique values are compressed to represent the SUM of cover, respectively, for the parameters grass/herbs, shrub and canopy over a transect line. Unique values for the NDVI are compressed to represent the MEAN value over the length of transect line. The reason for establishing the MEAN for NDVI and the SUM for the field data, is the 30 x 30 m spectral representation of the area by Landsat. One NDVI value represents an area of 30 x 30m, were the cover parameters only represent the area along the transect line, corresponding to maximum 7 x 100 m.

3.3 Reclassifying & Change Detection

The resulted tables of the second relation are to be used in the "reclassify" tool in ArcGIS. This tool allows the user, to select a range of values in a raster and convert them into new pre established value. In this case the NDVI raster is converted to vegetation density. The classes are used to determine which range of NDVI corresponds to which vegetation class. The same is to be done to class the NDVI raster to represent the LAI.

Classifying has to be done several times for one Landsat image, non-biome specific classification one time, and biome specific classification an x amount of times based on the number of biomes in which data has been collected. Data is been cross referenced with other data (LAI, Shapefiles and Google Earth) to determine the accuracy of the classification. When the classification is observed to be correct, further processing commences. Meaning, Landsat data from other years will be processed in order to detect change.

These vegetation classes are to be used within ArcGIS 10. The NDVI is classed by the "Reclass" tool, which uses a "Class Table". Within this table, cell values of a raster can be determined for conversion into specific classes. The tool is used for NDVI's of several years. In order to discriminate between biome, a shapefile containing the spatial locations of the different biomes has to be segmented. This results in an individual shapefile for each biome, and outlines the spatial locations. These shapefiles combined represent the entire catchment, a single shapefile represents a biome. Reclassifying the NDVI raster, follows the steps to outline the spatial locations of the biomes using the "clip" tool in ArcGIS. Followed by, reclassifying each segment of the raster with a class table corresponding to the biome it depicts.



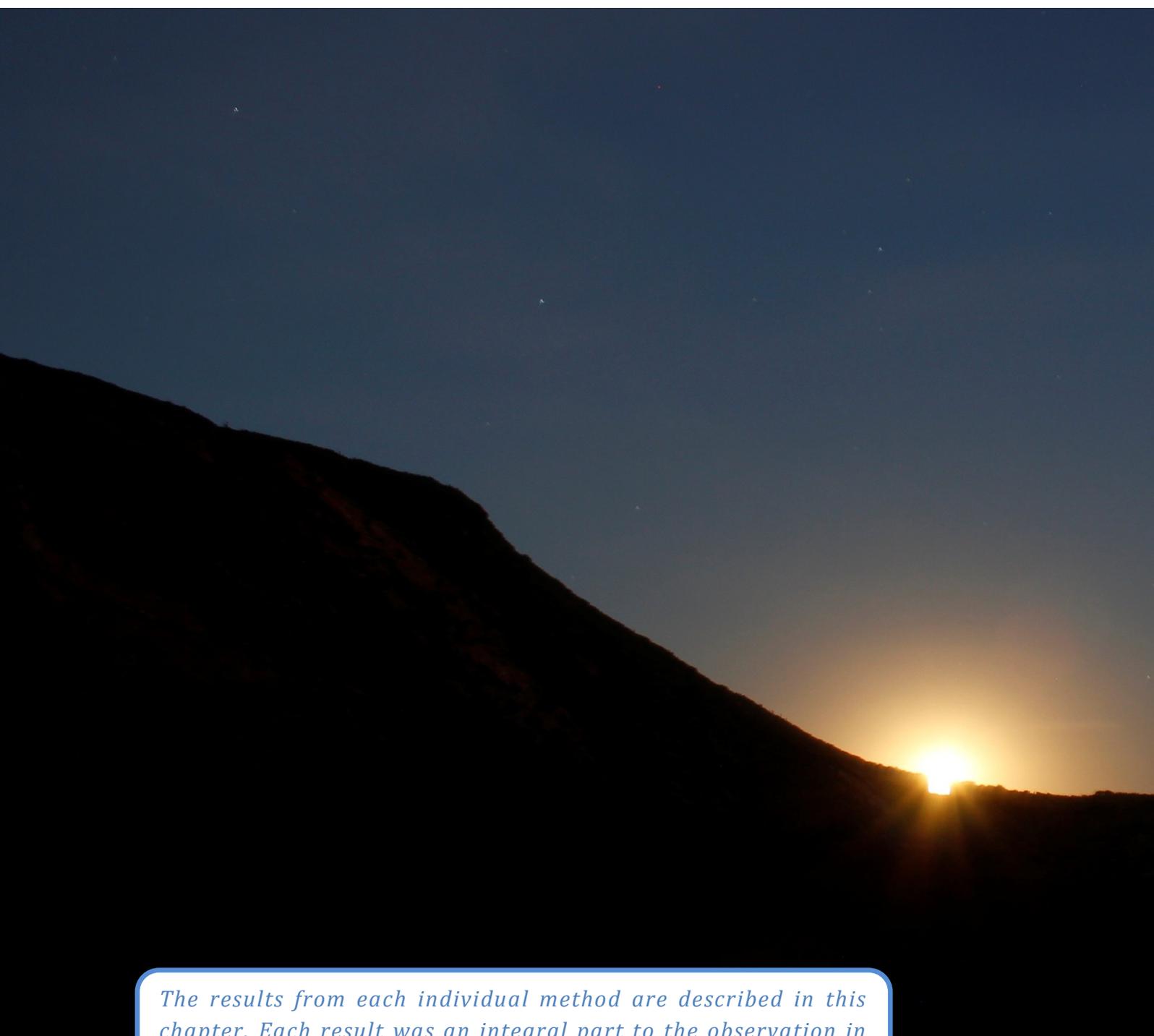
Schematic 4: Change detection process

Cross-referencing, classed images by using the NDVI raster of the corresponding year, shapefiles based on biome and degradation level. Visual observation, based on the knowledge of the characteristics of NDVI processing. Low NDVI means low cover, assumption high degradation, coarse structured vegetation type. High NDVI means high cover, assumption low degradation, dense structured vegetation type.

Change Detection, by subtracting the cover densities from a recent year of a year before that.
 Example:
 2013 minus 2001

The resulting cover density rasters, were then used to determine the change in vegetation density. This was done by subtracting the vegetation density rasters from each other. This resulted in a raster which showed the increase and decrease of cover density in the entire catchment. To determine whether areas that are degraded show signs of regeneration, a shapefile with data on the spatial locations of degradation intensity was used. By using the tool "zonal statistics" in ArcGIS it is possible to determine specifically for each degradation level whether there are signs of regeneration. By using the degradation shapefile, zones were established for each degradation level. The change rasters were then used to provide input values. The resulting raster provided data on the overall major change in each zone (degradation level). The tool sums all values and selects that value that has the highest occurrence in each zone. This will determine whether a degraded area has seen an increase or decrease in cover density over an X time span.

To map the vegetation Change the Vegetation Cover maps were subtracted from each other, which resulted in a map depicting growth and decay. These maps are then statistically analysed, by using the tool "zonal statistics" in ArcGIS. This allows for a fast measurement, of what the major changes are in the different zones, which each outline a specific degradation level. Done for each period of time, we can see change in vegetation between two years.



The results from each individual method are described in this chapter. Each result was an integral part to the observation in vegetation density changes of degraded areas.

Results & Analysis



4.1. Landsat Data

Based on the annual rainfall data provided by the ARC, Landsat images of the years 1987, 1992 and 2001 were selected, because of similarities in the amounts of precipitation. Thus for these years and 2013 the NDVI was calculated over the month of June. Images of the years in between were not used because of selection criteria of minimum cloud cover and/or images of the month June were not available in those years.

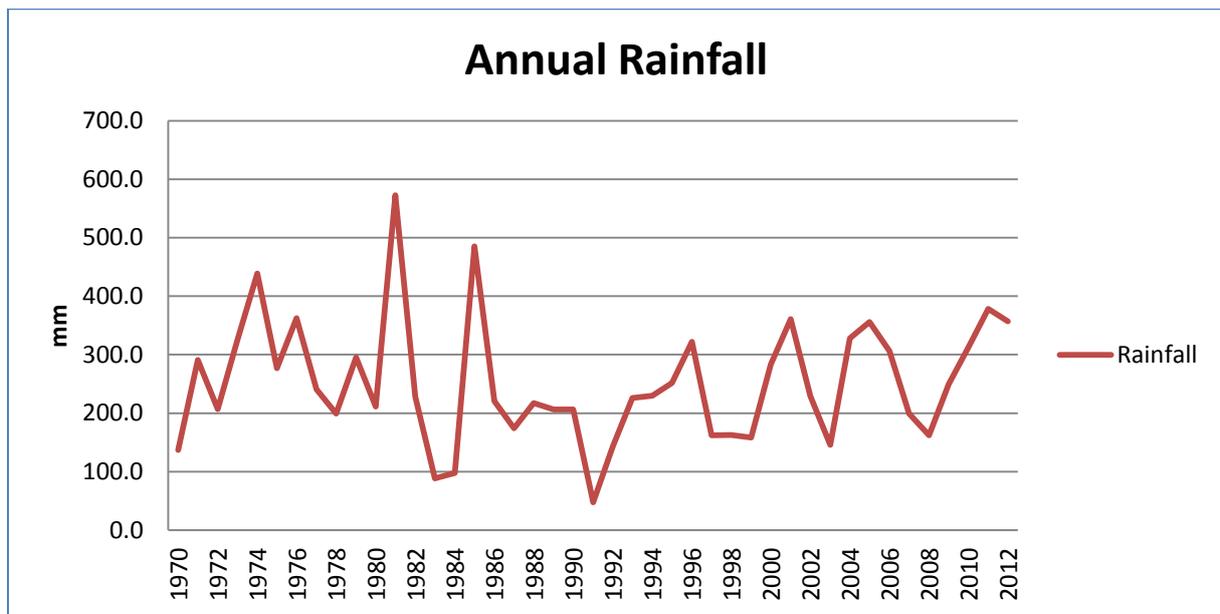


Figure 17: Annual rainfall in the Baviaanskloof, collected at Rust en Vrede. Data Source ARC 2012

After analyse of the NDVI maps of each year and observed that there are several large areas with low values, < 0.0000 . However, these areas were expected to have much higher values as in the field it appeared that these areas had a significant percentage of cover. But, due to the sun's gradient and the time the satellite images were taken it became apparent that these areas are shaded.

Note: the selection of the area for field surveys were initially selected based on the results of a NDVI raster of 2001. At the time Landsat8 Images for 2013 were not yet available. Plot location were thus established on the observable variation and distribution of NDVI values of a different year than when the plot locations were visited. However, this is only the case with the first fifteen plot locations. The other AOI's were visited after the release of the first Landsat8 images. The remaining AOI's and plot locations, forty-four, were thus selected based on a NDVI raster from the in which field data was collected. Furthermore, there was no cloud free data available for the year 2013, in the month June. Therefore it was chosen to use the month May as basis material. Older Landsat data for the month May did not meet the requirements of a cloud free image, or was lacking in availability.

It can be seen in figure 15, that differences in perception seem to have an effect on the reflection of the NDVI, when a comparison is drawn on the annual rainfall data. Rainfall was highest in June 2001, observable due to the high amounts of NDVI values, represented in the colour red. Lowest rainfall was during 1990 which also has an effect on how the NDVI is represented, overall lower values, represented by yellow colours. The years 2013 and 1987 seem similar in the amounts of rainfall, although there is no data available on the precipitation in 2013. These zoomed in images can be viewed in full extent in the separate appendix.

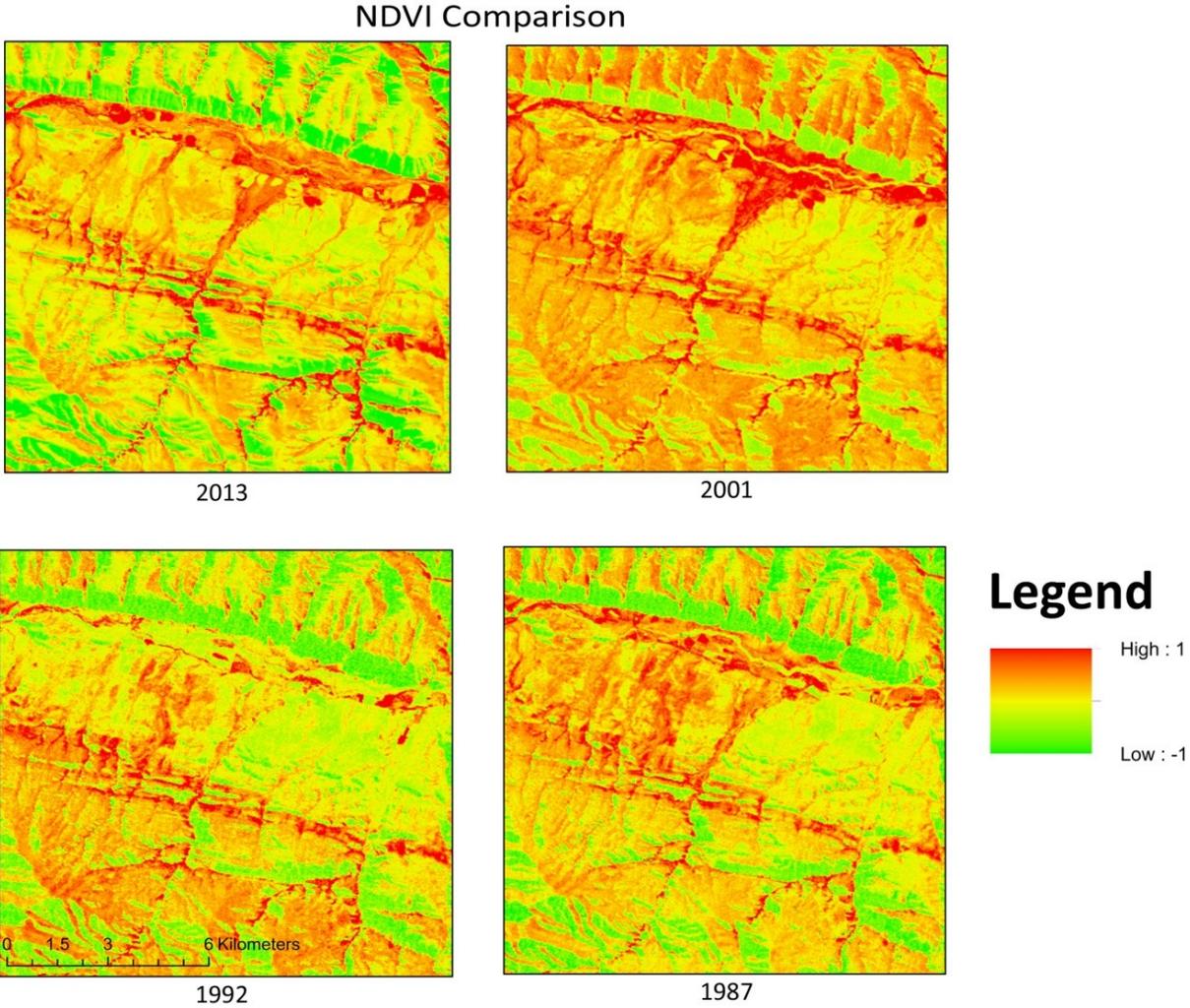


Figure 18: A comparison between the different years, showing the differences in the NDVI from year to year.

4.2 Resulted density classes

The overall relation between vegetation density and NDVI was found at $R^2=0.8725$, after data compression and conversion. Two values were removed from the total data set as they were not representative for the whole data set. For each of the biomes a relation was generated, also after data compression and conversion. The relations found are, *Thicket*; $R^2= 0.8989$ *Doringsveld*; $R^2=0.7688$ and *Renosterveld*; $R^2=0.9891$. The data was compressed, converted and classed which resulted in the relation indiscriminately of biome and the relations discriminately towards the three biomes in which field data was collected.

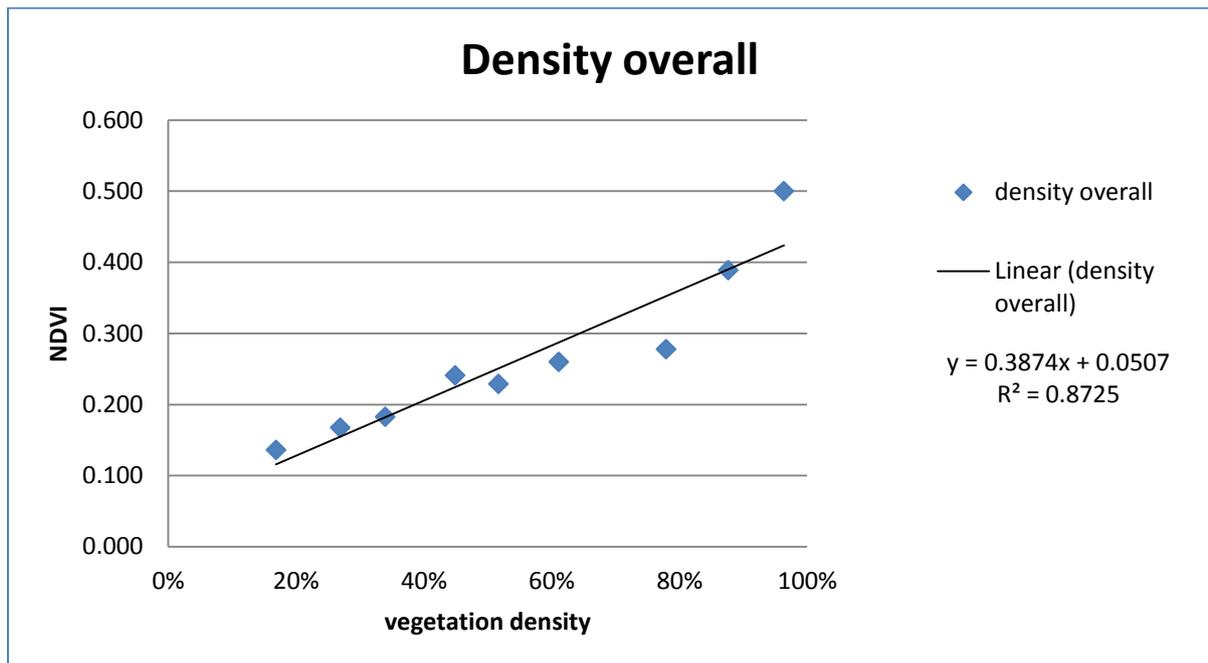


Figure 19: Overall relation between total vegetation density and NDVI

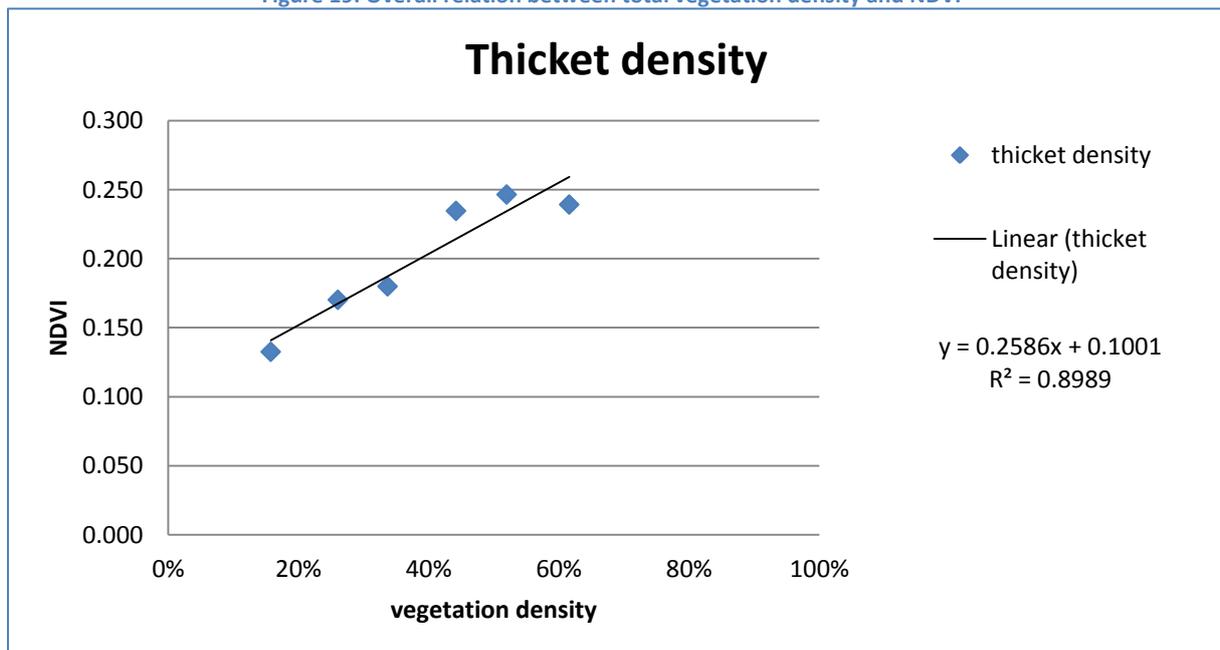


Figure 20: Relation between Thicket density and NDVI

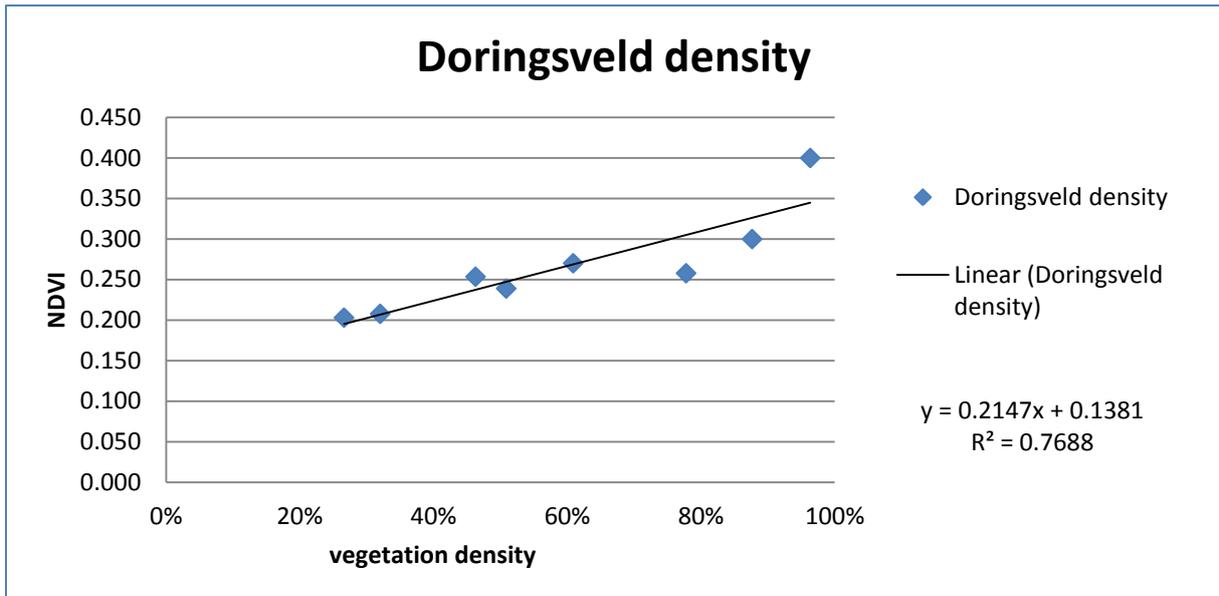


Figure 21: Relation between Doringsveld and NDVI

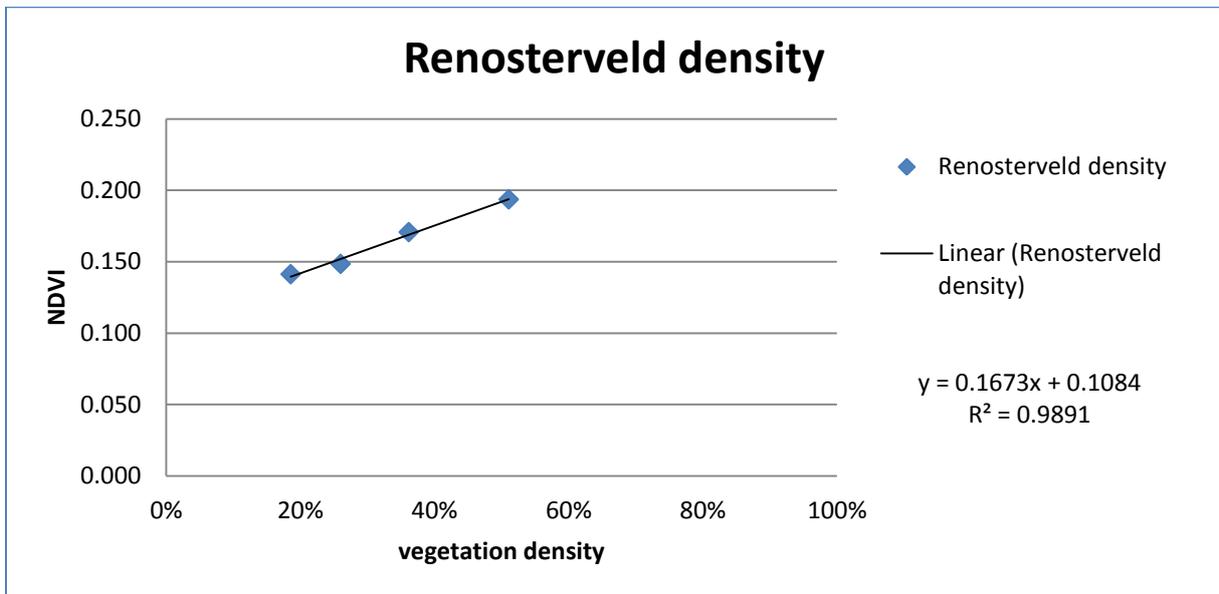


Figure 22: Relation between Renosterveld and NDVI

The relations and table 1 were the result of compressing and converting the data from 59 transect. The data is a total of eighteen hundred unique values for canopy density, shrub density and grass/herb density. Unfortunately no data was collected in fynbos, it was difficult to reach fynbos on the account of steep cliffs. The NDVI data collected in ArcGIS, summed up to a total of five hundred and ninety values each corresponding to a specific transect section and cover percentage.

Class Density	Total		Thicket		Doringsveld		Renosterveld	
	Density	NDVI	density	NDVI	density	NDVI	density	NDVI
0 - 10	--	--	--	--	--	--	--	--
10 - 20	16.87%	0.136091	15.74%	0.132627	--	--	18.56%	0.141287
20 - 30	26.91%	0.167461	26.05%	0.170277	26.59%	0.203084	26.00%	0.148492
30 - 40	33.95%	0.182708	33.68%	0.180020	32.00%	0.207799	36.16%	0.170736
40 - 50	44.89%	0.240982	44.20%	0.234666	46.27%	0.253613		
50 - 60	51.67%	0.228903	51.98%	0.246521	50.85%	0.239017	51.07%	0.193668
60 - 70	61.11%	0.259887	61.58%	0.239275	60.87%	0.270194	--	--
70 - 80	77.91%	0.277711	--	--	77.76%	0.257903	--	--
80 - 90	87.63%	0.388886	--	--	87.63%	0.300000	--	--
90 - 100	96.33%	0.500000	--	--	96.33%	0.400000	--	--

Table 1: Cover class table as result from class conversion

Note: in table 1 rounded figures can be found in the "total density" and "doringsveld density" columns. These rounded figures are based on the absolute maximum NDVI values found in 2013 raster. In the case of doringsveld 0.40000 is the respective maximum NDVI value in that biome. These rounded numbers were used to maximise the effectiveness of the cover class table during reclassification. The numbers have had an effect on the R^2 relation. In the overall case, this was 0.1 decrease of the R^2 relation and in the case of doringsveld it was an increase of 0.02 R^2 relation.

Decrease of the overall relation had the effect that the classification, significantly improved. Earlier tryout showed that areas were classed with much higher density values than possible. Therefore it was chosen to use these rounded values.

4.2.b LAI relation

The results of ten plot locations and the relation to the NDVI values of that location was found $R^2=0.7437$. Results were also similar for each of the different Biomes, in which samples were taken (respectively, thicket and doringsveld). However the number of samples for each separate biome was limited, therefore it was chosen not specify the LAI to NDVI relation based on biome.

Plotnr	NDVI	LAI
14	0.25	2.5
13	0.19	0.55
11	0.33	3.23
7	0.21	1.79
8	0.23	1.89
6	0.22	1.83
31	0.31	5.3
30	0.16	0.84
20	0.29	3.56
21	0.28	2.38

Table 2: NDVI to LAI class table. Showing the distribution of LAI values from the field that correspond to NDVI values derived from ArcGIS

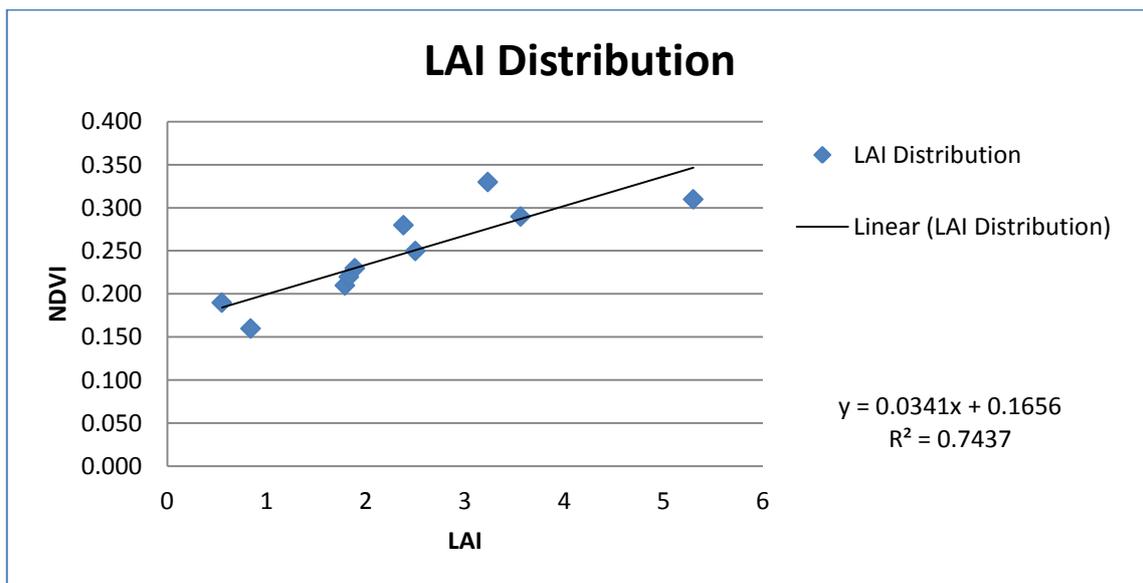


Figure 23: LAI distribution in comparison to NDVI

4.3 Re-classed Results

Using the linear equation resulted from R^2 relation, the following density class tables, table 3, were created. The data presented in this table were entered in ArcGIS, using the "reclass" tool. After classification in ArcGIS, the similarities between the overall relation and the biome relations disappeared. Using the overall relation as a non-biome specific classification, the NDVI raster was classed lower in areas where the assumption was high vegetation cover density. After classifying the image biome specific, based on the spectral signatures of the different biomes and their spatial distribution, it was observed that the classification had a higher accuracy. Comparing the NDVI data, LAI distribution and vegetation cover density distribution made this clear.

Total		Thicket		Doringsveld		Renosterveld	
Density	NDVI	Density	NDVI	Density	NDVI	Density	NDVI
0%	0.050700	0%	0.100100	0%	0.138100	0%	0.108400
10%	0.089440	10%	0.125960	10%	0.159570	10%	0.125130
20%	0.128180	20%	0.151820	20%	0.181040	20%	0.141860
30%	0.166920	30%	0.177680	30%	0.202510	30%	0.158590
40%	0.205660	40%	0.203540	40%	0.223980	40%	0.175320
50%	0.244400	50%	0.229400	50%	0.245450	50%	0.192050
60%	0.283140	60%	0.255260	60%	0.266920	60%	0.208780
70%	0.321880	70%	0.281120	70%	0.288390	70%	0.225510
80%	0.360620	80%	0.306980	80%	0.309860	80%	0.242240
90%	0.399360	90%	0.332840	90%	0.331330	90%	0.258970
100%	0.438100	100%	0.358700	100%	0.352800	100%	0.275700

Table 3: Density Class table, used as input data for the Reclass tool in ArcGIS. Used to converted a NDVI raster to a vegetation density raster. Note: four different tables,

In figure 24, a comparison is made between non-biome specific classification and biome specific classification. It can be observed that the biome specific classification images show a higher density in the upper corner of the zoomed in images. This reflects the field situation, which can be classed as doringsveld with a high abundance of *Accacia spec.*. Furthermore the distribution of vegetation density in the dusty fans, is more observable in the images that are reclassified using the biome specific classification. These zoomed images can be viewed in full extent in the separate appendix.

Note: In order to classify the whole catchment discriminative, the table for total density was used class remaining areas. These areas were located outside the areas containing the biomes, thicket, doringsveld and renosterveld. As those three biomes were differentiated from each other. The remaining areas contained the fynbos and forest biomes. These biomes were thus reclassified based on the data presented in the columns for "total density".

Reclassification Comparison, Non-Biome Specific Classification and Biome Specific Classification

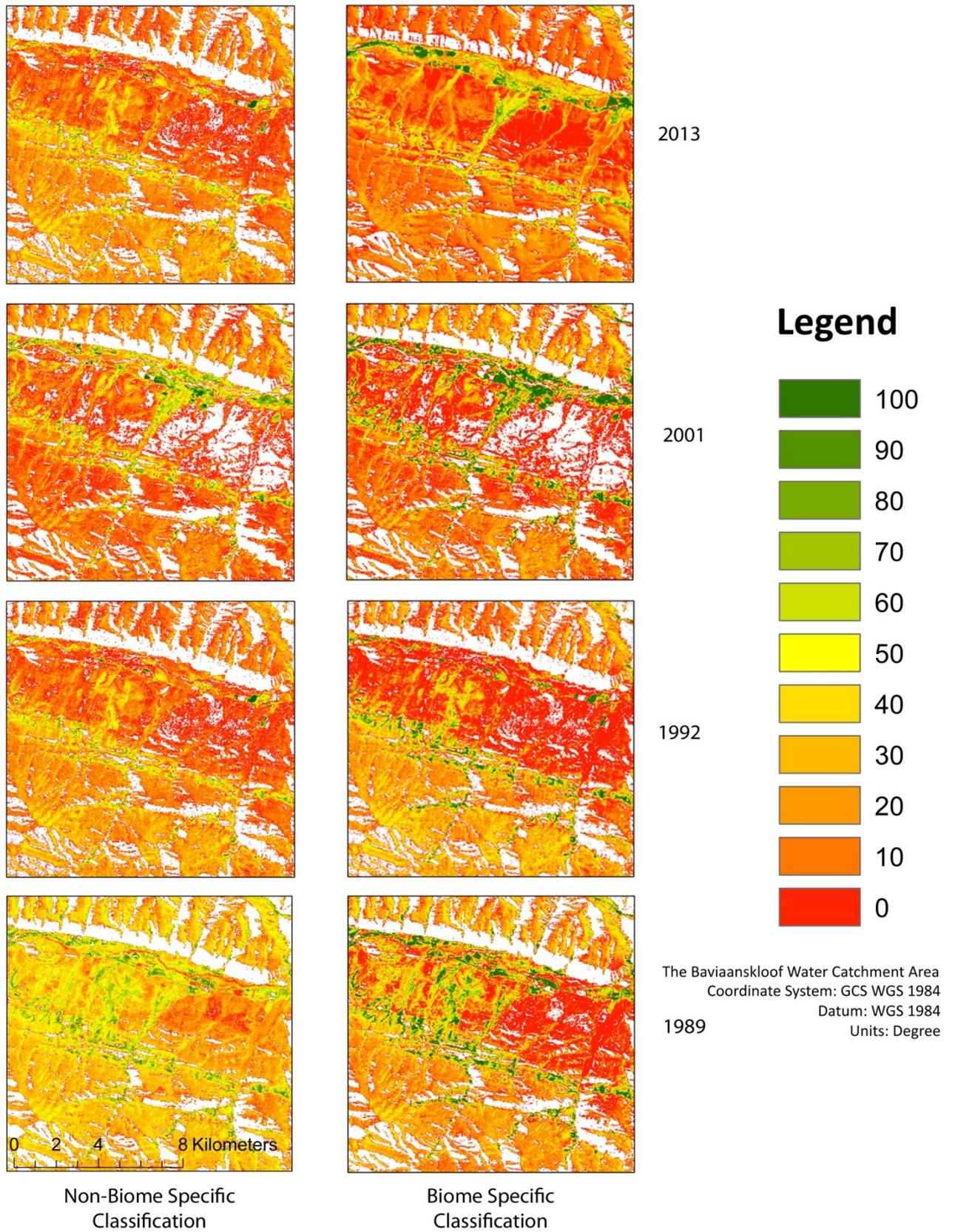


Figure 24: A comparison of the non-biome and biome specific classification as described in the methods.

Regeneration of degraded areas

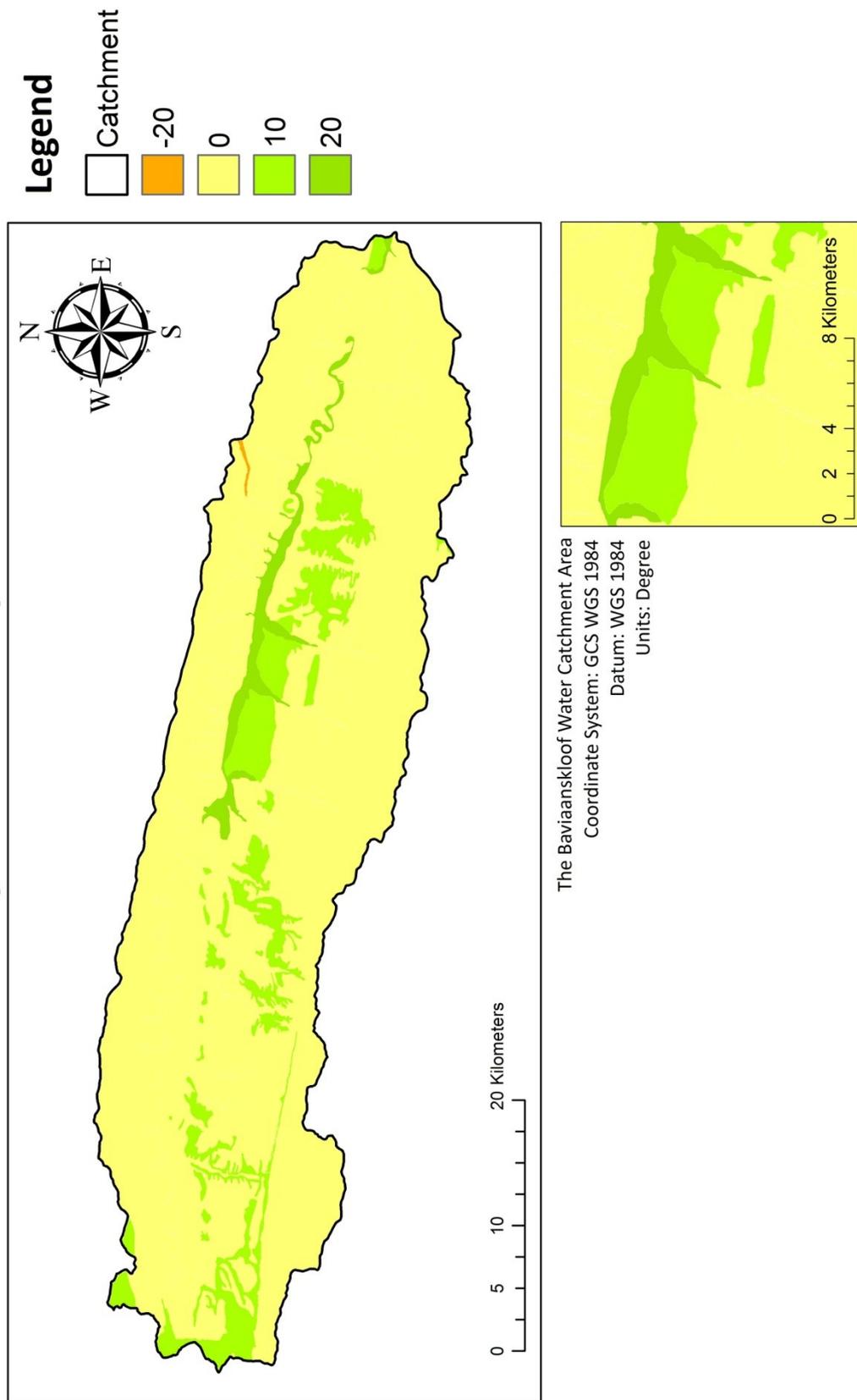


Figure 25: Regeneration of degraded areas.

5.4 Change Detection

Analysing vegetation change (by using change detection method) indicated that between 2001 and 2013, the vegetation density did change in specific areas. However, no over changes in vegetation density was observed between 1989 and 1992, 1992 and 2001. The heavily degraded areas within the Thicket biome, have seen an increase of 10 % in vegetation density. Within the, Renosterveld there is an increase of 10% in vegetation density and for Doringsveld an overall 20 % vegetation density increase. These areas are all degraded to some extent. Other biomes have seen no increase or decrease in vegetation density. Although a small area of Renosterveld, which had been classified with a degradation level of 4, has seen a decrease of 20% cover.

Note: Due to the occurrence of shaded areas in the Landsat images, it was not possible to determine the density of vegetation in those areas. The area has steep cliffs and canyons there is a high rate of interference of shade. This give problems when trying to determine a mean value in some areas, suggesting a sudden decrease in vegetation or sudden bloom of vegetation which could not be justified. To create a map representing the whole catchment area it was chosen to statistically analyse the area based on the rule of majority in a certain zone. Using the "zonal statistics" tool in ArcGIS.

The following graphs show the distribution of density classes over the four years: 1987,1992, 2001 and 2013. Doringsveld has increased overall, with the exception within the bare soil and 0 - 10 % classes. Thicket has seen a significant increase in vegetation density, especially within the ranges of 10 - 30% and 40 - 70%. Although, it seems that the ranges between 70 - 100% have dropped.

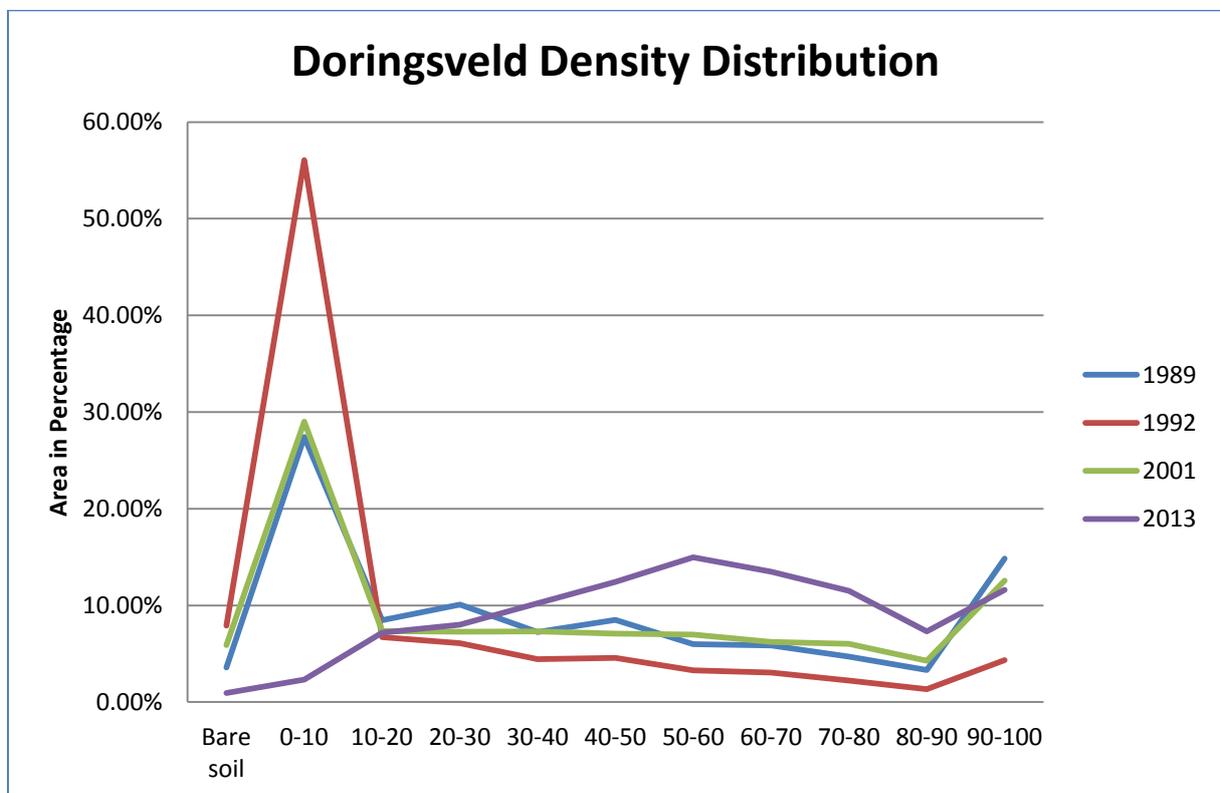


Figure 26: Doringsveld cover density distribution

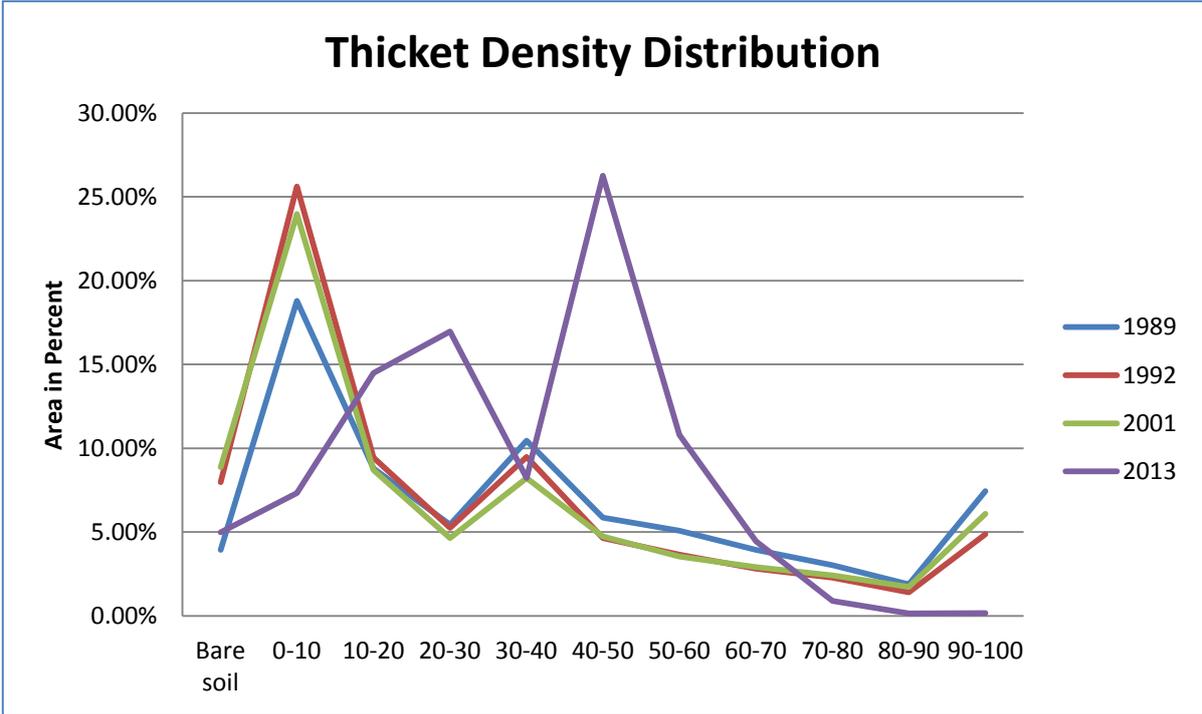
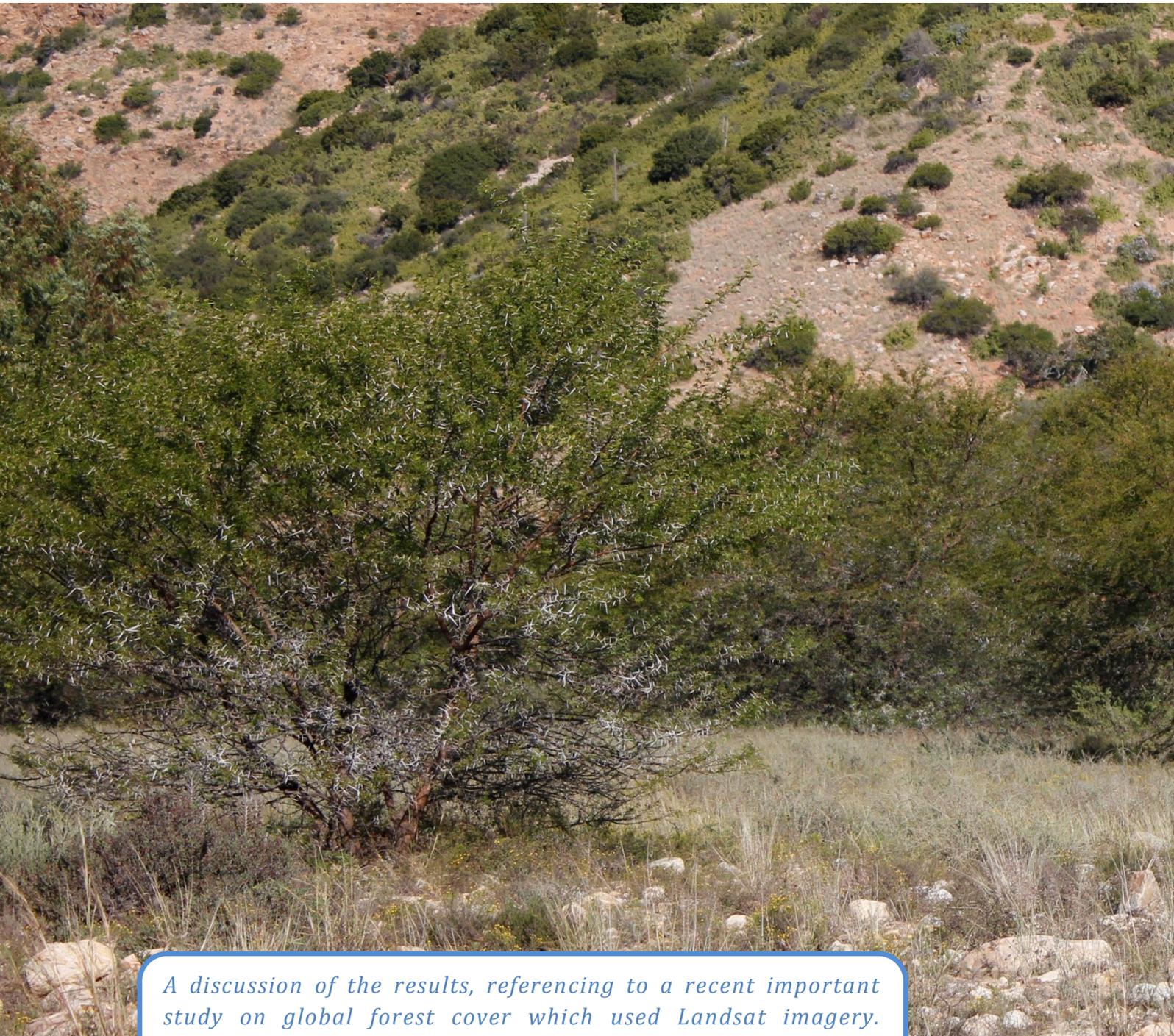


Figure 27: Thicket cover density distribution



A discussion of the results, referencing to a recent important study on global forest cover which used Landsat imagery. Concluding the study and providing recommendations for future studies on this subject and in the Baviaanskloof.

Discussion & Conclusion



5.1 Discussion

This study proved that it is possible to observe changes of vegetation density in degraded areas by remote sensing Landsat imagery, based on the results of vegetative regeneration in severely degraded areas within the Baviaanskloof. Similar to other studies (Huang et al. 2000; Crouse 2001; Suriyaprasit et al. 2008; Aziza et al. 2008), a strong relation was found between vegetation density and the NDVI. Furthermore, monitoring changes in specific biomes through remote sensing can be achieved, as was shown through this study.

Relations found between the NDVI and vegetation density were highly expected, the results were no surprise. As previous studies showed a high relation between canopy cover and the NDVI. Furthermore, in this study a relation was established between NDVI and vegetation density, which was classified through combining the canopy density, shrub density and grass/herb density. This indicates that biomes with low canopy cover can also be monitored using the NDVI. It was even shown that discriminative classification of the NDVI, based on biome differences, is possible and provides positive results.

It was thought that climatic influences, such as rainfall, could influence the observable vegetation density. When observing the annual rainfall count, high annual variations can be observed prior 1985. The period between 1985 and 1994 showed little variation (one exception in 1991, a drought period) with an overall lower observed rainfall than in the period before. The period between 1994 - 2012, had variation but in stable pattern. In addition, it was assumed that land use change and a decrease in grazing activity, would stimulate the natural regeneration of the area. Furthermore, in combination with a stable annual rainfall pattern, a gradual increase of vegetation density should be observable from 1987 - 2013.

Expectations of a gradual increase of vegetation were not observed. On the contrary, between 1987 - 1992 and 1992 - 2001, the majority of the vegetation density of the degraded areas remained the same. It was only between 2001 - 2013 that the vegetation density increased, in specific degraded areas. An increase in vegetation occurred specifically on the alluvial plain and in areas covered by the thicket biome. On the alluvial plain it was the doringsveld biome, dominated by *Acacia spec.*, where the vegetation increased in density by twenty percent. In degraded areas, that consist of thicket, the vegetation increased with ten percent for each of the areas.

This increase of vegetation density could be attributed to ongoing land management changes and restoration efforts. These changes include the removal of "berms", small dykes along the alluvial plain, which were used for water retention. Furthermore, this allowed the water to flow over the natural flood plain. The removal of the "berms" was done during the study period of 2002 - 2012. The observed increase in cover density, could be attributed to an increase of water availability to the flood plain. This supports the observed increase. The increase of density in the thicket biome might be attributed to the thicket restoration project. This project replants Spekboom in degraded areas, it might be that this has had some impact. Although I would find unlikely it would have such a major impact, that it would be observable on a large spatial scale. Nonetheless, in two decades time were no restoration work has been conducted, there was no observable major change in vegetation density. In the decade time, were restoration has been executed we do see an increase. Which raises the question to what extent restoration of the landscape directly effects the biomes?

A recent study by Hanson et al. (2013) on global forest change, used Landsat Imagery to map forest loss and gain from 2000 to 2012. That global survey, was used as reference material in the later stages of this study. Using the interactive map, available for free on the internet, that Hanson et al produced similarities were found. From his material we can see small increases in forest in the floodplain of the Baviaanskloof, as well as similarities in density or cover percentages. However, the study produced by Hanson et al (2013) only incorporated the extent of forest cover, loss and gain. This means that areas, which are considered forests or have a abundance of tree cover such as the savanna and grassland areas on the floodplain are visible in that study. However, the areas consisting of thicket, renosterveld and/or fynbos were not represented in that study. Eliminating the possibility to reference the results of regeneration of vegetation in the severely degraded areas.

This study shows the importance of the restoration projects in the Baviaanskloof and the effect it has. It shows that with minimum means, degraded areas are able to regenerate on a short time scale. Even more, the study shows that we can observe and monitor the effects of restoration, with the use of remote sensing techniques. It also shows that degraded areas, require our aid as the change would be significantly less when no effort would have been made to restore the landscape of the Baviaanskloof.

5.2 Conclusion

This study can be concluded that the degraded areas in the Baviaanskloof have seen an increase in vegetation density, during the period of 2002 to 2013. Furthermore, it provides information on how to remote sense an area and observe changes over periods of time using Landsat images. It was possible to observe these changes by converting Landsat images to the NDVI and relating that to actual data on vegetation density and LAI, obtained from the field, it was possible to observe these changes. Not only did the study indicate that we can detect vegetation change in the past, this data could be used as well to make similar observations in the future. In five years time it will be possible to estimate the overall change between 2013 - 2017, by using 2013 as a baseline. This would provide more information on how restoration efforts influence the recovery of the Baviaanskloof catchment.

It was not observed that rainfall patterns have a influence on the changes of vegetation density. However differences were notable when comparing the NDVI results. However these differences could not be traced back after the change detection processes. Thus suggesting that the amount of rainfall has less effect on the regeneration of vegetation than other factors, such as restoration efforts and directly linked a healthier ecosystem.

Examining the relations between biomes and their spectral signature in the NDVI made it possible to detect and observe, a significant increase in vegetation density in highly degraded areas. This study can be used to show the impact on the regeneration of degraded areas after land use changes and land restoration efforts. It clearly shows that without restoration works, the density of vegetation in degraded areas, would probably have remained the same.

It was proven that it is possible to differentiate the spectral signatures for each biomes based on the actual reflectance of the NDVI for specific biomes. It was possible to do this by examining the different vegetation density levels and the corresponding NDVI values for each individual biome. This study proved, by biome specific reclassification it was possible to observe the regeneration in the

thicket and doringsveld biomes. Furthermore, the doringsveld biome regenerated by 20% percent. Although, it was possible to detect differences from one biome to another, there was more work involved in producing biome specific reclassification maps than it was to produce non-biome specific reclassification maps.

The suggestion that can be made from the results, is that restoration works have had an impact on the regeneration of vegetation in degraded areas. This has to be further examined, but it is clearly noticeable that during the time period in which there was no restoration efforts no significant increase was observable. While, during the time period where restoration efforts were made there was a significant increase of vegetation density observable in degraded areas.

5.3 Recommendation

Currently a new Landsat sensor is in orbit, providing high detailed images, every sixteen days. In order to follow the effects of restoration works closely, quick remote sensing assessments can be made on a year to year basis. Providing data for a report that can be set up each five years. As a strong method is provided, within this report, this can be done fast and accurate. The cover class tables, provide a baseline on which a focus can be made.

To generate stronger analysis, an inventory on the spectral signature of the all the biomes in the area needs to be added to the existing database. Filling gaps were needed to eliminate any error caused by assumptions made by the writer. I propose to use the clump method, as it is an easy and fast option to be used. The clump method can be taught to community members in the catchment, in order to provide low cost field assistance. Creating job opportunity, building capacity and further integration for/in restoration works, executed by Working for Water in collaboration with Living Lands.

The effects of restoration works, should be assessed on a year by year basis, the coming five years. Quick and fast remote sensing, to generate maps on vegetation cover density and regeneration. The generated maps then provide the basis for a updated report, on the effects of the restoration works. On detailed scale, effects of vegetative regeneration on biodiversity should be monitored. Which should result in an integrated and sustainable management scheme, on the local biodiversity and natural resources.

Shade and cloud cover, are two factors that cause the NDVI to represent low values in areas where there should be high values. These two factors can be eliminated when following the methodology in this study. After reclassifying the NDVI, shade and cloud error can be eliminated when there is a desire to detect change according to certain zones. In this study, the effect of shade was eliminated in this manner, whether it would work on cloud cover has not been tested, but it is highly likely.

A other way to deal with shade cover, is to gather data in the same manner as described, but in shaded areas. It would likely, that a relation could be found between vegetation density and the NDVI in shaded areas. This assumption is based on the differences between the NDVI values of raster cells in shaded areas. Would be very interesting to understand this.

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