Remote sensing assessment of land restoration interventions in South Africa

ARCHFORD MUCHANDO
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ABSTRACT

Restoration interventions have been implemented in the Baviaanskloof catchment following the launch of the Subtropical Thicket Restoration Programme (STRP) in 2004. This was necessitated by the need to restore landscapes that were heavily degraded due to long periods of overgrazing by livestock. Since the year 2005, over 1 000 ha of degraded land in the Baviaanskloof were put under active restoration whereby native Spekboom (*Portulacaria afra*) was planted to revegetate the land. Over two decades ago, some of the landowners in the Baviaanskloof have removed livestock from their farms to allow for natural vegetation regeneration. Currently, four restoration intervention types are present in the area a) Revegetation only with Spekboom without protection from livestock grazing, b) Protecting (fencing) the Spekboom revegetated areas from livestock and wild animals grazing also known as 'thicket wide plots', c) Planting Spekboom in livestock exclusion areas and d) Excluding livestock from degraded areas. The aim of this research was to assess the impact of these restoration interventions on green vegetation cover observed through satellite imagery.

Firstly, Normalised Difference Vegetation Index (NDVI) classes that describe greenness over time were generated from Landsat satellite images from 2000 to 2018. These NDVI classes were computed using an unsupervised classification method. Six and three NDVI classes that widely occur in restoration and non-restoration areas respectively were selected for further analysis. Secondly, the inter-annual and intra-annual (seasonal variations) trends for the nine selected NDVI classes were estimated based on average NDVI per class. The results from the trend analyses show a relatively similar trend regardless of the restoration intervention which was also compared to the non-restored areas. Lastly, the Before-After Control-Impact (BACI) comparative model was also used to assess the variability in NDVI trends between restored (impact) areas and multiple non-restored (control) sites over time. The findings show that the impact on the green vegetation cover varies across the restoration interventions. Eliminating grazing from Spekboom revegetated areas can provide the required solution in restoring the degraded subtropical thickets. This is because the Spekboom revegetated areas that are protected from either wild animals or livestock grazing have recorded a significant increase in green vegetation cover in comparison with non-restored areas. While a substantial decrease in green vegetation cover was detected in revegetated areas that are still open to livestock grazing. These findings can be used by the restoration authorities for management and planning purposes thus they can provide feedback to the restoration authorities on restoration interventions. The comparative method used in this study can be applied to any landscape in South Africa and the world at large for screening of the restoration interventions.

Keywords: Degradation, Restoration interventions, Impacts, NDVI, BACI design, Green vegetation cover

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AGB: Above Ground Biomass
BACI: Before–After Control-Impact
CAM: Crassulacean Acid Metabolism
DEM: Digital Elevation Model
EOS: End of Season
ETM: Enhanced Thematic Mapper
FAO: Food and Agricultural Organisation
GEE: Google Earth Engine
IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
ISODATA: Iterative Self-Organizing Data Analysis Technique
LaSRC: Landsat Surface Reflectance Code
LOS: Length of Season
MODIS: Moderate Resolution Imaging Spectroradiometer
NDVI: Normalised Difference Vegetation Index
NIR: Near Infra-Red
OLI: Operational Land Imager
RS: Remote Sensing
SAVI: Soil-Adjusted Vegetation Index
SDG: Sustainable Development Goals
SOS: Start of Season
SR: Surface Reflectance
SRTM: Shuttle Radar Topography Mission
STRP: Subtropical Thicket Restoration Programme
TM: Thematic Mapper
TOA: Top of the Atmosphere
UNCCD: United Nations Convention to Combat Desertification
UTM: Universal Transverse Mercator
WGS: World Geodetic System

1. INTRODUCTION

1.1. Background

Land degradation is currently a critical and disturbing global environmental threat that is undermining the sustainable development goals such as poverty alleviation, climate change mitigation and combating biodiversity loss (IPBES, 2018). The United Nations' Food and Agricultural Organisation (2008) refers to land degradation as "a long-term decline in ecosystem function and productivity." Poor agricultural practices, overgrazing, deforestation and recurrence of droughts are among the drivers of the ever-increasing land degradation (Hammad & Tumeizi, 2012; Nkonya et al., 2016) These are also exacerbated by the need for economic development and ever-increasing population which results in the conversion of land for crop cultivation due to the increasing demand for food (Geist & Lambin, 2004). This problem is of concern in fragile ecosystems of arid and semi-arid regions and has led to ecosystem services degradation, creating barriers to sustainable development and accelerating climate change (Cerretelli et al., 2018).

The increasing knowledge about the extent of land degradation and its adverse effects has led to continuous efforts to control it at global and national levels (Reif & Theel, 2017). Internationally, the United Nations Convention to Combat Desertification (UNCCD) was launched in 1994 with the objective to control desertification and alleviate drought effects especially in Africa (UNCCD, 2018). The United Nations have also developed the Sustainable Development Goals (SDG) in 2015, where SDG 15.1 specifically aims to combat desertification and promote the restoration of degraded lands. SDG 15.3 was developed with the aim to achieve a land-degradation-neutral world by the year 2030 (UNCCD, 2018). To achieve these targets, various ecological restoration measures have been implemented at different levels across the world, and these have received increasing attention (Perring et al., 2015). These restoration methods involve revegetating lands by either planting or re-seeding to halt or reverse land degradation through improved vegetation cover and the soil conditions among others. These measures provide solutions to halt or reverse land degradation by accelerating the recovery of an ecosystem thereby improving ecosystem health status and sustainability (Li, Cui, Zhang, Okuro, & Drake, 2009; Pan et al., 2016).

However, ecological restoration impacts cannot be ascertained if they are not subjected to monitoring. According to Dawson et al. (2016) and Hooper et al. (2016) without post-implementation ecological rehabilitation monitoring, determining the impacts and understanding the recovery trajectories is often impossible. As such, effective monitoring is an essential component of restoration as it provides feedback on restoration activities, results, and management to the restoration practitioners. Monitoring is important to guarantee that restoration activities are executed and performing as designed, to evaluate if goals are being met and if needed, to adapt or improve the design for future restoration projects (National Academies of Sciences Engineering, and Medicine, 2017).

The monitoring of restoration activities can also be challenging due to several issues, ranging from socio-economic to environmental factors. This is supported by Meroni et al. (2017) stating that assessing the impact of restoration projects is often challenging due to lack of information, poor accessibility, lack of cheap and standardized methods. Additionally, Ntshotsho et al. (2015) have given an example of South

Africa, where rehabilitation authorities face challenges to monitor restoration activities due to limited funding and inadequate skills.

Remote sensing (RS) techniques have proved to be suitable for ecological restoration monitoring because of their ability to provide satellite data on vegetation cover at relatively low cost and provide other solutions to obstacles associated with the monitoring processes (Chance, Cobourn, & Thomas, 2018). For example, Meroni et al. (2017) used RS to evaluate the impact of different reforestation interventions in Senegal using Landsat and MODIS satellite data. In Mongolia, Huang & Liu (2013) assessed the impact of an ecological restoration project on a coal mine degraded area using Landsat 7 data.

Changes in vegetation cover trends can be assessed using the remote sensing observations of Normalised Difference Vegetation Index (NDVI). The NDVI which is derived from the near-infrared (NIR) and visible red (R) remote sensing data is a good measure of the vegetation greenness, vegetation cover, Leaf Area Index and biomass patterns (de Bie et al., 2012; Forkel et al., 2013; Tong et al., 2017). The changes in NDVI trends can be used to monitor vegetation dynamics over long periods. Studies have been undertaken to monitor vegetation changes using NDVI time series, for example, Schucknecht et al. (2013) have found NDVI very suitable to monitor the inter-annual variation in vegetation greenness. In another study, Meroni et al. (2017) have also used NDVI time series to assess the land restoration interventions impact on vegetation cover in Senegal from 2002 to 2015.

Implementing restoration measures aim at changing vegetation cover and patterns before and after intervention period and between restored (impact) sites and non-restored (control) sites. A comparison of the before-after NDVI trends for the intervention sites with non-intervention sites is also critical in assessing the restoration impacts. According to Underwood (1994), the use of Before-After Control-Impact (BACI) design allows for the determination of the restoration impact independent of natural temporal differences. This method combined with remote sensing NDVI data was recently used for the first time by Meroni et al. (2017) to assess land restoration interventions in semi-arid environments of Senegal.

Computing NDVI time series have been made easier with the introduction of cloud-computing platforms such as the Google Earth Engine (GEE). GEE is a cloud-based platform that facilitates easy access to high-performance computing resources and provides researchers remote access to petabytes of satellite imagery such as Landsat 4-8, Sentinel, MODIS, Aster, topography, climate, landcover data among others (Google Earth Team, 2015). In GEE, data can be visualized, downloaded and time series graphs plotted (Agapiou, 2016; Gorelick et al. (2017). Researchers use the platform for detecting changes, mapping trends and quantifying differences on the earth's surface (Google Earth Team, 2015). With GEE, research results can also be easily disseminated to the recipients including the general public.

In Baviaanskloof, South Africa, an ecological restoration project was initiated by Grounded, Commonland and Living Lands in partnership with other stakeholders such as the local farmers and the Coca Cola Africa Foundation to restore the South African succulent thicket. The landscapes were degraded by long periods of overgrazing by goats coupled with unsustainable land management (Mills & Fey, 2004; Lechmere-Oertel et al. (2005). According to Van Luijk et al. (2013) animal husbandry has led to degradation of more than 16 000 km^2 of the subtropical thicket in South Africa.

1.2. Problem Statement

In the Baviaanskloof water catchment located in the Eastern Cape Province of South Africa, various ecological restoration interventions have been implemented to resuscitate the heavily degraded subtropical thickets. These restoration activities include passive restoration where livestock was removed from the degraded areas by some farmers more than 20 years ago. This was implemented to allow for the natural regeneration of vegetation in degraded areas. Following the launch of the Subtropical Thicket Restoration Programme (STRP) in 2004, more than 1 000 ha of degraded land was also put under active restoration since the year 2005 in the Baviaanskloof where native Spekboom (*Portulacaria afra*) was planted to revegetate the landscape. Additionally, to enable an alternative source of income after the removal of livestock, the restoration partnership (Grounded in partnership with various stakeholders) are engaged in more sustainable and profitable farming practices of planting exotic species such as organic lavandin and rosemary plants with the aim to bring a return of financial, natural and social capital (Grounded, 2018).

Studies have indicated that restoring the thicket with Spekboom is not simple and does not provide quick returns in terms of significant vegetation cover (Marais et al., 2009; Vyver et al., 2012). The planting of spekboom is also unlikely to restore the thicket to its original pristine state but would provide an alternative functional state that subsequently provides better ecosystem services (Marais et al., 2009). Various studies have been undertaken to evaluate the impacts of different ecological restoration projects in the Eastern Cape province. These studies focused mainly on Spekboom survival rates (Vyver et al., 2012; Mills et al., 2015; Duker et al., 2015) and assessment of carbon stocks (Vyver et al., 2013) in various restoration projects in the Eastern Cape Province. However, no available scientific study has been undertaken specifically for the complete Baviaanskloof to evaluate the multi-year impacts of both Spekboom planting and livestock exclusion on green vegetation cover trends.

This research addresses this knowledge gap by assessing the impact of restoration interventions on vegetation cover based on NDVI trend and variability to determine the effectiveness of these actions.

1.3. Research objectives and questions

The main objective of the study is to assess the impact of restoration interventions using Remote Sensing (RS) in the Baviaanskloof water catchment located in the Eastern Cape Province of South Africa. The specific research objectives and questions used to address this objective are presented in Table 1.

Specific objectives and research questions

Table 1: A list of research objectives and their respective questions that were addressed in this study.

Specific objectives	Research questions
1. To perform vegetation classification of the study area based on Landsat NDVI time series (2000 to 2018).	i. What NDVI-based number of classes gives the best separability of vegetation classes?
2. To determine the intra-annual and inter-annual NDVI trends variability for vegetation classes.	ii. What is the magnitude and direction of the NDVI trend in vegetation condition in the study area? iii. What is the temporal variation of NDVI trends within and between years for individual classes?
3. To assess NDVI trends variability between restored and non-restored sites based on baseline value and fluctuations.	iv. How much does the overall greenness differ before and after restoration compared to non-restored areas?

In this study, the following assumptions were made:

- NDVI is suitable for determining long-term vegetation cover changes induced by Spekboom planting and livestock exclusion restoration activities.

- Fusion of Landsat 5, 7 and 8 NDVI time series data is suitable for assessing the impact of restoration interventions.

2. MATERIALS AND METHODS

2.1. Study Area

The Baviaanskloof (Valley of baboons) catchment is comprised of private farms spread over an area of more than 40 000 ha and falls within the boundaries of the Baviaanskloof Mega-Reserve in the Eastern Cape Province of South Africa (Grounded, 2018). The catchment is important for supporting agriculture and rural livelihoods. Located more than 100 km to the west of the city of Port Elizabeth, the catchment however contributes about 30% of this city water needs (Boshoff, 2008). It is located in a 75 km long stretching valley between the parallel east-west running Kouga and Baviaanskloof mountains (Weel, Watson, Weel, Venter, & Reeves, 2015).

The topography of the catchment is heavily rugged with steep gorges, lower mountain slopes, high mountain peaks and restricted to a central valley that contains the perennial Baviaanskloof river that flows between the Kouga and Baviaanskloof mountains (Weel et al., 2015). The larger Kouga mountain has many peaks spreading especially from the western to the central regions of the mountain. The eastern region of the mountain is relatively less rugged with hills occurring at less than 900 m in altitude and the highest peak of 1 757 m (Baviaans Tourism, 2018).

In terms of climate, the catchment falls with the semi-arid climate with rainfall mainly occurring in autumn and spring and is highly variable ranging from 500 mm to 700 mm per annum in the eastern region, while the western part receives rainfall of about 300 mm. The driest period occurs between December and February. The area is characterized by warm summers with maximum temperatures of above 30°C, and in winter, temperatures below 10°C are also recorded (Weel et al., 2015).

For the vegetation, the plateaus and the upper mountain slopes are mainly dominated by Fynbos while the lower slopes and valleys are dominated by the subtropical thicket (Weel et al., 2015). The subtropical thickets dominated by Spekboom occupy in the form of solid thickets and thicket mosaics. The other biomes that occur in the area are forest, grassland, succulent Karoo, nama-Karoo and savanna biomes. These are home to more than 1 000 plant species (Baviaans Tourism, 2018).

For their income, the private landowners in Baviaanskloof are mostly involved in livestock farming especially the Angora goats and sheep. Apart from livestock farming, the landowners are also involved in eco-tourism as an extra source of income. In this study report, the ‘study area’ refers to private farms shown in Figure 1.

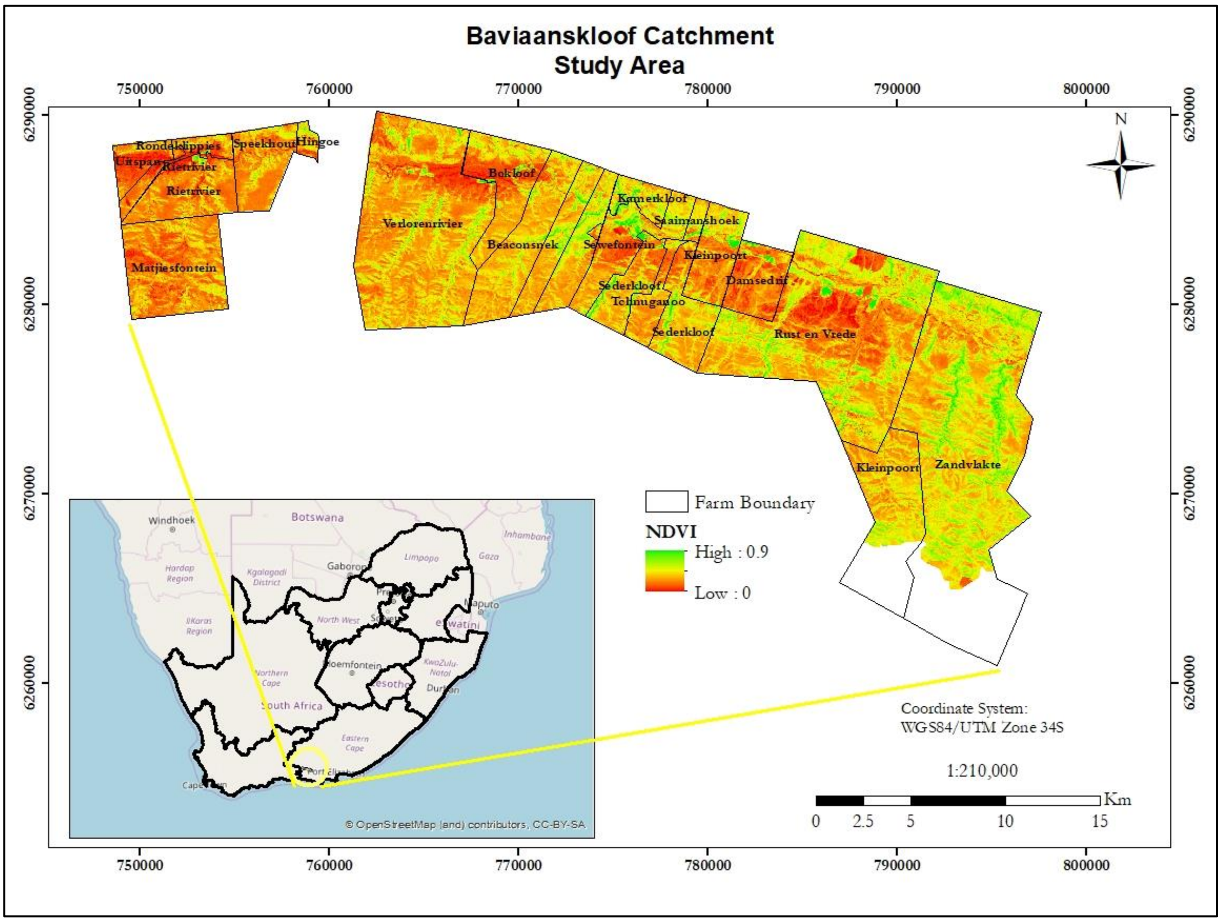

Figure 1: Map showing the study area. The background shows the Landsat NDVI data and the divisions represent the private farm boundaries.

2.2. Data

2.2.1. Landsat data

For objectives 1 and 2, the satellite datasets used in this research are the 16-Day Landsat 5 TM, Landsat 7 ETM and Landsat 8 OLI Surface Reflectance Tier 1 with a 30 m spatial resolution. These datasets were accessed through Google Earth Engine (GEE) platform. The GEE platform provides atmospherically corrected, calibrated, orthorectified, Level 1 Terrain (L1T) and Top of the Atmosphere (TOA) satellite data generated using a docker supplied by the United States Geological Survey (USGS) (Google Earth Team, 2015). The datasets LANDSAT/LT05/C01/T1_SR, LANDSAT/LE07/C01/T1_SR and LANDSAT/LC08/C01/T1_SR for Landsat 5, 7 and 8 respectively, provided by GEE have been atmospherically corrected using Landsat Surface Reflectance Code (LaSRC). The LaSRC includes a cloud, shadow, water and snow mask generated using the cfmask and per-pixel saturation mask (Google Earth Team, 2015; Foga et al., 2017). The cfmask populate pixels affected by the cloud and the cloud shadows in Landsat Level-1 data (Foga et al., 2017). In this study, the removal of clouds and cloud shadows was performed in GEE using the Pixel Quality Assessment Band. The pixel quality attributes were generated from the cfmask algorithm (Google Earth Team, 2015). These satellite images were then used to generate NDVI time series data. The NDVI data with a maximum of 23 images per year for the whole study period (2000 to 2018) was then used in the study. The reason for the selection of the Landsat data for this study was based on Landsat's ability to provide high spatial and temporal resolution images (i.e., 30 m and 16-day respectively) which is also suitable for monitoring intervention sites as small as 0.2 ha (smallest demonstration plot) in the study area. It also provides a large archive of historical data from 1984 which is important for long-term monitoring of the vegetation.

Annual greenest-pixel (maximum) TOA reflectance composites of Landsat 5, 7 and 8 downloaded through GEE were also used in this study to address objective 3. These composites are made from level L1T orthorectified scenes, using the TOA reflectance (Google Earth Team, 2015). The greenest pixel in these datasets represents for each location a pixel with the highest NDVI selected from the first day of each year until the last day of the year. A total of 18 annual maximum NDVI images were used in this study.

2.2.2. Other data

Apart from the Landsat data, various other datasets were used in this study such as the slope, altitude, and aspect. These were extracted from the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) 30 m dataset and accessed through the GEE. The datasets were clipped using the study area boundary before downloading. For this study, the aspect was set to four cardinal directions, i.e., North, East, South, and West. The NDVI time series data in the form of comma separated values format were computed in GEE for all the restored, selected non-restored areas and NDVI classes. Other datasets used were sourced from the Living Lands such as the large scale spekboom planting boundaries, planting dates, lavandin and rosemary field boundaries together with the farm boundaries. The boundaries for the small scale (demonstration) Spekboom plots were collected by the student during data collection in the field.

All the data layers used in this study were masked to the study area boundary and projected to WGS84/UTM Zone 34S. Table 2 shows a list of all the data that was used in this study including their specifications and source.

Table 2: List of all the data used in the study.

Data	Resolution (m)	Period	Source
Landsat 5 TM	30	2004-2012	Google Earth Engine https://earthengine.google.com/
Landsat 7 ETM+	30	2000-2003	Google Earth Engine https://earthengine.google.com/
Landsat 8 OLI	30	2013-2018	Google Earth Engine https://earthengine.google.com/
Landsat 5 Annual Maximum NDVI Composite	30	2004-2012	Google Earth Engine https://earthengine.google.com/
Landsat 7 Annual Maximum NDVI Composite	30	2000-2003	Google Earth Engine https://earthengine.google.com/
Landsat 8 Annual Maximum NDVI Composite	30	2013-2017	Google Earth Engine https://earthengine.google.com/
NDVI time series (csv format)	-	2000-2018	Google Earth Engine https://earthengine.google.com/
Altitude	30	2000	SRTM DEM
Slope	30	2000	SRTM DEM
Aspect	30	2000	SRTM DEM
Lavandin and Rosemary field boundaries	-	2018	Living Lands
Large scale Spekboom planting boundaries	-	2018	Living Lands
Small scale (Demonstration plots) Spekboom planting boundaries	-	2018	Fieldwork
Spekboom Planting dates	-	2018	Living Lands
Baviaanskloof Farm Boundaries	-	2018	Living Lands

2.3. Methods

Figure 2 presents the methodology that was followed in this study. The methods are divided into four main sections based on the research questions that were addressed. The methodology is presented in the following order: i) Identifying distinct NDVI classes based on their wide occurrence in restoration interventions, ii) Inter-annual NDVI trend assessment of the NDVI classes, iii) Estimation of intra-annual (annual seasonal variations) of the NDVI classes and iii) Impact assessment of restoration interventions with comparison to non-restoration areas.

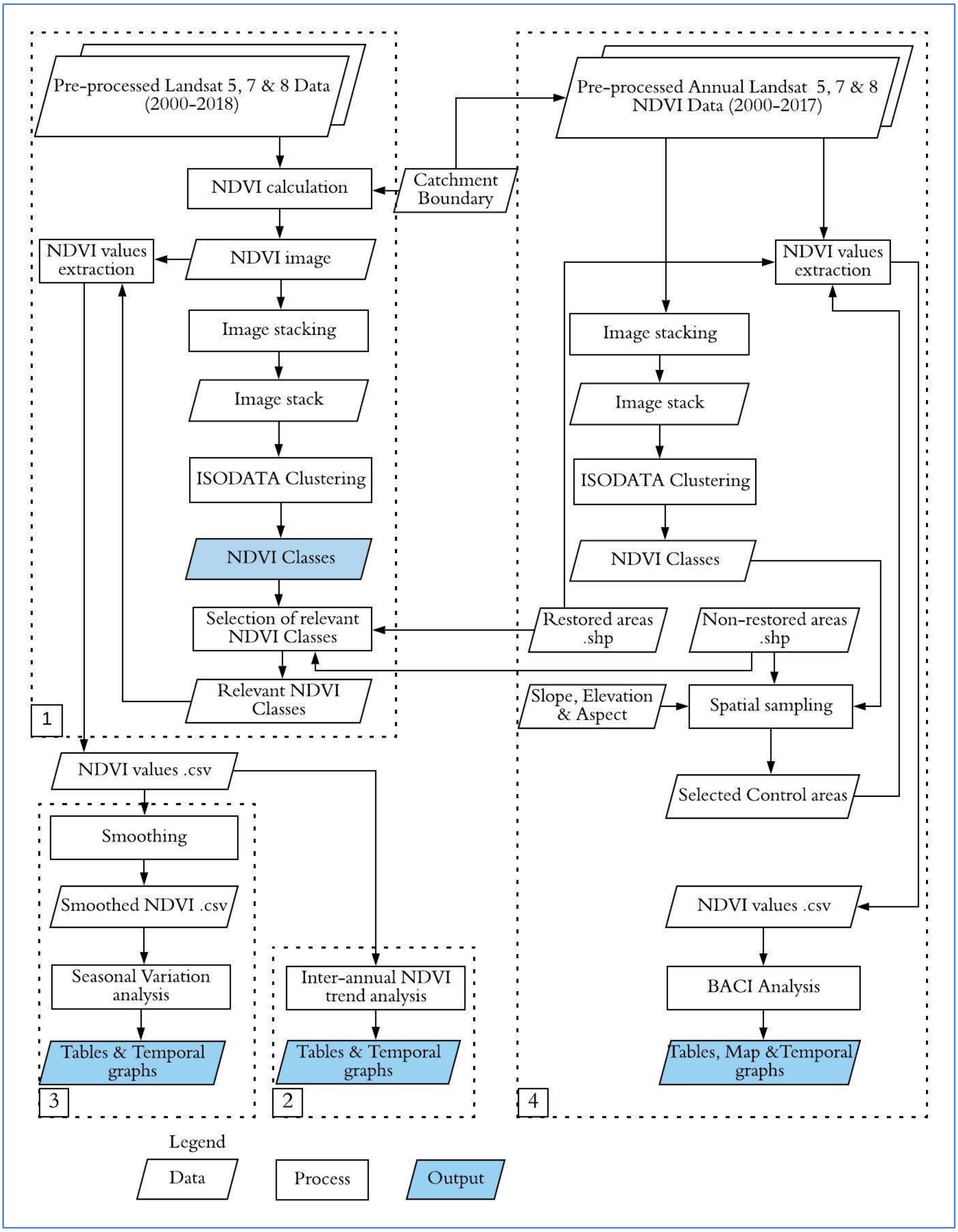

Figure 2: Flow chart showing the research methods. The dashed lines represent the methods limit for each research question.

2.3.1. Identifying distinct NDVI classes

2.3.1.1. Generating NDVI classes

To identify the NDVI classes that widely occur in restoration interventions, pixels that follow similar NDVI trajectory over time were clustered using an unsupervised classification method in Erdas Imagine 2018 (Hexagon Geospatial, 2018). The NDVI time series data used in unsupervised classification were computed through the GEE platform. Based on the objectives of the study and suitability of the NDVI, the GEE Code Editor scripts were developed to extract NDVI data from the atmospherically corrected, orthorectified, calibrated, surface reflectance and cloud-free 16-day Landsat images. The NDVI time series were generated using Landsat 5, 7 and 8 from 2000 to 2018. The scripts for computing the NDVI data were composed of the following components:

- A feature collection with the study area,
- Functions for selecting Landsat 5, 7 and 8,
- Time frame for image collection 2000 to 2018,
- Applying the pixel quality assessment band for cloud and cloud shadow removal,
- Commands to run the normalized difference using the following formula:

NDVI = (Near Infrared - Red) / (Near Infrared + Red)

- Commands to export the NDVI images (for ISODATA clustering).

After exporting the NDVI images computed from cloud-free satellite images, the images were stacked using Erdas Imagine 2018 (Hexagon Geospatial, 2018). The 2013 Landsat 8 NDVI data was used to fill in the data gap between 2012 and 2013 caused by the unavailability of satellite coverage. Landsat 8 NDVI data was selected for gap filling because of better quality and improved signal-to-noise ratio (Harris Geospatial, 2019). This decision was considered assuming that no significant vegetation changes occurred during this period. In this study, the classification was based on the iterative self-organized unsupervised algorithm (ISODATA) in Erdas Imagine 2018 (Hexagon Geospatial, 2018). This method identifies and clusters spectrally or temporally pixels in NDVI time series images based on minimum spectral distance. The algorithm iteratively clusters the pixels until it reaches the maximum number of iterations or the maximum percentage of pixels that have not changed is reached (de Bie et al., 2011). The method was considered suitable for this study because it requires minimal initial input from the user and most useful when training data is not available (Memarsadeghi, Mount, Netanyahu, & Le Moigne, 2007).

To achieve a maximum separability of NDVI classes, a multiple of unsupervised classification runs based on predefined parameters was performed. The predefined number of classes was set from 10 to 100 classes, with iterations set at 50, while the convergence threshold was set at 1. As performed by de Bie et al. (2011) and de Bie et al. (2012) a class separability analysis was performed by calculating divergence statistics between all the pairs of signatures. To identify the optimum run that gives the best separability of classes, the minimum and average divergence indices that represent each run were retained. These divergence indices were then plotted against all the number of classes. Plot interpretation was then carried out to identify the optimal run. A better optimum run is identified by a distinguishable peak in average separability (de Bie et al., 2011). Therefore, this study also identified the optimum run based on average separability.

2.3.1.2. Relevant NDVI classes

To identify the NDVI classes that widely occur in restoration intervention and non-restoration areas, the restoration interventions were first classified according to their type as shown in Table 3. The spatial distribution of these restoration intervention types is presented in Figure 3. A pragmatically set limit of area coverage of 80% was then used to identify the NDVI classes that widely occur in these restoration intervention types.

Table 3: A list of four restoration intervention types and one non-restoration type used in this study, their descriptions and area in hectares

Type	Description	Area (Ha)
1	Revegetation (spekboom planting) only	789.2
2	Revegetation (spekboom planting) and animal exclusion, i.e., fenced plots	4.7
3	Revegetation (spekboom planting) and livestock exclusion	525.4
4	Livestock exclusion only	8 188.9
5	Non-restored	33 845.1
TOTAL		**43 354.4**

Figure 3 shows the spatial distribution of restoration intervention areas in the study area. The non-restored areas cover a large area of more than 30 000 ha. In terms of the restored areas, livestock have excluded from more than 8 000 ha while areas that are revegetated with Spekboom amounts to more than 1 300 ha.

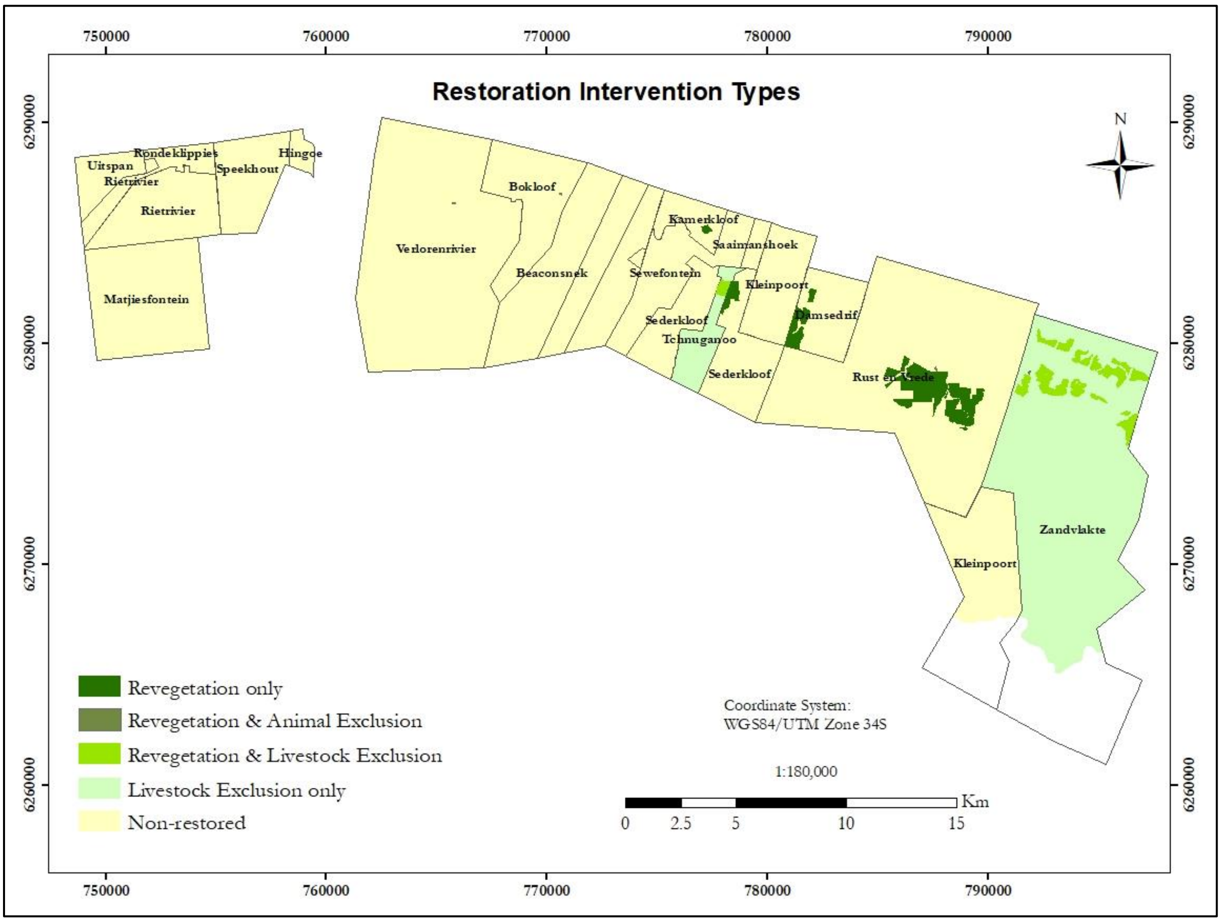

Figure 3: Spatial distribution of the restoration and non-restoration areas in the study area. The divisions represent the farm boundaries.

The NDVI classes that widely occur in restoration interventions were identified from the NDVI classes that represent the optimum run from the unsupervised classification. The NDVI classes were ranked from high to low according to area coverage (%). The following classes occurrence was set.

- Classes that occur in 3 or more of the restoration intervention areas but not in non-restored areas
- Classes that occur in 2 of the restoration intervention areas but not in non-restored areas
- Classes that occur in 1 of the restoration intervention areas but not in non-restored areas
- Classes that occur in both restoration intervention areas and non-restored areas
- Classes that only occur in non-restored areas.

2.3.2. NDVI trend estimation

2.3.2.1. Inter-annual NDVI trend significance

To estimate the historical development trajectory of the vegetation in the study area, an inter-annual trend analysis was performed for the selected NDVI classes. According to Hamed (2008) trend analysis is an important subject in determining variability in inter-annual vegetation changes. It is used to establish a relationship between NDVI (x) and time (y) (Liu, Zheng, & Yin, 2018). It assumes that vegetation changes linearly and gradually over time (Ghazaryan et al., 2016). In this study, before estimating the inter-annual trend significance, spatially averaged NDVI time series values were computed in GEE and downloaded in comma-separated values (CSV) format. The wide NDVI data gap between 2012 and 2013 was filled using the 2013 Landsat 8 NDVI data as performed in the unsupervised classification. Additionally, the linear interpolation method was used to fill in cloud and cloud shadow data gaps in the time series (Mondal, Jeganathan, Amarnath, & Pani, 2017). After the gap filling, the time series data was split into 5-year segments. Thus, for the complete dataset, i.e., 2000 to 2018 NDVI time series, the splitting resulted in the following segments, 2000-2004, 2005-2009, 2010-2014 and 2015-2018.

In this study, a simple linear regression model was fitted in R statistical software 3.5.1 (R Core Team, 2018) on a 5-year 16-day NDVI time series to obtain the beta and the p-value. The formula for the linear regression model is given as follows:

$$\gamma = \alpha + \beta\chi$$

Where a is the intercept, β is the beta (slope), and x is constant. The slope derived from the linear regression indicates the direction and magnitude of vegetation changes over time (Tong et al., 2016). A positive slope value from this model indicates an increase in vegetation greenness (greening) thus, an increase in vegetation cover for that specific vegetation class, while a negative slope indicates a decrease in vegetation greenness (browning) which is also an indicator of degradation (Ju & Masek, 2016; Tong et al., 2016). Additionally, the significance of the slope in this study was determined at 95% confidence level. The minimum and maximum NDVI including the range was also extracted from the time series to determine the inter-annual vegetation changes.

With the aim to evaluate the extent of the impact of using the 2013 Landsat 8 NDVI data to fill in the data gap between 2012 and 2013, the linear regression model was also fitted on selected time series data with a data gap filled using the Landsat 7 NDVI data. This was performed only for the 2010 to 2014 period which was also affected by this data gap.

2.3.2.2. Intra-annual NDVI trend variation

With the aim to test if the restoration interventions lead to a vegetation cover that is less affected by a dry season or that maintains a more stable greenness (photosynthetic activity) all year-round, a phenological analysis based on the NDVI time series was performed. Thompson et al. (2009) state that Spekboom dominated areas maintain greenness throughout the year owing due to its capacity to shift between C3 and CAM photosynthesis. In this study, the phenological assessment was carried out at vegetation class-specific level. According to McCloy & Lucht (2004), the variations in seasonal NDVI trends are linked to vegetation phenology such as the start of the season (SOS), the peak, the end of the season (EOS) and the length of the season (LOS). The SOS is defined as the period of the greatest and constant increase characterised by the most green-up in the vegetation using the 16-day NDVI data. On the other hand, EOS is characterised by the greatest and constant decrease in vegetation greenness. The peak is the maximum NDVI point in the annual cycle. The LOS is then described as the duration of the green period from the SOS to the EOS (Tateishi & Ebata, 2004; Beck et al., 2006).

Various methods have been developed and used in different studies to extract the phenological metrics. One such method is the TIMESAT algorithm which uses an adaptive Savitzky–Golay filtering method developed by Jönsson & Eklundh (2004) to analyse time series of the satellite sensor data. In this study, a greenbrown package available in the R software package 3.5.1 (R Core Team, 2018) was used to extract the vegetation phenological metrics following the study by Forkel et al. (2015). This package was developed to analyse trend changes and phenology assessments in time series of vegetation indices such as the NDVI (Muro et al., 2018). To remove noise caused by undetected cloud and cloud shadows that may affect the assessment, the NDVI time series data was smoothened using the Savitzky-Golay Smoothing Filter in R statistical software 3.5.1 (R Core Team, 2018). The Savitzky-Golay algorithm operates well on equally spaced time series by fitting a local regression on the signal. It operates as a weighted sum over a predefined window size (Dai, Selesnick, Rizzo, Rucker, & Hudson, 2017). After the smoothing of the time series, the extraction of the phenological metrics, SOS, EOS, peak, and LOS was performed using the derivative of the seasonal NDVI curve as described by Forkel et al. (2015). A one-year temporal window was selected in this study for the analysis following the visual interpretation of the time series plots which presented a unimodal seasonality (see example in Appendix 1).

A total of three independent years, i.e. 2007, 2015 and 2017 were selected for the assessment. The year 2007, represents the period before the first Spekboom revegetation activities in the study area. Whereas 2015 represent the period when the last revegetation activity was carried out in the study area. Furthermore, 2017 was also selected to estimate the effects of drought on vegetation developments as this was an exceptionally dry year, based on the information obtained from the farmers.

2.3.3. Restoration impact analysis

To assess the impact of the restoration interventions on green vegetation cover with respect to non-restoration areas, a comparative Before-After-Control-Impact (BACI) method was used. The assessment to measure the vegetation changes was based on the maximum annual NDVI values. The BACI method was selected because it detects change in NDVI trends independent of environmental factors such as variations in rainfall (Schwarz, 2018). The BACI method compares the conditions of the restored area (impact) before and after restoration with nearby non-restored (control) areas conditions (Zucca, Wu, Dessena, & Mulas, 2015). This method combined with remote sense data was used by Meroni et al. (2017) to assess the impact of ecological restoration activities in Senegal. To avoid the possibility of getting BACI results that are affected by the poor choice of a single control site, this study adopted the use of multiple control sites as recommended by Smith, (2006). As such, the NDVI at a single impact site was compared to five other control sites. BACI is robust for multiple sampling before and after impact to maximize the detection of the changes independent of environmental factors (Meroni et al., 2017). Thus, in this study, the temporal observations per site used for both before and after intervention ranged from 3 to 13 years. To ensure a balanced sample, an equal number of observations before and after the interventions were used in all the assessments except for the assessment of livestock exclusion areas only. This is considered statistically important as it improves the power of the test (Meroni et al., 2017).

To ensure a complete assessment of the restoration impacts, all the restored areas with a total area of over 9 500 ha (shown in Table 3) were used in this study. During the process, some of the restored sites (vector polygons) in large scale restoration interventions were merged. This was only performed for the restored sites in Spekboom revegetated areas that are protected from animal grazing, and Spekboom revegetated areas that are protected from livestock grazing. The merging of the restored sites was based on the following conditions:

1. Sites under the same management unit (farm),
2. Sites in the same restoration intervention type,
3. Sites that share one or more boundaries,
4. Sites restored in the same year and during the same season (rain or dry season) and
5. Sites that share the same aspect.

Furthermore, another spatial sampling was performed to select non-restored (control) areas. Control sites that met all the conditions listed below were chosen for the assessment. These conditions were developed to ensure that the BACI model produces more reliable results.

a. Share similar NDVI classes with the impact site prior intervention,
b. Within the same altitude range with the impact site,
c. Within the same slope range with the impact site,
d. Share similar aspect with the impact site,
e. Have not been used for crop production pre and post-intervention,
f. Relatively close to the impact areas and
g. Separated by a minimum distance of at least the width of the impact area to minimize the edge effect.

To fulfill the requirement (a) regarding similar NDVI classes for the pre-restoration period, an ISODATA clustering was performed in Erdas Imagine 2018 (Hexagon Geospatial, 2018) on maximum annual NDVI time-series data from the year 2000 to 2007 which represents the period before the first active restoration in the study area. The predefined number of classes was set at 5 to 50, the number of iterations was set at 50 while the convergence threshold was set at 1. Separability analysis was then performed to identify the optimum run that show the maximum separability of classes following the same approach by de Bie et al. (2011) also described in section 2.3.1.1. The output of 12 NDVI classes (shown in Appendix 2) was selected and used as input data in spatial sampling.

The altitude, slope and aspect data images were extracted from SRTM DEM data in GEE. The spatial sampling was performed for each impact site in ArcGIS 10.6.1 (Esri, 2018), with the 12 NDVI classes, altitude, slope and aspect data as input data (shown in Appendix 3). Potential control sites that had the same NDVI classes, same altitude, and slope range and similar aspect with the impact areas were identified.

Control sites with relatively similar size to the impact site were then generated in areas that met all the conditions. This ensures a relatively balanced sampling size (Meroni et al., 2017). The study considers the effects of climate and soil variability in the BACI model to have been catered for by selecting control sites that are relatively close to the impact sites. After the control sites were generated, these together with the impact sites were uploaded into GEE to extract the annual maximum NDVI data for the period before and after the intervention (2000 to 2007) for the BACI statistical analysis.

To estimate the ecological impacts of the restored areas as compared to non-restored areas over time, a linear mixed-effects model was fitted on NDVI site level as performed by Meroni et al. (2017) using the lmer function from the lme4 package in the R statistical program 3.5.1 (R Core Team, 2018). For this study, the fixed effects were period (before and after intervention), the site class (impact and control) and their interaction. For the random effects, the study used the site (restored and non-restored site-specific number) and the year (sampling year). The linear mixed-effects model used for ecological restoration impact assessment is shown below.

BACI **<** - *lmer (NDVI ~ Period + SiteClass + Period*SiteClass + (1|Year) + (1|Site))*

Where *lmer* = linear mixed effects regression, *NDVI* = Normalised Difference Vegetation Index, *Period* = before/after, *SiteClass* = impact/control, *Year* = sampling year, *Site* = restored and non-restored site-specific number.

To determine the restoration impact, the BACI effect was used which is obtained from the interaction between the site class and the period. The conclusion was based on the BACI contrast and the significance of the contrast was determined by the p-value from the BACI ANOVA (Luke, 2017) at a confidence level of 0.95. The BACI contrast was calculated as follows:

$$BACI\ contrast = (CA\mu - CB\mu) - (IA\mu - IB\mu)$$

Where μ is the NDVI, *CA* is Control sites After the intervention, *CB* is Control sites Before the intervention while *IA* and *IB* stand for Impact site After the intervention and Impact site Before the intervention respectively. A negative BACI contrast indicates that the NDVI of the impact site has increased more or decreased less with respect to the NDVI values of the control sites. While, a positive contrast indicates that the NDVI of control sites have increased more or decreased less than the NDVI of the impact site (Meroni et al., 2017). The assessments to estimate the restoration impacts was based on Table 4.

Table 4: A matrix table showing a list of the restoration intervention assessments performed in the study and the aim of each assessment.

Assessment	Impact site		Control sites	Aim
1	Type 1	vs	Type 5	Assess the impacts of revegetation
2	Type 2	vs	Type 5	Assess the impacts of both revegetation and fencing the revegetated areas to remove animals
3	Type 3	vs	Type 5	Assess the impacts of both revegetation and removing livestock from the revegetated areas
4	Type 4	vs	Type 5	Assess the impacts of removing livestock from the farms
5	Type 2	vs	Type 4	Assess the added value of both revegetation and fencing the revegetated areas to remove animals on livestock exclusion areas
6	Type 3	vs	Type 4	Assess the added value of revegetation on livestock exclusion areas

3. RESULTS

3.1. NDVI classes for restoration evaluation

3.1.1. Distinct NDVI classes

The results of the separability analysis to determine classes with similar trends in NDVI between 2000 and 2018 are presented in Figure 4 and Figure 5. Figure 4 shows a complex and increasing trend with no clear high peaks in the average separability. Before 38 classes, the plot shows too much gain in the average separability which was then followed by several minor peaks from classes 39 to 97 which means that there is no clear pattern in NDVI in the study area. A slight value difference between class 74 and class 76 is shown. To facilitate the processing and interpretation of the results, 39 classes were selected in this study as the optimal run. These 39 classes were assumed to best represent the vegetation classes in the study area that were identified based on their similar NDVI trajectory behaviour from 2000 to 2018. This was also done taking into consideration of the study's objective and limited time available for the analysis.

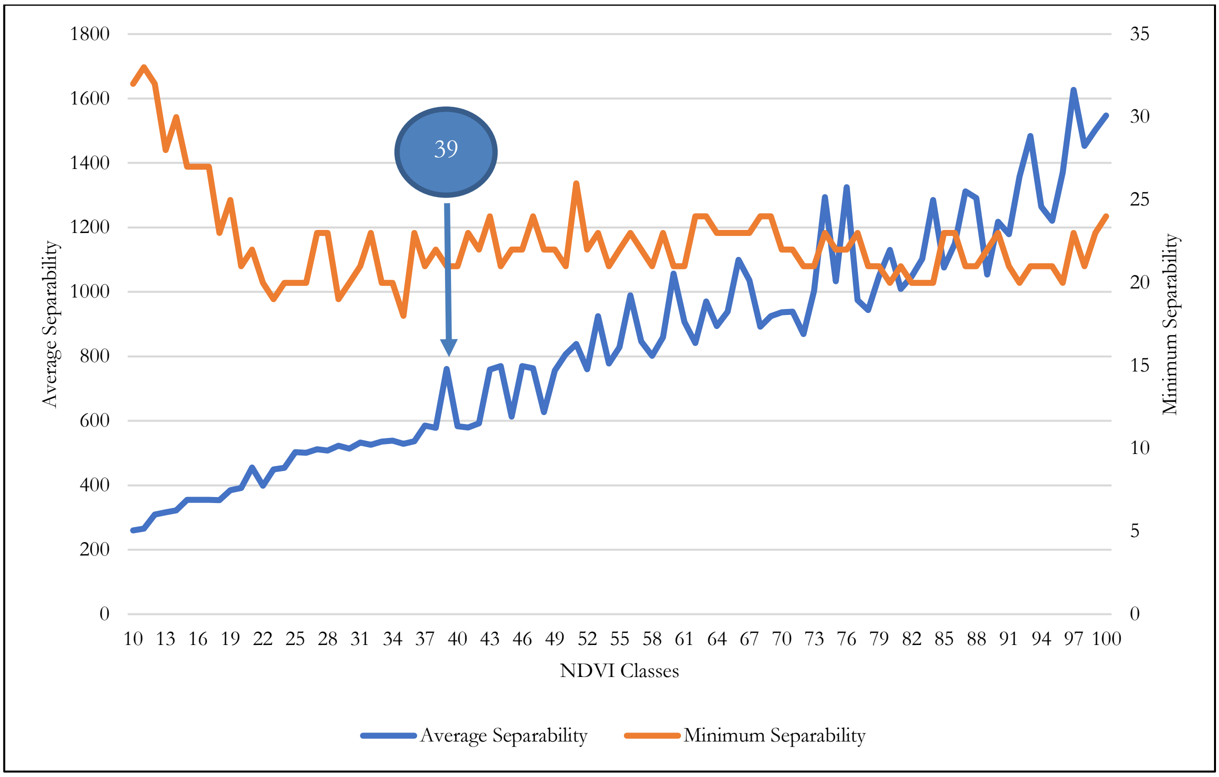

Figure 4: Separability statistics. Increasing peaks with an increasing number of classes on average separability

Figure 5 shows a map of the selected 39 NDVI classes, an output from ISODATA clustering. The legend presents the classes in increasing order. Thus, the lower number of classes represent the areas with trends of low NDVI, and a higher number of classes represent areas of high NDVI over time. The lower number of classes mainly represent long-term degraded areas such as bare soil and open shrub areas, while the higher classes represent the dense bush and forest areas mainly in riverine zones. The results also show a relative increase in areas with high mean NDVI towards the east.

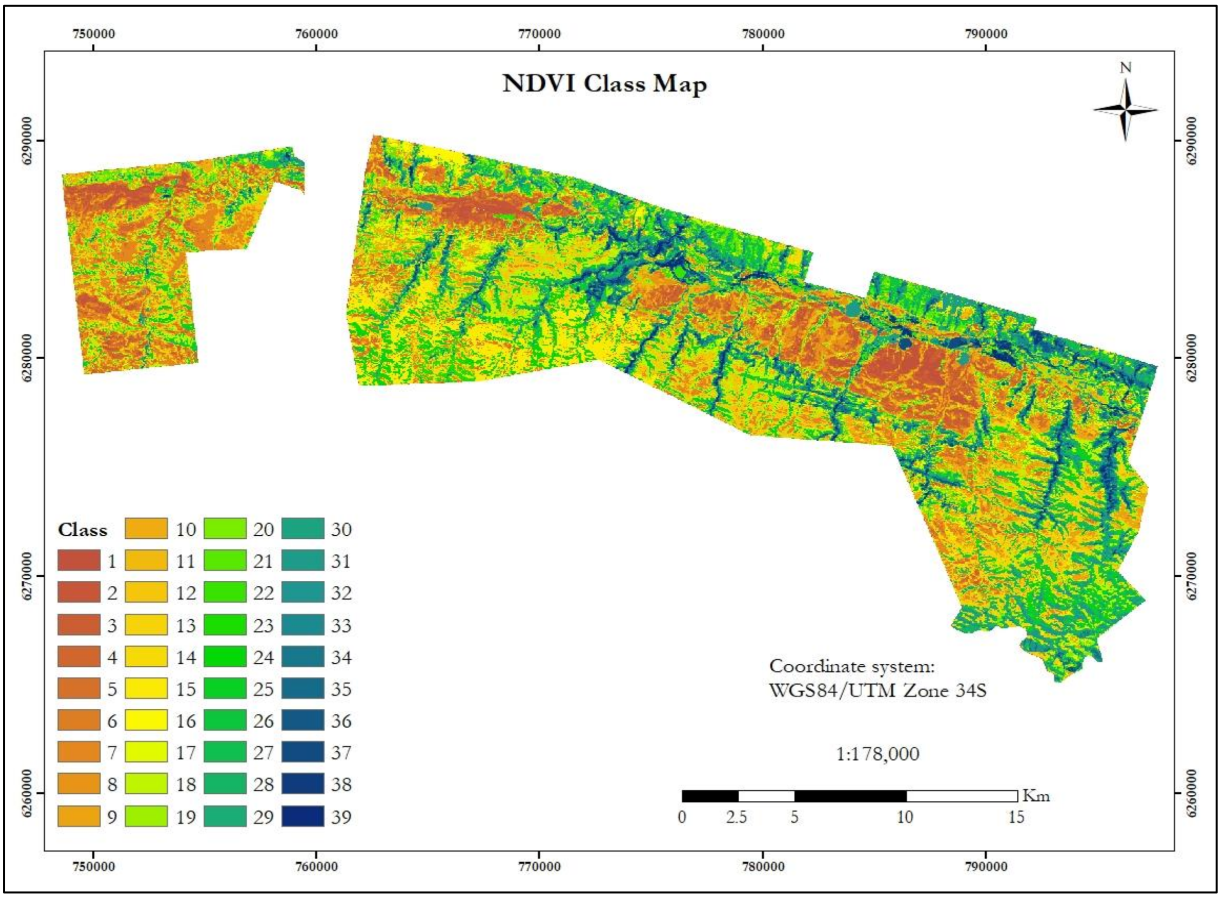

Figure 5: NDVI class map of the selected 39 classes for the study. The image was produced using all available cloud-free Landsat images from 2000 to 2018.

3.1.2. Selection of relevant NDVI classes

Figure 6 shows the overall occurrence of NDVI classes in different restoration intervention areas. The NDVI classes are spatially distributed over the whole study area, meaning all the classes occur in all the restored and non-restored areas.

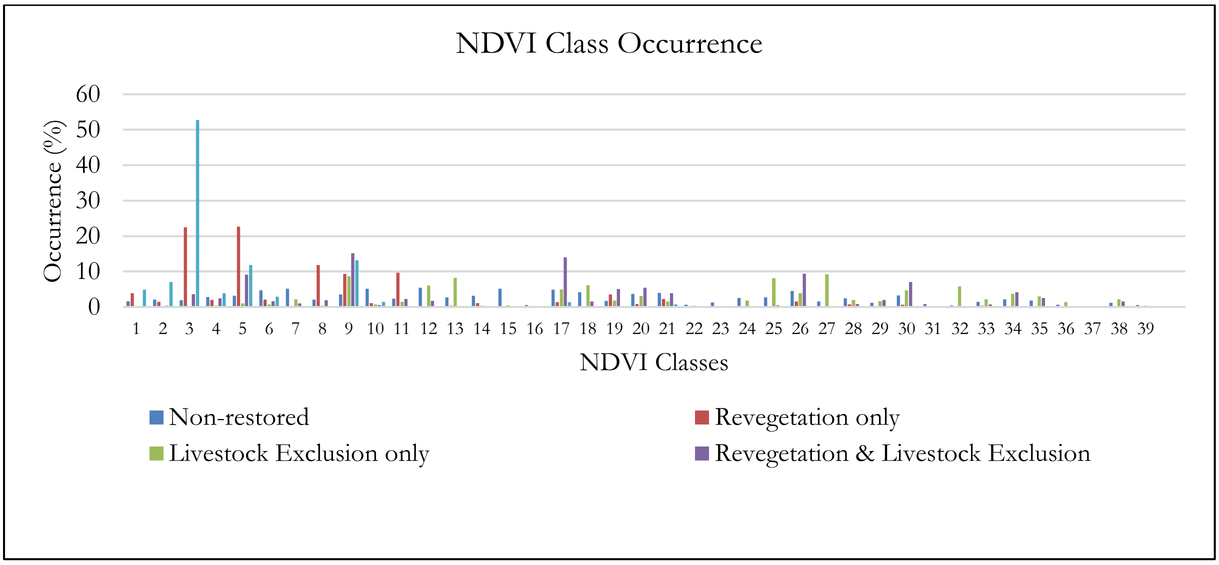

Figure 6: Occurrence of NDVI classes in restoration intervention areas including non-restored areas.

Table 5 shows a list of the classes that comprise at least 80% (area cover) of the intervention type area. Six classes were identified to be widely occurring in restored areas while seven classes were found to be widely occurring in non-restored areas. All the six NDVI classes in restored areas were considered for further analysis, while only three classes (10, 15 and 28) that widely occur in non-restored were selected further. These three classes in non-restored areas were assumed to cover classes with low, medium and high NDVI values over time. The nine classes were therefore considered representative of the vegetation in restored and non-restored.

Table 5: List of NDVI classes selected for analysis in this study

Restored areas		**Non-restored areas**
NDVI Class	**Intervention Type**	**NDVI Class**
Class 03	Revegetation only	Class 04
	Revegetation & Livestock exclusion	Class 06
	Revegetation & Animal exclusion	Class 10
Class 08	Revegetation only	Class 14
Class 19	Revegetation & Livestock exclusion	Class 15
Class 27	Livestock Exclusion only	Class 24
Class 32	Livestock Exclusion only	Class 28
Class 35	Livestock Exclusion only and Revegetation & Livestock exclusion	

3.2. Changes in NDVI

3.2.1. Inter-annual NDVI trend

Table 6 shows the results of the NDVI trend analysis that was performed to estimate the historical trajectory of the nine NDVI classes that represent restored and non-restored areas. The results show a relatively similar trend among all the classes regardless of the restoration intervention type. Between 2000 and 2009, the results show a significant decrease in NDVI for all the classes except for class 15 which recorded a non-significant decrease in the period between 2005 and 2009. The average beta for the NDVI classes during this period was -0.00005, with class 15 recording the highest loss with a beta of -0.00010. In terms of the maximum NDVI for the same period, the highest peaks in NDVI with an average of 0.53 was recorded between 2000 and 2004 and this same period also recorded a wide range in NDVI with an average of 0.32. However, after this loss in NDVI, a significant increase with an average beta of 0.00005 was recorded between 2010 and 2014 for all the classes except for classes 3 and 8. This overall increase coincides with the period when most of the degraded areas were revegetated with Spekboom. This increase in NDVI was however followed by a substantial decrease in NDVI for all classes between 2015 and 2018. This period recorded a significant decrease with an average beta of -0.00015. The highest decrease in NDVI of -0.00029 was detected in class 32 which widely occur in Spekboom revegetated areas that have been protected from animal grazing. All the classes recorded a similar trend direction with relatively similar magnitude. Although the most significant decrease in NDVI was detected between 2015 and 2018, it is during this period when the highest maximum NDVI was detected for all classes with an average of 0.57 and an average range of 0.36. The results also show an increase in maximum NDVI with increasing NDVI class value regardless of the restoration interventions.

To determine the direction and magnitude of the change in NDVI over time, the following six trend classes were used in this study.

- N3: significant negative trend (beta < 0 and p ≤ 0.05)
- N2: non-significant negative trend (beta < 0 and 0.05 < p ≤ 0.1)
- N1: no trend with negative tendency (beta < 0 and p > 0.1)
- P1: no trend with positive tendency (beta > 0 and p > 0.1)
- P2: non-significant positive trend (beta > 0 and 0.05 < p ≤ 0.1)
- P3: significant positive trend (beta > 0 and p ≤ 0.05)

Table 6: Results of the NDVI trend analysis using linear regression model

		Classes								
		Restored areas						Non-restored areas		
Period		3	8	19	27	32	35	10	15	28
2000-2004	Beta	-0.00007	-0.00009	-0.00008	-0.00006	-0.00005	-0.00006	-0.00004	-0.00010	-0.00006
	P-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Min NDVI	0.12	0.15	0.18	0.25	0.22	0.35	0.21	0.13	0.28
	Max NDVI	0.43	0.58	0.61	0.53	0.59	0.59	0.42	0.44	0.57
	Range	0.31	0.43	0.43	0.28	0.37	0.24	0.21	0.31	0.29
	R^2	0.32	0.27	0.26	0.25	0.18	0.27	0.19	0.34	0.30
2005-2009	Beta	-0.00005	-0.00006	-0.00006	-0.00003	-0.00004	-0.00005	-0.00003	-0.00001	-0.00002
	P-value	0.0000	0.0000	0.0000	0.0025	0.0006	0.0002	0.0014	0.5067	0.0171
	Min NDVI	0.15	0.17	0.20	0.25	0.27	0.28	0.19	0.18	0.24
	Max NDVI	0.38	0.48	0.55	0.51	0.56	0.64	0.46	0.38	0.50
	Range	0.23	0.31	0.35	0.26	0.29	0.36	0.27	0.20	0.26
	R^2	0.23	0.18	0.16	0.08	0.10	0.12	0.09	0.00	0.05
2010-2014	Beta	0.00001	0.00002	0.00003	0.00007	0.00008	0.00006	0.00003	0.00005	0.00005
	P-value	0.1018	0.0914	0.0053	0.0000	0.0000	0.0000	0.0010	0.0000	0.0000
	Min NDVI	0.16	0.20	0.28	0.32	0.35	0.40	0.24	0.24	0.32
	Max NDVI	0.36	0.47	0.56	0.60	0.63	0.68	0.44	0.48	0.55
	Range	0.20	0.27	0.28	0.27	0.28	0.28	0.20	0.25	0.22
	R^2	0.02	0.03	0.07	0.28	0.38	0.27	0.09	0.14	0.26
2015-2018	Beta	-0.00008	-0.00010	-0.00012	-0.00026	-0.00029	-0.00012	-0.00008	-0.00023	-0.00009
	P-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Min NDVI	0.15	0.18	0.24	0.19	0.20	0.33	0.22	0.14	0.25
	Max NDVI	0.40	0.48	0.59	0.65	0.69	0.74	0.51	0.48	0.62
	Range	0.25	0.30	0.35	0.46	0.50	0.41	0.29	0.34	0.37
	R^2	0.28	0.24	0.28	0.52	0.54	0.32	0.21	0.59	0.25

Examples of the trend plots for two selected NDVI classes are shown in Figure 7. The plots show a similar NDVI trend direction for the classes with a relatively similar magnitude. These classes 3 and 10 were selected because they have recorded the widest occurrence in restored and non-restored areas respectively. Similar results for NDVI classes 3 and 10 were also recorded after fitting the linear regression model on NDVI time series data with a data gap filled using 2012 Landsat 7 NDVI data. A non-significant NDVI increase of 0.00002 was detected for class 3, while class 10 recorded a significant increase in NDVI of 0.00003.

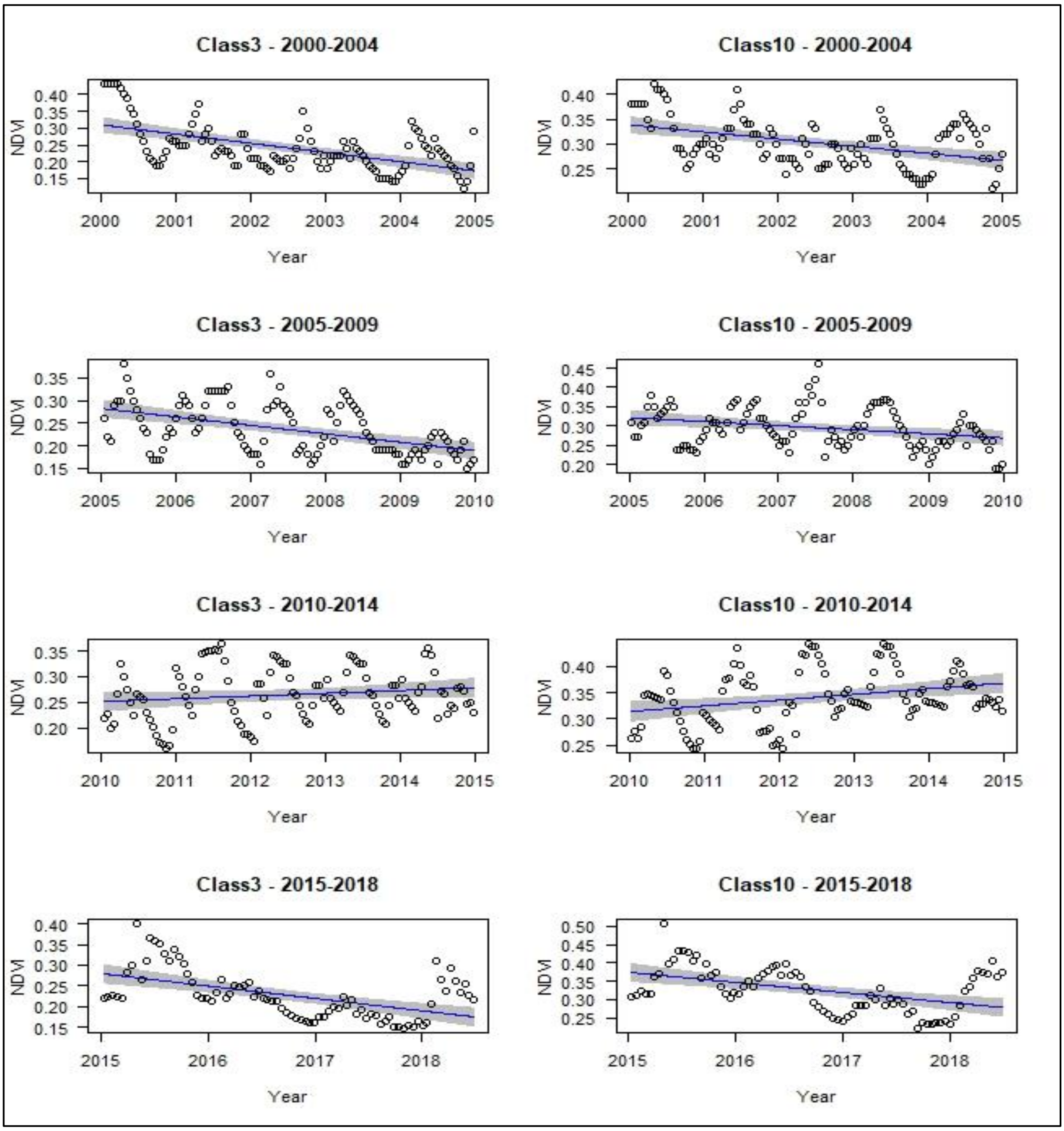

Figure 7: Plots showing the trend direction for NDVI classes 3 and 10 from 2000 to 2018.

3.2.2. Intra-annual NDVI trend

Table 7 shows the temporal characteristics of the start of the season (SOS), the end of the season (EOS), the length of the season (LOS) and their peaks for the year 2007, 2015 and 2017. All four phenological metrics (SOS, EOS, LOS and peak) show a relatively similar across the NDVI classes. In 2007, the period before the first Spekboom revegetation in the study area, there was a small variation in the start of the growing season. The SOS varies between March and April, where two-thirds of the NDVI classes recorded a green-up of vegetation in March. The end of the growing season for that same year also varies between July and August. In 2015, the period when the last revegetation was implemented, the same trend was also recorded in terms of SOS which varies between March and April. However, there is a considerable variation in terms of the end of the growing season across NDVI classes regardless of the restoration interventions. It ranges from an early EOS in July to a delayed EOS in November which indicate a relatively stable greenness of vegetation. In 2017, there was an early start in the growing season which started between February and March with the end of the growing season recorded as early as June until August. However, phenology information for classes 15 and 32 was not successfully extracted because the NDVI trends for these classes were constantly very low throughout the year for these two classes (see Appendix 1).

In terms of the LOS and the peak of the growing season, the longest growing season was recorded in 2015, with an average of six months and reached an average peak of 0.51. The shortest growing season was recorded in the year 2017 with an average of four months and an average peak of 0.33.

Table 7: Vegetation phenology information for the year 2007, 2015 and 2017. E and L represent early and late respectively. NA means no phenological metrics were extracted during that period.

		Classes								
Year	Metrics	Restored areas						Non-restored		
		Class3	**Class8**	**Class19**	**Class27**	**Class32**	**Class35**	**Class10**	**Class15**	**Class28**
2007	**SOS**	E-Mar	E-Mar	L-Mar	L-Mar	L-Mar	E-Apr	L-April	L-April	L-Mar
	EOS	L-Jul	E-Jul	E-Jul	E-Aug	E-Jul	E-Jul	L-Aug	L-Jul	L-Jul
	LOS	5	4.5	5	4.5	4.5	3	4	3	4
	PEAK	0.32	0.41	0.51	0.48	0.51	0.62	0.4	0.36	0.47
2015	**SOS**	L-Mar	L-Mar	E-May	L-Mar	L-Mar	L-Mar	L-Mar	E-Apr	L-Mar
	EOS	E-Nov	L-Oct	E-Nov	L-Jul	L-Aug	E-Aug	E-Nov	E-Sep	L-Nov
	LOS	7.5	7	6	5	5	4.5	7.5	5	8
	PEAK	0.34	0.46	0.55	0.57	0.6	0.66	0.43	0.46	0.52
2017	**SOS**	E-Feb	E-Mar	E-Mar	L-Mar	N/A	E-Feb	E-Feb	N/A	L-Jan
	EOS	E-Jun	L-Jun	L-Jul	L-Jun	N/A	E-Aug	E-Aug	N/A	E-Jun
	LOS	4	3.5	4.5	3	N/A	6	6	N/A	4.5
	PEAK	0.21	0.27	0.37	0.23	N/A	0.51	0.31	N/A	0.41

Some examples of the plots with all the phenological metrics for classes 3 and 10 are shown in Figure 8. The two NDVI classes show relatively identical trend pairs with a similar form for each year. Table 8 was also provided to aid in the interpretation of the time codes presented in the x-axis of the plots.

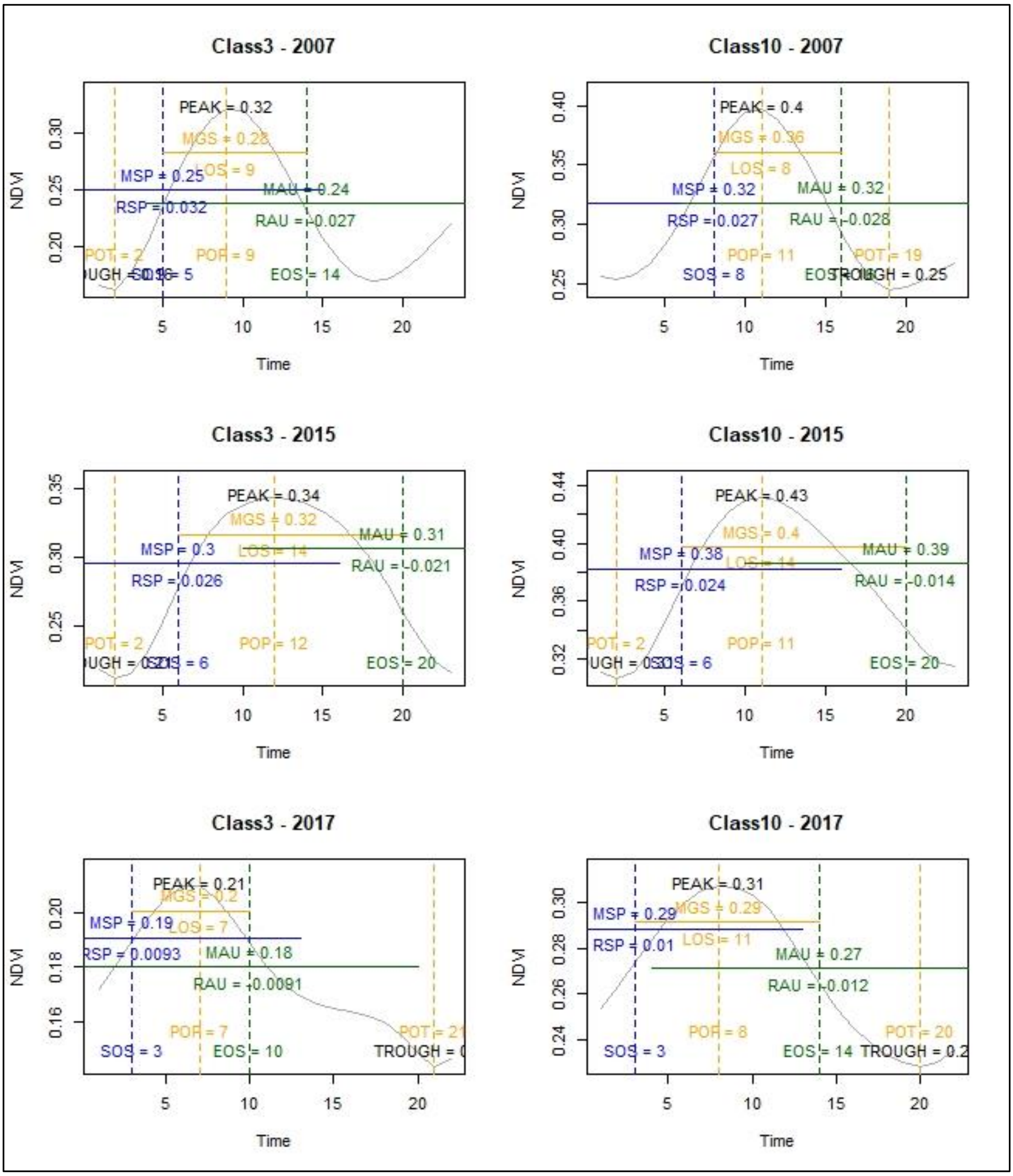

Figure 8: Plots showing vegetation phenology metrics for classes 3 and 10.

Table 8: Table shows the information for use to interpret the SOS and EOS in Figure 7.

	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2007	**Time Code**	1&2	3&4	5&6	7&8	9&10	11&12	13&14	15&16	17	18&19	20&21	22&23
2015		1&2	3&4	5&6	7	8&9	10&11	12&13	14&15	16&17	18&19	20&21	22&23
2017		1&2	3	4&5	6&7	8&9	10&11	12&13	14&15	16&17	18&19	20	21&22

3.3. Restoration impact estimates

Table 10 shows a summary of the results of the analysis performed to evaluate the impact of the ecological restoration interventions per farm (Figure 1 and Figure 9) in the study area. The complete detailed results of these assessments are shown in Appendix 4. In this study, a total of six impact assessments were carried out which relate to 88 impact sites and 440 control sites. For the interpretation of the assessments, a complete description is provided in Table 9.

Table 9: Detailed description of the restoration impact assessments carried out in this study.

Assessment	Description (Impact *versus* Controls)
1	Revegetation only (29 impact sites) *versus* non-restored areas (145 control sites)
2	Revegetation and animal exclusion (5 impact sites) *versus* non-restored areas (25 control sites)
3	Revegetation and livestock exclusion (24 impact sites) *versus* non-restored areas (120 control sites)
4	Livestock exclusion only (2 impact sites) *versus* non-restored areas (10 control sites)
5	Revegetation and animal exclusion (2 impact sites) *versus* livestock exclusion areas (10 control sites)
6	Revegetation and livestock exclusion (26 impact sites) *versus* livestock exclusion areas (130 control sites)

The results in Table 10 show that the highest number of restored sites (80%) with a significant positive contrast was detected in Spekboom revegetated areas that are protected from animal grazing (assessment 2). This means that these restored sites have more NDVI as compared to the non-restoration areas. All the five sites that were assessed in comparison to 25 non-restoration areas have recorded a negative contrast with a mean of -0.031 which relates to an increase of 10% in NDVI. A substantial increase in NDVI with a contrast of -0.078 was detected in Zandvlakte which is also shown in Figure 10, graph A. None of the sites in these restored areas have recorded a significant positive contrast.

The second highest number of restored sites (33%) with a significant increase in NDVI was detected in the assessment of Spekboom revegetated areas that are protected from livestock grazing as compared to the non-restored areas (assessment 3). However, the results also show that a substantial number of restored sites (67%) have a similar NDVI with the non-restoration areas as they recorded a non-significant contrast. In terms of the overall NDVI trend, the NDVI increased with a mean of -0.009 which corresponds to a 2% increase in vegetation cover. This means that despite the 67% of the sites that have a non-significant contrast, vegetation cover has increased by 2% in these revegetated areas that are protected from livestock grazing. Additionally, none of the sites in these restored areas have recorded a significant positive contrast.

The results (Table 10) also show that 14% of restored areas (131.7 ha, see Figure 9) in Spekboom revegetation areas that were compared to the non-restoration areas have recorded a significant positive contrast (assessment 1). These are the only restored sites (in Rust en Vrede) that have recorded less NDVI as compared to non-restored areas across all the restoration interventions (see Figure 9). The restored site with the most significant positive contrast of 0.05 (see Figure 10, plot B) was also detected in these areas. However, another 14% of the restored sites have recorded more NDVI in comparison to non-restoration areas, as a significant negative contrast was detected at these sites. Additionally, a substantial number of the restored sites (72%) have recorded a non-significant BACI contrast, meaning that there is no significant difference in NDVI between these restored sites and non-restored sites. The overall contrast of these restored sites shows a decrease in NDVI of 0.006 which relates to a decrease in NDVI by 2% with respect to non-restored areas.

The highest number of restored sites with a non-significant contrast was detected in livestock exclusion areas. The impact assessment (1) of these restored sites shows a relatively similar NDVI with the non-restoration areas. Although these livestock exclusion sites have recorded a negative contrast with a mean of -0.015, none of them have increased significantly in NDVI in comparison to the non-restored sites.

The results of the impact assessment of Spekboom revegetated areas that are protected from either livestock or wild animal grazing in comparison to livestock exclusion areas show a no significant change in NDVI over time. This means the NDVI in livestock exclusion areas only is relatively similar to the revegetated areas that are protected from livestock and wild animal grazing.

Generally, the results show that excluding livestock and wild animals from the revegetated areas has the potential of improving vegetation cover in degraded sites. This was shown in the impact assessment of revegetated areas that protected from either wild animal or livestock grazing as they have recorded a significant negative BACI contrast at 80% and 33% of the sites respectively. Revegetation of degraded areas without removal of livestock or wild animals shows no improvement in NDVI with a comparison to non-restored areas.

Table 10: Summary of results of the six impact restoration assessments performed in the study. The green colours indicate the restoration inventions that recorded more NDVI as compared to non-restored areas and the % represents the number of restored sites.

Assessment	**Farm**	**N° of Impact Sites**	**Average & Relative Contrast**	**N° of Sites**		**BACI ANOVA**		
				β < 0	**β > 0**	**Sites with significant positive contrast ($p < 0.05$)**	**Sites with significant negative contrast ($p < 0.05$)**	**Sites with no significance change**
1	Damsedrif	4	0.011 (4%)	50%	50%			100%
	Kamerkloof	1	0.010 (2%)		100%			100%
	Rust en Vrede	21	-0.002 (-1%)	62%	38%	19%	19%	62%
	Sederkloof	3	0.003 (1%)	33%	67%			100%
Total 1		**29**	**0.006 (2%)**	**55%**	**45%**	**14%**	**14%**	**72%**
2	Bokloof	1	-0.104 (-6%)	100%			100%	
	Damsedrif	1	-0.029 (-11%)	100%			100%	
	Rust en Vrede	1	-0.023 (-4%)	100%				100%
	Verlorenrivier	1	-0.010 (-7%)	100%			100%	
	Zandvlakte	1	-0.078 (-23%)	100%			100%	
Total 2		**5**	**-0.031 (-10%)**	**100%**			**80%**	**20%**
3	Tchnuganoo	1	0.004 (1%)		100%			100%
	Zandvlakte	23	-0.022 (-6%)	87%	13%		35%	65%
Total 3		**24**	**-0.009 (-2%)**	**83%**	**17%**		**33%**	**67%**
4	Tchnuganoo	1	-0.020 (-4%)	100%				100%
	Zandvlakte	1	-0.010 (-2%)	100%				100%
Total 4		**2**	**-0.015 (-3%)**	**100%**				**100%**
5	Zandvlakte	2	0.007 (3%)	50%	50%	50%		50%
Total 5		**2**	**0.007 (3%)**	**50%**	**50%**	**50%**		**50%**
6	Tchnuganoo	1	-0.020 (-6%)	100%				100%
	Zandvlakte	25	0.002 (1%)	44%	56%	8%	4%	88%
Total 6		**26**	**-0.009 (-2%)**	**46%**	**54%**	**8%**	**4%**	**88%**
Grand Total		**88**	**-0.009 (-2%)**					

The spatial distribution of the impact of restoration interventions in the study area is shown in Figure 9. The results show that 284.9 ha of restored sites (green colour) have more NDVI as compared to the non-restoration areas while another 131.7 ha of restored sites (red colour) have recorded less NDVI in comparison to non-restored areas. The significant decrease in NDVI was detected only in Rust en Vrede in revegetation areas that are still open to livestock grazing. However, 9 091.6 ha of the restored sites (grey colour) have recorded a non-significant contrast. Of these 9 091.6 ha, about 8 100 ha was detected in areas that only protected from livestock grazing.

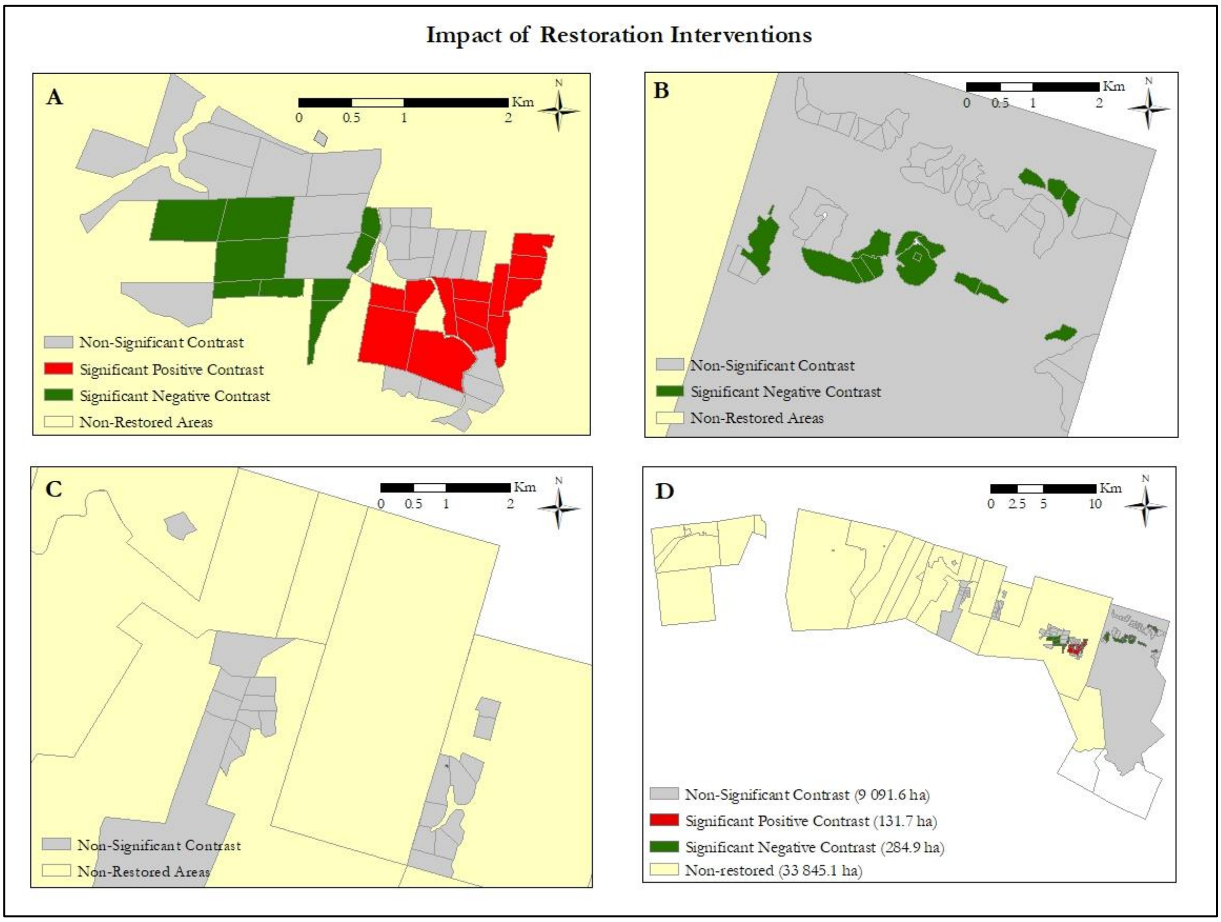

Figure 9: Maps showing the impact of the restoration interventions as compared to non-restoration areas. Map A shows Rust en Vrede; Map B shows Zandvlakte, Map C shows Kamerkloof, Tchnuganoo, Sederkloof and Damsedrif, and Map D shows the complete study area.

The representative examples of the data (both impact and controls) that were used in the BACI analysis are shown in Figure 10. Plot A shows a restored site that has recorded the highest significant increase in NDVI by 0.07 as compared to non-restored areas. This restored site is in a Spekboom revegetated area that is protected from animal grazing. The second plot, plot B, shows a site that was revegetated yet still open to livestock and has recorded the highest significant decrease in NDVI by 0.05 with a comparison to non-restored areas. As for the non-significant change in NDVI, plot C represents a site that is revegetated and protected from livestock grazing that has recorded a non-significant increase in NDVI of 0.03. Plot D shows a site that was only revegetated but still open to livestock and has recorded a non-significant decrease in NDVI of 0.03.

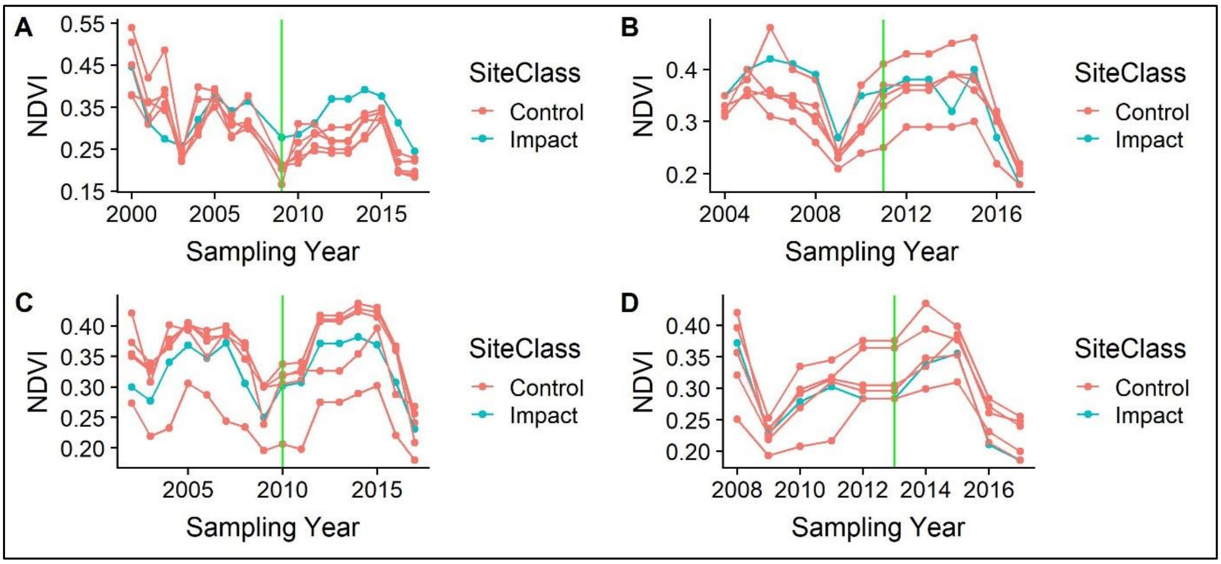

Figure 10: NDVI temporal profiles for four selected impact sites (cyan lines) from the restoration intervention types in the following order: A) Revegetation and animal exclusion, B) Revegetation only, C) Revegetation and livestock exclusion and D) Revegetation only. Their respective control sites are shown in red lines. The green vertical lines indicate the intervention year, and it separates the period before and after the intervention.

4. DISCUSSION

4.1. Impacts of restorations

This study highlights the impact of restoration interventions on changes in green vegetation cover in the Baviaanskloof. These restoration interventions include revegetation of degraded areas with Spekboom, exclusion of animals from revegetated areas by establishing a fence around them, revegetation of areas that are protected from livestock grazing and removal of livestock from degraded areas. The study assessed the impact of these restoration interventions on inter-annual NDVI trend trajectories, the seasonal variations across the NDVI classes and NDVI trends variability in comparison to non-restoration areas.

The results of the inter-annual NDVI trend assessment show a relatively similar trend behaviour across all the classes, representing restored and non-restored sites. For the period 2000 to 2010, there was a significant decrease in NDVI for all the classes. Even the classes that widely occur in animal exclusion areas recorded a loss in vegetation cover during this period. A similar trend was also observed by Nyamugama & Kakembo (2015) who reported a loss in above ground biomass (AGB) between 1972 and 2010 in the Andries Vosloo Kudu Nature Reserve and other nature reserves located in the Eastern Cape Province of South Africa. Their study suggested the anthropogenic activities as the major driver of loss in vegetation during this period. However, the period that followed, i.e., between 2010 and 2014, all the NDVI classes recorded an increase in NDVI. All the classes recorded a significant increase in vegetation cover except for classes 3 and 8 which widely occur in revegetated areas. This increase in NDVI coincides with the period when most of the degraded areas in Baviaanskloof were revegetated with Spekboom. However, it cannot be concluded that this increase in vegetation cover was a result of restoration interventions since this similar trend was also detected in non-restored areas. Therefore, this can be potentially linked to an increase in precipitation. The largest decrease in NDVI was detected between 2015 and 2018. This heavy loss in vegetation cover irrespective of the restoration intervention can be attributed to the effects of drought reported in the last three years.

The annual vegetation phenology reflects a relatively similar trend across all NDVI classes irrespective of the restoration intervention type. None of the classes show a stable greenness of vegetation all year-round in all the three years (2007, 2015 and 2017). All the NDVI classes show the effects of seasonal variations which was also reported by Fox, Hoffman, & Hoare (2012) in Namaqualand located in the North Western Cape Province of South Africa. The longest growing season with a mean of six months was recorded in 2015. Although this study observed the lack of more recent vegetation phenological studies in the subtropical thickets of South Africa, this growing season length of six months is also consistent with the result reported by Hoffman (1989) in the lower Sundays River Valley in the South Eastern Cape Province of South Africa. The shortest growing season with a mean of 4 months was reported in 2017, and this can be attributed to the effects of drought as this was an exceptionally dry year which can also be explained by the low peaks in NDVI. Due to the drought effects, the phenological metrics could not be extracted for classes 15 and 35 which occur widely in non-restored and livestock exclusion areas respectively. The NDVI values for these two classes were constantly low throughout the year. In terms of the start of the growing season, although there are slight variations in the timing of the greening in vegetation for 2007 and 2015, the growing season generally shows an early autumn green-up in March. The same autumn green-up of vegetation was also reported by Hoffman (1989). This means that the start of the season may not have shifted significantly in the last two decades. A unique mid-summer green-up was detected in 2017 which was also reported by Esler & Rundel (1999) in the succulent karoo in the Goegap Nature

Reserve located in the Namaqualand. The results of the assessment show that all nine NDVI classes respond to seasonal variations.

In terms of the BACI analysis results shown in Figure 10, there are variations in the impact across the restoration interventions. The highest increase in vegetation cover was detected in revegetated areas that are fenced to protect them from animal grazing. The NDVI in these areas has increased with an average of 0.031 which represents a 10% increase in vegetation cover. The increase in vegetation cover can potentially be alluded to the exclusion of animals from browsing in the revegetated sites which allows for the planted Spekboom to grow and regeneration of other canopy tree species. This increase in vegetation cover can also be explained by a study by van der Vyver et al. (2013) in Rhinosterhoek and Krompoort which reported an increase in AGB in restored sites as compared to non-restored sites and linked the findings to the protection of the restored sites with a 2-m high fence. However, this was only implemented at a micro-scale (demonstration plots); therefore, removing wild game from restored sites can be considered not feasible at large scale level and will create conflict with overall goals of conservation. Another improvement in vegetation cover was detected at 33% of the sites in the revegetated areas that are protected from livestock grazing. The restored areas in this intervention type recorded a significant increase in NDVI of 0.009 which corresponds to an increase in vegetation cover of 2%. Considering the restoration investment of about ZAR 1 685/ha (Vyver et al., 2012), this 2% increase in vegetation cover can be considered not significant; however, since most of the sites were restored eight years ago (2011), these may have easily succumbed to the drought effects reported in the last three years. The significant increase in NDVI recorded at 33% of the sites can be attributed to the protection of revegetated sites from livestock grazing. Parsons et al. (2007) also observed a significant increase in survival and growth of planted cuttings in livestock exclusion areas as compared to areas open to livestock grazing. However, the number of sites with a significant increase in vegetation cover could have been more under this intervention type if they were not subjected to wild herbivory animals. A study by Mills & Cowling (2006) in the Kudu Reserve of South Africa have recorded relatively low AGB in woody plants in Spekboom restored sites that are more prone to the wild herbivory effect.

However, apart from the significant increase in vegetation cover recorded in other restoration interventions, a significant decrease in vegetation cover was detected in Spekboom revegetated areas that are still open to livestock grazing. This restoration intervention type has reported the only significant decrease in NDVI at 14% of the sites across all the restoration interventions as compared to non-restoration areas. The reason for the loss of vegetation even after revegetation in these areas may have been driven by heavy browsing by livestock especially the goats which were observed in some revegetated areas during data collection. This adverse impact of continued grazing by livestock on vegetation development have also been reported in other areas such as Sundays River catchment, South Africa (Rutherford, Powrie, & Husted, 2014) and Australia (Parsons et al., 2007). Mills (2010) has also mentioned how continued grazing by livestock and game animals in revegetated areas can potentially limit vegetation development; therefore, recommended for removal of livestock after revegetation for a period of three to five years. The effect from livestock grazing was potentially aggravated by long periods of drought in the last three years, and this could have resulted in limited growth especially in restored areas that were planted in 2015 in Damsedrif farm. Apart from the grazing effect, Duker, Cowling, du Preez, & Potts (2015) have also reported the effect of frost especially on Spekboom planted in bottom valleys in Kaboega Farm located in Port Elizabeth.

The intervention by solely protecting degraded areas from livestock grazing has also not recorded a significant increase in green vegetation cover as shown in the results. None of the sites have recorded an increase in vegetation cover as a non-significant change was detected at all the sites. The results show that the removal of livestock without active restoration does not immediately improve vegetation cover in degraded areas. Lechmere-Oertel et al. (2005), Sigwela, Kerley, Mills, & Cowling (2009) and Vyver et al. (2012) state that spontaneous recovery of plant species including Spekboom does not occur in browsing-degraded thickets as the ecosystem is locked in vegetation decrease trend and this trend can only be changed by active revegetation. They attributed this to high temperatures of exposed soil and compromised water holding capacity which constraints the establishment of new seedlings.

In terms of both inter-annual and intra-annual NDVI trends, the results show a relatively similar trend across all the nine NDVI classes irrespective of the restoration interventions. However, based on the BACI method, variations in restoration intervention's impacts were detected. Many restored sites have recorded a non-significant change in NDVI, and these are potential sites for future monitoring. The results from this method also show that protecting Spekboom revegetated areas from both livestock and wild animals grazing is more effective in improving green vegetation cover in degraded areas as compared to areas that are open to livestock and game animal grazing. Eliminating grazing from revegetated areas also allows for the establishment of the new planted Spekboom and spontaneous growth of other canopy tree species (Adie & Yeaton, 2013). For example, assessment of the revegetated areas protected from animals and livestock grazing recorded 80% and 33% respectively of the sites with significant improvement in vegetation cover after the intervention. These sites have their Spekboom revegetated areas protected from domestic and wild herbivores. However, large scale wild animals' exclusion may not be feasible as it contradicts with the objectives of conservation. Additionally, the removal of livestock from revegetated areas can be considered; however, taking into consideration that livestock farming is the main source of income for many farmers in the Baviaanskloof, some landowners can be reluctant to remove their livestock without a reliable alternative source of income.

4.2. Reflection on data and methods

4.2.1. Landsat time series

Long-term impact assessment of restoration intervention requires satellite data of adequate temporal and spatial resolution to capture the trend characteristics both before and after intervention (Dawson et al., 2016; Hausner et al., 2018). Landsat data have been used in many studies to conduct time-series analysis because of its high spatial (30 m) and temporal (16-day) resolution coupled with a longer historical temporal range (Dong et al., 2015; Silva et al., 2018) and this made it ideal for use in this study. Its spatial resolution of 30 m was suitable for assessment restoration impact at small restored sites such as the 0.22 ha in Damsedrif. However, the high frequency of data gaps due to clouds and cloud shadows could have introduced some uncertainties in the results especially in generating NDVI classes, inter-annual NDVI trend analysis and in phenological assessments. Additionally, another possible source of uncertainty is in the use of Landsat 5, 7 and 8 for NDVI, all with spectral differences. These spectral band differences, especially in the Near Infrared (NIR) bands, induce some spectral reflectance differences and consequently differences in NDVI (Roy et al., 2016).

4.2.2. NDVI classes

NDVI is a vegetation index that has been widely used in assessing vegetation condition and derives information on land use and land cover changes (Maselli, 2004) and this made it useful in evaluating vegetation condition in this study. The NDVI classes computed by running the unsupervised classification was ideal for representing the vegetation classes with similar trends in NDVI that widely occur in restoration intervention areas. The assumption was that distinct NDVI classes that explicitly separate restored areas from non-restored areas would be generated as the ISODATA clustering method clusters together NDVI pixels that follow a relatively similar temporal trajectory behaviour (de Bie et al., 2012). However, the selection of the optimum number of NDVI classes in this study was limited by the lack of an average divergence trend with a clear peak. The absence of a clear peak was previously in another study by de Bie et al. (2012) attributed to the use of fine spatial resolution satellite input data. Their study compared the two outputs from SPOT and MODIS data. The absence of a distinguishable peak in the average separability was observed in the output from MODIS data. They concluded that the finer the spatial resolution of the satellite data used, the more complex the NDVI pattern. Therefore, this means the use of Sentinel 2 data with a finer resolution than the Landsat will provide a more complex NDVI pattern but improves the discrimination of vegetation in the study area.

As the aim was to identify the distinct NDVI classes that widely occur in the restoration intervention areas, a limit of 80% was pragmatically set. The NDVI classes that met the pragmatically set limit of 80% were selected to represent different restoration intervention types in assessing vegetation growth trend and response to seasonal variations. The limit used was successfully applied as it separated NDVI classes according to their occurrence. However, the results from the inter-annual NDVI trend and seasonal variation analyses could not reflect any differences among all the selected NDVI classes as they all followed a similar trend. As such, identification of distinct NDVI classes can be improved performing the NDVI trend and seasonal variations analyses at the pixel level.

Although NDVI has been widely used in assessing vegetation condition, Weiss, Gutzler, Coonrod, & Dahm (2004) states that it is affected by low values especially from sparsely vegetated areas which increase uncertainties in interpreting NDVI, particularly in arid and semi-arid regions. It is affected by the spectral reflectance of the background exposed soil. Considering that some areas in Baviaanskloof are sparsely vegetated due to land degradation, this could have added some uncertainties in the interpretation of the NDVI classes. Therefore, future studies can make use of other vegetation indices such as the soil adjusted vegetation index (SAVI) that reduces soil brightness effects (Sashikkumar et al., 2017).

4.2.3. NDVI trend variability analysis

NDVI trend analysis using the linear regression model was useful in estimating and understanding the temporal trajectory of different NDVI classes from the period before the active restoration interventions to post-restoration intervention. Linear regression method has been used by various studies to estimate the vegetation cover dynamics induced by restoration initiatives (Zhang, Wang, & Ge, 2015; Tong et al., 2016; Wilson & Norman, 2018), climate change (Zhu et al., 2016), land degradation (Eckert, Hüsler, Liniger, & Hodel, 2015) etc. In this study, this method was used to estimate the NDVI temporal trajectory from the year 2000 to 2018, and this was performed using the spatially averaged and temporal NDVI values. Additionally, the significance of the change in NDVI in this study was determined at $p = 0.05$.

The linear regression model was implemented in this study to estimate the empirical vegetation cover trend. Different NDVI trend estimates were expected between the restored and non-restored areas especially for the period after the intervention; however, the estimates from the linear model show that all the selected NDVI classes followed a similar trajectory in terms of the direction of change, at a relatively similar magnitude. The significance of change was relatively similar for all the classes, and even if the confidence level were to be increased to a p-value of 0.01, similar results would have been produced. Furthermore, the presence of noise in the time series data could have introduced some uncertainties (de Jong, de Bruin, de Wit, Schaepman, & Dent, 2011) in the linear model as an overall mean R^2 of 0.23 was recorded which indicates high variability in the data.

Apart from monitoring the vegetation development trend using the linear regression method, vegetation phenology has also been used by various studies to estimate climate variability impacts on ecosystems (Tang et al., 2015). Researchers such as Van Leeuwen (2008) have used vegetation phenology to estimate the effects of forest restoration on vegetation recovery. However, there has not been any specific study on vegetation phenology in the subtropical thicket of Baviaanskloof except for some study by Hoffman (1989) who undertook a study on vegetation phenology in lower Sundays River valley and Fox, Hoffman, & Hoare (2012) who also assessed the phenological pattern of vegetation in Namaqualand. In this study, vegetation phenology was used to estimate vegetation recovery due to different restoration interventions. Annual phenological metrics were extracted for selected NDVI classes using the greenbrown package in R. This was done for both restored and non-restored areas and was performed for only three selected years (2007, 2015 and 2017).

Most of the studies have extracted pheno-metrics on smoothened time series data; as such, the time series in this study was smoothened using the Savitzky-Golay filter package in R software. However, this filtering algorithm is threshold dependent, and this could have introduced some uncertainties in the data. Although variations in peak values were detected for different NDVI classes, the timing of the SOS and the EOS including the LOS were relatively similar among the classes. From the metrics extracted, it can be concluded that none of the NDVI classes have recorded a stable photosynthetic activity all year-round. Therefore, the extraction of the phenological metrics can potentially be improved in future studies by calculating the parameters of NDVI class values computed at a pixel scale.

4.2.4. The BACI design

The BACI design using the linear mixed effects model has been used extensively in many studies to assess the ecological impact of different projects around the world (Conner, Saunders, Bouwes, & Jordan, 2015). Among the users of the BACI design are Wayne et al. (2016), Rocha et al. (2017), Sills et al. (2017) and Maher, Nelson, Larson, & Sala (2018). It was however first used by Meroni et al. (2017) to assess the restoration intervention impact on vegetation cover changes based on NDVI. The rationale is that restoration intervention project will induce a different NDVI change trend from before to after the intervention.

In this study, multiple sites and multiple sampling years before/after were used to estimate the impact of different restoration interventions because it improves the discriminative power of the BACI model. One of the advantages of the BACI design is its robustness to continuous monitoring of changes after intervention (Smokorowski & Randall, 2017). The multiple (five) control sites were selected over the single control site in this study to be able to measure the temporal change that occurs in the absence of the intervention. The selection of control areas with NDVI classes with the impact site just before the intervention is also important in improving the discrimination power of the model (Meroni et al., 2017). This study used the 2007 NDVI class map; however, using a such a map to assess sites restored in 2015 could have introduced some errors in the selection of the control areas due to changes in vegetation. As such, future studies can consider the use of more recent NDVI class maps in the selection of control areas with relatively similar class composition with the impact site. Considering the rugged terrain in the study area, this method was improved by adding the slope, elevation, and aspect in spatial sampling to identify control areas as also recommended by Meroni et al. (2017). This has been useful in correcting for topographical variations as vegetation growth is also determined by the topography. To capture the impacts of the restoration interventions, all areas that have been modified by natural and anthropogenic activities before and after the intervention were excluded for analysis. Furthermore, to be able to improve the statistical power of the test, restoration interventions were categorised according to their type and a balanced number of samples before and after was used in this study (Meroni et al., 2017; Smokorowski & Randall, 2017).

The results obtained by running this model indicate a slight mean increase in NDVI by 2% for all the 88 restoration sites assessed. However, the detection of a high number of sites with a non-significant change in vegetation cover can not only be linked to the ineffectiveness of the restoration interventions but can also be attributed to the length of the time series especially the post-intervention period. Rutherford et al. (2014) state that passive restoration of the degraded subtropical thickets may require about 40 years; however, in this study the length of the post-restoration period for livestock exclusion areas was 15 years, and this could have contributed to the detection of the non-significant change in vegetation cover by the model. Additionally, the average length period of the post-restoration of 6 years for revegetated areas could also have contributed to the highest number of sites with non-significant change as Spekboom restoration actions require longer periods to produce significant vegetation cover. Therefore, more time is required for the restoration interventions in the study areas to record a significant increase in the vegetation cover.

4.3. Applicability

The results from this study show variation in impact across restoration interventions. Elimination of grazing in revegetated areas has shown the potential in restoring the degraded landscapes thereby fulfilling the project objectives. The restoration practitioners, in this case, the Living Lands together with its stakeholders can make use of the results to identify restoration intervention types that provide the best turnover in terms of meeting the restoration objectives. The BACI method used in this study can also be used for continuous monitoring of the restoration interventions and can be used in other vegetation restoration projects to identify areas that require improvement (Meroni et al., 2017). The method can be applied to all other vegetation restoration projects in South Africa and the world at large regardless of the topography. Topography can be corrected for in rugged terrains during the spatial sampling stage as performed in this study (Meroni et al., 2017).

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The main aim of this study was to assess the impacts of restoration interventions in the degraded subtropical thickets of Baviaanskloof based on multi-year earth observation data. In 2004, the Subtropical Thicket Restoration Programme (STRP) was launched in South Africa, and this has led to the revegetation with native Spekboom of more than 1 000 ha of degraded land in the Baviaanskloof. Apart from the active revegetation through the STRP, livestock was also removed over 20 years ago from more than 8 000 ha of land to allow for natural regeneration of vegetation. The assessment of these restoration interventions was completed using the Landsat NDVI time series data. The results show variations in impact among the different restoration interventions. Protecting Spekboom revegetated areas from wild animals and livestock grazing have shown tremendous potential in restoring the degraded landscapes. A total of 80% of the restored sites have recorded a significant increase in vegetation cover in revegetated areas that are protected from both wild animals and livestock grazing. This increase in vegetation cover may be explained by limiting grazing effects from both domestic and wild animals. Furthermore, this type of restoration intervention was only implemented at micro-scale for demonstration purposes. However, the removal of wild animals from revegetated areas at macro-scale can create conflict with the objectives of conservation. Another significant increase in green vegetation cover was also detected at 33% of the sites in livestock exclusion areas that have been revegetated with Spekboom. This means that removing livestock from revegetated areas allows for both the planted Spekboom to establish and spontaneous recovery of other plant species. However, livestock farming is the main source of income for many farmers in the Baviaanskloof; therefore, these landowners can be reluctant to remove their livestock without another reliable source of income. The effects of not removing livestock from revegetated areas were detected in areas that were revegetated with Spekboom while they are still open to livestock grazing. These areas recorded the highest number (14%) of impact sites in this study with a significant decrease in green vegetation cover even after revegetation. The BACI method used in this study can be considered for identification of restoration areas that require improvement in other restoration projects. The results of the BACI model can be used by the restoration officials (Living Lands and its stakeholders) for management and planning purposes such as identifying areas for potential monitoring in the future. The findings can also be used to evaluate if the restoration objectives are to be met.

5.2. Recommendations

- Future studies can improve the monitoring of the impacts through the use of Sentinel 2 that provides very high spatial and temporal resolution. However, this can only be used on recently restored areas.
- For the future research, to further improve the discrimination power of the BACI design, more recent NDVI class maps should be considered in spatial sampling to attain a relatively balanced class composition between the control areas and the impact site just before the intervention.
- The inter-annual NDVI class trend and the seasonal variations analyses can be enhanced by conducting the assessments at the pixel level instead of class spatial NDVI averages.
- More reliable alternative sources of income can be introduced in the area if the number of farmers who adopt the livestock exclusion intervention is to be increased in Baviaanskloof. In this case, the current lavandin and rosemary planting project can be improved to enable the farmers to realize the full benefits of switching from livestock farming to essential oil crop production.

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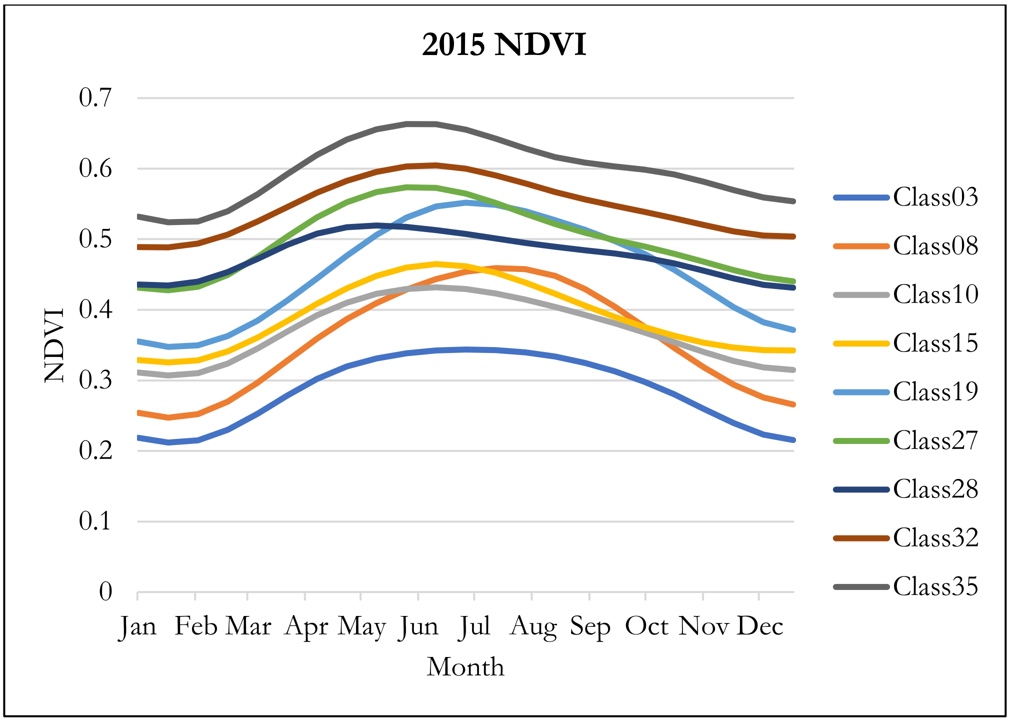
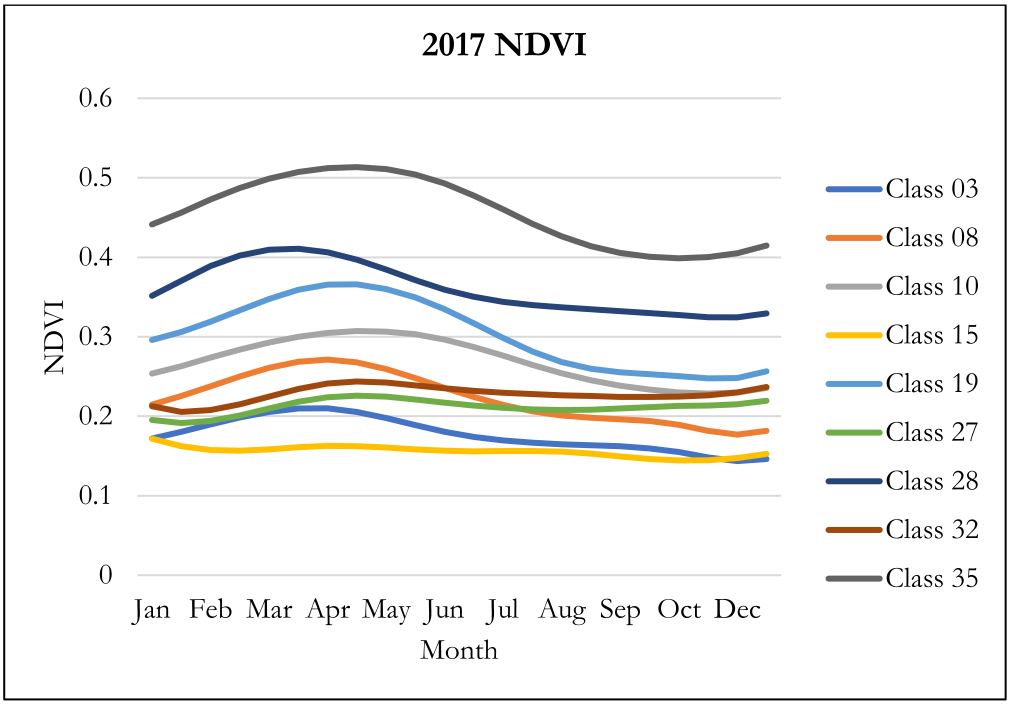
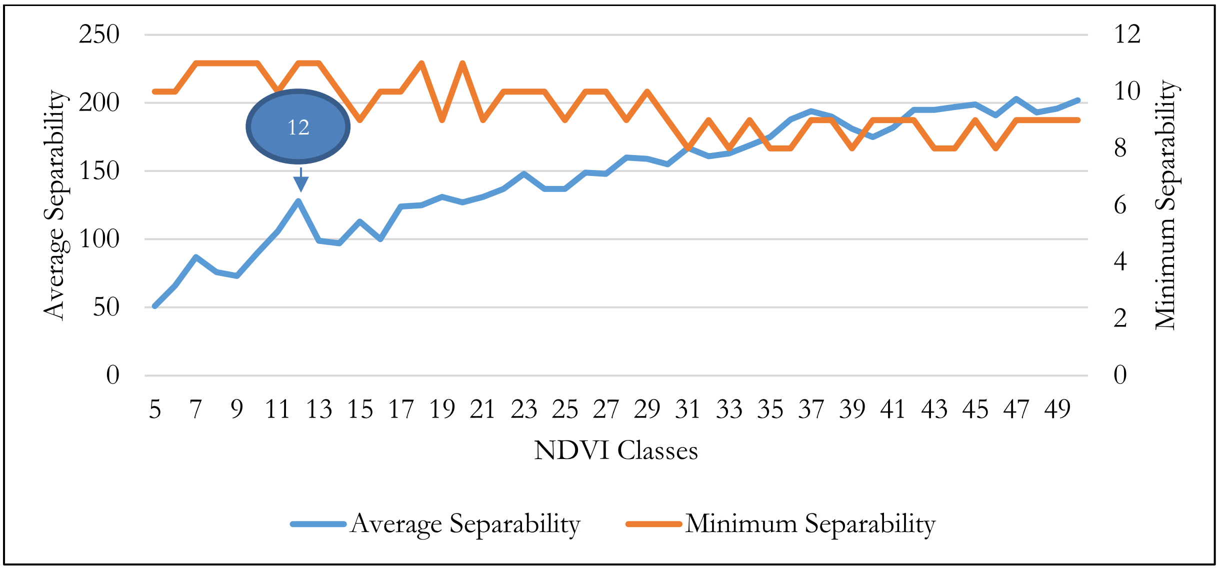
6. APPENDICES

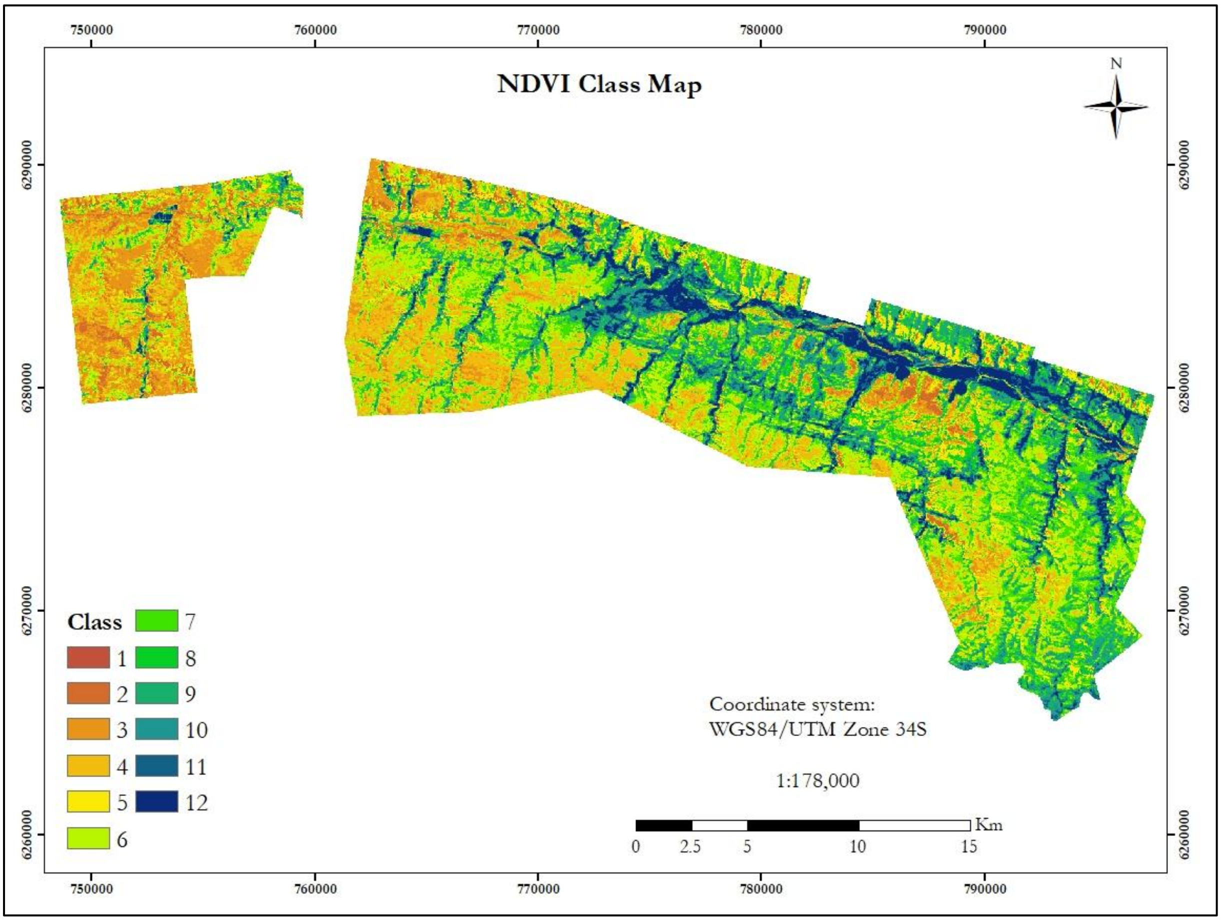
Appendix 1: NDVI classes showing a unimodal seasonality



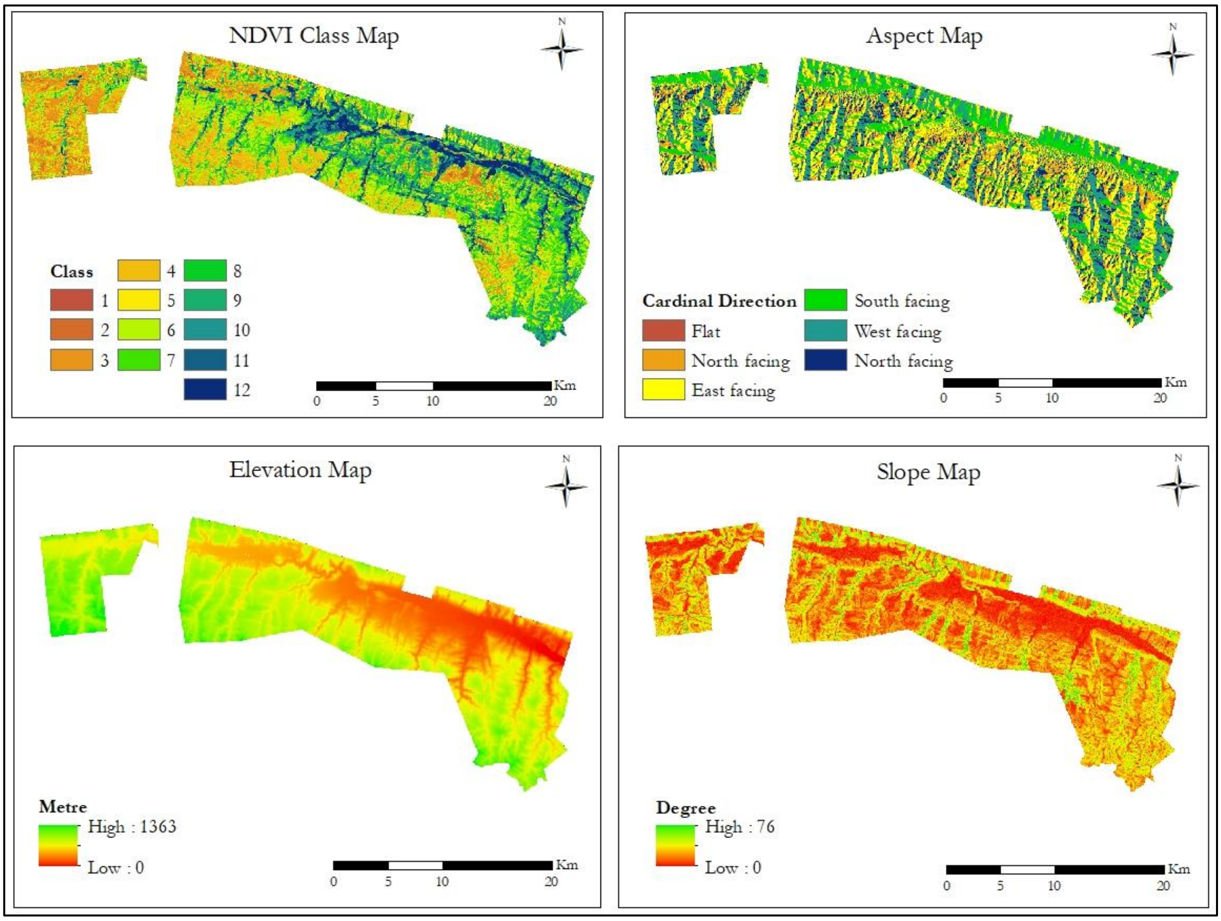


Appendix 2: Divergence statistics and 12 NDVI classes map





Appendix 3: Spatial data used for spatial sampling



Appendix 4: Detailed results of the BACI analysis

Statistical results from the comparative analysis of revegetation only to non-restored

Comparison of Revegetation only to Non-restored areas					
ID	**Rust 01**	**Rust 02**	**Rust 03**	**Rust 04**	**Rust 05**
GPS Coordinates	24.077671, -33.593161	24.083971, -33.589786	24.092148, -33.590595	24.088518, -33.594693	24.085798, -33.598627
Area (ha)	20.19	20.28	28.39	41.18	52.72
Year of intervention	Mar-13	Dec-12	February and March 2013	Dec-12	May and June 2012
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation					
BACI results					
P-value	0.2765	0.2009	0.9223	0.5209	0.0121
Contrast	-0.01	-0.01	0.001	-0.01	-0.03
Relative contrast	-3	-3	0	-3	-10
Standard Deviation	0.02	0.01	0.01	0.02	0.02
Mean NDVI Before (Impact)	0.30	0.29	0.26	0.29	0.30
Mean NDVI Before (Control)	0.28	0.25	0.25	0.28	0.27
Mean NDVI After (Impact)	0.31	0.30	0.28	0.30	0.32
Mean NDVI After (Control)	0.28	0.26	0.26	0.28	0.28
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation only to non-restored

Comparison of Revegetation only to Non-restored areas					
ID	**Rust 06**	**Rust 07**	**Rust 08**	**Rust 09**	**Rust 10**
GPS Coordinates	24.094978, -33.594119	24.100178, -33.59784	24.092355, -33.601917	24.103711, -33.601033	24.100665, -33.604255
Area (ha)	53.07	52.87	67.01	10.36	14.13
Year of intervention	Sep-12	Apr-12	Sept, Oct & Nov 2012	Apr-11	Dec-12
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	Low Spekboom stocking	N/A	N/A	Low Spekboom stocking	N/A
BACI results					
P-value	0.3364	0.1364	0.0158	0.0055	0.0162
Contrast	-0.01	-0.01	-0.02	-0.03	-0.02
Relative contrast	-3	-3	-6	-9	-6
Standard Deviation	0.02	0.01	0.02	0.02	0.01
Mean NDVI Before (Impact)	0.29	0.30	0.32	0.33	0.33
Mean NDVI Before (Control)	0.26	0.23	0.26	0.28	0.25
Mean NDVI After (Impact)	0.31	0.33	0.35	0.36	0.36
Mean NDVI After (Control)	0.27	0.25	0.27	0.28	0.26
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation only to non-restored

Comparison of Revegetation only to Non-restored areas					
ID	**Rust 11**	**Rust 12**	**Rust 13**	**Rust 14**	**Rust 15**
GPS Coordinates	24.106067, -33.598517	24.107706, -33.59785	24.107463, -33.600123	24.108983, -33.602191	24.112167, -33.600765
Area (ha)	4.44	7.15	14.08	7.02	21.12
Year of intervention	Apr-12	Mar & Apr 2012	Feb-11	Dec-10	Feb & Mar 2011
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	Low Spekboom stocking	Low Spekboom stocking	N/A	Low Spekboom stocking	N/A
BACI results					
P-value	0.5311	0.4598	0.4901	0.8806	0.8146
Contrast	-0.01	-0.004	0.004	0.002	0.001
Relative contrast	-3	-2	1	1	0
Standard Deviation	0.02	0.01	0.01	0.02	0.01
Mean NDVI Before (Impact)	0.34	0.23	0.30	0.30	0.31
Mean NDVI Before (Control)	0.29	0.23	0.21	0.29	0.25
Mean NDVI After (Impact)	0.37	0.23	0.30	0.31	0.31
Mean NDVI After (Control)	0.31	0.23	0.22	0.30	0.25
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation only to non-restored

Comparison of Revegetation only to Non-restored areas					
ID	**Rust 16**	**Rust 17**	**Rust 18**	**Rust 19**	**Rust 20**
GPS Coordinates	24.106508, -33.604774	24.108306, -33.612052	24.112563, -33.605344	24.11686, -33.610506	24.121367, -33.599861
Area (ha)	66.5	14.58	28.11	21.06	22.56
Year of intervention	Dec-12	Apr-11	Feb-11	Feb & Mar 2011	Jun & Jul 2011
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	N/A	N/A	N/A	N/A
BACI results					
P-value	0.0489	0.0544	0.0013	0.9611	0.0001
Contrast	0.02	-0.03	0.03	-0.001	0.05
Relative contrast	6	-8	10	0	14
Standard Deviation	0.01	0.02	0.01	0.03	0.02
Mean NDVI Before (Impact)	0.33	0.37	0.31	0.40	0.37
Mean NDVI Before (Control)	0.28	0.34	0.26	0.38	0.32
Mean NDVI After (Impact)	0.32	0.40	0.29	0.41	0.33
Mean NDVI After (Control)	0.29	0.33	0.26	0.39	0.33
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation only to non-restored

Comparison of Revegetation only to Non-restored areas					
ID	**Rust 21**	**Damsedrif 1**	**Damsedrif 2**	**Damsedrif 3**	**Damsedrif 4**
GPS Coordinates	24.118166, -33.607998	24.037364, -33.564258	24.035415, -33.569721	24.030054, -33.571791	24.028968, -33.583298
Area (ha)	14.55	17.76	29.04	31.87	54.88
Year of intervention	Apr & Aug 2011	Oct-13	August & October 2013	June to August 2013	August & October 2013
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	Low Spekboom stocking	Low Spekboom stocking	Low Spekboom stocking	Low Spekboom stocking
BACI results					
P-value	0.0041	0.1042	0.7736	0.1053	0.9769
Contrast	0.04	0.03	-0.004	0.02	-0.0003
Relative contrast	11	10	-1	6	0
Standard Deviation	0.02	0.02	0.02	0.02	0.01
Mean NDVI Before (Impact)	0.36	0.29	0.30	0.33	0.28
Mean NDVI Before (Control)	0.29	0.30	0.29	0.27	0.28
Mean NDVI After (Impact)	0.33	0.28	0.32	0.34	0.30
Mean NDVI After (Control)	0.29	0.31	0.30	0.30	0.31
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation only to non-restored

Comparison of Revegetation only to Non-restored areas				
ID	**Sederkloof 1**	**Sederkloof 2**	**Sederkloof 3**	**Kamerkloof**
GPS Coordinates	23.999772, -33.559329	23.996613, -33.566461	23.996613, -33.566462	23.985539, -33.537245
Area (ha)	33.64	19.27	9.03	12.39
Year of intervention	October & November 2014	March & May 2015	Jan-15	Sep-11
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	N/A	N/A	Low Spekboom stocking
BACI results				
P-value	0.6668	0.3886	0.7674	0.5833
Contrast	-0.01	0.01	0.01	0.01
Relative contrast	-3	3	3	2
Standard Deviation	0.02	0.01	0.03	0.03
Mean NDVI Before (Impact)	0.32	0.36	0.39	0.41
Mean NDVI Before (Control)	0.35	0.39	0.42	0.38
Mean NDVI After (Impact)	0.32	0.30	0.34	0.42
Mean NDVI After (Control)	0.35	0.34	0.37	0.39
Number of controls	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation & animal exclusion to non-restored

Comparison of Revegetation & Animal Exclusion to Non-restored areas					
ID	**Bokloof**	**Damsedrif**	**Verlorenrivier**	**Rust en Vrede**	**Zandvlakte**
GPS Coordinates	23.913648, -33524396	24.031254, -33.569684	23.862022, -33.529425	24.099188, -33.591274	24.144663, -33.59150
Area (ha)	0.96	0.22	0.69	1.05	0.68
Year of intervention	Jul-09	Apr-08	Jul-08	Apr-08	Apr-08
Framework of intervention	Research/Trial	Research/Trial	Research/Trial	Research/Trial	Research/Trial
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Condition of the Fence	Damaged	Good	Good	Good	Good
Field mission evaluation	Low Spekboom stocking	Successful	Successful	Relatively successful	Relatively successful
BACI results					
P-value	0.0457	0.0004	0.0052	0.2391	0.0001
Contrast	-0.01	-0.03	-0.02	-0.01	-0.08
Relative contrast	-6	-11	-7	-4	-23
Standard Deviation	0.01	0.01	0.02	0.02	0.03
Mean NDVI Before (Impact)	0.24	0.26	0.32	0.28	0.34
Mean NDVI Before (Control)	0.28	0.27	0.31	0.27	0.35
Mean NDVI After (Impact)	0.25	0.27	0.32	0.25	0.33
Mean NDVI After (Control)	0.27	0.23	0.28	0.23	0.26
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & animal exclusion to livestock exclusion

Comparison of Revegetation & Animal Exclusion to Livestock Exclusion areas		
ID	**Zandvlakte1**	**Zandvlakte2**
GPS Coordinates	24.144663, -33.59150	24.168679, -33597262
Area (ha)	0.68	1.03
Year of intervention	Apr-08	Apr-08
Framework of intervention	Research/Trial	Research/Trial
Type of intervention	Spekboom planting	Spekboom planting
Condition of the Fence	Good	Damaged
Field mission evaluation	Relatively successful	Low Spekboom stocking
BACI results		
P-value	0.1169	0.0025
Contrast	-0.02	0.03
Relative contrast	-5	10
Standard Deviation	0.02981	0.018738
Mean NDVI Before (Impact)	0.34	0.30
Mean NDVI Before (Control)	0.36	0.28
Mean NDVI After (Impact)	0.33	0.26
Mean NDVI After (Control)	0.33	0.28
Number of controls	5	5
Control areas management	Closed to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to non-restored

Comparison of Revegetation & Livestock Exclusion to Non-restored areas					
ID	**Zandvlakte 01**	**Zandvlakte 02**	**Zandvlakte 03**	**Zandvlakte 04**	**Zandvlakte 05**
GPS Coordinates	24.149041, -33.575804	24.150386, -33.578298	24.159765, -33.580175	24.163645, -33.580637	24.169858, -33.583368
Area (ha)	7.08	21.09	14.02	14.13	14.15
Year of intervention	Oct-11	Sep-11	August & September 2011	August & September 2011	Aug-11
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	Low Spekboom stocking	Low Spekboom stocking	Low Spekboom stocking	N/A
BACI results					
P-value	0.4893	0.6725	0.8419	0.5095	0.5158
Contrast	-0.01	0.01	0.002	-0.01	-0.01
Relative contrast	-2	2	1	-3	-2
Standard Deviation	0.03	0.03	0.02	0.02	0.02
Mean NDVI Before (Impact)	0.44	0.42	0.33	0.40	0.42
Mean NDVI Before (Control)	0.42	0.41	0.39	0.38	0.34
Mean NDVI After (Impact)	0.45	0.42	0.34	0.41	0.43
Mean NDVI After (Control)	0.42	0.42	0.39	0.39	0.35
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to non-restored

Comparison of Revegetation & Livestock Exclusion to Non-restored areas					
ID	**Zandvlakte 06**	**Zandvlakte 07**	**Zandvlakte 08**	**Zandvlakte 09**	**Zandvlakte 10**
GPS Coordinates	24.17355, -33.586389	24.177384, -33.587567	24.182701, -33.590481	24.187295, -33.591345	24.186875, -33.586165
Area (ha)	7.64	23.3	26.11	33.04	7.03
Year of intervention	Dec-11	Dec-11	Feb-12	November & December 2011	Nov-10
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	N/A	N/A	N/A	N/A
BACI results					
P-value	0.7375	0.5303	0.0937	0.6344	0.0092
Contrast	-0.01	-0.01	-0.02	-0.01	-0.03
Relative contrast	-2	-2	-6	-3	-7
Standard Deviation	0.03	0.02	0.02	0.02	0.02
Mean NDVI Before (Impact)	0.42	0.41	0.34	0.39	0.46
Mean NDVI Before (Control)	0.41	0.35	0.34	0.37	0.40
Mean NDVI After (Impact)	0.44	0.42	0.38	0.40	0.50
Mean NDVI After (Control)	0.41	0.36	0.35	0.37	0.41
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to non-restored

Comparison of Revegetation & Livestock Exclusion to Non-restored areas					
ID	**Zandvlakte 11**	**Zandvlakte 12**	**Zandvlakte 13**	**Zandvlakte 14**	**Zandvlakte 15**
GPS Coordinates	24.191031, -33.5874	24.197205, -33.591427	24.201553, -33.5922684	24.194795, -33.610339	24.192479, -33.607073
Area (ha)	14.29	26.28	7.09	52.61	7.07
Year of intervention	November & December 2011	Dec-11	Dec-11	Jun-12	Feb-12
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	N/A	N/A	**Low Spekboom stocking**	**Low Spekboom stocking**
BACI results					
P-value	0.0200	0.0561	0.9720	0.1529	0.0200
Contrast	-0.03	-0.03	-0.0004	-0.02	-0.03
Relative contrast	-6	-7	0	-6	-10
Standard Deviation	0.02	0.02	0.02	0.02	0.02
Mean NDVI Before (Impact)	0.49	0.44	0.44	0.34	0.31
Mean NDVI Before (Control)	0.39	0.37	0.39	0.29	0.35
Mean NDVI After (Impact)	0.52	0.46	0.45	0.36	0.35
Mean NDVI After (Control)	0.39	0.37	0.40	0.29	0.36
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to non-restored

Comparison of Revegetation & Livestock Exclusion to Non-restored areas					
ID	**Zandvlakte 16**	**Zandvlakte 17**	**Zandvlakte 18**	**Zandvlakte 19**	**Zandvlakte 20**
GPS Coordinates	24.180857, -33.601794	24.168532, -33.598405	24.161471, -33.595819	24.161504, -33.598652	24.153681, -33.593862
Area (ha)	48.36	26.23	13.54	40.30	26.45
Year of intervention	Dec-10	Jun-10	Jun-10	October & November 2011	Oct-11
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	Relatively successful	Relatively successful	Successful	N/A	Relatively successful
BACI results					
P-value	0.0004	0.0028	0.0429	0.0046	0.0759
Contrast	-0.06	-0.06	-0.04	-0.04	-0.02
Relative contrast	-14	-20	-12	-10	-6
Standard Deviation	0.03	0.04	0.03	0.02	0.02
Mean NDVI Before (Impact)	0.42	0.30	0.33	0.40	0.34
Mean NDVI Before (Control)	0.32	0.30	0.30	0.33	0.30
Mean NDVI After (Impact)	0.44	0.32	0.36	0.41	0.35
Mean NDVI After (Control)	0.27	0.26	0.29	0.30	0.28
Number of controls	5	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to non-restored

	Comparison of Revegetation & Livestock Exclusion to Non-restored areas			
ID	**Zandvlakte 21**	**Zandvlakte 22**	**Zandvlakte 23**	**Tchnuganoo**
GPS Coordinates	24.151327, -33.591813	24.143157, -33.596273	24.141582, -33.599996	23.994865, -33.559216
Area (ha)	26.01	26.46	7.39	33.87
Year of intervention	Jun-10	Oct-11	Apr-12	March & June 2015
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	Relatively successful	Relatively successful	Low Spekboom stocking	Low Spekboom stocking
BACI results				
P-value	0.0451	0.0091	0.9923	0.6908
Contrast	-0.03	-0.04	0.0001	0.004
Relative contrast	-10	-11	0	1
Standard Deviation	0.03	0.01	0.02	0.01
Mean NDVI Before (Impact)	0.29	0.37	0.33	0.36
Mean NDVI Before (Control)	0.29	0.34	0.32	0.32
Mean NDVI After (Impact)	0.32	0.38	0.36	0.31
Mean NDVI After (Control)	0.29	0.32	0.35	0.27
Number of controls	5	5	5	5
Control areas management	Open to livestock grazing	Open to livestock grazing	Open to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to livestock exclusion

Comparison of Revegetation & Livestock exclusion to Livestock Exclusion areas					
ID	**Zandvlakte 01**	**Zandvlakte 02**	**Zandvlakte 03**	**Zandvlakte 04**	**Zandvlakte 05**
GPS Coordinates	24.149041, -33.575804	24.150386, -33.578298	24.159765, -33.580175	24.163645, -33.580637	24.169858, -33.583368
Area (ha)	7.08	21.09	14.02	14.13	14.15
Year of intervention	Oct-11	Sep-11	August & September 2011	August & September 2011	Aug-11
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	Low Spekboom stocking	Low Spekboom stocking	Low Spekboom stocking	N/A
BACI results					
P-value	0.5919	0.6642	0.0712	0.1909	0.5898
Contrast	-0.01	0.01	0.01	0.01	0.003
Relative contrast	-2	2	3	3	1
Standard Deviation	0.02	0.02	0.01	0.01	0.01
Mean NDVI Before (Impact)	0.44	0.42	0.33	0.40	0.42
Mean NDVI Before (Control)	0.43	0.41	0.36	0.36	0.36
Mean NDVI After (Impact)	0.45	0.42	0.34	0.41	0.43
Mean NDVI After (Control)	0.43	0.42	0.38	0.39	0.38
Number of controls	5	5	5	5	5
Control areas management	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to livestock exclusion

Comparison of Revegetation & Livestock exclusion to Livestock Exclusion areas					
ID	**Zandvlakte 06**	**Zandvlakte 07**	**Zandvlakte 08**	**Zandvlakte 09**	**Zandvlakte 10**
GPS Coordinates	24.169189, -33.586585	24.17355, -33.586389	24.177384, -33.587567	24.182701, -33.590481	24.187295, -33.591345
Area (ha)	14.63	7.64	23.3	26.11	33.04
Year of intervention	Sep-11	Dec-11	Dec-11	Feb-12	November & December 2011
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	N/A	N/A	N/A	N/A
BACI results					
P-value	0.1304	0.7523	0.9674	0.8528	0.0967
Contrast	0.01	0.002	0.0003	0.001	0.01
Relative contrast	3	0	0	0	3
Standard Deviation	0.01	0.01	0.01	0.01	0.01
Mean NDVI Before (Impact)	0.35	0.42	0.41	0.34	0.39
Mean NDVI Before (Control)	0.38	0.45	0.40	0.38	0.48
Mean NDVI After (Impact)	0.36	0.44	0.42	0.38	0.40
Mean NDVI After (Control)	0.40	0.46	0.41	0.41	0.50
Number of controls	5	5	5	5	5
Control areas management	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to livestock exclusion

Comparison of Revegetation & Livestock exclusion to Livestock Exclusion areas					
ID	**Zandvlakte 11**	**Zandvlakte 12**	**Zandvlakte 13**	**Zandvlakte 14**	**Zandvlakte 15**
GPS Coordinates	24.186875, -33.586165	24.191031, -33.5874	24.197205, -33.591427	24.194795, -33.610339	24.192479, -33.607073
Area (ha)	7.03	14.29	33.37	52.61	7.07
Year of intervention	Nov-10	November & December 2011	Dec-11	Jun-12	Feb-12
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	N/A	N/A	Low Spekboom stocking	Low Spekboom stocking
BACI results					
P-value	0.0250	0.2002	0.5085	0.2497	0.9668
Contrast	-0.02	-0.01	-0.01	0.01	-0.0004
Relative contrast	-4	-2	-2	3	0
Standard Deviation	0.02	0.01	0.02	0.01	0.01
Mean NDVI Before (Impact)	0.46	0.49	0.44	0.34	0.31
Mean NDVI Before (Control)	0.50	0.52	0.42	0.34	0.29
Mean NDVI After (Impact)	0.50	0.52	0.46	0.36	0.35
Mean NDVI After (Control)	0.52	0.54	0.43	0.37	0.33
Number of controls	5	5	5	5	5
Control areas management	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to livestock exclusion

Comparison of Revegetation & Livestock exclusion to Livestock Exclusion areas					
ID	**Zandvlakte 16**	**Zandvlakte 17**	**Zandvlakte 18**	**Zandvlakte 19**	**Zandvlakte 20**
GPS Coordinates	24.180857, -33.601794	24.170861, -33.595902	24.168532, -33.598405	24.16713, -33.595334	24.161471, -33.595819
Area (ha)	48.36	7.05	26.23	7.27	13.54
Year of intervention	Dec-10	Jan-12	Jun-10	Feb-12	Jun-10
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	Relatively successful	Low Spekboom stocking	Relatively successful	No Spekboom observed	Successful
BACI results					
P-value	0.2166	0.2430	0.0099	0.0024	0.4570
Contrast	-0.01	0.01	0.02	0.04	-0.01
Relative contrast	-2	2	6	12	-3
Standard Deviation	0.02	0.01	0.01	0.02	0.02
Mean NDVI Before (Impact)	0.42	0.45	0.33	0.34	0.37
Mean NDVI Before (Control)	0.36	0.41	0.33	0.34	0.32
Mean NDVI After (Impact)	0.44	0.52	0.32	0.39	0.37
Mean NDVI After (Control)	0.36	0.49	0.33	0.44	0.32
Number of controls	5	5	5	5	5
Control areas management	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to livestock exclusion

Comparison of Revegetation & Livestock exclusion to Livestock Exclusion areas					
ID	**Zandvlakte 21**	**Zandvlakte 22**	**Zandvlakte 23**	**Zandvlakte 24**	**Zandvlakte 25**
GPS Coordinates	24.161504, -33.598652	24.153681, -33.593862	24.151327, -33.591813	24.143157, -33.596273	24.141582, -33.599996
Area (ha)	40.30	26.45	26.01	26.46	7.39
Year of intervention	October & November 2011	Oct-11	Jun-10	Oct-11	Apr-12
Framework of intervention	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting	Large Scale Planting
Type of intervention	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting	Spekboom planting
Field mission evaluation	N/A	Relatively successful	Relatively successful	Relatively successful	Low Spekboom stocking
BACI results					
P-value	0.3626	0.9241	0.4406	0.8846	0.4897
Contrast	-0.01	-0.001	-0.01	-0.001	0.01
Relative contrast	-3	0	-3	0	3
Standard Deviation	0.01	0.01	0.02	0.01	0.01
Mean NDVI Before (Impact)	0.40	0.34	0.32	0.37	0.33
Mean NDVI Before (Control)	0.36	0.31	0.31	0.36	0.34
Mean NDVI After (Impact)	0.41	0.35	0.33	0.38	0.36
Mean NDVI After (Control)	0.36	0.32	0.31	0.38	0.37
Number of controls	5	5	5	5	5
Control areas management	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing	Closed to livestock grazing

Statistical results from the comparative analysis of revegetation & livestock exclusion to livestock exclusion

Comparison of Revegetation & Livestock exclusion to Livestock Exclusion areas	
ID	**Tchnuganoo**
GPS Coordinates	23.994865, -33.559216
Area (ha)	33.87
Aspect	North facing
Year of intervention	March & June 2015
Framework of intervention	Large Scale Planting
Type of intervention	Spekboom planting
Field mission evaluation	Low Spekboom stocking
BACI results	
P-value	0.1589
Contrast	-0.02
Relative contrast	-6
Standard Deviation	0.01
Mean NDVI Before (Impact)	0.36
Mean NDVI Before (Control)	0.34
Mean NDVI After (Impact)	0.31
Mean NDVI After (Control)	0.27
Number of controls	5
Control areas management	Closed to livestock grazing

Statistical results from the comparative analysis of livestock exclusion to non-restored

Comparison of Livestock Exclusion to Non-restored areas		
ID	**Zandvlakte**	**Tchnuganoo**
GPS Coordinates	24.167104, -33.638666	23.984959, -33.582005
Area (ha)	7508.57	615.63
Year of intervention	Jan-05 (Arbitrary)	Jan-05 (Arbitrary)
Framework of intervention	Research/Trial	Research/Trial
Type of intervention	Livestock Exclusion	Livestock Exclusion
Field mission evaluation	Successful	Successful
BACI results		
P-value	0.0941	0.5198
Contrast	-0.02	-0.01
Relative contrast	-4	-2
Standard Deviation	0.016723	0.015358
Mean NDVI Before (Impact)	0.39	0.37
Mean NDVI Before (Control)	0.39	0.39
Mean NDVI After (Impact)	0.39	0.35
Mean NDVI After (Control)	0.37	0.37
Number of controls	5	5
Control areas management	Open to livestock grazing	Closed to livestock grazing