Above Ground Carbon (AGC) baseline assessment, using species specific allometric models, across three degradation classes in Baviaanskloof Spekboom Thicket (BST)

May 2020

GEF – 5 SLM: Baviaanskloof component, South Africa

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Report information

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Suggested citation: Bolus, C., Harris, D., Reeler, J., Powell, M., Powell, R., Ngwenya, M. 2020. Above Ground Carbon (AGC) baseline assessment, using species specific allometric models, across three degradation classes in Baviaanskloof Spekboom Thicket. GEF-5 SLM, Rhodes University. Internal report.

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Date and place of release: May 2020, Cape Town.

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ACKNOWLEDGEMENTS

Thanks must be given to the Living Lands team of Otto Beukes, Melloson Allen, Justin Gird and Marijn Zwinkels for assisting with recruiting field assistants, access to site and field logistics. Living Lands was very supportive during the process. Mdoda Ngwenya was key in carrying out field sampling in thorny spekboom thicket conditions and terrain, with field assistants of Christo Witbooi, Hanton Winvogel, Mathew Statu, Prestiana Swarts, Hayward Mathews and Ryan van Wyngaardt. Mike Powell (Rhodes Restoration Research Group), Rebecca Powell, James Gambiza (Rhodes University), Dugal Harris and James Reeler assisted in planning and conceptualizing the study. Tony Dold (Schonland Herbarium curator and taxonomist) must be thanked for his assistance at the Schonland Herbarium, Rhodes University, Grahamstown. The Sewefontein trust and Tchnuganoo trust members must be acknowledged for their assistance with access to the sites and sharing local knowledge of the rough terrain. In addition the Department of Geography and Environmental Sciences at Stellenbosch and Department of Geography at Rhodes University must be thanked for the loan of their DGPS.

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ACRONYMS AND ABBREVIATIONS

AGC	Above ground carbon
ABC	Above ground biomass carbon
ABFRP	Addo Elephant National Park, Baviaanskloof Nature Reserve and Great Fish River Nature Reserve Restoration Project
ATB	Albany Thicket Biome
°C	Degrees Celsius
%	Percentage
<	Less than
>	Greater than
=	Equal to
~	Approximately
BGC	Below ground carbon
BST	Baviaanskloof Spekboom Thicket
C	Carbon
cm	Centimeter
DEA	Department of Environmental Affairs
DEA-NRM	Department of Environmental Affairs – Natural Resource Management Program
DGPS	Differential GPS
GIS	Geographic Information System
GPS	Global positioning system
ha	Hectare
ha^{-1}	Per hectare
ha^{-1} yr^{-1}	Per hectare per year
Kg	Kilogram
Log_{10}	Logarithmic value to the base of 10
m	Meter
m^2	Square meter
mm	Millimeter
n	Sample size
NRM	Natural Resource Management Programme
PD	Project Description
RRRG	Rhodes Restoration Research Group
SD	Standard deviation
SE	Standard error
SOP	Standard Operating Procedure
ST	Subtropical thicket
STRP	Subtropical Thicket Restoration Programme
TCS	Total carbon stocks
T	Ton
T C ha^{-1}	Tons of carbon per hectare
T C ha^{-1} yr^{-1}	Tons of carbon per hectare per year
V-C-S	Verified Carbon Standard

Executive summary

A carbon baseline assessment was done as part of the GEF-5 SLM Baviaanskloof restoration project in the Studtis area of the Baviaanskloof, Eastern Cape. The purpose of the baseline it to enable the securing of carbon credits through ecological carbon sequestration from the current restoration action on subtropical thicket. The carbon baseline assessment is required for the Project Description (PD) when going through a verification and validation process such as the Verified Carbon Standard (VCS under Verra). The carbon baseline assessment is required as a benchmark from which carbon gain can be measured.

A carbon baseline assessment (94 sample plots) of above ground carbon (AGC) stocks was done, which include above ground biomass carbon (ABC) and litter carbon on three degradation classes of Baviaanskloof Spekboom Thicket (BST). These were severely degraded, moderately degraded and pristine BST. Severely degraded sampling on BST was undertaken on the two trust-owned farms of Tchnuganoo and Sewefontein in the western Baviaanskloof. The sampling of moderately degraded and pristine BST, was done on the neighbouring privately-owned Dr Van der Watt farm and contributed data toward the development of a simplified remote sensing methodology for future monitoring of AGC stocks (Harris *et al.* 2019). Species specific allometric models developed by van der Vyver & Cowling (2019) were used to calculate ABC.

The results showed the following for the three BST degradation classes:

Degradation class (BST)	ABC t ha^{-1}	Litter t C ha^{-1}	AGC t ha^{-1}
Severely degraded	6.17 (SE: 0.64)	1.85 (SE: 0.43)	8.02 (SE: 0.90)
Moderately degraded	14.47 (SE: 1.27)	4.17 (SE: 0.43)	18.63 (SE: 1.43)
Pristine	21.39 (SE: 1.11)	9.57 (SE: 0.71)	30.95 (SE: 1.44)

There was a difference of ~22 t C ha^{-1} between the AGC of severely degraded and pristine BST. *Portulacaria afra* (Spekboom) incidence was found to be minimal in the severely degraded areas, while it was found in abundance in the pristine BST, as to be expected. Spekboom is a keystone species which is planted as truncheons in restoration efforts. The carbon baseline assessment illustrates the carbon depletion of BST in the severely degraded landscapes of the Baviaanskloof, and shows the potential to gain ~22 t C ha^{-1} of AGC with successful restoration action.

A number of species dominated the carbon of the different degradation classes of the Baviaanskloof Spekboom Thicket (BST). The table below show the species which contribted more than 50% of the ABC together, within each degradation class.

Degradation classes (BST)	Severely degraded	Moderately degraded	Pristine
Species which together contributed to over 50% of ABC	• *Pappea capensis* • *Searsia longispina* • *Pteroni incana*	• *Euclea undulata* • *Portulacaria afra* (spekboom) • *Putterlickia pyracantha* • *Searsia longispina*	• *Portulacaria afra* (spekboom) • *Euclea undulata*

Spekboom contributed the highest ABC in the pristine BST class at 29 % (6.19 t C ha^{-1}) followed by moderately degraded BST at 13 % (1.83 t C ha^{-1}). The spekboom was minimal on the severely degraded sites with 1.13 % (0.07 t C ha^{-1}) contribution to ABC stocks in this class.

1 Introduction

1.1 CLIMATE CHANGE AND RESTORATION AS A UNEP FOCUS

There is a pressing and global need to address climate change as called on by the United Nations Environmental Programme[*]. Concurrently there is a global need to address degradation through restoration[†] to protect biodiversity and bolster essential ecosystem services. The GEF5 Sustainable Land Management (SLM) project aims to contribute to addressing these global problems, with local impacts, through the restoration of degraded subtropical thicket (part of the Albany Thicket Biome) and the sequestration of ecological carbon with the overall aim of Sustainable Land Management (SLM).

The COP21 of the United Nations Framework Convention on Climate Change was held in Paris in December 2015. Leading up to the meeting, countries set out their Intended Nationally Determined Contributions (INDCs) to address the issue of climate change. These were then formalised into Nationally-determined contributions with the signature and later ratification of the Paris Agreement arising from this meeting. The Paris Agreement creates the opportunity and stimulus for new mechanisms to be developed so that South Africa can contribute to the target of keeping global warming to below 2 degrees[‡]. In 2019 the South African Carbon Tax Bill was signed into law (Republic of SA 2019), and creates the potential mechanism for a local carbon market to assist South Africa in meeting its NDCs (Reeler 2018).

The UN Environment Programme proposes that restoration should be a key component for both mitigation of and adaptation to climate change[§], and has declared 2021 to 2030 the UN Decade of Ecosystem Restoration. The GEF5 SLM project was started in the western Baviaanskloof, Eastern Cape, in 2017 with the aim of implementing and supporting SLM. One of the outcomes is to restore degraded subtropical thicket and sequester carbon with the aim of validating the carbon sequestered so that the carbon credits can potentially be sold in the local or international carbon market (Reeler 2018). Studies have shown that there is potential to sell carbon credits gained from spekboom thicket restoration on carbon markets (Marais *et al.* 2009, Purnell & Mills 2015), but that the returns are not universally large. This could contribute to much needed local income streams and support local ecological and agricultural sustainability. There are both regenerative agricultural initiatives and conservation initiatives in the Baviaanskloof area, with private and communal land owners (as per comms Beukes 2018).

[*] https://www.unenvironment.org/explore-topics/climate-change

[†] https://www.unenvironment.org/news-and-stories/press-release/un-environment-and-partners-show-global-restoration-success

[‡] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

[§] https://www.unenvironment.org/news-and-stories/press-release/new-un-decade-ecosystem-restoration-offers-unparalleled-opportunity?_ga=2.125638282.1490425219.1574843223-1009315574.1574843223

1.2 SUBTROPICAL THICKET RESTORATION AND CARBON SEQUESTRATION

Spekboom thicket found in the Baviaanskloof is a form of subtropical thicket, which is part of the Albany Thicket Biome (Hoare *et al.* 2006) and holds a wide diversity of succulent, forb and shrub species (Vlok & Euston-Brown 2002). Spekboom thicket (ST) in this study will refer to the *Portulacaria afra* (spekboom)-rich subtropical thicket types found in the Albany Thicket Biome (ATB). Subtropical thicket has been severely degraded by historical over grazing, in many areas of its domain (Lloyd *et al.* 2002, Lechmere-Oertel 2003) with less than 10% still considered intact or pristine (Lechmere-Oertel 2003); hence the need for restoration efforts. Degraded succulent thicket leads to a reduced ability for ST ecosystems to harvest water, cycle carbon and leads to large loss in organic carbon (Lechmere-Oertel 2003). The proportion of the landscape which promotes infiltration can be reduced from 60% to 0.6% in degraded thicket landscapes (Lechmere-Oertel 2003). This has a significant impact on the ecological functionality of subtropical thicket, and many potential consequences for sustainable land management and land productivity.

Spekboom is a keystone species (Lechmere-Oertel 2003) in spekboom thicket and it also has the potential to stimulate biodiversity recovery, as it acts as an 'ecosystem engineer' (van der Vyver *et al.* 2013). Considerable research has shown the potential for spekboom to sequester carbon in subtropical thicket (Mills *et al.* 2005 a & b; Mills & Cowling 2006 & 2014, van der Vyver *et al.* 2013). There are significant carbon stocks in pristine subtropical thicket both below (in soils) and above ground (van der Vyver & Cowling 2019). Much of the carbon can actually be below ground in the soils- up to 93 (SE: 7) t C ha^{-1} (Mills & Cowling 2010). However there are substantial stocks above ground too with a potential gain of 30 t C Ha^{-1} that can be achieved after 25 to 30 years of restoration action (van der Vyver & Cowling 2019). The rate of carbon sequestration can be variable across the ATB and is still being researched but 2.3 t C ha^{-1} yr^{-1} (AGC) is achievable under the right habitat conditions (van der Vyver & Cowling 2019).

A number of restoration efforts of spekboom thicket have been implemented, with the largest being the Addo Elephant National Park, Baviaanskloof Mega Reserve and Great Fish River Nature Reserve Restoration Project (ABFRP), implemented by the Department of Environmental Affairs – Natural Resource Management Program (DEA-NRM) (Mills *et al.* 2015). The varied levels of success of these restoration efforts has demonstrated the challenges of thicket restoration, with factors such as planting method (van der Vyver 2018, Mills *et al.* 2015) as well as ecological factors such as frost (Duker *et al.* 2015) needing to be taken into account.

Planting spekboom is one method for restoring subtropical thicket. There are also other restoration efforts which can support restoration such as erosion control measures and water interception with small ponds which are being implemented by Living Lands (as per comms Beukes 2018). Planting other thicket species is considered difficult and possibly un-economical (van der Vyver *et al.* 2012), however there is further research into planting other thicket species for spekboom thicket restoration which may yield results (as per comms Powell 2019, Beukes 2018). The ABFRP has been restoring degraded thicket since 2007 using spekboom truncheons with mixed success (Mills *et al.* 2015). They have also completed extensive carbon baselines assessment and have produced a Project Design (PD) document (Reeler *et al.* 2011) for validation. There are several smaller projects which are involved in the restoration of spekboom thicket for carbon sequestration, such as the Jobs for Carbon project under the Gouritz Cluster Biosphere Reserve, in the Klein Karoo (Bolus *et al.* 2016).

1.3 CARBON BASELINES AS A CONTRIBUTION TO THE GEF-5 SLM

This study contributes to the GEF – 5 SLM Baviaanskloof component outcome 3.2 (“Carbon baseline sampling and assessments undertaken for 200 hectares in the Baviaanskloof”) of the GEF-5 SLM (“Securing multiple ecosystems benefit through SLM in the productive but degraded landscapes of South Africa”) project.

A carbon baseline assessment is required to assess the carbon stocks before restoration is done to enable the monitoring of carbon sequestration over time. This study uses the standard operating procedures (SOPs) developed for the Addo Elephant National Park, Baviaanskloof Mega Reserve and Great Fish River Nature Reserve Restoration Project (ABFRP) (DEA 2010) as a basis for the baseline assessment. This was used as part of the Project Document (Reeler *et al.* 2011) developed for verification of carbon sequestration through V-C-S (Verified Carbon Standard under VERRA)[**]. The SOPs are informed by the Clean Development Mechanism (CDM) methodology AR-ACM-0003, Afforestation and reforestation of lands except wetlands - Version 2.0 [††] (CDM 2013). Using the carbon baselines SOP, carbon sequestered through the planting of spekboom can be quantified and carbon credits can potentially be obtained and sold by following the verification processes (Reeler 2018).

1.4 THE NEED FOR NEW SIMPLIFIED MONITORING METHODOLOGIES

The process of project development and validation of a carbon project can be expensive using the CDM and VCS standards potentially costing over a million Rands (~$68280 @R14.65 to 1$) (Reeler 2018). A substantial component of the cost is carbon baseline monitoring. This is because extensive field work must be done, on the ground to measure carbon stocks in woody biomass, litter, deadwood, and below ground in the soil if this carbon pool is to be monitored. Therefore there is a vital need to find more simplified and cost effective methods of monitoring, so that carbon assessments can be affordable, especially for smaller projects where local farmers and NGOs are involved. This study supported the development of a simplified method by Harris *et al.* (2019), using satellite imagery, for assessing above ground biomass carbon (ABC) stocks. Soil carbon monitoring still requires further research and development to create a simplified methodology for the Albany Thicket Biome for below ground carbon (BGC) stocks.

[**] https://verra.org/project/vcs-program/

[††] The methodology for this project is the CDM methodology AR-AM0003 v2: It can be downloaded from https://cdm.unfccc.int/methodologies/DB/C9QS5G3CS8FW04MYYXDFOQDPXWM4OE .

1.5 PROJECT GOALS

The project goals for this study were as follows:

a) Complete carbon baselines assessments on two trust-owned farms in the western part of the Baviaanskloof, Eastern Cape Province, where restoration is taking place on severely degraded spekboom thicket, as part of the GEF SLM Baviaanskloof component (3.2a).
b) Sample on moderately degraded and pristine spekboom thicket for the development of a simplified carbon assessment methodology using satellite imagery by Dugal Harris (see Harris *et al.* 2019).

2 Study site

2.1 LOCATION

The carbon baseline sample sites are located near Studtis in the western part of the Baviaanskloof in the Sarah Baartman district, Eastern Cape, South Africa (Figure 1). The study areas are in an agricultural area adjacent to the Baviaanskloof Mega Reserve, on its western side. The location of the restoration sites, done on three farms for this study, are ~77 km by road to the South East of Willomore along the R332, which is the nearest town (33° 32’ 51.3” S, 23° 58’ 12.9” E or lat: - 33.549141, long: 23.969420).

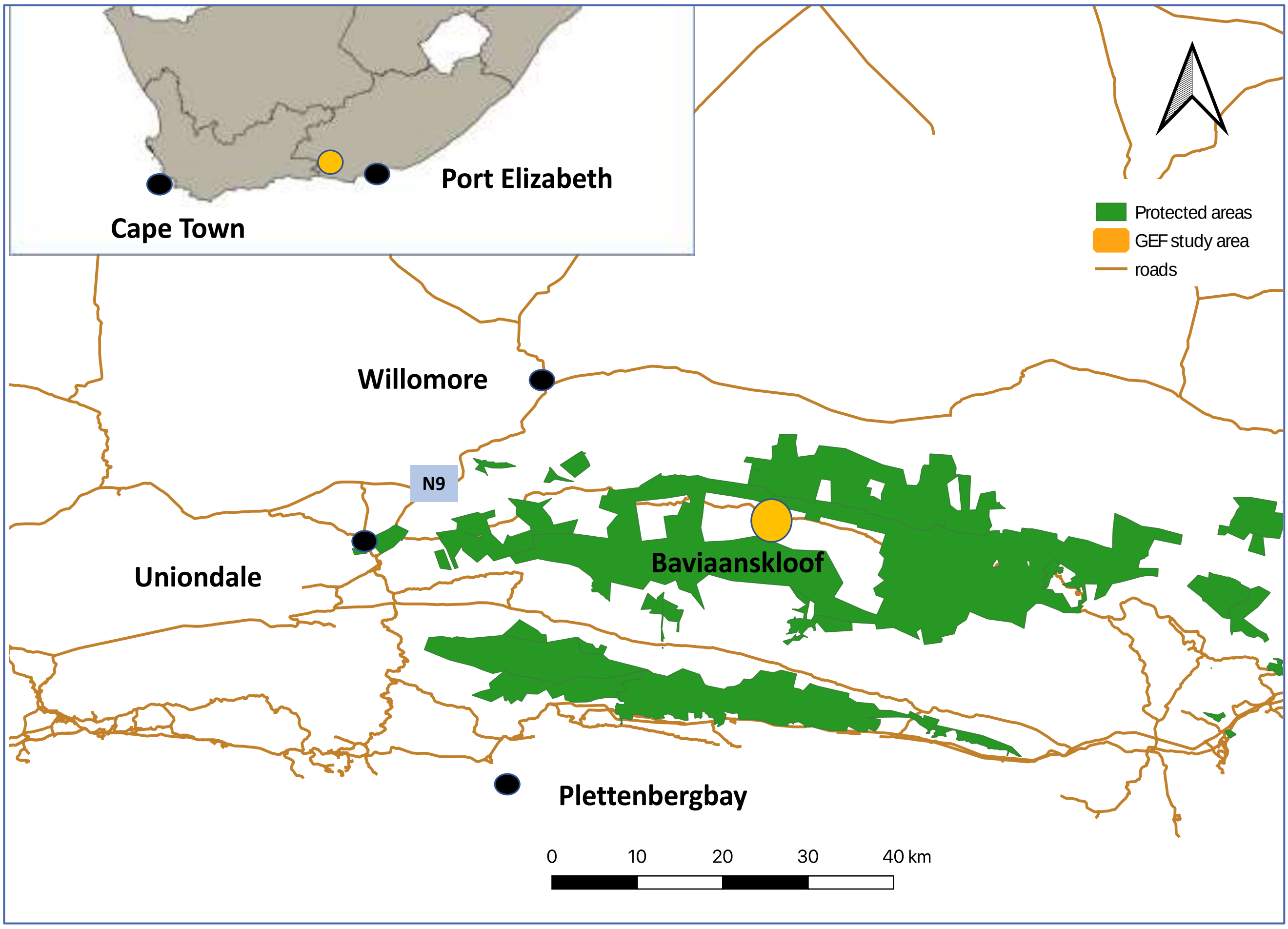

Figure 1 The site location of the GEF – 5 SLM project in the Eastern Cape Province, South Africa.

The Baviaanskloof municipality has a population of approximately 17761[‡‡], of which the sparsely populated western Baviaanskloof makes up a small fraction of this. The western Baviaanskloof is faced with the two major challenges of weak rural economic development and ecological degradation from historical land use – challenges common to many rural arid areas in South Africa (Meadows & Hoffman 2002). The main economic activities are agriculture (livestock farming and irrigated arable farming) and tourism.

[‡‡] https://census2011.adrianfrith.com/place/267

2.2 CLIMATE, TOPOGRAPHY AND GEOLOGY

The Baviaanskloof experiences high seasonal and daily temperature fluctuations with maximum annual temperatures reaching up to 44 °C, and a difference of up to 28°C between night and day time temperatures (Eastern Cape Parks 2009). The mean annual temperature is 17°C (van Luijk *et al.* 2013), while the mean annual rainfall is 451 mm; total rainfall decreases towards the west of the Baviaanskloof in summer. In the Studtis area the mean annual rainfall is just over 300 mm per annum, with the last few years recording well below this level (as per comms Beukes 2018). Rainfall is spread out evenly throughout the year with peaks in spring and autumn (Powell 2009). The Baviaanskloof river runs in a south easterly direction within the Baviaanskloof valley, and is surrounded by steep mountains on either side reaching an average of over 1200m in height above sea-level (Eastern Cape Parks, 2009).

These mountains are made up of Table Mountain quartzites which are erosion resistant (Powell 2009), whilst the valleys are typified by Bokkeveld shales. The dominant formations found in the Table Mountain Group in the Baviaanskloof are the Peninsula, Skurweberg and Goudini Formations (Euston-Brown 1995). Enon Conglomerates are also found which consist of densely packed pebbles in a sandy matrix (Powell 2009). The Bokkeveld shales produce nutrient rich soils in comparison to the nutrient poor soils derived from the Table Mountain quartzites (Vlok 1989). Due to the high variation of geology in the Baviaanskloof soils are varied and therefore include Ferralsols, Cambisols and Leptisols (Mills & Cowling 2010).

2.3 BIOMES AND VEGETATION

The Baviaanskloof has a number of intersecting biomes: the Fynbos Biome, Albany Thicket Biome, Forest Biome, Grassland Biome, Savanna Biome, Succulent Karoo and Nama-Karoo Biome (East Cape Parks, 2009). Spekboom is found in natural abundance in this region in the xeric forms of the intact Albany Thicket Biome which stretches from the Eastern Cape into the Western Cape.

The study site has two forms of spekboom thicket : Baviaanskloof Spekboom Thicket (BST) and Groot Arid Spekboomveld (Euston-Brown 2006). The study takes place in Baviaanskloof Spekboom Thicket vegetation. The vegetation map developed by Euston-Brown 2006 (Figure 2), relied on and integrated previous mapping done by (Vlok *et al*, 2005), mapping products of the STEP project (Vlok & Euston-Brown 2002, Vlok *et al.* 2003), previous botanical studies and mapping exercises done in the planning domain (Vlok 1989; Euston-Brown 1995a,b & 2000) as well as the vegetation map of South Africa (Mucina *et al*, 2005) and Cowling (1984).

From the (Euston Brown 2006) study **Baviaanskloof Spekboom Thicket** is distinguished by the abundance of *Portulacaria afra, Aloe speciosa, Panicum maximum, Cenchrus ciliaris, Pappea capensis, Putterlickia pyracantha, Schotia latifolia, Stipa dregeana subsp dregeana.* ***Groot Arid Spekboomveld*** is found in the more arid and colder tolerance limit of spekboom and has indicator species of *Euclea undulata, Cadaba aphylla, Gymnosporia polyacantha, Gymnosporia szyszyowiczii, Euphorbia* species (non-arborescent), *Crassula ovata, Atriplex subsp. inflata*, *Rhigozum obovatum* and *Portulacaria afra*. These two thicket types both fall under the **Groot Thicket** vegetation type in Muscina & Rutherford (2006).

The Baviaanskloof Spekboom Thicket (Figure 2) in which the carbon assessment took place is largely found on the northern aspect of the hill slopes, which grades into the Baviaanskloof Thicket Savanna and Groot Woodland found along the Baviaanskloof river. The Groot Arid Spekboomveld is found nearby toward the east in areas which have been historically grazed and are dryer. **Baviaanskloof Thicket Savanna** has indicator species of *Acacia karoo, Cenchrus ciliaris, Celtis africana, Rhus tomentosa, Plumbago auriculate* and *Lycium* species while **Groot Woodland** has indicator species of *Loxostylis alata, Passerina falcifolia, Aspalathus kougaensis, Euphorbia grandidens, Smellophyllum capense, Pittosporum viridifolium, Cussonia spicata, Streptocarpus zeyherii, Protea nitida, Nerine humilis, Agathosma* species, *Haworthia* species, *Haemanthus* species, *Agathosma puberula, Leucadendron nobile, Protea lorifolia and* contains a number of endemic species (Euston Brown 2006).

On the upper plateau to the south, **Kouga Grassy Fynbos** is found and its ecology is significantly influenced by fire. Rainfall also tends to increase higher up in the mountains where the fynbos biome is found. Recent fires in the Kouga burnt large tracts of the fynbos up to the BST edge. Indicator species for Kouga Grassy Fynbos are *Pentachistis eriostoma, Merxmuellera arundinaceae, Themeda triandra, Cymbopogon marginatus, Hypodiscus striatus, Rhodocoma fruticosa, Restio triticeus, Ischyrolepis gaudichaudiana, Protea nitida, Protea tenax, Erica cerinthoides, Erica simulans, Erica demissa, Leucadendron salignum, Leucadendron nobile, Leucospermum cuneiforme, Agathosma mucronulata, Muraltia juniperifolia* and *Pinus pinaster* (Euston Brown 2006).

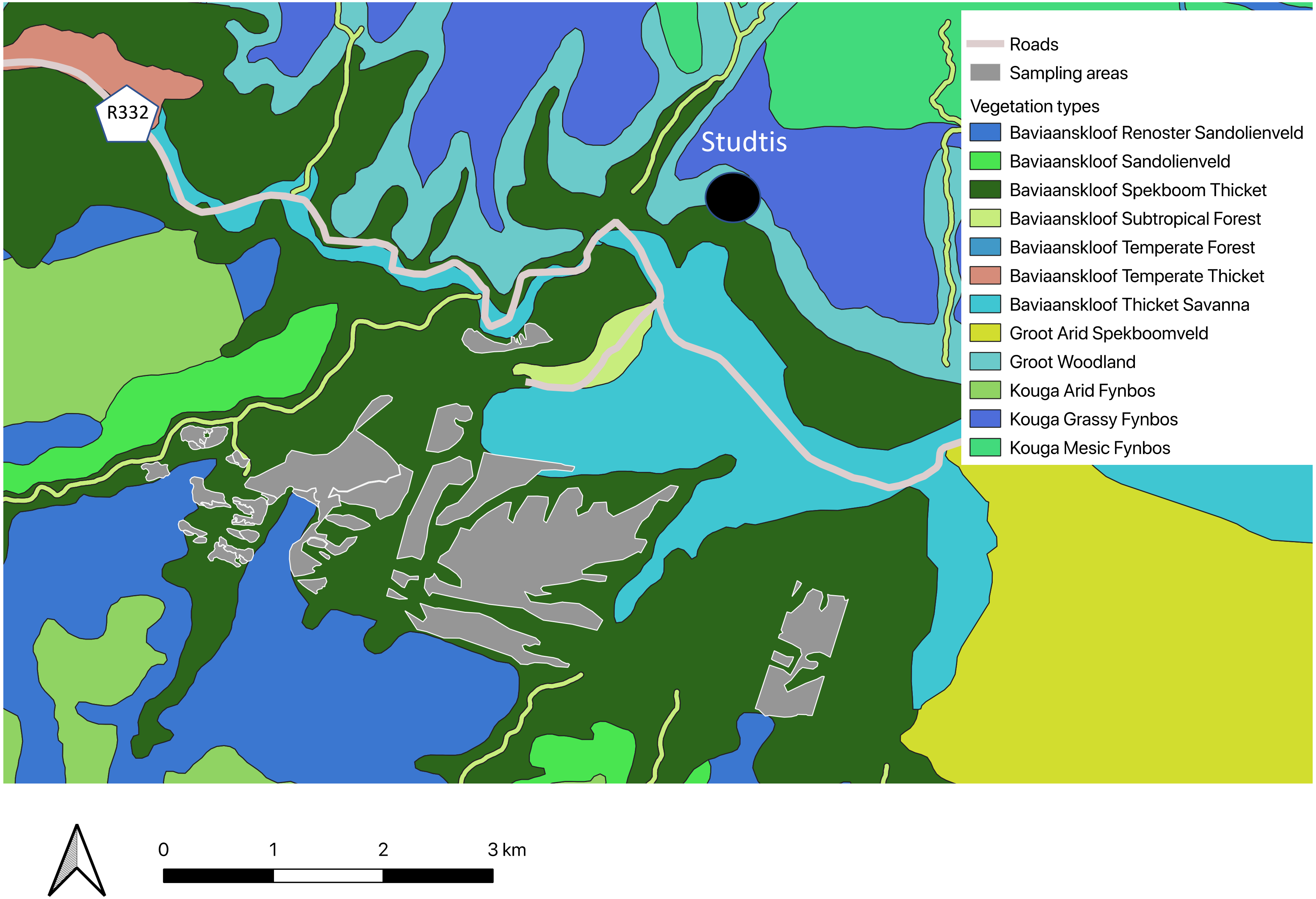

Figure 2 The vegetation types from (Euston-Brown 2006), surrounding the areas sampled. The sampling took place in Baviaanskloof Spekboom Thicket (BST).

3 Methodology

A project-specific SOP was developed (Bolus *et al.* 2018) for the carbon baseline assessment based on the Addo Elephant National Park, Baviaanskloof Mega Reserve and Great Fish River Nature Reserve Restoration Project (ABFRP) – Standard Operating Procedure (DEA 2010) and from the Clean Development Mechanism (CDM) methodology AR-ACM-003, Afforestation and reforestation of lands except wetlands - Version 2.0[§§].

3.1 MAPPING AND RANDOM PLOT ALLOCATION

Sampling was done in three degradation classes namely severely degraded, moderately degraded and pristine Baviaanskloof Spekboom Thicket (BST). The severely degraded BST areas were identified and mapped by Regalis Environmental Services using the expertise of the ecologist and botanist, Jan Vlok (Vlok 2017). These areas would have had an estimated spekboom cover of 30 - 50% (Vlok 2017). Moderately degraded and pristine BST areas on the Dr Van der Watt farm were mapped by Dugal Harris (Harris 2017) based on vegetation density, using WorldView-3 imagery, and within the Vlok (2010) BST boundaries. See figure 3 for examples of the three degradation classes of BST.

Carbon baseline sampling plots were randomly allocated according to the methodology across the severely degraded BST areas on the farms of Sewefontein and Tchnuganoo, which are to be restored by Living Lands (Figure 4). Random plots were also allocated on the moderately degraded and pristine BST on the Dr Van der Watt farm. This was done using a Geographical Information System (GIS) random allocation tool. If a plot was unable to be sampled due to the reasons listed in the SOP (DEA NRM 2010), then it was excluded, and the next numerical plot was sampled so as to avoid bias or skewing the results. Reasons for excluding plots include plot placed in the wrong vegetation type (e.g. Fynbos ecotone), plot placed on a cliff face (steep access) or plot placed on an access road.

[§§] The methodology for this project is the CDM methodology AR-AM0003 v2: It can be downloaded from https://cdm.unfccc.int/methodologies/DB/C9QS5G3CS8FW04MYYXDFOQDPXWM4OE .

Figure 3 An example of the three Baviaanskloof Spekboom Thicket (BST) degradation classes of pristine (top left), moderately degraded (top right) and severely degraded (bottom) (photo credit: Ngwenya, M)

3.2 BAVIAANSKLOOF SPEKBOOM THICKET (BST) AREAS WHICH WERE SAMPLED

Sampling was done on the three different farms namely Tchnuganoo, Sewefontein and Dr Van der Watt farms (see Table 1 and Figure 4). A total of ninety four plots were sampled across severely degraded, moderately degraded and pristine BST.

Tchnuganoo is a farm owned by a trust and has severely degraded BST. The Tchnuganoo potential restoration area of BST makes up a total of ~45 hectares (Table 1). **Sewefontein** is a farm owned by a trust and has the largest area of severely degraded BST of the farms sampled with a total of potential restoration area of ~228 hectares. The privately owned **Dr Van der Watt farm** was also sampled as it has significant areas of moderately degraded (~29 ha) and pristine (~ 68 ha) BST which were mapped and accessible for sampling.

Table 1 The number of plots sampled and areas mapped of the three degradation classes of BST.

Degradation class (BST)	Farm	Number of plots sampled	Size of mapped area (ha)
Severely degraded	Tchnuganoo	15	~45
Severely degraded	Sewefontein	20	~228
Moderately degraded	Dr Van der Watt	29	~29
Pristine	Dr Van der Watt	30	~68
	Total	**94**	

Thirty five plots were sampled for the severely degraded BST baseline (see Appendix 7.1 for GPS points), twenty nine plots for the moderately degraded BST, and thirty plots for the pristine areas (see Appendix 7.2 for GPS points) .

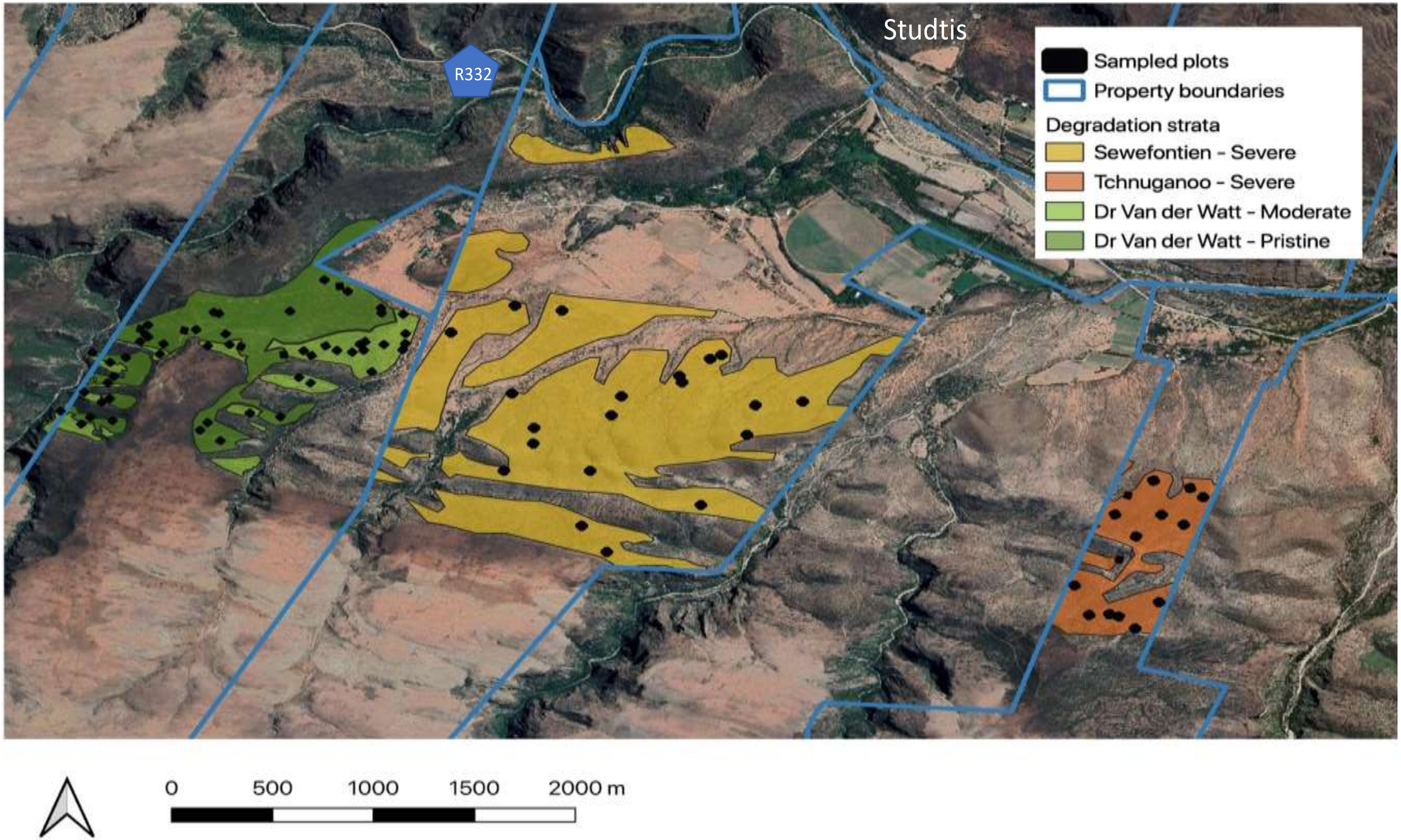

Figure 4 The above ground carbon (AGC) baseline plots, in the three degradation classes, across the different sites sampled.

3.3 FIELD TRIAL TO DEVELOP SOP

A field trial was conducted to assess the DEA-NRM SOP (DEA 2010) in BST so that it could be further developed for more efficient sampling and so that the number of plots sampled could be maximized with the available manpower and budget (see Harris 2019). Three plots were tested on the pristine spekboom thicket sites and two plots on the severely degraded sites. This sampling effort was evaluated for each of the SOP carbon pools namely, above ground biomass carbon (ABC), litter, deadwood and soil carbon (Harris *et al.* 2019).

From the field trial it was concluded that deadwood would not be measured as a carbon pool as its contribution to total carbon versus the labour to measure all deadwood was not efficient based on the available budget (Harris *et al.* 2019). Soil carbon sampling was deemed too expensive to measure, given the limited budget and current carbon credit price (Reeler 2018), and was also excluded. It is important to note that under the proposed carbon methodology, a standardised (non-sampling) means of assessing accrual of soil carbon exists. Due to the conservative estimates within this tool, the accumulation of carbon would be underestimated, but at present the return obtained on additional soil sampling would not underwrite the cost of such sampling.

It was considered most efficient to sample a plot size of 10 x 10 m for moderately degraded and pristine BST sites, and 20 x 20 m plots for severely degraded BST sites. Larger plots were deemed necessary for the severely degraded plots to obtain sufficient sampling because degraded sites can have very low vegetation cover and carbon. A nested plot of 5 x 5 m (within each plot) was used to measure all woody trees and shrubs (including succulent trees and shrubs) for all heights, while only plants > 50 cm in height would be measured in the rest of the plot. This was found to be efficient for sampling and representative of the ABC stocks.

3.4 FIELD SAMPLING USING THE DEVELOPED SOP

Using the developed SOP (Bolus *et al.* 2018), a further eighty nine random plots were sampled on severely degraded (33), moderately degraded (29) and intact spekboom thicket (27) areas that are being restored. At each site the following was done:

1. Plot setup (Figure 5).
2. Fixed point photography – 5 m diagonally away from each corner (Appendix 7.4-7.7).
3. Above ground biomass (ABC) measurement which included living tree and shrub (including succulents) measurement.
4. ABC sampling was done within 10 x 10 m plot size (moderately degraded and pristine sites) and 20 x 20 m plot sizes (severely degraded sites). This was done for plants of > 50 cm in height.
5. Nested ABC sampling (5 x 5m), within the plot, at the SW corner to measure relevant plants of all heights.
6. Litter monitoring within four 50 x 50 cm quadrants (H1-4), 1 m diagonally away from each plot corner.
7. DGPS marking of four permanent corner pegs.

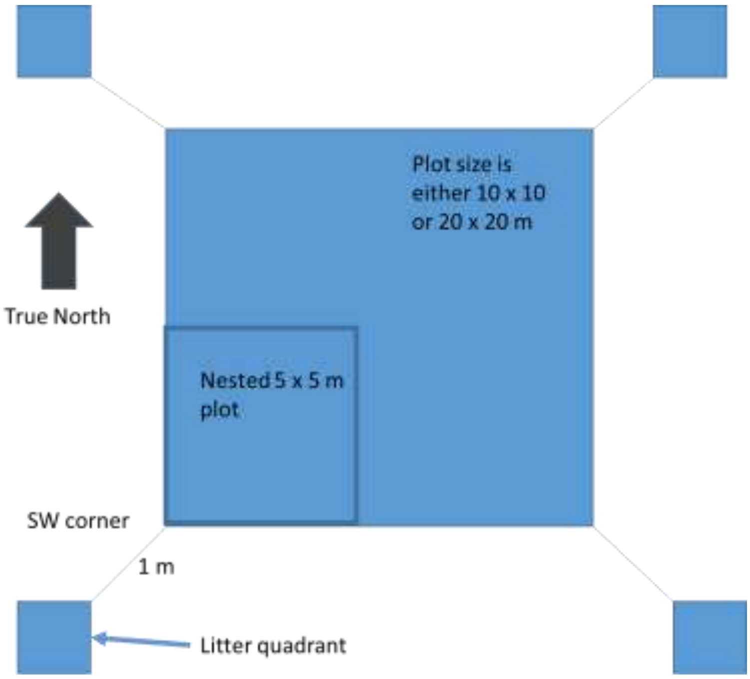

Figure 5. The plot layout has four litter quadrants 1 m diagonally away from each corner point. A 10 x 10 m plot is setup for pristine and moderately degraded BST sites while a 20 x 20 m plot is setup for severely degraded sites.

3.4.1 Above ground biomass carbon (ABC)

For ABC, the living trees and shrubs (including succulent trees and shrubs) were measured within the 10 x 10 m (moderately degraded and pristine BST) monitoring plot areas, for plants > 50 cm in height (see Figure 6). A nested plot of 5 x 5 m was placed in the SW corner of the plot to measure trees and shrubs (including succulent trees and shrubs), of all heights. In the case where there were two plants growing close to each other a rope was used to define the intersection of the fringes. This allows the separation of plants and their respective canopies to be measured. Plants were categorized according to the guilds based on thicket architecture (van der Vyver & Cowling 2019) which they fell into, namely Large Canopy Dominant (LCD), Other Canopy Dominant (OCD), Dwarf Shrubs (DS) and Shrubs.

Variables that were recorded were: plant height (cm), canopy width (cm) and canopy length (cm). Stem length up to base of rosette for *Aloe speciosa* (cm) according to requirements for allometric measurements from van der Vyver & Cowling (2019).

Figure 6. Left: Christo Kleinbooi and Mathew Statu measuring plant height, canopy width and canopy length, on severely degraded BST lands on Tchnuganoo in the Baviaanskloof. Right: Mdoda Ngwenya taking DGPS measurements of a plot in pristine BST (photo credit: Bolus, C).

3.4.2 Botanical sample collection and identification

A sample of the plant in the plot (a small branch with leaves, and a flower if available) was taken for each plant species measured. The botanical samples were labelled (Bolus 2018) and then pressed to be preserved for archiving, and further species identification if needed. Pressed botanical specimens are stored at the Rhodes Restoration Research Group (RRRG) in Grahamstown. A photo of the plants was also taken, ensuring that any distinguishing characteristics were clearly visible. These were then archived. Plants were identified to at least genus level using source books, where possible. Additional cross referencing of the identified species was done at the Schonland Herbarium, Rhodes University, Grahamstown with the help of Tony Dold (Schonland Herbarium curator and taxonomist) to get species level identification where possible. Ninety nine different plants were collected and measured in the field. Of these seventy eight plants were identified to species level. Sixteen were identified to genus level and five species could not be identified at all; these samples had no distinguishing characteristics due to the dry season dehydration. All species were classified into one of four guilds: Large Canopy Dominant (LCD), Other Canopy Dominant (OCD), Dwarf Shrubs (DS) and Shrubs.

3.4.3 Litter sampling and drying

Litter sampling was conducted within the four 50 x 50 cm quadrants (Figure 5). All ground litter (leaves, fruits, small wood ≤ 5 cm in diameter) falling inside and intersecting the four 50 x 50 cm frames was collected (see Figure 7). The four samples were pooled per plot, and the litter collected from the field was dried to constant mass at 60 °C and weighed.

<u>Variables that were recorded were: wet litter mass (g), and dry litter mass (g).</u>

Figure 7 Left: an example of litter found under a spekboom canopy in pristine BST. Right: Ryan Wyngaardt collecting litter in a 0.5 x 0.5 m quadrant in moderately degraded BST (photo credit: Bolus, C).

3.4.4 Quality control and assurance procedures applied

All personnel involved in the baseline monitoring were trained adequately in the methodology to ensure accurate data collection. All data were entered by qualified persons. Data captured were quality controlled and checked for errors against the original sheets. Data errors were checked by a qualified ecologist. Where errors were observed, measurements on the samples were re-done and the errors corrected.

A field inventory was completed in order to ensure that no samples were lost between the field and the warehouse laboratory. Datasheets were scanned as a backup of the data. An inventory of the samples was also done at the warehouse to confirm that all samples had been stored correctly.

3.5 DATA ANALYSIS

3.5.1 Above ground biomass carbon (ABC)

Species specific allometric models from van der Vyver & Cowling (2019) (Table 2) were used to calculate the carbon in the measured plants. The data analysis relied on van der Vyver & Cowling (2019) allometric models as most recent and comprehensive research published to date, covering a broad list of spekboom thicket species. The allometric models employ canopy dimensions and plant height to estimate plant biomass; this is much easier to measure than basal stem diameter for stem-rich and often impenetrable thicket vegetation.

From van der Vyver & Cowling (2019:p14) the following is explained about how to use the Table 2 allometric models to get ABC:

> 'The x variable (Table 2) is the x predictor variable where, Hgt/H = plant height (cm), CD = mean crown diameter, CD.H = CD.Hgt, CA.H = $\pi(CD/2)^2$, and SL = stem length up to base of rosette for *Aloe speciosa*.
>
> To get an individual estimate use the power function $Y_n = a.x^b$, and substitute a = exp (log(a)) and b (Table 2).
>
> This estimate, naïve y (Y_n) can be corrected following Nickless *et al.* (2011) and Zou *et al*. (2009) to derive corrected Y_c with $Y_c = \exp(\ln(Y_n) + \sigma^2/2)$. The lower (LC) and Upper confidence limits (UC) can be obtained by multiplying Y_c with the tabled LC and UC values.
>
> *Models are based on dry weight instead of freshly felled weight (no need for applying a dry:wet ratio)'

Dry biomass is then converted to carbon content using the multiplication factor of 0.48 (Lamlom & Savidge 2003).

Table 2 Table of values used to calculate ABC, using species specific allometric models from van der Vyver & Cowling (2019). * = no need for applying a dry:wet ratio.

Species	x.var	r2	log (a)	b	σ	LC	UC
Aloe speciosa	CA.SL	0.85	-13.31	1.1	0.72	0.3	3.36
Aloe striata	Hgt	0.74	-6.53	1.79	0.8	0.26	3.85
Asparagus capensis	CD	0.85	-12.07	2.33	0.55	0.4	2.5
Azima tetracantha	CA.H	0.95	-15.63	1.15	0.36	0.55	1.81
*Blepharis capensis**	CA.H	1	-11.36	0.78	0.18	0.75	1.34
Boscia oleoides	CA.H	0.81	-18.89	1.33	0.39	0.52	1.91
Brachylaena ilicifolia	CD.H	0.96	-17.13	1.79	0.28	0.63	1.58
Capparis sepiaria	CD	0.89	-10.48	2.4	0.4	0.52	1.94
Carissa haematocarpa	Hgt	0.93	-15.86	3.75	0.33	0.58	1.72
Cotyledon velutina	CD	0.83	-7.88	2.17	0.37	0.54	1.84
Crassula mesembryanthemoides	CD	0.75	-7.62	1.62	0.42	0.49	2.02
Crassula muscosa	CA.H	0.97	-9.71	0.77	0.26	0.66	1.53
*Crassula ovata**	CD.H	0.87	-14.92	1.62	0.9	0.21	4.65
Crassula perforata	CD.H	0.98	-10.65	1.27	0.25	0.67	1.5
Drosanthemum lique	CD	0.93	-13.59	3.05	0.52	0.42	2.38
Ehretia rigida	CD.H	0.99	-13.18	1.43	0.13	0.81	1.24
Euclea undulata	CD	0.95	-11.28	2.6	0.42	0.5	2.01
Euphorbia coerulescens	CA.H	0.97	-8.95	0.88	0.4	0.52	1.93
Euphorbia mauritanica	CD.H	0.6	-10.06	1.17	0.64	0.34	2.95
Euphorbia triangularis	Hgt	0.98	-15.19	3.18	0.35	0.56	1.79
Galenia filiformis	CD	0.74	-12.27	2.52	0.58	0.38	2.63
Grewia robusta	CD	0.91	-11.87	2.66	0.35	0.56	1.78
Gymnosporia polyacantha	CA.H	0.99	-15.41	1.14	0.3	0.61	1.64
Jathropa capensis	CA.H	0.72	-13.23	0.97	0.48	0.45	2.22
Lycium cinereum	CD.H	0.95	-9.18	1.04	0.3	0.61	1.65
*Lycium ferocissimum**	CD.H	0.66	-7.48	0.85	0.77	0.27	3.68
Malephora lutea	CA.H	0.93	-7.47	0.67	0.31	0.6	1.66
*Panicum maximum**	CD	0.85	-12.34	2.42	0.55	0.4	2.49
Mesembryanthemum guerichianum	Hgt	0.98	-7.46	1.73	0.08	0.87	1.15

Species	x.var	r2	log (a)	b	σ	LC	UC
Pappea capensis	CD	0.98	-12.07	2.79	0.27	0.64	1.56
*Plumbago auriculata**	CD.H	0.8	-14.03	1.47	0.64	0.34	2.91
Portulacaria afra	CA.H	0.94	-11.15	0.94	0.58	0.38	2.65
Psilocaulon junceum	CD	0.96	-10.21	2.28	0.36	0.55	1.82
Ptaeroxylon obliquum	CD.H	0.98	-18.06	1.87	0.48	0.45	2.23
Pteronia incana	CA.H	0.95	-11.68	0.94	0.44	0.48	2.08
Putterlickia pyracantha	CA.H	0.78	-7.9	0.66	0.79	0.26	3.8
Rhigozum obovatum	CA.H	0.9	-12.39	0.94	0.53	0.41	2.43
Ruschia multiflora	CA.H	0.9	-7.43	0.58	0.3	0.61	1.63
Schotia afra	CA.H	0.93	-14.34	1.08	0.61	0.36	2.78
*Vachellia karoo**	CA.H	0.97	-20.91	1.35	0.33	0.58	1.72

Species which were measured in the field were placed into guilds relevant to spekboom thicket, namely Large Canopy Dominant (LCD), Other Canopy Dominant (OCD), Shrubs and Dwarf Shrubs (DS), as per van der Vyver & Cowling (2019). Those species which were found in Table 2 did not need surrogates and the allometric equation was applied as is. For those species not found on Table 2, a surrogate list was compiled, so that surrogates were either of similar genus or guild, preferably both (Appendix 7.3). Surrogates were also utilised for species which did not have known wet dry ratios (Appendix 7.3). These were applied from the wet:dry species surrogate table from van der Vyver & Cowling (2019), which were also sourced from wet:dry ratios developed by Powell (2009).

3.5.2 Litter

The litter carbon was sampled in four 0.5 m^2 (effectively 1 m^2 per plot). The data was pooled per plot. Dry litter biomass was converted to carbon content using the multiplication factor of 0.48 (Lamlom & Savidge 2003). The equation to calculate litter carbon in t ha^{-1} is therefore as follows:

Litter (C t ha^{-1}) = dry litter biomass (t) x 0.48 x 10^4

4 Results

4.1 SEVERELY DEGRADED BAVIAANSKLOOF SPEKBOOM THICKET SITES

4.1.1 Tchnuganoo - above ground carbon stocks (AGC)

Fifteen plots were sampled on the severely degraded spekboom thicket restoration site of Tchnuganoo (Table 3). Tchnuganoo was found to have a mean ABC of 6.31 (SE: 1.17) t C ha^{-1} and mean litter of 2.46 (SE: 0.92) t C ha^{-1} . This gives a total AGC of 8.77 (SE: 1.83) t C ha^{-1} . There was a SE:Mean of 20.9% with total carbon ranging from 1.07 to 26.56 t C ha^{-1} .

Table 3 Severely degraded BST above ground biomass carbon (ABC) and litter carbon stocks for Tchnuganoo.

Plot code	ABC (t C ha^{-1})	Litter (t C ha^{-1})	Total AGC (t C ha^{-1})
ST-02	7.65	6.03	13.68
ST-07	0.84	0.55	1.39
ST-15	13.60	1.59	15.19
ST-17	5.27	0.86	6.12
ST-18	3.29	1.56	4.85
ST-19	8.79	3.13	11.92
ST-22	12.23	0.97	13.20
ST-35	3.05	1.44	4.49
ST-39	7.74	4.52	12.26
ST-43	8.89	0.75	9.64
ST-45	2.50	0.77	3.27
ST-48	13.15	13.42	26.56
ST-49	2.65	0.51	3.16
TCH-01	4.44	0.28	4.72
TCH-03	0.54	0.53	1.07
Mean	6.31	2.46	8.77
n	15	15	15
SD	4.37	3.45	6.85
SE	1.17	0.92	1.83
SE : Mean	18.5%	37.4%	20.9%
Largest	13.60	13.42	26.56
Smallest	0.54	0.28	1.07

4.1.2 Sewefontein - above ground carbon stocks (AGC)

Twenty plots were sampled on the severely degraded spekboom thicket restoration site of Sewefontein (Table 4). Sewefontein was found to have a mean ABC of 6.07 (SE: 0.75) t C ha^{-1} and mean litter of 1.39 (SE: 0.32) t C ha^{-1}, which was slightly less than Tchnuganoo. This gives a total of AGC of 7.46 (SE: 0.85) t C ha^{-1}. There was an SE:Mean of 11.3% with total carbon ranging from 2.01 to 15.85 t C ha^{-1}.

Table 4 Severely degraded BST above ground biomass carbon (ABC) and litter carbon stocks for Sewefontein.

Plot code	**ABC (t C ha^{-1})**	**Litter (t C ha^{-1})**	**Total AGC (t C ha^{-1})**
SS-01	3.69	0.54	4.23
SS-02	3.42	1.07	4.5
SS-03	1.4	0.61	2.01
SS-04	8.55	4.2	12.75
SS-05	12.49	2.38	14.87
SS-07	5.35	1.93	7.28
SS-08	6.35	0.76	7.11
SS-09	5.13	0.62	5.75
SS-10	7.24	0.91	8.15
SS-11	8.62	1.22	9.84
SS-12	6.8	0.22	7.02
SS-13	5.3	0.63	5.92
SS-14	2.45	0.57	3.02
SS-15	4.25	5.42	9.67
SS-16	5.42	0.45	5.88
SS-17	5.79	0.34	6.13
SS-18	15.08	0.77	15.85
SS-19	2.36	1.48	3.84
SS-20	5.75	3.04	8.78
SS-21	5.9	0.73	6.63
Mean	6.07	1.39	7.46
n	20	20	20
SD	3.28	1.38	3.69
SE	0.75	0.32	0.85
SE : Mean	12.4%	22.7%	11.3%
Largest	15.08	5.42	15.85
Smallest	1.40	0.22	2.01

4.1.3 Summary of carbon baselines across both severely degraded sites

Thirty five plots were sampled on the severely degraded spekboom thicket sites of Tchnuganoo and Sewefontein (Table 5). When the sites were pooled there was a mean ABC of 6.17 (SE: 0.64) t C ha^{-1} and mean litter of 1.85 (SE: 0.43) t C ha^{-1}. This gives a total AGC of 8.02 (SE: 0.9) t C ha^{-1}. There was an SE:Mean of 11.2% with total carbon ranging from 1.07 to 26.56 t C ha^{-1}.

Table 5 Combined above ground biomass carbon (ABC) and litter carbon stocks for severely degraded BST on Tchnuganoo and Sewefontein.

	ABC (t C ha^{-1})	**Litter (t C ha^{-1})**	**Total AGC (t C ha^{-1})**
Mean	6.17	1.85	8.02
n	35	35	35
SD	3.72	2.50	5.23
SE	0.64	0.43	0.90
SE : Mean	10.4%	23.2%	11.2%
Largest	15.08	13.42	26.56
Smallest	0.54	0.22	1.07

4.2 MODERATELY DEGRADED BAVIAANSKLOOF SPEKBOOM THICKET SITES

Twenty nine plots were sampled on the moderately degraded spekboom thicket sites on Dr Van der Watt farm (Table 6). There was a mean ABC of 14.47 (SE: 1.27) t C ha^{-1} and mean litter of 4.17 (SE: 0.43) t C ha^{-1}. This gives a total AGC of 18.63 (SE: 1.43) t C ha^{-1}. There was an SE:Mean of 7.7 % with total carbon ranging from 7.25 to 37.93 t C ha^{-1}.

Table 6 Moderately degraded BST above ground biomass carbon (ABC) and litter carbon stocks for Dr Van der Watt farm.

Plot code	ABC (t C ha^{-1})	Litter (t C ha^{-1})	Total AGC (t C ha^{-1})
MV-01	11.09	4.72	15.81
MV-02	7.06	9.56	16.61
MV-03	12.72	5.08	17.8
MV-04	10.65	6.93	17.58
MV-05	29.71	8.19	37.9
MV-06	10.32	0.81	11.13
MV-08	5.13	4.58	9.72
MV-09	10.2	1.25	11.46
MV-11	14.65	3.42	18.07
MV-12	7.01	0.24	7.25
MV-13	15.92	2.56	18.48
MV-14	16.35	1.59	17.94
MV-16	27.21	4.87	32.08
MV-17	14.08	3.67	17.75
MV-18	17.68	3.36	21.04
MV-19	8.07	2.82	10.89
MV-20	12.31	2.71	15.02
MV-21	14.79	2.28	17.08
MV-22	13.74	2.76	16.5
MV-23	13.51	5.19	18.7
MV-24	8.81	7.45	16.26
MV-25	13.2	5.81	19.01
MV-27	31.3	6.63	37.93
MV-28	25.38	6.25	31.63
MV-31	19.92	4.09	24.01
MV-32	6.5	5.31	11.81
MV-33	12.43	2.85	15.28
MV-34	15.95	2.34	18.28
MV-35	13.83	3.57	17.4
Mean	14.47	4.17	18.63
n	29	29	29
SD	6.70	2.25	7.57
SE	1.27	0.43	1.43
SE : Mean	8.7%	10.2%	7.7%
Largest	31.30	9.56	37.93
Smallest	5.13	0.24	7.25

4.3 PRISTINE BAVIAANSKLOOF SPEKBOOM THICKET SITES

Thirty plots were sampled on the pristine spekboom thicket sites on Dr Van der Watt farm (Table 7). There was a mean ABC of 21.39 (SE: 1.11) t C ha^{-1} and mean litter of 9.57 (SE: 0.71) t C ha^{-1}. This gives a total AGC of 30.95 (SE: 1.44) t C ha^{-1}. There was an SE:Mean of 4.7 % with total carbon ranging from 17.24 to 45.82 t C ha^{-1}.

Table 7 Pristine BST above ground biomass carbon (ABC) and litter carbon stocks for the Dr Van der Watt farm.

Plot code	**ABC (t C ha^{-1})**	**Litter (t C ha^{-1})**	**Total AGC (t C ha^{-1})**
INT01	25.66	13.29	38.95
INT03	12.48	12.43	24.9
INT07	24.12	17.34	41.46
PV01	24.37	13.16	37.53
PV02	18.49	12.37	30.86
PV03	32.09	13.73	45.82
PV04	17.9	6.25	24.15
PV05	29.72	7.76	37.48
PV06	24.24	11.79	36.03
PV07	11.95	5.29	17.24
PV08	12.59	8.2	20.79
PV09	28.22	10.63	38.85
PV10	25.96	13.12	39.07
PV11	29.48	5.34	34.81
PV12	17.53	14.48	32.01
PV13	30.64	13.42	44.06
PV14	14.72	5.53	20.25
PV15	12.48	12.58	25.06
PV16	21.54	13.49	35.03
PV17	28.11	10.74	38.86
PV18	21.44	7.44	28.88
PV19	23.08	5.65	28.73
PV20	16.24	11.1	27.34
PV21	16.88	3.97	20.85
PV22	21.68	4.85	26.53
PV23	16.78	11.07	27.84
PV24	16.94	4.61	21.55
PV25	18.88	7.77	26.65
PV26	19.2	4.45	23.65
PV27	28.18	5.13	33.31
Mean	21.39	9.57	30.95
n	30	30	30
SD	6.00	3.83	7.76
SE	1.11	0.71	1.44
SE : Mean	5.2%	7.4%	4.7%
Largest	32.09	17.34	45.82
Smallest	11.95	3.97	17.24

4.4 SUMMARY OF ABOVE GROUND CARBON (AGC) STOCKS ACROSS SITES

Across the different sites and degradation classes, as to be expected the Sewefontein and Tchnuganoo sites (severely degraded) had the lowest overall carbon baseline at an AGC of 8.02 (SE: 0.9) t C ha^{-1} (Table 8).

Table 8 The mean AGC, ABC and litter for sites sampled, with SE values (t C ha^{-1}).

Degradation class (BST)	Farm	ABC (t C ha^{-1})	Litter (t C ha^{-1})	Total AGC (t C ha^{-1})
Degraded	Tchnuganoo & Sewefontein	6.17 (SE:0.64)	1.85 (SE: 0.43)	8.02 (SE: 0.9)
Moderately degraded	Dr Van der Watt	14.47 (SE: 1.27)	4.17 (SE: 0.43)	18.63 (SE: 1.43)
Intact	Dr Van der Watt	21.39 (SE: 1.11)	9.57 (SE: 0.71)	30.95 (SE: 1.44)

This is similar to the AGC of 6.8 t C ha^{-1} (van der Vyver & Cowling 2019) and 6 t C ha^{-1} (Powell 2009 :p56) estimated in degraded BST (Table 9). As expected the pristine site (PV) held the highest carbon with a mean total of 30.95 (SE: 1.44) t C ha^{-1} , followed by the moderately degraded site (MV) with a mean of 18.63 (SE: 1.43) t C ha^{-1} (Table 8). This shows a difference of 22.93 t C ha^{-1} between the pristine and severely degraded sites and 10.61 t C ha^{-1} between the moderately degraded and the severely degraded sites.

Table 9 Comparable litter, ABC and AGC results found in studies by Powell 2009 and van der Vyver & Cowling 2019, in BST.

Study	Degradation class	ABC t C ha^{-1}	Litter t C ha^{-1}	AGC t C ha^{-1}
Powell 2009	Degraded BST	4.00	1.39	6.32
Powell 2009	Intact BST	29.00	4.85	33.85
Van der Vyver & Cowling 2019	Degraded BST	6.24	0.56	6.8
Van der Vyver & Cowling 2019	Intact BST	27.88	8.04	35.92

4.5 SUMMARY OF ABOVE GROUND BIOMASS CARBON (ABC) STOCKS BASED ON SPECIES

A few species dominated the carbon of the different degradation classes of the Baviaanskloof Spekboom Thicket (BST) (Table 10). The top ten species contributed 88 %, 82 % and 90 % of the total carbon per degradation class for severely degraded, moderately degraded and pristine BST respectively.

Table 10 The contribution of carbon (t C ha^{-1}) by the top ten species to ABC in the three degradation classes, as well as the % contribution to the ABC of each degradation class (LCD = Large canopy dominant, OCD = other canopy dominant, DS=dwarf shrub, Shrub = shrubs, spek = spekboom.)

Severely degraded			
Species	Guild	t C ha^{-1}	% contribution to total ABC
Pappea capensis	LCD	2.16	34%
Searsia longispina	OCD	0.70	11%
Pteronia incana	DS	0.58	9%
Euclea undulata	LCD	0.57	9%
Grewia robusta	OCD	0.47	7%
Lycium ferocissimum	OCD	0.27	4%
Rhigozium obovatum	OCD	0.26	4%
Putterlickia pyracantha	OCD	0.23	4%
Aloe ferox	OCD	0.15	2%
Carissa haematocarpa	OCD	0.15	2%
Moderately degraded			
Species	Guild	t C ha^{-1}	% contribution to total ABC
Euclea undulata	LCD	2.79	19%
Portulacaria afra	spek	1.83	13%
Putterlickia pyracantha	OCD	1.52	11%
Searsia longispina	OCD	1.36	9%
Pappea capensis	LCD	1.26	9%
Carrisa haematocarpa	OCD	1.11	8%
Passerina rubra	DS	0.67	5%
Grewia robusta	OCD	0.53	4%
Crassula ovata	Shrub	0.40	3%
Polygala myrtifolia	OCD	0.39	3%
Pristine			
Species	Guild	t C ha^{-1}	% contribution to total ABC
Portulacaria afra	spek	6.20	29%
Euclea undulata	LCD	4.62	22%
Putterlickia pyracantha	OCD	1.94	9%
Searsia longispina	OCD	1.64	8%
Pappea capensis	LCD	1.42	7%
Carrisa haematocarpa	OCD	1.08	5%
Crassula ovata	Shrub	0.72	3%
Grewia robusta	OCD	0.60	3%
Gymnosporia nemorosa	OCD	0.53	2%
Aloe pluridens	OCD	0.47	2%

Within the severely degraded BST, *Pappea capensis, Searsia longispina and Pteronia incana* comprised more than 50 % of the ABC. In the moderately degraded class it was *Euclea undulata, Portulacaria afra* (spekboom), *Putterlickia pyracantha and Searsia longispina.* While in the pristine BST, spekboom and *Euclea undulata* both made up over 50 *% of* the ABC. This illustrates the carbon dominance of a few species, which were mostly canopy species. The spekboom is insignificant in the severely degraded sites, contributing only 1.1% carbon, while it contributes the highest ABC in the pristine BST at 29 %, and a reduced 13 % in the moderately degraded BST.

Pappea capensis dominates the carbon of the severely degraded sites, as a last remnant of pristine BST, while *Searsia longispina* and the dwarf shrub, *Pteronia incana*, also contibuted significant carbon. The six species *Pappea capenis, Searsia longispina, Euclea undulata, Grewia robusta, Carissa* *haematocarpa and Putterlickia pyracantha* were found across all three degradation classes in the top ten contributors of carbon. These species may be important species to support spekboom thicket restoration, as they appear to be hardy and contibute significantly to above ground biomass carbon.

From the ninety nine species measured, 56, 69 and 63 were observed and measured in the severely degraded, moderately degraded and pristine BST classes respectively. This shows a slight reduction in the number of tree and shrub species (including succulent trees and shrubs) in the severely degraded class when compared with the moderately degraded and pristine classes. However the abundance of species is much decreased in the severely degraded sites as evident from the above ground biomass results. This is actually good news for restoration, as the remaining species have not been completely removed and could possibly be nurtured back into abundance, through innovative restoration methods and avoided grazing.

5 Discussion and recommendations

The results show that that there is potential to sequester above ground carbon through successful restoration from a AGC baseline of 8.02 (SE: 0.9) t C ha^{-1} to a potential of 30.95 (SE: 1.44) t C ha^{-1} as found in pristine sites. This is a gain of up to ~22 t C ha^{-1}, when fully restored to the intact state. This is lower but comparable to AGC in other Baviaanskloof Spekboom Thicket studies where van der Vyver (2019) estimates an AGC of 35.92 t C ha^{-1} and Powell (2009: p56) ~35 t C ha^{-1} . Pristine above ground biomass carbon (ABC) showed stocks of 21.39 t C ha^{-1} (SE: 1.11) while litter was 9.57 t C ha^{-1} (SE: 0.0.7). Litter carbon was higher but also comparable with van der Vyver & Cowling (2019) at 8.04 and Powell (2009) at 4.85 (SE: 0.99).

However, the restoration and regrowth process may take more than 30 years to achieve equivalent densities to the pristine areas, depending on the restoration success. There was a wide range in mean AGC amongst plots not only in degraded sites (1.07 to 26.56 t C ha^{-1}), moderately degraded sites (7.25 to 37.93 t C ha^{-1}) but also intact sites (17.24 to 45.82 t C ha^{-1}). This shows the patchiness of carbon within different degradation states of spekboom thicket. However the number of samples kept the SE:Mean to below 12% for severely degraded (n=35) and below 10% for the moderately degraded (n= 29) and pristine (n=30), which shows that the mean AGC estimates are reliable.

There is still a gap in the knowledge about what local rates of sequestration can be achieved in the Baviaanskloof Spekboom Thicket, through restoration. Mills *et al.* (2014) suggest that 15 t CO_2 ha^{-1} yr^{-1} may not be unusual for semi-arid environments with CAM plants (succulents), which is the equivalent to ~5.5 t C ha^{-1} yr^{-1} . This is likely the upper end as van der Vyver (2018, p:133) estimates that ~ 1 C ha^{-1} yr^{-1} can be sequestered realistically, reaching a maximum of between 23.8 - 32.8 t C ha^{-1} , for above ground carbon. Van der Vyver (2019) suggests this can be increased under optimum habitat conditions and through the removal of herbivory.

A simplified soil carbon assessment methodology is also urgently required to bring down costs and labour so that soil carbon is not excluded from restoration initiatives, it being the largest carbon pool in subtropical thicket (Mills & Cowling 2010, van der Vyver *et al.* 2013). This may require the development of soils models, as was done in the Australian carbon monitoring programme (Government of Australia 2018). Mills & Cowling (2006) found that in soils over 50 cm deep at a densely planted site restored over 27 years at Krompoort, Eastern Cape, a high of 0.26 kg C m^{-2} yr^{-1} or 2.6 t C ha^{-1} yr^{-1} was sequestered. However, there is no such specific data for the Studtis area as yet. Very little has been researched about soil carbon sequestration rates in spekboom thicket restoration and is an area which requires further interrogation especially since soil carbon can be up to 93 t C ha^{-1} (Mills & Cowling 2010) in some thicket types or ~ 100 when restored after 35 years with spekboom (van der Vyver *et al.* 2013). Soil sampling research should also be done under various degradation states in the spekboom rich thicket types to ascertain the different carbon sequestration potentials in the soil. Additionally, methods of restoration which maximize soil organic carbon production need to be investigated as they would support soil carbon sequestration in spekboom thicket.

It is recommended that further above ground carbon (AGC) and below ground carbon (BGC) sampling be done on other spekboom rich vegetation types in the Baviaanskloof such as Groot Arid

Spekboomveld in various degradation states. This is required to improve understanding of the variation in carbon stocks across the landscape and can further contribute to a simplified methodology which can be applied across different vegetation types and ecological variables. Ideally it should be done by stratifying within spekboom thicket types by different ecological variables such as historical herbivory, aspect, soil types and rainfall. Twenty random plots may be required in each stratification in order to have data which has a low standard error (SE) and show the potential carbon stocks for areas with different ecological traits. It is clear that spekboom thicket carbon stocks in the Studtis area are variable, even when considered pristine with high spekboom cover, and may be influenced by a number of ecological and/or historical factors. This data could also strengthen the development of the simplified remote sensing carbon monitoring methodology developed by Harris *et al.* (2019) with broader data points temporally and spatially.

Survivorship success rates have been found to be variable in the Subtropical Thicket Restoration Programme (Mills & Robson 2017, Mills *et al*. 2018) in the Eastern Cape, from data collected from restoration initiatives from over 10 years. This suggests that variable success should also be expected through the restoration of spekboom thicket in the Baviaanskloof until methods have been further refined and tested. Mills *et al.* (2015) suggest a process of 'prescribing innovation' to improve the success of restoration to find methods which are relevant to different ecological conditions. This should be considered when implementing restoration protocols so that 'a one size fits all' approach is not adopted but rather restoration methods are tailored to the landscape. This approach may help improve restoration and carbon sequestration success across different sites.

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7 Appendices

7.1 GPS POINTS – SEVERELY DEGRADED PLOTS SAMPLED ON SEWEFONTEIN (SS) & TCHNUGANOO (ST/TCH)

Plot code	x - co-ordinate	y -co-ordinate	Plot code	x - co-ordinate	y -co-ordinate
SS01	23.96282672	-33.56878452	TCH01	23.99071369	-33.56519127
SS02	23.95777278	-33.55878672	TCH03	23.98992639	-33.56639571
SS03	23.97030287	-33.56139136	ST03	23.99024993	-33.56924455
SS04	23.96043697	-33.55354994	ST07	23.99411677	-33.56478182
SS05	23.96148005	-33.56714084	ST15	23.98778105	-33.57088168
SS07	23.95450859	-33.55492791	ST17	23.99218383	-33.56431449
SS08	23.96194815	-33.56365809	ST18	23.99228136	-33.57194518
SS09	23.95734925	-33.56366873	ST19	23.99108437	-33.56782514
SS10	23.96307493	-33.56016856	ST22	23.98855902	-33.57274962
SS11	23.95895268	-33.56096429	ST35	23.99103472	-33.57360901
SS12	23.96894104	-33.55634727	ST39	23.99467141	-33.56534376
SS13	23.96832706	-33.55658751	ST43	23.98960378	-33.57271705
SS14	23.96684672	-33.55808507	ST45	23.99361073	-33.56705110
SS15	23.96361611	-33.55896979	ST48	23.99243476	-33.56644884
SS16	23.96669926	-33.55767502	ST49	23.99017050	-33.57287809
SS17	23.97076585	-33.55952879			
SS18	23.95891414	-33.56194959			
SS19	23.96785510	-33.56581009			
SS20	23.95791274	-33.55322941			
SS21	23.97328041	-33.55929474			

7.2 GPS POINTS – MODERATELY DEGRADED (MV) AND PRISTINE (PV/INT) PLOTS SAMPLED ON DR VAN DER WATT FARM

Plot code	x - co-ordinate	y -co-ordinate	Plot code	x - co-ordinate	y -co-ordinate
INT-01	23.93803954	-33.55468063	MV01	23.95198996	-33.55598292
INT-03	23.94337741	-33.55578322	MV02	23.95033351	-33.55736488
INT-07	23.94036118	-33.55476782	MV03	23.94275281	-33.55564787
PV01	23.93799080	-33.55544415	MV04	23.94786385	-33.55572791
PV02	23.94217962	-33.55368738	MV05	23.93624413	-33.55806965
PV03	23.93543501	-33.55614561	MV06	23.94930066	-33.55612996
PV04	23.94254725	-33.55497594	MV08	23.94707529	-33.55806999
PV05	23.93650892	-33.56045446	MV09	23.95213414	-33.55558801
PV06	23.94116847	-33.56105360	MV11	23.94848263	-33.55602383
PV07	23.94571691	-33.55630096	MV12	23.95098703	-33.55564858
PV08	23.94869459	-33.55199379	MV13	23.94711331	-33.55632505
PV09	23.94781088	-33.55156818	MV14	23.95214247	-33.55496023
PV10	23.93531525	-33.56024196	MV16	23.93484293	-33.56065897
PV11	23.94226280	-33.56172044	MV17	23.94998552	-33.55546146
PV12	23.94096024	-33.55470461	MV18	23.93498286	-33.55866240
PV13	23.93839772	-33.55517016	MV19	23.93637979	-33.55678274
PV14	23.94547057	-33.56021383	MV20	23.94645449	-33.55772767
PV15	23.94190799	-33.55360993	MV21	23.93372076	-33.55984420
PV16	23.94597088	-33.55354328	MV22	23.94970144	-33.55563411
PV17	23.94158049	-33.56057949	MV23	23.94382833	-33.55997564
PV18	23.93922817	-33.55560381	MV24	23.94158292	23.94158292
PV19	23.95086753	-33.55366291	MV25	23.94991271	23.94991271
PV20	23.93720581	-33.55646904	MV27	23.94355880	-33.55963187
PV21	23.93635605	23.93635605	MV28	23.93902432	23.93902432
PV22	23.93825660	23.93825660	MV31	23.94402108	-33.55960414
PV23	23.95082361	23.95082361	MV32	23.94799954	-33.55831761
PV24	23.93839749	23.93839749	MV33	23.93592726	23.93592726
PV25	23.94905705	23.94905705	MV34	23.94670273	23.94670273
PV26	23.93657564	23.93657564	MV35	23.95201209	23.95201209
PV27	23.94175382	-33.56079376			

7.3 SPECIES LIST AND SURROGATE SPECIES FOR ALLOMETRIC MODEL

Species name (sampled)	Guild	Species surrogate (van der Vyver & Cowling 2019)	Wet dry species surrogate (van der Vyver & Cowling 2019)
Aloe arborescens	OCD	*Aloe speciosa*	*A.striata*
Aloe ferox	OCD	*Aloe speciosa*	*A.striata*
Aloe pluridens	OCD	*Aloe speciosa*	*A.striata*
Aloe sp1	DS	*Aloe striata*	*A.striata*
Asparagus africanus	DS	*Asparagus capensis*	*A.capensis*
Asparagus capensis	DS	*Asparagus capensis*	*A.capensis*
Asparagus racemosus	DS	*Asparagus capensis*	*A.capensis*
Asparagus refractus	DS	*Asparagus capensis*	*A.capensis*
Asparagus scandens	DS	*Asparagus capensis*	*A.capensis*
Asparagus sp1	DS	*Asparagus capensis*	*A.capensis*
Asparagus striatus	DS	*Asparagus capensis*	*A.capensis*
Azima tetracantha	OCD	*Azima tetracantha*	*A.tetracantha*
Boscia oleoides	LCD	*Boscia oleoides*	*B.oleoides*
Buddleja saligna	OCD	*Brachylaena ilicifolia*	*P.capensis*
Cadaba aphylla	OCD	*Euphorbia mauritanica*	*E.coerulescens*
Carissa haematocarpa	OCD	*Carissa haematocarpa*	*C.haematocarpa*
Chrysocoma sp1	DS	*Galenia filiformis*	*G.filiformis*
Cotyledon orbiculata	DS	*Cotyledon velutina*	*C.ovata*
Cotyledon sp1	DS	*Cotyledon velutina*	*C.ovata*
Cotyledon woodii	DS	*Cotyledon velutina*	*C.ovata*
Crassula ovata	Shrubs	*Crassula ovata*	*C.ovata*
Crassula perforata	DS	*Crassula perforata*	*C.perforata*
Crassula rupestris	DS	*Crassula perforata*	*C.perforata*
Crassula sp	DS	*Crassula perforata*	*C.perforata*
Crassula sp1	DS	*Crassula perforata*	*C.perforata*
Crassula sp2	DS	*Crassula perforata*	*C.perforata*
Crassula sp3	DS	*Crassula perforata*	*C.perforata*
Crasulla muscosa	DS	*Crasulla muscosa*	*C.muscosa*
Cussonia spicata	OCD	*Aloe speciosa*	*C.spicata*
Diospyros scabrida	OCD	*Euclea undulata*	*E.undulata*
Dodonaea angustifolia	OCD	*Brachylaena ilicifolia*	*P.capensis*
Elaeodendron capense	LCD	*Brachylaena ilicifolia*	*P.capensis*
Eriocephalus africanus	DS	*Pteronia incana*	*P.incana*
Euclea crispa	LCD	*Euclea undulata*	*E.undulata*
Euclea undulata	LCD	*Euclea undulata*	*E.undulata*
Euphorbia heptagona	DS	*Euphorbia coerulescens*	*E.coerulescens*
Euphorbia mauritanica	Shrubs	*Euphorbia mauritanica*	*E.coerulescens*
Euphorbia triangularis	OCD	*Euphorbia triangularis*	*E.coerulescens*
Galenia pubescens	DS	*Galenia filiformis*	*G.filiformis*
Grewia robusta	OCD	*Grewia robusta*	*G.robusta*

Species name (sampled)	Guild	Species surrogate (van der Vyver & Cowling 2019)	Wet dry species surrogate (van der Vyver & Cowling 2019)
Gymnosporia capitata	OCD	*Gymnosporia polyacantha*	*G.capitata*
Gymnosporia nemorosa	OCD	*Gymnosporia polyacantha*	*G.capitata*
Helichrysum dregeanum	DS	*Pteronia incana*	*P.incana*
Hermannia flammea	DS	*Pteronia incana*	*P.incana*
Hermannia gracilis	DS	*Pteronia incana*	*P.incana*
Hermannia holosericea	DS	*Pteronia incana*	*P.incana*
Hermannia pulverata	DS	*Pteronia incana*	*P.incana*
Hermannia sp	DS	*Pteronia incana*	*P.incana*
Isoglossa sylvatica	DS	*Blepharis capensis*	*n/a*
Kalanchoe rotundifolia	DS	*Crassula perforata*	*C.perforata*
Leonotis ocymifolia	DS	*Blepharis capensis*	*n/a*
Limeum aethiopicum	DS	*Galenia filiformis*	*G.filiformis*
lycium afrum	OCD	*Lycium ferocissimum*	*L.ferocissimum*
Lycium americanum	OCD	*Lycium ferocissimum*	*L.ferocissimum*
Lycium c.f. schizocalyx	OCD	*Lycium cinereum*	*L.ferocissimum*
Lycium ferossiumum	OCD	*Lycium ferocissimum*	*L.ferocissimum*
Lycium horridum	OCD	*Lycium ferocissimum*	*L.ferocissimum*
Lycium sp1	OCD	*Lycium ferocissimum*	*L.ferocissimum*
Lycium sp2	OCD	*Lycium ferocissimum*	*L.ferocissimum*
Lycium sp3	OCD	*Lycium ferocissimum*	*L.ferocissimum*
Maytenus undata	OCD	*Putterlickia pyracantha*	*G.capitata*
Nymania capensis	OCD	*Rhigozum obovatum*	*G.polycantha*
Oak silver spp1	LCD	*Brachylaena ilicifolia*	*P.capensis*
Olea europaea subsp. cuspidata	LCD	*Brachylaena ilicifolia*	*P.capensis*
Opuntia ficus-indica	OCD	*Euphorbia triangularis*	*E.coerulescens*
Osyris lanceolata c.f.	OCD	*Brachylaena ilicifolia*	*P.capensis*
Pappea capensis	LCD	*Pappea capensis*	*P.capensis*
Passerina rubra	DS	*Pteronia incana*	*P.incana*
Pelargonium peltatum	DS	*Blepharis capensis*	*n/a*
Pelargonium tetragonum	DS	*Blepharis capensis*	*n/a*
Pollichia sp1	DS	*Galenia filiformis*	*G.filiformis*
Polygala asbestina c.f.	OCD	*Putterlickia pyracantha*	*G.capitata*
Polygala leptophylla	OCD	*Putterlickia pyracantha*	*G.capitata*
Polygala myrtifolia	OCD	*Putterlickia pyracantha*	*G.capitata*
Portulacaria afra	spek	*Portulacaria afra*	*P.afra*
Pteronia incana	DS	*Pteronia incana*	*P.incana*
Pteronia sp	DS	*Pteronia incana*	*P.incana*
Putterlickia pyracantha	OCD	*Putterlickia pyracantha*	*G.capitata*
Rhigozum obovatum	OCD	*Rhigozum obovatum*	*G.polycantha*
Ruschia sp	DS	*Ruschia multiflora*	*R.multiflora*
Schotia latifolia	LCD	*Schotia afra*	*S.afra*
Searsia dentata	OCD	*Gymnosporia polyacantha*	*G.polycantha*

Species name (sampled)	Guild	Species surrogate (van der Vyver & Cowling 2019)	Wet dry species surrogate (van der Vyver & Cowling 2019)
Searsia fastigiata	OCD	*Gymnosporia polyacantha*	*G.polycantha*
Searsia glauca	OCD	*Gymnosporia polyacantha*	*G.polycantha*
Searsia longispina	OCD	*Gymnosporia polyacantha*	*G.polycantha*
Searsia lucida	OCD	*Gymnosporia polyacantha*	*G.polycantha*
Searsia refracta	OCD	*Gymnosporia polyacantha*	*G.polycantha*
Searsia undulata	OCD	*Gymnosporia polyacantha*	*G.polycantha*
Smelophyllum capense	OCD	*Brachylaena ilicifolia*	*P.capensis*
Solanum tomentosum	DS	*Pteronia incana*	*P.incana*
Tarchonanthus camphoratus	OCD	*Brachylaena ilicifolia*	*P.capensis*
Tephrosia spp	DS	*Jathropha capensis*	*J.capensis*
Unknown sp1	DS	*Pteronia incana*	*P.incana*
Unknown sp2	DS	*Pteronia incana*	*P.incana*
Unknown sp4	DS	*Pteronia incana*	*P.incana*
Vachellia karoo	LCD	*Vachellia karoo*	*V.karoo*
Ysterhout sp	OCD	*Brachylaena ilicifolia*	*P.capensis*
Zygophyllum morgsana	OCD	*Plumbago auriculata*	*P.auriculata*
Zygophyllum sp	OCD	*Plumbago auriculata*	*P.auriculata*

7.4 FIXED POINT PHOTOS – SEVERELY DEGRADED BST PLOTS (TCHNUGANOO FARM)

FPP: TCH-01 (1)

FPP: ST-02 (4)

FPP: TCH-03 (1)

FPP: ST-07 (1)

FPP: ST-15 (1)

FPP: ST-17 (1)


FPP: ST-18 (1)


FPP: ST-19 (1)


FPP: ST-22 (1)


FPP: ST-35 (1)


FPP: ST-39 (1)


FPP: ST-43 (1)

FPP: ST-45 (1)

FPP: ST-48 (1)

FPP: ST-49 (1)

7.5 FIXED POINT PHOTOS – SEVERELY DEGRADED BST PLOTS (SEWEFONTEIN FARM)


FPP: SS-01 (1)


FPP: SS-02 (1)


FPP: SS-03 (1)


FPP: SS-04 (1)


FPP: SS-05 (1)


FPP: SS-07 (1)

 FPP: SS-08 (1)	 FPP: SS-09 (1)	 FPP: SS-10 (1)
 FPP: SS-11 (1)	 FPP: SS-12 (1)	 FPP: SS-13 (1)

FPP: SS-14 (1)

FPP: SS-15 (1)

FPP: SS-16 (1)

FPP: SS-17 (1)

FPP: SS-18 (3)

FPP: SS-19 (1)

 FPP: SS-20 (1)	 FPP: SS-21 (1)	

7.6 FIXED POINT PHOTOS – MODERATELY DEGRADED BST PLOTS (DR VAN DER WATT FARM)


FPP: MV-01 (1)


FPP: MV-02 (1)


FPP: MV-03 (1)


FPP: MV-04 (1)


FPP: MV-05 (1)


FPP: MV-06 (2)


FPP: MV-08 (1)


FPP: MV-09 (1)


FPP: MV-11 (1)


FPP: MV-12 (1)


FPP: MV-13 (1)


FPP: MV-14 (1)

 FPP: MV-16 (1)	 FPP: MV-17 (2)	 FPP: MV-18 (1)
 FPP: MV-19 (2)	 FPP: MV-20 (1)	 FPP: MV-21 (1)


FPP: MV-22 (1)


FPP: MV-23 (1)


FPP: MV-24 (2)


FPP: MV-25 (3)


FPP: MV-27 (1)


FPP: MV-28 (1)


FPP: MV-31 (1)


FPP: MV-32 (2)


FPP: MV-33 (1)


FPP: MV-34 (1)


FPP: MV-35 (1)

7.7 FIXED POINT PHOTOS – PRISTINE BST PLOTS (DR VAN DER WATT FARM)

 FPP: PV-01	 FPP: PV-02	 FPP: PV-03
 FPP: PV-04	 FPP: PV-05	 FPP: PV-06

 FPP: PV-07	 FPP: PV-08	 FPP: PV-09
 FPP: PV-10	 FPP: PV-11	 FPP: PV-12


FPP: PV-13


FPP: PV-14


FPP: PV-15


FPP: PV-16


FPP: PV-17


FPP: PV-18


FPP: PV-19

FPP: PV-20

FPP: PV-21

FPP: PV-22

FPP: PV-23

FPP: PV-24


FPP: PV-25


FPP: PV-26


FPP: PV-27


FPP: INT-01


FPP: INT-03


FPP: INT-07