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**Habitat, plant communities and threats to the Robertson Granite
Renosterveld**

by

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Declaration

I declare that this dissertation is my own unassisted work, which is being submitted for the degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been previously submitted for any degree or examination in any other university.

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A handwritten signature in black ink, appearing to read 'J. M. M.', is written above a horizontal line.

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Abstract

The Robertson Granite Renosterveld (FRg3) vegetation type is found north of La Colline in the Breede River Valley near Robertson at altitudes of between 250 – 850 m a.s.l. This vegetation type is identified as understudied because of the isolated character of its granite pluton, which made it virtually unknown and led to it being identified as a priority for scientific research. As a result, the current study aims to improve the current understanding of plant communities, important habitat characteristics, threats, and identify dominant and endemic species in the FRg3. To investigate the species composition and communities within the FRg3, 53, 10m x 5m plots were sampled across the vegetation type for cover abundance of all the plant species coupled with environmental variables (altitude, and the ground covers of herbaceous vegetation, litter, bare ground, and rock). In addition, soils (~0-10 cm depth) were tested for pH (KCl), total organic carbon (C), soil texture (sand, silt, and clay), exchangeable phosphorus (P), and extractables of boron (B), sodium (Na), magnesium (Mg), potassium (K), and calcium (Ca). Fire is an important ecological disturbance in the Fynbos biome; therefore, Google Earth Engine (GEE) was explored to assess the fire history (2000-2023) of the FRg3 and map the outputs using image collections from MODIS/061/MCD64A1. The plant communities were classified using dissimilarity hierarchical cluster analysis, which showed that the FRg3 comprises five major plant communities, the following four of these communities are found in fire affected areas: *Dodonaea viscosa* – *Euryops tenuissimus*; *Dicerothamnus rhinocerotis* - *Dodonaea viscosa*, *Passerina obtusifolia*–*Restio capensis*, and *Muraltia heisteria* – *Restio capensis*; and the fifth community (*Pteronia paniculata*–*Dicerothamnus rhinocerotis*) is found in areas that have not burnt since 2000. The FRg3 had three major fires (2000, 2006, and 2017) over 24 years (2000-2023). In 2000, approximately 35% of the FRg3 burnt, while in 2006 and 2017 the fire

burnt approximately 24% and 53% respectively. There have been overlaps in areas burned by multiple fires (2000 & 2017 = 23%; 2006 & 2017 = 22%), and almost half (47%) of the vegetation type did not burn at all over the 24 years. The soil analysis showed significant differences ($P \leq 0.05$) in pH, Na, and texture (sand and clay) across the five communities. The FRg3 still retained most (99%) of its natural vegetation in 2023; however, there are disturbances and threats to the vegetation type, such as land clearing for agricultural purposes, and alien invasive plants such as *Hakea sericea* were observed within the vegetation type in 2023. The 24-year (2000-2023) changes in vegetation structure of the FRg3 were investigated using the Normalized Difference Vegetation Index (NDVI), which was computed from Landsat 5 and 8 over five different time periods (2000 – 2006, 2006 – 2013, 2013 – 2017, 2017 – 2023, and 2000 – 2023). This analysis showed an increase in FRg3 biomass (taller vegetation) between 2000 and 2006, largely because the area that burnt in 2000 had recovered despite the fire in 2006 which only burnt the small northern portion of the FRg3. The FRg3 lost most of its above-ground biomass in 2017 due to a fire that burnt over half of it. The FRg3 had the most biomass in 2013 and 2023, likely due to the lack of natural or anthropogenic disturbances.

Key words: Accuracy, change detection, fire, Google Earth Engine (GEE) habitat, Landsat, MODIS, Normalized Difference Vegetation Index (NDVI), plant communities, Robertson Granite Renosterveld (FRg3), threats, vegetation structure.

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Abbreviations

ANOVA – Analysis of Variance

ARVI – Atmospherically Resistant Vegetation Index

B – Boron

C – Carbon

Ca – Calcium

CARI – Chlorophyll Absorption Ratio Index

CCA – Canonical Correspondence Analysis

CFR – Cape Floristic Region

DEM – Digital Elevation Model

EN – Endangered

EVI – Enhanced Vegetation Index

FRg3 – Robertson Granite Renosterveld

GABAM – Global Annual Burned Area Maps

GEE – Google Earth Engine

GPS – Global Positioning System

GWIS – Global Wildfire Information System

K – Potassium

LC – Least Concern

LSD – Least Significant Difference

Mg – Magnesium

MODIS – Moderate Resolution Imaging Spectroradiometer

Na – Sodium

NBA – National Biodiversity Assessment

NDVI – Normalized Difference Vegetation Index

NGI – National Geo-spatial Information

NT – Near Threatened

NVM – National Vegetation Map

P – Phosphorus

PA – Producer's Accuracy

PCA – Principal Component Analysis

RLE – Red List of Ecosystems

SANBI – South African National Biodiversity Institute

SAVI – Soil Adjusted Vegetation Index

SD – Standard Deviation

UA – User's Accuracy

VU - Vulnerable

Chapter 1: General Introduction

1.1. Background

The Cape Floristic Region (CFR) is a renowned global biodiversity hotspot for its exceptional floral diversity of up to 9 000 plant species (Goldblatt and Manning, 2002; Rouget *et al.*, 2014; West *et al.*, 2016). This region is restricted to the south-western tip of South Africa and is characterised by a Mediterranean climate (Snijman, 2013). The Fynbos is the dominant of the four biomes (Albany Thicket, Forest biomes, Fynbos, and Succulent Karoo) found within the CFR (Rutherford *et al.*, 2006). However, the floristic data used to explore the relationship among the CFR vegetation types is inconsistent with the concept of the Fynbos Biome (Bergh *et al.*, 2014). This is primarily because the renosterveld, a predominantly nutrient-rich Mediterranean vegetation type, is distinct from the nutrient-poor fynbos vegetation types, referred to as heathlands (Bergh *et al.*, 2014). The Fynbos biome experiences an average annual rainfall of 480mm, predominantly in winter (Cowling and Holmes, 1992; Pierce and Cowling; Rebelo *et al.*, 2006). Mediterranean regions are habitats for fire-prone and fire-driven heathland-shrublands (Van Wilgen *et al.*, 2010; Simons, 2017; Bergh *et al.*, 2014; Cousins *et al.*, 2018). Thus, Fire plays an important role in maintaining fynbos ecosystem function. However, it can also damage infrastructure and threaten crops and livestock (Van Wilgen *et al.*, 2010).

The Fynbos biome exhibits exceptional endemism and diversity of plant species (Low and Rebelo, 1996; Hall, 2018) with approximately 69% of the plant species found only in the Fynbos (Goldblatt and Manning, 2002). One of the ecological pressures to the Fynbos biome is invasion by alien plants such as *Acacia* and *Hakea* species (Richardson and Van Wilgen, 1986; Witkowski and Mitchell, 1987; Witkowski 1991; Topp and Loos, 2019). These alien invasive plants can alter the ecological processes such as fire regime, cycling of nutrients, and water

availability. This can alter the composition and structure of plant communities and potentially induce secondary invasion of weedy plants (Yelenik *et al.*, 2004).

The Fynbos biome is made of three major vegetation groups namely: fynbos types, renosterveld types, and the strandveld types (Rebelo *et al.*, 2006). The current study focuses on one of the renosterveld types which together constitutes 29% of the Fynbos Biome (Rebelo *et al.*, 2006; Curtis, 2013). The term Renosterveld stemmed from the abundant presence of the *Dicerotheramnus rhinocerotis* shrub formally known as *Elytopappus rhinocerotis* (McDowell and Moll, 1992; Kemper *et al.*, 1999; Bergh, 2006). Renosterveld has a good representation of plants from the following families: Liliaceae (McDowell and Moll, 1992), Oxalidaceae, Asteraceae, and Iridaceae (McDowell and Moll, 1992; Kemper *et al.*, 1999). However, the Restionaceae, Ericaceae, and Proteaceae, which are some of the most typical fynbos plants are less prevalent in the renosterveld (Boucher, 1983; Moll *et al.*, 1984; McDowell and Moll, 1992).

Renosterveld appears more uniform grey from afar when compared to other fynbos ecosystems, this is because of the dominance of shrubs in the family Asteraceae, which creates an illusion of low diversity and a uniform habitat (Curtis, 2013). The reality is that the renosterveld has high species diversity and richness (Curtis, 2013). Furthermore, the renosterveld is divided into the Lowland and Mountain Renosterveld, where the Lowland Renosterveld is characterised by nutrient rich soils, high species richness and diversity, and it is heavily fragmented (primarily by agricultural activity) with less than 15% of its natural extent remaining (Rebelo *et al.*, 2006; Curtis, 2013; McDowell and Moll, 1992). Mountain Renosterveld is characterised by more nutrient poor soils, less species diversity, and it has not been transformed by agricultural activities due to its steep terrain (Paterson-Jones, 1998; Rebelo *et al.*, 2006; Curtis, 2013).

The renosterveld is subdivided into the Shale Renosterveld (covering 86%), Granite Renosterveld (covering 6%), and the remaining 8% is covered by the Alluvium Renosterveld, Dolerite Renosterveld, Silcrete Renosterveld, and Limestone Renosterveld (McDowell and Moll, 1992; Rebelo *et al.*, 2006). The Granite Renosterveld consists of three distinct vegetation types according to the South African National Vegetation Map (SANBI, 2012) including Kamiesberg Granite Renosterveld (FRg 1), Swartland Granite Renosterveld (FRg 2), and the Robertson Granite Renosterveld (FRg 3) (Rebelo *et al.*, 2006).

This study focused on the Robertson Granite Renosterveld (FRg 3) which forms part of the Mountain Renosterveld distributed along the low altitudes between 250 – 850 m a.s.l. of the Tierberg, north of La Colline in the Breede River Valley near Robertson, Western Cape, South Africa (Rebelo *et al.*, 2006). The FRg3 consists of relatively dense and tall grassy shrubland with a presence of succulent plant species; small trees are also scattered across the vegetation type (Rebelo *et al.*, 2006). The FRg3 has been described as grass-dominated (*Ehrharta calycina*, *Ficinia ramosissima*, *Pentameris eriostoma*) with a low diversity of geophytes (Rebelo *et al.*, 2006). However, it is important to note that there are observable increases in species richness and diversity after a managed fire on other studied renosterveld vegetation (Cousins *et al.*, 2018). The lower slopes of the FRg3 are primarily used for agricultural purposes where livestock also grazes (Rebelo *et al.*, 2006). Livestock grazing reduces the biomass of an ecosystem, which then results in reduced probability of a fire event in that particular ecosystem (Shezi *et al.*, 2021). In addition, Similar to fire, grazing by livestock negatively affects the species richness (O'Connor *et al.*, 2011) and diversity, except for less palatable dwarf succulent and alien invasive plant species (Shezi *et al.*, 2021). Furthermore, for a fire-dependent ecosystem like the fynbos, heavy grazing could lead to a significant decline in the richness and diversity of plant species, or even

local extirpation in extreme cases, particularly for those with seeds rely on fire to germinate (O'Connor, 1991).

1.1.1 Field vegetation studies

Vegetation studies are important as they provide information on wildlife habitats for biodiversity management and conservation (Ejtehadi *et al.*, 2005). Furthermore, plot-based vegetation studies are still relevant to date as they capture vegetation information at a fine scale (species level), which can be missed by remote sensing techniques (Tomppo *et al.*, 2008; Seymour *et al.*, 2025; Soga and Gaston, 2025). Hence, a combination of remote sensing techniques and plot-based vegetation sampling offers a powerful tool to obtain vegetation information on landscapes from a broad scale to a fine scale (Townsend and Walsh, 2001; Tomppo *et al.*, 2008).

Vegetation is often studied to understand the relationship between plant species distribution and their habitat characteristics/environmental factors. Vegetation studies provide information on the species richness and diversity which is then used for vegetation assessment and classification per community (Van Staden *et al.*, 2021). Furthermore, vegetation studies help to improve the management and conservation of ecosystems (Ejtehadi *et al.*, 2005) and mitigate the pressures and threats the ecosystem might be facing (Skowno, 2019). Vegetation sampling differs in terms of plot size, habitat characteristics, growth form and disturbances measured across different biomes (Werger, 1972; Campbell, 1983; Campbell, 1984; Cowling and Witkowski, 1994; Cowling *et al.*, 1994; Witkowski and O'Connor, 1996; Van Staden *et al.*, 2021). This is because there is no objective definition of a minimal plot size for vegetation sampling, hence, the concept of optimal plot size was introduced to provide the most satisfactory relationship between effort expended and information obtained (Werger, 1972; Boucher, 1987).

Table 1.1 shows the methods commonly used in previous phytosociological studies with the data collected, optimal plot size, and the measuring scale.

The Braun-Blanquet cover abundance scale is the commonly used methodology for phytosociological studies (Campbell and Moll, 1977; Boucher, 1987; Joubert and Moll, 1992), and it also faced criticism (Werger, 1974). The main argument was that the Braun-Blanquet method originates from Europe where the flora is different from that of South Africa (Gibbs Russell *et al.*, 1985). The environmental and floristic intricacies of South African vegetation compared to that of Europe could complicate the subjective decision-making of the researcher, particularly if they lack adequate experience of applying the Braun-Blanquet method. Therefore, the application of the Braun-Blanquet on a broad scale might be simple in a European context compared to South Africa (Rutherford and Westfall, 1986). The Domin scale and Braun-Blanquet scales are similar in use (Wikum and Shanholtzer, 1978), however, the Domin scale has a less complex ordinal score and percentage conversion (Van der Maarel, 1979; Tichý, *et al.*, 2020), providing easier and efficient field data recording. In addition, the Domin scale has a lower proportional overestimation of vegetation cover compared to the Braun-Blanquet (Lévesque, 1996). In that regard, the Domin scale is another commonly used method (O'Neill *et al.*, 2013; Devaney and Perrin, 2015), which will be employed in this study as an alternative to the Braun-Blanquet cover scale.

Table 1.1 Summary of plot vegetation studies showing the collected data, number of plots, optimal plot size, and the measuring scale used for each study.

Title	Data collected	No of plots	Plot size	Measuring scale	reference
“A Phytosociological Study of Orange Kloof, Table Mountain, South Africa.”	Environmental & phytosociological data	48	10x10m	Braun-Blanquet	McKenzie <i>et al.</i> (1977)
“A Phytosociological Study of Signal Hill, Cape Town, utilizing both perennial and ephemeral species.”	Environmental & phytosociological data	53	10x10m & 20x5m	Braun-Blanquet	Joubert & Moll (1992)
“The Forest Communities of Table Mountain, South Africa”	Environmental & phytosociological data	105	10x10m & 20x5m	Braun-Blanquet	Campbell & Moll (1977)
“The efficient use of small plots in a fynbos phytosociological study in the northern Cederberg: a quick way to collect plant-environmental data”	Environmental & phytosociological data	22	2x2m, 2x4m & 4x4m	Braun-Blanquet	Mustart <i>et al.</i> (1993)
“Fragmentation of South African renosterveld shrublands: effects on plant community structure and conservation implications”	Phytosociological data	69	10x5m	Category system	Kemper <i>et al.</i> (1999)
“Influence of fire on critically endangered Swartland Shale Renosterveld in the Cape Floristic Region”	Fire data	18	10x10m & 5x5m	Unspecified	Cousins <i>et al.</i> (2018)
“A phytosociological study of transects through the western Cape coastal foreland, South Africa”	Environmental & phytosociological data	539	10x5m	Braun-Blanquet	Boucher (1987)
“Saltmarsh angiosperm assessment tool for Ireland (SMAATIE).”	Vegetation data	3,467	2x2m	Domin	Devaney & Perrin (2015)
“ <i>The Irish semi-natural grasslands survey 2007-2012</i> . National Parks and Wildlife Service, Department of Arts, Heritage and the Gaeltacht.”	Environmental & phytosociological data	361	2x2m	Domin	O’Neill <i>et al.</i> (2013)

1.1.2 Fire ecology

Fire plays a crucial role in the vegetation dynamics of the fynbos biome (Bond *et al.*, 1984; Bond and Van Wilgen, 1996; Simons, 2017; Cousins *et al.*, 2018; Verboom *et al.*, 2024), hence, vegetation studies of the fynbos ecosystems highlighted fire as an important ecological process in the biome (Bond and Van Wilgen, 1996; Cousins *et al.*, 2018; Verboom *et al.*, 2024). Vegetation studies on fynbos ecosystems highlighted that the species richness and diversity

declines with time after a fire (Kruger, 1983; Cowling and Pierce, 1988; Bond and Van Wilgen, 1996; Verboom *et al.*, 2024), however, according to Verboom *et al.* (2024) such declines have not been observed in the renosterveld. However, Van der Merwe and Van Rooyen (2011) and Cousins *et al.* (2018) showed that the renosterveld displays a significantly higher species richness and diversity after a fire event, as many species flower and ‘become apparent’ only in the early post-fire period (1–3 years). Therefore, fire influences the species composition in renosterveld vegetation types, which differs in relation to time since fire (Cousins *et al.*, 2018).

Nonetheless, fire ecology of the renosterveld is under-researched (Curtis, 2013; Cousins, 2018), despite precious fire studies attempts to understand it (Cowling and Pierce, 1988; Bond and Van Wilgen, 1996; Cousins, 2018). A good understanding of the renosterveld fire ecology is important to understand the fire-dependency of species within renosterveld vegetation types (Curtis, 2013). Remote sensing is a powerful tool that can be used to study the history of fires in ecosystems (Sunar and Özkan, 2001; Szpakowski and Jensen, 2019). Different remote sensing techniques and datasets (Table 1.3) have been used to map historic fire events and their extent (commonly referred to as fire scars). The Moderate Resolution Imaging Spectroradiometer (MODIS) is a widely used satellite for mapping history (De Klerk, 2008; Long *et al.*, 2019; Durta *et al.*, 2023).

1.1.3 Vegetation change detection

Literature has shown that the leading cause of biodiversity decline is the change in land cover due to invasive species, agricultural activities, climate change, and urban sprawl-development, which makes it important to monitor and assess the changes on the earth’s surface (Guo and Arnolds, 2018; Moncrieff, 2021). Remote sensing techniques offer a cost-effective and efficient approach to monitor the changes in landscapes (Willis, 2015; Anderson, 2018).

Accurate and updated information on the extent, distribution, and composition of ecosystems is important for better sustainable use of resources (Lu, *et al.*, 2004; Rutherford and Mucina, 2006; Willis, 2015) because ecosystems are generally degraded by anthropogenic practices, which is a global concern (Wenhua, 2004; Rutherford and Mucina, 2006; Bai, 2013). Therefore, mapping these changes simplifies the spatial complexities of vegetation cover (Rutherford and Mucina, 2006), and provides policy/decision-makers with accurate and updated information to make informed conservation decisions (Rutherford and Mucina, 2006; Malinga *et al.*, 2015).

Remote sensing is a powerful tool for mapping historical changes of ecosystems and landscapes by obtaining the reflectance of electromagnetic waves from the canopies using passive sensors (Xue and Su, 2017). Several vegetation indices (NDVI, EVI, ARVI, SAVI, and CARI) are used for different purposes in vegetation studies. However, the Normalized Difference Vegetation Index (NDVI) is a commonly used index (Table 1.3). This index quantifies the canopy density, which is used as an indicator for vegetation health (Heute, 1988; Karnieli *et al.*, 2010; Shammi and Meng, 2021). However, the disadvantage of NDVI is that it is not sensitive to soil background and atmospheric effects, hence, it is usually coupled with other indices such as the Enhanced Vegetation Index (Matsushita *et al.*, 2007; Xue and Su, 2017; Shammi and Meng, 2021).

The Enhanced Vegetation Index (EVI) is another commonly used index (Shammi and Meng, 2021) which helps to reduce the effects of environmental factors such as atmospheric conditions and soil background (Matsushita *et al.*, 2007). Hence, it is often coupled with NDVI (Xue and Su, 2017; Shammi and Meng, 2021). Another vegetation index that considers the atmospheric effects is the Atmospherically Resistant Vegetation Index (ARVI), this index is often coupled with NDVI when performing vegetation assessments (Kaufman and Tanre, 1992;

Xue and Su, 2017). Huete (1988) added that the Soil Adjusted Vegetation Index (SAVI) is another index usually coupled with NDVI to improve its sensitivity to soil background. The Chlorophyll Absorption Ratio Index (CARI) is used to quantify chlorophyll on plant leaves (Kim *et al.*, 1994), the index was introduced because the reflectance of leaves can be constant despite the different levels of chlorophyll present in the leaves (Xue and Su, 2017).

Table 1.3 A summary of commonly used satellite sensors and image collections for mapping vegetation change with their different spatial and temporal resolution, the classification technique and index, the preferred use of the imagery and the costs of the imagery. The records highlighted in grey represent image collections commonly used to map historic fire extents.

Satellite Sensor used & imagery collection	Spatial resolution	Temporal resolution	Temporal scale	Index	Classification technique	Details on preferred use of the sensor	Price	Reference
Landsat 5 TM	30 x 30 m for the multispectral bands and 60 x 60 m for the thermal infrared band	16 days	1984 - 2013		maximum likelihood classifier	Appropriate for regional scale mapping (i.e vegetation change, urban development, wildfire)	Free	Kotzé and Fairall (2006), Pandain <i>et al.</i> (2014), Pleniou <i>et al.</i> (2012), Daldegan, <i>et al.</i> (2014)
Landsat 8 OLI	30 x 30 m for the multispectral bands and 15 x 15 m for the panchromatic bands	16 days	2013 - present	NDVI	SVM	Appropriate for regional scale mapping (i.e vegetation change, urban development, wildfire)	Free	Gadal <i>et al.</i> , (2019)
Sentinel-2A	10 m (four visible and near-infrared bands), 20 m (six red edge and shortwave infrared bands) and 60 m (three atmospheric correction bands).	10 days	2015 - present	NDVI	SVM	Appropriate for fine scale vegetation mapping at community level.	Free	Gadal <i>et al.</i> , (2019); Moncrieff (2021)
Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua	Medium to coarse, 250m x 250m, 500m x 500m, and 1km x 1km	1-2 days	1999 - present	NDVI	object-oriented classification	Appropriate for regional, continental, and global scale mapping of land cover changes. It is also capable of mapping fire activities.	Free	De Klerk, 2008; Giglio, <i>et al.</i> , 2003; Gitas, <i>et al.</i> , 2003

MODIS (MCD64A1)	500m x 500m	1-2 days	2000 - present	Appropriate for mapping fire events with exact burn dates	Free	De Klerk, 2008; Giglio <i>et al.</i> , 2003; Gitas <i>et al.</i> , 2003; Giglio <i>et al.</i> , 2016
Landsat 7 and 8 (TM/ ETM +/OLI) (Global Annual Burn Area Map (GABAM))	30m x 30m	16 days	1985 - 2019	Appropriate for fine scale mapping of fire scars	Free	Long <i>et al.</i> , 2019;
MODIS (Global Wildfire Information System (GWIS))	500m x 500m	1-2 days	2001 - 2019	Appropriate for mapping fire scars	Free	Vadrevu <i>et al.</i> , 2022; Dutra <i>et al.</i> , 2023

1.3 Rationale

The renosterveld is the most fragmented and threatened vegetation group within the Fynbos Biome (Stander, 2016), and this is primarily due to human-induced disturbances such as agricultural practices (Bergh *et al.*, 2014; Stander, 2016). Approximately a third of renosterveld flora is endemic to the Cape Floristic Region (Stander, 2016). In addition, the renosterveld has faunal endemism with species such as *Psammobates geometricus* (commonly known as the Geometric tortoise) classified as Critically Endangered (Hofmeyr *et al.*, 2017; Hofmeyr and Baard, 2018) while others like *Certhilauda brevirostris* (commonly known as the Agulhas long-billed lark) are classified as Near Threatened (De Kock and Lee, 2019; Evans, 2021).

Approximately 90% of the low-lying renosterveld vegetation has been substituted by orchards and vineyards (Moncrieff, 2021). Only a small portion of the renosterveld (6%) occurs on granites (Rebelo *et al.*, 2006) where the FRg3 is also found. The topography of the FRg3 is very mountainous with very steep slopes. Therefore, this makes it impossible for agricultural machinery to cultivate a larger extent of the vegetation type. Hence, the FRg3 still maintains most of its natural habitat (Rebelo *et al.*, 2006; Ntshanga *et al.*, 2021) and is classified as Least Concern (LC) by Skowno *et al.* (2019). However, the FRg3 is so understudied that it is considered to be virtually unknown (Rebelo *et al.*, 2006), this is primarily due to its isolated character on a granite pluton. Rebelo *et al.* (2006) further made a recommendation that the vegetation type needed scientific attention and to date only one previous study on the vegetation type has been undertaken (Hesewu, 2022).

The South African National Vegetation Map (NVM) has been the basis for the Terrestrial Ecosystem Map, which is crucial for spatially explicit conservation planning in South Africa.

The first iteration of the NVM was published in 2006 (Rutherford and Mucina, 2006); since then, it has been the mandate of the South African National Biodiversity Institute's (SANBI) to improve and refine parts of the map that shows the different vegetation types. This study forms part of the NVM which is a key input dataset for the National Biodiversity Assessment (NBA) (Skowno *et al.*, 2019). Therefore, since the NBA relies on updated information on ecosystems, results from this study will provide an updated representation of the FRg3 on a national scale through NBA. Furthermore, this study will contribute to the Red List of Ecosystems (RLE) assessment (conducted by SANBI in collaboration with many experts) by providing an update on the threats faced by the FRg3. Information on extent of threats to the FRg3 will form part of Criterion D in the RLE assessment, which focuses on the disturbance of biotic processes occurring within a fraction (plant communities of the FRg3) of an ecosystem (Skowno and Monyeki, 2021).

The FRg3 is presently listed as Least Concern (LC) on the RLE status (Government of South Africa, 2022). However, the primary threats to the vegetation type were not compiled during the 2022 assessment due to lack of comprehensive data on the FRg3 condition including disturbances such as alien invasive species, land overutilization, fire regime, and other environmental degradation (Government of South Africa, 2022). There was an attempt to map the extent of the FRg3 using remote sensing techniques (Hesewu, 2022) and the study identified the dominant species through cursory site visits. However, the plant communities that characterise the vegetation type were not fully described. Furthermore, Hesewu (2022) did not investigate the fire history, threats, and changes in vegetation structure over time of the FRg3.

1.5 Aims and objectives

- I. Identify the plant communities that make up the Robertson Granite Renosterveld (FRg3) and investigate their relationship with the habitat or environmental characteristics
 - a) Classify the plant communities within the FRg3
 - b) Determine the relationship between environmental variables and the plant communities.
 - c) Identify the threats to the FRg3.

- II. Investigate the fire history of the Robertson Granite Renosterveld (FRg3) from 2000 to 2023 and how fire influences the distribution of plant communities within the vegetation type.
 - a) Investigate the fire history and map the extent of each fire event within the FRg3
 - b) Identify the communities situated in fire-affected locations

- III. Investigate the changes in vegetation structure from 2000 to 2023
 - a) Quantify the changes in vegetation structure using NDVI imagery from 2000 to 2023
 - b) Describe the relationship between fire and the changes in vegetation structure over the 24 years

1.4 Study site

The Robertson Granite Renosterveld (FRg3) is located in the Langeberg local municipality, north of Robertson, Western Cape, South Africa (Figure 1.1). Furthermore, the FRg3 is in a very limited area of the Breede River Valley at altitudes of between 250 and 850 m.a.s.l (Rebelo *et al.*, 2006). The FRg3 is largely covered by private properties with five parent farms (De Hex Rivier, Diep Kloof, Klein Asgeibos, Kruispad, Langevalley, Norree, and Zand River) occupying the vegetation type (Figure 1.1). According to the 2018 version of the NVM, the FRg3 covers an area of 1 923ha. The vegetation of FRg3 is classified as dense 2m tall

shrubland with patches of grasses and scattered trees, the vegetation type also has an above average succulent element (Rebelo *et al.*, 2006).

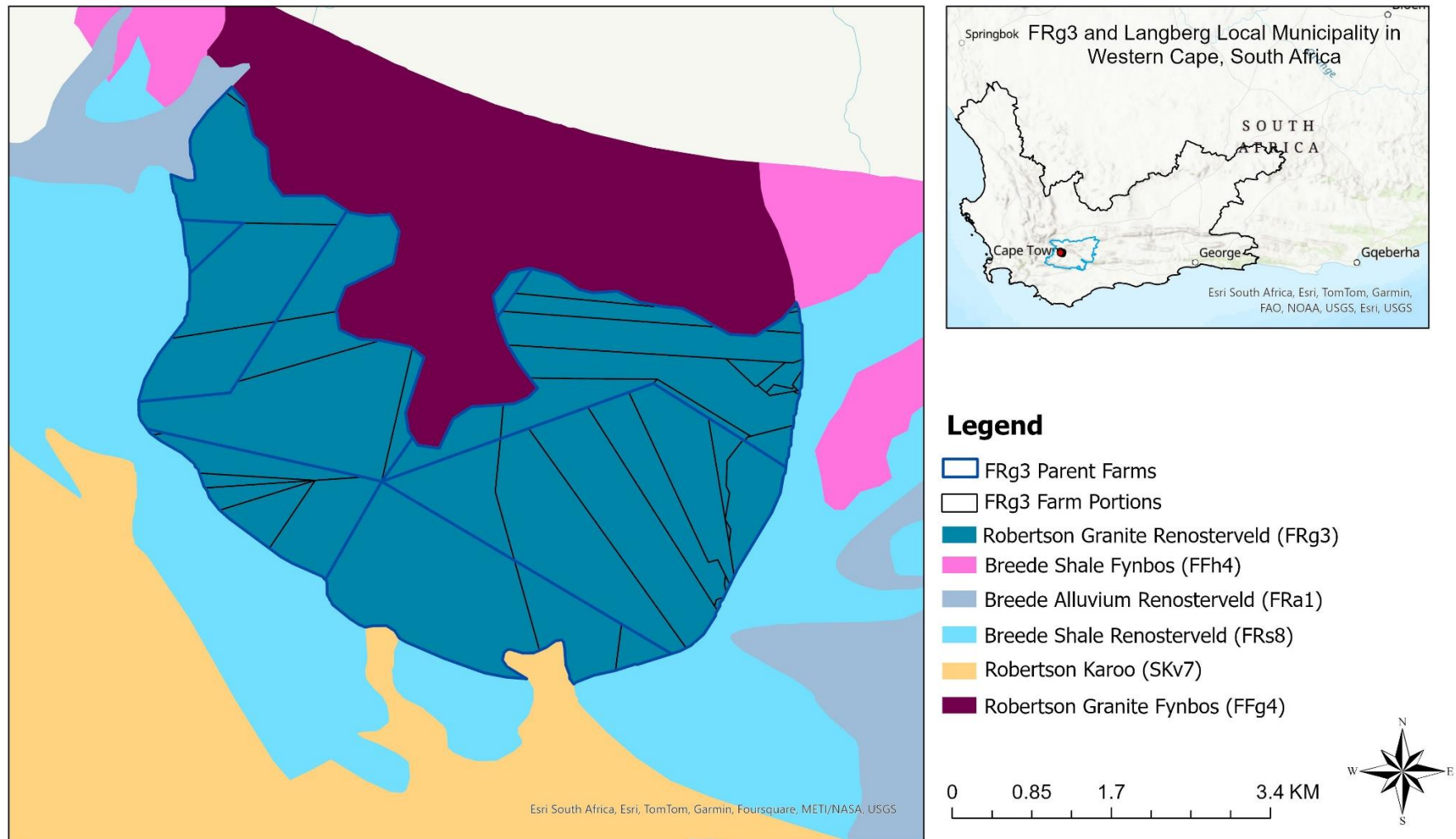


Figure 1.1: Robertson Granite Renosterveld (FRg3) and the five surrounding vegetation types. The insert highlights the Langeberg Local Municipality, Robertson, Western Cape, South Africa (19.89°E ,33.77°S).

The mean annual rainfall at the FRg3 is between 360-740mm (Rebelo *et al.*, 2006). Furthermore, this vegetation type experiences winter rainfall peaking between May and August. The maximum average daily temperature within the FRg3 is 28.7 °C in February and the minimum average temperature of 4.0 °C is usually in July (Rebelo *et al.*, 2006).

According to Rebelo *et al.* (2006) some of the important taxa found within the vegetation type include tall shrubs (*Euclea undulata*, *Rhus lucida*, *Rhus tomentosa*, *Rhus pallens*, *Olea europaea* subsp. *africana*, *Euryops tenuissimus*, *Dodonaea viscosa* var. *angustifolia*, *Myrsine africana*); low shrubs (*Dicerotheramnus rhinocerotis* (formally known as *Elytropappus rhinocerotis*), *Pteronia incana*, *Pteronia pallens*, *Eriocephalus africanus* var. *africanus*, *Oedera squarrosa*, *Euryops rehmannii*, *Maytenus oleoides*, *Senecio pinifolius*); succulent shrubs (*Euphorbia burmannii*, *Ruschia caroli*, *Tylecodon paniculatus*); and graminoids (*Ehrharta calycina*, *Ehrharta thunbergia*, *Ficinia ramosissima*, *Ischyrolepis gaudichaudiana*, *Pentameris eriostoma* (formally known as *Pentaschistis eriostoma*)).

1.6 Study approach and thesis structure

This study employed a combination of plot-based vegetation sampling and remote sensing to improve the current understanding of the Robertson Granite Renosterveld (FRg3) vegetation type. Hierarchical cluster dendrograms were created to classify the sampled plots into plant communities that characterised the FRg3. Furthermore, the species diversity, evenness, and abundance were calculated to provide a broader understanding of the plant diversity of the vegetation type. The relationship between environmental variables and plant communities was investigated using multivariate analyses. This study spanned over two years and incorporated a 24-year (2000 – 2023) historical analysis of fire (MODIS) satellite imagery and landcover (Landsat) imagery.

This study is made up of three data chapters (chapter 2, 3, and 4). Chapter 2 focuses on the plant communities found within the FRg3 and their relationship with environmental variables. Chapter 3 focuses on the fire history of the vegetation type and how fire has influenced the distribution of plant communities across the vegetation type. Chapter 4 focuses on how the vegetation structure of the FRg3 has changed over 24 years (2000 – 2023), and how fire has contributed to the structural changes of the vegetation during the specified period. Chapter 5 summarizes and synthesizes the key findings from the three data chapters and provides the recommendations for future research on the vegetation type. The three data chapters are written as independent papers to be submitted for publication at a later stage even though the reference lists and appendices are merged for all chapters at the end of the thesis. In that regard, there will be some inevitable repetition as there is some overlapping topics shared among the chapters.

Chapter 2: Plant communities and habitat characteristics of the Robertson Granite Renosterveld (FRg3)

Abstract

Understanding the ecology of plant communities for a particular ecosystem/vegetation type is crucial for policy and decision-makers as it helps make scientifically informed decisions and implement the necessary conservation measures where needed. This chapter aims to classify the plant communities of Robertson Granite Renosterveld (FRg3) and investigate their relationship with environment or habitat characteristics. A total of 53, 10m x 5m plots were positioned across the FRg3 to investigate the composition and cover abundance of species within the vegetation type. In addition, environmental variable (altitude, topographic variables, and the ground covers of herbaceous vegetation, litter, bare ground, and rock) and soil characteristics (pH [KCl], total organic carbon (C), extractable boron (B), exchangeable phosphorus (P), extractable sodium (Na), extractable magnesium (Mg), extractable potassium (K), extractable calcium (Ca), and soil texture (sand, silt, and clay)) were recorded from each plot. Multivariate analyses (PCA & CCA) were performed to assess the relationship between habitat characteristics/environmental variables, and with the plant communities. Soil analysis showed significant differences ($P \leq 0.05$) in pH, Na, and texture (sand and clay) across the five communities. Plant communities were classified using dissimilarity hierarchical cluster analysis, which identified the five major plant communities within FRg3 as follows: *Dodonaea viscosa*–*Euryops tenuissimus*, *Dicerothamnus rhinocerotis*–*Dodonaea viscosa*, *Passerina obtusifolia*–*Restio capensis*, *Pteronia paniculata*–*Dicerothamnus rhinocerotis*, and *Muraltia heisteria*–*Restio capensis*. There were no statistically significant differences in the species richness, evenness, and diversity (Shannon and Simpson) across the five major plant communities found in the FRg3. However, *Pteronia paniculata*–*Dicerothamnus rhinocerotis* community has the highest richness while *Passerina*

obtusifolia–*Restio capensis* has the lowest. The species evenness is very similar across the five communities. The primary threats to the vegetation type include invasion by alien shrubs/tree species from the genus *Hakea* and *Acacia*, and various agricultural activities; these pressures only affected 1% of the FRg3.

Keywords: Environmental factors, Plant communities, habitat, soils, threats

2.1 Introduction

Vegetation community studies provide information on species richness and diversity of ecosystems, which is important for conservation and biodiversity management (Ejtehadi *et al.*, 2005; Van Staden *et al.*, 2021). The communities are differentiated using physiognomic, floristic, and structural characteristics (Stark & Hudson, 1985). In addition, sampling often varies across different biomes in terms of plot size, habitat characteristics, and disturbances (Campbell, 1983; Campbell, 1984; Cowling & Witkowski, 1994; Cowling *et al.*, 1994; Witkowski and O'Connor, 1996; Van Staden *et al.*, 2021). Due to its nutrient-rich soil, the lowland renosterveld is highly fragmented with less than 15% of its natural extent remaining (Kemper *et al.*, 1999; Cowan, 2014).

Most of the fragmentation results from crop agriculture, which is the key driver of land degradation within the renosterveld ecosystems (Kemper *et al.*, 2000; Kotzé and Fairall, 2006; Rouget *et al.*, 2006; Topp & Loos, 2019). Another source of land degradation within these ecosystems is the presence of invasive alien plants such as species in the Australian genera *Acacia* (wattles), *Eucalyptus*, and *Hakea* (Topp & Loos, 2019). However, mountain renosterveld ecosystems are categorised by nutrient-poor soils and steep slopes (Rebelo *et al.*, 2006; Curtis, 2013). The steep slopes prevent agricultural machinery from ploughing on the mountainous terrain (Kemper, 2000; Rebelo *et al.*, 2006; Topp & Loos, 2019). Hence, some renosterveld ecosystem types are classified as least threatened (Rebelo *et al.*, 2006).

The environment or habitat characteristics play an important role in shaping the composition and structure of plant communities in particular areas (Herault & Thoen, 2009; Birhanu *et al.*, 2021; Rippel *et al.*, 2024), which make the relationship between plant communities and habitat characteristics an important question in plant ecology (Burke, 2001;

Yavitt *et al.*, 2009; Birhanu *et al.*, 2021). Numerous plant ecology studies have been conducted on different vegetation types within the Cape Floristic Region (CFR) and the Fynbos biome (Campbell, 1983; Campbell, 1984; Moll *et al.*, 1984; Curtis, 2013; Cowan, 2014; Topp & Loos, 2019). However, little attention was given to the Robertson Granite Renosterveld (FRg3) (Rebelo *et al.*, 2006).

Vegetation assessment (classification and mapping) is a key component for scientifically informed decisions on environmental issues (Gibbons & Freudenberger, 2006; Brown *et al.*, 2013). Hence, the demand for phytosociological data has increased to guide ecosystem management and conservation policies (Brown *et al.*, 2013). The National Vegetation Map of South Africa, Lesotho and Swaziland (NVM) provides a classification of plant communities across South Africa (Dayaram *et al.*, 2017). However, the NVM is less effective at classifying the vegetation communities at a local scale (Greenberg *et al.*, 2006; Dayaram *et al.*, 2017). Hence, most vegetation types, including the FRg3, have been coarsely mapped and not fully described (Rebelo *et al.*, 2006; Dayaram *et al.*, 2019; Hesewu, 2021). Therefore, fine-scale vegetation data on plant communities and habitat characteristics of the FRg3 is needed to inform the NVM and improve the confidence of decision-makers with up-to-date information about the vegetation type.

2.1.1 Aim and Objectives

This chapter aimed to classify the plant communities within the Robertson Granite Renosterveld (FRg3) and investigate their relationship with the habitat/environmental characteristics. The first objective was to determine the plant communities found within the FRg3. The outcomes of this objective were presented in the form of a cluster dendrogram. The second objective was to determine the relationship between environmental variables (slope

aspect, slope gradient, slope position, altitude, soil texture and chemical components) and plant communities within the FRg3 using multivariate analyses such as Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA). The third objective was to determine the species diversity, richness, and evenness of the FRg3. The last objective was to determine the threats to the vegetation type.

2.2 Methods

2.2.1. Preliminary site visit

A preliminary site visit was conducted from 09 March 2023 to 11 March 2023. The purpose of this preliminary site visit was to get a visual understanding of the distribution of the different plant communities found in the FRg3. The information obtained from the preliminary site visit played an important role in developing a clearer idea of where the potential plots could be placed to adequately represent the communities within the vegetation type.

2.2.2. Fieldwork preparations

To ensure a comprehensive analysis of vegetation data, the localities of plots (centroid) for potential plant communities within the FRg3 were created on ArcGIS Pro 3.0 before visiting the field. A stratified random sampling method was used to strategically position plots to capture communities from different slope aspects and slope positions. A layer containing 25 m interval contour lines was created from a Digital Elevation Model (DEM) on ArcGIS Pro (Appendix 1.1). The contour line layer was overlaid with the FRg3 boundary layer and a layer of demarcated farm boundaries to observe the steepness and accessibility to the potential plots. The FRg3 is situated primarily on private land, therefore, the landowners were contacted through the Rooiberg Breede River Conservancy to request permission to access their property and collect

data for this study. Furthermore, a collections permit was obtained on the 19th of May 2023 from CapeNature.

At the start, an electronic field herbarium was created based on the taxa that Rebelo *et al.* (2006) and Hesewu (2021) listed. The field herbarium contained a preliminary list of species that could be found on the FRg3 with their pictures to make species identifications easier and more efficient on the field. In addition, a collections project named *Thapelo's MSc* (<https://www.inaturalist.org/projects/thapelo-s-msc-project>) was created on iNaturalist for this study on the 06th of March 2023. This project was generally created to visualize observations using iNaturalist search tools to automatically include observations that match specified parameters such as location, life form, date, taxa, and others tailored to the project's needs (Carrieseltzer, 2018). The platform was used to verify the identifications made in the field.

2.2.3 Data collection

2.2.3.1 Arrangement of plots

Fifty-three 10 x 5m plots were subjectively positioned across the FRg3 based on floristic, structural, and habitat homogeneity. Areas affected by disturbances such as invasive alien species, agricultural activity, roads/pathways, and old fields were avoided during the placement of the plots. Due to the steep slopes of the FRg3, the rectangular-shaped plots were positioned with the longer side parallel to the contour to mitigate cross-community sampling as stated by Dearborn & Danby (2017). Four plots were demarcated on each of the three different slope positions along the catena (upper-middle-lower slope) for each slope aspect (North, South, East, and West). The remaining plots sampled communities on the bottom (flat) lands.

2.2.3.2 Habitat characteristics

Habitat characteristics recorded at each plot included the position of the plot on the slope, the slope gradient and aspect, and the Global Positioning System (GPS) coordinates (longitude, latitude, and altitude). In addition, the presence of exposed rocks, termite mounds, and evidence of herbivory were noted when describing the demarcated plots. Furthermore, the percentage covers of litter, bare ground, rock, and total canopy cover within each plot were recorded. The estimated percentage covers were determined using the Domin cover-abundance scale (Table 1.1). The Domin scale and Braun-Blanquet scale are similar in use (Table 1.1; Wikum and Shanholtzer, 1978), however, the Domin scale was the preferred measuring scale on the current study for its advantages highlighted in Chapter 1.

Table 1.1: The Domin scale with its ordinal score, percentage conversion range and the converted percentage cover against the Braun-Blanquet abundance scale with its traditional ordinal score, extended score, percentage cover range, and the converted percentage cover.

Domin scale			Braun-Banquet abundance scale			
Ordinal score	Cover range (%)	Converted percentage cover	Traditional ordinal score	Extended ordinal score	Cover range (%)	Converted percentage cover
+	<1	0.1				
1	<1	0.3	r	r	<1	0.1
2	<1	0.5	+	+	<1	0.5
3	1-4	3	1	1	1-5	3
4	5-10	8		2m	<5	4
5	11-25	18		2a	5-12.5	9
6	26-33	30		2b	12.6-25	19
7	34-50	42	2		5-25	15
8	51-75	63	3	3	26-50	38
9	76-90	83	4	4	51-75	63
10	91-100	98	5	5	76-100	88

2.2.3.3 Species

Species observed within each plot were recorded and their cover-abundance was estimated using the Domin cover-abundance scale (Table 1.1). Furthermore, species that occurred within a 1m wide belt outside the plot but not inside the plot were recorded and assigned the value “O” as per McKenzie *et al.* (1977) and Joubert & Moll (1992). However, these species were excluded from the statistical analyses (since they were outside the 10x5m boundary) but were included when compiling the species list of the FRg3. Specimen samples of species that were difficult to identify in the field were collected to be later sent to the herbarium for identification.

iNaturalist was also used to confirm some plant identifications made in the field. Photographic images of species within the plots were captured using a smartphone camera and uploaded onto *Thapelo's MSc* iNaturalist project, the VEGMAPhoto (s Afr) project (<https://www.inaturalist.org/projects/vegmaphoto-s-afr>) on iNaturalist was tagged to every uploaded observation. The Rooi Breede River Conservancy highlighted a concern about compromising the locations of sensitive species, therefore, the location of the species was set to private on iNaturalist for all records to avoid compromising the location of sensitive species. For each record, at least five (5) images were captured as follows (i) the inflorescence/flower; (ii) the stem/buck, (iii) a close view of leaves (top and bottom sides); (iv) the canopy of the plant; and (v) the landscape where the plant(s) was found.

Environmental disturbances that occurred in the area around the plot were recorded. The observations of alien invasive species were recorded on iNaturalist to confirm their identification and their coordinates were noted. Furthermore, a GPS was used to record the coordinates of other forms of disturbance (old fields, plantations, and agricultural land).

2.2.3.4 Soil data collection and preparation

Soil samples were collected from the four corners and the centre of each plot using a garden trowel, at a depth of 0 – 15 cm, or as deep as possible on rocky surfaces. The five samples were mixed in a plastic bag and labelled by plot number. The soil samples were later air-dried at room temperature.

2.2.4 Data analyses

2.2.4.1 Vegetation data analyses

The South African Nation Biodiversity Institute (SANBI) Red List of South African Plants website (<http://redlist.sanbi.org/index.php>) was used to obtain the taxonomic information on all species occurring within the FRg3. Alien plants are not evaluated on the Red List of South African Plants website, thus, iNaturalist and Royal Botanic Gardens, Kew (<https://powo.science.kew.org/>) were used to obtain the taxonomic information on these species. Species with a height greater or equal to 1.5m were classified as tall shrubs and those with a height less than 1.5m were classified as Low Shrubs (Rebelo *et al.*, 2006). Grass-like species (i.e. *Restio* and *Pentameris*) were classified as Graminoids (Burgess *et al.*, 1988; Kull and Aan, 1997), while the thick-leaf shrubby/rosette-like species exhibiting traits of storing water in the leaves were classified as Succulent (Burgess *et al.*, 1988). The species with tuberous and subterraneous organs such as bulbs, rhizomes, tubers, and corms, were classified as geophytes (Procheş, *et al.*, 2006).

2.2.4.2 Community classification

Vegetation data was captured in Excel and rearranged (Row = species name; Column = plot No.) for community classification. The ordinal scores from the Domin scale were converted to the percentage covers shown in Table 1.1. The *pvclust* and *hclust1d* packages in R studio version 4.3.2 were used to create a hierarchical cluster dendrogram based on a dissimilarity index

using the Euclidean distance and Ward's method. The dendrograms were plotted using the *Rcmdr* and *grDevices* packages to display the most similar and dissimilar plots. The most similar plots were grouped into communities.

The FRg3 plant communities were mapped on ArcGIS Pro. The community boundaries were demarcated using the field plot information and historical (pre-1970s) aerial photographs from the National Geo-spatial Information (NGI) website (<http://www.cdngiportal.co.za/CDNGIPortal/>) as a guide. The NGI imagery was first georeferenced and overlaid with the plot centroids (which are already classified into communities). The extent of each community was mapped with reference to the position of the plot centroids, where the historical imagery was primarily employed to derive patterns that helped determine the extent of each demarcated community. This study did not explore the riparian areas, however, the forest polygons along the riverine localities were digitized together with community polygons from NGI imagery. The map elements (North Arrow, legend, and scale bar) were inserted into the map, and the output was exported as an image (.jpg).

2.2.4.3 Species richness, diversity, evenness, accumulation and species abundance

Species richness, diversity and evenness were calculated for each community using the *vegan* package in RStudio. The processing began with calculating richness using the *specnumber()* tool. The Shannon's diversity was calculated using the *diversity()* tool and specified "Shannon" as the index. The Simpson's diversity was also calculated using the same *diversity()* tool and "Simpson" specified as the index. Species evenness was first calculated using the Shannon diversity results, however, this approach indicated a value of 1 (indicating an absolute equal distribution) for all plots, which is unlikely and ecologically unrealistic for species

to have an absolute equal distribution. Therefore, the Simpsons diversity was then used to calculate the evenness. This was calculated using the formula: $Evenness = \frac{1 / Simpson\ diversity}{Species\ richness}$

The *aggregate()* tool was employed after each calculation (richness, evenness, and diversity) to determine the mean and standard deviation (SD) of species richness, evenness, and diversity across the five communities. Furthermore, One-way ANOVAs were performed to compare species richness, evenness and diversity between the plant communities. The output from these calculations were visualized using boxplot figures created in the *ggplot2* package.

The computation of species rank abundance curve began with loading the *vegan* package, followed by summing up the presence of species across all plots within the FRg3 (represented by 1 on the data). The rank was then sorted in descending order and the *ggplot2* package was used to plot the rank abundance graph. Furthermore, the *Text()* tool was used to annotate the five most abundant species on the rank abundance curve. The 10 most abundant species within the vegetation type were tabulated using the *head()* tool and rank number 10 was specified only to show the top 10 species.

The species accumulation curve was also created using the *vegan* package. The *specaccum()* tool was used to calculate the accumulation of species with an increase in sample size (number of plots). The output was visualized graphically using the *plot()* tool.

The Jaccard and Sørensen's indices were computed to compare pairwise species composition among the communities. The processing began with defining the community factor based on the five classified communities. The indices were computed using the *vegdist()* tool, then the function *calc_avg_similarity()* was used to calculate the average similarities between the communities. After calculating the Jaccard and Sørensen similarities, the Jaccard results were

converted into a matrix while Sørensen results were converted into a data frame. The outputs were visualized using heatmaps clustered by the Euclidean distance.

2.2.4.4 Soil analysis

Soils were analysed at the Elsenburg, Department of Agriculture Laboratory, for multiple variables: pH (KCl); Exchangeable Acidity; Extractable Boron (B); Extractable Calcium (Ca); Extractable Magnesium (Mg); Extractable Potassium (K); Extractable Sodium (Na); Total cations exchange capacity (T-value); Extractable Phosphorus (P); Organic Carbon (C); Resistance (Ohms); Soil texture (%Clay; %Sand; and %Silt). The analyses were performed following the methods in the Non-Affiliated Soil Analysis Work Committee (1990). The analyses of the above-mentioned components began with soil preparation which involved crushing the air-dried soil samples and sieving them through a 2 mm sieve to remove large particles and debris. Samples were then placed into suitably marked containers and filled to no more than 75% of the container capacity. The methods and procedures are detailed in Table 1.2.

Table 1.2: Methods and procedures for the extraction and analysis of different soil chemical components (phosphorus (P), boron (B), and soil pH (KCl)) following guidelines in the Non-Affiliated Soil Analysis Work Committee (1990).

Chemical component	Methods/procedure
Extractable phosphorus (P)	<p>The extraction of phosphorus (P) using the Olsen method for the ICP OES analysis.</p> <ul style="list-style-type: none"> • Prepare 0.5 mol dm⁻³ solution of NaHCO₃. • Adjust the pH to 8.5 using 50% NaOH. • Mix 50 cm³ of the NaHCO₃ solution with 2.5g of the sieved soil sample and shake for 30 minutes on a reciprocating shaker at 180 oscillations per minute. • Filter the mixture through a Whatman No.40 filter paper. • Calibrate the ICP OES instrument in accordance with the phosphorus standards. • Introduce the soil extracts into the ICP OES instrument using a spray chamber and a nebulizer. • Record the emission intensities at the specified phosphorus wavelength upon equipment calibration. • The recorded emission intensities were then converted into phosphorus concentrations which were recorded in mg/kg.
Extractable boron (B)	<p>The extraction and testing of boron (B) was performed through the Calcium Chloride (CaCl₂) extraction method.</p> <ul style="list-style-type: none"> • Prepare 0.02 mol dm⁻³ CaCl₂ solution (Dissolve 3g CaCl₂·2H₂O with 72-76% of CaCl₂ in 1 dm³ of de-ionized water). • Prepare curcumin-oxalic acid (C₂₁H₂₀O₆ · C₂H₂O₄) solution (Mix 0.04g of finely ground curcumin and 5g of oxalic acid then dissolve the mixture in 100 cm³ redistilled ethanol. • Boil 25g of the 2 mm soil samples with 50 cm³ 0.02 dm³ of the CaCl₂ solution for 15 minutes. • Filter the boiled solution through Whatman No.41 filter paper into a plastic bottle. • Calibrate the ICP OES instrument in accordance with the boron standards. • Introduce the soil extracts into the ICP OES instrument using a spray chamber and a nebulize. • Record the emission intensities at the specified boron wavelength upon equipment calibration. • The recorded emission intensities were then converted into boron concentrations which were recorded in mg/kg.
pH (KCl)	<p>The pH level of the soils was tested using the potassium chloride (KCl) method.</p> <ul style="list-style-type: none"> • Prepare KCl solution 1 mol dm⁻³ (dissolve 74.5g of KCl in 1 dm³ deionized water). • Mix 25 cm³ of the KCl solution with 10g of the sieved soil and stir rapidly for 5 seconds using a glass rod. • Stir again after 50 minutes and leave for 10 minutes to settle. • Calibrate the pH meter using the standard buffer solution (pH=4.0 and 7.0 or 0.8). • Inset the calibrated pH electrode into the soil suspension and record the pH values displayed. • Rinse the electrode with deionized water after each measurement to mitigate contamination.

<p>Extractable calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), and sodium (Na).</p>	<p>Extractable Ca, Mg, P, K, and Na were extracted and tested using the Citric Acid extraction solution.</p> <ul style="list-style-type: none"> • Prepare Citric acid (heated at 80°C), Hydrochloric acid (concentrate), and Nitric acid (concentrate). • Mix 20 g of sieved soil with 200 cm³ of 1% citric acid in a 500 cm³ flask. • Shake the flask and leave to settle in an oven at 80°C, then shake the solution every 10 minutes then remove it after an hour. • Filter the mixture through a Whatman No.42 filter paper once settled. • The stock solutions for P, K, Ca, Mg, and Na were used to make a series of standards to calibrate the ICP OES instrument. • Therefore, the soil extracts were introduced into the ICP OES instrument using a spray chamber and a nebulizer. • Record the emission intensities at the specified P, K, Ca, Mg, and Na wavelengths upon equipment calibration. • The recorded emission intensities were then converted into phosphorus concentrations which were recorded in mg/kg.
<p>Organic Carbon (C) using the Walkley-Black method</p>	<p>Carbon levels in the soils of the vegetation type were tested using the Walkley-Black method.</p> <ul style="list-style-type: none"> • Grind the soil to pass through a 0.35 mm sieve. • Prepare potassium dichromate solution (K₂Cr₂O₇), sulfuric acid (H₂SO₄), iron (II) ammonium sulphate solution (Fe(NH₄)₂(SO₄)₂·6H₂O), and diphenylamine sulphonate indicator (C₁₂H₁₀NNaO₃S). • Begin oxidation by mixing 10 cm³ of K₂Cr₂O₇ solution, 20 cm³ of H₂SO₄, and 1g of sieved soil in a 500 cm³ Erlenmeyer flask. • After swirling the flask vigorously for about 1 minute, leave the mixture to settle for 30 minutes, then dilute with 150 cm³ of deionized water. • Diphenylamine indicator (1 cm³) and phosphoric acid (10 cm³) were added to the mixture and titrated with Fe(NH₄)₂(SO₄)₂·6H₂O until the colour changed from purple to a green endpoint. • The blank determination was performed to account for any background reagents. • The organic carbon content was calculated in percentages using the following formula: • %Organic Carbon = $\frac{[cm^3 Fe(NH_4)_2(SO_4)_2 \text{ blank} - cm^3 Fe(NH_4)_2(SO_4)_2 \text{ sample}] \times M \times 0.3 \times f}{soil \text{ mass } (g)}$ • Where M = the concentration of the Fe (NH₄)₂(SO₄)₂ in mol dm⁻³ calculated using the formula: $M = \frac{10cm^3K_2Cr_2O_7 \times 0.167 \times 6}{cm^3 Fe (NH_4)_2(SO_4)_2}$

2.2.4.5 Soil statistical analysis

One-way ANOVAs were performed on the soil properties and other habitat characteristics to determine statistical differences ($P \leq 0.05$) between the five major plant communities. This was done using the packages *agricolae* and *multcompView* in R. Fisher's least significant difference (LSD) is one of the commonly used methods involving the comparison of

two or more means (Okwonu & Ahad, 2020); this method was used to identify the specific values between communities that were significantly different from each other.

2.2.4.6 Habitat characteristics influencing the community classification

The environmental data was captured on a separate spreadsheet and rearranged (Rows = Plot No.; Columns = environmental variables). The fire frequencies (detailed in chapter 3) were combined with the environmental information for statistical analysis. The more descriptive variables were also converted into numeric variables for them to be analysable when performing the different ordinations. For example, slope position (Upper, Middle, and Lower slope) was then converted into numbers using the following approach: 1=Upper-slope, 2=Middle-slope, and 3=Lower-slope. A similar numeric conversion was done fire frequency (No fire = 0, fire of 2000 only = 1, fire of 2006 only = 2, fire of 2017 only = 3, Overlap of 2000 & 2006 = 4, Overlap of 2000 & 2017 = 5, Overlap of 2006 & 2017 = 6). A Principal Component Analysis (PCA) was performed in R using the *vegan* package to identify patterns and reduce the dimensionality of the environmental variables (Wold *et al.*, 1987; Richardson, 2009; Mishra *et al.*, 2017). The ordination determined the variations and correlations among environmental variables. In addition, the PCA helped to detect the important variables possibly driving the variations.

The Canonical Correspondence Analysis (CCA) was then performed in R using the following packages: *vegan*; *ggplot2*; and *ggrepel* to investigate the association of species with environmental variables. The data preparation and arrangement began with importing both vegetation and environmental data into R studio. The CCA was performed where the environmental variables were added to the ordination using the *envfit()* tool. Only environmental variables exhibiting significant differences (from one-way ANOVAs) were included in the

ordination. The *ordiellipse()* tool was employed to group plots that belong to the same community and add an ellipse around each cluster.

2.2.4.7 Environmental disturbance and threats to the vegetation type

The localities of alien invasive plants found within the FRg3 were mapped on ArcGIS Pro using the coordinates from the GPS. Other forms of disturbance such as agricultural lands, plantations, and old fields were digitized from Google Earth Pro, this platform was preferred because it provides up-to-date (2024) imagery. Upon digitization, prior knowledge about the landscape of FRg3 obtained from the field surveys was employed to confirm the classification of digitized features.

2.3 Results

2.3.1 Community classification results

The results indicate that the FRg3 comprises grassy and shrubby communities with a presence of succulent species. The dominant grasses include *Pentameris eriostoma* with some patches of *Eragrostis curvula*. The shrub communities consisted of both tall and short shrub communities. The tall shrub communities were dominated by *Dodonaea viscosa* and *Passerina obtusifolia*, whereas short shrub communities were dominated by *Pteronia paniculata*; *Dicrothamnus rhinocerotis*; *Muraltia heisteria*. Figure 1.1 displays the five distinct clusters representing specific plant communities, which were named based on the two most dominant species; the phytosociological table in Appendix 1.3 shows the species composition for each major community as well as the environmental characteristics related to each plot within the major communities.

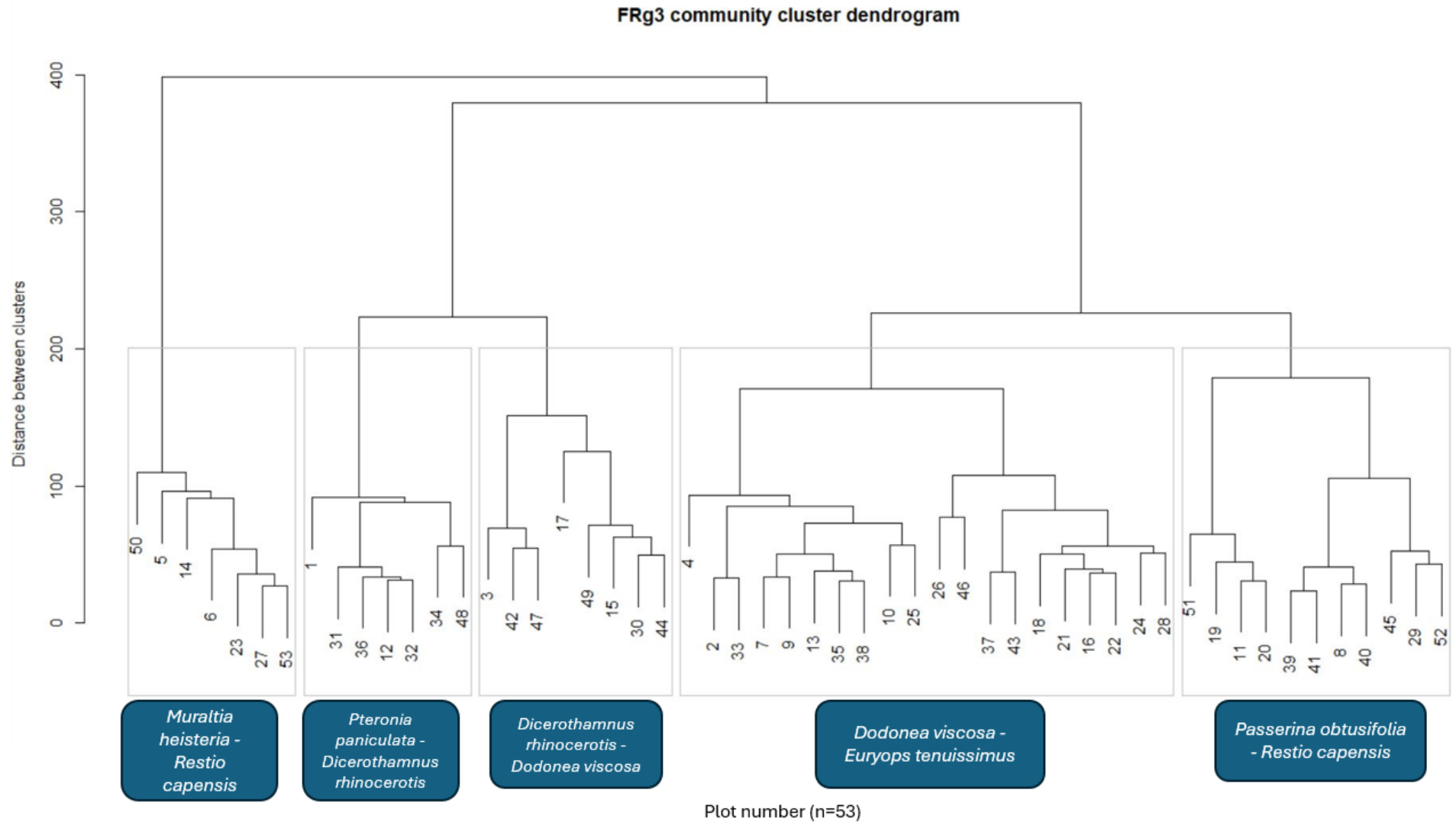


Figure 1.1: Hierarchical cluster dendrogram of 53 plots clustered into five groups by similarity to make up the five major plant communities found within the Robertson Granite Renosterveld (FRg3). The communities were named based on the two most dominant species and the clustering threshold was set at 200.

Plots on the first cluster from the left (Figure 1.1) represent the community dominated by *Muraltia heisteria* with some grass patches (*Restio capensis* and *Pentameris eriostoma*). The average height of species in these communities is approximately one meter.

The second cluster represents a shrubby community with some succulent elements. This community is dominated by *Pteronia paniculata* with some patches of *Dicerotheramnus rhinocerotis*. The average height of this shrubby community is approximately one meter and there is a presence of dwarf succulents within the communities which makes it very distinct from the *Muraltia heisteria* community described above. The larger shrubs (*Dodonaea viscosa* and *Searsia pallens*) were also observed on rocky areas within the same communities. Most of these communities had droppings of animals which suggested the presence of herbivores. In addition, there were observations of lichen covering the exposed rocks and stems of *Pteronia paniculata*.

The third cluster represents a shrubby community dominated by *Dicerotheramnus rhinocerotis*. Species that appeared frequently in this community include *Dodonaea viscosa*, and *Pteronia paniculata*. The average height of these communities is approximately one meter. The presence of lichen was observed covering the exposed rocks in some of the *Dicerotheramnus rhinocerotis* communities, especially those with a high presence of *Pteronia paniculata*.

The fourth cluster represents a shrubby community dominated by *Dodonaea viscosa*. The community is relatively dense and tall (~2m) compared to other communities within the vegetation type. Some species such as *Euryops tenuissimus*; *Restio capensis*; *Dicerotheramnus rhinocerotis*; *Passerina obtusifolia*, and *Pteronia paniculata* appeared in most of the *Dodonaea viscosa* communities.

The last cluster represents a dense *Passerina obtusifolia* community. This community is dominated by tall shrubs with an average height of approximately 1.5m. The abiotic elements

found within this community include exposed rocks and termite mounds. Other species occurring mostly within this community include *Restio capensis*; *Pentameris eriostoma*; and *Dodonaea viscosa*.

The *Muraltia heisteria*–*Restio capensis* community was commonly found on steep upper slopes of the FRg3 mountains (Figure 1.2). The *Pteronia paniculata*–*Dicerotheramnus rhinocerotis* community is commonly found on the south-facing moderate to steep slopes. The *Dicerotheramnus rhinocerotis*–*Dodonaea viscosa* community is mostly found on the south-facing moderate to steep slopes and usually occurs on the middle-slope areas along the catena. The *Dodonaea viscosa*–*Euryops tenuissimus* community is widespread across the vegetation type and occurs on different slope aspects, gradients, and positions on the mountainous FRg3. The *Passerina obtusifolia*–*Restio capensis* community is widespread across the south-facing slopes of the vegetation type.

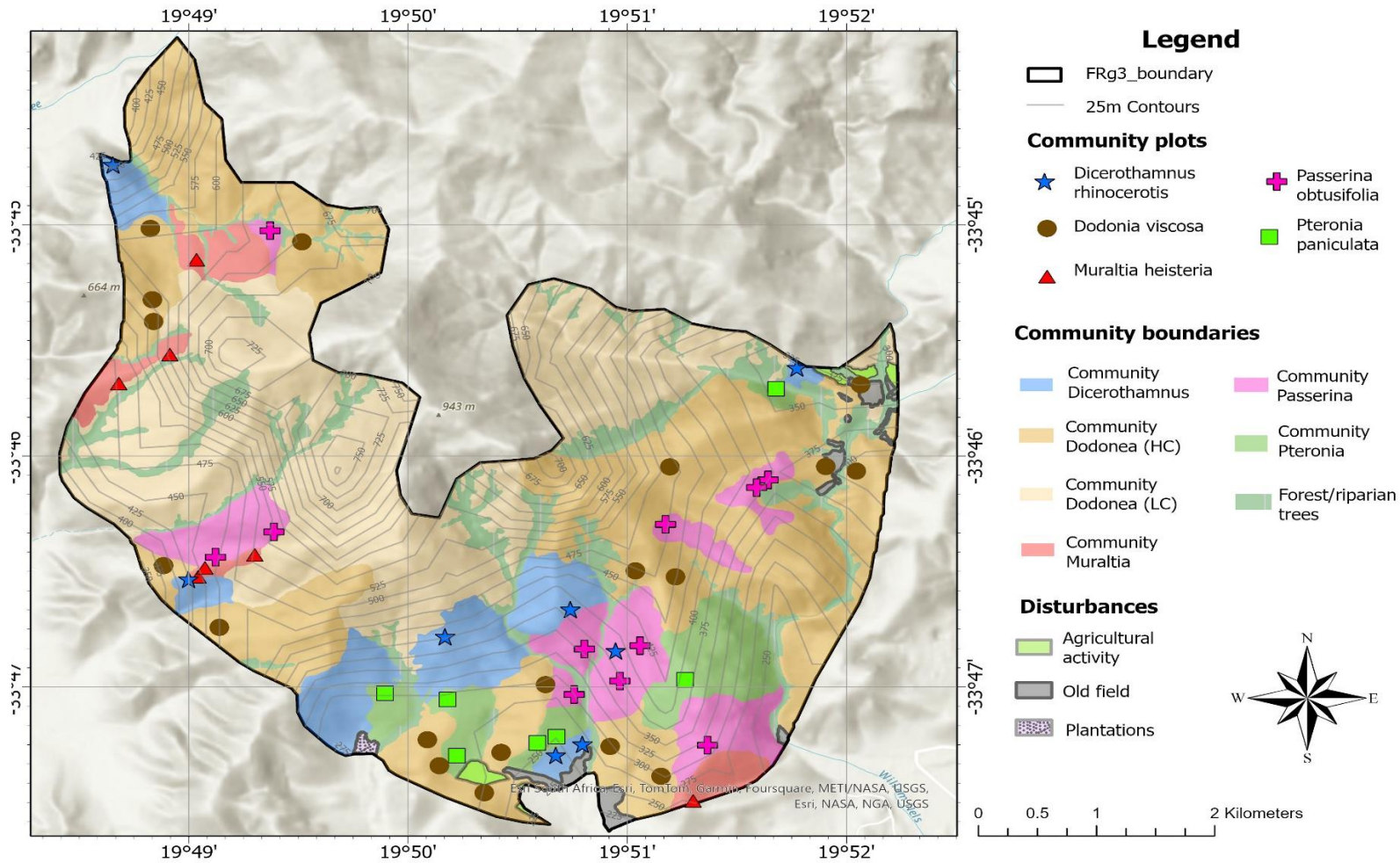


Figure 1.2: Five major plant communities found within the Robertson Granite Renosterveld (FRg3). The plant communities are represented by different colours (Red = *Muraltia heisteria*–*Restio capensis* community; Green = *Pteronia paniculata*–*Dicrothamnus rhinocerotis* community; Blue = *Dicrothamnus rhinocerotis*–*Dodonaea viscosa* community; Brown = *Dodonaea viscosa*–*Euryops tenuissimus* community, Pink = *Passerina obtusifolia*–*Restio capensis* community). HC = High Confidence; LC = Low Confidence.

2.3.1.2 Species richness, diversity, evenness, accumulation and rank abundance curves

The current study has revealed that the FRg3 comprises species from 38 families and 66 genera (see Appendix 1.4). The lowest number of species in a plot across the five communities is nine, and the maximum is 20 (Figure 1.3). The *Pteronia paniculata–Dicerotheramnus rhinocerotis* community exhibits the highest species richness with an outlier stretching the range and increasing the margin of error. The *Passerina obtusifolia–Restio capensis* community has the lowest species richness with one of the highest variability (SD) compared to other communities. Species evenness in this community is very similar to the *Pteronia paniculata–Dicerotheramnus rhinocerotis* community, which showed a slightly lower evenness (0.07) compared to other communities. There were no statistically significant differences in the species richness, evenness, and diversity (Shannon and Simpson) across the five major plant communities found in the FRg3 (Figure 1.3). However, the Shannon diversity index indicated that the *Pteronia paniculata–Dicerotheramnus rhinocerotis* community has a slightly higher species diversity compared to other communities and the *Passerina obtusifolia–Restio capensis* community has the lowest diversity. In general, species within the FRg3 have a very similar evenness across all communities. The species rank abundance curve indicated that the most widespread and dominant species within the vegetation type is *Dodonea viscosa*, followed by *Pentameris eriostoma*, then *Dicerotheramnus rhinocerotis* (Figure 1.4). The rank abundance curve was supported by Table 1.3, which showed the 10 most dominant species within each of the plant communities. The species accumulation curve (Figure 1.4) has shown that the number of species increases with an increase in the number of samples, as such, a higher sample size would be recommended for future similar studies in the FRg3.

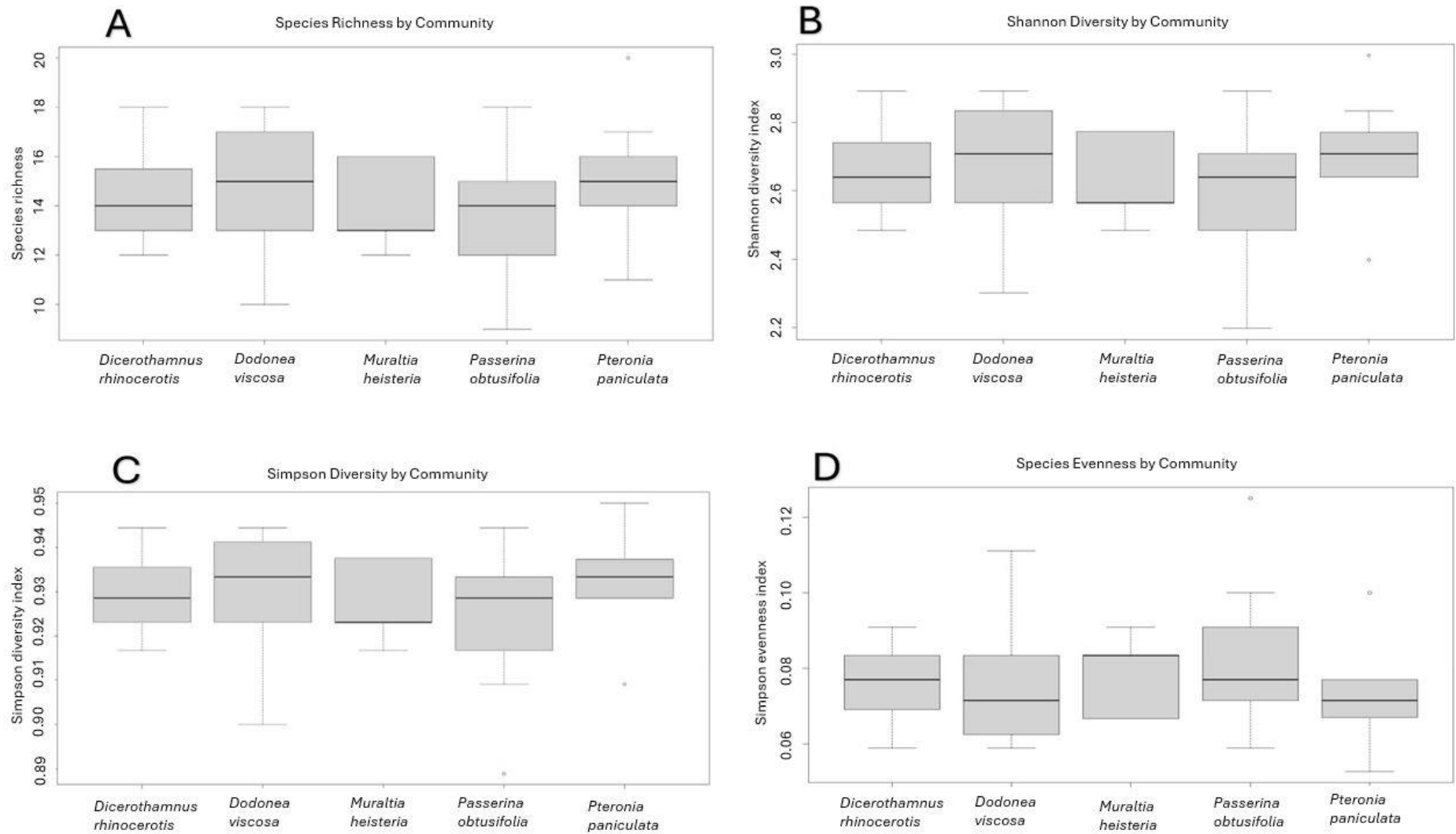


Figure 1.3: Species richness (A), Shannon diversity (B) Simpson diversity (C), and species evenness (D) across the five major plant communities within the Robertson Granite Renosterveld (FRg3).

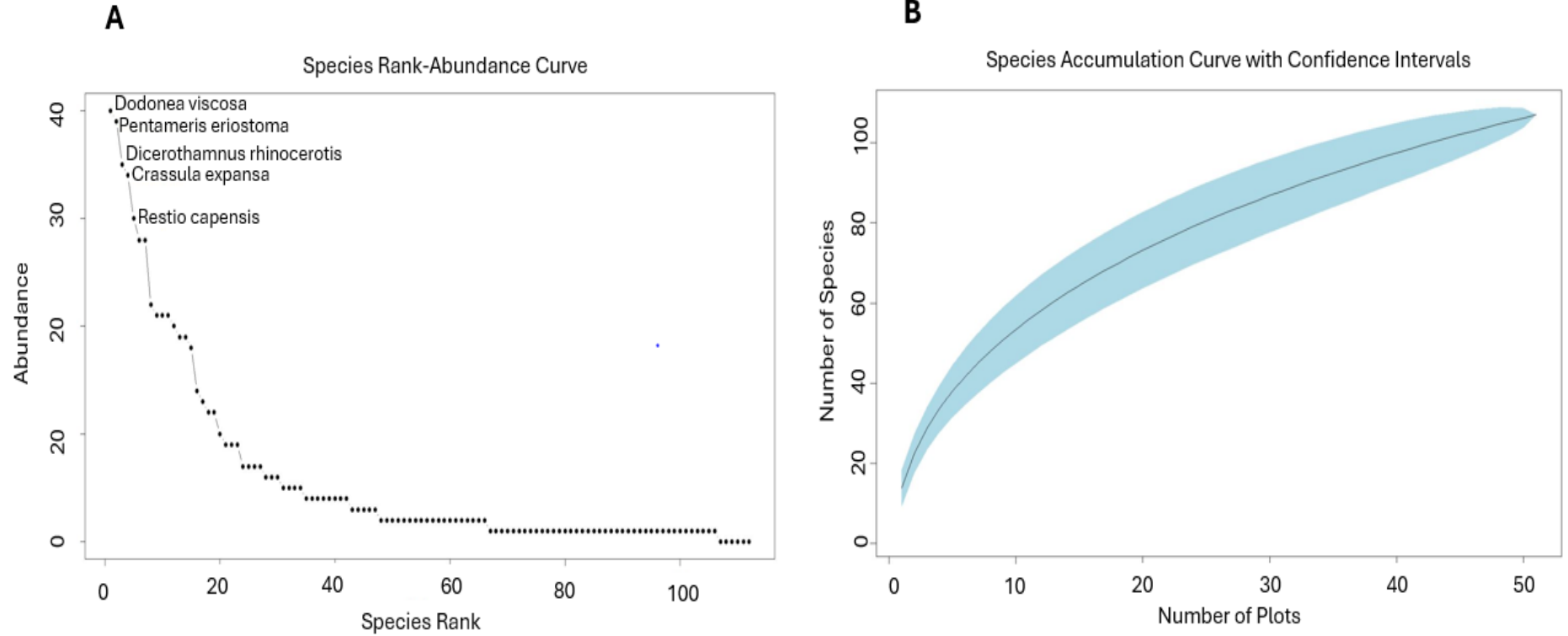


Figure 1.4: Species rank abundance curve (A) showing the frequency of species occurrence in the FRg3, and the species accumulation curve (B) showing accumulation of species (with the shading showing +95% confidence intervals) with an increase in sample size.

Table 1.3: The ten most dominant species across the five communities ranked from most abundant to least abundant across the Robertson Granite Renosterveld (FRg3). The total abundance summed the number of plots where each species occurs across the FRg3 plant communities.

Species	Rank	Species abundance per community					Total Abundance across FRg3
		<i>Dicrothamnus rhinocerotis</i> – <i>Dodonea viscosa</i>	<i>Dodonea viscosa</i> – <i>Euryops tenuissimus</i>	<i>Muraltia heisteria</i> – <i>Restio capensis</i>	<i>Passerina obtusifolia</i> – <i>Restio capensis</i>	<i>Pteronia paniculata</i> – <i>Dicrothamnus rhinocerotis</i>	
<i>Dodonea viscosa</i>	1	5	16	5	10	4	40
<i>Pentameris eriostoma</i>	2	7	16	3	9	4	39
<i>Dicrothamnus rhinocerotis</i>	3	8	13	5	4	5	35
<i>Crassula expansa</i>	4	6	11	2	8	7	34
<i>Oedera uniflora</i>	5	6	13	6	6	3	34
<i>Restio capensis</i>	6	4	10	5	9	2	30
<i>Crassula atropurpurea</i>	7	5	9	0	8	6	28
<i>Eriocephalus africanus</i>	8	4	11	4	4	5	28
<i>Euryops tenuissimus</i>	9	4	10	2	4	2	22
<i>Pteronia paniculata</i>	10	6	7	0	2	7	22

2.3.1.2.1 Similarities in species composition between community pairs

The Jaccard and Sørensen's Indices were used to test the similarities in species composition of community pairs within the FRg3. The pair of *Muraltia heisteria*–*Restio capensis* community and *Pteronia paniculata*–*Dicrothamnus rhinocerotis* community is the most dissimilar with the lowest index values from both Jaccard and Sørensen. However, it is important to note the *Muraltia heisteria*–*Restio capensis* community had the least overlap in species composition with other communities (Figure 1.5). There is a high similarity in species composition of *Dicrothamnus rhinocerotis*–*Dodonaea viscosa* community and *Pteronia paniculata*–*Dicrothamnus rhinocerotis* community (Figure 1.5). The remainder of the plant communities show a moderate similarity in species composition when paired amongst each other (Figure 1.5)

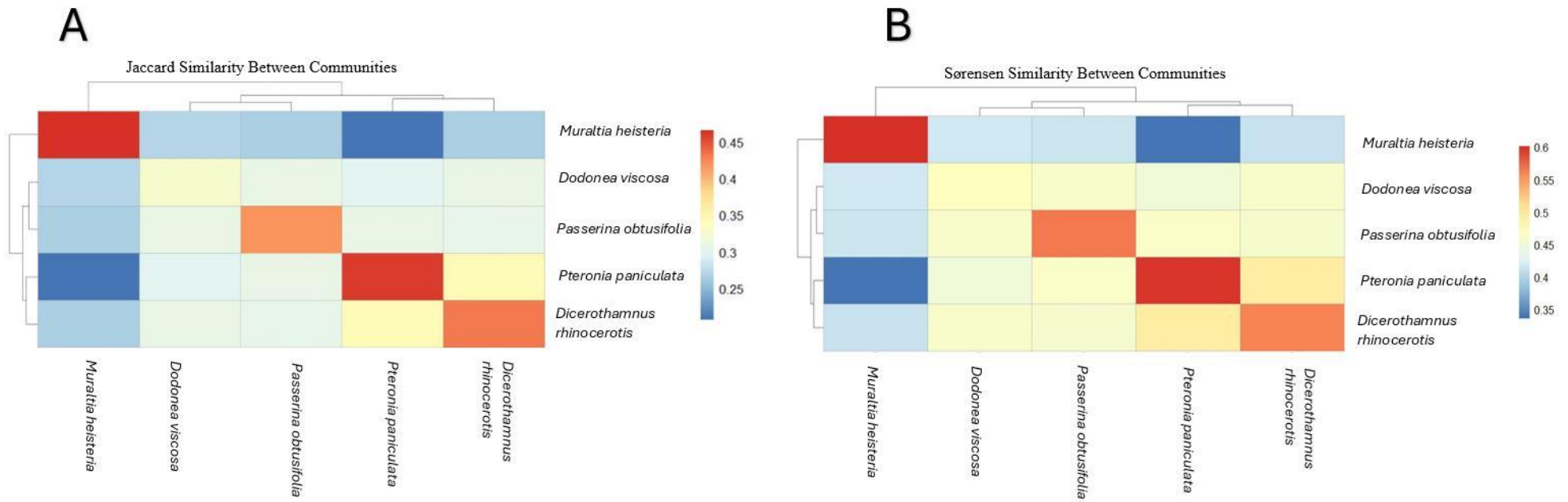


Figure 1.5: Comparison of similarity in species composition between pairs of plant communities within the FRg3 using the Jaccard (A) and Sørensen's (B) Indices. Bright (reddish) colour represents high similarity, while dark/deep (blueish) colour represents low similarity.

2.3.2 Environmental characteristics

Table 1.5 indicates that principal components (PC) 1 and 2 respectively are responsible for 33.6% and 16.5% of the variation in habitat characteristics of the FRg3. Hence, Figure 1.6 was plotted using the first two components to display the relations among environmental factors across different communities. Percentage sand was negatively correlated with most of the other environmental variables (B; Na; Mg; K; Ca; pH). Furthermore, sand was positively correlated with electrical resistance, bare ground, and acidity. The herbaceous cover is positively correlated to pH; Na; and clay, while negatively correlated to C; P; acidity; sand; and bare ground. There is also a strong positive correlation between clay, altitude, and herbaceous cover; these habitat characteristics are closely associated with *Muraltia heisteria–Restio capensis* community and *Dodonea viscosa–Euryops tenuissimus* community.

Table 1.5: Principal Component Analysis (PCA) showing proportions of variance and standard deviation of environmental variable in all 6 principal components of the Robertson Granite Renosterveld (FRg3).

Importance of components:						
	PC1	PC2	PC3	PC4	PC5	PC6
Standard deviation	2.39	1.68	1.35	1.23	1.18	0.98
Proportion of Variance	0.34	0.17	0.12	0.09	0.08	0.06
Cumulative Proportion	0.34	0.50	0.61	0.70	0.78	0.84

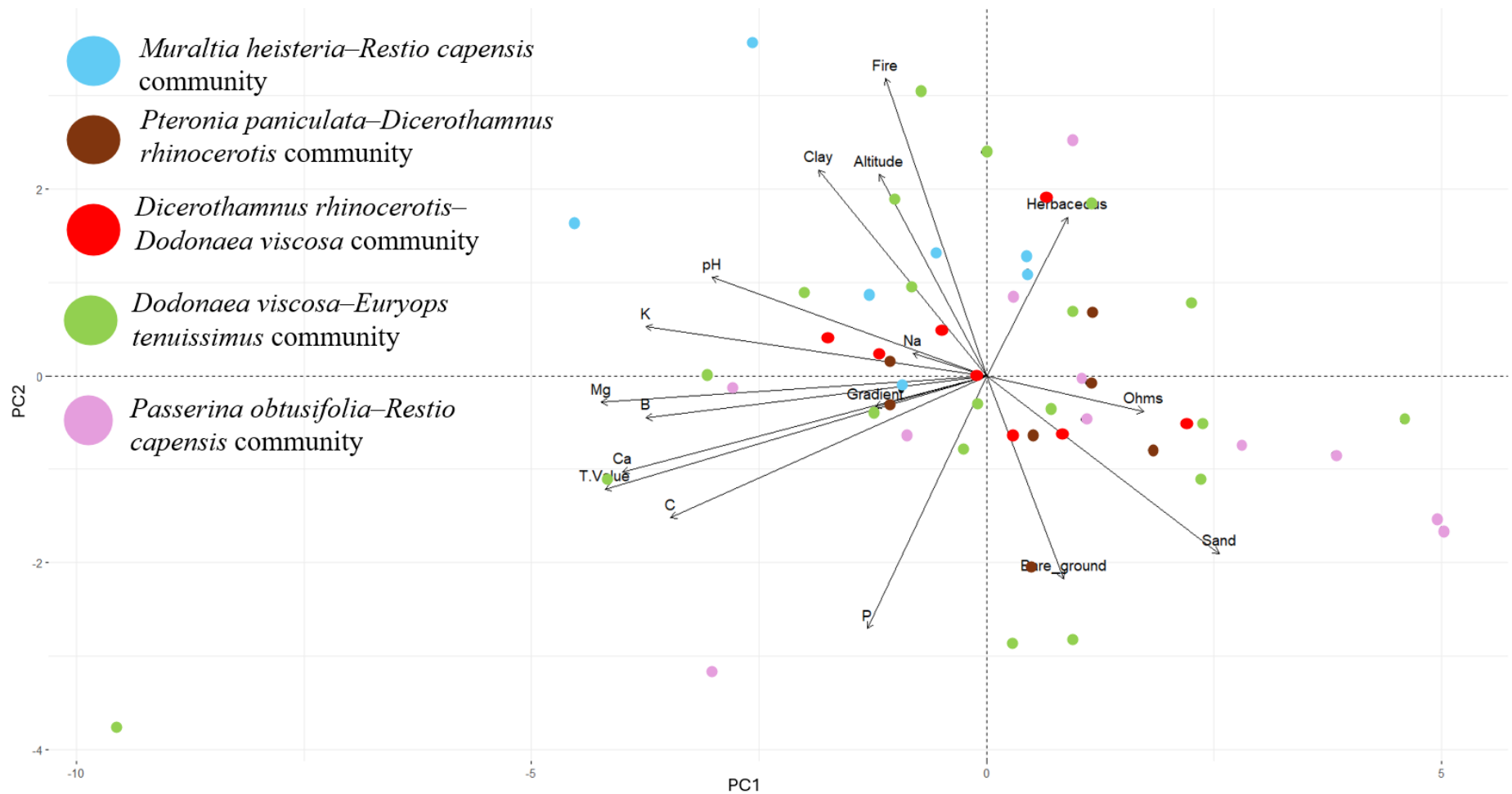


Figure 1.6: Principal Component Analysis (PCA) biplot shows the relationship among different habitat characteristics and their association with the five major plant communities occurring at the Robertson Granite Renosterveld.

Seven of the habitat characteristics measured drive the variance among the plots and communities within the vegetation type (Figure 1.7). In addition, there is a positive correlation between fire occurrences and gradient, altitude, clay, and pH (Figure 1.7). There is also a positive correlation between Na and herbaceous cover, which are negatively correlated to the rest of the environmental variables.

Table 1.6: Canonical Correspondence Analysis (CCA) showing the eigenvalues, proportion of the variance explained, and cumulative proportion of the six CCA axes of the Robertson Granite Renosterveld (FRg3). The table further shows the Chi-Square value indicating the total variance explained by the CCA.

Importance of components:						
	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6
Eigenvalue	0.52	0.46	0.40	0.38	0.32	0.28
Proportion of the variance Explained	0.12	0.10	0.09	0.09	0.07	0.06
Cumulative Proportion	0.12	0.22	0.31	0.40	0.47	0.53
Chi-Square: 4.45						

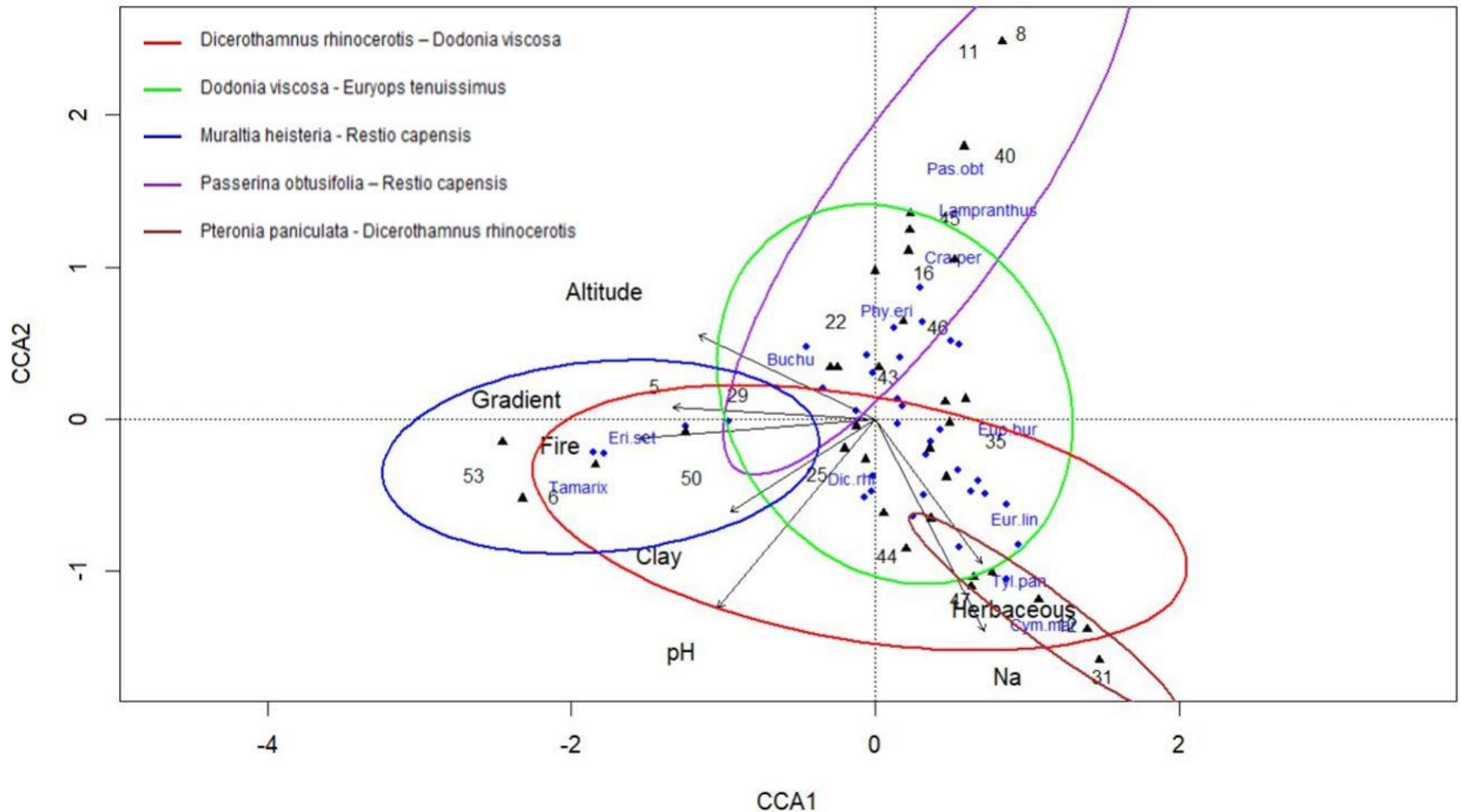


Figure 1.7: Canonical Correspondence Analysis (CCA) tri-plot showing the relationship among environment variables, plot distribution, and species found within the Robertson Granite Renosterveld (FRg3). The ellipses circled the five different plant communities in the FRg3 which are distinguished by different colour shades. Species names are abbreviated by the first three letters of the genus and species name.

2.3.3 Soil characteristics

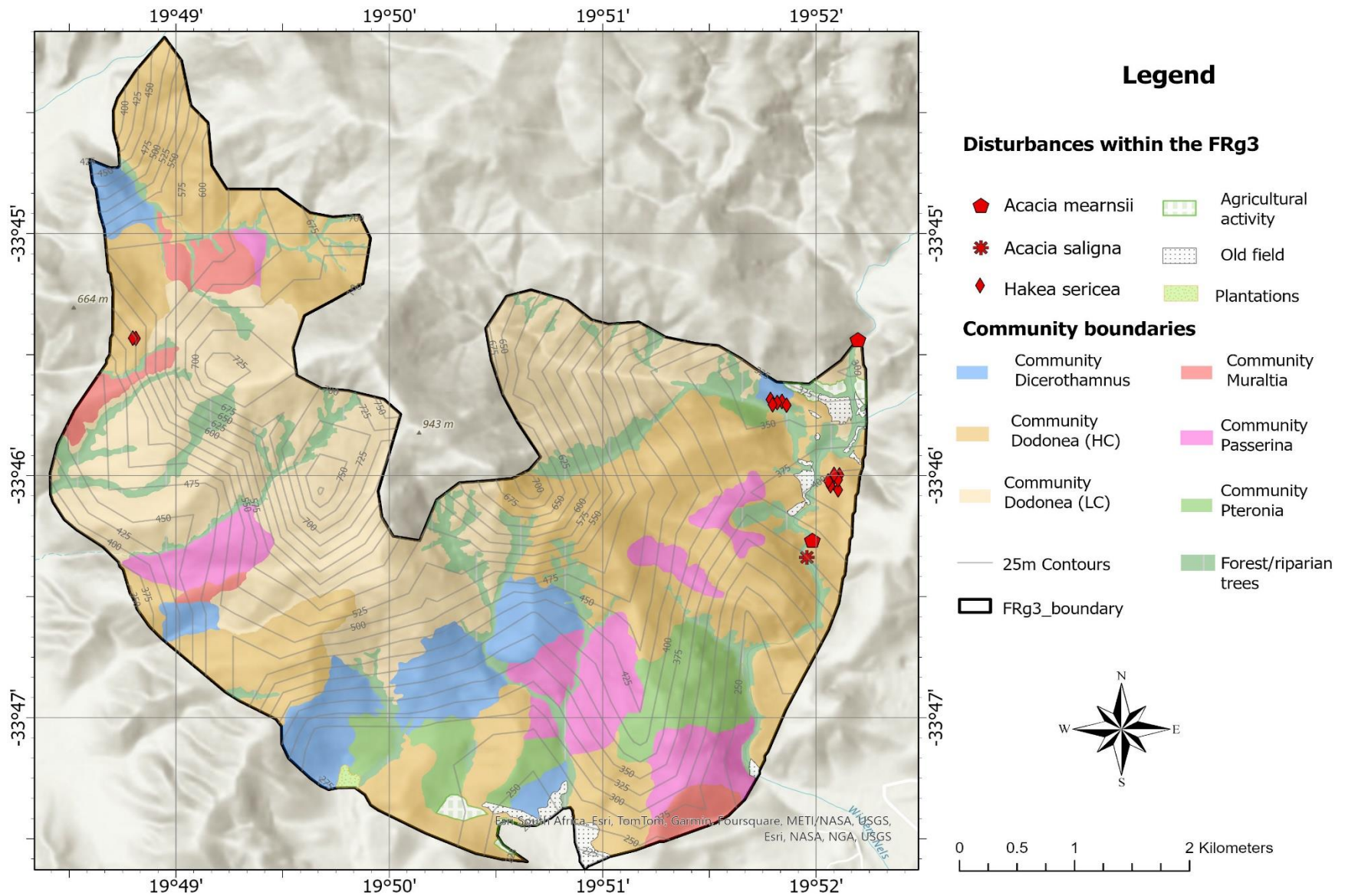
Table 1.7: Mean and standard deviations for habitat characteristics of the five major plant communities within the Robertson Granite Renosterveld (FRg3). Different letters indicate significant differences within rows ($P < 0.05$, Fisher's LSD).

Habitat characteristics	Community Name				
	<i>Dicrothamnus rhinocerotis– Dodonaea viscosa</i>	<i>Dodonea viscosa– Euryops tenuissimus</i>	<i>Muraltia heisteria– Restio capensis</i>	<i>Passerina obtusifolia– Restio capensis</i>	<i>Pteronia paniculata– Dicrothamnus rhinocerotis</i>
pH (KCl)	4.93 ± 0.28^a	4.85 ± 0.66^a	5.25 ± 0.4^a	4.24 ± 0.56^b	4.91 ± 0.46^a
Resistance (Ohms)	2771 ± 820	2195 ± 1299	3575 ± 1162	3485 ± 1725	2610 ± 1204
Ca (mg/kg)	2.58 ± 0.73	3.36 ± 2.97	4.07 ± 1.89	2.18 ± 1.46	2.46 ± 0.71
Mg (mg/kg)	1.25 ± 0.33	1.21 ± 0.56	1.24 ± 0.38	0.85 ± 0.55	1.16 ± 0.32
K (mg/kg)	78.25 ± 15.00	93.95 ± 30.46	103.67 ± 15.12	74.64 ± 33.23	89.72 ± 14.44
Na (mg/kg)	51.5 ± 27.85^a	32.11 ± 13.49^b	28 ± 4.34^b	25.91 ± 12.61^b	48.86 ± 14.98^a
P (mg/kg)	10.13 ± 2.03	17.58 ± 12.17	11.67 ± 1.86	17.09 ± 10.27	13.43 ± 5.53
T_Value (mg/kg)	5.32 ± 0.95	5.98 ± 3.13	6.44 ± 1.89	5.12 ± 2.19	5.07 ± 0.8
B (mg/kg)	0.26 ± 0.08	0.23 ± 0.10	0.23 ± 0.04	0.18 ± 0.07	0.24 ± 0.08
C (%)	1.77 ± 0.19	1.84 ± 0.76	1.9 ± 0.2	1.99 ± 0.73	1.52 ± 0.19
Sand (%)	72 ± 2.14^a	73.53 ± 3.32^a	68 ± 7.24^b	74.27 ± 2.57^a	73.29 ± 3.15^a
Silt (%)	11 ± 1.51	9.68 ± 2.52	12.33 ± 4.27	9.45 ± 1.29	9.71 ± 2.43
Clay (%)	17 ± 1.85^b	16.79 ± 1.32^b	19.67 ± 3.72^a	16.27 ± 1.85^b	17 ± 1.64^b
Altitude (m.a.s.l)	339 ± 90^b	407 ± 123^b	524 ± 38^a	411 ± 145^{ab}	359 ± 68^b
Slope Gradient (°)	26 ± 13.97	21.21 ± 12.79	39.33 ± 13.66	21 ± 16.19	18.14 ± 11.80
Herbaceous cover (%)	73.13 ± 17.51	54.47 ± 19.64	42.5 ± 23.82	51.36 ± 36.06	53.57 ± 20.96
Bare ground (%)	30.63 ± 12.66	24.74 ± 13.89	19.67 ± 10.13	26.36 ± 10.27	36.43 ± 19.94

There are no significant differences in most soil characteristics across the Robertson Granite Renosterveld except for pH, Na, Sand, and Clay (Table 1.7). The *Passerina obtusifolia*–*Restio capensis* community showed the lowest pH level. In contrast, the *Muraltia heisteria*–*Restio capensis* community showed the lowest Sand percentage and highest Clay percentage, which were significantly different from other communities on both results.

2.3.4 Disturbances and Threats to the Robertson Granite Renosterveld (FRg3)

Environmental disturbances have been observed within the FRg3. The disturbances are generally on the lower gentle slopes of the mountainous FRg3. Figure 1.8 shows the disturbances within the vegetation type and how they are distributed across the vegetation type. Some of the disturbances include the infestation by alien invasive plant species, agricultural practices, plantations, and old fields. The old fields refer to the lands previously used for agricultural purposes (currently fallow) or cleared and converted to private leisure areas.



2.4 Discussion

A total of 113 species were recorded across the vegetation type, 18 species are endemic to the Western Cape and two of the endemics are classified as Near Threatened (NT), one is Endangered (EN) and one is Vulnerable (VU) (Appendix 1.4; SANBI, 2024). There are no significant differences in species evenness between the five major plant communities in the FRg3, with slightly higher diversity for the *Dodonea viscosa* - *Euryops tenuissimus* community (Figure 1.3). The FRg3 is dominated by tall shrubs such as *Dodonea viscosa* which appeared in 40 plots, an overall frequency of 75% (Table 1.3). Furthermore, Rebelo *et al.* (2006) mentioned that grasses are also widespread within this vegetation type; this is consistent with Table 1.4, which showed that *Pentameris eriostoma* was present in 39 plots (frequency of 74%) across different communities. The five communities are described below.

2.4.1. *Muraltia heisteria*–*Restio capensis* community

This community is categorised by *Muraltia heisteria*, which is the dominant species, followed by grass-like patches of *Restio capensis* and *Pentameris eriostoma*. The community occurs on the high-lying mountains (avg. 482m a.s.l) with steep slopes (avg. 37°). Furthermore, the community covers the smallest area of 61ha (3.16%) when compared to other communities within the vegetation type. The community is associated with the following habitat characteristics: high-lying steep mountain slopes, higher pH, and high clay percentage. These habitat characteristics are consistent with those stated by Forest *et al.* (2007), who highlighted that *Muraltia* species are commonly situated on high mountains of the Cape region. These communities are mostly found on the north-facing slopes of the FRg3, however, there were observations of *Muraltia heisteria*–*Restio capensis* communities on the south and east-facing slopes. Therefore, it can be argued that the slope aspect is not an important habitat characteristic

that could significantly influence the distribution of this community and this habitat variable was not mentioned as significant to the distribution of the species by Forest and Manning (2006) and Forest *et al.* (2007).

The *Muraltia heisteria–Restio capensis* community has the lowest herbaceous cover when compared to other communities within the FRg3 (Table 1.7). In addition, this community has the lowest percentage of sand, which is significantly different from the sand percentage of the other four communities (Table 1.7). Similar results were observed with the Clay percentage, where the community has the highest percentage of Clay which is significantly different from the other four communities. This community has the lowest species richness (13 to 16 species per plot) compared to other communities within the vegetation type. However, approximately 25 species across *Muraltia heisteria–Restio capensis* communities are endemic to the Cape region of South Africa, and of the 25, nine are endemic to the Western Cape province. All endemic species present in this community have a conservation status of Least Concern (LC) (Appendix 1.4; SANBI, 2024).

4.2.2. *Pteronia paniculata–Dicerotheramnus rhinocerotis* community

This community is dominated by *Pteronia paniculata*, followed by *Dicerotheramnus rhinocerotis*. The community covers 106 ha (5.51%) of the FRg3 and is commonly found on the lower mountains (avg. 360 m a.s.l) with a moderate slope gradient (avg. 18°) as opposed to the *Muraltia heisteria–Restio capensis* community on higher and steeper slopes. According to Smitheman & Perry (1990), *Pteronia paniculata–Dicerotheramnus rhinocerotis* communities particularly occur on gentle slopes, and the aspect is not an important attribute as these communities can be found on both the north and south-facing slopes. This information is consistent with Table 1.7 indicating that the *Pteronia paniculata–Dicerotheramnus rhinocerotis*

communities are mainly found on the gentle lower slopes of the FRg3 mountains. Smitheman & Perry (1990) added that the communities typically have between 25% and 50% of bare ground, similar results were observed in Table 1.7 which revealed that *P. paniculata* has the highest average percentage cover of bare ground (36%). Furthermore, Smitheman and Perry (1990) highlighted that the presence of lichen is common within *Pteronia paniculata*–*Dicrothamnus rhinocerotis* communities, this was also observed on the rocky surfaces and *P. paniculata* stems while collecting the plot data. This community has an average of 15 species per plot, and some of the species found within this community include *P. incana*; *Dodonaea viscosa*; and *Searsia pallens*. This community is found in the southern edge of the FRg3 where it borders with the Robertson Karoo (Figure 1.1). The close proximity of *Pteronia paniculata*–*Dicrothamnus rhinocerotis* community to the Robertson Karoo vegetation type southern border of FRg3 could explain the high presence of succulent species like *Crassula atropurpurea*, *Crassula expansa*, *Crassula perfoliate*, *Crassula muscosa*, and *Cotyledon orbiculata* within the community.

4.2.3. *Dicrothamnus rhinocerotis*–*Dodonaea viscosa* community

This community occurs on gentle to steep slopes (approximately 26°) of the FRg3, where the average altitude is 339 m a.s.l. Furthermore, this community covers 7.75% (149 ha) of the FRg3 and it is found on the south, southeast, and southwest-facing slopes of the FRg3 mountains which aligns with the distribution outlined by Smitheman & Perry (1990). Both the *Dicrothamnus rhinocerotis*–*Dodonaea viscosa* community and the *Pteronia paniculata*–*Dicrothamnus rhinocerotis* community have high sodium (Na) levels which are significantly different from the other three communities found within the vegetation type (Table 1.7). Therefore, it can be argued that Na is an important soil characteristic that drives the distribution of communities within the FRg3. This community has the highest herbaceous cover of 73%

(Table 1.7), which is consistent with the results of Smitheman & Perry (1990) who estimated their cover between 65% and 85%. Similar to the *Pteronia paniculata*–*Dicrothamnus rhinocerotis*, the *Dicrothamnus rhinocerotis*–*Dodonea viscosa* community has exposed rocks and a bare ground percentage cover above 30%. This community has a species richness of between 12 and 18 species per plot, and some of the species include *Dodonea viscosa* and *Pteronia paniculata*.

4.2.4. *Dodonea viscosa*–*Euryops tenuissimus* community

This community is the most widespread across the vegetation type and occurs on different slope aspects and slope positions along the catena. This study mapped 653 ha (33.95%) of this community with high confidence, and 586 ha (30.47%) with low confidence. The confidence level is low on the mapped 586 ha because ground truthing could not be done on those localities as they were inaccessible. Most of the habitat characteristics of this community are similar to those of the *Passerina obtusifolia*–*Restio capensis* community. Both communities have an average height of 1.5 – 2m and an average herbaceous cover of ~50%. In addition, both communities have the lowest average clay percentage compared to the other three communities found within the FRg3 (Table 1.7). The species richness within this community is between 10 and 18 species per plot, and some of the common species within this community include *Restio capensis*, *Dicrothamnus rhinocerotis*, and *Passerina obtusifolia*.

4.2.5. *Passerina obtusifolia*–*Restio capensis* community

This community has a widespread distribution similar to *Dodonea viscosa*–*Euryops tenuissimus* community. However, the *Passerina obtusifolia*–*Restio capensis* community is commonly found on the south-west-facing slopes and covers 164 ha (8.53%) of the FRg3. This was consistent with the distribution of the *Passerina obtusifolia* community outlined by

Smitheman & Perry (1990). In addition, this community has the lowest pH (4.24), which is significantly different from that of the other four communities within the FRg3 (Table 1.7). This result was similar to those of Smitheman & Perry (1990) which highlighted that *Passerina obtusifolia* species thrived on the acidic soil (pH = 3.3 – 4.7) of the Karoo National Botanical Garden. Therefore, it can be argued that pH level provides favourable conditions for particular species to thrive, which makes it one of the important environmental variables that drive the distribution of this community within the FRg3. Some of the common species in order of abundance include *Restio capensis*, *Pentameris eriostoma*, and *Dodonea viscosa*. This community has a species richness of between 9 and 18 species per plot with 50% of the plots having a species richness of between 12 and 15 species per plot.

The vegetation type had an average herbaceous cover of 55% across its extent. According to Mills *et al.* (2024), deficiency of P, Ca, and B in the soil limits plant growth. Therefore, it could be suggested that the above-average herbaceous cover is explained by the presence of P, Ca, and B in the FRg3 soils. However, Table 1.7 indicated that these chemical components do not influence the composition and distribution of plant communities within the FRg3 ($P > 0.05$). Important environmental attributes that significantly ($P < 0.05$) influence the community composition and distribution include altitude, gradient, pH, Na, clay %, and fire occurrences (Table 1.7). However, there is no clear correlation between the distribution of communities and the slope aspects as well as slope positions of plant communities along the catena.

4.2.6. Disturbances and threats to the FRg3

The Robertson Granite Renosterveld has retained much of its natural vegetation extent despite the current and past anthropogenic activities in the landscape. The main threat to the vegetation type recorded is the spread of alien invasive species, particularly *Hakea sericea*

(Richardson and Van Wilgen, 1986; Figure 1.8). This species thrives in nutrient-poor soils and high-altitude mountain slopes with full sun exposure (Milberg & Lamont 1997; Lamont *et al.*, 2016; Jacobson *et al.*, 2023). A landowner within FRg3, indicated that the first occurrence of *H. sericea* was observed less than 10 years ago. During the field survey, 14 individuals were observed on the far east and far west of the vegetation type. These observations were made on the high mountain slopes of the vegetation type. iNaturalist was also consulted for more alien invasive species records on the vegetation type; two observations of *Acacia mearnsii* and one observation of *A. saligna* individuals were found. These observations were supported by Musil *et al.* (2005) and Topp & Loos (2019), who highlighted that the main biological threat to the renosterveld ecosystems is the spread of alien invasive plant species such as *A. saligna*. Therefore, these species could spread and become a threat to the FRg3 if not managed early.

Agriculture is the major driver of habitat loss in Renosterveld ecosystems (Kemper *et al.*, 2000; Cowan, 2013; Todd & Unit, 2010; Topp & Loos, 2019). This is generally because of the nutrient-rich soil common among the Renosterveld ecosystems which makes it suitable for agricultural activities (Moll, 1990; Kemper *et al.*, 2000; Rebelo *et al.*, 2006; Cowman, 2013). However, only 1% (19 ha) of the FRg3 has been transformed due to land clearing for leisure facilities and agricultural purposes. The minimal disturbance on the vegetation type is mainly because the terrain of the FRg3 is too steep for transformation (Rebelo *et al.*, 2006; Topp & Loos, 2019), and the cultivation machinery cannot be operated on the steep slope.

2.5 Conclusion

The Robertson Granite Renosterveld consists of five major plant communities named based on the two dominant species: *Dodonaea viscosa*–*Euryops tenuissimus* community, *Dicerothamnus rhinocerotis*–*Dodonaea viscosa* community, *Passerina obtusifolia*–*Restio capensis* community,

Pteronia paniculata–Dicerotheramnus rhinocerotis community, and *Muraltia heisteria–Restio capensis* community. The vegetation of FRg3 has a total species richness of 113 species and an average species richness of 14 species per 50m² rectangular plot. The community dominated by *Dodonaea viscosa* is the most widespread, covering over 600 ha of the vegetation type. Other localities could not be accessed during this study period, which presents a research opportunity for future scientific exploration of the vegetation type. The distribution of these communities was influenced by habitat characteristics such as slope gradient, soil acidity, altitude, and fire occurrence. 99% of the vegetation type has not been transformed and maintains its natural state. Some disturbances have been observed, such as alien invasive species, livestock grazing, and agricultural activities. The topography of the FRg3 vegetation type is generally steep and rocky which is primarily why agricultural activities have not transformed it. However, alien plants such as *Hakea sericea* are adapted to thrive in nutrient-poor rocky mountain slopes, which makes them a problem on the vegetation type. The communities found in riparian zones of the FRg3 were not explored in this study. Therefore, this presents a research opportunity for future studies on the vegetation type.

Chapter 3: Fire history of the Robertson Granite Renosterveld (FRg3) from 2000 to 2023 and the influence of fire on the distribution of plant communities within the FRg3 vegetation type

Abstract

Fire is an essential part of Mediterranean ecosystems and has a significant contribution to their functioning. The Fynbos biome is both fire-dependent and fire-adapted, making fire an important ecological process within Fynbos shrublands. This chapter aims to investigate a 24-year (2000–2023) fire history of the Robertson Granite Renosterveld (FRg3), and how past fire events have influenced the distribution of plant communities within the vegetation type. MODIS/061/MCD64A1 fire data was obtained from Google Earth Engine (GEE), and the imagery was used to map the extent of each fire event from 2000 to 2023 on ArcGIS Pro. The MODIS datasets revealed that the FRg3 had three fire events in 24 years (2000, 2006, and 2017). The fire of 2000 burnt 35.52% of the FRg3, while in 2006 it burnt 24.70% of the FRg3, and in 2017 it burnt 53.51% of the FRg3. Almost half (46.49%) of the vegetation type did not burn at all throughout these fire events. Furthermore, the results showed that the *Muraltia heisteria–Restio capensis* community, *Dodonea viscosa–Euryops tenuissimus* community, *Passerina obtusifolia–Restio capensis* community, and *Dicerotheramnus rhinocerotis–Dodonea viscosa* community (described in Chapter 2) are commonly found on fire-affected areas while *Pteronia paniculata–Dicerotheramnus rhinocerotis* communities are found in areas that have not burnt in 24 years. Thus, fire plays an important role in influencing the distribution of plant communities within the vegetation type. Fire patterns observed for the duration of this study indicate that the fire season within the FRg3 is between January and March, this period is the hottest and driest, providing favourable conditions for the ignition and spread of wildfires within the area. This chapter further revealed that fires in the FRg3 usually start from the northwestern high slopes in the neighbouring

vegetation types (Robertson Granite Fynbos, Breede Alluvium Renosterveld, and Breede Shale Renosterveld). The low wind speeds (<13 km/h) sometimes result in the back-burn towards the lower slopes of the FRg3.

Keywords: Google Earth Engine, MODIS, Plant communities, Robertson Granite Renosterveld

3.1 Introduction

Fire as a disturbance factor affects the reproduction of many plant species in ecosystems globally (Keeley & Fotheringham, 2001; Beck *et al.*, 2005; Van Wilgen, 2009; Van Wilgen *et al.*, 2010; Rutherford *et al.*, 2011). This ecological process clears much of the above-ground biomass to create suitable conditions for the recruitment and coexistence of different species within plant communities (Pierce & Moll, 1994; Van Wilgen *et al.*, 2010). In addition, fire triggers the germination of some species which contributes to shaping the distribution of plant communities and maintaining healthy ecosystems (Keeley & Fotheringham, 2000; Van Wilgen *et al.*, 2010; Cousins *et al.*, 2018).

Mediterranean biomes are said to be the most fire-prone globally (Capitanio & Carcaillet, 2008; Van der Merwe & Van Rooyen, 2011). Fire is often an important ecological process that controls the vegetation dynamics and structure in these kinds of vegetation types (Van der Merwe & Van Rooyen, 2011), where the pre-fire vegetation highly influences the post-fire regeneration (Hanes, 1971; Trabaud & Lepart, 1980; Lloret & Vila, 2003). The pre-fire characteristics include species composition and biomass (Bartos *et al.*, 1994; Turner *et al.*, 2003; Han *et al.*, 2015). Furthermore, there are also post-fire characteristics that influence post-fire vegetation regeneration which include the edaphic characteristics and topographic position, fire severity, species life history strategies of the plants (Lamont *et al.*, 2020), and the pre-fire vegetation composition (Maia *et al.*, 2012; Lee *et al.*, 2014; Han *et al.*, 2015).

In the Cape Floristic Region, an estimated 90% of the fynbos species are strongly linked to fire events (Cousins *et al.*, 2018). Fire events affect the germination and recruitment of the dominant shrubs within a particular ecosystem (Bond *et al.*, 1984; Van Wilgen, 2013; Lamont *et al.*, 2020). However, frequent fynbos fires (4 – 5 years) could eliminate the seedling recruits of

dominant shrubs; the frequent fires are favourable to resprouting species and could lead to a decreased species diversity within the ecosystem (Van Wilgen, 2013). Fynbos ecosystems are managed by prescribed burning to control native woody species, reduce fire hazards, and rejuvenate the vegetation within the biome (Van Wilgen *et al.*, 1990). Furthermore, fire in fynbos ecosystems could influence the species composition, successional patterns, and vegetation structure (Van der Merwe & Van Rooyen, 2011).

Similar to fynbos, renosterveld ecosystems are fire-prone, however, their dependency on fire is still unclear (Van der Merwe & Van Rooyen, 2011; Cousins *et al.*, 2018). Therefore, there is a need to clearly understand the renosterveld fire ecology for appropriate conservation intervention to be implemented when necessary (Rebelo *et al.*, 2006; Cousins *et al.*, 2018). Studies highlighted that Mountain Renosterveld vegetation types tend to have higher vegetation cover from three to ten years after a fire event than that observed in the first two years post-fire (Van der Merwe & Van Rooyen, 2011). Therefore, similar results can be expected on the fire history analysis of the Robertson Granite Renosterveld (FRg3).

Studies have been conducted on the Mediterranean and Fynbos fire ecology and have shown the importance of fire on Fynbos ecosystems (Van der Merwe & Van Rooyen, 2011; Cousins *et al.*, 2018). However, there is a knowledge gap on the fire history of the Robertson Granite Renosterveld. This information is important as it can help FRg3 farm owners and the local municipality to predict future potential fire events, and plan accordingly.

Remote sensing has been used to map historic fire events and their extent (commonly referred to as fire scars). The Moderate Resolution Imaging Spectroradiometer (MODIS) is a widely used satellite for mapping fire history (De Klerk, 2008; Long *et al.*, 2019; Durta *et al.*, 2023). The awesome-gee-community-catalogue has curated Global Annual Burned Area Maps

(GABAM) using all Landsat images available on GEE (Roy *et al.*, 2024). The imagery has a spatial resolution of 30m (Roy *et al.*, 2024). However, the disadvantage of the image is that it only has one band (b1), and no information on the burnt area such as the exact burn dates. In addition, the GABAM has been criticized for generally overestimating the fire extent compared to MODIS/061/MCD64A1 (Durta *et al.*, 2023). MODIS/061/MCD64A1 as an alternative dataset for mapping the extent of fire events has five bands (BurnDate; Uncertainty; QA; FirstDay; and LastDay) containing more information about the fire events as opposed to the GABAM. The disadvantage of this dataset is that it has a coarser spatial resolution (500m) compared to GABAM (Table 1.3). Fire studies show that despite its coarse spatial resolution, MODIS/061/MCD64A1 is still the most commonly used dataset for mapping the spatial extent of fire events (Long *et al.*, 2019).

3.1.1 Aim and Objectives

This chapter aimed to investigate the fire history of the Robertson Granite Renosterveld (FRg3) from 2000 to 2023 and show how fire influences the distribution of its plant communities (see Chapter 2) within the vegetation type. The first objective was to investigate the fire history using MODIS Burned Area satellite imagery and map the extent of each fire event within the FRg3. Furthermore, the surface area (ha) of the fire-affected portions was calculated for each fire event including portions that burnt in more than one fire event. The second objective was to identify the communities situated in fire-affected locations. The plot points representing plant communities within the FRg3 were mapped against each fire event; the habitat characteristics of the burnt area (slope gradient and altitude) were tabulated against the fire-affected area in percentages (relative to the total extent of the FRg3), to determine the influence of habitat characteristics on the extent of the fire event.

3.2 Methods

3.2.1 Data acquisition

To explore the fire history of the FRg3, the extent of each fire event within the vegetation type was mapped using Google Earth Engine (GEE) from 2000 to 2023. MODIS fire data set with a coverage of the FRg3 is only available from November 2000 on GEE, thus, the fire analysis was performed as far back as MODIS data allows. The MODIS/061/MCD64A1 imagery has a spatial resolution of 500m and five bands (BurnDate; Uncertainty; QA; FirstDay; and LastDay). The Climatic information on the dates when the FRg3 burnt was obtained from the South African Weather Services. The data included the wind speed, wind direction, temperature (min & max), humidity, and precipitation.

3.2.2 Data analysis

The plot information mapped in chapter 2 was overlaid with each of the fire year MODIS fire imagery to identify the plant communities found in fire-affected areas, and those found in areas that did not burn at all.

The area (ha) affected by each fire event was calculated using the following formula:

Area burnt (ha) = $\frac{(\text{Pixel size}) \times (n)}{1\,000\,000}$ Where: n = total number of pixels covered by the burn area,

and pixel size is in meters. The percentage cover of the area burnt was then calculated using the

following formula: Aerial burn cover (%) = $\frac{\text{Area burnt (km}^2\text{)}}{\text{Size of study area (km}^2\text{)}} \times 100$

A Venn diagram was created using the calculated aerial cover (ha and %) of each fire event and that of areas burnt on multiple occasions, to provide a more holistic understanding of the overlaps of the areas that burnt and did not burn.

3.3 Results

The Robertson Granite Renosterveld (FRg3) has experienced three fire events in the past 24 years (2000 – 2023). The first fire burnt the vegetation type in January 2000, covering 683 ha (35.52%) of the FRg3. The second fire started on the 26th of February 2006 and progressed to the 3rd of March 2006, burning the northern portion that covers 475 ha (24.70%) of the vegetation type. The third and most recent fire event started on the 21st of March 2017 and burnt until the 27th of March 2017, this fire covered 1029 ha (53.51%) of the vegetation type. Appendices 3.1 and 3.2 show the extent of the 2006 and 2017 fires respectively on a finer scale.

From the five communities found in the FRg3 (Chapter 2), four of them (*Dodonaea viscosa*–*Euryops tenuissimus*, *Passerina obtusifolia*–*Restio capensis*, *Dicerothamnus rhinocerotis*–*Dodonaea viscosa*, and *Muraltia heisteria*–*Restio capensis*) were found on areas that have been affected by fire and prone to potential fire events (Figure 3.1; Figure 3.5). Furthermore, most of the *Muraltia heisteria*–*Restio capensis* communities, mapped on high mountains within the FRg3, are in areas that have been more recently burned (2017), while *Pteronia paniculata*–*Dicerothamnus rhinocerotis* communities, mapped on lower lying slopes, are in areas that did not burn at all (Figure 3.5). Approximately 35% of the vegetation type (FRg3) burnt in 2000; the *Pteronia paniculata*–*Dicerothamnus rhinocerotis* community is the only community that is located in an area that did not burn in 2000 (Table 3.1; Figure 3.1).

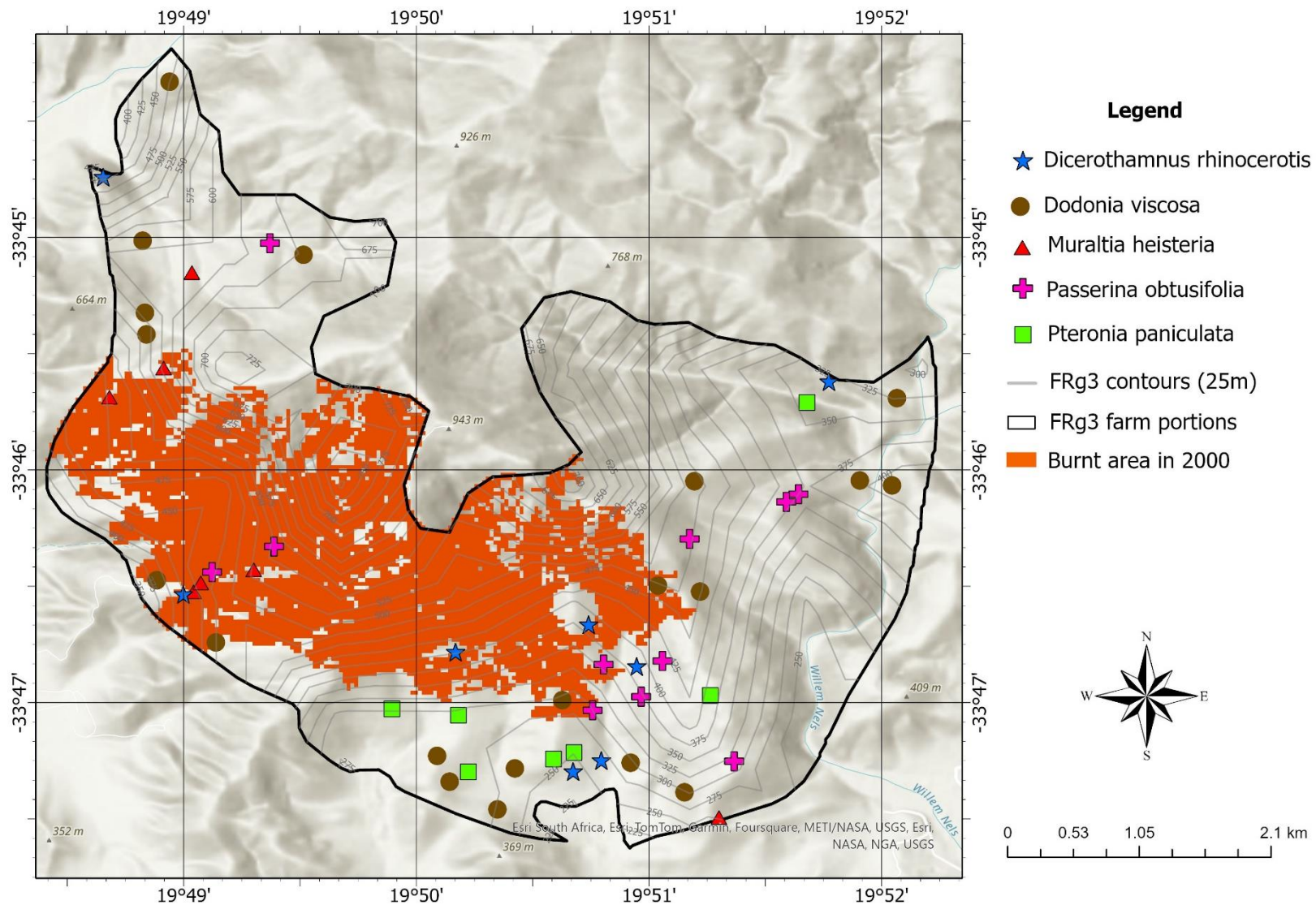


Figure 3.1: Map of the fire extent in 2000 and vegetation sampling plot points representing the five major plant communities located on the burnt and unburnt areas of the Robertson Granite Renosterveld (FRg3) and on different altitudes, slope aspects and gradients.

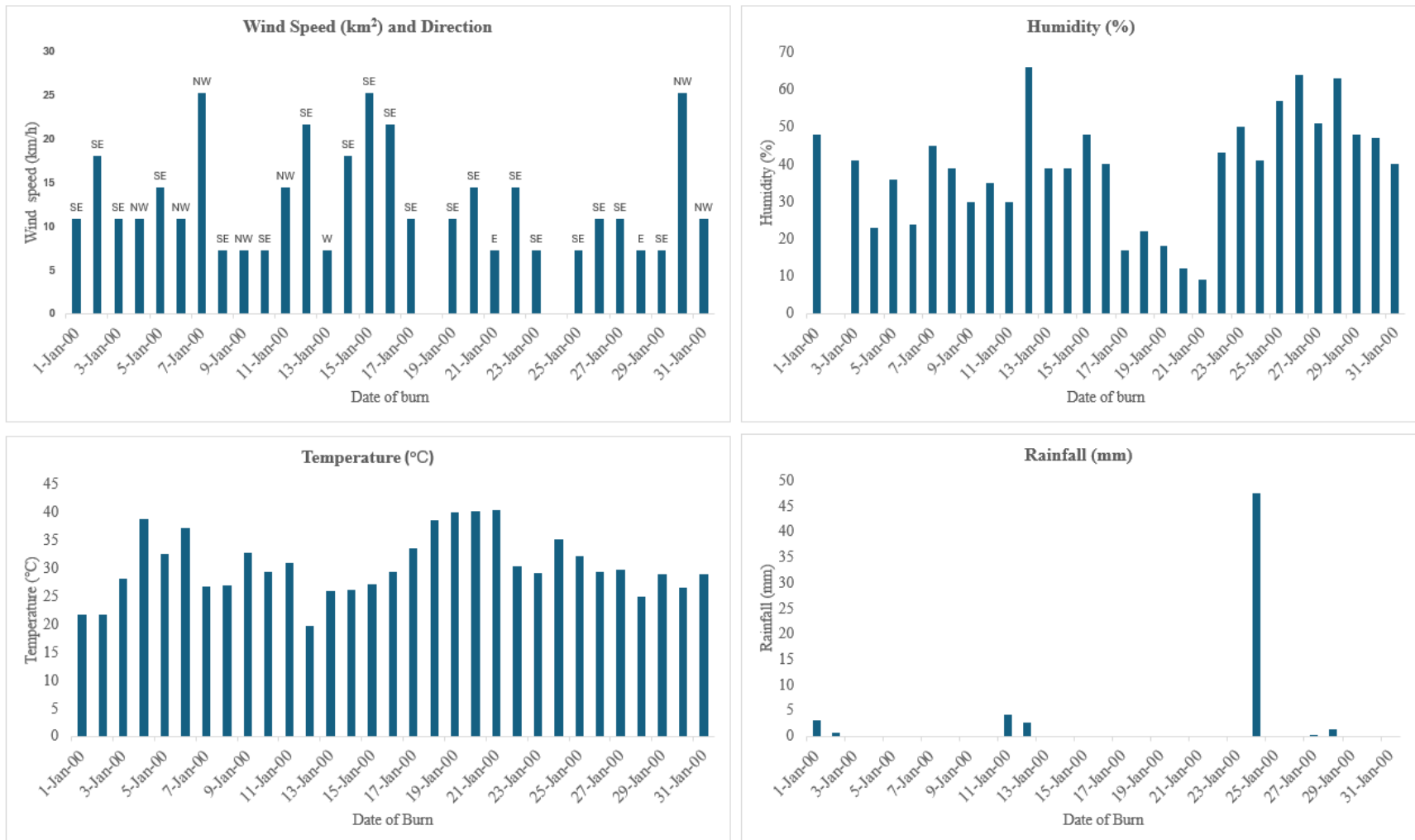


Figure 3.2: Summary of climatic conditions for the fire event in the Robertson Granite Renosterveld (FRg3) in 2000. This included wind speed and direction (SE = Southeast, NW = Northwest, W = West, E = East), humidity, temperature, and rainfall.

The second fire in the FRg3 occurred in 2006 and burnt over six days (the 26th of February 2006 to the 03rd of March 2006) (Figure 3.3). The fire started on one of the hottest days and burnt approximately 28% of the vegetation type. On the first day of fire, it was raining; therefore, the fire could have been ignited by lightning. Furthermore, the fire was spread by the north-westerly winds travelling at up to 18km/h. Approximately 72% of the vegetation type did not burn during the period (see Appendix 3.2 for fine scale map from GABAM).

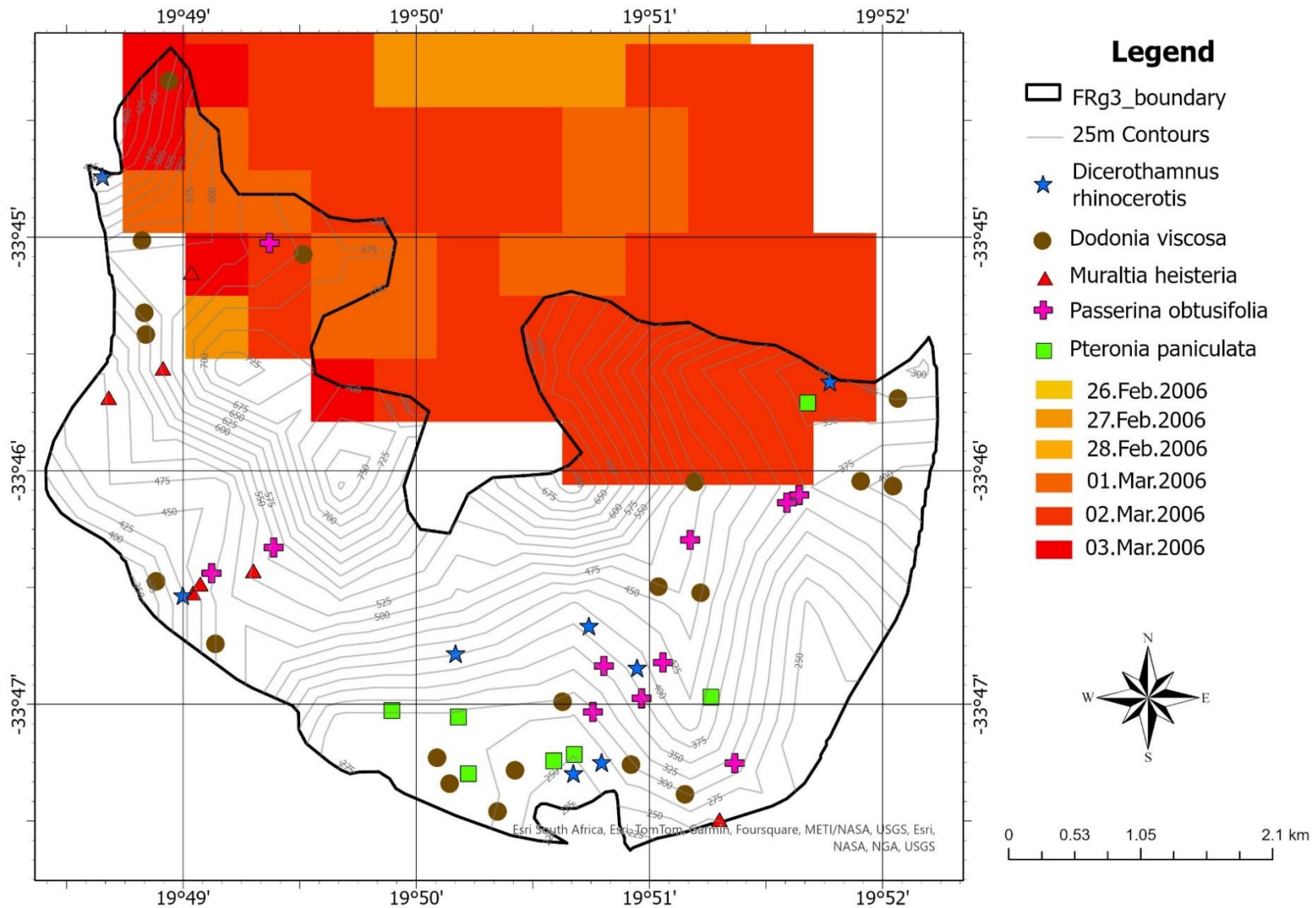


Figure 3.3: Map of fire extent in 2006 (with burn dates) and vegetation sampling plots representing the five major plant communities located on burnt and unburnt areas of the Robertson Granite Renosterveld (FRg3) and on different altitudes, slope aspects and gradients.

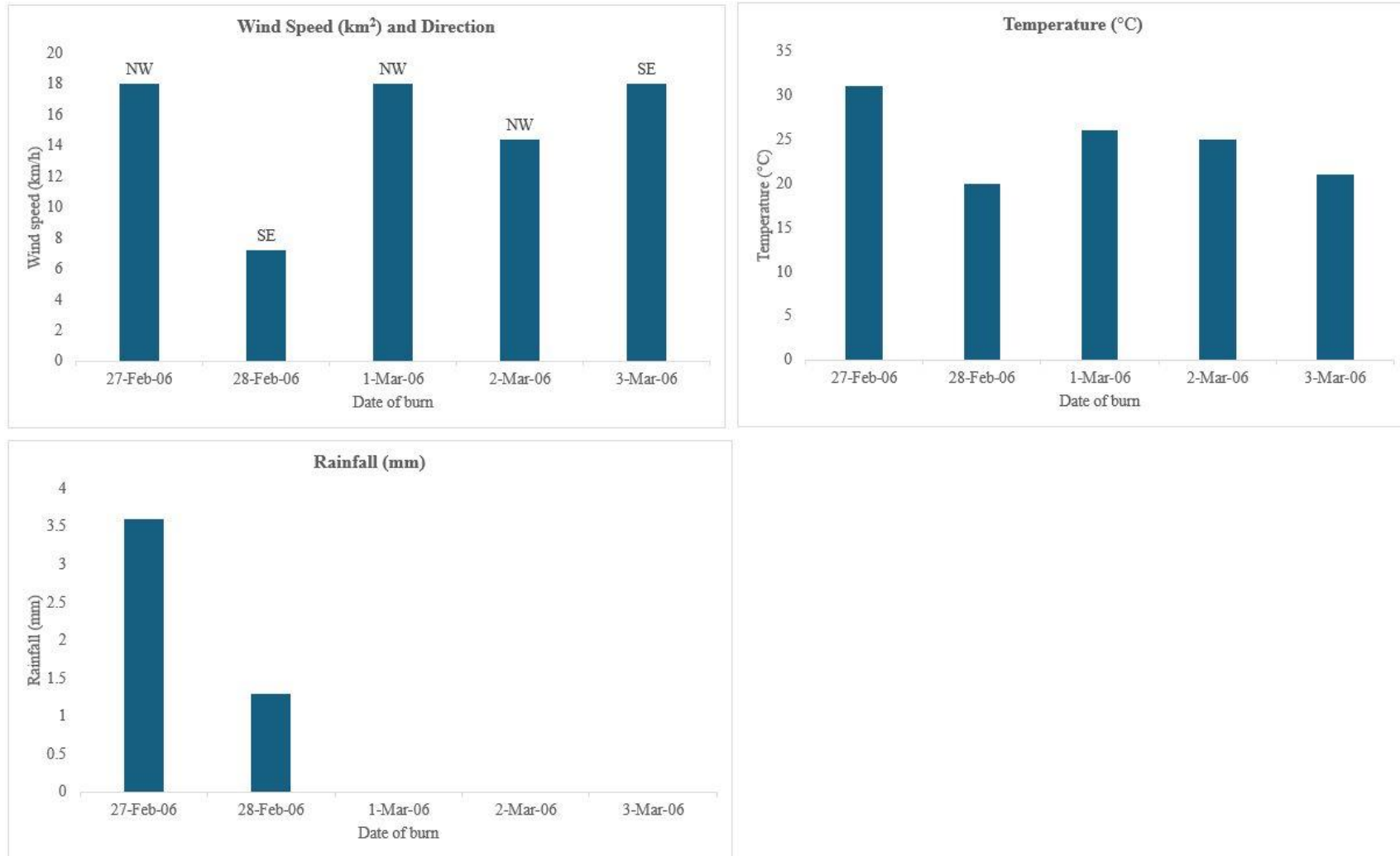


Figure 3.4: Summary of climatic conditions for the fire event in the Robertson Granite Renosterveld (FRg3) in 2006. This included wind speed and direction (SE = Southeast, NW = Northwest, W = West, E = East), temperature, and rainfall.

The third and most recent fire in the FRg3 occurred in 2017 (Figure 3.5) and it burnt over a period of seven days (the 21st of March 2017 to the 27th of March 2017). The fire started on one of the hottest days and burnt approximately 53% of the vegetation type (Table 3.1). This fire was burning in the opposite direction to the southeasterly winds, resulting in backburns towards the southerly lower slopes. The humidity was relatively low on the day the fire started. Approximately 47% of the vegetation type did not burn during this period (see Appendix 3.3 for fine scale map from GABAM). The *Pteronia paniculata–Dicerotheramnus rhinocerotis* community is the only community that is not in areas that did not burn in 2017.

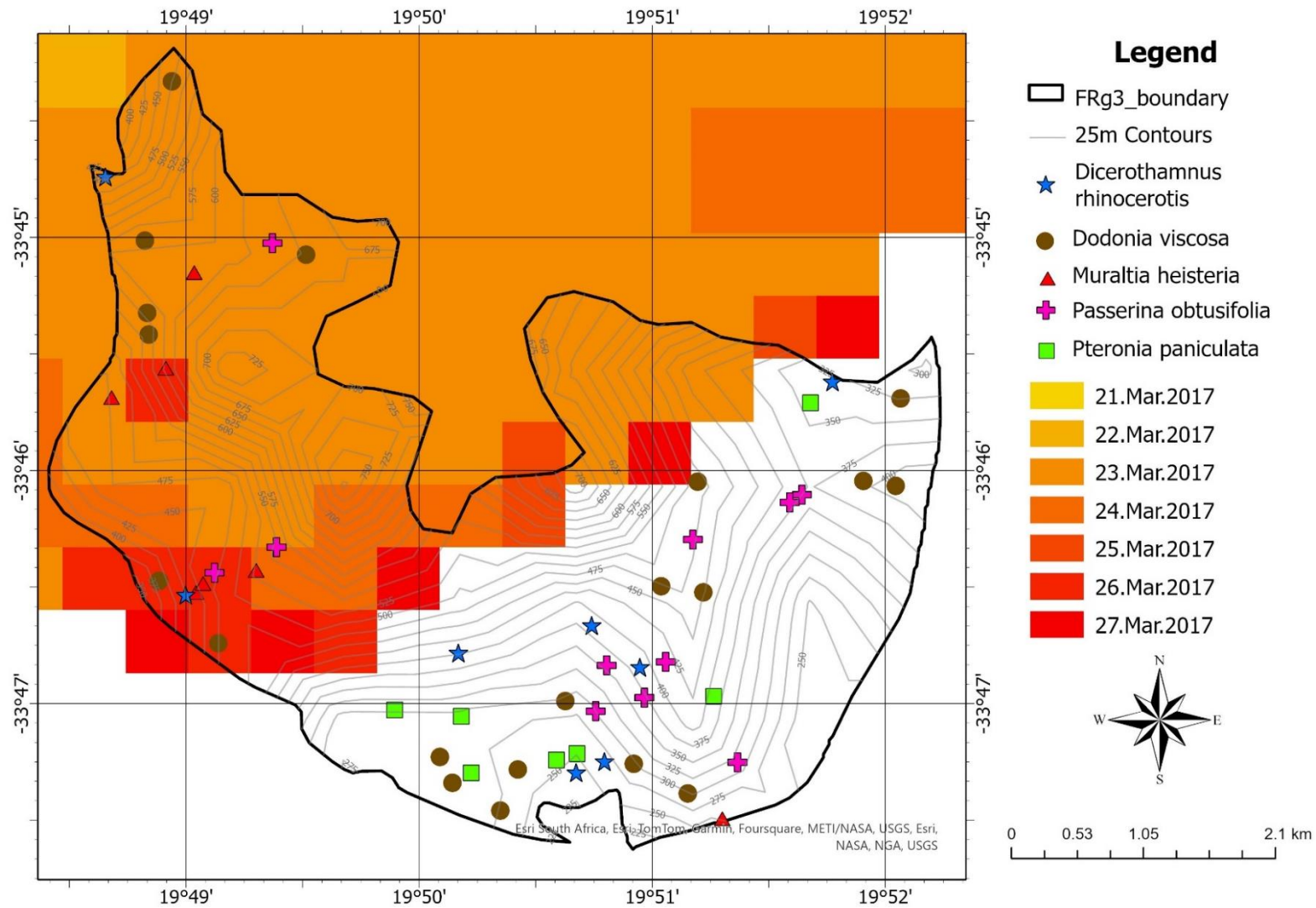


Figure 3.5: Map of fire extent in 2017 (with burn dates) and vegetation sampling plot points representing the five major plant communities located on burnt and unburnt areas of the Robertson Granite Renosterveld (FRg3) and on different altitudes, slope aspects and gradients.

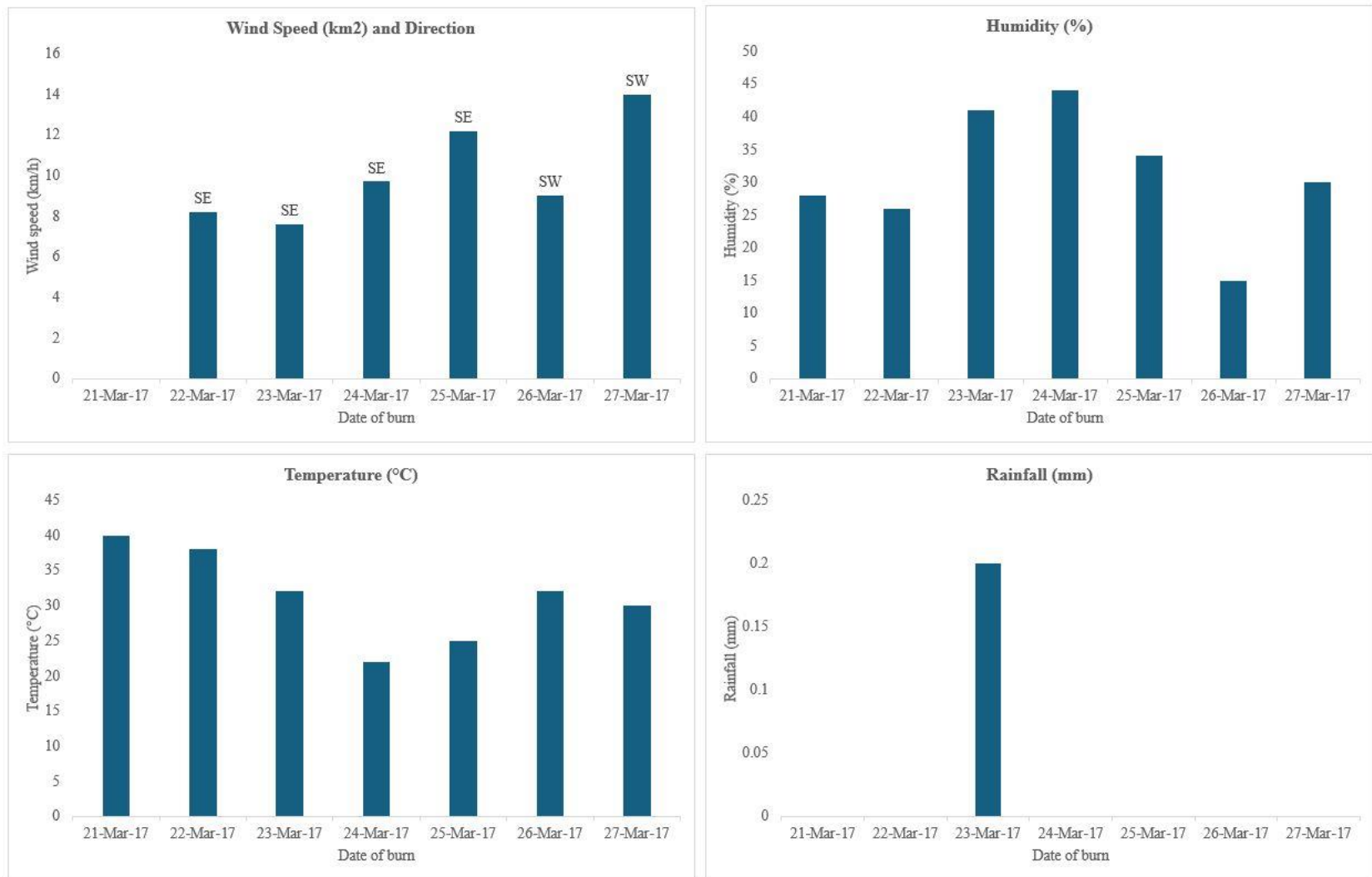


Figure 3.6: Summary of climatic conditions for the fire event in the Robertson Granite Renosterveld (FRg3) in 2017. This included wind speed and direction (SE = Southeast, NW = Northwest, W = West, E = East), humidity, temperature, and rainfall.

Approximately 23% of the vegetation type was burnt in both 2000 and 2017 (Table 3.1; Figure 3.7). The *Pteronia paniculata–Dicerotheramnus rhinocerotis* community is the only community that is not in areas that have been burnt by both fire events. This fire burnt the steep higher slopes of the FRg3. Approximately 22% burnt in both 2006 and 2017 (Table 3.1; Figure 3.8). Only the *Dodonaea viscosa–Euryops tenuissimus* and *Passerina obtusifolia–Restio capensis* communities are located on areas that burnt in both 2006 and 2017. Approximately 50% did not burn at all in 24 years (2000 – 2023).

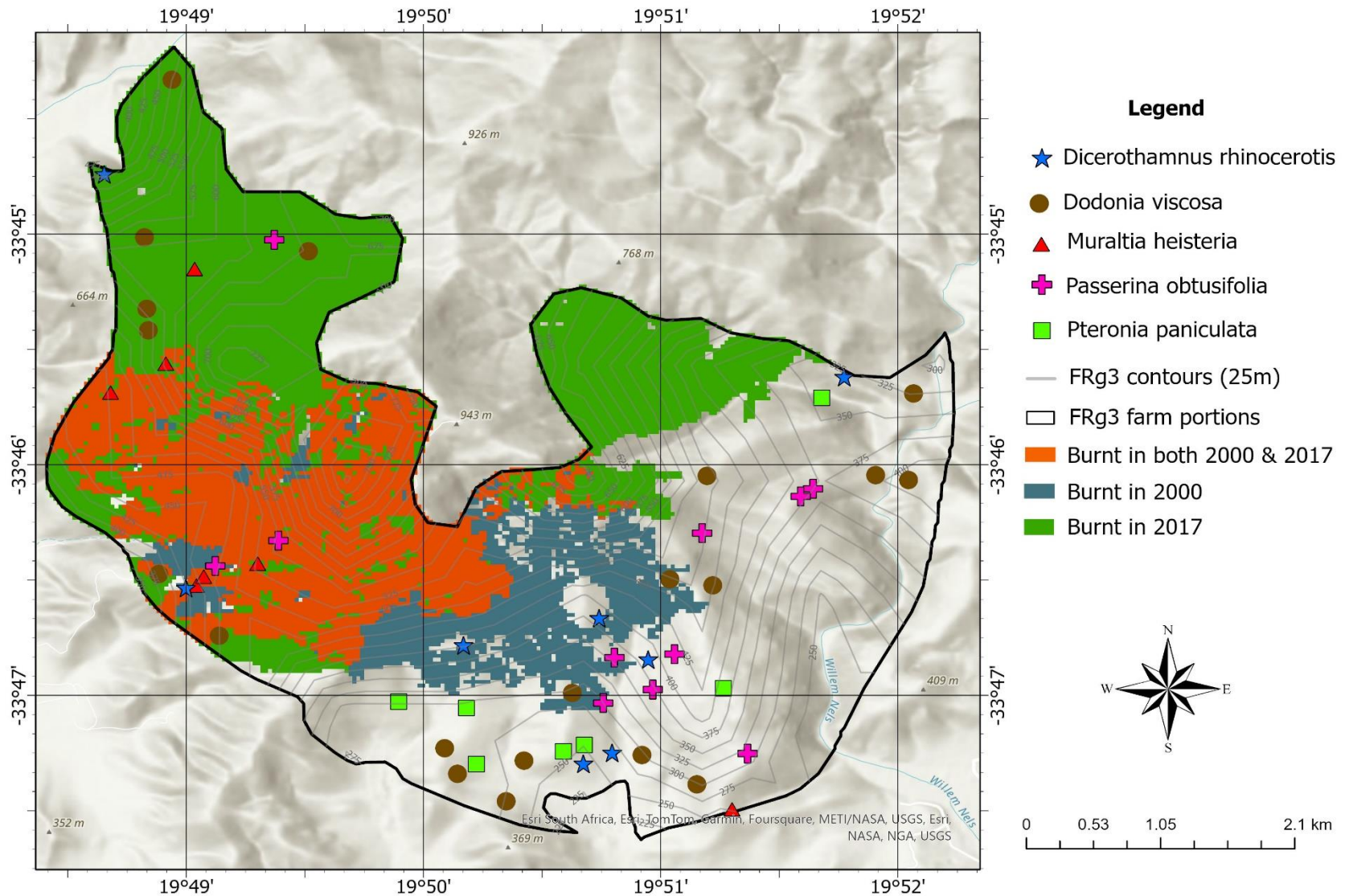


Figure 3.7: Map of burnt area within the Robertson Granite Renosterveld (FRg3) in 2000 and 2017. The map further shows plant communities in fire-affected localities and those in areas that did not burn at all in both years (transparent areas in the FRg3 boundary).

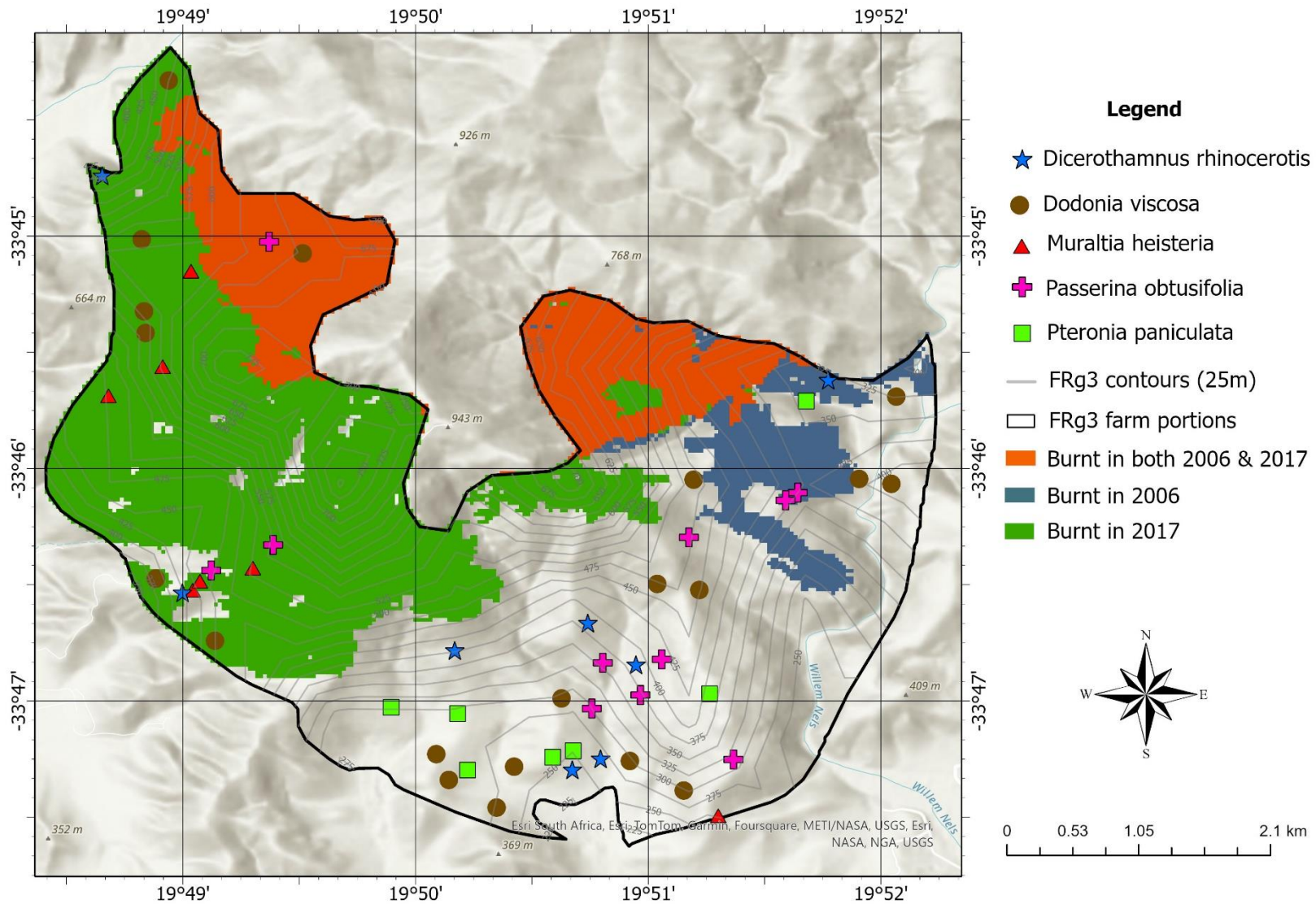


Figure 3.8: Map of the burnt area within the Robertson Granite Renosterveld (FRg3) in 2006 and 2017. The map further shows plant communities in fire-affected localities and those in areas that did not burn at all in both years (transparent areas in the FRg3 boundary).

The average air temperature during the fire events ranged from 25.67°C to 31.29°C and the fires were generally transported by North-westerly and Southeasterly winds at average wind speeds ranging from 8.67km/h to 14.4 km/h, with a peak of 25km/h. The three fire events (2000, 2006, and 2017) occurred on dry hot days which are favourable conditions for the fire to flourish. Furthermore, the fire events of both 2006 and 2017 affected the higher altitude areas above 400m a.s.l (Table 3.1; Figure 3.8).

Table 3.1: A summary of fire events with the number of plots burnt during each fire event, the average altitude and slope gradient on the burnt area, and the percentage cover of areas burnt for the three fire events and overlaps in multiple fires.

Year of the fire event	No. of plots burnt	Average of Altitude (m a.s.l)	Average Gradient (°)	Area burnt (%)
2000	6	315.00	25.83	35.52
2006	3	501.33	21.67	24.70
2017	5	481.80	18.60	53.51
2000&2006	0	0	0	0
2000&2017	9	508.00	34.87	23.42
2006&2017	4	459.00	24.25	22.91
Not burnt	26	345.81	20.23	46.49

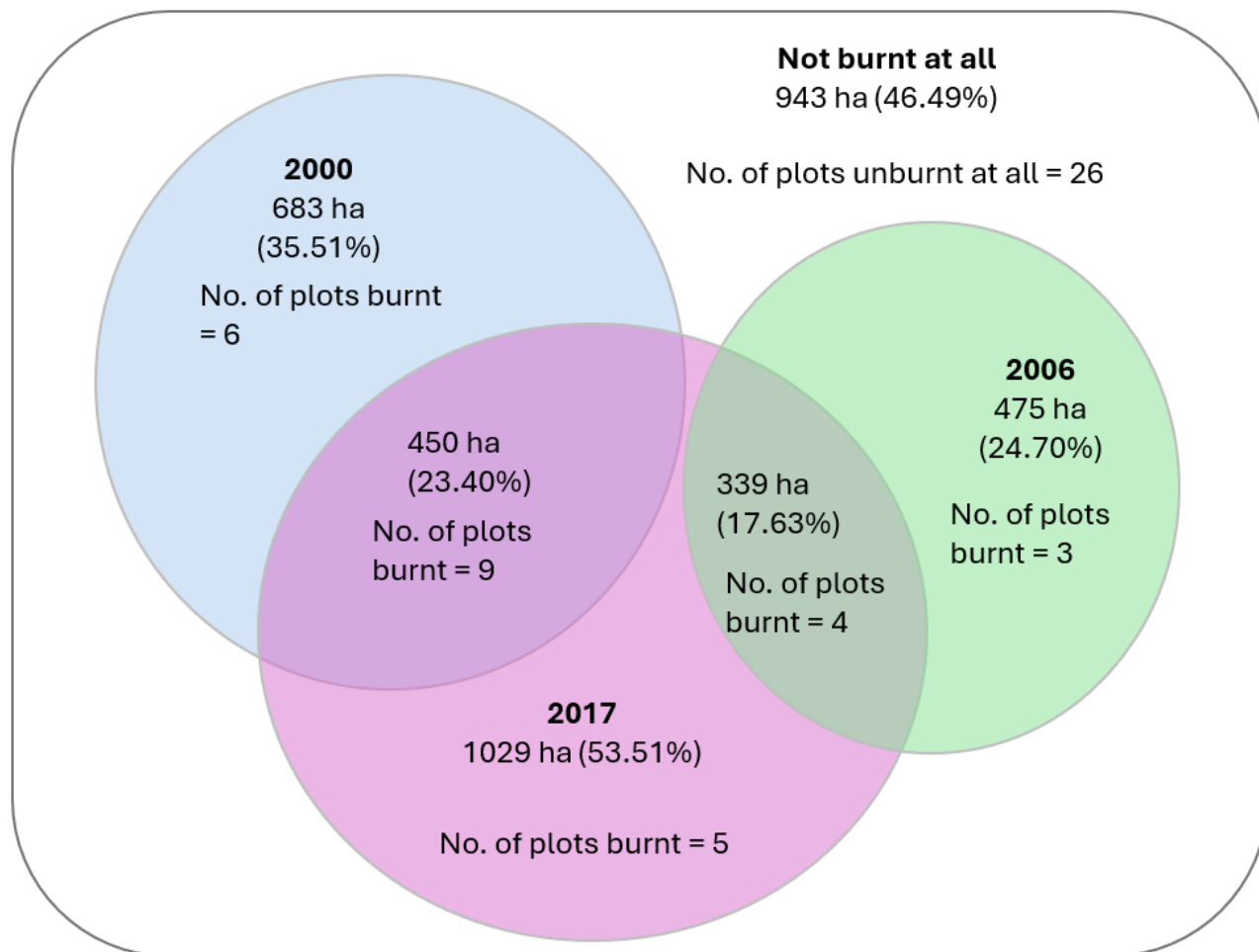


Figure 3.9: Venn diagram showing the overlap in fire occurrences within the Robertson Granite Renosterveld (FRg3) for the three fire events (2000, 2006, and 2017) over 24 years (2000 – 2023). The numbers in bold indicate the year of burn, and the area burnt is shown in ha, while the percentage cover of the fire is inside the brackets.

3.4 Discussion

The fire season at the Robertson Granite Renosterveld (FRg3) is typically between February and March (Figure 3.3; Figure 3.5), this period is the hottest and driest of the year with strong southeasterly winds of up to 25 km/h (Figure 3.2); this provides favourable conditions for fire ignition and spread. The fire of 2000 accounted for the burning of 683 ha (35.50%) of the vegetation type. The 2006 fire accounted for the burning of 475 ha (24.39%) of the vegetation type while that of 2017 accounted for the burning of 1029 ha (53.5%). These fire events affected

the northern portion of the vegetation type with 339 ha (17.63%) being burnt in both 2006 and 2017 fire events. Furthermore, 450 ha (23.40%) of the vegetation type burnt in both 2000 and 2017 (Figure 3.9). There are plant communities which are typically situated in the FRg3 fire-prone areas (*Muraltia heisteria*–*Restio capensis*; *Dicerotheramnus rhinocerotis*–*Dodonaea viscosa*; *Dodonaea viscosa*–*Euryops tenuissimus*; and *Passerina obtusifolia*–*Restio capensis*) and only one community found in areas that were not affected by fire (*Pteronia paniculata*–*Dicerotheramnus rhinocerotis*) in 24-year study period (2000-2023). In that regard, it can be argued that frequent burning influences the structure and composition of plant communities within the vegetation type.

Hanes (1971) and Van der Merwe & Van Rooyen (2011) pointed out that altitude is an important attribute to consider when investigating post-fire features. Findings from this study indicated that areas not affected by fire in 24 years are commonly found at altitudes lower than 400 m.a.s.l. Approximately half of the FRg3 was not affected by fire in over two decades. These findings support the narrative of Kraaij & Van Wilgen (2014) and Cousins *et al.* (2018) that the renosterveld is not fire dependent. Furthermore, Le Roux (2011), Cousins *et al.* (2018), and Burghardt *et al.* (2021) highlighted that fragments of the renosterveld vegetation (especially on private lands) remain unburned through multiple fire seasons due to fire suppression by landowners. Therefore, fires ignited by lightning or humans are extinguished as soon as possible as farmers see them as a threat to their farms. As a result, it could be suggested that fires in the FRg3 are managed and extinguished before they reach the lower lying areas of the vegetation type.

The vegetation type burnt during the summer season, and fires occurred under a wide range of conditions (Simons, 2018) including high temperatures, low humidity and relatively

high wind speed and constant wind direction (Kraaij & Van Wilgen, 2014; Hayasaka *et al.*, 2019). During the fire event of 2017, the vegetation type experienced the highest average temperature (31°C) and lowest humidity (31%) compared to other fire events. Therefore, this could explain why the most recently recorded fire burned more of the area (ha) than the previous fire events. Trollope *et al.* (2002) and Sharples *et al.* (2012) highlighted that the slope gradient is also an important variable that influences the size and spread of fire. In contrast, Table 3.1 shows that there is no relationship between fire events and the gradients of the FRg3.

The fire event of 2017 burnt in the opposite direction to the wind (Figure 3.6; Appendix 3.1). According to Luke & McArthur (1978) and Trollope *et al.* (2002) wind speed influences the burning rate and fire direction. Wind speeds ranging between zero and 13 km/h can convert a head-fire into a back-burn on steep slopes (Trollope *et al.*, 2002). Therefore, this explains why the fire of 2017 was burning in the opposite direction to the wind because the climatic and topographic conditions on the burn date provide favourable conditions for the occurrence of a back-burn.

The main observation from Figure 3.5 is that the *Muraltia heisteria–Restio capensis* community was commonly found in the higher altitude and fire-stricken regions of the vegetation type during the study period. At the same time, the *Pteronia paniculata–Dicerotheramnus rhinocerotis* community was commonly found in lower altitude areas that had not been touched by fire in over two decades. This was consistent with Cousins *et al.* (2018) stating that many fragments of the remaining Renosterveld are not affected by fire for extended periods which could be decades in some cases. The *Pteronia paniculata–Dicerotheramnus rhinocerotis* is located close to the agricultural land where there is also a presence of grazing livestock. Therefore, since this community is in the proximity of grazing livestock, the grazers

could be reducing the biomass within the community, which reduces the fuel load and the probability of fire within the community as per Shezi *et al.* (2021). In addition, the *Pteronia paniculata–Dicerotheramnus rhinocerotis* community is located on the southern portion of the FRg3 where it borders with the Robertson Karoo (and may have lower rainfall than the rest of the FRg3), therefore, this community could have adopted the low fire frequency of the Karoo vegetation types (van der Merwe *et al.*, 2016) since it did not burn at all in at least 24 years (2000-2023). The dominant species within the *Muraltia heisteria–Restio capensis* community are dispersed by ants (myrmecochorous). Therefore, the recent fire (Figure 3.5) could have directly stimulated the germination of these species, and the fire would have cleared the dense above-ground biomass and opened gaps for the recruitment of seedlings from species that characterise the FRg3 (Chapter 2; van der Merwe & van Rooyen 2011).

3.5 Conclusion

Fire as a driving force of Mediterranean ecosystems is an important ecological process within the Robertson Granite Renosterveld (FRg3). The FRg3 experienced three fire events in 24 years (2000 – 2023). The northern, high altitude portion of the vegetation type is the most fire-prone as it burned on two out of the three fire events during the study period. Furthermore, the community composition and vegetation structure within the FRg3 could be shaped by fire. The renosterveld fire cycle is between 10 and 15 years (unless there is a human-induced ignition/controlled burn), this correlates with the findings from this study. Hence, the next fire event could be expected between the years 2027 and 2032. The fires rarely affect the low-lying areas of the vegetation type, this study suggests that the farm owners could be extinguishing the fire before it reaches their residential and agricultural lands as it could potentially damage their properties.

Chapter 4: Changes in vegetation structure of the Robertson Granite Renosterveld over 24 years (2000 – 2023)

Abstract

Change detection plays a crucial role in informing decisions and policy by revealing how a landscape has changed from a historical baseline to the present, at which point it is often modified or degraded due to particular pressures. Vegetation change detection analyses is commonly performed using the Normalized Difference Vegetation Index (NDVI). Trends and patterns on the changes in vegetation structure of an ecosystem can help predict potential change, which can provide decision makers with informed projections in order to implement conservation intervention where needed. This chapter aims to investigate how the vegetation structure of the Robertson Granite Renosterveld (FRg3) has changed over 24 years (the years 2000 – 2023). Furthermore, the chapter will investigate the influence of fire on the changes in vegetation structure over the 24-year period. NDVI was computed on Landsat 5 and Landsat 8 imagery to assess changes in vegetation structure over five different time periods (2000 – 2006, 2006 – 2013, 2013 – 2017, 2017 – 2023, 2000 – 2023). The classified NDVI images had overall accuracies of above 70%. The FRg3 had an increase in biomass between 2000 & 2006 despite having burnt in 2006, largely because the area that burnt in 2000 had recovered despite the other fire in 2006 which only burnt the small northern portion of the FRg3. A high biomass was observed in the vegetation type between 2006 and 2013. In 2017, the FRg3 vegetation type lost most of its biomass due to a fire that burnt over half of it (Chapter 3). The FRg3 vegetation type had the most shrubby and dense vegetation structure in both 2013 and 2023, likely due to the lack of human-induced or natural disturbances.

Keywords: Change detection, Fire, FRg3, Landsat, Normalized Difference Vegetation Index (NDVI), Robertson Granite Renosterveld, Vegetation structure.

4.1 Introduction

Change detection is defined as “the process of identifying the differences in the state of an object or phenomenon by observing it at different times” (Singh, 1989). Change detection is a common application of remotely sensed data especially when studying the changes in vegetation structure and phenology (Singh, 1989; Lu *et al.*, 2004). These changes may influence the decision-making and management of biodiversity (Lu *et al.*, 2004; Al Rawashdeh, 2012; Gandhi *et al.*, 2015). Therefore, accurate and timely change detection is crucial to understanding the interactions and relationships between natural phenomena and humans for better management of resources (Lu *et al.*, 2004; Aly *et al.*, 2016).

The surface characteristics are usually represented in band ratios when processing satellite imagery, and the differences between two bands are referred to as an index (Aly *et al.*, 2016). The Normalized Difference Vegetation Index (NDVI) is the commonly used index for detecting changes in vegetation cover and structure (Gandhi *et al.*, 2015; Ibrahim & Al-Mashagbah, 2016; Muavhi, 2021; Coetzee, 2022). This vegetation index comprises the near-infrared and red bands. Hence, green plants appear reddish on a satellite image because the high chlorophyll content reflects infrared wavelengths (Kshetri, 2018; Sabins & Ellis, 2020). This index is defined using the following formula:

$$\text{NDVI} = [\text{B}_{\text{nir}} - \text{B}_{\text{red}}] / [\text{B}_{\text{nir}} + \text{B}_{\text{red}}]$$

where B_{nir} is the reflectance of near-infrared and B_{red} is the visible red reflectance (Singh, 1989; D’Allestro & Parente, 2015; Gandhi *et al.*, 2015; Kshetri, 2018). NDVI values theoretically range from -1 to +1, where the negative values symbolise waterbodies, while bare lands are symbolised by values around zero and dense vegetation is symbolised by values greater than 0.6 (Meneses-Tovar, 2011; Gandhi *et al.*, 2015; Aly *et al.*, 2016; Ibrahim & Al-Mashagbah,

2016). NDVI uses multi-spectral imagery to obtain indices of vegetation, waterbodies, agricultural land, and bare land using two (red and near-infrared) band combinations of satellite imagery (Gandhi *et al.*, 2015; D'Allestro & Parente, 2015).

The general NDVI thresholds used for the classification of vegetation structure are as follows: <0.1 = snow/bare land/sand; $0.2 - 0.3$ = shrub and grassland; $0.4 - 0.5$ = Dense shrubland/dense woodland; and $0.6 - 0.8$ = tropical rainforest (Gross, 2005; Badamasi *et al.*, 2010; El-Gammal *et al.*, 2014). However, the classes are not universal across the world (Badamasi *et al.*, 2010; Taufik *et al.*, 2016; Hashim *et al.*, 2019), as such, different studies have different NDVI thresholds assigned to the classes that are relevant to their vegetation type (Badamasi *et al.*, 2010; El-Gammal *et al.*, 2014; Taufik *et al.*, 2016). Therefore, the differences in NDVI thresholds suggest that as much as NDVI is commonly used as a proxy for analysing vegetation structure and health, the classification thresholds are often customized in the context of the area of study. For example, Badamasi *et al.* (2010) analysed the temporal changes (1986 – 2005) in the vegetation of Falgore Game Reserve using NDVI classes and thresholds customized in context of the Falgore Game Reserve vegetation. Furthermore, Taufik *et al.* (2016) computed NDVI using Landsat 8 imagery to identify the vegetated surface, non-vegetated surface and waterbodies in Klang, Selangor. The NDVI threshold of Taufik *et al.* (2016) was also customized to match the objective of their study, which was different from that of Badamasi *et al.* (2010).

Several factors can induce changes in the vegetation structure of ecosystems and alter the NDVI reflectance thereof (Liu *et al.*, 2015; Huang *et al.*, 2021). The change in vegetation structure can either be anthropogenic (land use/cover change) or consequent to climate change induced disturbances such as wildfires, droughts, and floods (Liu *et al.*, 2015; Yang *et al.*, 2019).

The vegetation structure of ecosystems is often altered primarily by fire (Liu *et al.*, 2015; Yang *et al.*, 2019; Lacouture *et al.*, 2020). Therefore, the relationship of fire in the Robertson Granite Renosterveld (FRg3) with changes in vegetation structure will be investigated in this study.

Landsat imagery consists of seven bands which offer a suitable spectral resolution for vegetation change detection using NDVI (Al Rawashdeh, 2012). In addition, image collections from this satellite have a long history of datasets and it is the most widely used for mapping long-term spatiotemporal changes in vegetation cover (Xie *et al.*, 2008). Landsat imagery is also used to map the changes in vegetation patterns within the Cape Floristic Region and Fynbos biome (Kotzé and Fairall, 2006). Hence, Landsat satellite imagery was used for this study to determine how the vegetation structure has changed in the FRg3 over 24 years (2000 – 2023).

4.1.1 Aim and Objectives

This chapter aimed to investigate the changes in vegetation structure of the FRg3 over 24 years (2000 – 2023). There were two objectives, the first objective was to quantify changes in vegetation structure using NDVI derived from Landsat 5 (2000 and 2006 imagery) and Landsat 8 imagery of 2013, 2017, and 2023. The second objective was to explore the influence of fire on the structural changes of the FRg3 vegetation over 24 years (2000-2023).

4.2 Methods

4.2.1 Data collection

Change detection was executed using Landsat satellite imagery for the years 2000, 2006, 2013, 2017, and 2023. Landsat 5 was used to visualise the vegetation structure of FRg3 for the years 2000 and 2006. And Landsat 8 was used to visualise the vegetation structure of FRg3 for the years 2013; 2017; and 2023. The imagery was acquired from Google Earth Engine (<https://developers.google.com/earth-engine/datasets/catalog/landsat>) for the spring season in

South Africa (between September and November) because it is the time when most plants within the fynbos and renosterveld ecosystems emerge and are in flower (Pierce & Cowling, 1984). Furthermore, this region experiences winter rainfall (Jacobsen *et al.*, 2009; Neumann *et al.*, 2011; Lee & Barnard, 2016). Therefore, there will be minimal to no cloud cover for imagery acquired for this period. Both Landsat 5 & 8 have a spatial resolution of 30m x 30m, however, Landsat 5 has seven (7) spectral bands while Landsat 8 has nine (9) spectral bands. Both Landsat 5 and 8 have a return period of 16 days.

4.2.2 Analyses

The downloaded satellite images were processed using ArcGIS Pro 3.0, and NDVI was computed to determine the changes in vegetation structure within the FRg3. The NDVI images were classified based on the NDVI threshold of Gross (2005) and El-Gammal *et al.* (2014), then customized according to the renosterveld vegetation (Table 4.1); the first class represented areas with very low vegetation cover including resprouting plants/establishing seedlings/bare lands, the second class represented grassy land, the third class represented areas covered by sparse shrubland with graminoid patches, the fourth class represented areas covered by dense shrub, the last class represented areas covered by tall dense trees normally found in riparian zones, there is also a patch of plantations within the FRg3 which were also categorised under this class.

Table 4.1: The Normalized Difference Vegetation Index (NDVI) classification thresholds customized for renosterveld vegetation.

NDVI values	Feature class
0 – 0.3	Bare land/resprouting plants/establishing seedlings
0.31 – 0.4	Grassy land
0.41 – 0.5	Sparse shrubland
0.51 – 0.6	Dense shrubland
> 0.61	Forest/Plantations

A workflow highlighting the image processing steps is shown in Figure 4.1. The NDVI value ranges were used to categorise each class into an appropriate vegetation structural class as per Sahebjalal & Dashtekian (2013) and Singh *et al.* (2015). Vegetation structural distribution histograms were computed for every classified NDVI image to quantify the representation of each class and determine the average NDVI values for each year of study.

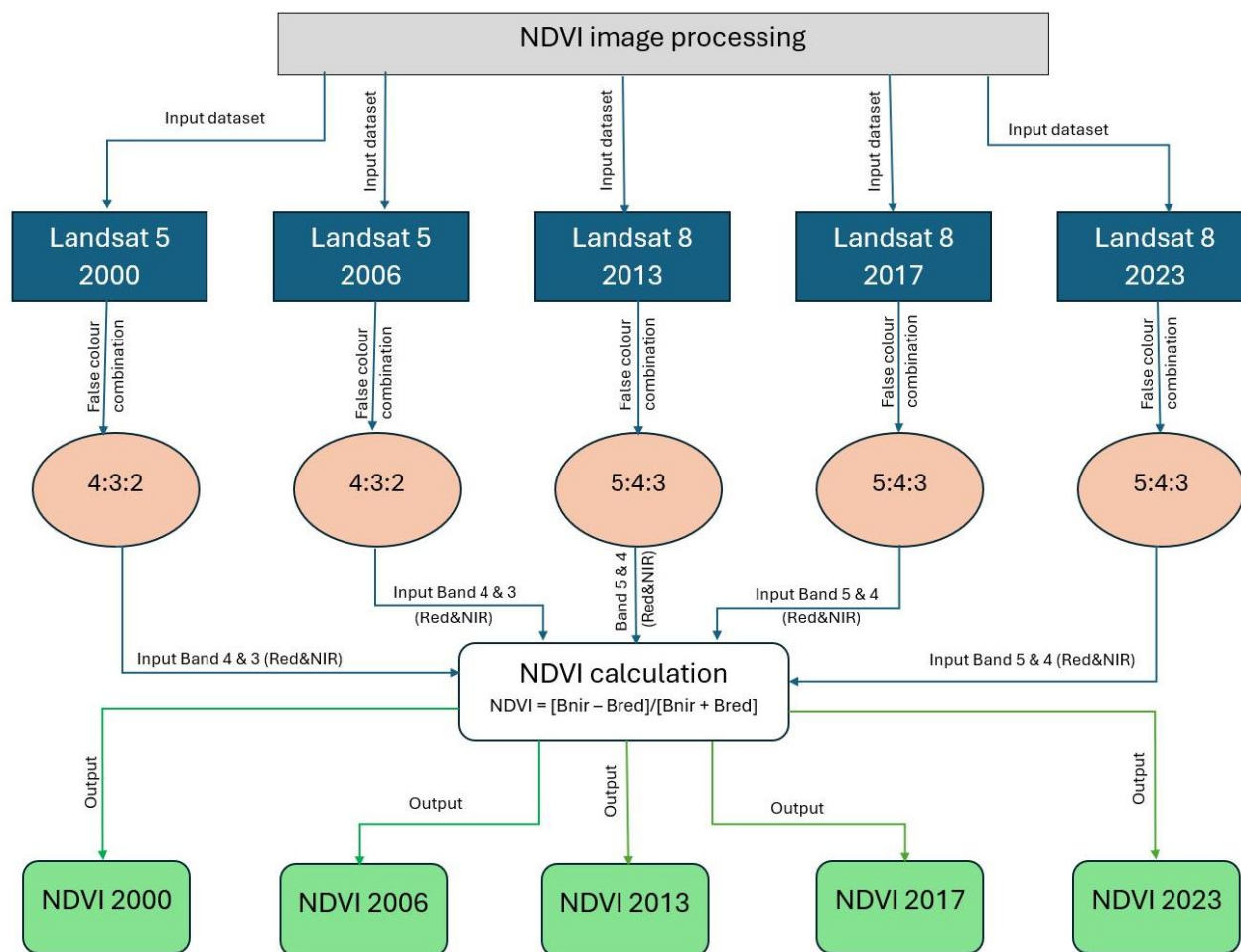


Figure 4.1: Workflow of the image processing to create NDVI images from Landsat 5 & 8 imagery. The blue squares represent the input Landsat imagery, and the numbers inside the oval/circles represent the false colour combination to reflect the near-infrared and red wavelengths. The green rectangle represents the NDVI outputs.

The change in vegetation structure within the FRg3 was calculated using the formula:

$$NDVI_{\text{change}} = NDVI_{\text{time2}} - NDVI_{\text{time1}}.$$

The positive $NDVI_{\text{change}}$ values indicate an increase in NDVI, while negative values show a decrease in NDVI. These changes in vegetation structure were calculated for each class in every image (i.e $NDVI_{\text{change}} = \text{Class}_{\text{time2}} - \text{Class}_{\text{time1}}$).

4.2.3 Accuracy assessment

The accuracy assessment of the classified features was conducted using an error matrix also known as a confusion matrix on ArcGIS Pro. 100 random points were generated and then overlaid onto the FRg3 boundaries. Then the points were appended to the classified imagery, with each point assigned its corresponding classified feature. The imagery on Google Earth Pro (<https://www.google.com/earth/>) was used to determine what the training points and validation points were. Each point representing a trained class (specific feature) was compared with the corresponding features displayed on Google Earth Pro to validate the classification of each feature. Through this comparison, the key accuracy matrices such as the Producer's Accuracy, User's Accuracy, and Overall Accuracy can be calculated for each class. The Producer's Accuracy was calculated by dividing the number of accurately classified points by the number of reference points for that particular class, to determine the percentage of accurately classified pixels for a specific class. The User's Accuracy was calculated by dividing the number of accurately classified points for each class by the total number of points classified as that particular class, to determine the reliability of the classified class. Lastly, the Overall Accuracy was calculated by adding the mean Producer's Accuracy and mean User's Accuracy and then dividing the sum by two. This process highlights the precision and reliability of the classified features.

4.3 Results

The Robertson Granite Renosterveld (FRg3) has experienced changes in vegetation structure over the 24 years (2000 – 2023) of focus. The NDVI values ranged from 0.12 to 0.87 over the whole 24-year period. There was an increase in biomass within the FRg3 between 2000 and 2023. The vegetation type transitioned from domination by grassy land to dense shrubland with some patches of tall trees (forest/plantation) (Figure 4.4, Figure 4.7). Furthermore, most of the area that was classified as bare in 2000 was covered by sparse shrublands with patches of grassy vegetation in 2023 (Figure 4.7).

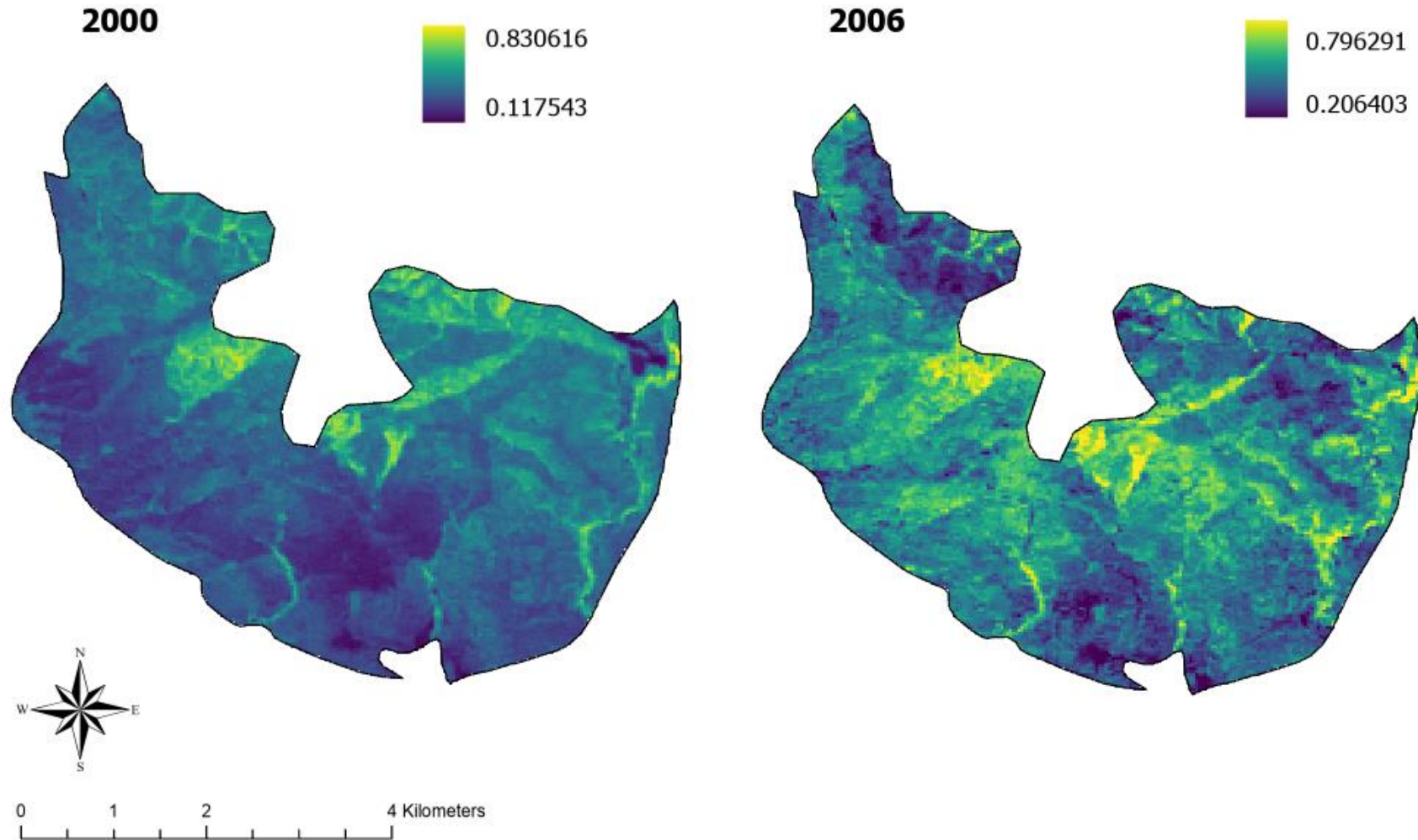


Figure 4.2: A comparison between the NDVI maps (derived from Landsat 5) of the Robertson Granite Renosterveld (FRg3) for the years 2000 and 2006. High NDVI values (bright/yellow) represent dense/high vegetation cover while lower values (dark/blue) represent low/sparse vegetation cover.

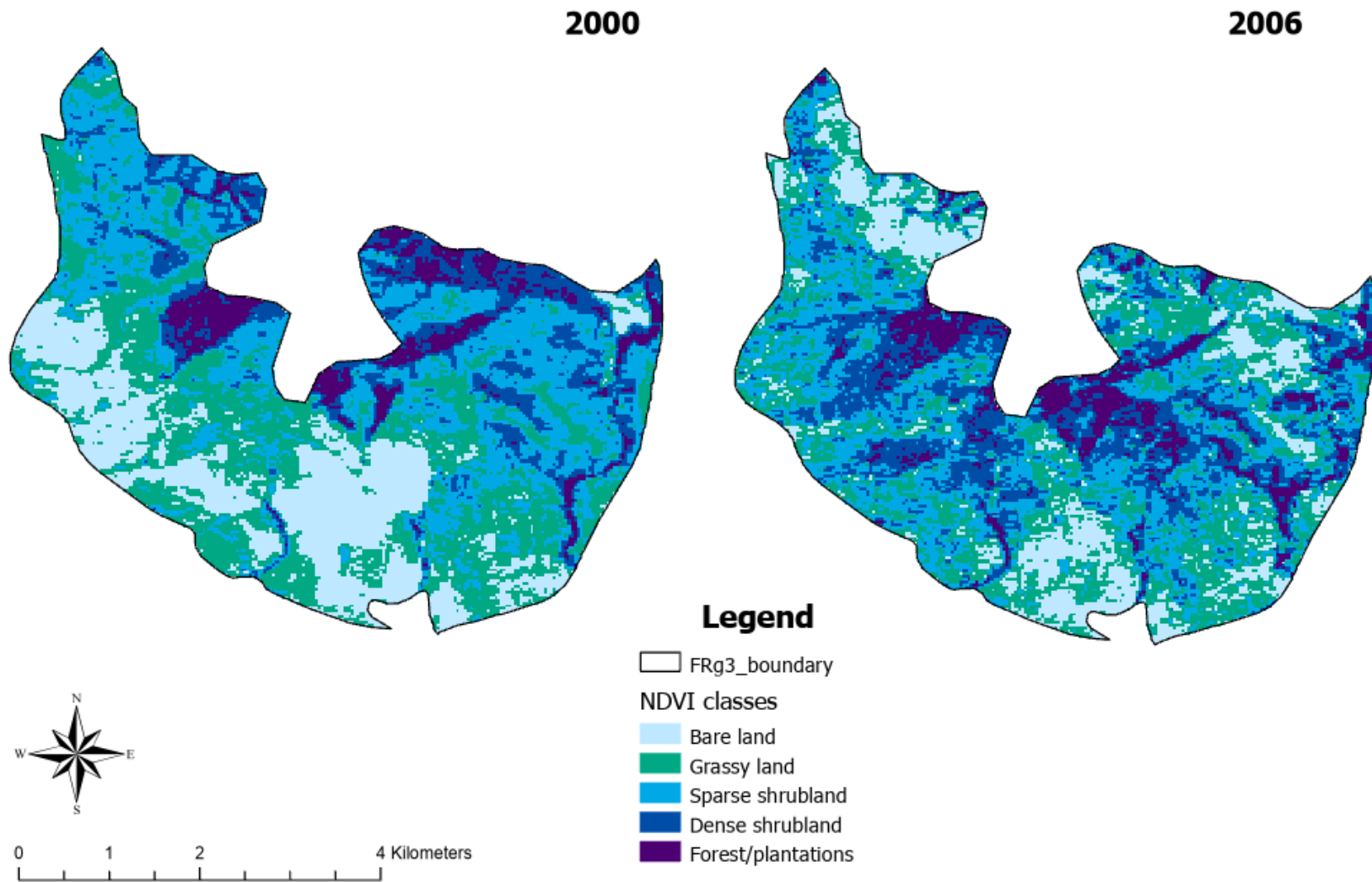


Figure 4.3: A comparison of classified NDVI maps (derived from Landsat 5) of the Robertson Granite Renosterveld (FRg3) for the years 2000 and 2006. The imagery was classified into five cover types namely: Bare land (which also includes low vegetation cover/establishing seedlings and non-vegetated areas), Grassy land, Sparse shrubland, Dense shrubland, and Forest/plantations.

The classified NDVI image of 2000 showed a total Producer's Accuracy (PA) of 77.63% and a total User's Accuracy (UA) of 73.33%. The forest/plantations class showed the highest PA of 90% and a moderate UA of 64.29%. This means that 90% of the forest/plantation pixels have been accurately classified with moderate reliability. The grassy land class showed the lowest PA (68%) and a very high reliability of the classified pixels (UA = 80.95%). The misclassified grassy land pixels were classified as either sparse shrubland, dense shrubland, or bare land. Classes from this imagery were classified with an overall accuracy of 75.48%.

The classified NDVI image of 2006 showed a total PA of 72% and a total UA of 69.73%. The forest/plantations classified pixels showed the highest PA of 79.17% and a moderate UA of 65.52%. This means that 79.17% of the forest/plantation pixels have been accurately classified with moderate reliability. The sparse shrubland class had the lowest PA (56.76%); the remaining 43.24% was misclassified as dense shrubland, forest/plantations, and grassy land. Furthermore, this class had the highest UA of 87.50% showing very high reliability of the sparse shrubland pixels. The classes from this imagery were classified with an overall accuracy of 70.87%.

Table 4.2: Error matrix for the NDVI classes in the years 2000 and 2006 (refer to Figure 4.3) with the Producer's Accuracy, User's Accuracy, and Overall Accuracy.

NDVI classes (2000)	Bare land	Grassy land	Sparse shrubland	Dense shrubland	Forest/plantation	Total	Producer's Accuracy (%)
Bare land	18	3	2	0	0	23	78.26%
Grassy land	1	17	5	2	0	25	68%
Sparse shrubland	0	1	23	5	3	32	71.88%
Dense shrubland	0	0	0	8	2	10	80%
Forest/plantation	0	0	0	1	9	10	90%
Total	19	21	30	16	14	100	77.63%
User's Accuracy (%)	94.74%	80.95%	76.67%	50%	64.29%	73.33%	Overall Accuracy =75.48%
NDVI classes (2006)	Bare land	Grassy land	Sparse shrubland	Dense shrubland	Forest/plantation	Total	Producer's Accuracy (%)
Bare land	3	1	0	0	0	4	75%
Grassy land	1	6	1	0	0	8	75%
Sparse shrubland	0	3	21	8	5	37	56.76%
Dense shrubland	0	0	2	20	5	27	74.07%
Forest/plantation	0	0	0	5	19	24	79.17%
Total	4	10	24	33	29	100	72%
User's Accuracy (%)	75%	60%	87.50%	60.61%	65.52%	69.73%	Overall Accuracy =70.87%

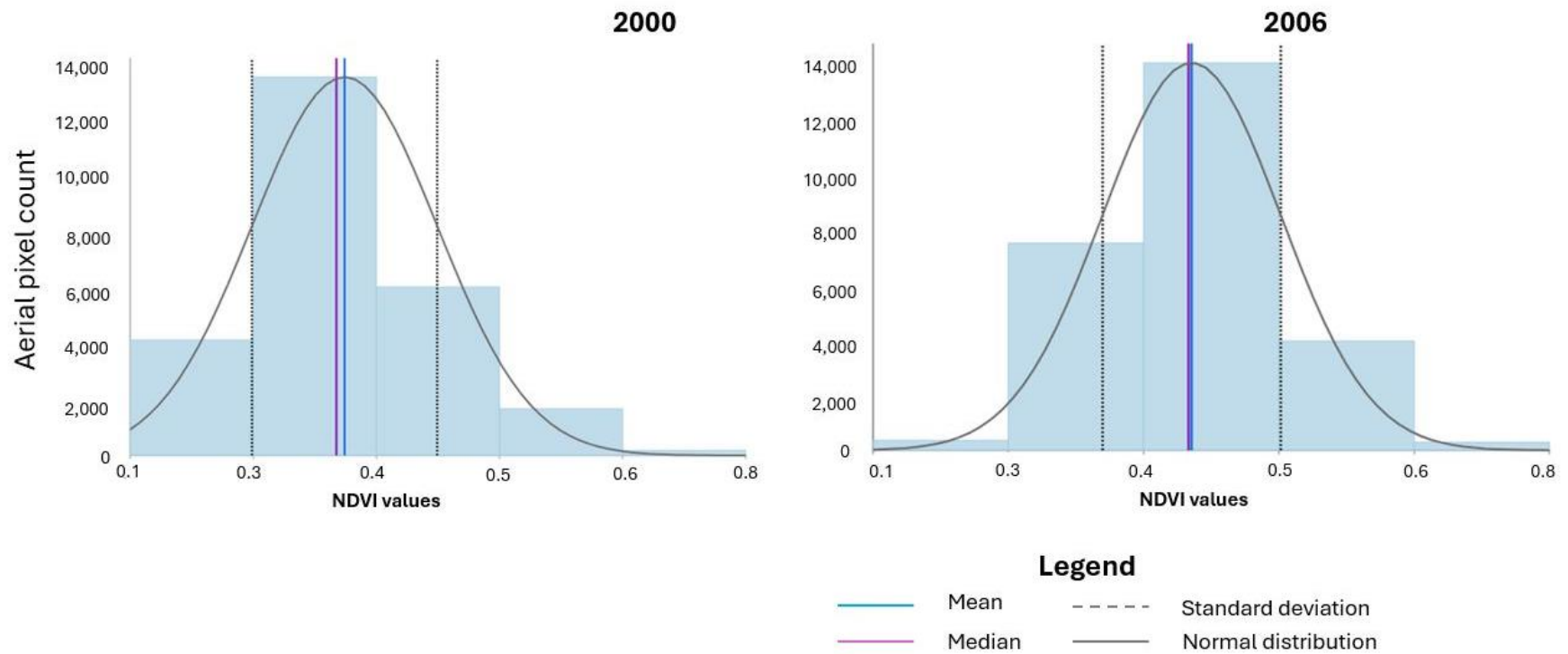


Figure 4.4: Vegetation structural distribution within the Robertson Granite Renosterveld (FRg3) in 2000 and 2006, with NDVI values and the total number of pixels for each NDVI threshold. The mean, median, standard deviation, and normal distribution are shown by the vertical lines symbolized by colour.

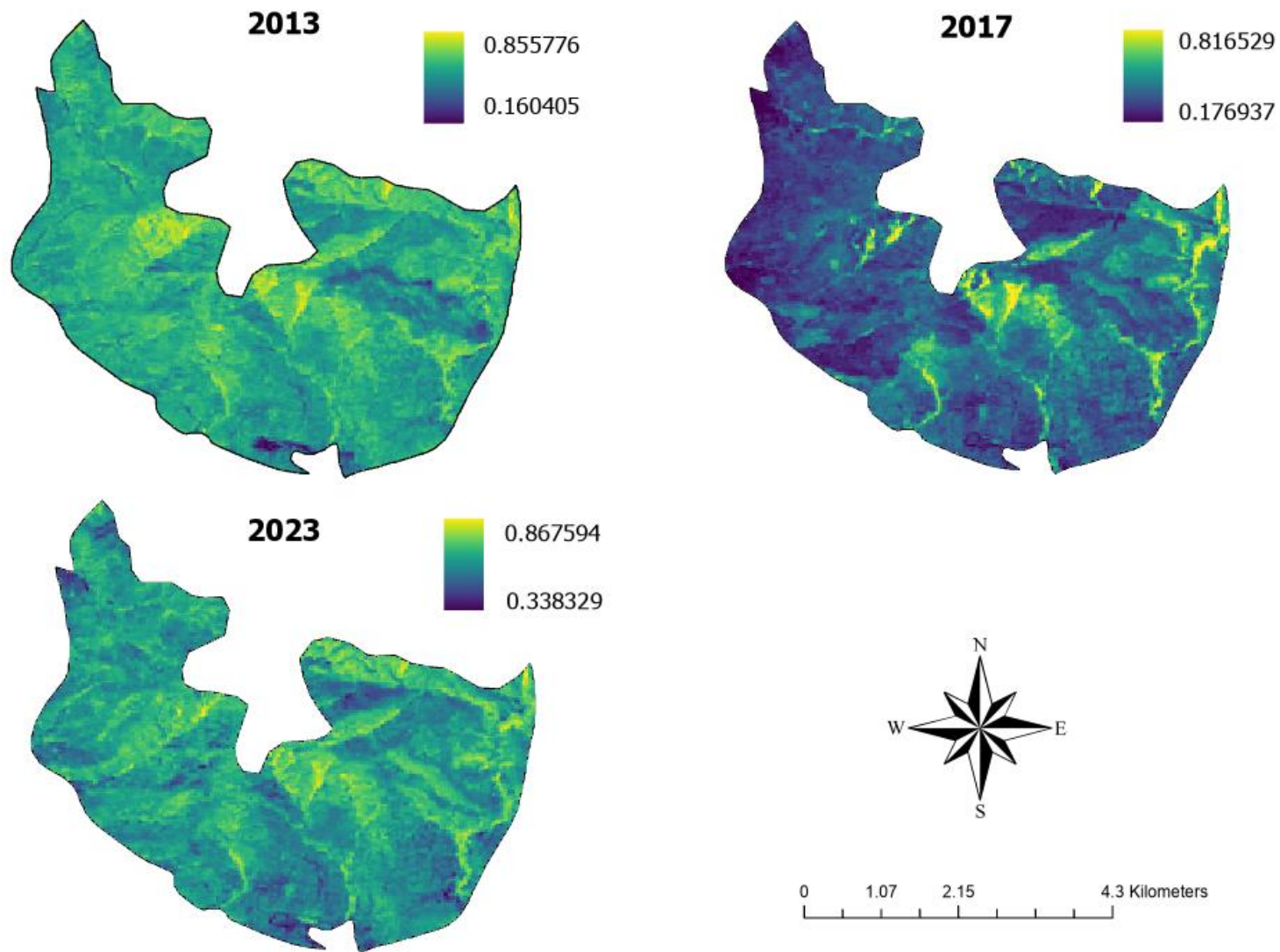


Figure 4.5: A comparison among NDVI maps (derived from Landsat 8) of the Robertson Granite Renosterveld (FRg3) for the years 2013, 2017, and 2023. High NDVI values (bright/yellow) represent dense/high vegetation cover while lower values (dark/blue) represent low/sparse vegetation cover.

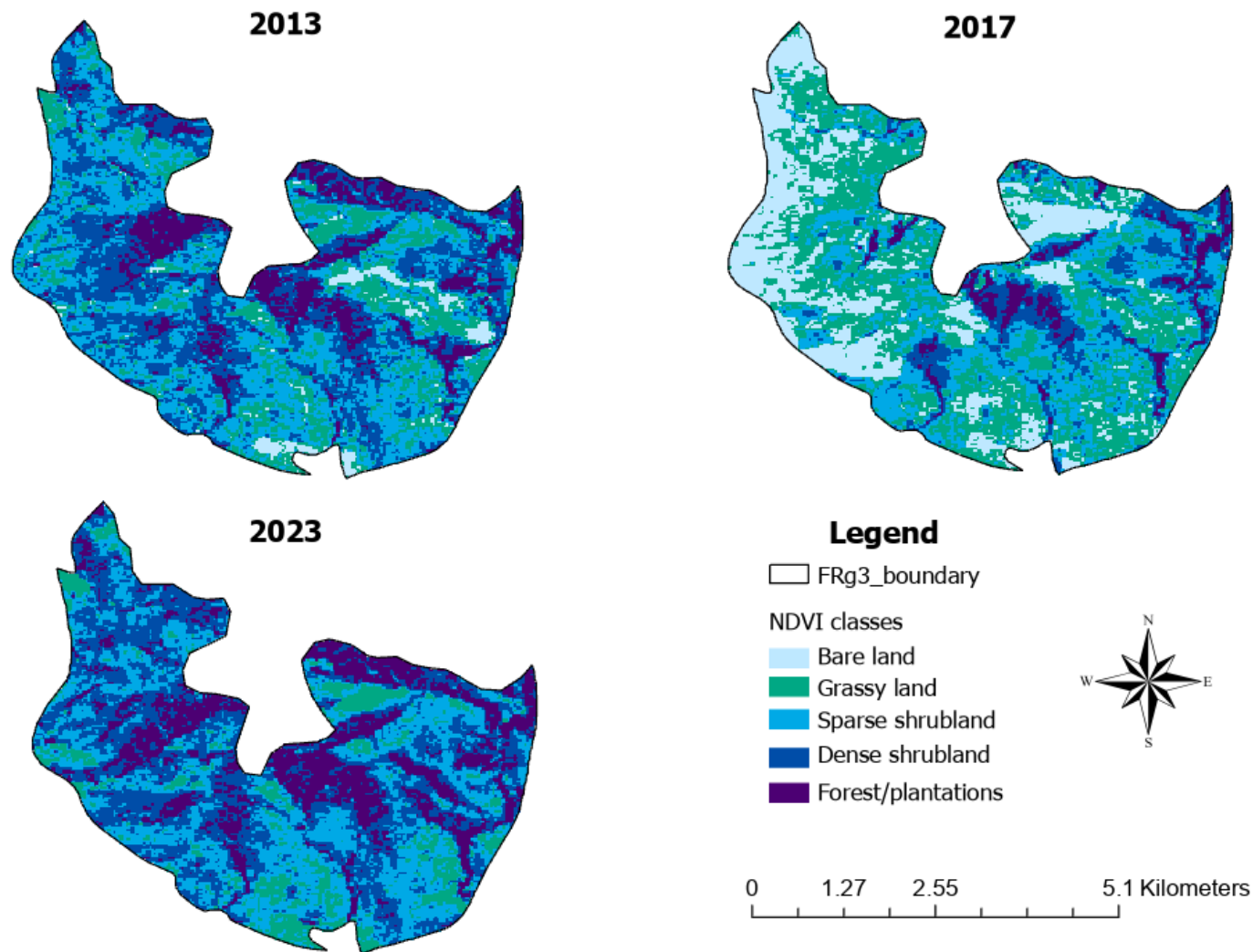


Figure 4.6: A comparison of classified NDVI maps (derived from Landsat 8) of the Robertson Granite Renosterveld (FRg3) for the years 2013, 2017, and 2023. The imageries were classified into five cover types namely: Bare land (which also includes low vegetation cover/establishing seedlings and non-vegetated areas), Grassy land, Sparse shrubland, Dense shrubland, and Forest/plantations.

The classified NDVI image of 2013 showed a total PA of 76.74% and a total UA of 80.51%. The dense shrubland class had the highest PA (86.67%) indicating that 86.67% of the dense shrubland pixels have been accurately classified. Furthermore, the classified dense shrubland pixels displayed a high reliability with a UA of 76.47%. The bare land class had the lowest PA of 57.14% indicating that 57% of the bare land pixels were accurately classified, and the remaining 42.86% were misclassified as either grassy land or sparse shrubland. Furthermore, this class had a UA of 80% showing a very high reliability of the bare land pixels. The classes from this imagery were classified with an overall accuracy of 78.63%.

The classified NDVI image of 2017 showed a total PA of 74.33% and a total UA of 74.38%. The forest/plantations class showed the highest PA of 81.25% and a high UA of 64.29%. This means that 81.25% of the forest/plantation pixels have been accurately classified with high reliability. The dense shrubland had the lowest PA (68.18%) indicating that 68.18% of dense shrubland pixels have been accurately classified, and the remaining 31.82% was misclassified as forest/plantation and sparse shrubland. Furthermore, this class had moderate reliability (UA = 65.22%). The classes from this imagery had an overall accuracy of 74.36%.

The classified NDVI image of 2023 showed a total PA of 76.43% and a total UA of 76.92%. The forest/plantations class showed the highest PA (85%) and a high UA (77.27%) which means that 85% of the forest/plantation pixels have been accurately classified with high reliability. The sparse shrubland class had the lowest PA of 68.57% meaning that 68.57% of the pixels in this class have been accurately classified and the remaining 31.43% was misclassified as dense shrubland, grassy land, and forest/plantations. Furthermore, the classified pixels representing sparse shrubland have high reliability (77.43%). The classified NDVI image of 2023 had an overall accuracy of 76.68%.

Table 4.3: Error matrix for the NDVI classes for the year 2013, 2017, and 2023 (refer to Figure 4.6), with the Producer's Accuracy, User's Accuracy, and Overall Accuracy. --- indicates no values/data for the class.

NDVI classes (2013)	Bare land	Grassy land	Sparse shrubland	Dense shrubland	Forest/plantation	Total	Producer's Accuracy (%)
Bare land	4	2	1	0	0	7	57.14%
Grassy land	1	18	2	0	0	21	85.71%
Sparse shrubland	0	2	17	5	0	24	70.83%
Dense shrubland	0	0	1	26	2	30	86.67%
Forest/plantation	0	0	0	3	15	18	83.33%
Total	5	22	21	34	18	100	76.74%
User's Accuracy (%)	80%	81.82%	80.95%	76.47%	83.33%	80.51%	Overall Accuracy =78.63%
NDVI classes (2017)							
Bare land	9	3	0	0	0	12	75%
Grassy land	2	13	3	0	0	18	72.22%
Sparse shrubland	0	3	24	5	0	32	75%
Dense shrubland	0	0	3	15	4	22	68.18%
Forest/plantation	0	0	0	3	13	16	81.25%
Total	11	19	30	23	17	100	74.33%
User's Accuracy (%)	81.81%	68.42%	80%	65.22%	76.47%	74.38%	Overall Accuracy =74.36%
NDVI classes (2023)							
Grassy land	---	8	3	0	0	11	72.73%
Sparse shrubland	---	2	24	7	2	35	68.57%
Dense shrubland	---	0	4	27	3	34	79.41%
Forest/plantation	---	0	0	3	17	20	85%
Total	---	10	31	37	22	100	76.43%
User's Accuracy (%)	---	80%	77.42%	72.97%	77.27%	76.92%	Overall Accuracy =76.68%

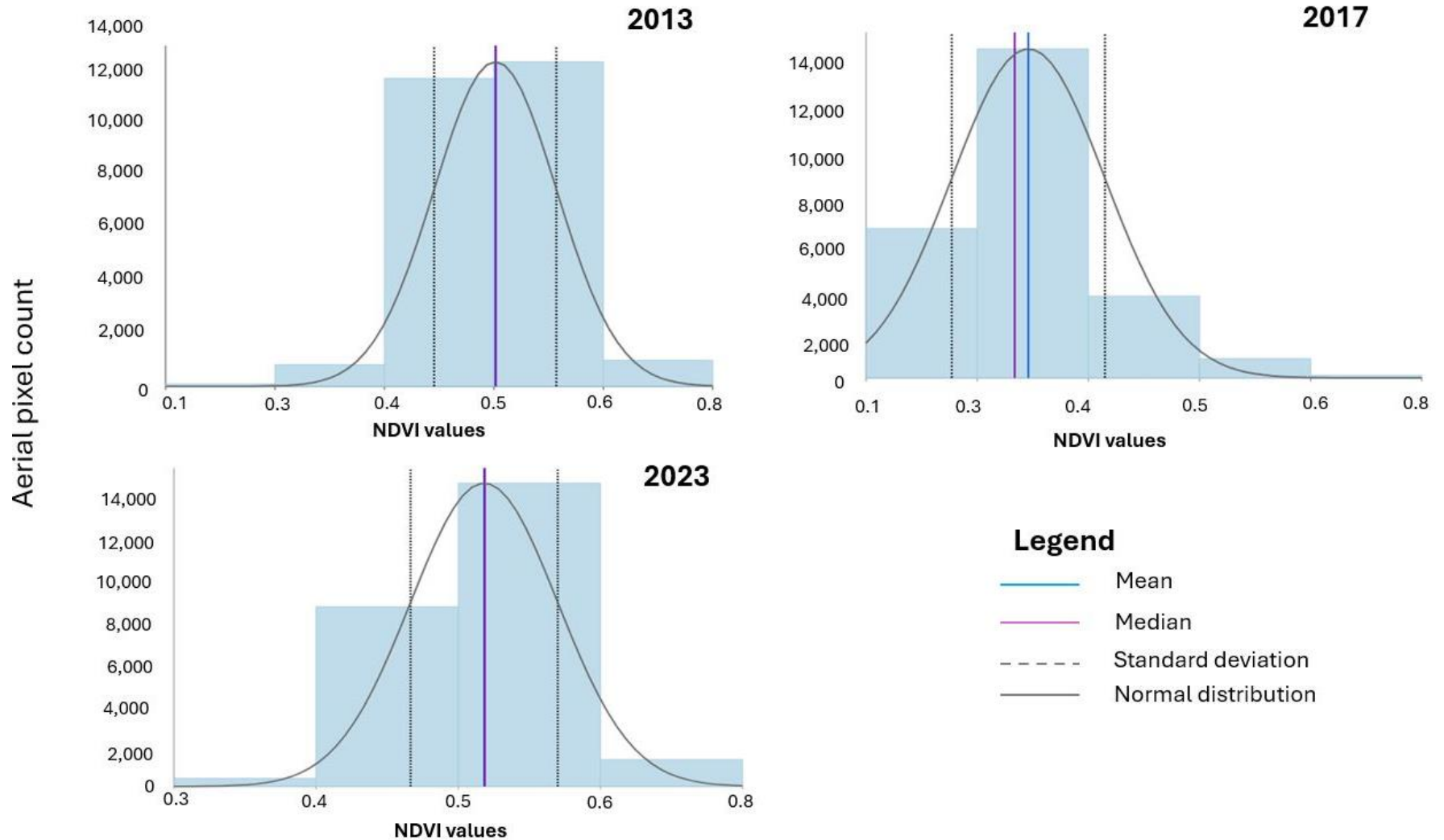


Figure 4.7: Vegetation structural distribution within the Robertson Granite Renosterveld (FRg3) in 2013, 2017 and 2023, with NDVI values (X-axis) and the total number of pixels (Y-axis) for each NDVI threshold. The Mean, Median, Standard deviation, and Normal distribution are shown by distinct vertical lines symbolized by colour.

Table 4.4: Mean, median and standard deviation of NDVI values of the FRg3 from the year 2000 to 2023 (refer to Figure 4.4 & 4.7). The columns highlighted in grey indicate the year in which there was a fire event.

NDVI statistical measures	2000	2006	2013	2017	2023
Mean	0.37	0.48	0.58	0.36	0.63
Median	0.36	0.48	0.58	0.35	0.63
Standard Deviation	0.11	0.08	0.08	0.09	0.07

Table 4.5: Percentage cover of classified vegetation structures within the FRg3 in the years 2000; 2006; 2013; 2017; and 2023. The columns highlighted in grey indicate the year in which there was a fire event.

Vegetation structure	2000	2006	2013	2017	2023
Bare lands (%)	16.19	1.37	0.36	21.72	0.00
Grassy land (%)	53.00	28.70	3.17	51.02	1.56
Sparse shrublands (%)	23.59	53.69	45.11	25.07	34.69
Dense shrublands (%)	6.52	15.13	47.55	1.81	58.55
Forest/plantation (%)	0.71	1.11	3.82	0.39	5.20

Table 4.6: NDVI changes detected in five time periods (2000 – 2006, 2006 – 2013, 2013 – 2017, 2017 – 2023, and 2000 – 2023).

Negative values indicate a negative change in vegetation structure (reduced height) while positive values indicate a positive change in vegetation structure (increased height).

Feature	Change detected									
	2000-2006		2006-2013		2013-2017		2017-2023		2000-2023	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Bare land	-287	-92.33	-23	-74.07	490	98.59	-496	-100	-313	-100
Grassy land	-470	-45.85	-593	-89.01	1033	94.42	-1064	-97.24	-995	-97.06
Sparse shrubland	582	56.02	-199	-15.98	-601	-68.84	399	59.49	215	31.98
Dense shrubland	167	57.00	752	68.15	-856	-93.04	1069	94.39	1007	88.87
Forest/plantation	8	38.10	63	70.27	-65	-87.84	92	91.36	87	86.44

4.4 Discussion

The vegetation structure of the Robertson Granite Renosterveld (FRg3) has changed in five different periods over 24 years (2000 – 2023), and the NDVI values ranged from 0.12 (Bare land) to 0.87 (Forest/plantations). Similar to Gandhi *et al.* (2015) and Lacouture *et al.* (2020), the lowest NDVI values were observed in less vegetated areas of the FRg3. The lowest average NDVI (0.37) within the FRg3 vegetation type was observed in the year 2000, this is largely due to the fire event of 2000 that burnt 35.5% of it (Chapter 3). This is consistent with Lacouture *et al.* (2020) who indicated that NDVI reflectance decreases after a fire event. This disturbance resulted in the presence of bare lands; it is important to note that the class of bare land also included post-fire recovering renosterveld with resprouting plants and establishing seedlings, very low height vegetated areas, and non-vegetated areas. Hence, there is a possible misclassification between the bare land and grassy land classes.

In 2006, the FRg3 experienced a fire event that burnt approximately 28% of the vegetation type (see Chapter 3). This fire event altered the vegetation structure on the northern part of the FRg3. The area burnt in 2000 was not burned by the fire of 2006. Therefore, this means that the area burnt in 2000 had time to regrow and regain its biomass which was classified as grassy vegetation with patches of short shrubs. In 2013, the vegetation type had regained most of its biomass with dense and sparse shrublands accounting for 47.55% and 45.11% respectively, there were also patches of dense trees and grassy lands accounting for 3.82% and 3.17% respectively. The dense shrublands and forest/plantations classes have a similar structure when observed from satellite imagery, hence, there is a margin of error between dense shrubland and forest/plantations because most of the misclassified dense shrubland pixels are classified as forest/plantations and vice versa. During this year, the vegetation type had recovered from the

previous fire and gathered biomass with an average NDVI of 0.58 (Table 4.4). As a result, the vegetation type experienced the biggest fire in 2017 which burnt more than half of the vegetation type (see Chapter 3) and converted most of the shrublands (dense and sparse) into grassy and bare lands (Figure 4.6 & Table 4.6).

According to Curtis *et al.* (2024), the renosterveld ecosystem takes up to 10 years to recover after a fire event and regrow enough biomass for the next fire event. Similar results were observed in this study as the longest period between fire events was 11 years (2006 – 2017), and the vegetation structure changes with each fire event. Therefore, it can be argued that the vegetation structure of the FRg3 experiences abrupt changes every fire cycle. However, it is important to note that there are other factors that can alter the vegetation structure of an ecosystem such as climate change, herbivory, and human-induced disturbances (Liu *et al.*, 2015; Huang *et al.*, 2021). Therefore, based on the current fire trends influencing the changes in vegetation structure of the FRg3, fire may be a major trigger for vegetation structural change. As a result, the next sudden change to the FRg3 vegetation structure can be anticipated between the years 2027 and 2032 since that is the period when the next fire event is expected (Chapter 3). However, the fire event could occur sooner than 2027 once the environmental conditions (fuel load, low humidity, low/no precipitation, and ignition) are favourable for a fire to occur as indicated by Lindley *et al.* (2014).

The lack of rainfall information between the period of the fire and the time when Landsat images were acquired limited the ability to analyse the relationship between microclimatic conditions and vegetation structural changes in the FRg3. As a result, including this information is recommended for future studies within the vegetation type as it could improve the understanding of vegetation dynamics of the FRg3.

4.5 Conclusion

The Robertson Granite Renosterveld (FRg3) vegetation structure has fluctuated over 24 years.

The changes in vegetation structure largely resulted from the fire events that occurred within the vegetation type from 2000 to 2023. Despite these disturbances, in 2023, the FRg3 had the highest biomass observed in 24 years (2000 – 2023). Based on the fire trends, frequency, and

accumulated fuel load, the next fire event is projected to occur between 2027 and 2032 or sooner.

Therefore, unless the FRg3 experiences any drastic climatic event or a sharp increase in herbivorous animals before the next fire event, the next abrupt change in vegetation structure within the FRg3 is likely to occur after the projected fire in chapter 3.

Chapter 5: Synthesis

5.1 Summary of key findings

The Robertson Granite Renosterveld (FRg3) is a diverse and species-rich vegetation type dominated by shrubs and grassy vegetation. This vegetation type is made up of five major plant communities (*Dodonaea viscosa*–*Euryops tenuissimus*, *Dicerotheramnus rhinocerotis*–*Dodonaea viscosa*, *Passerina obtusifolia*–*Restio capensis*, *Pteronia paniculata*–*Dicerotheramnus rhinocerotis*, and *Muraltia heisteria*–*Restio capensis*). Renosterveld ecosystems are generally dominated by Asteraceae species, which creates the illusion that the renosterveld lacks diversity (Curtis, 2013). The illusion was proven incorrect since the FRg3 displayed a wide range of species across the five major plant communities. Fire is a major contributor to the changes in vegetation structure that the FRg3 has experienced over time. Furthermore, fire has also influenced the structural and compositional patterns of plant communities within the vegetation type. Figure 5.1 summarises the findings from a combination of plot vegetation data with Remote Sensing techniques. Results from this study confirmed a point made by Townsend & Walsh (2001) and Seymour *et al.* (2025), stating that a combination of remote sensing and plot vegetation sampling methods provide a powerful tool when one seeks to understand the ecology of an ecosystem over time and cover remote and inaccessible areas of the ecosystem.

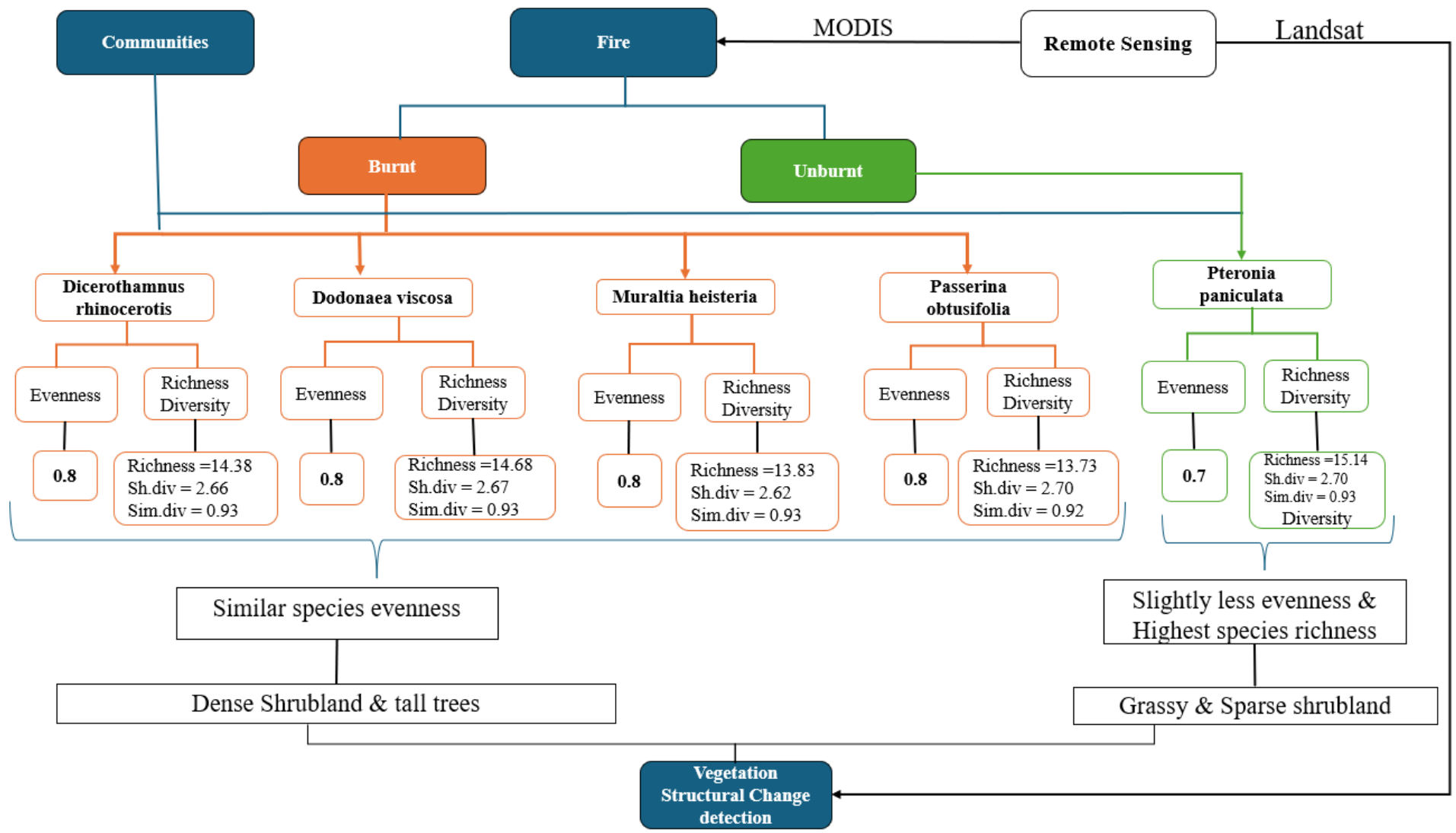


Figure 5.1: Graphic summary of the key findings from this study. The blue boxes represent input data chapters, the orange colour represents outputs from communities that recently (2017) burnt, while the green colour highlights the communities that were never burnt at all since 2000. Sh.div = Shannon diversity, Sim.div = Simpsons diversity.

5.2 Fire as an important ecological process

Fire plays a crucial role in ensuring healthy and functional ecosystems in the Cape Floristic Region, and the Fynbos in particular (Van Wilgen, 2009; Van Wilgen *et al.*, 2010; Rutherford *et al.*, 2011; Van der Merwe & Van Rooyen, 2011). This important ecological process has influenced the structure and composition of plant communities within the FRg3. Four (*Dicerotheramnus rhinocerotis–Dodonaea viscosa*, *Dodonaea viscosa–Euryops tenuissimus*, *Muraltia heisteria–Restio capensis*, and *Passerina obtusifolia–Restio capensis*) out of the five communities in the FRg3 are located on areas that were affected by the most recent fire of 2017 (Figure 5.1; Chapter 3). One of the things that these communities have in common is the similarity in how evenly distributed the species within these communities are. The species diversity is also very similar across these four communities.

The *Pteronia paniculata–Dicerotheramnus rhinocerotis* community is the only one that is located in sections of the FRg3 which have not burnt at all, or at least since 2000 (Chapter 3). In addition, this community displayed a slightly higher species richness compared to the other communities, but with a slightly lower evenness (Chapter 2). This community is located on the lower slopes of the vegetation near residential and agricultural lands. Therefore, one of the reasons this community did not burn could be because fire is seen as a threat to farmers' crops, livestock grazing areas and residential property. As a result, whenever there is a fire outbreak, the farm owners extinguish the fire before it reaches and potentially damages their infrastructure, livestock, and croplands, which is close to the localities of the *Pteronia paniculata–Dicerotheramnus rhinocerotis* community (Chapter 3).

Fire also contributes to the vegetation structural changes over the whole of the FRg3 (Chapter 4). According to literature sources, the fire frequency within the Fynbos biome is

between 15 and 25 years (Rebelo *et al.*, 2006) and the renosterveld has a fire frequency of between three and ten years (Boucher 1995; Rebelo *et al.*, 2006; Kraaij & van Wilgen, 2014). This is consistent with the six to eleven-year fire intervals in the FRg3 over the period explored (Chapter 3). Therefore, in the absence of any major natural or anthropogenic disturbance, the vegetation type may undergo an abrupt structural change almost every six to eleven years due to fire (Chapter 3). It is important to note that the fire frequency could change based on changes in climatic conditions, introduction and spread of woody alien invasive plants, and fire suppression by local community members/farm owners (Chapter 4).

This study has highlighted the favourable conditions (high biomass, fire ignition, strong winds, low humidity, and high temperatures) for a wildfire to thrive. Therefore, this information can be used to structure a prescribed/controlled burning programme (summarized in Figure 5.2) to reduce the fuel load, which will then reduce the severity of future fires while maintaining a functional ecosystem.

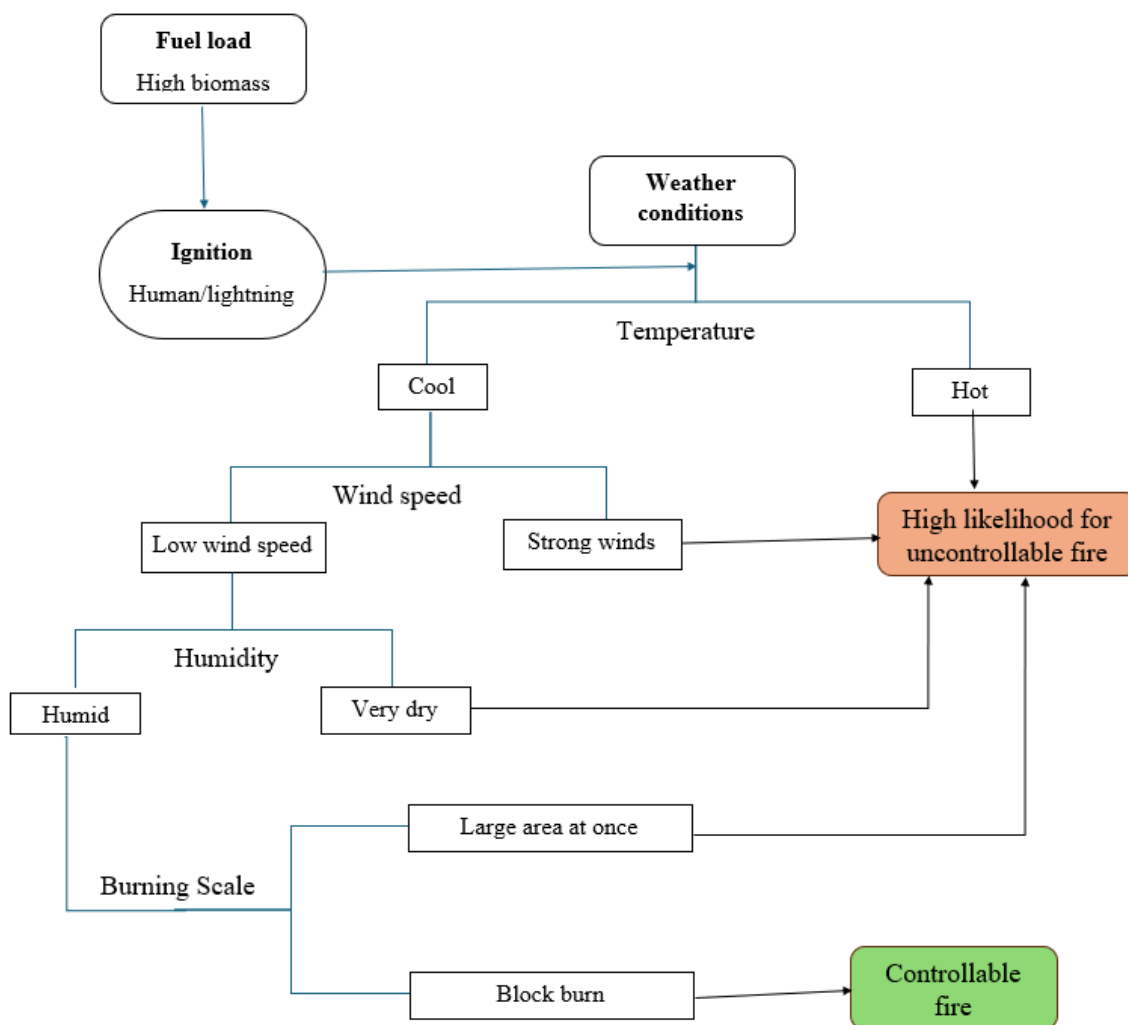


Figure 5.2: A summary of conditions needed for a prescribed/controlled burn. The green colour represents good conditions for a controlled burn while the red colour represents conditions for a wildfire (not favourable for a controlled burn).

5.3 What are the implications of the findings from this study for conservation management?

A large part of the natural extent of the FRg3 has been maintained (98.5%), however, the vegetation type is still currently facing numerous threats (Chapter 2). The disturbances include the spread of alien invasive alien plant species such as *Hakea sericea*, this Australian species only started to be observed within the vegetation type in the past 10 – 15 years (Farm owner,

personal conversation, October 2023). Findings from this study provided the exact localities for some of these alien invasive plant species, which can help the decision makers to develop informed eradication strategies before the species spreads beyond control. In addition to the threats, only (1%) of the vegetation type was cleared for leisure and agricultural purposes (Chapter 2). The model in Figure 5.3 can be used by decision-makers as a guide to further understand the ecological processes involved in ensuring a functional ecosystem (FRg3) and disturbances/threats that could cause the collapse of this ecosystem (FRg3).

This study forms part of the National Vegetation Map (NVM) which is a key input dataset for the National Biodiversity Assessment (NBA) (Skowno *et al.*, 2019). Therefore, since the NBA relies on updated information on ecosystems, outputs from this study will provide an updated representation of the FRg3 on a national scale through NBA. This study was conducted before a major disturbance within the FRg3, after accumulating biomass for six years (2017 – 2023). Therefore, the summary of ecological processes (Figure 5.4) could be used as a baseline to model future major disturbances (natural/human induced) at the FRg3, with their extent and ecological implications. Furthermore, findings from this study will contribute to the next Red List of Ecosystems (RLE) assessment (conducted by SANBI) for the FRg3. Results from Chapter 2 can be incorporated into Criterion D of the assessment which focuses on the disturbance of biotic processes within a fraction of an ecosystem type. Criterion D assesses where the extent of biotic disturbances will determine the risk of collapse of an ecosystem type where: $\geq 80\%$ disturbed = Critically Endangered (CR), $\geq 50\%$ disturbed = Endangered (EN), and $\geq 30\%$ disturbed = Vulnerable (VU) (Skowno and Monyeki, 2021). Since Criterion D focuses on changes that affect specific parts of an ecosystem (FRg3 communities, and not the whole vegetation type); understanding the communities within a type as was done in this study becomes

essential to understand if a portion of the FRg3 is threatened by either alien invasive species or land clearing. The outcome of the assessment will reflect whether these disturbances affect a loss of a whole community rather than being reflected as the loss of a small portion of the whole vegetation type.

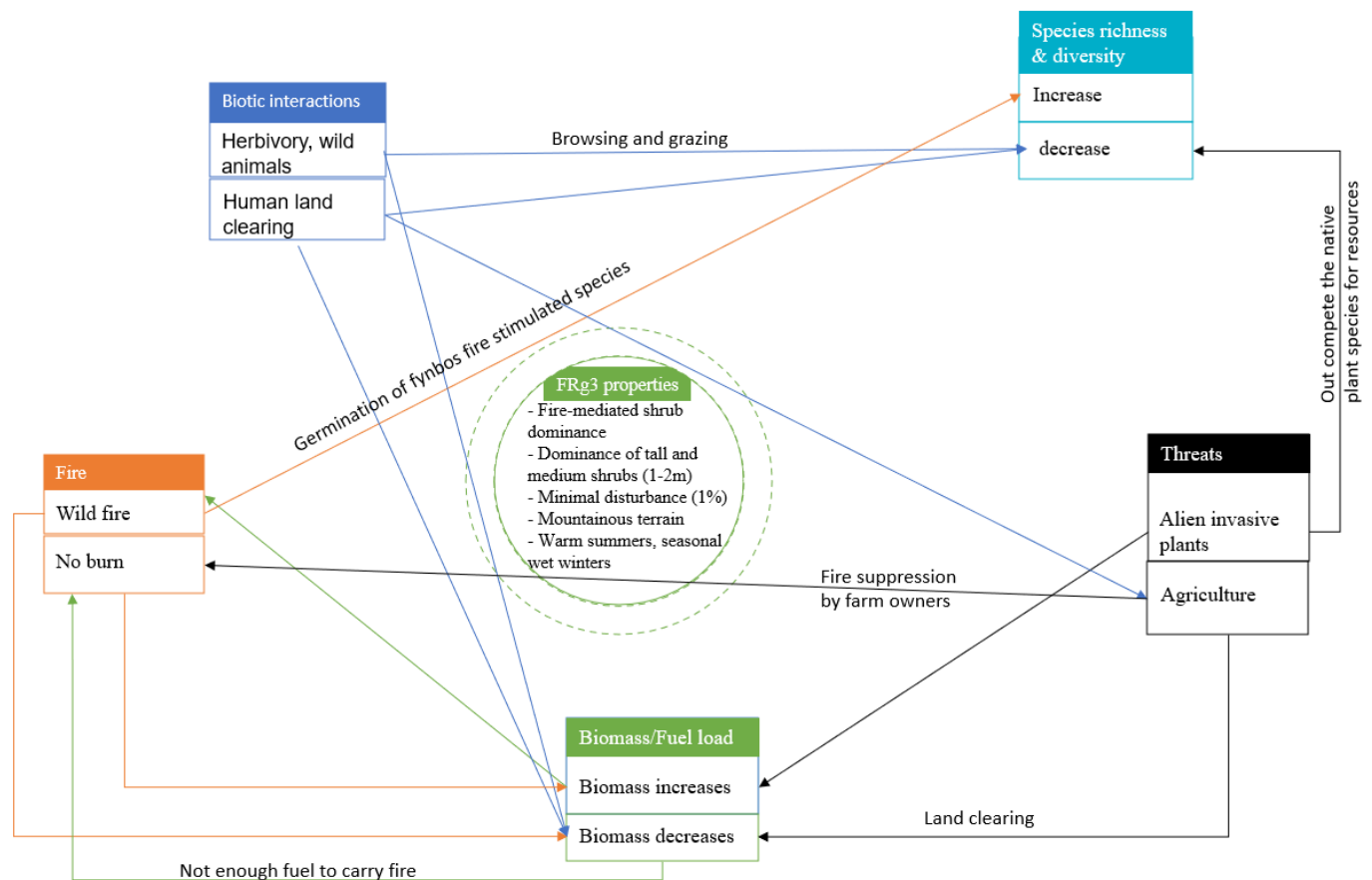


Figure 5.3: A summary of ecological processes within the FRg3, based on the IUCN Global Ecosystem Typology models for ecosystem types.

5.4 Limitations and Recommendations

The FRg3 is very mountainous with steep slopes. As a result, approximately 30% of the vegetation type was not explored. In addition, there are sections of the FRg3 located in private farms that could not be accessed because the farm owners could not be contacted for permission

to position plots in their lands. Furthermore, there were other areas located on too steep slopes and could not be accessed as it was unsafe. As a result, the area (30%) was mapped as *Dodonaea viscosa*–*Euryops tenuissimus* community with low confidence; this area was assigned to this community because the community is the most dominant and widespread compared to the other communities, and it occurs on both high and lower slopes and aspects (Chapter 2) of the FRg3. This presents an opportunity for future research on the areas that have not been explored by this study. In addition, the current study did not explore communities in the riparian areas, therefore, this is also an opportunity for future research on the vegetation type. The absence of rainfall data for the period between the fire event and the date when the Landsat imagery (used for change detection) was acquired has limited the ability to investigate the relationship between vegetation structural changes and microclimatic conditions in the FRg3. Therefore, including such data is recommended for future studies on the vegetation type as it would increase the understanding of the vegetation dynamics in the FRg3.

5.5 Conclusion

The main aim of this study was to improve the current understanding of the vegetation communities of the Robertson Granite Renosterveld (FRg3). This aim was achieved by breaking down this study into three data chapters which addressed (1) the plant communities found within the FRg3 vegetation type and their relationship to the habitat / environmental characteristics, the species richness and diversity, and the threats to the FRg3; (2) Fire history of the vegetation type and how it influenced the distribution of communities and the changes in vegetation structure over time, and (3) how the vegetation structure of the vegetation type changed over time and fire as the major contributor to the structural changes. This study has identified the four plant communities (*Dodonaea viscosa*–*Euryops tenuissimus*, *Dicrothamnus rhinocerotis*–*Dodonaea*

viscosa, *Passerina obtusifolia*–*Restio capensis*, and *Muraltia heisteria*–*Restio capensis*) found in fire affected areas, and one community (*Pteronia paniculata*–*Dicrothamnus rhinocerotis*) found in portions of the FRg3 that did not burn at all in 24 years (2000 – 2023). Furthermore, the study determined how fire has influenced the distribution of communities across the vegetation type, and how it influences the change in vegetation structure over time. The structure of the *Dodonaea viscosa*–*Euryops tenuissimus* and *Passerina obtusifolia*–*Restio capensis* communities is dense and shrubby (approximately 1.5 – 2m tall) with patches of grasses. The *Dicrothamnus rhinocerotis*–*Dodonaea viscosa* and *Muraltia heisteria*–*Restio capensis* communities have a similar structure to *Dodonaea viscosa*–*Euryops tenuissimus* and *Passerina obtusifolia*–*Restio capensis* communities, however, they are slightly shorter (approximately 1m tall). The *Pteronia paniculata*–*Dicrothamnus rhinocerotis* community is generally shrubby (sparse and approximately 1m tall) with a succulent element. This study has validated the importance of building a deeper understanding of a vegetation type at a finer resolution in order to better assess and manage our landscapes and highlighted the value of using a combination of both plot vegetation sampling and remote sensing data to extract ecological information about an ecosystem.

References

- Abd El-Kawy, O. R., Rød, J. K., Ismail, H. A., and Suliman, A. S. 2011. Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. *Applied Geography*, 31, 483–494.
- Acocks, J.P.H. 1975. Veld types of South Africa, edn 2. *Mem. Bot. Surv. S. Afr*, 40, 1–128.
- Al Rawashdeh, S. B. 2012. Assessment of change detection method based on normalized vegetation index in environmental studies. *International Journal of Applied Science and Engineering*, 10, 89–97.
- Altrudi, S. 2021. Connecting to nature through tech? The case of the iNaturalist app. *Convergence*, 27, 124–141.
- Aly, A. A., Al-Omran, A. M., Sallam, A. S., Al-Wabel, M. I., and Al-Shayaa, M. S. 2016. Vegetation cover change detection and assessment in arid environment using multi temporal remote sensing images and ecosystem management approach. *Solid Earth*, 7, 713–725.
- Anderson, C. B. 2018. Biodiversity monitoring, earth observations and the ecology of scale. *Ecology Letters*. doi:10.1111/ele.13106.
- Badamasi, M. M., Yelwa, S. A., AbdulRahim, M. A., and Noma, S. S. 2010. NDVI thresholdclassification and change detection of vegetation cover at the Falgore Game Reserve in Kano State, Nigeria. *Sokoto Journal of the social sciences*, 2, 174–194.
- Bai, Z., Dent, D., Wu, Y. and de Jong, R., 2013. Land degradation and ecosystem services. *Ecosystem services and carbon sequestration in the biosphere*, 357–381.
- Bartos, D. L., Brown, J. K., and Booth, G. D. 1994. Twelve years biomass response in aspen communities following fire. *Rangeland Ecology & Management/Journal of Range Management Archives*, 47, 79–83.
- Beck, J., Parminter, J., Alexander, M., MacDermid, E., Van Nest, T., Beaver, A., and Grimaldi, S. 2005. Fire ecology and management. *Forestry Handbook for British Columbia, 5th edition*. Forestry Undergraduate Society, Faculty of Forestry, UBC. Vancouver, BC, Canada, pp. 490–525.
- Bergh, N. 2006. *Dicerotheramnus rhinocerotis* (L.f.) Koekemoer. Compton Herbarium, Kirstenbosch Horticultural information. Available from: <https://pza.sanbi.org/dicerotheramnus-rhinocerotis> [Date accessed: 21/06/2023].

- Bergh, N.G., Verboom, G.A., Rouget, M. and Cowling, R.M. 2014. Vegetation types of the Greater Cape Floristic Region. In: Allsopp, N., Colville, J.F. and Verboom, G.A. (Eds.). *Fynbos: ecology, evolution, and conservation of a megadiverse region*. Oxford University Press.
- Birhanu, L., Bekele, T., Tesfaw, B., and Demissew, S. 2021. Relationships between topographic factors, soil and plant communities in a dry Afromontane forest patches of Northwestern Ethiopia. *PLoS ONE*, 16, e0247966. <https://doi.org/10.1371/journal.pone.0247966>
- Bond, W. J., Volk, J., and Viviers, M. 1984. Variation in seedling recruitment of Cape Proteaceae after fire. *The Journal of Ecology*, 72, 209–221.
- Bond, W.J., and Slingsby, P. 1983. Seed dispersal by ants in shrublands of the Cape Province and its evolutionary implications. *South African Journal of Science*, 79, 231–233.
- Boucher, C. 1983. Floristic and structural features of the coastal foreland vegetation south of the Berg River, western Cape Province, South Africa, *Bothalia*, 14, 669–674.
- Boucher, C. 1987. A phytosociological study of transects through the western Cape coastal foreland, South Africa. Doctoral dissertation, Stellenbosch University, Stellenbosch, South Africa.
- Boucher, C. 1995. Overview on management of renosterveld. In A.B. Low and F.E. Jones, (Eds). *The sustainable use and management of renosterveld remnants in the Cape Floristic Region, FCC Report 1995/4*. Flora Conservation Committee, Botanical Society of South Africa, Kirstenbosch, Cape Town, South Africa. pp. 47–50.
- Brown, L. R., Du Preez, P. J., Bezuidenhout, H., Bredenkamp, G. J., Mostert, T. H. C., and Collins, N. B. 2013. Guidelines for phytosociological classifications and descriptions of vegetation in southern Africa: checklist. *Koedoe: African Protected Area Conservation and Science*, 55, 1–10.
- Burgess, T. L., Shmida, A., Whitehead, E. E., Hutchinson, C. F., Timmermann, B. N., and Varady, R. G. 1988. Succulent growth-forms in arid environments. *Arid lands today and tomorrow*, 383–395.
- Burghardt, S., Topp, E. N., Esler, K. J., and Loos, J. 2021. Limited knowledge flow among stakeholders of critically endangered renosterveld in South Africa. *Ecology and Society*, 26, 17.

- Burke, A. 2001. Classification and ordination of plant communities of the Naukluft Mountains, Namibia. *Journal of Vegetation Science*, 12, 53–60.
- Burrell, A. L., Evans, J. P., and Liu, Y. 2018. The impact of dataset selection on land degradation assessment. *ISPRS Journal of Photogrammetry and Remote Sensing*, 146, 22–37. doi:10.1016/j.isprsjprs.2018.08.017.
- Campbell, B. M. 1983. Montane plant environments in the Fynbos Biome. *Bothalia*, 14, 283 – 298.
- Campbell, B.M. 1984. A classification of the mountain vegetation of the Fynbos Biome. *Mem. bot. Surv. S.Afr*, 50, 21.
- Capitanio, R., and Carcaillet, C. 2008. Post-fire Mediterranean vegetation dynamics and diversity: a discussion of succession models. *Forest Ecology and Management*, 255, 431–439.
- Carrieseltzer. 2018. Announcing Changes to Projects on iNaturalist. *iNaturalist April 2018*. Available from: <https://www.inaturalist.org/blog/15450-announcing-changes-to-projects-on-inaturalist> Accessed: 19 November 2024.
- Coetzee, C. 2022. Change Detection of Vegetation Cover Using Remote Sensing and GIS—A Case Study of the West Coast Region of South Africa. *Geography, Environment, Sustainability*, 15, 91–102.
- Cousins, S.R., Witkowski, E.T. and Esler, K.J. 2018. Influence of fire on critically endangered Swartland Shale Renosterveld in the Cape Floristic Region. *Applied Vegetation Science*, 2, 144–155.
- Cowan, O. S. 2014. The Peninsula Shale Renosterveld of Devil's Peak: phytosociology, system drivers and restoration potential.
- Cowling, R.M. 1987. Fire and its role in coexistence and speciation in Gondwanan shrublands. *South African Journal of Science*, 83, 106–112.
- Cowling, R.M. and Holmes, P.M. 1992. Endemism and speciation in a lowland flora from the Cape Floristic Region. *Biol. J. Linn. Soc*, 47, 367–383.
- Cowling, R.M. and Witkowski, E.T.F. 1994. Convergence and non-convergence of plant traits in climatically and edaphically matched sites in Mediterranean Australia and South Africa. *Australian Journal of Ecology*, 19, 220–232.

- Cowling, R.M., Witkowski, E.T.F., Milewski, A.V. and Newbey, K.R. 1994. Taxonomic, edaphic and biological aspects of narrow plant endemism on matched sites in mediterranean South Africa and Australia. *Journal of Biogeography*, 651–664.
- Currall, J.E.P., 1987. A transformation of the Domin scale. *Vegetation*, 72, 81–87.
- Curtis, O. E., Bond, W. J., and Chimphango, S. 2024. Diversity and fire responses in Renosterveld, the forgotten relation of fynbos, in southernmost Africa. *Journal of Arid Environments*, 225, 105261.
- Curtis, O.E. 2013. Management of critically endangered renosterveld fragments in the Overberg, South Africa. Doctoral dissertation, University of Cape Town, Cape Town, South Africa.
- D'Allestro, P., and Parente, C. 2015. GIS application for NDVI calculation using Landsat 8 OLI images. *International Journal of Applied Engineering Research*, 10, 42099–102.
- Daldegan, G.A., de Carvalho Júnior, O.A., Guimarães, R.F., Gomes, R.A.T., de Figueiredo Ribeiro, F. and McManus, C. 2014. Spatial patterns of fire recurrence using remote sensing and GIS in the Brazilian savanna: Serra do Tombador Nature Reserve, Brazil. *Remote Sensing*, 6, 9873–9894.
- Dayaram, A., Harris, L. R., Grobler, B. A., Van der Merwe, S., Rebelo, A. G., Ward Powrie, L., Vlok, J. H. J., Desmet, P. G., Qabaqaba, M., Hlahane, K. M., and Skowno, A. L. 2019. Vegetation map of South Africa, Lesotho and Swaziland 2018: a description of changes since 2006. *Bothalia-African Biodiversity & Conservation*, 49, 1–11.
- Dayaram, A., Rebelo, T., Skowno, A., and Powrie, L. 2017. Vegetation Map of South Africa, Lesotho and Swaziland 2009 and 2012: A description of changes from 2006. *Bothalia-African Biodiversity & Conservation*, 47, 1–10.
- De Klerk, H. 2008. A pragmatic assessment of the usefulness of the MODIS (Terra and Aqua) 1-km active fire (MOD14A2 and MYD14A2) products for mapping fires in the fynbos biome. *International Journal of Wildland Fire*, 17, 166–178.
- De Kock, C. and Lee, A.T. 2019. Agulhas long-billed lark (*Certhilauda brevirostris*) densities, population estimates and habitat association in a transformed landscape. *African Zoology*, 54, 161–168.
- Dearborn, K. D., and Danby, R. K. 2017. Aspect and slope influence plant community composition more than elevation across forest–tundra ecotones in subarctic Canada. *Journal of vegetation science*, 28, 595–604.

- Delgado-Aguilar, M.J., Hinojosa, L. and Schmitt, C.B. 2019. Combining remote sensing techniques and participatory mapping to understand the relations between forest degradation and ecosystems services in a tropical rainforest. *Applied Geography*, 104, 65–74.
- Dias, E., Elias, R.B. and Nunes, V. 2004. Vegetation mapping and nature conservation: a case study in Terceira Island (Azores). *Biodiversity & Conservation*, 13, 1519–1539.
- Ejtehadi, H., Amini, T. and Zare, H. 2005. Importance of vegetation studies in conservation of wildlife: a case study in Miankaleh wildlife refuge, Mazandaran province, Iran.
- El-Gammal, M. I., Ali, R. R., and Samra, R. A. 2014. NDVI threshold classification for detecting vegetation cover in Damietta governorate, Egypt. *Journal of American Science*, 10, 108–113.
- Entelki. (n.d). How does a lead pencil write on paper. Available from: <https://www.entelki.in/content/how-does-lead-pencil-write-paper-0#:~:text=Pencil%20writings%20do%20not%20smudge,for%20about%20three%20hundred%20years>. Date Accessed: 12/04/2023.
- Eswaran, H., Lal, R., and Reich, P. F. 2019. Land degradation: an overview. *Response to land degradation*, 20–35.
- Evans, S.W. 2021. The effects of habitat loss and fragmentation on updated estimates of the population of the Agulhas Long-billed Lark *Certhilauda brevirostris*, a South African endemic. *Ostrich*, 92, 243–256.
- Forest, F., and Manning, J. C. 2006. Evidence for Inclusion of South African Endemic *Nylandtia* in *Muraltia* (Polygalaceae). *Systematic Botany*, 31, 525–532.
- Forest, F., Nänni, I., Chase, M. W., Crane, P. R., and Hawkins, J. A. 2007. Diversification of a large genus in a continental biodiversity hotspot: temporal and spatial origin of *Muraltia* (Polygalaceae) in the Cape of South Africa. *Molecular Phylogenetics and Evolution*, 43, 60 – 74.
- Gadal, S. & Ouerghemmi, W. & Barlatier, R. and Mozgeris, G. 2019. Critical Analysis of Urban Vegetation Mapping by Satellite Multispectral and Airborne Hyperspectral Imagery. *MDPI*, 1, 97–104.

- Gandhi, G. M., Parthiban, S., Thummalu, N., and Christy, A. 2015. Ndvi: Vegetation change detection using remote sensing and gis—A case study of Vellore District. *Procedia computer science*, 57, 1199–1210.
- Gibbons, P., and Freudenberger, D. 2006. An overview of methods used to assess vegetation condition at the scale of the site. *Ecological management & restoration*, 7, S10–S17.
- Gibbs Russell, G.E., Reid, C., Van Rooy, J. and Smook, L. 1985. List of species of southern African plants. Edition 2. Recent literature and synonyms. Part 1. Cryptogams, Gymnosperms, Monocotyledons. *Memoirs of the Botanical Survey of South Africa*, 51, 1–152.
- Giglio, L., Descloitres, J., Justice, C.O. and Kaufman, Y.J. 2003. An enhanced contextual fire detection algorithm for MODIS. *Remote sensing of environment*, 87, 273–282.
- Gitas, I.Z., Mitri, G.H., Chuvieco, E., and Ventura, G. 2003. Object-oriented image analysis for burned area mapping using NOAA-AVHRR imagery in Creus Cape, Spain. In ‘Proceedings of the 4th International Workshop on Remote Sensing and GIS applications to Forest Fire Management: Innovative Concepts and Methods in Fire Danger Estimation’. 5–7 June 2003, Ghent University, Ghent, Belgium. (Eds E Chuvieco, P Martin, C Justice) pp. 170–174. (EARSeL, Ghent University: Ghent, Belgium)
- Global Fire Monitoring Centre. 2000. *South Africa, 2000. Fires in the Southern Cape Peninsula, Western Cape Province, South Africa January 2000* (IFFN No. 22 - April 2000). Available from: https://gfmc.online/iffn/country/za/za_14.html Date Accessed: 11/10/2024.
- Goldblatt, P. and Manning, J. 2002 Plant diversity of the Cape region of South Africa. *Annals of the Missouri Botanical Garden*, 89, 281–302.
- Government of South Africa. 2022. South African Red List of Terrestrial Ecosystems: assessment details and ecosystem descriptions. Government Notice 2747, Gazette 4526. Technical Report #7664, SANBI Pretoria, South Africa.
- Greenberg, J.A., Dobrowski, S.Z., Ramirez, C.M., Tuil, J.L. and Ustin, S.L. 2006. A bottom-up approach to vegetation mapping of the Lake Tahoe Basin using hyperspatial image analysis, *Photogrammetric Engineering & Remote Sensing*, 72, 581–589. <https://doi.org/10.14358/PERS.72.5.581>.

- Gross, D. 2005. Monitoring agricultural biomass using NDVI time series. *Food and Agriculture Organization of the United Nations (FAO), Rome.*
- Hall, S. 2018. *Determining restoration potential of alien-invaded Cape Flats Sand Fynbos; a comparison of different alien clearing treatments.* Available from: <https://www.bing.com/search?q=Determining+restoration+potential+of+alien-invaded+Cape+Flats+Sand+Fynbos%3B+a+comparison+of+different+alien+clearing+treatments&qs=n&form=QBRE&sp=-1&pq=determining+restoration+potential+of+alien-invaded+cape+flats+sand+fynbos%3B+a+comparison+of+different+alien+clearing+treatments&sc=0-126&sk=&cvid=78E90664F92C4529B6796109892BEFA4>.
- Han, J., Shen, Z., Ying, L., Li, G., and Chen, A. 2015. Early post-fire regeneration of a fire-prone subtropical mixed Yunnan pine forest in Southwest China: Effects of pre-fire vegetation, fire severity and topographic factors. *Forest Ecology and Management*, 356, 31–40.
- Hanes, T. L. 1971. Succession after fire in the chaparral of southern California. *Ecological Monographs*, 41, 27–52.
- Hashim, H., Abd Latif, Z., and Adnan, N. A. 2019. Urban vegetation classification with NDVI threshold value method with very high resolution (VHR) Pleiades imagery. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42, 237–240.
- Hayasaka, H., Yamazaki, K., and Naito, D. 2019. Weather conditions and warm air masses during active fire-periods in boreal forests. *Polar Science*, 22, 100472.
- Herauld, B., and Thoen, D. 2009. How habitat area, local and regional factors shape plant assemblages in isolated closed depressions. *Acta Oecologica*, 35, 385–392.
- Hesewu, Z. 2021. *Mapping and Description of the Robertson Granite Renosterveld Vegetation Unit.* (Unpublished Honours research). University of Cape Town. Cape Town.
- Hofmeyr, M.D. and Baard, E.H.W. 2018. *Psammobates geometricus.* The IUCN Red List of Threatened Species 2018: e.T18398A111553007. <http://dx.doi.org/10.2305/IUCN.UK.2018-2.RLTS.T18398A111553007.en>

- Hofmeyr, M.D., Henen, B.T. and Walton, S. 2017. Season, sex and age variation in the haematology and body condition of geometric tortoises *Psammobates geometricus*. *African Zoology*, 52, 21–30.
- Holmes, P. M., & Cowling, R. M. 1997. The effects of invasion by *Acacia saligna* on the guild structure and regeneration capabilities of South African fynbos shrublands. *Journal of Applied Ecology*, 317–332.
- Huang, C., Yang, Q., and Huang, W. 2021. Analysis of the spatial and temporal changes of NDVI and its driving factors in the Wei and Jing River Basins. *International Journal of Environmental Research and Public Health*, 18, 11863.
- Huete, A.R. 1988. A Soil-Adjusted Vegetation Index (SAVI). *Remote Sensing of Environment*, 25, 295–309.
- Hulshizer, R., & Blalock, E. M. 2007. Post hoc pattern matching: assigning significance to statistically defined expression patterns in single channel microarray data. *BMC bioinformatics*, 8, 1–16.
- Hussain, M., Chen, D., Cheng, A., Wei, H., and Stanley, D. 2013. Change detection from remotely sensed images: From pixel-based to object-based approaches. *ISPRS Journal of Photogrammetry and Remote Sensing*, 80, 91–106.
- Ibrahim, M., and Al-Mashagbah, A. 2016. Change detection of vegetation cover using remote sensing data as a case study: ajloun area. *Change*, 8, 1–5.
- Jacobsen, A. L., Esler, K. J., Pratt, R. B., and Ewers, F. W. 2009. Water stress tolerance of shrubs in Mediterranean-type climate regions: Convergence of fynbos and succulent karoo communities with California shrub communities. *American Journal of Botany*, 96, 1445–1453.
- Jacobson, T. K. B., Gerber, D., and Azevedo, J. C. 2023. Invasiveness, monitoring and control of *Hakea sericea*: a systematic review. *Plants*, 12, 751.
- Jewitt, D., Goodman, P. S., O'Connor, T. G., Erasmus, B. F. N., and Witkowski, E. T. F. 2016. Mapping landscape beta diversity of plants across KwaZulu-Natal, South Africa, for aiding conservation planning. *Biodiversity and Conservation*, 25, 2641–2654. doi:10.1007/s10531-016-1190-y
- Joubert, C., and Moll, E. J. 1992. A phytosociological study of Signal Hill, Cape Town, utilizing both perennial and ephemeral species. *Bothalia*, 22, 255–282.

- Karnieli, A., Agam, N., Pinker, Rachel T., Anderson, M., Imhoff, M.L., Gutman, G.G., Panov, N., and Goldberg, A. 2010. *Use of NDVI and Land Surface Temperature for Drought Assessment: Merits and Limitations*, 23, 618–633. doi:10.1175/2009JCLI2900.1
- Kaufman, Y.J. and Tanre, D. 1992. Atmospherically resistant vegetation index (ARVI) for EOS-MODIS. *IEEE transactions on Geoscience and Remote Sensing*, 30, 261–270.
- Keeley, J. E., and Fotheringham, C. J. 2001. History and management of crown-fire ecosystems: a summary and response. *Conservation Biology*, 15, 1561–1567.
- Kemper, J., Cowling, R. M., Richardson, D. M., Forsyth, G. G., and McKelly, D. H. 2000. Landscape fragmentation in South Coast Renosterveld, South Africa, in relation to rainfall and topography. *Austral Ecology*, 25, 179–186.
- Kemper, J., Cowling, R.M. and Richardson, D.M. 1999. Fragmentation of South African renosterveld shrublands: effects on plant community structure and conservation implications. *Biological Conservation*, 90, 103–111.
- Kim, M. S., Daughtry, C. S. T., Chappelle, E. W., McMurtrey, J. E., III, and Walthall, C. L. 1994. *The use of high spectral resolution bands for estimating absorbed photosynthetically active radiation (APAR)*. *Proceedings of the 6th Symposium on Physical Measurements and Signatures in Remote Sensing* (pp. 299–306). France Val D'Isere.
- Kotzé, I.J. and Fairall, N. 2006. Using Landsat TM imagery to map fynbos plant communities: a case study. *South African Journal of Wildlife Research-24-month delayed open access*, 36, 75–87.
- Kraaij, T., and Van Wilgen, B. W. 2014. Drivers, ecology, and management of fire in fynbos. In Allsopp, N. Colville, J. F. and Verboom, G. A. (Eds.), *Fynbos: Ecology, evolution, and conservation of a megadiverse region*. Oxford University Press, Oxford, UK, pp.47–72. <https://doi.org/10.1093/acprof:oso/9780199679584.001.0001>
- Kshetri, T. 2018. Ndvi, ndbi & ndwi calculation using landsat 7, 8. *GeoWorld*, 2, 32–34.
- Kull, O., and Aan, A. 1997. The relative share of graminoid and forb life-forms in a natural gradient of herb layer productivity. *Ecography*, 20, 146–154.
- Lacouture, D. L., Broadbent, E. N., and Crandall, R. M. 2020. Detecting vegetation recovery after fire in a fire-frequented habitat using normalized difference vegetation index (NDVI). *Forests*, 11, 749.

- Lamont, B. B., He, T., and Lim, S. L. 2016. Hakea, the world's most sclerophyllous genus, arose in southwestern Australian heathland and diversified throughout Australia over the past 12 million years. *Australian Journal of Botany*, 64, 77–88.
- Lamont, B. B., Pausas, J. G., He, T., Witkowski, E. T., and Hanley, M. E. 2020. Fire as a selective agent for both serotiny and nonserotiny over space and time. *Critical Reviews in Plant Sciences*, 39, 140–172.
- Le Roux, A. 2011. Brandvlei burns: A controlled burn in Breede Shale Renosterveld gives new life to plants, including the hitherto unknown *Moraea vuvuzela*. *Veld & Flora*, 97, 16–18.
- Lee, A. T., and Barnard, P. 2016. Endemic birds of the Fynbos biome: a conservation assessment and impacts of climate change. *Bird Conservation International*, 26, 52–68.
- Lee, J. M., Lee, S. W., Lim, J. H., Won, M. S., and Lee, H. S. 2014. Effects of heterogeneity of pre-fire forests and vegetation burn severity on short-term post-fire vegetation density and regeneration in Samcheok, Korea. *Landscape and ecological engineering*, 10, 215–228.
- Lévesque, E. 1996. Minimum area and cover-abundance scales as applied to polar desert vegetation. *Arctic and Alpine Research*, 28, 156 – 162.
- Lindley, T.T., Murdoch, G.P., Guyer, J.L., Skwira, G.D., Schneider, K.J.S., Nagle, S.R., VanSpeybroeck, K.M., Smith, B.R. and Beierle, M.J. 2014. Southern Great Plains Wildfire Outbreaks. *E-Journal of Severe Storms Meteorology*, 9, 1–43.
- Liu, Y., Li, Y., Li, S., and Motesharrei, S. 2015. Spatial and temporal patterns of global NDVI trends: correlations with climate and human factors. *Remote Sensing*, 7, 13233–13250.
- Lloret, F., and Vilà, M. 2003. Diversity patterns of plant functional types in relation to fire regime and previous land use in Mediterranean woodlands. *Journal of Vegetation Science*, 14, 387–398.
- Low, A.B., and Rebelo, A.T.G. 1996. *Vegetation of South Africa, Lesotho and Swaziland* (2nd ed.). Department of Environmental Affairs and Tourism, Pretoria, South Africa.
- Lu, D., Mausel, P., Brondizio, E., and Moran, E. 2004. Change detection techniques. *International Journal of Remote Sensing*, 25, 2365–2401. doi:10.1080/0143116031000139863.
- Maes, J., Teller, A., Erhard, M., Liqueste, C., Braat, L., Berry, P., Egoh, B., Puydarrieux, P., Fiorina, C., Santos, F. and Paracchini, M.L. 2013. Mapping and Assessment of

- Ecosystems and their Services. *An analytical framework for ecosystem assessments under action*, 5, 1–58.
- Maia, P., Pausas, J. G., Vasques, A., and Keizer, J. J. 2012. Fire severity as a key factor in post-fire regeneration of *Pinus pinaster* (Ait.) in Central Portugal. *Annals of forest science*, 69, 489–498.
- Malinga, R., Gordon, L.J., Jewitt, G. and Lindborg, R. (2015). Mapping ecosystem services across scales and continents—A review. *Ecosystem Services*, 13, 57–63.
- Manning, J. 2007. *Field Guide to Fynbos*. Struik, Cape Town.
- Matsushita, B., Yang, W., Chen, J., Onda, Y., and Qiu, G. 2007. *Sensitivity of the Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) to Topographic Effects: A Case Study in High-density Cypress Forest*. *Sensors*, 7, 2636–2651. doi:10.3390/s7112636
- McDowell, C., and Moll, E. 1992. The influence of agriculture on the decline of West Coast Renosterveld, south-western Cape, South Africa. *Journal of Environmental Management*. 35, 173–192.
- McKenzie, B., Moll, E. J., and Campbell, B. M. 1977. A phytosociological study of Orange Kloof, Table Mountain, South Africa. *Vegetatio*, 41–53.
- Meneses-Tovar, C. L. 2011. NDVI as indicator of degradation. *Unasylva*, 62, 39–46.
- Milberg, P. E. R., and Lamont, B. B. 1997. Seed/cotyledon size and nutrient content play a major role in early performance of species on nutrient-poor soils. *The New Phytologist*. 137, 665–672.
- Mills, A. J., van Mazijk, R., Allen, J. L., and Strydom, T. 2024. Soil geochemistry and constraint of tree seedlings immediately after germination on *Macrotermes* termite mounds in the Kruger National Park, South Africa. *Ecology and Evolution*, 14, 1–7.
- Mishra, S. P., Sarkar, U., Taraphder, S., Datta, S., Swain, D., Saikhom, R., and Laishram, M. 2017. Multivariate statistical data analysis-principal component analysis (PCA). *International Journal of Livestock Research*, 7, 60–78.
- Moll, E. J. 1990. Mediterranean vegetation in the Cape province, South Africa: a review of recent concepts. *Ecologia mediterranea*, 16, 291–298.

- Moll, E.J., Campbell, B.M., Cowling, R.M., Bossi, L., Jarman, M.L., and Boucher, C. 1984. *A description of major vegetation categories in and adjacent to the Fynbos Biome*. South African National Scientific Programmes. Report No, 83, 1–29.
- Moncrieff, G.R. 2021. Locating and Dating Land Cover Change Events in the Renosterveld, a Critically Endangered Shrubland Ecosystem. *Remote Sens*, 13, 1–13.
<https://dx.doi.org/10.3390/rs13050834>.
- Muavhi, N. 2021. A simple approach for monitoring vegetation change using time series remote sensing analysis: A case study from the Thathe Vondo Area in Limpopo Province, South Africa. *South African Journal of Science*, 117, 1–9.
- Mucina, L., and Rutherford, M.C. (Eds). 2006. The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia 19*. South African National Biodiversity Institute, Pretoria.
- Muraoka, H. and Koizumi, H. 2009. Satellite Ecology (SATECO)—linking ecology, remote sensing and micrometeorology, from plot to regional scale, for the study of ecosystem structure and function. *Journal of plant research*, 122, 3–20.
- Mustart, P. J., Moll, E. J., and Taylor, H. C. 1993. The efficient use of small plots in a fynbos phytosociological study in the northern Cederberg: a quick way to collect plant-environmental data. *Bothalia*, 23, 265 – 269.
- Naas, A.E., Halvorsen, R., Horvath, P., Wollan, A.K., Bratli, H., Brynildsrud, K., Finne, E.A., Keetz, L.T., Lieungh, E., Olson, C. and Simensen, T. 2023. What explains inconsistencies in field-based ecosystem mapping?. *Applied Vegetation Science*, 26, e12715.
- Nachtergaele, F., Petri, M. and Biancalani, R. (2011). Land degradation. *SOLAW background thematic report*, 3.
- Neumann, F. H., Scott, L., and Bamford, M. K. 2011. Climate change and human disturbance of fynbos vegetation during the late Holocene at Princess Vlei, Western Cape, South Africa. *The Holocene*, 21, 1137–1149.
- Non-Affiliated Soil Analysis Work Committee. 1990. *Handbook of standard soil testing methods for advisory purposes*. Soil Science Society of South Africa, Pretoria, South Africa.
- Ntshanga, N. K., Procheş, S., and Slingsby, J. A. 2021. Assessing the threat of landscape transformation and habitat fragmentation in a global biodiversity hotspot. *Austral Ecology*, 46, 1052–1069.

- O'Connor, T. G. 1991. Local extinction in perennial grasslands: a life history approach. *American Naturalist*, 137, 753–773.
- O'Connor, T. G., Martindale, G., Morris, C. D., Short, A., Witkowski, T. F., and Scott-Shaw, R. 2011. Influence of grazing management on plant diversity of highland sourveld grassland, KwaZulu-Natal, South Africa. *Rangeland Ecology & Management*, 64, 196–207.
- Okwonu, F. Z., and Ahad, N. A. 2020. Modification of Fisher-Hayter Test. *Journal of Advanced Research in Applied Mechanics*, 68, 1 – 8.
- Overberg Renosterveld Conservation Trust. 2014. General 'ideal' guidelines for renosterveld management https://overbergrenosterveld.org.za/wpcontent/uploads/2014/09/renosterveld_general_guidelines.pdf/. Date Accessed: 10/05/2023.
- Overberg Renosterveld Conservation Trust. 2023. Renosterveld Ecology, Evolution & Management. Available from: <https://overbergrenosterveld.org.za/research/>. Date Accessed: 12/05/2023.
- Palmer, M. W., and White, P. S. 1994. On the existence of ecological communities. *Journal of Vegetation Science*. 279–282.
- Pandian. M, Rajagopal.N, Sakthivel. G and Amrutha. D.E. 2014. Land use and land cover change detection using remote sensing and GIS in parts of Coimbatore and Tiruppur districts, Tamil Nadu. India.
- Paterson-Jones, C. 1998. Renosterveld's Floral Treasure: Headed for extinction. *Africa-Environment and Wildlife*, 6, 27–32.
- Patro, V.M. and Patra, M.R., 2014. Augmenting weighted average with confusion matrix to enhance classification accuracy. *Transactions on Machine Learning and Artificial Intelligence*, 2, 77–91.
- Phiri, D., Simwanda, M., Salekin, S., Nyirenda, V. R., Murayama, Y., and Ranagalage, M. 2020. Sentinel-2 data for land cover/use mapping: A review. *Remote Sensing*, 12, 2291.
- Pierce, S. M., and Cowling, R. M. 1984. Phenology of fynbos, renosterveld and subtropical thicket in the south eastern Cape. *South African Journal of Botany*, 3, 1–16.
- Pierce, S. M., and Moll, E. J. 1994. Germination ecology of six shrubs in fire-prone Cape fynbos. *Vegetatio*, 110, 25–41.

- Pleniou, M., Xystrakis, F., Dimopoulos, P. and Koutsias, N. 2012. Maps of fire occurrence—spatially explicit reconstruction of recent fire history using satellite remote sensing. *Journal of Maps*, 8, 499–506.
- Procheş, Ş., Cowling, R. M., Goldblatt, P., Manning, J. C., and Snijman, D. A. 2006. An overview of the Cape geophytes. *Biological Journal of the Linnean Society*, 87, 27–43.
- Raal, P.A. and Burns, M.E.R., 1996. Mapping and conservation importance rating of the South African coastal vegetation as an aid to development planning. *Landscape and urban planning*, 34, 389–400.
- Rebelo, A. G. 1995. Renosterveld: conservation and research. In: *The sustainable use and management of renosterveld remnants in the Cape Floristic Region: proceedings of a symposium*. FCC report 1995/4. Low, A. B. & Jones, F. E. (eds). Pp. 32–42. Flora Conservation Committee, Botanical Society of South Africa, Kirstenbosch, Cape Town
- Rebelo, A.G., Boucher, C., Helme, N., Mucina, L. and Rutherford, M.C. 2006. Fynbos Biome 4. *The vegetation of South Africa, Lesotho and Swaziland*, 192, 144–145.
- Rebelo, A.G., Boucher, C., Helme, N., Mucina, L., Rutherford, M.C., 2006. Fynbos Biome. In: Mucina, L., Rutherford, M.C. (Eds.), *The vegetation of South Africa, Lesotho and Swaziland*. Strelitzia, 19. South African National Biodiversity Institute, Pretoria, pp. 52–219.
- Richardson, M. 2009. Principal component analysis. URL: <http://people.maths.ox.ac.uk/richardsonm/SignalProcPCA.pdf> (last access: 3.5. 2013). Aleš Hladnik Dr., Ass. Prof., Chair of Information and Graphic Arts Technology, Faculty of Natural Sciences and Engineering, University of Ljubljana, Slovenia ales.hladnik@ntf.uni-lj.si, 6, 4.
- Richardson, D. M., and Van Wilgen, B. W. 1986. The effects of fire in felled *Hakea sericea* and natural fynbos and implications for weed control in mountain catchments. *South African Forestry Journal*, 139, 4–14.
- Rippel, T. M., DeCandia, A. L., Collier, M. A., McIntosh, C. L., Murphy, S. M., and Wimp, G. M. 2024. Habitat Characteristics and Plant Community Dynamics Impact the Diversity, Composition, and Co-occurrence of Sediment Fungal Communities. *Wetlands*, 44, 3.
- Rouget, M., Barnett, M., Cowling, R. M., Cumming, T., Daniels, F., Hoffman, M. T., Knight, A., Manuel, J., Nel, J., Parker, A., Raimondo, D., and Rebelo, T. 2014. Conserving the

- Cape Floristic Region. *Fynbos: ecology, evolution and conservation of a megadiverse region*, 321–336.
- Rouget, M., Jonas, Z., Cowling, R.M., Desmet, P.G., Mohamed, B., Mucina, L., Rutherford, M.C., and Powrie, L.W. 2006. Ecosystem Status and Protection Levels of Vegetation Types, 16. *The Vegetation of South Africa, Lesotho and Swaziland*. Mucina, L., Rutherford, M. (Eds.), 192, 725–737.
- Rutherford, M. C., Powrie, L. W., Husted, L. B., and Turner, R. C. 2011. Early post-fire plant succession in Peninsula Sandstone Fynbos: The first three years after disturbance. *South African journal of botany*, 77, 665–674.
- Rutherford, M.C. and Westfall, R.H. 1986. Biomes of southern Africa – An objective categorization. *Memoirs of the Botanical Survey of South Africa*, 54, 1–98.
- Sabins Jr, F. F., and Ellis, J. M. 2020. *Remote sensing: Principles, interpretation, and applications*. Waveland Press.
- Sahebjalal, E., and Dashtekian, K. 2013. Analysis of land use-land covers changes using normalized difference vegetation index (NDVI) differencing and classification methods. *African Journal of Agricultural Research*, 8, 4614–4622.
- SANBI. 2024. Red List for South African Plants. South African National Biodiversity Institute. Available from: <http://redlist.sanbi.org/> Accessed: 24 February 2025.
- South African National Biodiversity Institute. 2022. Red List of Ecosystems (RLE) for terrestrial realm for South Africa - remnants [Vector] 2021. Available from the Biodiversity GIS [website](#), downloaded on Monday, March 10, 2025
- Schroeder, C.A. 1967. The stem parasite *Cassytha filiformis* a botanical relative of avocado. *California Avocado Society*, 51, 159–160.
- Seymour, C.L., Seaton, D., Khatieb, S., Letsatsi, N., Skowno, A., Tokura, W., van der Merwe, S., Visser, V., and von Maltitz. 2025. Satellite-Derived Productivity Outputs for Land Degradation Assessment Vary With Biome and Rainfall. *Land Degradation & Development*, 0, 1–14.
- Sharples, J.J., McRae, R.H.D., and Wilkes, S.R. 2012. Wind-terrain effects on the propagation of wildfires in rugged terrain: fire channelling. *International Journal of Wildland Fire*, 21, 282–296.

- Shezi, T. A., O'Connor, T. G., and Witkowski, E. T. F. 2021. Impact of livestock grazing intensity on plant diversity of montane grassland in the northern Drakensberg, South Africa. *African Journal of Range & Forage Science*, 38, 67–79.
- Simons, M. B. 2017. An analysis of the fire regime and its effects on post-fire recovery in Namaqualand Granite Renosterveld vegetation. MSc thesis, University of Western Cape, Western Cape, South Africa.
- Singh, A. 1989. Digital change detection techniques using remotely sensed data. *International Journal of Remote Sensing*, 10, 989–1003.
- Singh, R. G., Engelbrecht, J., and Kemp, J. 2015. Change detection of bare areas in the Xolobeni region, South Africa using Landsat NDVI. *South African Journal of Geomatics*, 4, 138–148.
- Skowno, A. L., and Monyeki, M. S. 2021. South Africa's red list of terrestrial ecosystems (RLEs). *Land*, 10, 1048.
- Skowno, A.L., Poole, C.J., Raimondo, D.C., Sink, K.J., Van Deventer, H., Van Niekerk, L., Harris, L.R., Smith-Adao, L.B., Tolley, K.A., Zengeya, T.A., Foden, W.B., Midgley, G.F. and Driver, A. 2019. National Biodiversity Assessment 2018: The status of South Africa's ecosystems and biodiversity. Synthesis Report. South African National Biodiversity Institute, an entity of the Department of Environment, Forestry and Fisheries, Pretoria. pp. 1–214.
- Skowno, A.L., Raimondo, D.C., Poole, C.J., Fizzotti, B. and Slingsby, J.A. (eds.). 2019. *South African National Biodiversity Assessment 2018 Technical Report Volume 1: Terrestrial Realm*. South African National Biodiversity Institute, Pretoria.
<http://hdl.handle.net/20.500.12143/6370>.
- Smitheman, J., and Perry, P. 1990. A vegetation survey of the Karoo national Botanic Garden Reserve, Worcester. *South African Journal of Botany*, 56, 525–541.
- Stark, M. A. and Hudson, R. J. 1985. Plant communities' structure in Benoue National Park, Cameroon: a cluster association analysis. *African Journal of Ecology*, 23, 21–27.
- Snijman, D.A. 2013. Plants of the Greater Cape Floristic Region, Vol. 2: the Extra Cape flora. *Strelitzia* 30. South African National Biodiversity Institute, Pretoria.
- Soga, M., and Gaston, K. J. 2025. Extinction of experience among ecologists. *Trends in Ecology & Evolution*.

- South African Government. 2004. *National Environmental Management: Biodiversity Act No. 10*. South African Government. Pretoria.
- South African National Biodiversity Institute (SANBI). 2012. Vegetation Map App [Vector] 2012. Available from the Biodiversity GIS Website:
http://bgisviewer.sanbi.org/Html5Viewer/Index.html?configBase=http://bgisviewer.sanbi.org/Geocortex/Essentials/REST/sites/Vegmap/viewers/National_Vegetation_Map_2009/virtualdirectory/Resources/Config/Default&user=&extent=&layerTheme= Date Accessed [17/09/2023]
- Stander, A. 2016. *The importance of renosterveld conservation based on insect diversity sampled in West Coast Renosterveld in the Western Cape of South Africa* (Doctoral dissertation, Stellenbosch: Stellenbosch University).
- Taufik, A., Ahmad, S. S. S., and Ahmad, A. 2016. Classification of landsat 8 satellite data using NDVI thresholds. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, 8, 37–40.
- Tichý, L., Hennekens, S. M., Novák, P., Rodwell, J. S., Schaminée, J. H., and Chytrý, M. 2020. Optimal transformation of species cover for vegetation classification. *Applied Vegetation Science*, 23, 710–717.
- Tiruppur Districts, Tamil Nadu, India. *International Journal of Remote Sensing & Geoscience (IJRSG)*, 3, 15–20.
- Todd, S.W. and Unit, P.C., 2010. Vegetation and Plant Communities Associated with the Tillite and Dolerite Renosterveld Types of the Avontuur Conservation Area, Nieuwoudtville, South Africa.
- Tomppo, E., Olsson, H., Ståhl, G., Nilsson, M., Hagner, O. and Katila, M. 2008. Combining national forest inventory field plots and remote sensing data for forest databases. *Remote Sensing of Environment*, 112, 1982–1999.
- Topp, E.N. and Loos, J. 2019. Fragmented Landscape, Fragmented Knowledge: A Synthesis of Renosterveld Ecology and Conservation. *Environmental Conservation*, 46, 171–179. doi: 10.1017/S0376892918000498.
- Townsend, P.A., and Walsh, S.J. 2001. Remote sensing of forested wetlands: application of multitemporal and multispectral satellite imagery to determine plant community composition and structure in southeastern USA. *Plant Ecology*, 157, 129–149.

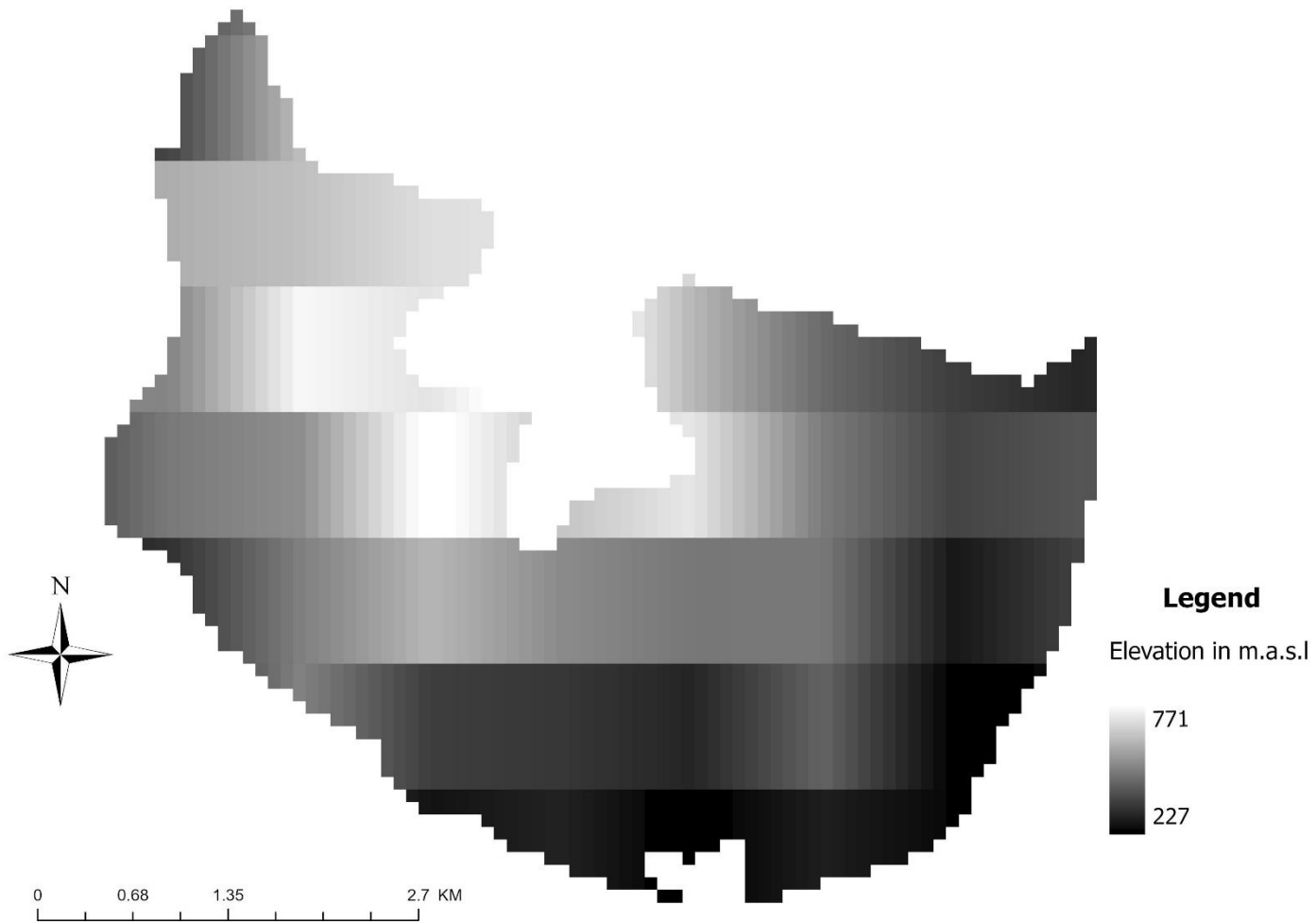
- Trabaud, L., and Lepart, J. 1980. Diversity and stability in garrigue ecosystems after fire. *Vegetation*, 43, 49–57.
- Trollope, W. S. W., Trollope, L. A., and Hartnett, D. C. 2002. Fire behaviour a key factor in the fire ecology of African grasslands and savannas. *Forest Fire Research and Wildland Fire Safety*, Millpress, Rotterdam, 1–15.
- Turner, M. G., Romme, W. H., Reed, R. A., and Tuskan, G. A. 2003. Post-fire aspen seedling recruitment across the Yellowstone (USA) landscape. *Landscape Ecology*, 18, 127–140.
- Unger, S., Rollins, M., Tietz, A., and Dumais, H. 2020. iNaturalist as an engaging tool for identifying organisms in outdoor activities. *Journal of Biological Education*. 1–11. doi:10.1080/00219266.2020.1739114.
- Van den Berckt, T. 2002. The ecological effect of *Acacia saligna* in a Sand Plain Fynbos ecosystem of the Western Cape, South Africa (Doctoral dissertation, Stellenbosch: Stellenbosch University).
- Van der Maarel, E. 1979. Transformation of cover-abundance values in phytosociology and its effects on community similarity. *Vegetatio*, 39, 97–114.
- Van der Merwe, H., and van Rooyen, M.W. 2011. Vegetation trends following fire in the Roggeveld, Mountain Renosterveld, South Africa. *South African Journal of Botany*, 77, 127–136.
- Van Staden, P.J., Bredenkamp, G.J., Bezuidenhout, H. and Brown, L.R. 2021. A reclassification and description of the Waterberg Mountain vegetation of the Marakele National Park, Limpopo province, South Africa. *Koedo*, 63, a1689. <https://doi.org/10.4102/koedoe.v63i1.1689>
- Van Wilgen, B. W. 2009. The evolution of fire and invasive alien plant management practices in fynbos. *South African Journal of Science*, 105, 335–342.
- Van Wilgen, B. W. 2013. Fire management in species-rich Cape fynbos shrublands. *Frontiers in Ecology and the Environment*, 11, e35–e44.
- Van Wilgen, B. W., Higgins, K. B., and Bellstedt, D. U. 1990. The role of vegetation structure and fuel chemistry in excluding fire from forest patches in the fire-prone fynbos shrublands of South Africa. *The Journal of Ecology*, 78, 210–222.

- Van Wilgen, B.W., Forsyth, G.G., De Klerk, H., Das, S., Khuluse, S., and Schmitz, P. 2010. Fire management in Mediterranean-climate shrublands: a case study from the Cape fynbos, South Africa. *Journal of Applied Ecology*, 47, 631–638.
- Verboom, G. A., Slingsby, J. A., and Cramer, M. D. 2024. Fire-modulated fluctuations in nutrient availability stimulate biome-scale floristic turnover in time, and elevated species richness, in low-nutrient fynbos heathland. *Annals of Botany*, 133, 819–832.
- Vlok, J. H. J. 1989. A new *Muraltia* species (Polygalaceae) from the southern Cape. *South African Journal of Botany*, 55, 1–10.
- Von Hase, A., Rouget, M., Maze, K. and Helme, N. 2003 *A fine-scale conservation plan for Cape Lowlands Renosterveld: Technical Report*. Report CCU2/03, Botanical Society of South Africa, Kirstenbosch.
- Wenhua, L. 2004. Degradation and restoration of forest ecosystems in China. *Forest Ecology and Management*, 201, 33–41.
- Werger M.J.A. 1974. On concepts and techniques applied in the Zurich-Montpellier method of vegetation survey. *Bothalia*, 11, 309–323.
- Werger, M. J. A. 1972. Species-area relationship and plot size: with some examples from South African vegetation. *Bothalia*, 10, 583–594.
- West, S., Cairns, R., and Schultz, L. 2016. What constitutes a successful biodiversity corridor? A Q-study in the Cape Floristic Region, South Africa. *Biological Conservation*, 198, 183–192.
- Wikum, D. A., and Shanholtzer, G. F. 1978. Application of the Braun-Blanquet cover-abundance scale for vegetation analysis in land development studies. *Environmental management*, 2, 323–329.
- Williams, L. J., and Abdi, H. 2010. Fisher's least significant difference (LSD) test. *Encyclopedia of research design*, 218, 840–853.
- Willis, K. S. 2015. Remote sensing change detection for ecological monitoring in United States protected areas. *Biological Conservation*, 182, 233–242. doi:10.1016/j.biocon.2014.12.006.
- Witkowski, E. T. F. 1991. Effects of invasive alien acacias on nutrient cycling in the coastal lowlands of the Cape fynbos. *Journal of Applied Ecology*, 1–15.
- Witkowski, E.T.F and Mitchell. D.T. 1987. Variations in Soil Phosphorus in the Fynbos Biome, South Africa. *The Journal of Ecology*, 75, 1159–1171.

- Witkowski, E.T.F. and O'Connor, T.G., 1996. Topo-edaphic, floristic and physiognomic gradients of woody plants in a semi-arid African savanna woodland. *Vegetatio*, 124, 9–23.
- Wold, S., Esbensen, K., and Geladi, P. 1987. Principal component analysis. *Chemometrics and intelligent laboratory systems*, 2, 37–52.
- Xie, V. and Sha, Z. & Yu, M. 2008. Remote sensing imagery in vegetation mapping: a review. *Journal of Plant Ecology*, 1, 9–23.
- Xue, J. and Su, B., 2017. Significant remote sensing vegetation indices: A review of developments and applications. *Journal of sensors*. 2017, 1–17.
- Yang, Y., Wang, S., Bai, X., Tan, Q., Li, Q., Wu, L., Tian, S., Hu, Z., Li, C., and Deng, Y. 2019. Factors affecting long-term trends in global NDVI. *Forests*. 10, 372.
- Yavitt, J.B., Harm, K.E., Garcia, M.N. 2009. Spatial heterogeneity of soil chemical properties in a lowland tropical moist forest, Panama. *Soil Research*, 47, 674–687.
- Yelenik, S.G., Stock, W.D. and Richardson, D.M. 2004. Ecosystem level impacts of invasive *Acacia saligna* in the South African fynbos. *Restoration Ecology*, 12, 44–51.

Appendices

Appendix 1.1: Digital Elevation Model (DEM) showing the elevation within the Robertson Granite Renosterveld (FRg3) in meters above sea level (m.a.s.l)



Appendix 1.4: List of species found within the Robertson Granite Renosterveld and their number of occurrences across the five major plant communities on the vegetation type. The species list further includes the conservation status (LC = Least Concern, NT= Near Threatened, VU =Vulnerable, EN=Endangered, N/A=Not Evaluated) and species endemism to a province (NOT = non-endemic, WC = Western Cape, EC = Eastern Cape, NC = Northern Cape, KZN=KwaZulu Natal, NW=North West, L=Limpopo).

Family	Genus	Species name	Abbreviation	Conservation status	Endemism	Species abundance per community					Total Abundance across FRg3
						<i>Dicerothamnus rhinocerotis– Dodonea viscosa</i>	<i>Dodonea viscosa– Euryops tenuissimus</i>	<i>Muraltia heisteria– Restio capensis</i>	<i>Passerina obtusifolia– Restio capensis</i>	<i>Pteronia paniculata– Dicerothamnus rhinocerotis</i>	
<i>Acholeplasmataceae</i>	<i>Phytoplasma</i>	<i>Phytoplasma</i> sp.	<i>Phy</i> (sp.)			1	0	0	0	0	1
<i>Aizoaceae</i>	<i>Acrodon</i>	<i>bellidiflorus</i>	<i>Acr-bell</i>	LC	WC	0	2	1	0	0	3
	<i>Carpobrotus</i>	<i>acinaciformis</i>	<i>Car-aci</i>	LC	WC	1	0	1	1	0	3
	<i>Cephalophyllum</i>	<i>diversiphyllum</i>	<i>Cep-div</i>	NT	WC	0	0	0	0	0	0
	<i>Drosanthemum</i>	<i>hispidum</i>	<i>Dro-his</i>	LC	NOT	0	1	0	0	1	2
	<i>Jordaaniella</i>	<i>Dubia</i>	<i>Jor-dub</i>	LC	WC	0	1	0	0	0	1
	<i>Lampranthus</i>	<i>watermeyeri</i>	<i>Lam-wat</i>	LC	NC	1	6	0	5	1	13
	<i>Ruschia</i>	<i>Ruschia</i> sp.	<i>Rus</i> (sp.)			2	7	1	6	5	21
	<i>Trichodiadema</i>	<i>Trichodiadema</i> sp.	<i>Tri</i> (sp.)			1	0	0	0	0	1
<i>Amaryllidaceae</i>	<i>Allium</i>	<i>vineale</i>	<i>All-vin</i>	N/A	Alien	0	0	0	0	0	0
	<i>Nothoscordum</i>	<i>gracile</i>	<i>Not-gra</i>	N/A	Alien	1	0	0	0	1	2
	<i>Tulbaghia</i>	<i>violacea</i>	<i>Tul-vio</i>	LC	WC/EC/KZ N	2	1	0	1	0	4
<i>Anacardiaceae</i>	<i>Searsia</i>	<i>laevigata</i>	<i>Sea-lae</i>	LC	WC/EC/NC	1	0	0	0	0	1
		<i>longispina</i>		LC	WC/EC/NC	0	3	0	0	0	3
		<i>lucida</i>		LC	NOT	0	0	1	0	0	1
		<i>pallens</i>		LC	NOT	2	4	0	2	1	9
		<i>undulata</i>		LC	NOT	0	0	0	0	0	0

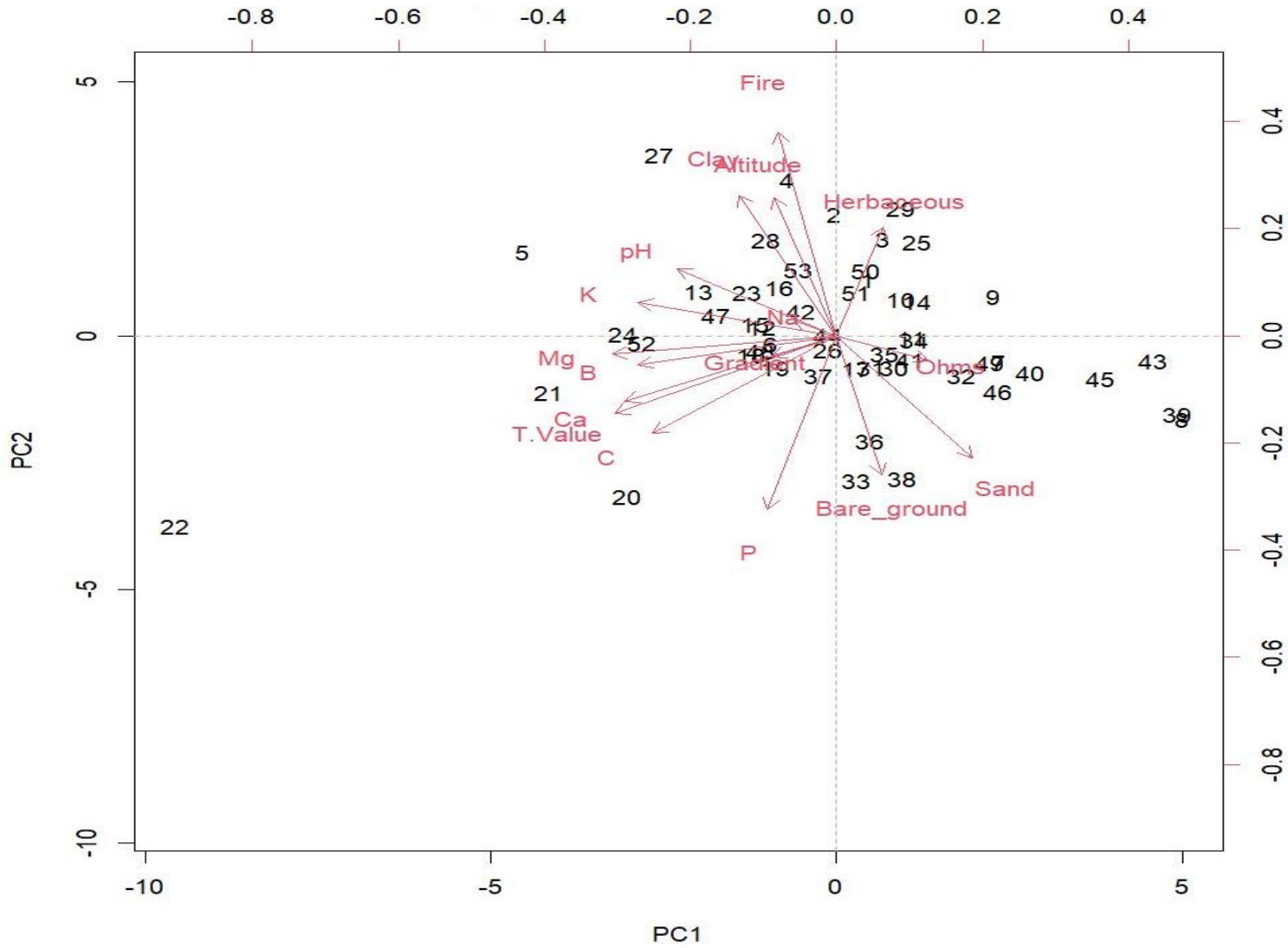
<i>Anemiaceae</i>	<i>Anemia</i>	<i>lepigera</i>	<i>Ane-lep</i>	N/A	Alien	0	0	0	0	0	0
<i>Apocynaceae</i>	<i>Gomphocarpus</i>	<i>Gomphocarpus</i> sp.	<i>Gom</i> (sp.)			0	1	0	0	0	1
	<i>Piранthus</i>	<i>geminatus</i>	<i>Pia-gem</i>	LC	WC	0	0	0	0	0	0
<i>Asparagaceae</i>	<i>Albuca</i>	<i>canadensis</i>	<i>Alb-can</i>	LC	NOT	0	1	0	0	0	1
	<i>Drimia</i>	<i>capensis</i>	<i>Dri-cap</i>	LC	WC/EC	0	1	1	0	0	2
	<i>Eriospermum</i>	<i>breviscapum</i>	<i>Eri-bre</i>	LC	WC	3	1	1	0	1	6
<i>Asphodelaceae</i>	<i>Aloe</i>	<i>microstigma</i>	<i>Alo-mic</i>	LC	WC/EC/NC	1	1	0	1	0	3
<i>Asteraceae</i>	<i>Berkheya</i>	<i>Armata</i>	<i>Ber-Arm</i>	LC	WC/MP/L	0	1	0	0	0	1
	<i>Chrysocoma</i>	<i>ciliata</i>	<i>Chr-cil</i>	LC	NOT	0	0	0	0	2	2
		<i>coma-aurea</i>		LC	WC	1	1	0	0	0	2
	<i>Cineraria</i>	<i>saxifraga</i>	<i>Cin-sax</i>	LC	EC	0	1	0	0	0	1
	<i>Dicrothamnus</i>	<i>rhinocerotis</i>	<i>Dic-rhi</i>	LC	NOT	8	13	5	4	5	35
	<i>Eriocephalus</i>	<i>africanus</i>	<i>Eri-afr</i>	LC	WC	4	11	4	4	5	28
	<i>Euryops</i>	<i>linifolius</i>	<i>Eur-lin</i>	LC	WC	0	1	0	0	0	1
		<i>tenuissimus</i>		LC	WC/NC	4	10	2	4	2	22
	<i>Felicia</i>	<i>fruticosa</i>	<i>Fel-fru</i>	LC	WC	0	0	0	1	1	2
	<i>Helichrysum</i>	<i>cymosum</i>	<i>Hel-cym</i>	LC	WC/KZN/E C	4	5	1	7	2	19
		<i>dasyanthum</i>		LC	WC/EC/NC	0	7	2	2	1	12
		<i>odoratissimum</i>		LC	NOT	0	1	0	0	0	1
		<i>rutilans</i>		LC	EC/NC/FS	0	1	0	0	0	1
		<i>teretifolium</i>		LC	WC/EC/KZ N	0	0	0	0	0	0
<i>Asteraceae</i>	<i>Metalasia</i>	<i>acuta</i>	<i>Met-acut</i>	LC	WC	1	5	4	3	0	13
		<i>plicata</i>		EN	WC	0	1	0	0	0	1
		<i>pungens</i>		LC	WC/EC	0	2	1	2	0	5
	<i>Oedera</i>	<i>garnotii</i>	<i>Oed-gar</i>	VU	WC	0	1	0	0	0	1
		<i>uniflora</i>		LC	WC	6	13	6	6	3	34
	<i>Osteospermum</i>	<i>moniliferum</i>	<i>Ost-mon</i>	LC	WC	0	0	0	0	0	0
	<i>Othonna</i>	<i>gymnodiscus</i>	<i>Oth-gym</i>	LC	WC/EC	0	0	0	0	0	0
	<i>Pteronia</i>	<i>fasciculata</i>	<i>Pte-fas</i>	LC	WC/NC	1	0	0	0	1	2
		<i>incana</i>		LC	WC/EC/NC	5	6	0	3	5	19

		<i>paniculata</i>		LC	NOT	6	7	0	2	7	22
	<i>Senecio</i>	<i>burchellii</i>	<i>Sen-bur</i>	LC	WC/EC/NC	0	1	0	0	0	1
<i>Boraginaceae</i>	<i>Lobostemon</i>	<i>echioides</i>	<i>Lob-ech</i>	LC	WC/EC/NC	0	0	1	2	0	3
		<i>trigonus</i>		LC	WC/EC	0	0	2	0	0	2
<i>Crassulaceae</i>	<i>Adromischus</i>	<i>caryophyllaceus</i>	<i>Adr-cary</i>	LC	WC	0	0	0	0	0	0
		<i>filicaulis</i>		LC	WC/NC	1	2	0	1	2	6
	<i>Cotyledon</i>	<i>orbiculata</i>	<i>Cot-orb</i>	LC	NOT	1	2	0	0	3	6
		<i>Cotyledon</i> sp.				0	2	0	0	0	2
	<i>Crassula</i>	<i>atropurpurea</i>	<i>Cra-atr</i>	LC	WC/NC	5	9	0	8	6	28
		<i>expansa</i>		LC	NOT	6	11	2	8	7	34
		<i>muscosa</i>		LC	NOT	0	4	1	3	4	12
		<i>perfoliata</i>		LC	EC	0	1	0	2	1	4
		<i>pubescens</i>		LC	WC/EC	0	1	0	0	1	2
		<i>rupestris</i>		LC	WC/EC	0	0	0	0	1	1
		<i>tetragona</i>		LC	WC/EC/NC	0	0	0	0	0	0
	<i>Tylecodon</i>	<i>paniculatus</i>	<i>Tyl-pan</i>	LC	NOT	0	2	0	0	3	5
<i>Ebenaceae</i>	<i>Euclea</i>	<i>undulata</i>	<i>Euc-und</i>	LC	NOT	1	4	0	1	1	7
<i>Ericaceae</i>	<i>Erica</i>	<i>setacea</i>	<i>Eri-set</i>	LC	WC	1	1	3	2	0	7
<i>Euphorbiaceae</i>	<i>Euphorbia</i>	<i>burmannii</i>	<i>Eup-bur</i>	LC	NOT	2	5	0	6	5	18
		<i>Mauritanica</i>		LC	NOT	2	2	0	0	1	5
		<i>tirucalli</i>		LC	NOT	0	1	0	0	0	1
<i>Fabaceae</i>	<i>Aspalathus</i>	<i>frankenoides</i>	<i>Asp-fra</i>	LC	WC/NC	0	1	0	0	0	1
		<i>hirta</i>		LC	WC/NC	0	1	0	0	0	1
		<i>vermiculata</i>		LC	WC/EC	0	0	1	0	0	1
	<i>Podalyria</i>	<i>calyptrata</i>	<i>Pod-cal</i>	LC	WC/EC	1	7	2	3	0	13
	<i>Psoralea</i>	<i>candicans</i>	<i>Pso-can</i>	LC	WC/EC	0	1	0	0	0	1
<i>Geraniaceae</i>	<i>Pelargonium</i>	<i>crispum</i>	<i>Pel-cri</i>	LC	WC	1	2	3	1	0	7
		<i>lobatum</i>		LC	WC/EC	0	1	0	0	0	1
		<i>peltatum</i>		LC	WC/EC	0	1	1	0	0	2
<i>Iridaceae</i>	<i>Ferraria</i>	<i>Ferrari</i> sp.	<i>Fer</i> (sp.)			0	0	0	0	0	0
	<i>Tritonia</i>	<i>pallida</i>	<i>Tri-pal</i>	NT	WC	0	0	0	1	0	1
<i>Lamiaceae</i>	<i>Stachys</i>	<i>aethiopica</i>	<i>Sta-aet</i>	LC	NOT	0	1	0	0	0	1

	<i>Cassytha</i>	<i>ciliolata</i>	<i>Cas-cil</i>	LC	WC/EC/NC	0	0	0	0	0	0
<i>Malvaceae</i>	<i>Hermannia</i>	<i>alnifolia</i>	<i>Her-aln</i>	LC	WC/EC	0	0	2	0	0	2
		<i>holosericea</i>		LC	WC/EC	0	1	0	0	0	1
		<i>incana</i>		LC	WC/EC/NC	0	0	2	0	0	2
		<i>Hermannia</i> sp.				0	3	0	0	0	3
<i>Montiniaceae</i>	<i>Montinia</i>	<i>caryophyllacea</i>	<i>Mon-car</i>	LC	NOT	1	0	0	0	0	1
<i>Oleaceae</i>	<i>Olea</i>	<i>europaea</i>	<i>Ole-eur</i>	LC	NOT	1	1	1	0	1	4
<i>Orchidaceae</i>	<i>Satyrium</i>	<i>erectum</i>	<i>Sat-ere</i>	LC	WC/EC/NC	1	0	0	0	0	1
<i>Oxalidaceae</i>	<i>Oxalis</i>	<i>depressa</i>	<i>Oxa-dep</i>	LC	NOT	0	0	1	0	0	1
		<i>purpurea</i>		LC	WC/NC/EC/ NW	0	0	0	0	1	1
<i>Plantaginaceae</i>	<i>Plantago</i>	<i>afra</i>	<i>Pla-af</i>	N/A	N/A	0	0	0	0	0	0
<i>Poaceae</i>	<i>Ampelodesmos</i>	<i>mauritanicus</i>	<i>Amp-mau</i>	N/A	Alien	0	0	0	0	0	0
	<i>Cymbopogon</i>	<i>marginatus</i>	<i>Cym-mar</i>	LC	NOT	1	0	0	1	0	2
	<i>Eragrostis</i>	<i>curvula</i>	<i>Era-cur</i>	LC	NOT	0	0	0	0	0	0
	<i>Pentameris</i>	<i>eriosoma</i>	<i>Pen-eri</i>	LC	WC/EC/NC	7	16	3	9	4	39
	<i>Tenaxia</i>	<i>stricta</i>	<i>Ten-str</i>	LC	NOT	0	1	0	1	2	4
<i>Polygalaceae</i>	<i>Muraltia</i>	<i>heisteria</i>	<i>Mur-hei</i>	LC	WC/EC/NC	0	4	6	4	0	14
<i>Proteaceae</i>	<i>Protea</i>	<i>laurifolia</i>	<i>Pro-lau</i>	LC	WC/NC	1	0	0	0	0	1
		<i>nitida</i>		LC	WC/EC	0	0	1	0	0	1
<i>Restionaceae</i>	<i>Restio</i>	<i>capensis</i>	<i>Res-cap</i>	LC	WC/EC/NC	4	10	5	9	2	30
	<i>Willdenowia</i>	<i>incurvata</i>	<i>Wil-inc</i>	LC	WC/NC	0	0	0	0	0	0
<i>Rhamnaceae</i>	<i>Phylica</i>	<i>ericoida</i>	<i>Phy-eri</i>	N/A	N/A	1	1	0	2	0	4
		<i>fruticosa</i>		LC	WC	0	0	1	1	0	2
<i>Rosaceae</i>	<i>Cliffortia</i>	<i>erectisepala</i>	<i>Cli-ere</i>	LC	WC/EC	0	1	0	0	0	1
<i>Rosaceae</i>	<i>Cliffortia</i>	<i>ruscifolia</i>	<i>Cli-rus</i>	LC	WC/EC/NC	0	2	0	3	0	5
<i>Rubiaceae</i>	<i>Anthospermum</i>	<i>spathulatum</i>	<i>Ant-spa</i>	LC	NOT	4	9	4	0	3	20
<i>Rutaceae</i>	<i>Agathosma</i>	<i>mundtii</i>	<i>Aga-mun</i>	LC	WC/NC	2	0	3	2	0	7
		<i>Agathosma</i> sp.		N/A	N/A	0	4	1	0	0	5
<i>Sapindaceae</i>	<i>Dodonea</i>	<i>viscosa</i>	<i>Dod-vis</i>	LC	NOT	5	16	5	10	4	40
<i>Scrophulariaceae</i>	<i>Nemesia</i>	<i>pageae</i>	<i>Nem-pag</i>	LC	WC	0	1	0	0	0	1

<i>Thymelaeaceae</i>	<i>Passerina</i>	<i>Passerina obtusifolia</i>	<i>Pas-obt</i>	LC	WC/EC/NC	1	9	0	9	2	21
<i>Zygophyllaceae</i>	<i>Roepera</i>	<i>Roepera spinosa</i>	<i>Roe-spi</i>	LC	WC/NC	0	1	0	0	1	2
Unknown species											
		Bulb 2				0	0	0	0	1	1
		shrub P22.2				0	1	0	0	0	1
		shrub P22.3				0	1	0	0	0	1
		shrublet P22.4				0	1	0	0	0	1
		Shrublet P45.1				0	1	0	1	0	2
		Small shrub				0	0	0	0	0	0
		Shrublet P50.1				0	0	1	0	0	1

Appendix 1.5: Principal Component Analysis (PCA) biplot showing the relationship among different habitat characteristics and the 53 sampled plots of the Robertson Granite Renosterveld.

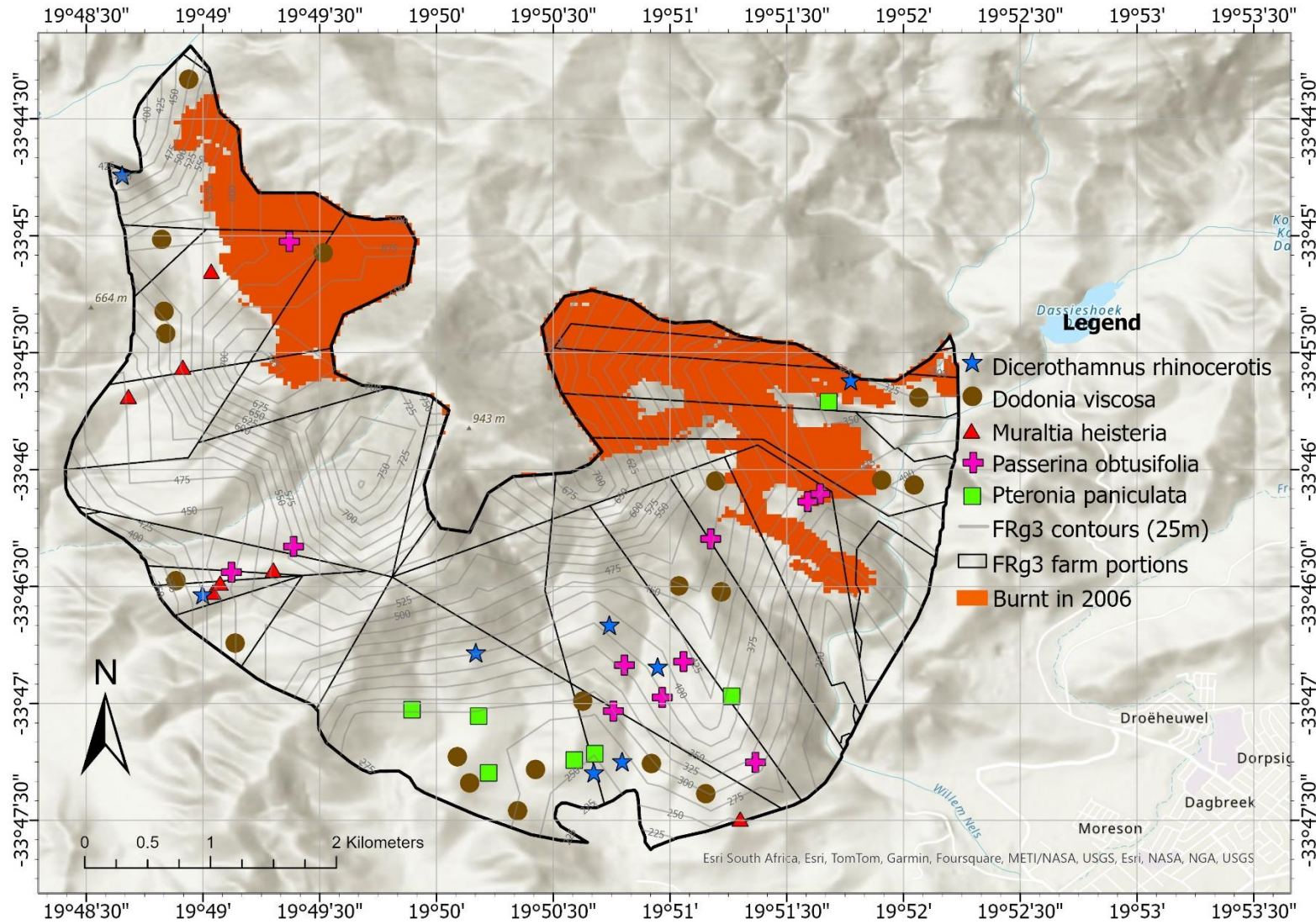


Appendix 3.1 Climatic conditions on the burn dates of the three fire events (2000, 2006, & 2017) within the Robertson Granite Renosterveld (FRg3). The wind direction was determined based on the forward direction of the wind. Cells/fields with no data were labelled as ---.

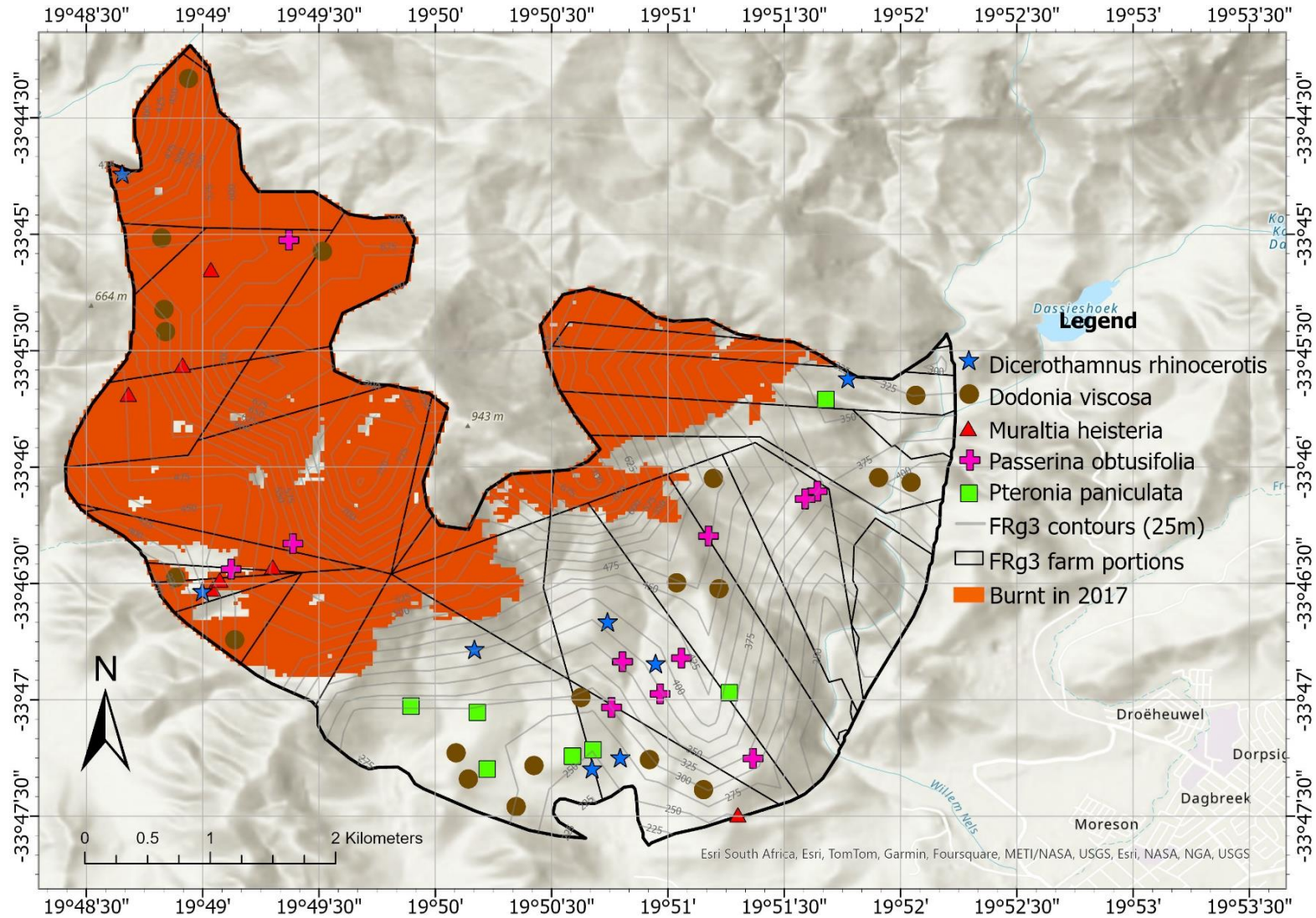
Date	Wind direction	Wind Speed (km/h)	Humidity (%)	Max Temperature (°C)	Rainfall (mm)
1-Jan-2000	SE	10.8	48	21.7	3.2
2-Jan-2000	SE	18	65	21.8	0.6
3-Jan-2000	SE	10.8	41	28.2	0
4-Jan-2000	NW	10.8	23	38.8	0
5-Jan-2000	SE	14.4	36	32.6	0
6-Jan-2000	NW	10.8	24	37.1	0
7-Jan-2000	NW	25.2	45	26.7	0
8-Jan-2000	SE	7.2	39	26.9	0
9-Jan-2000	NW	7.2	30	32.7	0
10-Jan-2000	SE	7.2	35	29.4	0
11-Jan-2000	NW	14.4	30	30.9	4.2
12-Jan-2000	SE	21.6	66	19.7	2.7
13-Jan-2000	W	7.2	39	25.9	0
14-Jan-2000	SE	18	39	26.2	0
15-Jan-2000	SE	25.2	48	27.2	0
16-Jan-2000	SE	21.6	40	29.4	0
17-Jan-2000	SE	10.8	17	33.5	0
18-Jan-2000	0	0	22	38.6	0
19-Jan-2000	SE	10.8	18	40	0
20-Jan-2000	SE	14.4	12	40.2	0
21-Jan-2000	E	7.2	9	40.4	0
22-Jan-2000	SE	14.4	43	30.4	0
23-Jan-2000	SE	7.2	50	29.1	0
24-Jan-2000	0	0	41	35.2	47.5
25-Jan-2000	SE	7.2	57	32.2	0
26-Jan-2000	SE	10.8	64	29.3	0
27-Jan-2000	SE	10.8	51	29.7	0.3

28-Jan-2000	E	7.2	63	24.9	1.3
29-Jan-2000	SE	7.2	48	28.9	0
30-Jan-2000	NW	25.2	47	26.5	0
31-Jan-2000	NW	10.8	40	28.9	0
Mean & SD		12.08 ± 6.50	39.67 ± 15.09	30.42 ± 5.43	1.93 ± 8.38
26-Feb-2006	SE	10.8	---	31	0
27-Feb-2006	NW	18	---	31	3.6
28-Feb-2006	SE	7.2	---	20	1.3
1-Mar-2006	NW	18	---	26	0
2-Mar-2006	NW	14.4	---	25	0
3-Mar-2006	SE	18	---	21	0
Mean & SD		14.4 ± 4.16	---	25.67 ± 4.31	0.82 ± 1.33
21-Mar-2017	0	0	28	40	0
22-Mar-2017	SE	8.2	26	38	0
23-Mar-2017	SE	7.6	41	32	0.2
24-Mar-2017	SE	9.7	44	22	0
25-Mar-2017	SE	12.2	34	25	0
26-Mar-2017	SW	9	15	32	0
27-Mar-2017	SW	14	30	30	0
Mean & SD		8.67 ± 4.11	31.14 ± 9.01	31.29 ± 6.42	0.03 ± 0.07

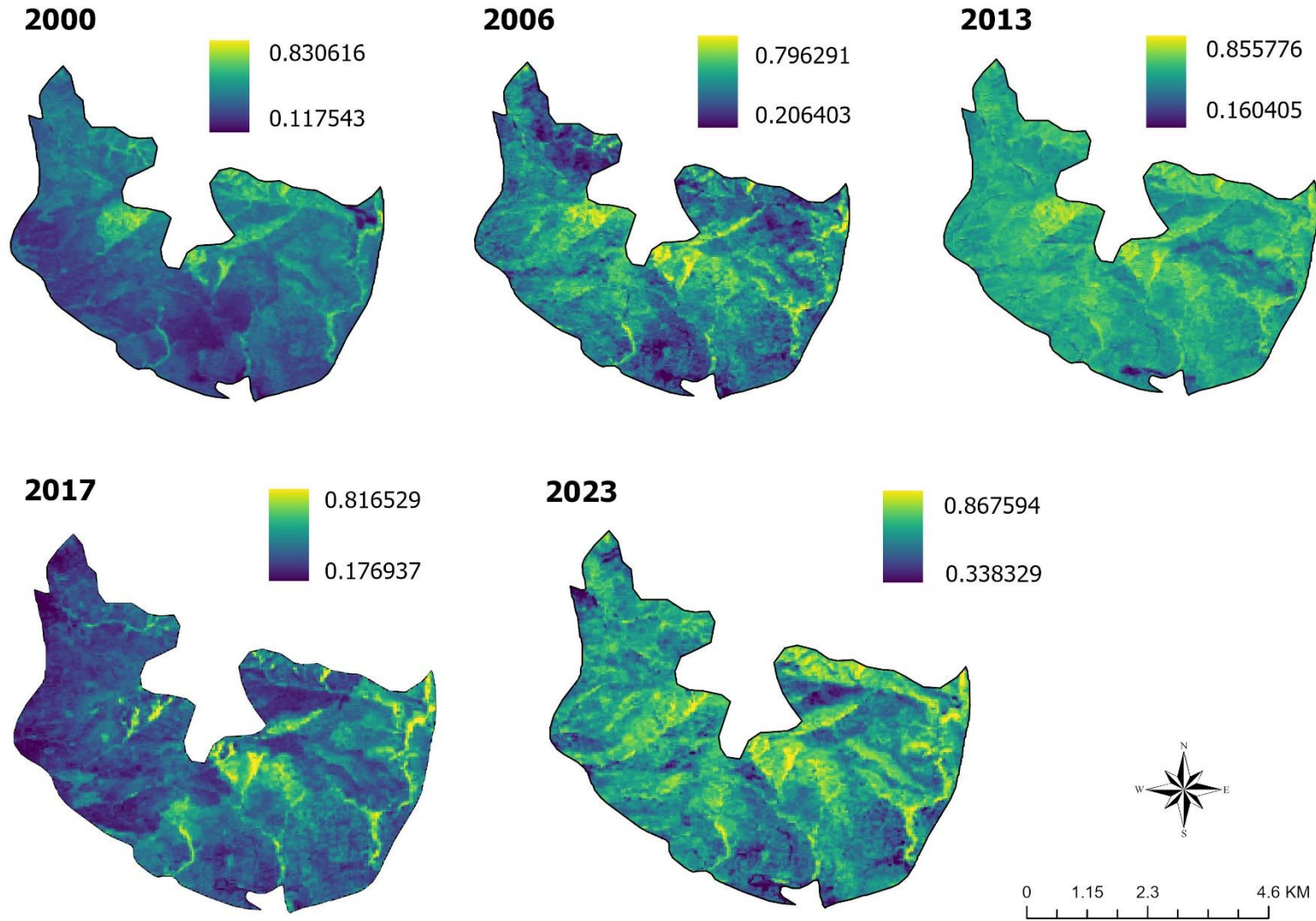
Appendix 3.2: Fine-scale map showing the portion of the Robertson Granite Renosterveld (FRg3) affected by fire in 2006. It includes the locality of the plant communities relative to the fire and topographic positions (altitudes, slope aspects and gradients).



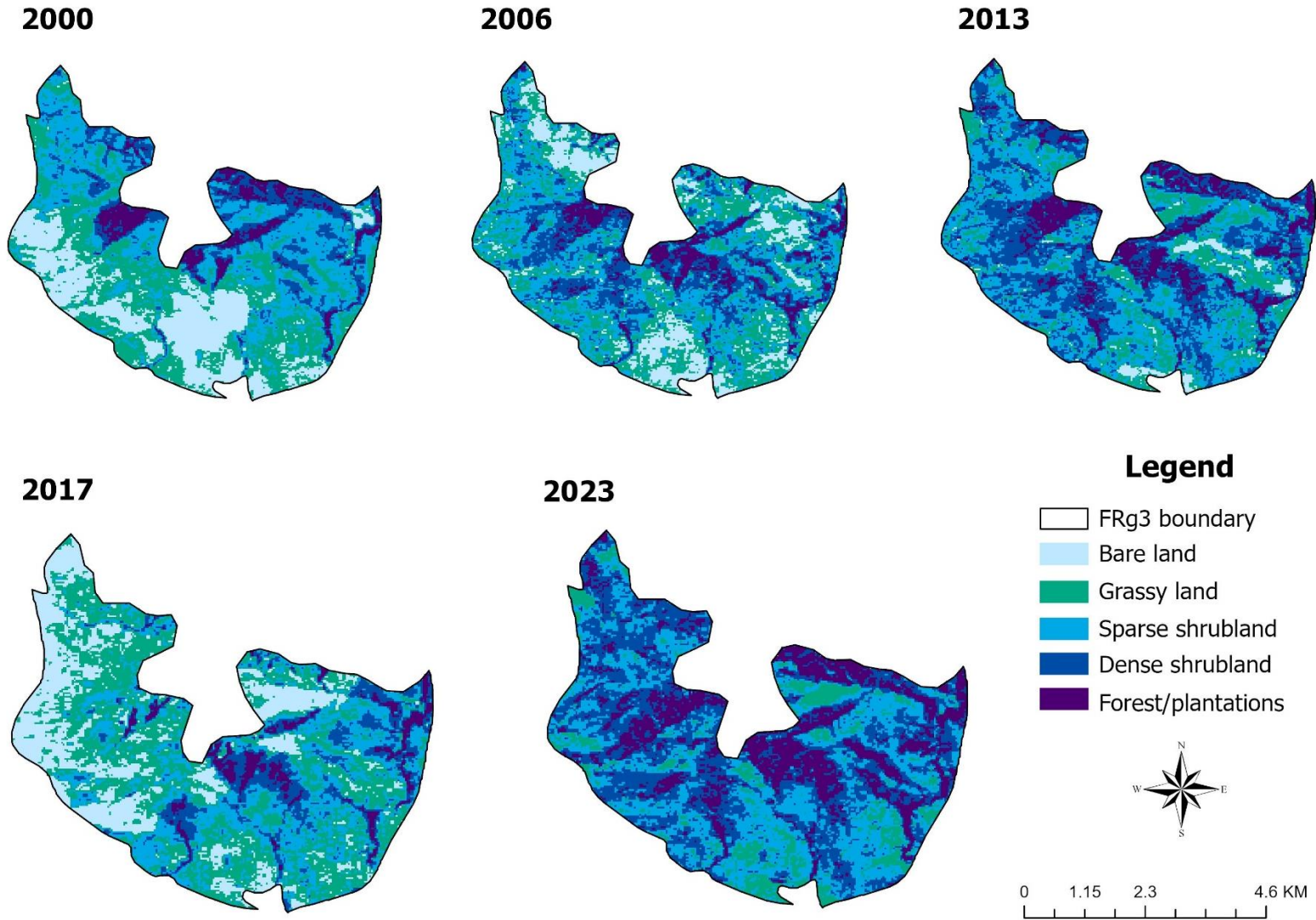
Appendix 3.3: Fine-scale map showing the portion of the Robertson Granite Renosterveld (FRg3) affected by fire in 2017. It includes the locality of the plant communities relative to the fire event and topographic positions (altitudes, slope aspects and gradients).



Appendix 1: A summary of NDVI differences within the Robertson Granite Renosterveld (FRg3) mapped from 2000 to 2023.



Appendix 2: A summary of classified NDVI maps comparing different vegetation structures across the Robertson Granite Renosterveld (FRg3) from 2000 to 2023.



Appendix 3: A summary of different vegetation structural distributions within the FRg3 from 2000 to 2023, with NDVI values (X-axis) and the total number of pixels (Y-axis) for each NDVI threshold.

