Mapping the distributions of ancient plant and animal lineages in southern Africa

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209514118

Submitted in fulfilment of the requirements for the degree of
Master of Science,
In the school of Agriculture, Earth and Environmental Science
University of KwaZulu-Natal, Durban
November 2014

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2014

Preface: Declaration of plagiarism

I hereby declare that this dissertation, submitted in fulfilment of the requirements for the degree of Master of Science in Environmental Science, to the University of KwaZulu-Natal, is a result of my own research and investigation, which has not been previously submitted, by myself, for a degree at this or any other institution. I hereby declare that this work is my own, unaided work; appropriately referenced where others' work has been used.

Ashlyn Levadia Padayachee

Date

Prof. Şerban Procheş

Date

Acknowledgements:

The success of this study would not have been possible without the help, guidance and direction given to me by the members of staff of the School of Agriculture, Earth and Environmental Science (University of KwaZulu-Natal), family and friends. I would like to acknowledge the following people:

God Almighty for blessing me with the courage and determination to complete this project

Prof. Şerban Procheş, my supervisor and the man with the brilliant ideas. Very sincere and heartfelt thanks for the motivation, guidance and direction throughout this project, for which without it, it would not have been accomplished. Thank you Prof, the 'pep-talks' which were much needed, especially towards the end.

Dr. Sandun Perera, who in the absence of my supervisor, stepped into the role of 'interim supervisor'. Thank you for your encouragement and motivation, not forgetting the help with analytical work in this project.

Prof. Aaron Bauer (Villanova University), for the provision of data and the advice regarding *Afroedura*.

Desika Moodley, the in-house 'R-guru'; for helping me understand the very complicated R software. Thank you for your friendship, encouragement and motivation.

My parents and sister for their emotional and spiritual support during this journey. Thank you for encouraging me in my academic pursuits.

The DAAD-NRF for financial support.

A sincere thank you to my family and friends; who I have not mentioned here, for their encouragement and support; mostly for providing me with my daily dose of laughter.

Abstract:

Southern Africa boasts a wealth of endemic fauna and flora. The focus of this study was to identify ancient biological lineages (faunal and floral lineages of Eocene age or older) endemic to southern Africa, and map the distributions of these lineages across the region. Seventy-four operational geographic units (OGUs) were delimited for distribution mapping. Twenty-seven ancient lineages were identified (seventeen plants and ten animals). For each of these lineages, individual distribution maps were generated. Total endemism and corrected weighted endemism maps were also generated collectively for all lineages. Four stages of cluster analysis were used to illustrate clusters of OGUs with similar lineage composition, using UPGMA agglomerative hierarchical clustering. Characteristic lineages were determined for clusters at each stage, and similarities between these clusters and previously recognised biogeographic units were discussed. A comparison between ancient endemic lineages and their sister lineages was conducted. Sister lineages were found to be often widespread and differed from ancient lineages in the types of habitat occupied and, in some cases, niche differences were noted. The mechanisms of ancient lineage survival in the region were investigated, and their importance for conservation in southern Africa emphasised.

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Abbreviations:

PD – Phylogenetic Diversity

CFR – Cape Floristic Region

SK – Succulent Karoo

MPA – Maputaland-Pondoland-Albany

EA – Eastern Afromontane

CFEA – Coastal Forests of Eastern Africa

OGUs – Operation Geographic Units

ORD – Orbitally forced Range Dynamics

QDS – Quarter Degree Square

WE – Weighted Endemism

CWE – Corrected Weighted Endemism

CWEA – Corrected Weighted Endemism for Area

UPGMA – Unweighted Pair-Group Method using Arithmetic Averages

Chapter 1: Introduction

Background:

The study of biogeography deals with the spatial patterns of distribution of biological diversity, allowing for the understanding of evolutionary processes and mechanisms of how these are distributed in a spatial context (Lomolino *et al.*, 2006). Understanding the spatial distribution patterns of biological diversity is essential in conservation planning. According to Malcolm *et al.* (2006), biodiversity hotspots are areas which are relatively small in size, comprising of high species richness and endemism, and under threat by land transformation. The spatial distribution of these areas are fundamental in conservation planning and implementation. The number of species under threat of extinction is far greater than the resources available to conserve these species; hence "hotspot" strategies have become a predominant effort in conservation planning (Hooper *et al.*, 2002; Cowling *et al.*, 2003). These strategies are justified by the presence of range-restricted endemic species within biodiversity hotspots; showing that not only has biodiversity been accounted for, but also (to some extent) the processes that have led to current biodiversity patterns (Cowling *et al.*, 2003; Thomas *et al.*, 2004; Malcolm *et al.*, 2006).

Species richness is one of the most commonly used measures in conservation planning, refering to the the number of species present in an area or region (Lamoreux *et al.*, 2006). Endemism is also a common measured using in conservation planning efforts. Endemism looks at species which are restricted to a specific region or area (Anderson, 1994). Species richness and endemism take into account the number of species present and the number of endemic species within a specific area or region, respectively (Lamoreux *et al.*, 2006).

According to Rodrigues & Gaston (2002), phylogenetic diversity (PD) is a biodiversity measure estimating the cumulative evolutionary history across sets of taxa, taking into consideration unique or shared features represented by taxa in a specific phylogenetic tree. The evolutionary history of species, which results in evolutionary distinctness, is a less known measure used in conservation efforts. Taking into consideration the factors which form the basis of hotspot delimitation (high species richness and endemism, under threat), evolutionary history of species, in conjunction with endemism, may encompass a greater conservation potential as opposed to species richness exclusively. Confusion arises in the case of recent radiations which can contribute to PD to the same effect as the survivial of ancient lineages, as the sum branch lengths of recently radiated species can add up to similar values (Tucker & Cadotte, 2013). To avoid such confusion, ancient lineages alone are the focus of this study. Taking into account the high numbers of endemic families and genera present within hotspots, these regions can be thought of as "reservoirs" of PD. Hence, hotspots are likely to be critical in conserving the evolutionary processes which give rise to biodiversity (Sechrest *et al.*, 2002; Lamoreux *et al.*, 2006).

High species richness coupled with high endemism as well as stable climates creates good conditions for the development of refugia (Médail & Diadema, 2009; Perera *et al.*, 2011). According to Ashcroft (2010) many discrepancies arise with the use of the term 'refugia' in the scientific literature; hence the use of the term requires clarification. In this study, the term 'refugia' refers to '*in situ* refugia', defined as areas which remain suitable for ancient lineages (>30My) (Ashcroft, 2010). The development of refugia is essential in facilitating the survival of ancient endemic lineages. Factors which affect the development of refugia include climate and geomorphology which will further be discussed.

Southern Africa (treated hereafter as comprising (at least partly) South Africa, Lesotho, Swaziland, Namibia, Zimbabwe, Zambia, Angola, Malawi and Botswana) exhibits high levels of species richness as well as endemism. Southern Africa covers an area of approximately 6 million km^2 (Moore *et al.*, 2009). In addition, five of the world's global hotspots of biodiversity are found within this region: the Cape Floristic Region (CFR), Succulent Karoo (SK), Maputaland-Pondoland-Albany (MPA), parts of the Eastern Afromontane (EA) and the Coastal Forests of Eastern Africa (CFEA) (Mittermeier *et al.*, 1998; Myers *et al.,* 2000). The CFR is also regarded as one of the six floral kingdoms of the world (Goldblatt, 1978; Burgess, 1998; Linder *et al.*, 2010). Southern Africa experiences mostly summer rainfall, exhibiting a longitudinal gradient with rainfall increasing towards the east. Year-round rainfall is experienced in the south-east, while a narrow strip of the south-western boarder experiences winter rainfall (Andrews & O'Brien, 2000; Philippon *et al.*, 2011). In terms of temperature and energy, southern Africa exhibits a latitudinal gradient in winter with temperature increasing from south to north. In summer, southern Africa exhibits a longitudinal gradient in productivity, increasing from west to east (Andrews & O'Brien, 2000). Different biota consequently inhabits these areas with distinct climates (Araújo *et al.*, 2005).

The relative climatic stability coupled with the relative tectonic stability exhibited in the southern African region means that this region is vital in the theoretical understanding of the development of refugia globally (Dynesius & Jansson, 2000; Thuiller *et al.,* 2006). The movement and change of plates result in the change of environments, possibly facilitating the survival of lineages in new habitats and niches (Marshak, 2008; Cowling *et al.*, 2009). Hence, the relative stability of the African Plate (especially latitudinally) possibly facilitates the survival of ancient endemic lineages. These refugia often harbour "living fossils", the modern survivors of such lineages, species having experienced little to no morphological changes (Nagalingum *et al.*, 2011). This study uses lineages which can be considered to be "living fossils", as a focus on the importance and potential for conservation within the southern African region.

Motivation:

Southern Africa exhibits a wealth of species richness, endemism and evolutionary history, with the potential development of refugia. This region is also one of the most threatened regions by land transformation (Myers *et al.*, 2000). Land transformation results in the loss of species as well as increased risk of extinctions to evolutionary ancient lineages. This study aims to emphasise the importance of conservation requirements in this region by using the example of ancient endemic lineages.

Aim:

This study aims at mapping ancient biological (floral and faunal) lineages within southern Africa, proposing mechanisms for the survival of these lineages, as well as, emphasising their importance for conservation in southern Africa.

Research Objectives:

The emphasis on conservation potential in the southern Africa region is a key aspect of this study. The following research objectives have been outlined in order to achieve this aim:

1. Identify the ancient plant and animal lineages to be mapped in the study;
2. Identify in the literature operational geographic units (OGUs) to be used;
3. Delimit OGUs for parts of the region where such are unavailable;
4. Collect presence/absence data for the lineages identified within these OGUs;
5. Map the ancient plant and animal lineages present in southern Africa across OGUs;
6. Regionalize southern Africa based on ancient lineage distributions;
7. Determine which lineages are characteristic for different biogeographic units;
8. Propose mechanisms for the survival of these lineages in southern Africa;
9. Discuss the distribution of lineages sister to the ancient lineages and other differences between the former and the latter;
10. Discuss the survival of these lineages in a global perspective.

As shown in this first chapter, the southern African region is unique in terms of species richness, endemism, climatic and tectonic stability; containing (at least partly) five biodiversity hotspots (Mittermeier *et al.*, 1998; Myers *et al.,* 2000; Dynesius & Jansson, 2000; Thuiller *et al.,* 2006). Chapter two consists of a review of literature regarding the uniqueness of southern Africa. Chapter three outlines the methodology used in this study. The fourth chapter comprises of results received from the aforementioned methodology, which are discussed further in chapter five. The final (sixth) chapter concludes the study and suggests key points to consider for future studies in this region.

Chapter 2: Literature Review

The following chapter comprises a review of literature with regards to southern Africa and the aspects of this region which make it unique. Geomorphology, climate and the biodiversity hotspots located in this region are further discussed, as these highlight the uniqueness of the region. Additionally, conservation approaches are dealt with as this plays a key role in the region of southern Africa. This chapter aims to determine the mechanisms of survival of ancient endemic lineages.

Geomorphology

Southern Africa is quite unique (only partly matched by Australia) in terms of its high levels of species richness and endemism, among the world's predominantly arid regions. The region covers approximately 6 million km^2 of land, most of which is represented by a fairly high plateau bordered by a narrow coastal plain. This coastal plain is characterised by low relief and is separated from the relatively uplifted African Plateau by the Great Escarpment (Moore *et al*., 2009).

The Great Escarpment of southern Africa is a semi-continuous mountain range system extending approximately 5000km from Angola and Namibia in the west, through South Africa, Lesotho and Swaziland, into Zimbabwe and Mozambique in the east (Clark *et al.*, 2011). The Great Escarpment and adjacent coastal plains support high levels of biodiversity in comparison to the species-impoverished African Plateau. It is generally accepted that the Great Escarpment began development during the Jurassic-early Cretaceous period (±201Myr to ±99.6Myr) (Clark *et al.*, 2011). According to López-Pujol *et al*. (2011) differences in composition of lineages on mountains can be linked to the age of the mountain range. Older mountain ranges were found to house older lineages, whereas younger mountain ranges showed the existence of recently radiated assemblages. Furthermore, mountainous regions provide refugia in the face of environmental and climate changes (López-Pujol *et al*., 2011).

The southern African region is relatively tectonically stable. The theory of plate tectonics plays a vital role in understanding the changes in environments due to plate motion. The more stable a region is; the less environmental changes will be experienced, resulting in more stable environments. Habitat stability is a key factor in the survival of ancient endemic lineages. According to Tolley *et al*. (2014), habitat stability is evident in the Fynbos and Succulent Karoo biomes of South Africa. Although the study was conducted in the Fynbos biome, the implied trend can be seen across southern Africa in the high number of ancient endemic lineages present. Hence, environmental heterogeneity coupled with stability facilitates the survival of ancient endemic lineages (Marshak, 2008; Cowling *et al*., 2009; Tolley *et al*., 2014)

Climate

The southern African region also exhibits relatively stable climatic conditions. Summer rainfall is predominant in this region, except for a narrow strip of land along the western coast of South Africa which experiences winter rainfall. Rainfall patterns show a longitudinal gradient with rainfall increasing towards the east. The south-eastern portion of the region experiences year-round rainfall (Andrews & O'Brien, 2000; Philippon *et al.*, 2011). Temperature and energy patterns differ seasonally. In winter a longitudinal gradient can be see across the region, while in summer a latitudinal gradient is evident (Andrews & O’Brien, 2000). This unique climatic pattern has been relatively stable through time, facilitating the survival of ancient endemic lineages. The climatic stability gives rise to refugia in which lineages have managed to survive to present day. This is further justified by Dynesius & Jansson (2000) who investigated the influence of orbitally forced range dynamics (ORD) on global endemism patterns. Regions which experienced lower climatic shifts over time housed more endemic species as opposed to those who experienced larger climatic shifts. These lower levels of ORD give rise to stable climatic environments (Dynesius & Jansson, 2000; Platts *et al*., 2013).

The unique topographical features in conjunction with the relatively stable tectonic conditions experienced in southern Africa give rise to the high levels of biodiversity which can be seen in this region.

Biodiversity Hotspots

Biodiversity hotspots (here after referred to as hotspots) are defined as regions with minimal land coverage, hosting greater than 0.5% of global flora, with approximately 70% of the land anthropogenically transformed. Hotspots are unique in that 44% of global plants and 35% of terrestrial vertebrates' entire ranges are completely found in a land area of approximately 1.4% (Brooks *et al.,* 2002; Malcolm *et al.*, 2006). Therefore, hotspots are relatively small regions hosting vast plant and animal diversity, currently under threat of extinction and substantial habitat loss (Malcolm *et al.*, 2006). Southern Africa encompasses three globally recognised biodiversity hotspots and parts of two others.

Cape Floristic Region

The Cape Floristic Region (CFR) is recognised as one of the six floral kingdoms of the world, as well as one of the global biodiversity hotspots owing to its uniquely high species diversity and endemism (Linder, 2005; Born *et al.*, 2007; Cowling *et al.*, 2009). The floral composition of the CFR is very unique with approximately 9 000 vascular plant species occurring in an area of approximately 90 000 km^2; of these 69% are endemic to the CFR (Born *et al*, 2007; Cowling *et al.*, 2009). The four most diverse and ecologically dominant plant families found in the CFR are Proteaceae, Restionaceae, Ericaceae, and Aizoaceae (Linder, 2005). Endemism in the CFR is similar to that of endemism found on islands. However, unlike islands, the CFR is not isolated geographically by an ocean, but rather differs from surrounding areas climatically and topographically (Linder, 2003). Climatically, the CFR differs from the rest of southern Africa as it experiences mostly winter rainfall patterns, whereas the rest of southern Africa experiences mostly summer to all year round rainfall patterns (Linder, 2003; Cowling *et al*., 2009). The Cape Fold Belt is a prominent feature of the CFR and comprises a series of mountain ranges which trend north-south along the Atlantic Ocean and west-east along the Indian Ocean (Cowling *et al*., 2009). The CFR is host not only numerous endemic plant species, but also to animal species. Endemism in smaller animals, such as geckos and chameleons, and even more so invertebrates, are very high in the CFR (Colville *et al*., 2014). However, animal endemism is poorly understood in this region, with plant endemism having taken much of the research focus.

Succulent Karoo

The Succulent Karoo (SK) is situated along the western coast of southern Africa, extending from southern Namibia to the Western Cape Province of South Africa. Of the approximately 5000 species found in the SK, 40% are endemic to this arid region (Jürgens, 1991; Lombard *et al.*, 1999; Klak *et al.*, 2004; Conservation International, 2005). The SK possesses the richest succulent flora worldwide; in addition, it is the only arid to semi-arid region to qualify as a global hotspot of biodiversity (Lombard *et al.*, 1999). Approximately 30% of worldwide succulent flora is found in this region (van der Merwe & van Rooyen, 2011). Vegetation is dominated by dwarf, succulent shrubs, as well as endemic geophytes. Aizoaceae, Euphorbiaceae, and Crassulaceae are the most ecologically significant plant families (Jürgens, 1991; Lombard *et al.*, 1999). The high levels of species richness, as well as high levels of endemism emphasise the importance of conservation, however; only approximately 2% of the region is formally conserved under protected areas (Lombard *et al.*, 1999).

Maputaland-Pondoland-Albany

The Maputaland-Pondoland-Albany (MPA) hotspot spans approximately 275 000 km^2 in area, encompassing three centres of endemism, including parts of South Africa, Mozambique and Swaziland. The three centres of endemism found in the MPA are the Maputaland, Pondoland and Albany centres of endemism (Critical Ecosystems Partnership Fund, 2010; Perera *et al.*, 2011; Di Minin *et al.*, 2013). The floral composition is unique to this region. The MPA hotspot host approximately 8 100 species, of which 1 900 are endemic to this region, also the temperate forests of the MPA host approximately 600 tree species, this being the richest temperate forests worldwide (Critical Ecosystems Parntership Fund, 2010; Perera *et al.*, 2011; Di Minin *et al.*, 2013). The MPA hosts among others a unique South African biome, the subtropical thicket, which is centred here (Conservation International, 2005; Smith *et al.*, 2008; Critical Ecosystems Partnership Fund, 2010). Topographically, the MPA has low-lying plains in the northern regions with more rugged terrain in the south. Along the coastal margin, climate ranges from subtropical to tropical in the northern regions to more temperate in the southern region, where some areas away from the coast experiencing substantial frost in winter (Di Minin *et al.*, 2013). Species found in the MPA are under risk of extinction owing to the increasing human population and demands placed on ecosystems services (Smith *et al.*, 2008; Critical Ecosystems Partnership Fund, 2010; Di Minin *et al*., 2013).

Eastern Afromontane

The southern African region incorporates parts of the Eastern Afromontane (EA) biodiversity hotspot. This hotspot is extensive, extending from Ethiopia in the north all the way through to Malawi, Zimbabwe and Mozambique in the south (Demos *et al.*, 2014). The EA comprises of three ancient massifs: Eastern Arc Mountains and the Southern Rift; Albertine Rift and the Ethiopian Highlands. In this study, the Eastern Arc Mountains are of importance due to their southern limit being in southern Malawi and outliers in Zimbabwe and Mozambique (Lawson, 2013). Like all other hotspots, the EA has very high levels of endemism which is under threat. This can be seen in the very high fragmentation of the EA, with almost 80% of land area already lost (Nielsen & Treue, 2012; Demos *et al*, 2014). The Chimanimani Mountains on the border between Mozambique and Zimbabwe form part of this region, which is also unique for its high levels of endemism (Conservation International, 2005; Critical Ecosystems Partnership Fund, 2012). Despite the uniqueness of this hotspot, it still remains understudied.

Coastal Forests of Eastern Africa

Southern Africa comprises of parts of the Coastal Forests of Eastern Africa (CFEA). The CFEA extends along the Indian Ocean from Somalia in the north, to Mozambique in the south (Conservation International, 2005; Timberlake *et al*., 2011). In the same manner as the EA hotspot, the CFEA hotspot shows substantial habitat fragmentation, although in this case the hotspot is entirely conterminous. The largest remaining forests in the CFEA can be found in Mozambique; however, the extent and condition of these forests is mostly unknown due to the lack of research (Timberlake *et al*., 2011). In the past, civil war was the major threat to the loss of habitats and subsequent biodiversity. Nowadays threats are mainly related to development, particularly in the exploration of oil and gas in Mozambique (Timberlake *et al*., 2011).

Conservation

In today's rapidly changing world, the need for conservation prioritisation efforts is evident (Hooper *et al.,* 2002; Cowling *et al.,* 2003; Isaac *et al*., 2007). The concept of "irreplaceability" in relation to "vulnerability" is fundamental in conservation planning (Brooks *et al*., 2006). Traditionally, conservation planning methods focused on species-based approaches. The usual target in this approach is represented by threatened and range-restricted endemic species, with economic, ecological, and scientific or some sort of cultural value, being given conservation priority (Rouget *et al*., 2003). However, endemism neither predicts species richness nor the number of threatened species. Hence, species endemism as a single consideration for conservation priorities has become somewhat obsolete (Isaac *et al*., 2007). To account for the discrepancies in the species-based approaches, conservation efforts then shifted towards area-centered approaches. This approach focuses on biodiversity which gives rise to biological processes responsible for species richness as well as endemism (Pressey *et al*., 2007). Area-centered approaches looks at areas which contain threatened or restricted-range endemic species, but also key ecological processes and an alarming degree of land degradation or transformation (Mittermeier *et al.*, 1998; Myers *et al.,* 2000).

A hybrid approach is represented by the 'biodiversity hotspot' strategies in conservation efforts (Mittermeier *et al.*, 1998; Myers *et al.,* 2000; Hooper *et al.,* 2002; Cowling *et al.,* 2003). Justification for these strategies lies in the high endemism, high species richness, as well as the numerous restricted-range endemic species found in hotspots. This newer strategy in conservation planning takes into consideration three important factors: endemism, degree of threat as well as restriction of range. The hotspot strategy is seen as more adequate than mere species-based approaches as it not only accounts for biodiversity but also the processes which give rise to this diversity (Cowling *et al*., 2003; Thomas *et al.,* 2004; Malcolm *et al.,* 2006). While the hotspot strategy targets the key factors for conservation, the way in which global hotspots have been delimited is far from adequate. Furthermore, the area-centered approach removes focus of species, thus preventing public awareness and participation campaigns (Purvis *et al*., 2000; Isaac *et al*., 2004; Isaac *et al*., 2007).

However, important refinements can be brought to the species-based approach, by looking at higher taxa or, more objectively, evolutionary lineages. The evolutionary history of species is an important component of biodiversity which takes into consideration historical and ecological processes resulting in speciation and evolution. The evolutionary history of all species in a given assemblage (whether defined geographically or otherwise) can be measured using phylogenetic diversity (PD). PD is a biodiversity measure which uses the length of evolutionary pathways that connect a select set of taxa, and hence can identify sets of taxa that maximise feature diversity, which in turn can be relevant to conservation efforts (Faith, 1992; Forest *et al.*, 2007). Thus, the extinction of species from species-rich clades will not result in a high loss of PD. However, the extinction of an old, monotypic lineage will result in a great loss of PD. This concept focuses on the irreplaceability of lineages. If the lineage is extinct, those particular features will be lost forever (Purvis *et al.*, 2000; Sechrest *et al.*, 2002; Forest *et al.*, 2007). Some researchers argue that PD is a more inclusive measure to use for setting conservation priorities, such as the EDGE of existence conservation programme (Purvis *et al*., 2000; Isaac *et al*., 2007; Rosauer *et al*., 2009, Tucker & Cadotte, 2013).

While each of these approaches has benefits, this study takes into consideration, to some extent, each of these conservation approaches. Although primarily considering ancient endemic lineages, the study also maps them geographically, in a region already recognised as having global importance by the biodiversity hotspot approach.

Chapter 3: Methodology

The following chapter outlines the methodology used in this study. The methods used to identify ancient endemic lineages, map the distribution of these lineages using endemism measures, as well as regionalisation of the southern African region are further discussed. Additionally, the methods used to compare these ancient lineages with their sister lineages are discussed.

Selection of Lineages

The matter of lineage antiquity is of course a relative one. After some exploratory work, the age limit for what is termed here an ancient lineage was set at 30My, roughly coinciding with the end of the Eocene Age and the beginning of the Oligocene Age. This was relevant to lineage survival in the face of climate change, as the transition between Eocene-Oligocene marked substantial changes in world's climate (Tsubamoto *et al.*, 2004). Consequently, when assessing the age of lineages, the stem ages of the broadest lineages endemic to the study area (see below) were used as lineage age values. Distribution data presented in literature were then reviewed to assess which lineages were truly endemic to southern Africa. The latitudinal limit set for lineage data collection in this study was 10°28'S (lineages endemic to the region south of this latitude were included in the study), meaning that East African endemics were excluded, while keeping southern Africa in the study in its broadest sense. Should the latitude limit be set further south, many of the selected lineages would be excluded from this study. The limit for the mapping region, however, was set at 14°45'. This difference was sufficient to make sure that an effect of decreasing endemism towards the north is not simply an artefact of the mapping method. Onezoom (Rosindell & Harmon, 2012), an online engine providing age estimates for all tetrapod vertebrates and seed plants, was used to identify ancient biological lineages endemic to southern Africa. As the age of some squamate lineages was not reliable in this engine, ancient lineages were identified from published papers on this group, two gecko lineages (*Rhoptropella* and *Narudasia*) meeting the age criterion as derived from the work of Gamble *et al.* (2011).

Mapping Lineage Distributions

Delimitation of Operational Geographic Units

Vegetation maps of southern African were overlain with the Quarter Degree Square grid (QDS) to delimit Operational Geographic Units (hereafter called OGUs). OGUs were created in ESRI ArcGIS 9.2 (ESRI, 2006), by merging QDS cells to form single units, which roughly coincide with vegetation units present in the southern African region (Perera *et al.*, 2011). OGUs were adjusted using QDS, allowing for easy delimitation of units. Distributional data is easily accessible at QDS level, simplifying the mapping process and scoring of data. The OGU scale was chosen as this minimised the false presence/absence error which would be optimised using a finer scale such as QDS (Perera *et al.*, 2011).

Distribution Maps

Distribution maps at species level, where available, were overlain with the OGU layer in order to score presence/absence data of lineages within OGUs. The data collected were used to draw up lineage incidence matrices, from which lineage distribution maps were developed using ESRI ArcGIS 9.2 (ESRI, 2006; Perera *et al.*, 2011).

Lineage incidence matrices were created by scoring the presence/absence of lineages within OGUs. Lineages were recorded as present even in the cases where a single QDS occupied an OGU. According to Linder (2001), there is no formally accepted definition for narrow or range-restricted species. For the purposes of this study, narrow endemic lineages were defined as those lineages occupying between 1 and 5 OGUs. Lineages occupying more than 5 OGUs were defined as broad endemic lineages.

Measures of Endemism

Measures of endemism are important in mapping biological diversity as these allow for the detection of priority conservation areas. Measures of endemism are also fundamental in understanding of evolution in a spatial context (Rosauer *et al*., 2009). Several such measures were used here are detailed below.

Total Endemism

The sum total of the selected lineages present within each OGU was calculated to give the total lineages present (Crisp *et al*., 2001), this allowed for the creation of a comprehensive map of ancient endemic lineages present in southern Africa.

Weighted Endemism and Corrected Weighted Endemism for Area

Weighted endemism (WE) for each OGU is defined as the sum of the reciprocal of the number of OGUs each lineage occupies, for each of the present lineages. WE is defined by the following formula:

$$WE = \sum 1/M_i \qquad \text{(equation 1)}$$

Where M_i refers to the number of OGUs each lineage occupies. The WE scores were tested for normality using the Shapiro-Wilk Test in R 3.1.0 (R Core Development Team, 2014). The test yielded results showing the data not to be from a normal distribution, and as such required normalisation of data. OGUs with no recorded lineages present were given zero values for the purpose of map creation. However, correlations between endemism and species richness are evident. This creates problems in detecting patterns of endemism (derived from Crisp *et al.*, 2001; Perera *et al.*, 2011).

Hence the WE formula is modified to reduce the correlation between endemism and species richness, resulting in a new measure, Corrected Weighted Endemism (CWE), defined as:

$$CWE = WE/b \qquad \text{(equation 2)}$$

Where WE refer to the weighted endemism value of each OGU and b refers to the total number of lineages present in the OGU (derived from Crisp *et al.*, 2001). However, the CWE formula works for presence/absence data scored on an equal area grid. The OGU scale used in this study did not conform to the equal area requirement; hence the CWE had to be modified to account for the OGUs. A new measure was derived by Perera *et al.* (2011), where the unequal area of OGUs were accounted for by dividing the WE scores of OGUs by the number of grid cells present in each OGU. This new measure is given the name Corrected Weighted Endemism for Area (CWEA) (Perera *et al.*, 2011).

$$\text{CWEA} = \text{WE}/g \qquad \text{(equation 3)}$$

Where WE is the normalised weighted endemism scores for each OGU and g is the number of grid cells present in the OGU. The scores for CWEA were then tested using the Shapiro-Wilk Test in R (R Core Development Team, 2014). Test results showing data that is not normally distributed required normalization. The normalised scores were then used in the creation of a CWEA map using ESRI ArcGIS 9.2 (ESRI, 2006).

Data Analysis:

Cluster Analysis:

According to James & McCulloch (1990), the purpose of a cluster analysis is to group together objects by maximising the similarity between the objects, while minimising the similarity between groups or clusters. In this study, a cluster analysis was performed based on the shared lineages between OGUs. The lineage incidence matrix created was converted to a similarity matrix based on Jaccard's Index of Similarity implemented in FreeTree 0.9.1.50 software (Pavlicek *et al.,* 1999). Jaccard's Index of Similarity does not take into account negative values and the similarity between two OGUs is not influenced by the rest of the OGUs being studied. Hence it is independent of the number of OGUs analysed in the study (Real & Vargas, 1996). The similarity matrix was converted into distance values using the unweighted pair-group method using arithmetic averages (UPGMA) algorithm, to be used in the hierarchical cluster analyses. The distance matrix was then inputted into R which was used to perform the hierarchical cluster analysis (R Core Development Team, 2014). The dendogram produced was edited and the results were then mapped using ESRI ArcGIS 9.2 (ESRI, 2006). Four different stages of clustering were produced. The first stage of clustering corresponded to the dendogram produced in R software. The second and third stages of clustering manually merged clusters consecutively in an attempt to form more geographically contiguous clusters. The fourth stage of clustering considered all of southern Africa as one cluster. Each of these different stages of clustering was mapped in ESRI ArcGIS 9.2, with the corresponding dendogram appended (ESRI, 2006).

Characteristic Lineages

Characteristic lineages refer to the lineages which have distributions representative of different clusters of OGUs, at the different stages of clustering. In order to determine which lineages are characteristic to the different cluster, a measure of the endemism of the lineage to a particular cluster and a measure of filling of the cluster were multiplied (Procheş & Ramdhani, 2012).

The following equations were used to calculate the measure of endemism of the lineage to a particular cluster and the measure of filling of the lineage in the cluster:

$$E = (l/L) \times 100 \qquad \text{(equation 4)}$$

Where E refers to the percentage measure of endemism of the lineage, l refers to the number of present values of the lineage in the cluster and L refers to the total number of present values of the lineage.

$$F = (c/C) \times 100 \qquad \text{(equation 5)}$$

Where F refers to the percentage measure of filling, c refers to the number of OGUs present in the cluster which have the lineage present and C refers to the total number of OGUs in the cluster.

The following equation was used to calculate the characteristic lineage of clusters:

$$CL = (E \times F)/100 \qquad \text{(equation 6)}$$

Where CL refers to the percentage measure of character, E and F refer to the percentage measures of endemism and filling, respectively.

Lineages with ≥50% CL were chosen as characteristic lineages for each cluster stage. However, some characteristic lineages were present in clusters across the different stages of clustering. In these cases, the lineage was set as a characteristic lineage for the stage at which the lineage had the highest CL value.

In some cases, these lineages had the same CL value at both stages. In these cases, the lineages were set as characteristic lineages for the higher stage.

Sister Lineage Analysis

Using the online engine ‘Onezoom’ (Rosindell & Harmon, 2012), the sister lineages of the selected ancient endemic lineages were identified. An analysis of the literature was conducted to determine the distribution, habitat, and broad morpho-ecological characteristics (‘guild’), relevant to the ecological niche of the ancient endemic lineages and sister lineages. In this manner, similarities and differences between ancient endemic lineages and sister lineages were detected to emphasise the uniqueness of these ancient endemic lineages and their possible biogeographic connections. Sister lineages were determined by including all species adjacent to the ancient endemic lineage at the stem node on the phylogenetic tree present on Onezoom (Rosindell & Harmon, 2012).

Chapter 4: Results

Selection of Lineages

Seventeen plant lineages, six reptiles, two mammals, one bird, and one amphibian lineage met the age and endemism criteria (Table A.2, Appendix A).

Mapping Lineage Distributions

Seventy-four OGUs were created using vegetation maps of southern Africa (Born *et al*., 2007; Perera *et al*., 2011; Sayre *et al*., 2013; see Data Source, Appendix B) (Figure B1, Appendix B; Table A1, Appendix A). Based on the presence/absence of lineages in these OGUs (see Appendix A), eighteen lineages were classified as broad endemic lineages and nine were classified as narrow endemic lineages (Table A.2, Appendix A).

A total endemism map was created using the sum total of lineages within each OGU. A Shapiro-Wilk Test for normality indicated that the total endemism scores were not from a normal distribution ($W = 0.2619$; $p = 2.2^{-16}$). The scores were then normalised to generate the total endemism map. Figure 4.1 below shows the total endemism of southern Africa. The highest total endemism scores were found along the coastal regions of southern Africa, but also along parts of the Great Escarpment (indicated in red). Total endemism shows a decreasing pattern towards inland regions.

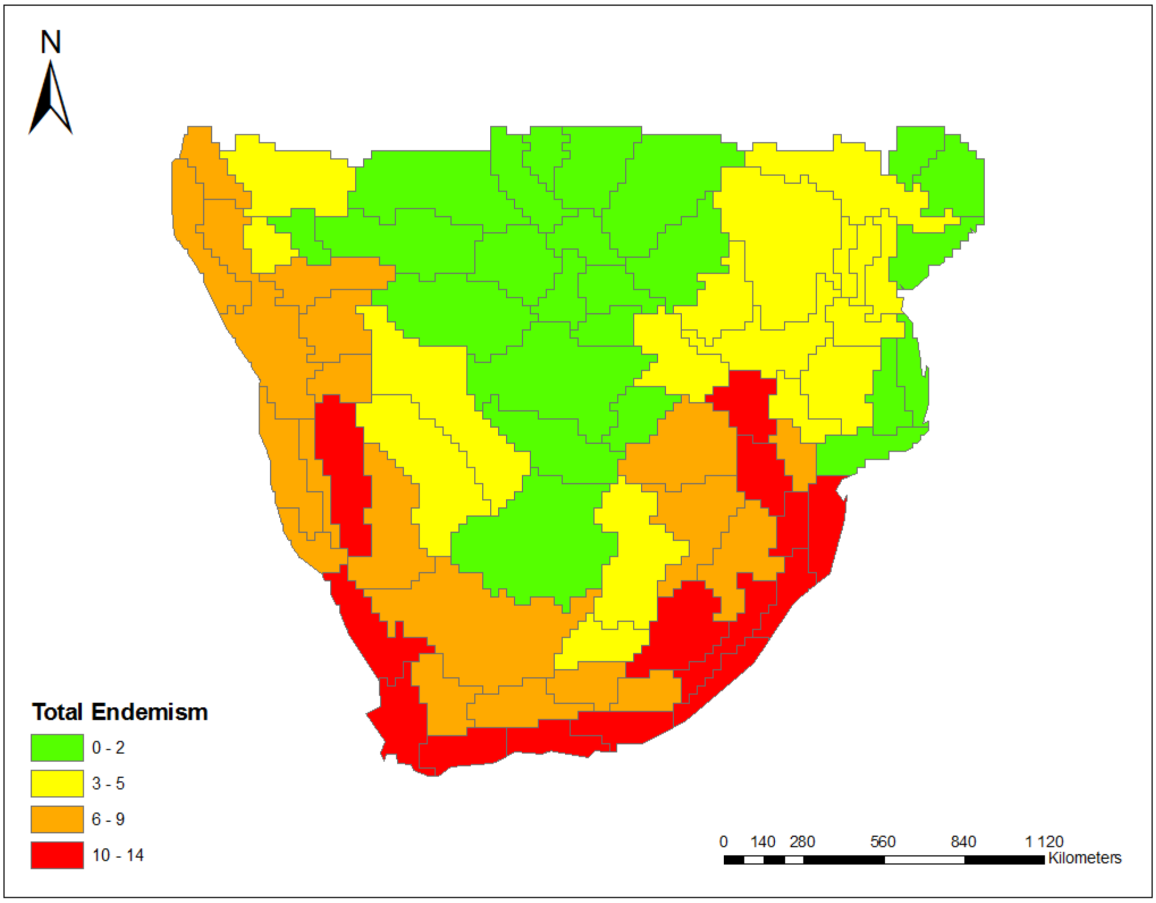

Figure 4.1: Total endemism map for the ancient plant and tetrapod lineages of southern Africa. A graduated colour symbol was used to display total endemism scores using four classes of Jenks Natural Breaks in ArcGIS ArcMap (ESRI, 2006). Operational Geographic Units with the highest number of ancient endemic ancient lineages are shown in red and those with the lowest number of ancient endemic lineages are shown in green.

A WE map was created. However, as the OGUs are not equal area units, the WE scores were corrected for area. The Shapiro-Wilk Test for normality indicated that the CWEA were not normally distribution ($W = 0.4773$; $p = 8.5^{-15}$). Figure 4.2 shows the CWEA for southern Africa. The highest values were found along the coastal regions of southern Africa. In the same manner as total endemism, CWEA shows a decreasing pattern towards inland regions, although there were localised high values in mountainous areas of Namibia and Zimbabwe.

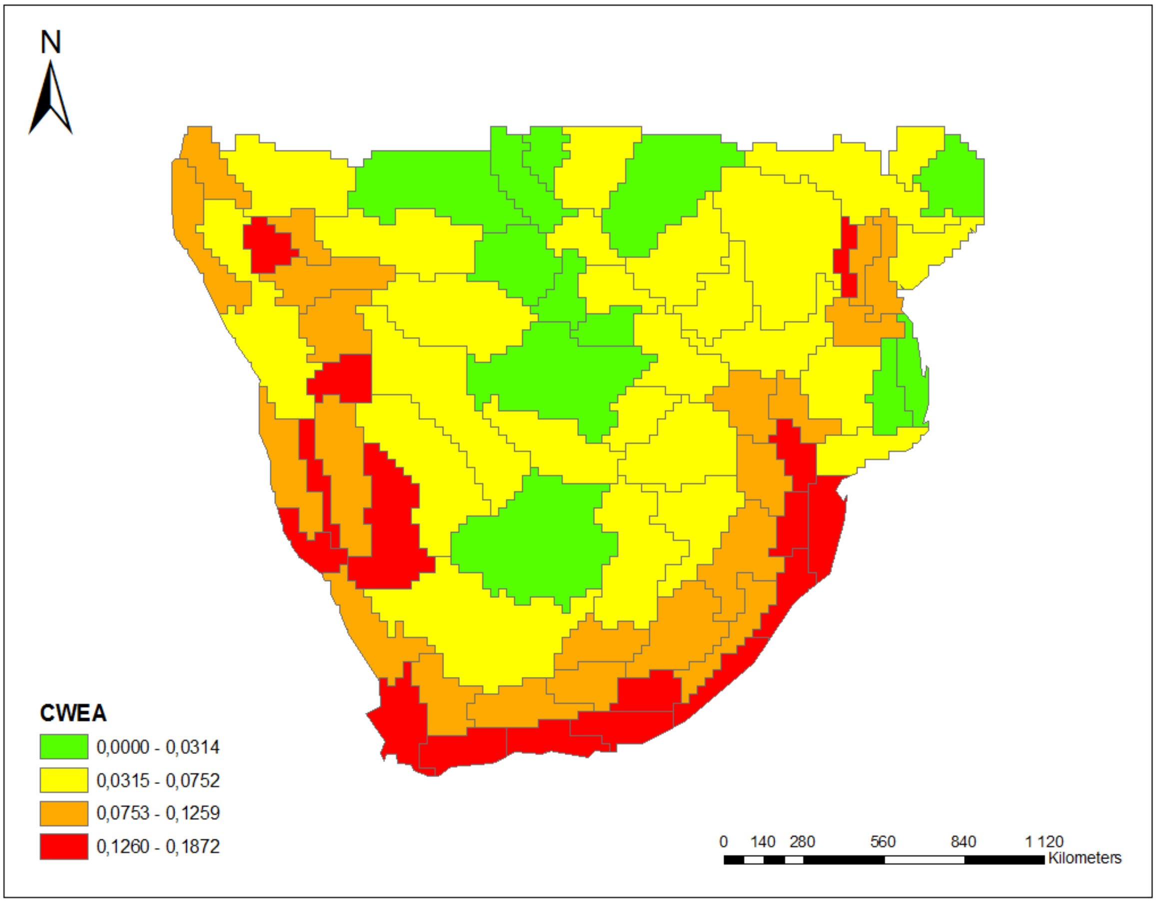

Figure 4.2: Corrected Weighted Endemism for southern Africa. A graduated colour symbol was used to display CWEA scores using four classes of Jenks Natural Breaks in ArcGIS ArcMap (ESRI, 2006). OGUs shown in red indicated the highest CWEA scores, whereas green units have the lowest CWEA scores.

Data Analysis

Cluster Analyses and Characteristic Lineages

Four stages of cluster analyses were performed. Fourteen clusters were produced at stage one, five clusters at stage two and four clusters at stage three. The fourth stage used all of southern Africa as one cluster. Characteristic lineages were determined for each stage of clustering. At stage one, five characteristic lineages were determined for three clusters. Three characteristic lineages were determined for one cluster at stage two of the cluster analysis. At stage three, nine characteristic lineages were determined for three clusters. Two characteristic lineages were determined for stage four clustering (whole of southern Africa).

Figure 4.3 shows the results of the hierarchical cluster analysis as resulting directly from the analysis. The branches of the dendogram show the fourteen clusters derived at stage one of clustering. The branches are colour-coded to correspond with the cluster map indicating the fourteen clusters. Most clusters are conterminous, with the exception of a few lineage-poor clusters situated inland and along the Mozambique coast. The characteristic lineages are indicated on the cluster map corresponding to the clusters in which these were determined. *Stangeria* was determined to be characteristic to cluster A7 (situated along the coast of southern Africa). Greyiaceae was determined as characteristic for cluster A8 (situated directly north of cluster A7). Geissolomataceae, Roridulaceae, Nivenioideae, *Hypocalyptus* and *Anthochortus* + *Willdenowia* were determined as characteristic for cluster A9 (situated along the south-western coast of southern Africa).

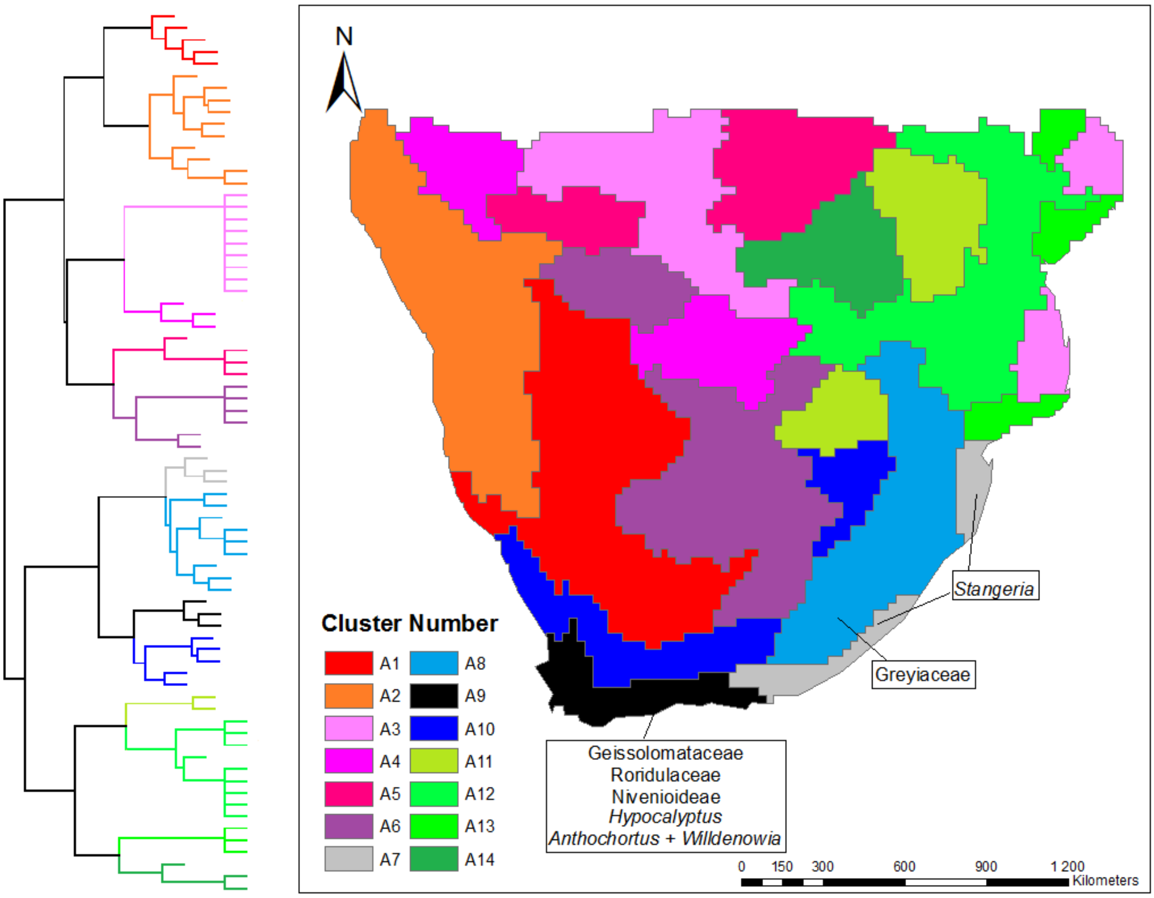

Figure 4.3: The results of the first stage of hierarchical cluster analysis. The resulting dendogram from the cluster analysis is presented with a cluster map. The colours of the branches of the dendogram correspond with the associated clusters on the map. Seven characteristic lineages were identified (*Stangeria Hypocalyptus*, *Anthochortus* + *Willdenowia*, Greyiaceae, Geissolomataceae, Nivenioideae and Roridulaceae).

Figure 4.4 shows the second stage of hierarchical clusters, as resulted from merging stage-one clusters to increase cohesiveness. The branches of the dendogram show the five contiguous clusters derived manually for stage two clusters. The branches are colour coded to correspond with the cluster map indicating the five clusters on the map. The characteristic lineages are indicated on the cluster map corresponding to the clusters in which these were determined. *Rhoptropus, Welwitschiaceae* and *Moringa ovalifolia* were determined as characteristic lineages for cluster B2 (situated in the western part of southern Africa, roughly coinciding with Namibia).

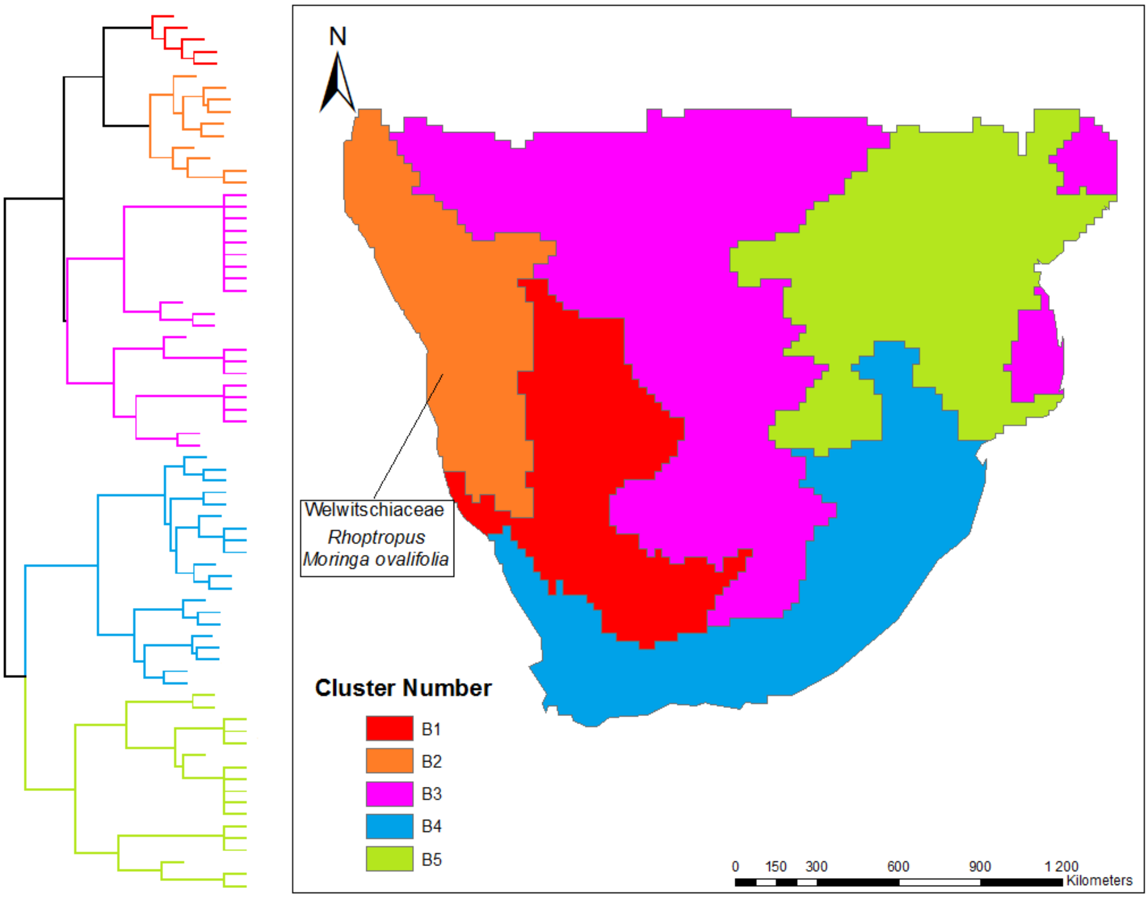

Figure 4.4: The results of the second stage of hierarchical clusters. The associated dendogram corresponds to the clusters indicated on the map. Three characteristic lineages were identified (*Rhoptropus*, Welwitschiaceae and *Moringa ovalifolia*).

Figure 4.5 shows the results of the third stage of hierarchical clusters. The branches of the dendogram show the four contiguous clusters derived manually for stage three clusters. The branches are colour coded to correspond with the OGU map indicating the four clusters on the map. The characteristic lineages are indicated on the OGU map corresponding to the clusters in which these were determined. *Petromus typicus* and *Grielum* are characteristic lineages in cluster C1 (situated along the western coast of southern Africa). Promeropidae, *Bradypodion*, Bruniaceae, Grubbiaceae + Curtisiaceae, *Agapanthus* and Achariaeae were determined as characteristic lineages for cluster C3 (situated in the southern coastal areas of southern Africa). *Platysaurus* was determined as a characteristic lineage for cluster C4 (situated towards the north-eastern regions of southern Africa).

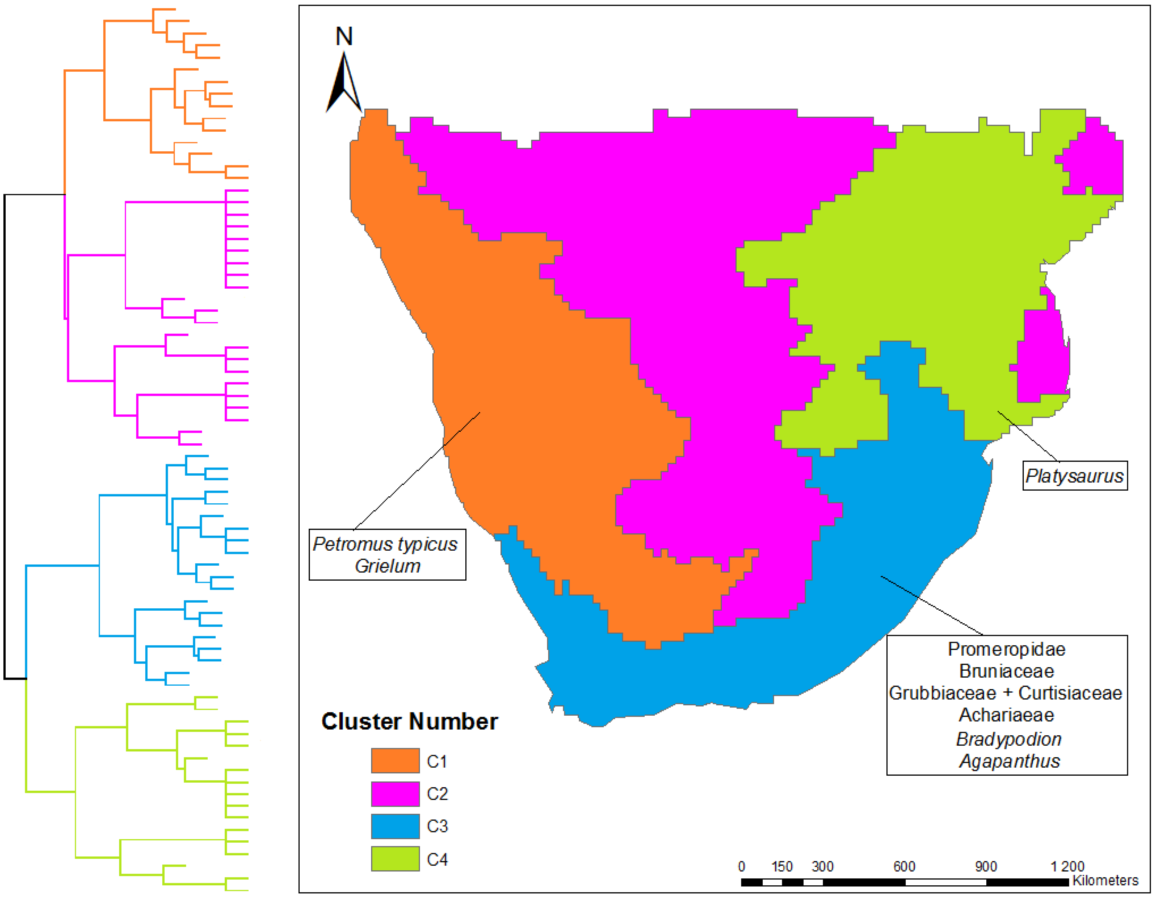

Figure 4.5: Third-stage hierarchical cluster analysis. The clusters indicated on the map correspond with the associated dendogram. Nine characteristic lineages were identified (*Platysaurus*, *Petromus typicus*, *Grielum*, Promeropidae, *Bradypodion*, Bruniaceae, Grubbiaceae + Curtisiaceae, *Agapanthus* and Achariaeae).

Figure 4.6 shows the results of the hierarchical cluster analysis. The OGU map represents a single unit comprising of southern Africa, on which the characteristic lineages are indicated. *Afroedura* (reptile lineage) and *Tulbaghia* (plant lineage) were determined as characteristic lineages for the whole of southern Africa

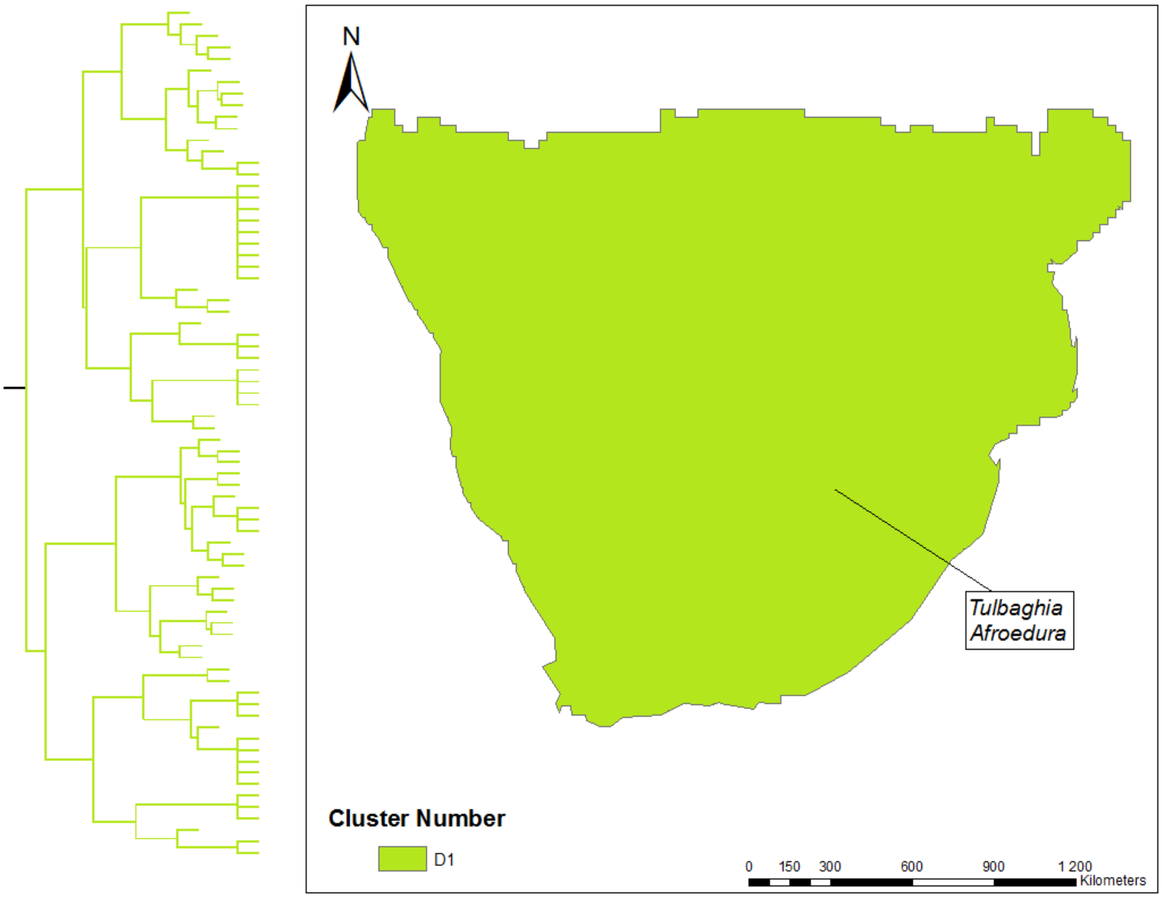

Figure 4.6: The results of fourth stage of hierarchical cluster analysis. Two characteristic lineages were determined for southern Africa (*Afroedura* and *Tulbaghia*).

Ancient Lineages and their Sister Lineages

In a comparison of ancient endemic lineages selected in this study, with their sister lineages, it was determined that many sister lineages have widespread distributions across the world (Table A.3, Appendix A). The oldest lineage (Grubbiaceae + Curtisiaceae) classified here as a broad endemic lineage (91.9My, Table A.2, Appendix A), is located along the south-western coast of the region, extending into the eastern part of the region. The sister lineage to Grubbiaceae + Curtisiaceae (Nyssaceae + Hydrostachydaceae + Loasaceae + Hydrangeaceae, Table A.3, Appendix A) was determined to have a widespread distribution. The lineages *Stangeria*, *Nectaropetalum* and *Hypocalyptus*, are all classified as narrow endemic lineages occurring only along the south west or south east coast of the region (Table A.2, Appendix

A). However, the sister lineages to these all have widespread distributions across the world (Table A.3, Appendix A).

Differences in guild and habitat types were also noted between sister lineages and ancient endemic lineages. Differences in guild were noted for four ancient endemic lineages (Greyiaceae, Welwitschiaceae, Achariaeae and Nivenioideae) and their sister lineages (Table A.3, Appendix A). Five ancient lineages (Bruniaceae, Geissolomataceae, Greyiaceae, Roridulaceae and Welwitschiaceae) were found to occupy different habitats in comparison with their sister lineages (Table A.3, Appendix A). While guild and habitat differences were not noted for animal lineages, remarkable trait differences between Promeropidae and its sister lineage were noted (tail and beak length).

Chapter 5: Discussion

Lineage selection and mapping

The highest number of lineages meeting the age criterion (≥30My) was plant lineages (17 out of 27 lineages). The remaining ten lineages were animal lineages (six reptiles, two mammals, one bird and one frog lineage). Traditionally, plants have been the primary focus of many diversity mapping efforts, with a particular focus on the CFR (Linder, 2003; Linder, 2005; Born *et al*., 2007; Cowling *et al*., 2009; Verboom *et al*., 2009). In recent years, research on animals has increased, however this group still remains, to some extent, understudied (Colville *et al*., 2014).

The OGUs created in this study were based, roughly, on the vegetation units present in southern Africa. Figure B.1 (Appendix B) shows OGUs towards the north and central parts of the study region are generally broader than those located towards the south and along the coast. The vegetation characteristics towards the north of southern Africa are generally homogenous, and this is evident in the largely arid central region of southern Africa. The coastal regions of southern Africa exhibit a greater heterogeneity of vegetation units; hence the OGUs here are generally finer in scale.

Lineages were classified as broad or narrow based on the distribution maps generated (Table A.2, Appendix A). The majority of the narrow ancient endemic lineages were plants restricted to the south-western part of the region, with the exception of *Nectaropetalum* and *Stangeria,* from the east (Figure B.13 & Figure B.16, Appendix B). *Rhoptropella*, the only reptile narrow ancient endemic lineage, is endemic to Namibia (Figure B.23, Appendix B).

Patterns of Endemism

The Eocene-Oligocene transition; used here as a cut-off date, is an interesting time in the evolution of plant and animal lineages, particularly when considering tectonic and climatic changes. Tectonic activity resulted in the opening of the Southern Ocean passages, which has been attributed to climate changes as a result of changes to ocean circulation patterns (Liu *et al*., 2009). During this transition, periods of warming were followed by cooling periods, which created harsh environmental conditions (Zachos *et al*., 2001; Tsubamoto *et al*., 2004). Between 50 and 52 My ago (early Eocene), the Earth experienced a peak in warming. This was followed by an abrupt cooling period during the Eocene-Oligocene transition, which resulted in the accumulation of continental ice sheets (Zachos *et al*., 2001; Liu *et al*., 2009).

Despite all of these changes, the fact that Africa did not migrate substantially across latitudinal belts, means that climate may have been comparatively stable. Over shorter time frames, Dynesius & Jansson (2000) showed southern Africa to have been fairly climatically stable, particularly in the coastal regions. Altwegg *et al*. (2014) also predicted relatively stable future conditions, particularly for the coastal region. In the face of all these changes, climatic stability resulted in a refugium for ancient endemic lineages (Dynesius & Jansson, 2000; Habel *et al*., 2013; Lawson, 2013; Altwegg *et al*., 2014). The relative tectonic stability of southern Africa gives rise to environmental stability, which facilitates the survival of ancient endemic lineages (Marshak, 2008; Cowling *et al*., 2009; Tolley *et al*., 2014). Many recent studies indeed highlight southern Africa as having a wealth of accumulated evolutionary history, in comparison with other continental regions, using phylogenetic diversity and phylogenetic endemism maps (Fritz & Rahbek, 2012; Procheş & Ramdhani, 2013; Costion *et al*., 2014; Rosauer & Jetz, 2014), or even by producing maps of lineage diversity for lineages of a given age, as done in this study (Davies & Buckley, 2011).

More interesting are the patterns observed within southern Africa. In this study, the total endemism and CWEA maps (Figure 4.1 & Figure 4.2) showed coastal regions and the adjacent Great Escarpment exhibiting the highest concentration of ancient endemic lineages. The Great Escarpment is a key geomorphologic feature in southern Africa. Mountain ranges provide not only environmental heterogeneity, but also refugia for ancient endemic lineages (López-Pujol *et al*., 2011). Interestingly, the Nyanga and Chimanimani mountains have some of the highest concentrations of ancient endemic lineages. In this case, environmental heterogeneity coupled with isolation enhances the refugial function of these mountains (Clark *et al*., 2011; López-Pujol *et al*., 2011).

These patterns, to some extent, reflect the currently recognised biodiversity hotspots in southern Africa (Conservation International, 2005). The CFR, MPA and SK biodiversity hotspots coincided with the patterns of endemism shown here (Figure 4.1 & Figure 4.2). The high values for the Chimanimani and Nyanga Mountains reflected the Eastern Afromontane biodiversity hotspot. However, the CFEA was not reflected in the patterns of endemism observed here. This makes sense, as none of the lineages endemic to this region were included in this study, as a result of not complying with the age criterion set in this study (Figure 4.1 & Figure 4.2). Mountainous regions were found to have high concentrations of ancient endemic lineages (Naukluft, Hunsberge, Nyanga and Chimanimani). This pattern conforms with observations that mountainous regions have higher levels of endemism, more specifically older mountainous regions have older lineage assemblages (Clark *et al.*, 2011; López-Pujol *et al.*, 2011). A decreasing trend in the concentration of ancient endemic lineages towards the inland regions was observed on the total endemism and CWEA maps. This can be attributed to the lower environmental heterogeneity observed in the central and northern regions of southern Africa, which is dominated by species-poor, arid habitats (Figure 4.1 & Figure 4.2) (Clark *et al.*, 2011).

The patterns presented here for the richness of endemic plant lineages (Figure 4.2) is similar to those illustrated by elsewhere for species richness and endemism. Steenkamp *et al.* (2005) showed coastal regions to have the greatest endemism, emphasising the CFR, SK and MPA hotspots. Minter *et al.* (2004) showed similar patterns for the richness of frog species in South Africa at a quarter-degree scale (QDS). In terms of frog species richness, the coastal regions, particularly the CFR and MPA regions were of importance (Minter *et al.*, 2004). Furthermore, in a study conducted by Cumming & Child (2009), looking at the taxonomic and functional richness of a representative sample of birds in South Africa, similar patterns were once again illustrated. Particularly, the functional richness of birds in South Africa was greatest along coastal regions, emphasising the importance of the CFR and MPA hotspots (Cumming & Child, 2009). Hence the importance of the CFR, SK and MPA hotspots, as highlighted in this study, are not merely a matter of concordance with the currently delimited biodiversity hotspots. The presence of ancient lineages in these regions possibly reflects centres of origin of these ancient lineages, highlighting these as centres where lineages diversified and remained through the Eocene-Oligocene transition to present day. Nevertheless, the presence of these lineages in these hotspots could be explained as a result of climatic suitability and stability in the face of changes which were experienced during the Eocene-Oligocene transition, in which these areas provided climatic refugia for ancient endemic lineages (Dynesius & Jansson, 2000; Zachos *et al*., 2001; Liu *et al*., 2009; Habel *et al*., 2013; Lawson, 2013; Altwegg *et al*., 2014)

Regionalisation of southern Africa

The cluster analyses conducted (with the exception of stage 4) were compared with White's Vegetation Unit Map (hereafter called White's units) and WWF's Ecoregion Biome Map (hereafter called WWF Ecoregions) by determining the percentage of cluster units comprising White's units and WWF Ecoregions (White, 1983; Olson *et al*., 2001).

In comparison with White's units, at stage one of the cluster analysis, six of the cluster units were found to comprise, greater than 50% of White's units. Cluster unit A1 comprised 60.15% of White's 'Grass and Shrubland Semi-desert' unit. Cluster units A4 and A6 comprised 56.73% and 61.73% of White's 'Arid Fertile Savanna', respectively. Cluster unit A9 comprised 64.26% of the 'Fynbos' unit. Cluster unit A11 comprised 83.10% of White's 'Moist Infertile Savanna', while A12 made up 55.11% of the 'Mopane Savanna' unit (Table A.4, Appendix A). Similarly, at stages two and three, cluster unit B1 comprised 65.13% and 51.03% of the 'Shrubland and Grassy Semi-desert' unit, respectively (Table A.5 & Table A.6, Appendix A). This overlap can be, however, partly attributed to the methods of clustering chosen at these stages of clustering (manual definition of clusters and lineage-based clustering).

Similarly, cluster units at stage one showed overlaps with the WWF Ecoregions. This was the case for cluster units A8 (comprising 53.84% of 'Drakensburg montane, grasslands, woodlands and forests' unit') and A11 (56.70% comprising 'Southern miombo woodlands') (Table A.7, Appendix A). Notably, at stage two and stage three, none of the cluster units comprised more than 50% of any of the WWF Ecoregions (Table A.8 & Table A.9, Appendix A). The similarities between the OGUs created in this study and White's Units and the WWF Ecoregions can be attributed to the fact that the OGUs were delimited based (roughly) on the vegetation characteristics of the southern African region, which is also a factor in the delimitation of White's Units and the WWF Ecoregions (White, 1983; Olson *et al*., 2001).

The characteristic lineages which were determined for each stage of clustering showed that at finer clustering scales, narrow ancient endemic lineages were emphasised as important. As the clustering scale became coarser, broad ancient endemic lineages were noted as important.

The relationship between ancient endemic lineages and their sister lineages

According to Procheş & Ramdhani (2013), for lineages with widespread distributions, the center of origin can be determined by examining their sister lineages (following the “out-of” hypothesis). Two lineages were noted to emphasise the “out of southern Africa” scenario. These being *Tulbaghia* and *Agapanthus*, of which both sister lineages (core Allioideae and core Amaryllidaceae, respectively; Table A.3, Appendix A) are widespread. *Tulbaghia* + core Allioideae, is sister to *Agapanthus* + core Amaryllidaceae, indicative of southern Africa being the centre of origin, with the common ancestor likely originating from southern Africa. In these cases, dispersal out of southern Africa seems to be the probable scenario. With regards to the remaining lineages, while the possibility of an “out of southern Africa” scenario is possible, it is more possible that dispersal to southern Africa is the case (Table A.3, Appendix A).

In the case of Grubbiace + Curtisiaceae (classified here as a broad endemic) and its sister lineage (widespread), *Stangeria*, *Nectaropetalum* and *Hypocalyptus* (all classified as narrow endemic lineages) and their sister lineages (all widespread), the “out of southern Africa” scenario is a distinct possibility.

Interesting differences in guild and habitat types between sister lineages and endemic lineages were noted. Greyiaceae, a family of grassland trees and shrubs, which is sister to Francoaceae (herbaceous, forest dweller) is one of these examples. Welwitschiaceae, sister to Gnetaceae, is an even more interesting example. Welwitschiaceae is restricted to the Kaokoveld Centre, as opposed to Gnetaceae which is fairly widespread globally in rainforests. Also, Welwitschiaceae is classified here as a shrub (although its growth form is highly distinctive), whereas Gnetaceae range from trees to lianas (Table A.3, Appendix A). Based on the divergence in growth forms of these sister lineages, this could be an example of dispersal to southern Africa in which Welwitschiaceae adapted to arid conditions of the Namib Desert, but could also represent a vicariance event, with the two lineages diverging in terms of growth form. The irid subfamily Nivenioideae (shrubs) which is sister to Crocoideae (geophytes), is another example of growth form divergence, with the shrubby growth form having almost certainly evolved in southern Africa. The Nivenioideae have thus become adapted to the fynbos biome, which is fire-prone (Geerts *et al*., 2012). The Achariaeae (Achariaceae), sister to *Chiangiodendron*, are likely a case of dispersal to southern Africa, similar to that of Welwitschiaceae and its sister lineage. Regardless of occupying similar habitats (Table A.3, Appendix A), the Achariaeae are herbaceous or vines, while *Chiangiodendron* is a tree, as are most other genera in the family whether in southern Africa or elsewhere.

While guild-level differences were not detected in the animal lineages, trait differences were noted between the ancient endemic lineages and their sister lineages, particularly with the sugarbirds and their sister lineage. The sugarbirds (Promeropidae) have longer tail-feathers and bills as opposed to their sister lineage, *Modulatrix*, a fairly non-descript passerine.

While the unique gemorphological, tectonic and climatic features, as well as the high levels of biodiversity in the study region have been highlighted, the importance of ancient endemic lineages requires further attention. This study aimed at highlighting the importance of ancient endemic lineages. These lineages are evolutionary distinct lineages (Isaac *et al*., 2007), many of which are old, monotypic lineages. In the context of PD (which aims at preserving feature diversity), should these lineages become extinct, feature diversity would be lost as the unique features of these lineages would also become extinct (Purvis *et al*., 2000; Sechrest *et al.*, 2002; Forest *et al.*, 2007; Isaac *et al*., 2007; Rosauer *et al*., 2009, Tucker & Cadotte, 2013). Hence, it is imperative to incorporate PD into conservation strategies. One such way of doing this is by incorporating ancient endemic lineages into conservation strategies.

Limitations

As with any study using externally-produced data, data availability resulted in certain limitations.

First, the lack of taxon-specific, dated phylogenetic trees posed difficulties, especially for reptile lineages. The 'Onezoom' online engine (Rosindell & Harmon, 2012) employed here as a main source of dates for lineage ages, helped resolve this issue. While the plant tree in this engine is rather incomplete, and the resolution of the dates for the animal tree is poor in some cases. Overall, the ages of the lineages provided by this source were deemed as adequate, and where this was not the case, other sources were used as a guide. As more accurate dates for the relevant speciation events become available, some lineages (e.g. *Moringa ovalifolia*) may prove to be insufficiently old and new ones may be added, but this is unlikely to alter the overall patterns presented here.

In principle, the manual selection of lineages also has the potential to pose problems. However, this approach was dictated by the lack of comprehensive distribution datasets in the case of plants. The most comprehensive such dataset (Heywood *et al.*, 2007) was viewed as sufficiently accurate by Hawkins *et al*. (2011) to be used in producing a global map of plant higher diversity, but even if this were correct, it is limited to the family-level. This would mean that many of the species, and genus, level plant lineages selected here would be overlooked.

Chapter 6: Conclusions and Recommendations

The focus of this study was to map ancient endemic (plant and animal) lineages within southern Africa, proposing mechanisms of survival and emphasising conservation importance in southern Africa.

Twenty-seven lineages were selected based on age and endemicity criteria, and maps generated for all lineages. Coastal regions were observed as having the highest concentration of ancient endemic lineages (Figure 4.1 & Figure 4.2, Chap. 4). The patterns of endemism reflected in these maps, to some extent, corresponded with the biodiversity hotspots found in southern Africa, of which the CFR, SK and MPA hotspots are most represented.

Cluster analyses reflected similarities with White's units and the WWF Ecoregions. Clusters produced in this study were shown to comprise ≥50%, in some cases, of White's units and the WWF Ecoregions. This was a result of the delimiting methods to produce OGUs (roughly based on vegetation characteristics in southern Africa), as well as, the methods of clustering used at the second and third stages of clustering (White, 1983; Olson *et al*., 2001).

The Great Escarpment is an important geomorphologic feature in the region, providing environmental heterogeneity, essential in the facilitation of specialist ancient endemic lineages (Clark *et al*., 2011; López-Pujol *et al*., 2011). In addition, relative tectonic stability provides environmental stability which is essential to the development of refugia (Marshak, 2008; Cowling *et al*., 2009; Tolley *et al*., 2014). Furthermore, the relatively stable climatic conditions shown in the southern African region further facilitate the survival of ancient endemic lineages (Dynesius & Jansson, 2000; Platts *et al*., 2013; Altwegg *et al*., 2014).

While the results of this study largely match the globally recognised hotspots of biodiversity for southern Africa, this approach does not consider other measures of diversity such as PD. PD is a good measure towards this end, as it not only accounts for the evolutionary history of species but also emphasised the importance of old, monotypic lineages (Purvis *et al*., 2000; Isaac *et al*., 2007; Rosauer *et al*., 2009, Tucker & Cadotte, 2013), as was done in this study. Species-based conservation approaches can be enhanced by focusing particularly on distinctive species, such as ancient ones (Isaac *et al*., 2007), or even by accounting for higher taxa or evolutionary lineages. The evolutionary history of lineages is important as this determines evolutionary distinctiveness of species (Sechrest *et al*., 2002; Lamoreux *et al*., 2006). This, in turn, ensures that feature diversity is preserved (Forest *et al*., 2007). The ancient endemic lineages selected in this study are a good example of preserving feature diversity, as many of these lineages are old, monotypic lineages. Should these lineages go extinct; the unique features of these lineages will be lost (Sechrest *et al*., 2002; Lamoreux *et al*., 2006; Forest *et al*., 2007). Additionally, the delineation of these hotspots still remains inadequate. It has also been pointed out that the 'hotspot approach' to conservation hinders public participation in conservation efforts by removing the focus on species (Purvis *et al*., 2000; Isaac *et al*., 2004; Isaac *et al*., 2007). Therefore, ancient lineages can serve a twofold purpose in conservation efforts. First, ancient lineages can be used as 'flagship lineages' in the prioritisation of new conservation areas (where this may still be necessary, even though southern Africa is a world leader in terms of conservation planning; Cowling *et al*., 1999; Cowling *et al*., 2003; Brooks *et al*., 2006; Smith *et al*., 2008)). Flagship lineages will promote public participation in conservation efforts. Second, ancient lineages can also be used in assessing the functioning of current conservation areas towards preserving these distinctive lineages (Tucker & Cadotte, 2013).

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Appendix A: Tables

Table A.1: OGU names and codes.

	OGU Name:	OGU Code:
1.	Wolkberg-Soutpansberg	WBSP
2.	Southern Mopane	SNMP
3.	Waterberg-Central Bushveld	WBCB
4.	Chimanimani	CHMN
5.	Save-Inhambane	SINH
6.	Northern Mpumalanga Escarpment	NMPE
7.	Northern Middleveld	NMLV
8.	Mesic Highveld	MHVD
9.	Southern Middleveld	SMLV
10	Southern Maputaland	SMPL
11.	Kalahari Savanna	KHLS
12.	Dry Highveld	DHVD
13.	KZN-Drakensberg-Mpumalanga Escarpment	KDME
14.	Orange River Karoo	ORKR
15.	Drakensberg	DBRG
16.	Natal-Transkei Midlands	NTMD
17.	Natal Coastal Belt	NLCB
18.	Sneeuberg	SBRG
19.	Amatola-Winterberg	ATWB
20.	Pondoland-Southern Transkei Coastal Belt	PTCB
21.	Albany Coastal Belt	ABCB
22.	Lower Karoo Region	LKRR
23.	Knysna	KNYS
24.	Overberg	OBRG
25.	Western Fynbos	WFYN
26.	Namaqualand	NQLD
27.	Roggeveld-Hantam	RVHT
28.	Upper Karoo	UPKR
29.	Fish River Canyon	FRCN
30.	Hunsberge	HBRG
31.	Fish River	FHRV
32.	Naukluft	NKLT
33.	Sandy Namib	SNMB
34.	Brandberg	BBRG
35.	Rocky Namib	RNMB
36.	Windhoek-Auas	WHAS
37.	Central Namibian Steppe	CNST
38.	Tsumbe	TSBE

39.	Namibian Grassy Savanna	NGSN
40.	Western Kalahari	WKLH
41.	Kalahari Steppe	KLHS
42.	Kanye-Werda	KNWD
43.	Limpopo-Serowe	LPSR
44.	Gaborone	GBRN
45.	Central Kalahari	CKLH
46.	Eastern Namibian Grassy Savanna	ENGS
47.	Angolan Nama-Karoo	ANKR
48.	Ondangwa	ODGW
49.	Cubango	CBNG
50.	Cunene	CUNE
51.	Okavango Delta	OKDL
52.	Sowa Salt Pan	SWSP
53.	Nxai Salt Pan	NXSP
54.	Makgadikgadi Salt Pan	MGSP
55.	Cuito	CITO
56.	Zambezian Baikiaea	ZMBK
57.	Zambezian Flooded Grasslands	ZMFG
58.	Chobe	CHBE
59.	Zambezian Miombo	ZMMB
60.	Zambezian Mopane-Miombo	ZMMM
61.	Limpopo-Banhine	LPBH
62.	Northern Maputaland-Inhambane	MINH
63.	Limpopo-Inhambane	LINH
64.	Pomene -Inhambane	PINH
65.	Buzi	BUZI
66.	Quelimane-Zambezi	QMZB
67.	Tete-Zambezi	TTZB
68.	Namuli	NMLI
69.	Runde	RNDE
70.	Matopo	MTPO
71.	Munyati-Chitungwiza	MUCT
72.	Mafungabusa-Chizarira	MACH
73.	Nyanga	NYGN
74.	Matandwe-Mwabvi	MTMW

Table A.2: Ancient plant and animal lineages endemic to southern Africa, their stem ages and endemicity type (broad/narrow).

	Lineage:	Age(My):	Source:	Endemicity:
1.	Promeropidae	40	Onezoom	Broad
2.	Heleophrynidae	34	Onezoom	Broad
3.	*Bradypodion*	49	Onezoom	Broad
4.	*Platysaurus*	49.5	Onezoom	Broad
5.	*Afroedura*	111.7	Onezoom	Broad
6.	*Rhoptropus*	87.4	Onezoom	Broad
7.	*Rhoptropella*	±50	Gamble *et al., (2010)*	Narrow
8.	*Narudasia*	100-75	Gamble *et al., (2010)*	Broad
9.	*Malacothrix typica*	48	Onezoom	Broad
10.	*Petromus typicus*	45.3	Onezoom	Broad
11.	Bruniaceae	76.2	Onezoom	Broad
12.	Geissolomataceae	53.7	Onezoom	Narrow
13.	Lanariaceae	39.8	Onezoom	Narrow
14.	Greyiaceae	41.1	Onezoom	Broad
15.	Grubbiaceae + Curtisiaceae	91.9	Onezoom	Broad
16.	Roridulaceae	70.2	Onezoom	Narrow
17.	*Stangeria*	83.4	Onezoom	Narrow
18.	Welwitschiaceae	87.1	Onezoom	Broad
19.	*Agapanthus*	46.7	Onezoom	Broad
20.	*Moringa ovalifolia*	48.6	Onezoom	Broad
21.	*Anthochortus + Willdenowia*	35.8	Onezoom	Narrow
22.	*Nectaropetalum*	60.2	Onezoom	Narrow
23.	*Tulbaghia*	48.7	Onezoom	Broad
24.	*Grielum*	35.4	Onezoom	Broad
25.	Nivenioideae	51.7	Onezoom	Narrow
26.	*Hypocalyptus*	37.5	Onezoom	Narrow
27.	*Achariaeae*	31.8	Onezoom	Broad

Table A.3: Comparison of ancient endemic lineages with their sister lineages.

Ancient southern African lineage:				Sister lineage:			
Lineage:	Distribution:	Guild:	Habitat:	Lineage:	Distribution:	Guild:	Habitat:
Grubbiaceae + Curtisiaceae	southern Africa	trees, shrubs	fynbos, forest	Nyssaceae + Hydrostachydaceae + Loasaceae + Hydrangeaceae (OneZoom)	widespread (Watson and Dallwitz, 1992)	trees, shrubs, lianas, herbaceous, hydrophytes	varied
Bruniaceae	South Africa	shrubs	fynbos	Columelliaceae (OneZoom)	South America (Watson and Dallwitz, 1992)	trees, shrubs	rainforest
Geissolomataceae	Cape	shrubs	fynbos	Strasburgeriaceae (OneZoom)	New Zealand, New Caledonia (Watson and Dallwitz, 1992)	trees	forest
Lanariaceae	South Africa	herbaceous	fynbos	Hypoxidaceae (OneZoom)	widespread (Watson and Dallwitz, 1992)	herbaceous, geophyte	varied
Greyiaceae	Southern Africa	trees, shrubs	grassland	Francoaceae* (corrected according to APW)	Chile (Watson and Dallwitz, 1992)	herbaceous	forest
Roridulaceae	Cape	shrub	fynbos	Actinidiaceae (OneZoom)	Asia, tropical America (Watson and Dallwitz, 1992)	trees, shrubs, woody vines	forest
Stangeria	Southern Africa	cf. shrubs	grassland, forest	Core Zamiaceae (OneZoom)	widespread	cf. shrubs	forest
Welwitischiaceae	Namibia, Angola	cf. shrubs	arid	Gnetaceae (OneZoom)	widespread (tropical) (Watson and Dallwitz, 1992)	trees, shrubs, lianas	forest
Moringa ovalifolia	Namibia	tree	arid	*Moringa oleifera*	Himalayas	tree	savanna, forest

				(OneZoom)			
Nectaropetalum	Eastern South Africa	trees, shrubs	forest	*Erythroxylum* (OneZoom)	widespread (Plowman and Hensold, 2004)	trees, shrubs	forest
Grielum	Western South Africa, Namibia	herbaceous	arid, fynbos	*Neurada* (OneZoom)	Mediterranean, Sahero-Arabian (GRIN, 2015)	herbaceous	arid, Mediterranean
Achariaeae	Southern Africa	herbaceous, vines	forest, grassland	*Chiangiodendron* (OneZoom)	Mexico (Wendt, 1988)	trees	forest
Hypocalyptus	Cape	trees, shrubs	fynbos	*Argryolobium* + *Ormosia* + *Acosmium* + core Bossiaeeae (OneZoom)	widespread (GRIN, 2015)	trees, shrubs	varied
Tulbaghia	Southern Africa	geophyte	varied	Core Allioideae (OneZoom)	widespread (Sassone *et al.*, 2014)	geophyte	varied
Agapanthus	Southern Africa	herbaceous	grassland, fynbos	core Amaryllidaceae (OneZoom)	widespread (Stevens, 2015)	herbaceous, geophytes, shrubs	varied
Anthochortus + *Willdenowia*	Cape	shrubs	fynbos	core Restioneae + core Willdenowieae (OneZoom)	Africa (Stevens, 2015)	shrubs	varied
Nivenioideae	Cape	shrubs	fynbos	Crocoideae (OneZoom)	Southern Africa, Europe, Madagascar, central Asia (Stevens, 2015)	geophytes	varied
Malacothrix typica	Southern Africa	mice	arid, fynbos,	*Lophiomys* + *Leimacomys* + *Steatomys* (OneZoom)	Africa (IUCN, 2014)	mice	forest, shrubland, Mediterranean, grassland,

							savanna, arable land
Petromus typicus	Namibia, Angola, northwest South Africa	rats	arid	Core Hystricoidea (OneZoom)	Americas, Africa	mice, porcupines	shrubland, tundra, arid, forest
Promeropidae	Southern Africa	passerines	fynbos, forest, grassland	*Modulatrix* (OneZoom)	East Africa (Barker *et al.*, 2004)	passerine	forest
Bradypodion	Southern Africa	chameleons	varied	*Calumma* + *Furcifer* + *Chamaeleo* (OneZoom)	Madagascar, Africa, Comoros, southern Europe, southern Asia, India, Sri Lanka (IUCN, 2014)	chameleons	varied
Heleophrynidae	Southern Africa	frogs	forest, fynbos	Core Neobatrachia (OneZoom)	Widespread	frogs	varied

Regionalisation Analysis:

White’s Units Analysis

Table A.4: The percentage overlaps of each cluster in comparison with White’s Units for stage one of the cluster analyses.

Cluster Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total Area of cluster (km^2)		49,67	37,56	33,25	21,25	25,44	43,88	7,80	28,27	9,05	19,86	20,44	33,98	8,60	13,00
White’s Units	Afro Alpine	0,00	0,00	0,02	0,00	0,00	0,00	0,00	2,55	0,00	0,00	0,00	0,00	0,07	0,00
	Arid Fertile Savanna	30,54	7,41	6,50	56,73	10,75	61,73	0,00	2,38	0,00	0,00	8,96	1,64	0,00	8,42
	Desert	5,98	27,66	5,48	1,39	0,13	0,00	0,00	0,00	0,00	2,24	0,00	0,65	2,51	2,86
	Dry Forest and Thicket	0,00	0,00	26,11	12,73	25,25	0,00	19,06	3,23	1,09	0,49	0,00	0,00	0,00	21,19
	Fynbos	0,00	0,00	0,00	0,00	0,00	0,00	6,28	0,00	64,26	4,22	0,00	0,00	0,00	0,00
	Hydromorphic Grassland	0,00	0,00	7,86	0,00	5,33	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Moist Infertile Savanna	0,00	0,00	30,69	3,89	37,05	1,70	17,12	22,02	0,00	2,35	83,10	37,90	41,51	46,38
Montane Forest	0,00	0,00	0,00	0,00	0,00	0,00	0,00	9,36	0,00	0,00	0,00	0,00	0,00	0,00
Mopane Savanna	1,48	24,19	8,50	25,26	21,21	0,15	0,00	2,24	0,00	0,00	5,82	55,11	1,90	21,15
Mosaic of Forests	0,00	0,00	7,20	0,00	0,00	0,00	48,43	7,15	0,00	0,00	0,00	3,20	45,22	0,00
Sedge and Reed Swamp	0,00	0,00	6,91	0,00	0,29	0,05	0,00	0,00	0,00	0,00	0,00	0,00	4,91	0,00
Shrubland and Grassy Semi-Desert	60,15	38,97	0,00	0,00	0,00	21,61	3,66	2,35	18,53	45,84	0,00	0,00	0,00	0,00
Succulent Semi-Desert	1,64	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,89	16,53	0,00	0,00	0,00	0,00

Swamp Forest and Mangrove	0,00	0,00	0,23	0,00	0,00	0,00	1,10	0,04	0,00	0,00	0,00	0,11	1,95	0,00
Tropical Lowland and Rainforest	0,00	0,00	0,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00	0,00
Unpalatable Grasslands	0,00	0,00	0,12	0,00	0,00	14,76	0,68	48,58	5,06	27,23	2,12	1,35	1,24	0,00

Table A.5: The percentage overlaps of each cluster in comparison with White’s Units for stage two of the cluster analyses.

Cluster Number		1	2	3	4	5
Total Area of cluster (km^2)		45,79	41,44	123,81	64,99	76,02
White’s Units	Afro Alpine	0,00	0,00	0,01	1,11	0,01
	Arid Fertile Savanna	26,38	14,18	35,56	1,03	4,58
	Desert	6,48	25,07	1,74	0,69	1,06
	Dry Forest and Thicket	0,00	0,00	14,38	4,00	3,62
	Fynbos	0,00	0,00	0,00	11,00	0,00
	Hydromorphic Grassland	0,00	0,00	3,21	0,00	0,00
	Moist Infertile Savanna	0,00	0,00	17,13	12,35	51,91
	Montane Forest	0,00	0,00	0,00	4,07	0,00
	Mopane Savanna	0,00	23,70	11,03	0,98	30,03
	Mosaic of Forests	0,00	0,00	1,93	8,92	6,55
	Sedge and Reed Swamp	0,00	0,00	1,93	0,00	0,56
	Shrubland and Grassy Semi-Desert	65,13	35,44	7,66	18,06	0,00

Succulent Semi-Desert	1,77	0,00	0,00	5,73	0,00
Swamp Forest and Mangrove	0,00	0,00	0,06	0,15	0,27
	0,00	0,00	0,09	0,00	0,01
Tropical Lowland and Rainforest					
Unpalatable Grasslands	0,00	0,00	5,26	30,24	1,31

Table A.6: The percentage overlaps of each cluster in comparison with White's Units for stage three of the cluster analyses.

Cluster Number		1	2	3	4
Total Area of cluster (km^2)		87,23	123,81	64,99	76,02
White's Units	Afro Alpine	0,00	0,01	1,11	0,01
	Arid Fertile Savanna	20,58	35,56	1,03	4,58
	Desert	15,31	1,74	0,69	1,06
	Dry Forest and Thicket	0,00	14,38	4,00	3,62
	Fynbos	0,00	0,00	11,00	0,00
	Hydromorphic Grassland	0,00	3,21	0,00	0,00
	Moist Infertile Savanna	0,00	17,13	12,35	51,91
	Montane Forest	0,00	0,00	4,07	0,00
	Mopane Savanna	11,26	11,03	0,98	30,03
	Mosaic of Forests	0,00	1,93	8,92	6,55
	Sedge and Reed Swamp	0,00	1,93	0,00	0,56
	Shrubland and Grassy Semi-Desert	51,03	7,66	18,06	0,00

Succulent Semi-Desert	0,93	0,00	5,73	0,00
Swamp Forest and Mangrove	0,00	0,06	0,15	0,27
	0,00	0,09	0,00	0,01
Tropical Lowland and Rainforest				
Unpalatable Grasslands	0,00	5,26	30,24	1,31

WWF Ecoregion Analysis

Table A.7: The percentage overlaps of each cluster in comparison with WWF Ecoregions for stage one of the cluster analyses.

Cluster Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total Area of Clusters (km^2)		45,791	41,437	33,252	22,750	25,437	43,875	7,800	28,272	9,054	19,860	20,438	32,478	8,600	13,000
WWF Ecoregions	Albany Thicket	0,00	0,00	0,00	0,00	0,00	0,00	11,76	0,00	5,81	1,04	0,00	0,00	0,00	0,00
	Angolan Miombo Woodlands	0,00	0,00	12,60	3,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Angolan Mopane Woodlands	0,00	13,00	0,00	22,37	3,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Central Zambezian Miombo Woodlands	0,00	0,00	0,73	0,00	17,41	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	Drakensburg Alti-montane Grasslands and Woodlands	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,92	0,00	0,00	0,00	0,00	0,00	0,00
	Drakensburg Montane Grasslands, Woodlands and Forests	0,00	0,00	0,00	0,00	0,00	0,56	27,73	53,84	0,00	5,03	0,19	0,40	0,00	0,00

East African Mangroves	0,00	0,00	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,11	2,66	0,00
Eastern Miombo Woodlands	0,00	0,00	9,83	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,64	1,21	0,00
Eastern Zimbabwe Montane Forest-Grassland Mosaic	0,00	0,00	0,00	0,04	0,00	0,00	0,00	0,00	0,00	0,00	1,04	1,38	0,00	0,00
Etosha Pan Halophytics	0,00	0,42	0,00	1,67	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Highveld Grasslands	0,00	0,00	0,00	0,00	0,00	16,33	0,00	13,52	0,00	28,91	1,32	0,00	0,00	0,00
Kalahari Acacia-Baikiaeae Woodlands	0,92	2,49	8,29	27,58	10,85	27,40	0,00	0,00	0,00	0,00	4,63	2,00	0,00	17,12
Kalahari Xeric Savanna	48,77	13,27	0,00	0,00	23,46	42,37	0,00	0,00	0,00	0,00	0,05	0,00	0,00	0,00
Kaokoveld Desert	0,00	7,29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Knysa-Amatole Montane Forests	0,00	0,00	0,00	0,00	0,00	0,00	0,19	0,21	2,20	0,11	0,00	0,00	0,00	0,00
Kwazulu-Cape Coastal Forest Mosaic	0,00	0,00	0,00	0,00	0,00	0,00	11,91	2,11	0,00	0,00	0,00	0,00	0,00	0,00
Lower Fynbos Renosterveld	0,00	0,00	0,00	0,00	0,00	0,00	0,17	0,00	34,05	0,04	0,00	0,00	0,00	0,00
Maputaland Coastal Forest Mosaic	0,00	0,00	0,00	0,00	0,00	0,00	25,81	0,00	0,00	0,00	0,00	0,00	7,60	0,00
Maputaland-Pondoland Bushland and Thicket	0,00	0,00	0,00	0,00	0,00	0,00	10,09	3,73	0,00	0,00	0,00	0,00	0,00	0,00
Montane Fynbos and Renosterveld	0,00	0,00	0,00	0,00	0,00	0,00	0,23	0,00	39,36	4,19	0,00	0,00	0,00	0,00
Nama-Karoo	41,73	3,50	0,00	0,00	0,00	12,31	6,75	0,70	4,50	29,11	0,00	0,00	0,00	0,00
Namib Desert	0,02	17,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Namibian Savanna	4,18	41,72	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Woodlands														
South Malawi Montane Forest Grassland Mosaic	0,00	0,00	0,28	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	8,91	0,00
Southern Africa Bushveld	0,00	0,00	0,16	0,03	0,00	0,82	0,00	11,00	0,00	0,23	28,95	17,57	0,00	33,52
Southern Africa Mangroves	0,00	0,00	0,00	0,00	0,00	0,00	0,85	0,05	0,00	0,00	0,00	0,00	0,00	0,00
Southern Miombo Woodlands	0,00	0,00	5,81	6,54	14,34	0,00	0,00	0,00	0,00	0,00	56,70	14,10	5,35	17,63
Southern Zanzibar-Inhambane Coastal Forest Mosaic	0,00	0,00	7,55	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,44	21,82	0,00
Succulent Karoo	4,34	0,74	0,00	0,00	0,00	0,00	0,00	0,00	12,05	30,98	0,00	0,00	0,00	0,00
Western Zambezian Grasslands	0,00	0,00	1,67	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Zambezian Baikiaea	0,00	0,00	27,28	11,89	24,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	21,04

Woodlands														
Zambezian Cryptosepalum Dry Forest	0,00	0,00	1,51	0,00	0,44	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Zambezian and Mopane Woodlands	0,00	0,00	5,77	0,01	23,43	0,15	3,31	10,84	0,00	0,00	7,13	61,07	29,11	7,79
Zambezian Coastal Flooded Savanna	0,00	0,00	0,31	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,59	14,90	0,00
Zambezian Flooded Grassland	0,00	0,00	12,33	0,00	5,53	0,05	0,00	0,00	0,00	0,00	0,00	0,00	4,91	0,00
Zambezian Halophytics	0,00	0,00	5,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,69	2,51	2,90

Table A.8: The percentage overlaps of each cluster in comparison with WWF Ecoregions for stage two of the cluster analyses.

Cluster Number		1	2	3	4	5
Total Area of cluster (km^2)		41,437	45,791	123,814	64,985	76,016
WWF Ecoregions	Albany Thicket	0,00	0,00	0,00	2,54	0,00
	Angolan Miombo Woodlands	0,00	0,00	4,05	0,00	0,00
	Angolan Mopane Woodlands	13,00	0,00	4,73	0,00	0,00
	Central Zambezian Miombo Woodlands	0,00	0,00	3,77	0,00	0,00
	Drakensburg Alti-montane Grasslands and Woodlands	0,00	0,00	0,00	1,71	0,00
	Drakensburg Montane Grasslands, Woodlands and Forests	0,00	0,00	0,20	28,29	0,22
	East African Mangroves	0,00	0,00	0,07	0,00	0,35
	Eastern Miombo Woodlands	0,00	0,00	2,64	0,00	0,84
	Eastern Zimbabwe Montane Forest-Grassland Mosaic	0,00	0,00	0,00	0,00	0,88
	Etosha Pan Halophytics	0,42	0,00	0,36	0,00	0,00

Highveld Grasslands	0,00	0,00	5,79	14,72	0,35
Kalahari Acacia-Baikiaeae Woodlands	2,49	0,92	19,23	0,00	5,03
Kalahari Xeric Savanna	13,27	48,77	19,83	0,00	0,01
Kaokoveld Desert	7,29	0,00	0,00	0,00	0,00
Knysa-Amatole Montane Forests	0,00	0,00	0,00	0,45	0,00
Kwazulu-Cape Coastal Forest Mosaic	0,00	0,00	0,00	2,35	0,00
Lower Fynbos Renosterveld	0,00	0,00	0,00	4,78	0,00
Maputaland Coastal Forest Mosaic	0,00	0,00	0,00	3,10	0,86
Maputaland-Pondoland Bushland and Thicket	0,00	0,00	0,00	2,83	0,00
Montane Fynbos and Renosterveld	0,00	0,00	0,00	6,79	0,00
Nama-Karoo	3,50	41,73	4,36	10,64	0,00
Namib Desert	17,06	0,00	0,00	0,00	0,00

Namibian Savanna Woodlands	41,72	4,18	0,00	0,00	0,00
South Malawi Montane Forest Grassland Mosaic	0,00	0,00	0,08	0,00	1,01
Southern Africa Bushveld	0,00	0,00	0,34	4,86	21,02
Southern Africa Mangroves	0,00	0,00	0,00	0,12	0,00
Southern Miombo Woodlands	0,00	0,00	4,51	0,00	26,84
Southern Zanzibar-Inhambane Coastal Forest Mosaic	0,00	0,00	2,03	0,00	2,65
Succulent Karoo	0,74	4,34	0,00	11,15	0,00
Western Zambezian Grasslands	0,00	0,00	0,45	0,00	0,00
Zambezian Baikiaea Woodlands	0,00	0,00	14,60	0,00	3,60
Zambezian Cryptosepalum Dry Forest	0,00	0,00	0,50	0,00	0,00
Zambezian and Mopane Woodlands	0,00	0,00	6,42	5,11	32,64

	0,00	0,00	0,08	0,00	1,94
Zambezian Coastal Flooded Savanna					
Zambezian Flooded Grassland	0,00	0,00	4,47	0,00	0,56
Zambezian Halophytics	0,00	0,00	1,47	0,00	1,07

Table A.9: The percentage overlaps of each cluster in comparison with WWF Ecoregions for stage three of the cluster analyses.

Cluster Number		1	2	3	4
Total Area of cluster (km^2)		87,229	123,814	64,985	76,016
WWF Ecoregions	Albany Thicket	0,00	0,00	2,54	0,00
	Angolan Miombo Woodlands	0,00	4,05	0,00	0,00
	Angolan Mopane Woodlands	6,17	4,73	0,00	0,00
	Central Zambezian Miombo Woodlands	0,00	3,77	0,00	0,00
	Drakensburg Alti-montane Grasslands and Woodlands	0,00	0,00	1,71	0,00
	Drakensburg Montane Grasslands, Woodlands and Forests	0,00	0,20	28,29	0,22
	East African Mangroves	0,00	0,07	0,00	0,35
	Eastern Miombo Woodlands	0,00	2,64	0,00	0,84
	Eastern Zimbabwe Montane Forest-Grassland Mosaic	0,00	0,00	0,00	0,88

Etosha Pan Halophytics	0,20	0,36	0,00	0,00
Highveld Grasslands	0,00	5,79	14,72	0,35
Kalahari Acacia-Baikiaeae Woodlands	1,67	19,23	0,00	5,03
Kalahari Xeric Savanna	31,91	19,83	0,00	0,01
Kaokoveld Desert	3,46	0,00	0,00	0,00
Knysa-Amatole Montane Forests	0,00	0,00	0,45	0,00
Kwazulu-Cape Coastal Forest Mosaic	0,00	0,00	2,35	0,00
Lower Fynbos Renosterveld	0,00	0,00	4,78	0,00
Maputaland Coastal Forest Mosaic	0,00	0,00	3,10	0,86
Maputaland-Pondoland Bushland and Thicket	0,00	0,00	2,83	0,00
Montane Fynbos and Renosterveld	0,00	0,00	6,79	0,00
Nama-Karoo	23,57	4,36	10,64	0,00

Namib Desert	8,11	0,00	0,00	0,00
Namibian Savanna Woodlands	22,01	0,00	0,00	0,00
South Malawi Montane Forest Grassland Mosaic	0,00	0,08	0,00	1,01
Southern Africa Bushveld	0,00	0,34	4,86	21,02
Southern Africa Mangroves	0,00	0,00	0,12	0,00
Southern Miombo Woodlands	0,00	4,51	0,00	26,84
Southern Zanzibar-Inhambane Coastal Forest Mosaic	0,00	2,03	0,00	2,65
Succulent Karoo	2,63	0,00	11,15	0,00
Western Zambezian Grasslands	0,00	0,45	0,00	0,00
Zambezian Baikiaea Woodlands	0,00	14,60	0,00	3,60
Zambezian Cryptosepalum Dry Forest	0,00	0,50	0,00	0,00
Zambezian and Mopane Woodlands	0,00	6,42	5,11	32,64

	0,00	0,08	0,00	1,94
Zambezian Coastal Flooded Savanna				
Zambezian Flooded Grassland	0,00	4,47	0,00	0,56
Zambezian Halophytics	0,00	1,47	0,00	1,07

Appendix B: Maps

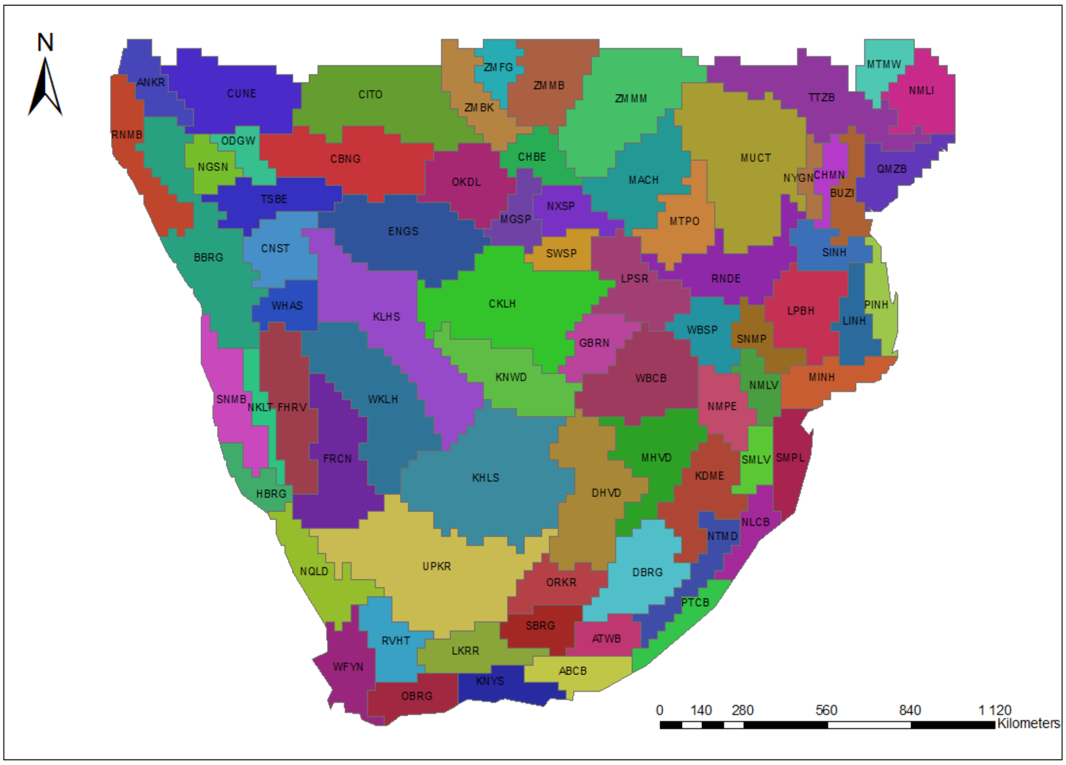

Figure B.1: Operational Geographic Units (OGUs) Map for southern Africa (see Table A.1 for OGU names and corresponding codes, Appendix A).

Plant Lineages

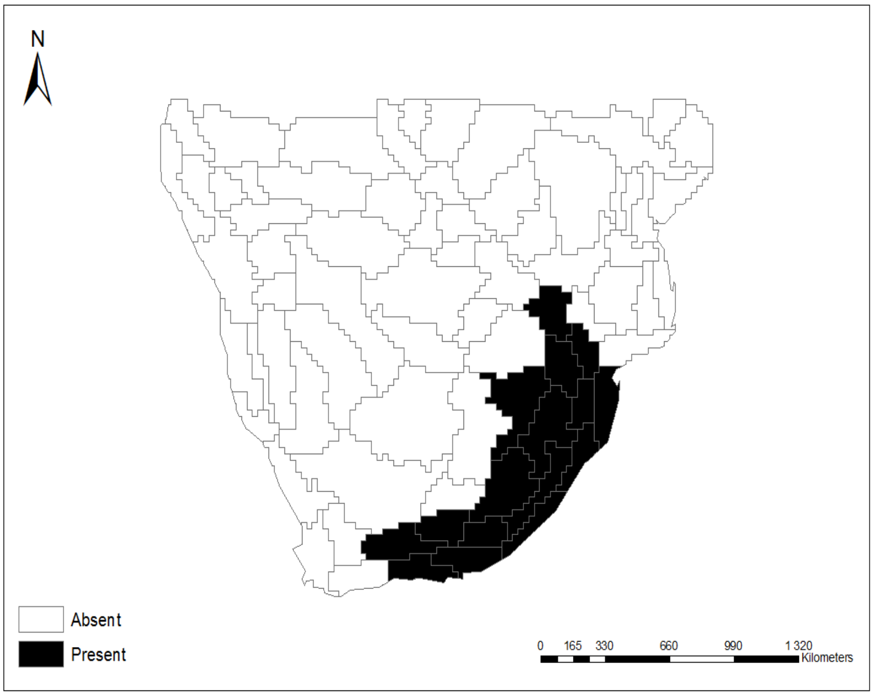

Figure B.2: The distribution of Achariaeae in southern Africa.

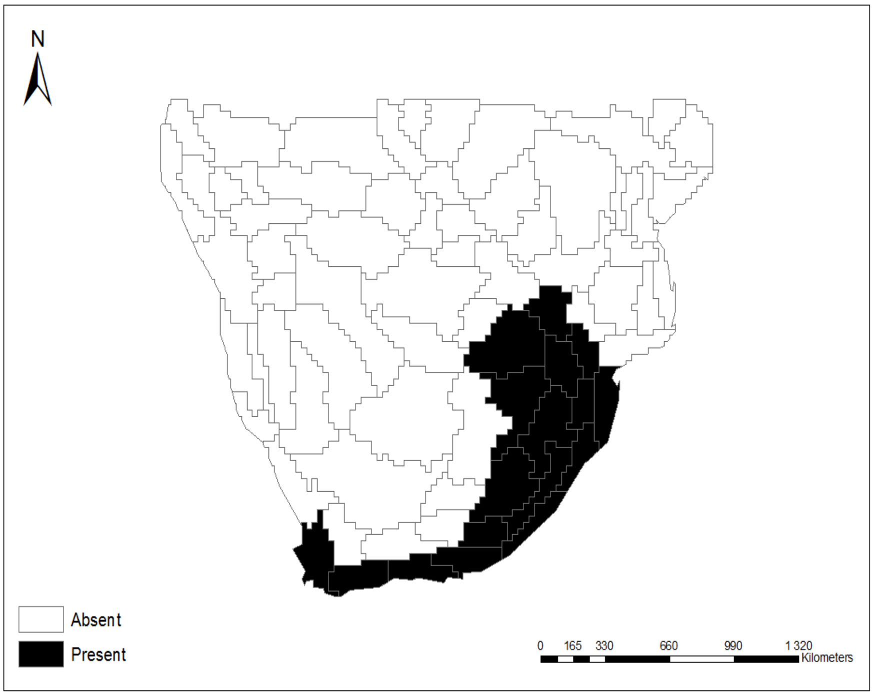

Figure B.3: The distribution of *Agapanthus* in southern Africa.

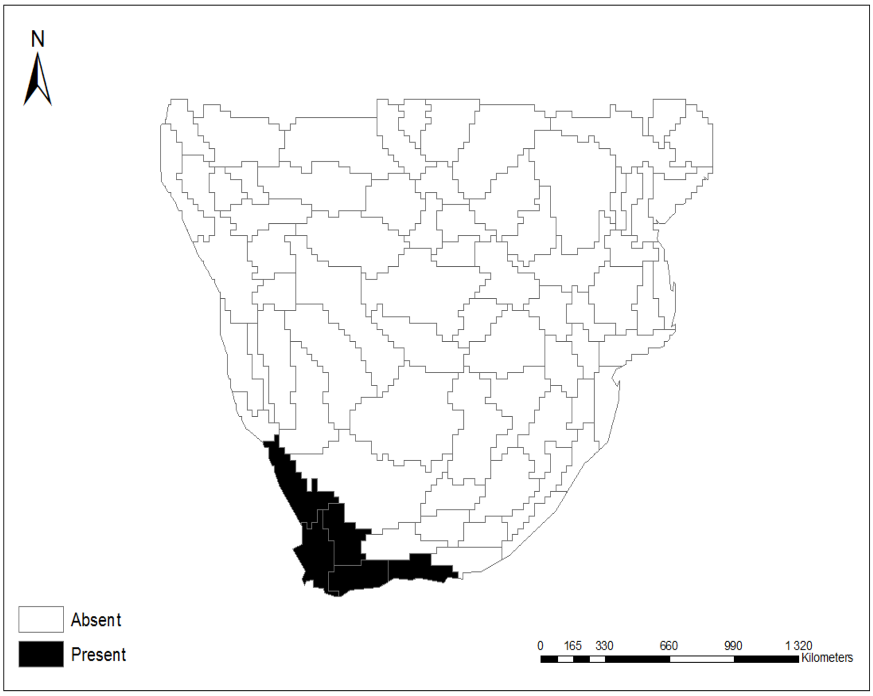

Figure B.4: The distribution of *Anthochortus* + *Willdenowia* in southern Africa.

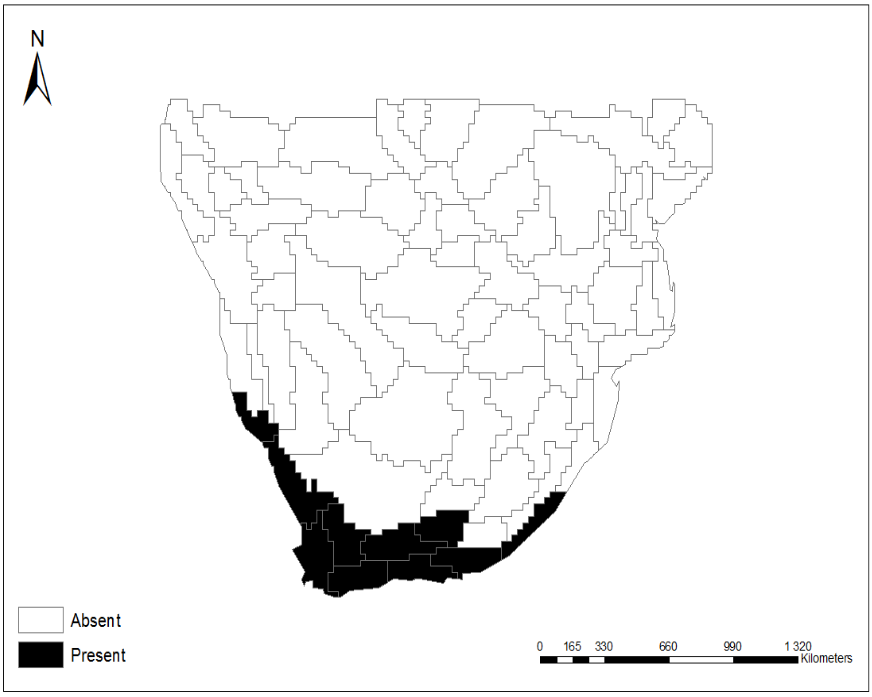

Figure B.5: The distribution of Bruniaceae in southern Africa.

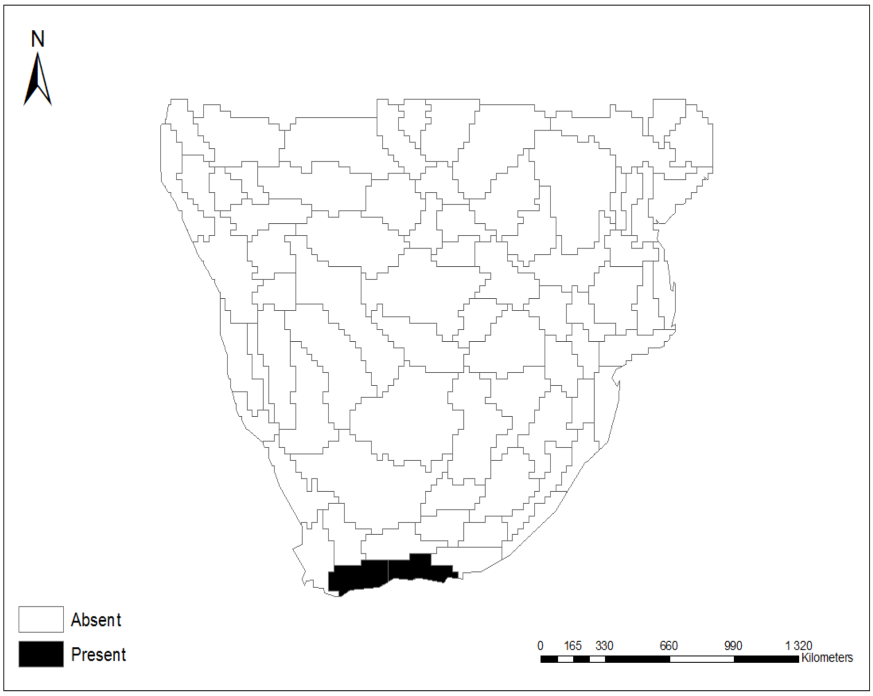

Figure B.6: The distribution of Geissolomataceae in southern Africa.

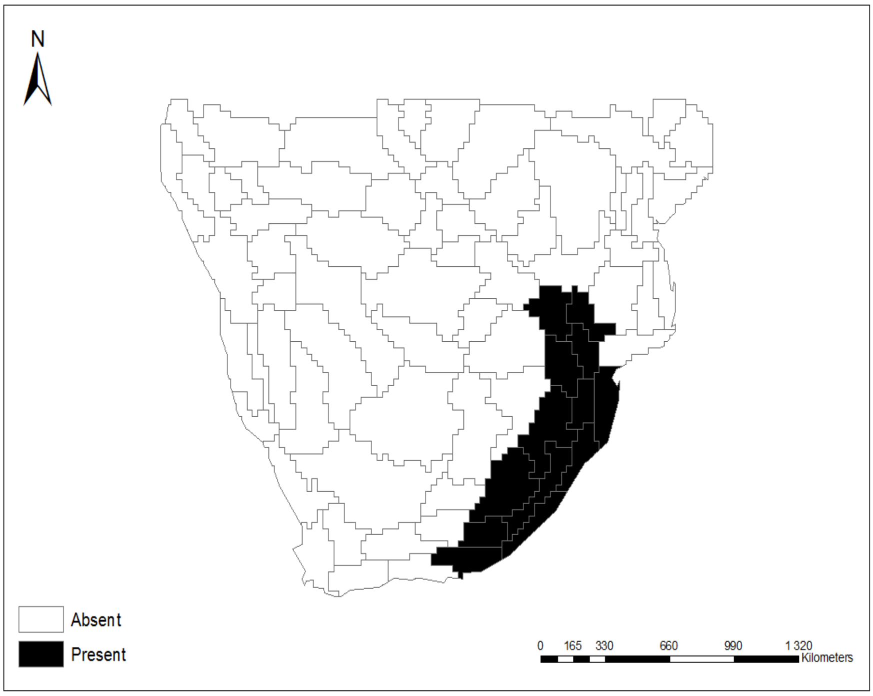

Figure B.7: The distribution of Greyiaceae in southern Africa.

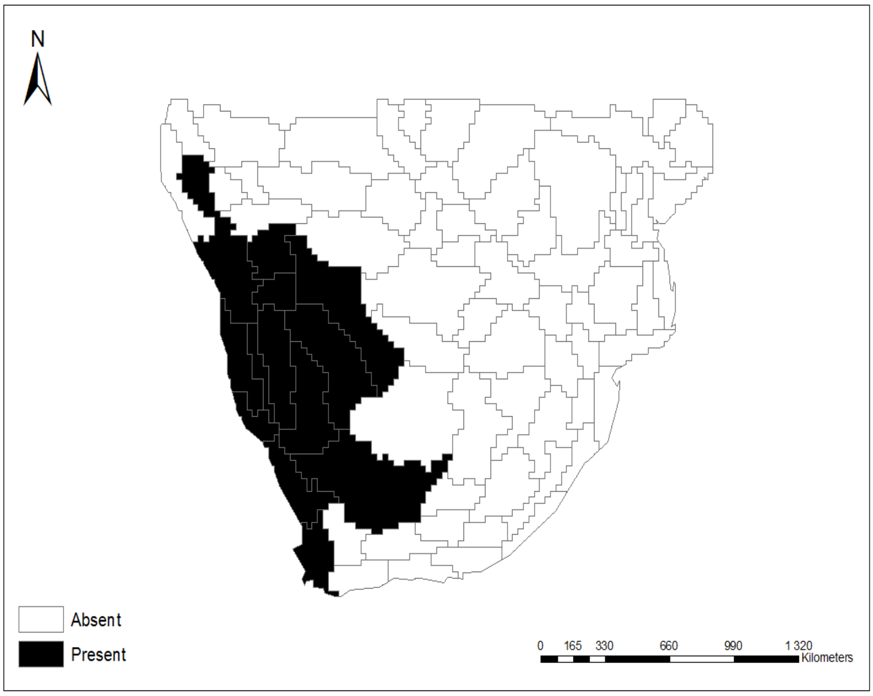

Figure B.8: The distribution of *Grielum* in southern Africa.

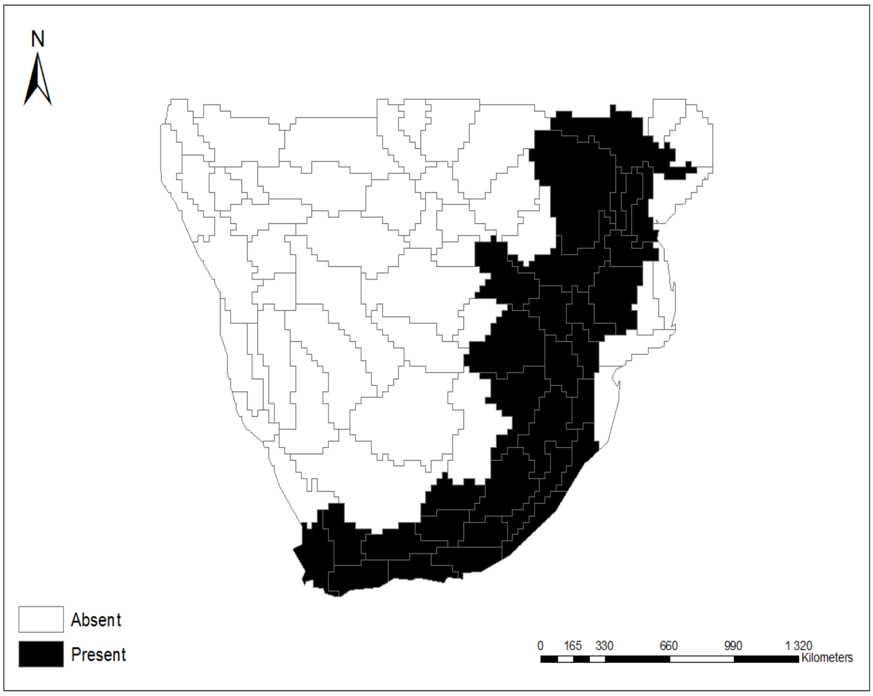

Figure B.9: The distribution of Grubbiaceae + Curtisiaceae.

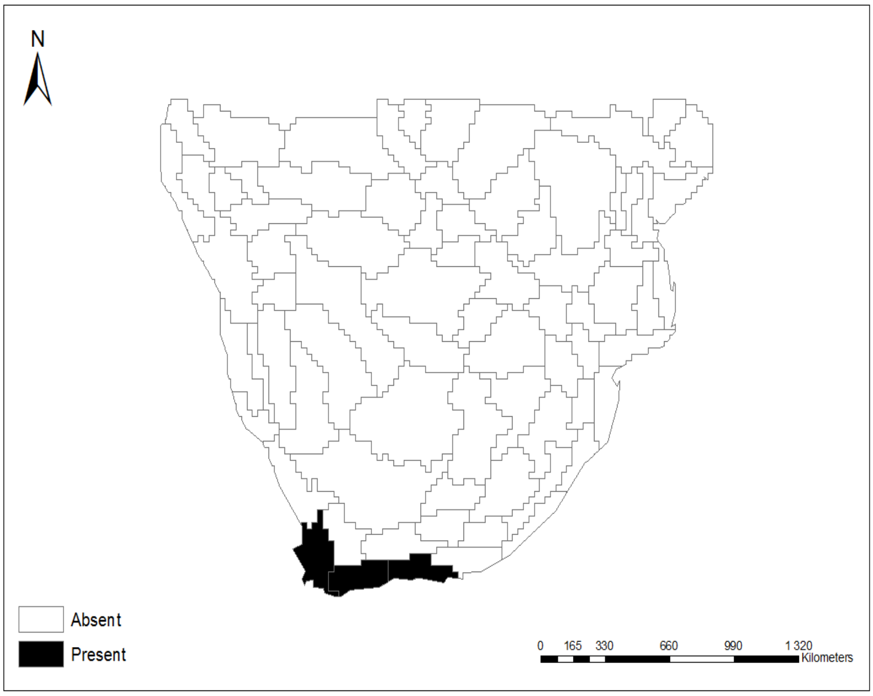

Figure B.10: The distribution of *Hypocalyptus* in southern Africa.

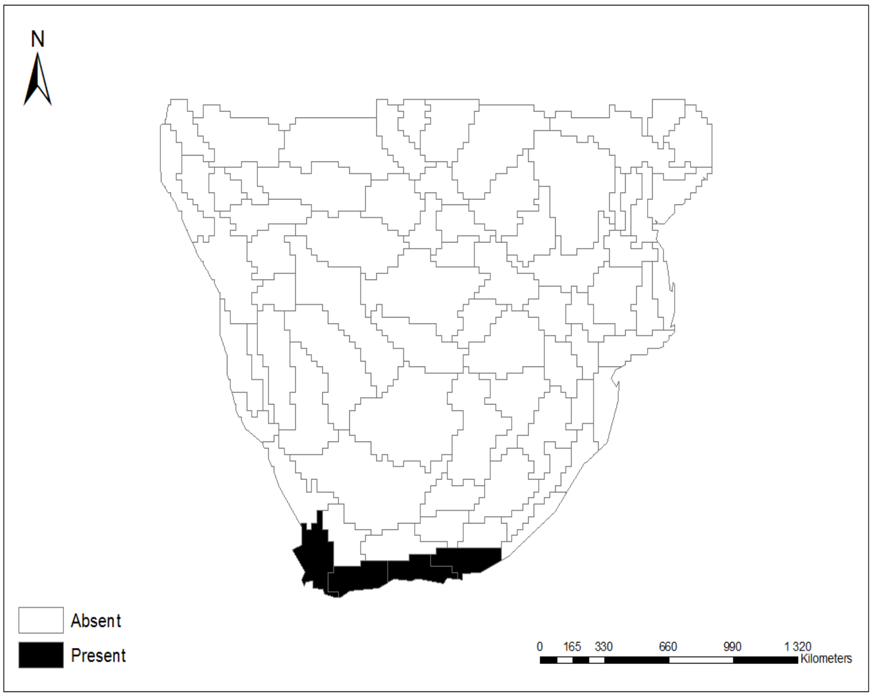

Figure B.11: The distribution of Lanariaceae in southern Africa.

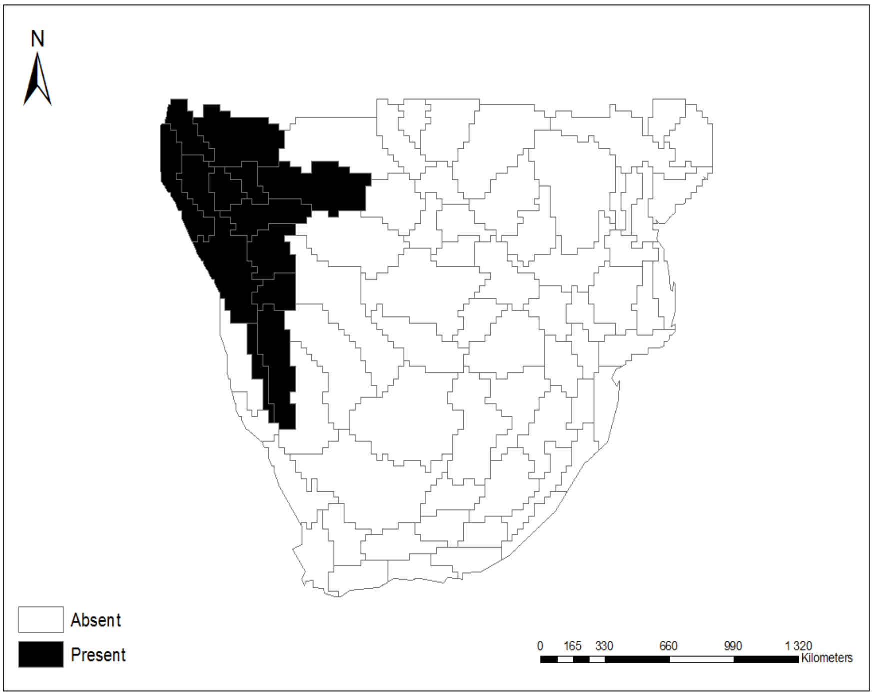

Figure B.12: The distribution of *Moringa ovalifolia* in southern Africa.

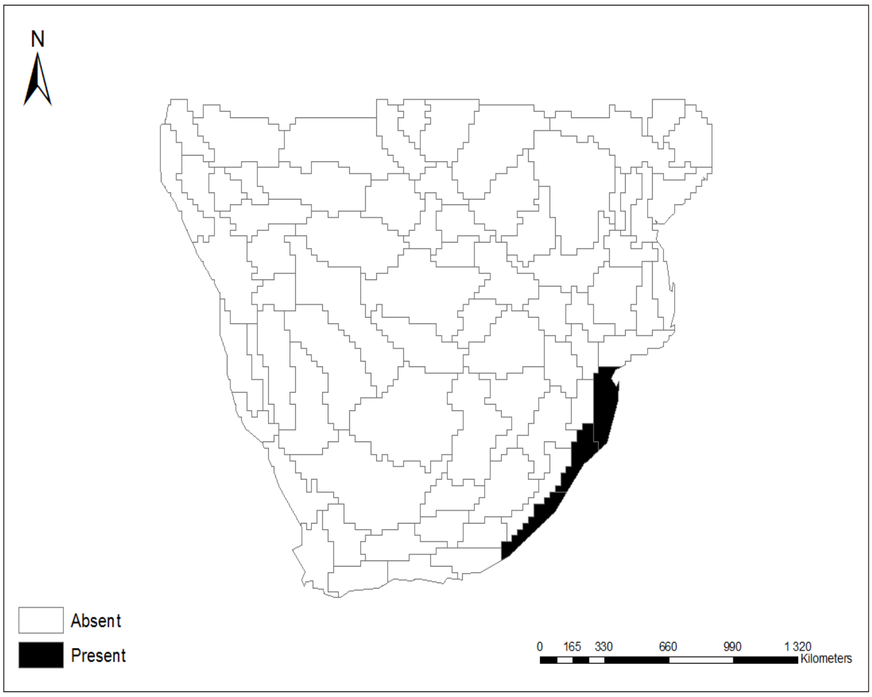

Figure B.13: The distribution of *Nectaropetalum* in southern Africa.

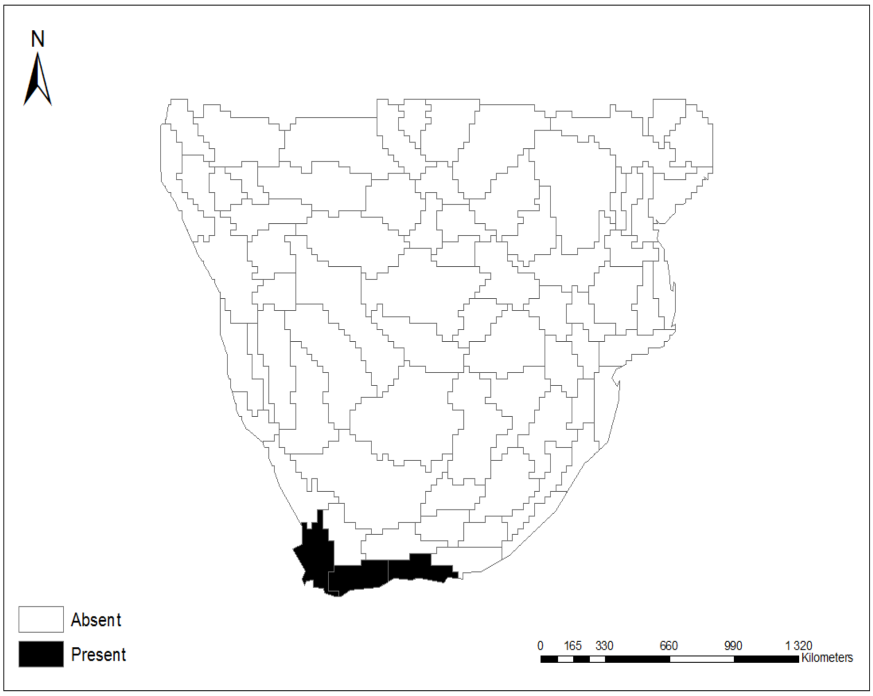

Figure B.14: The distribution of Nivenioideae in southern Africa.

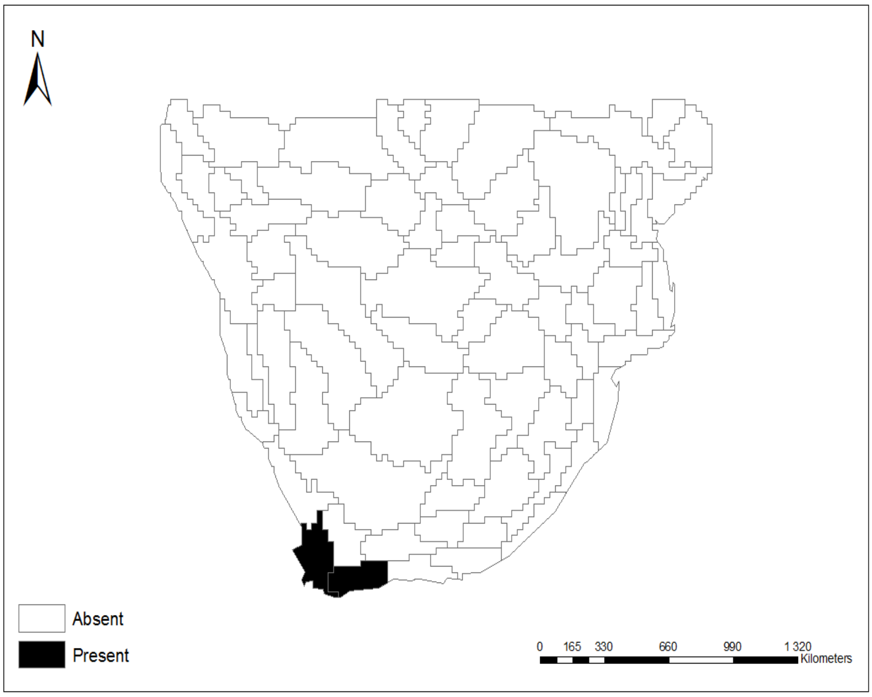

Figure B.15: The distribution of Roridulaceae in southern Africa.

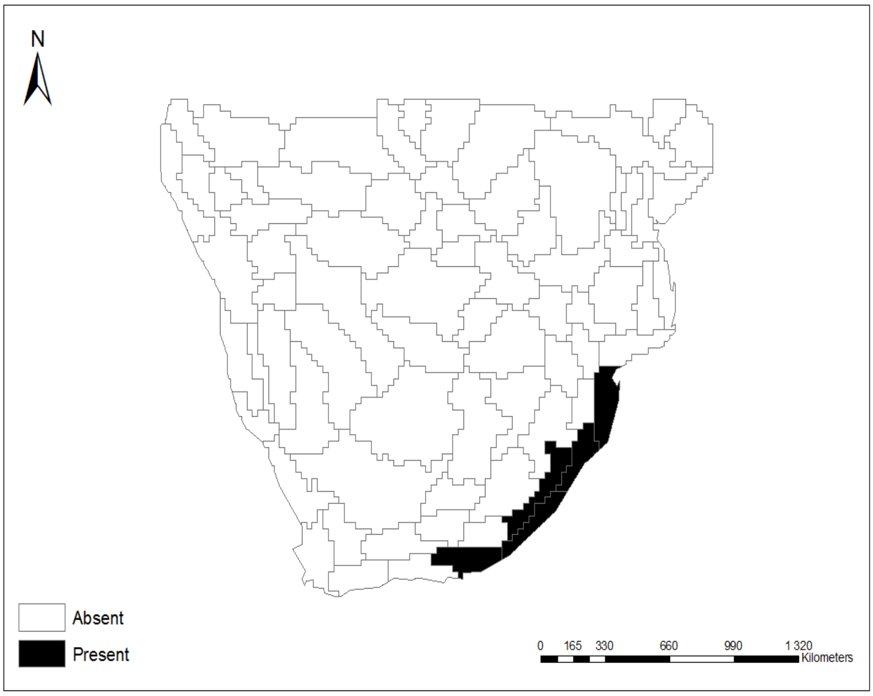

Figure B.16: The distribution of *Stangeria* in southern Africa.

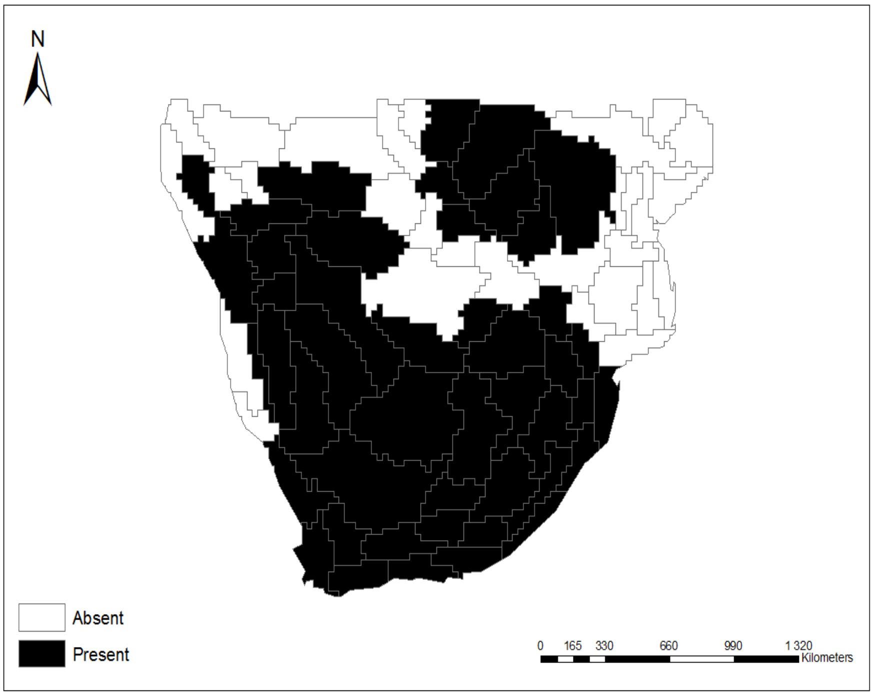

Figure B.17: The distribution of *Tulbaghia* in southern Africa.

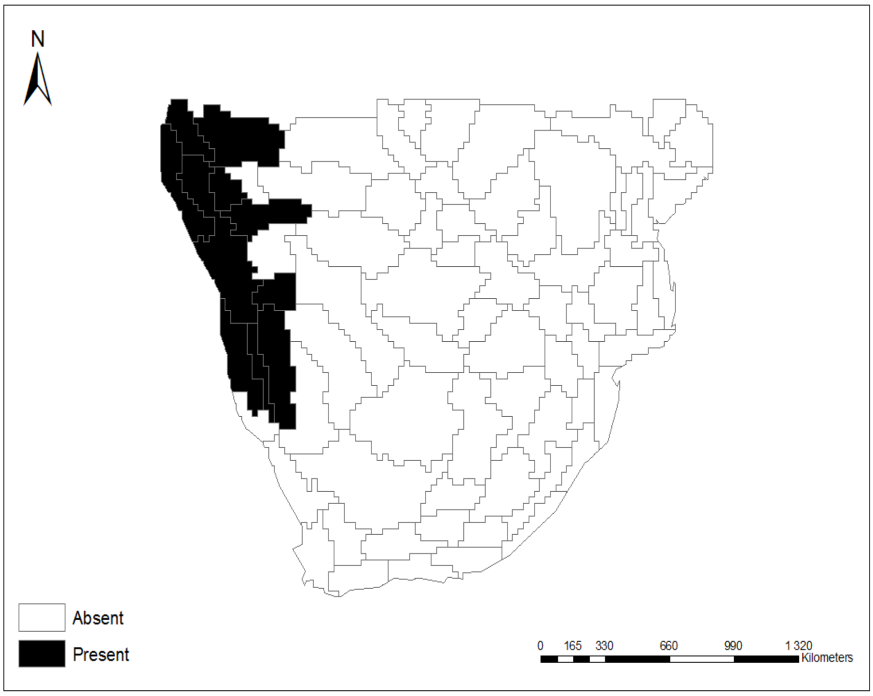

Figure B.18: The distribution of Welwitschiaceae in southern Africa.

Reptile Lineages

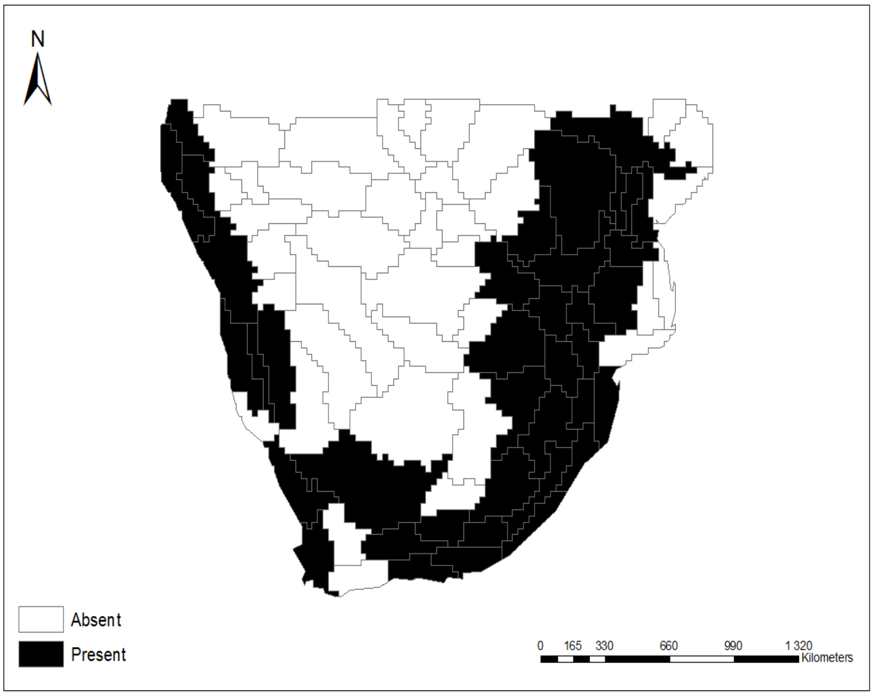

Figure B.19: The distribution of *Afroedura* in southern Africa.

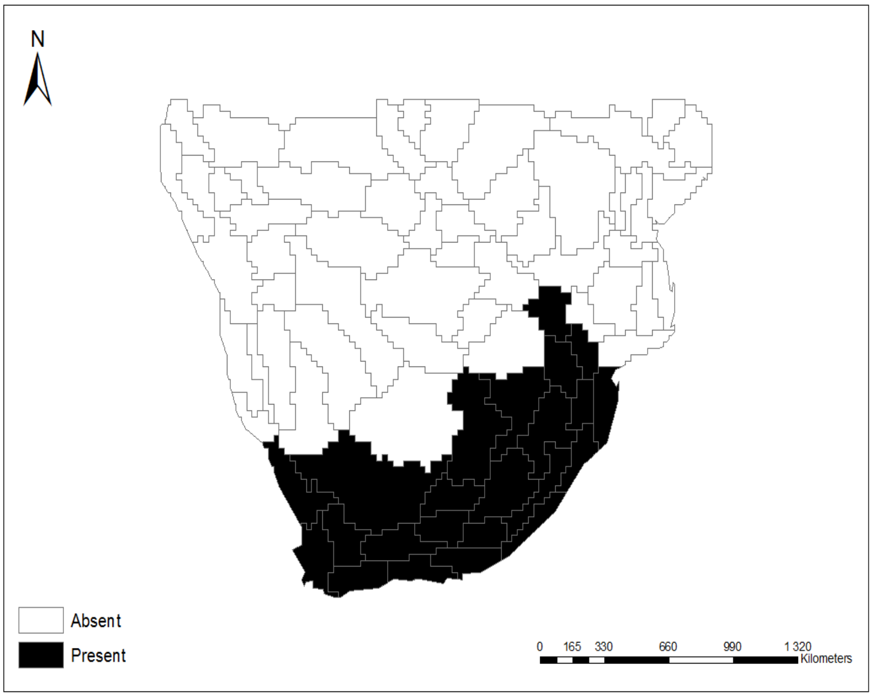

Figure B.20: The distribution of *Bradypodion* in southern Africa.

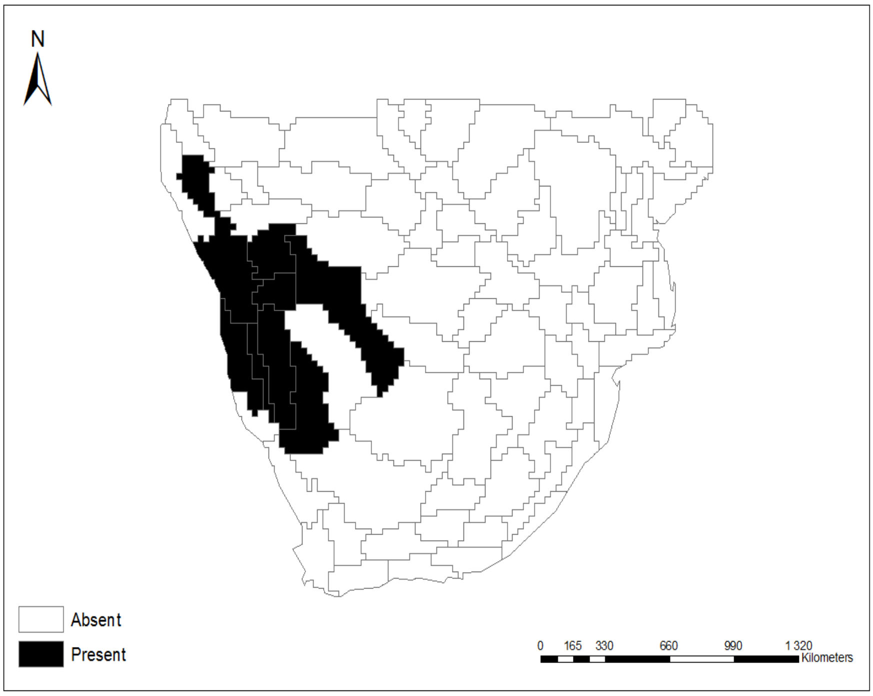

Figure B.21: The distribution *Narudasia* in southern Africa.

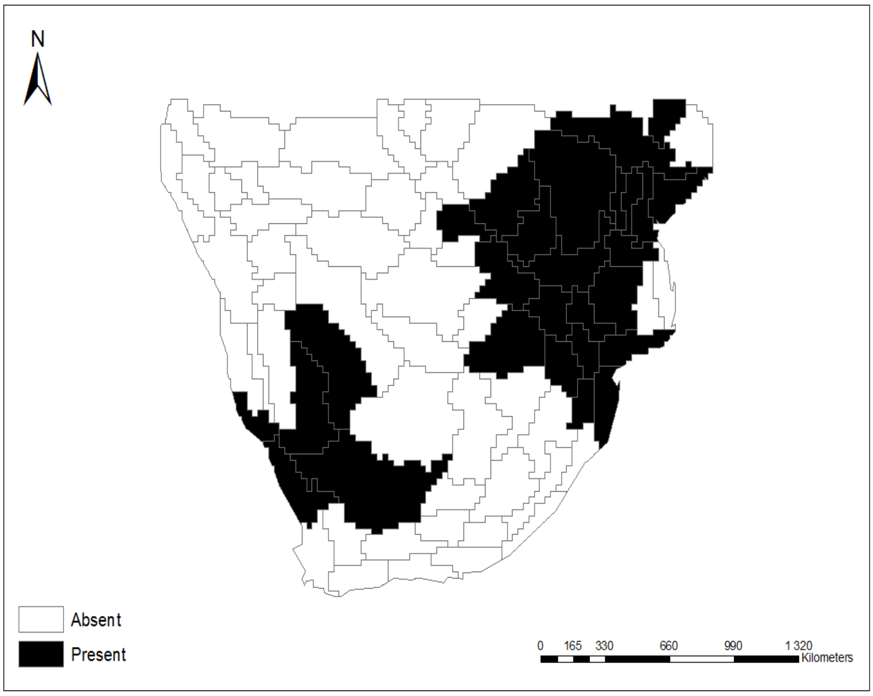

Figure B.22: The distribution of *Platysaurus* in southern Africa.

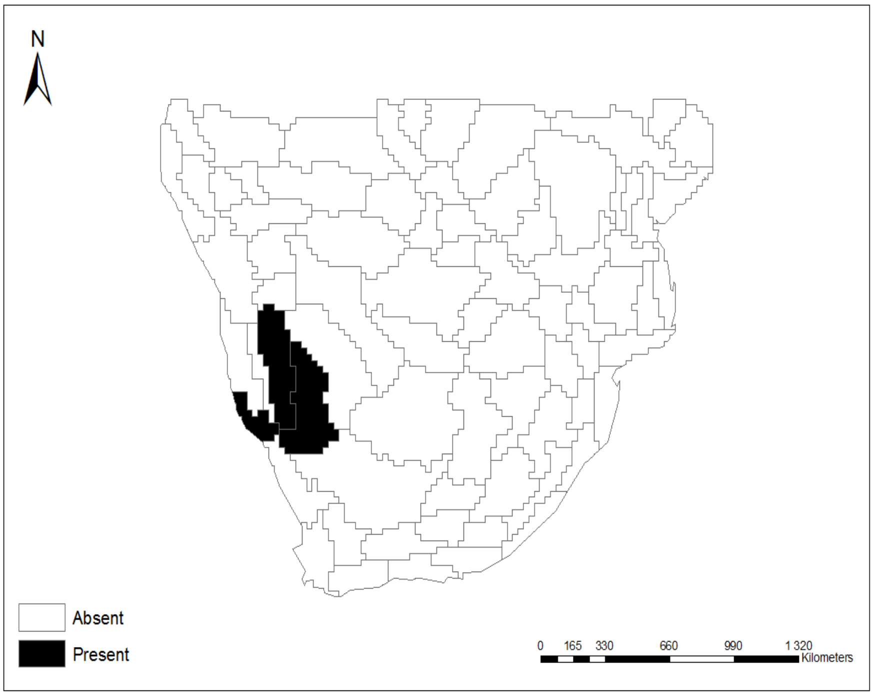

Figure B.23: The distribution of *Rhoptropella* in southern Africa.

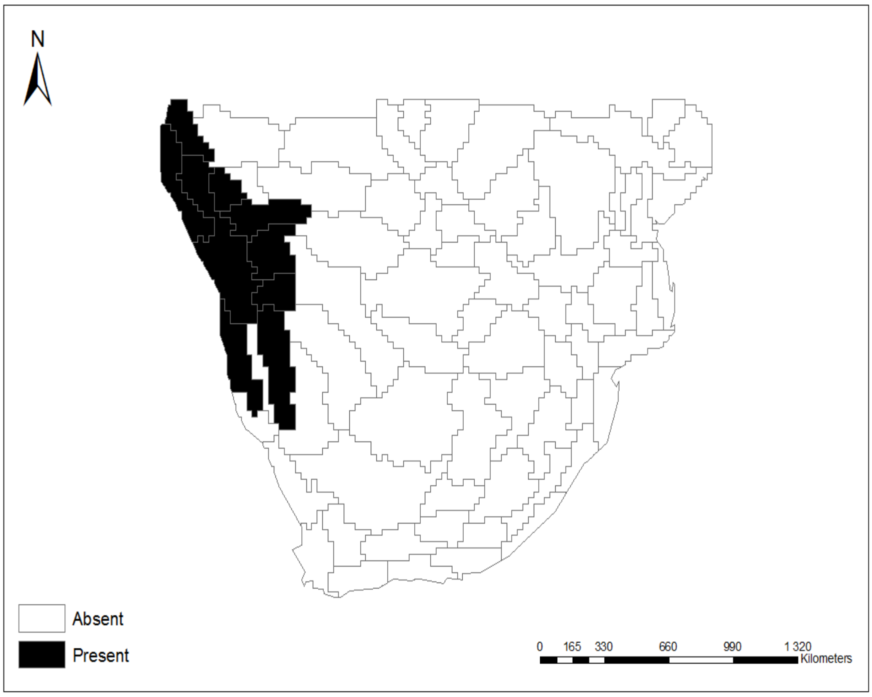

Figure B.24: The distribution of *Rhoptropus* in southern Africa.

Mammal Lineages

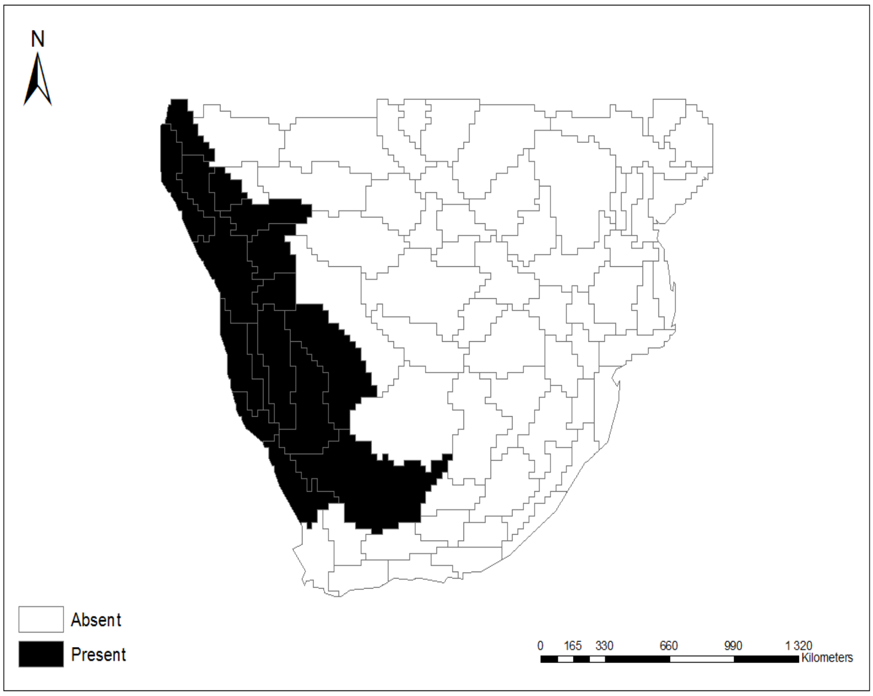

Figure B.25: The distribution of *Malacothrix typica* in southern Africa.

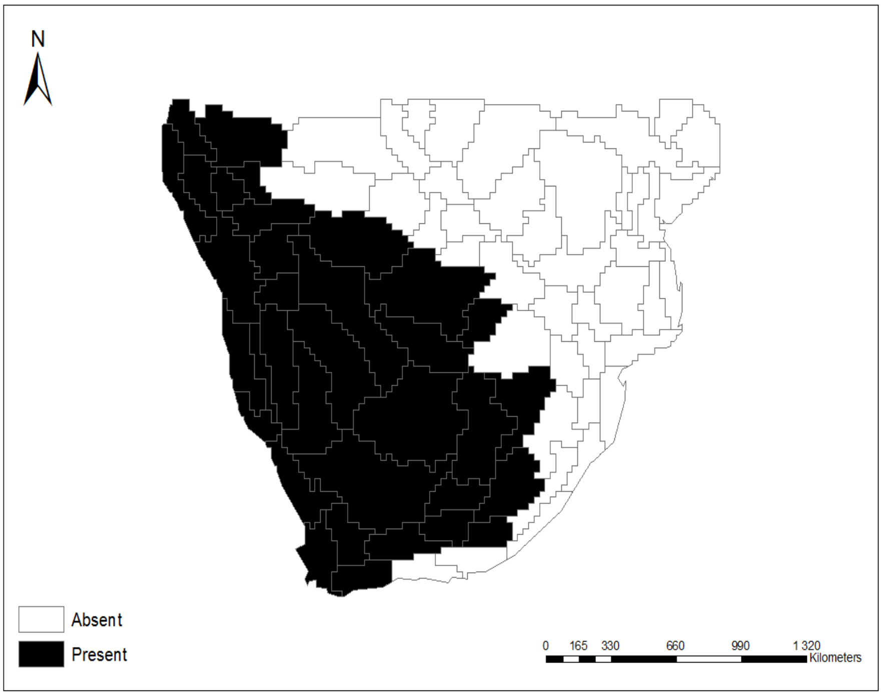

Figure B.26: The distribution of *Petromus typicus* in southern Africa.

Bird Lineage

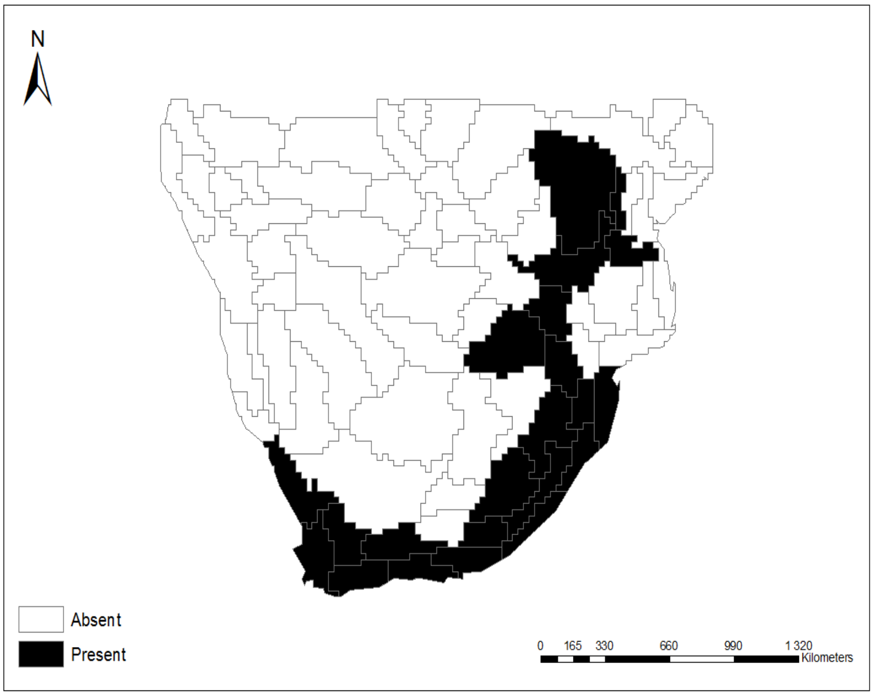

Figure B.27: The distribution of Promeropidae in southern Africa.

Amphibian Lineage

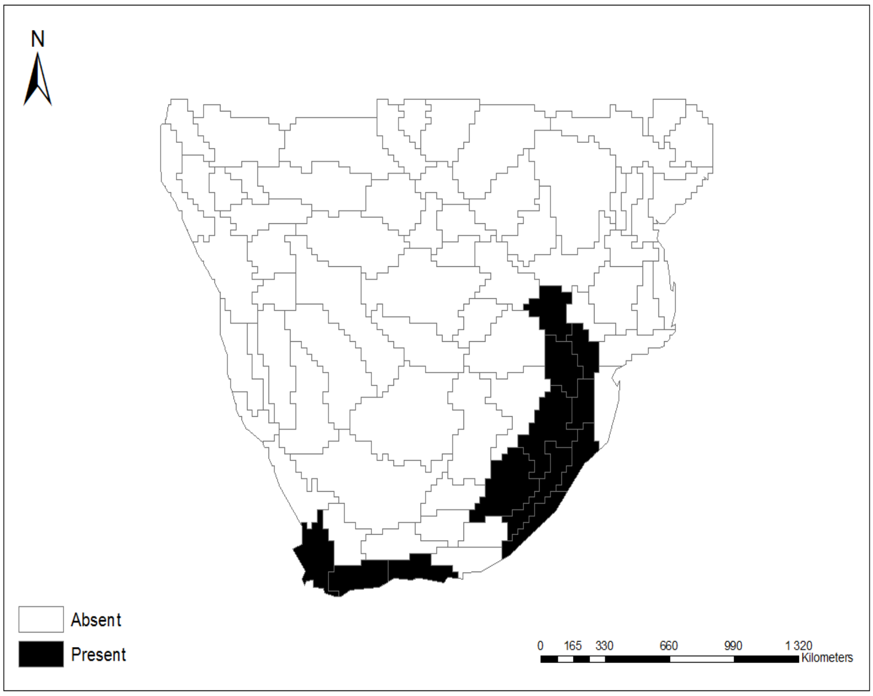

Figure B.28: The distribution of Heleophrynidae in southern Africa.

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Appendix C: Cluster Analyses

Appendix C1:

Table C1.1: Unit A1 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A1: (CL%)
1.	*Grielum*	34.46
2.	*Rhoptropella*	26.67
3.	*Petromus typicus*	21.33
4.	*Malacothrix typica*	15.15
5.	*Platysaurus*	11.85
6.	*Narudasia*	10.00
7.	*Tulbaghia*	7.11
8.	Bruniaceae	2.00
9.	*Bradypodion*	0.87
10.	*Afroedura*	0.54
11.	Promeropidae	0.00
12.	Heleophrynidae	0.00
13.	*Rhoptropus*	0.00
14.	Geissolomataceae	0.00
15.	Lanariaceae	0.00
16.	Greyiaceae	0.00
17.	Grubbiaceae + Curtisiaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	Welwitschiaceae	0.00
21.	*Agapanthus*	0.00
22.	*Moringa ovalifolia*	0.00
23.	*Anthochortus* + *Willdenowia*	0.00
24.	*Nectaropetalum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in A1:

UPKR - Upper Karoo
FRCN - Fish River Canyon
HBRG - Hunsberge
WKLH - Western Kalahari
KLHS - Kalahari Steppe

Table C1.2:, Unit A2 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A2: (CL%)
1.	*Rhoptropus*	90.00
2.	Welwitschiaceae	81.00
3.	*Moringa ovalifolia*	67.50
4.	*Petromus typicus*	66.67
5.	*Narudasia*	45.00
6.	*Malacothrix typica*	30.30
7.	*Grielum*	27.69
8.	*Afroedura*	9.73
9.	*Tulbaghia*	8.00
10.	*Rhoptropella*	3.33
11.	Promeropidae	0.00
12.	Heleophrynidae	0.00
13.	*Bradypodion*	0.00
14.	*Platysaurus*	0.00
15.	Bruniaceae	0.00
16.	Geissolomataceae	0.00
17.	Lanariaceae	0.00
18.	Greyiaceae	0.00
19.	Grubbiaceae + Curtisiaceae	0.00
20.	Roridulaceae	0.00
21.	*Stangeria*	0.00
22.	*Agapanthus*	0.00
23.	*Anthochortus* + *Willdenowia*	0.00
24.	*Nectaropetalum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A2:

FHRV - Fish River
NKLT - Naukluft
SNMB - Sandy Namib
BBRG - Brandberg
RNMB - Rocky Namib
WHAS - Windhoek-Auas
CNST - Central Namibian Steppe
TSBE - Tsumbe
NGSN - Namibian Grassy Savanna
ANKR - Angolan Nama-Karoo

Table C1.3: Unit A3 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A3: (CL%)
1.	Promeropidae	0.00
2.	Heleophrynidae	0.00
3.	*Bradypodion*	0.00
4.	*Platysaurus*	0.00
5.	*Afroedura*	0.00
6.	*Rhoptropus*	0.00
7.	*Rhoptropella*	0.00
8.	*Narudasia*	0.00
9.	*Malacothrix typica*	0.00
10.	*Petromus typicus*	0.00
11.	Bruniaceae	0.00
12.	Geissolomataceae	0.00
13.	Lanariaceae	0.00
14.	Greyiaceae	0.00
15.	Grubbiaceae + Curtisiaceae	0.00
16.	Roridulaceae	0.00
17.	*Stangeria*	0.00
18.	Welwitschiaceae	0.00
19.	*Agapanthus*	0.00
20.	*Moringa ovalifolia*	0.00
21.	*Anthochortus* + *Willdenowia*	0.00
22.	*Nectaropetalum*	0.00
23.	*Tulbaghia*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A3:

OKDL - Okavango Delta
SWSP - Sowa Salt pan
MGSP -Makgadikgadi Salt Pan
CITO - Cuito
ZMBK - Zambezian Baikiaea
ZMFG - Zambezian Flooded Grasslands
LINH - Limpopo-Inhambane
PINH - Pomene-Inhambane
NMLI - Namuli

Table C1.4: Unit A4 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A4: (CL%)
1.	*Moringa ovalifolia*	11.11
2.	*Malacothrix typica*	9.09
3.	Welwitschiaceae	3.33
4.	Promeropidae	0.00
5.	Heleophrynidae	0.00
6.	*Bradypodion*	0.00
7.	*Platysaurus*	0.00
8.	*Afroedura*	0.00
9.	*Rhoptropus*	0.00
10.	*Rhoptropella*	0.00
11.	*Narudasia*	0.00
12.	*Petromus typicus*	0.00
13.	Bruniaceae	0.00
14.	Geissolomataceae	0.00
15.	Lanariaceae	0.00
16.	Greyiaceae	0.00
17.	Grubbiaceae + Curtisiaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	*Agapanthus*	0.00
21.	*Anthochortus* + *Willdenowia*	0.00
22.	*Nectaropetalum*	0.00
23.	*Tulbaghia*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A4:

CKLH - Central Kalahari
ODGW - Odangwa
CUNE - Cunene

Table C1.5: Unit A5 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A5: (CL%)
1.	*Tulbaghia*	8.89
2.	*Moringa ovalifolia*	2.08
3.	Promeropidae	0.00
4.	Heleophrynidae	0.00
5.	*Bradypodion*	0.00
6.	*Platysaurus*	0.00
7.	*Afroedura*	0.00
8.	*Rhoptropus*	0.00
9.	*Rhoptropella*	0.00
10.	*Narudasia*	0.00
11.	*Malacothrix typica*	0.00
12.	*Petromus typicus*	0.00
13.	Bruniaceae	0.00
14.	Geissolomataceae	0.00
15.	Lanariaceae	0.00
16.	Greyiaceae	0.00
17.	Grubbiaceae + Curtisiaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	Welwitschiaceae	0.00
21.	*Agapanthus*	0.00
22.	*Anthochortus* + *Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Nivenioidea	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A5:

CBNG - Cubango
CHBE - Chobe
ZMMB - Zambezian Miombo
ZMMM - Zambezian Mopane-Miombo

Table C1.6: Unit A6 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A6: (CL%)
1.	*Malacothrix typica*	18.18
2.	*Tulbaghia*	13.33
3.	*Bradypodion*	2.90
4.	Grubbiaceae + Curtisiaceae	0.56
5.	Promeropidae	0.00
6.	Heleophrynidae	0.00
7.	*Platysaurus*	0.00
8.	*Afroedura*	0.00
9.	*Rhoptropus*	0.00
10.	*Rhoptropella*	0.00
11.	*Narudasia*	0.00
12.	*Petromus typicus*	0.00
13.	Bruniaceae	0.00
14.	Geissolomataceae	0.00
15.	Lanariaceae	0.00
16.	Greyiaceae	0.00
17.	Roridulaceae	0.00
18.	*Stangeria*	0.00
19.	Welwitschiaceae	0.00
20.	*Agapanthus*	0.00
21.	*Moringa ovalifolia*	0.00
22.	*Anthochortus* + *Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A6:

KLHS - Kalahari Savanna
DHVD - Dry Highveld
ORKR - Orange River Karoo
KNWD - Kanye-Werda
GBRN - Gaborone
ENGS - Eastern Namibian Grass Savanna

Table C1.7: Unit A7 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A7: (CL%)
1.	*Stangeria*	60.00
2.	*Nectaropetalum*	44.44
3.	Greyiaceae	23.08
4.	Achariaeae	18.75
5.	*Agapanthus*	17.65
6.	Bruniaceae	13.33
7.	*Bradypodion*	13.04
8.	Promeropidae	9.09
9.	Lanariaceae	8.33
10.	*Afroedura*	8.11
11.	*Tulbaghia*	6.67
12.	Grubbiaceae + Curtisiaceae	4.45
13.	Heleophrynidae	2.78
14.	*Platysaurus*	1.23
15.	*Rhoptropus*	0.00
16.	*Rhoptropella*	0.00
17.	*Narudasia*	0.00
18.	*Malacothrix typica*	0.00
19.	*Petromus typicus*	0.00
20.	Geissolomataceae	0.00
21.	Roridulaceae	0.00
22.	Welwitschiaceae	0.00
23.	*Moringa ovalifolia*	0.00
24.	*Anthochortus* + *Willdenowia*	0.00
25.	*Grielum*	0.00
26.	Nivenioideae	0.00
27.	*Hypocalyptus*	0.00

OGUs included in unit A7:

SMPL - Southern Maputaland

PTCB - Pondoland-Southern Transkei Coastal Belt

ABCB - Albany Coastal Belt

Table C1.8: Unit A8 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A8: (CL%)
1.	Greyiaceae	69.23
2.	Heleophrynidae	59.26
3.	Achariaeae	56.25
4.	*Agapanthus*	52.94
5.	*Bradypodion*	39.13
6.	Promeropidae	32.32
7.	Grubbiaceae + Curtisiaceae	30.00
8.	*Afroedura*	24.32
9.	*Tulbaghia*	20.00
10.	*Stangeria*	8.88
11.	*Platysaurus*	6.58
12.	*Nectaropetalum*	3.70
13.	*Malacothrix typica*	1.35
14.	*Rhoptropus*	0.00
15.	*Rhotropella*	0.00
16.	*Narudasia*	0.00
17.	*Petromus typicus*	0.00
18.	Bruniaceae	0.00
19.	Geissolomataceae	0.00
20.	Lanariaceae	0.00
21.	Roridulaceae	0.00
22.	Welwitschiaceae	0.00
23.	*Moringa ovalifolia*	0.00
24.	*Anthochortus* + *Willdenowia*	0.00
25.	*Grielum*	0.00
26.	Nivenioideae	0.00
27.	*Hypocalyptus*	0.00

OGUs included in unit A8:

WBSP - Wolkberg-Soutpansberg
NMPE - Northern Mpumalanga Escarpment
NMLV - Northern Middleveld
SMLV - Southern Middleveld
KDME - KZN-Drakensberg-Mpumalanga Escarpment
DBRG - Drakensberg
NTMD - Natal-Transkei Midlands
NLCB - Natal Coastal Belt
ATWB - Amatola-Winterberg

Table C1.9: Unit A9 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A9: (CL%)
1.	Nivenioideae	100
2.	*Hypocalyptus*	100
3.	Geissolomataceae	66.67
4.	Roridulaceae	66.67
5.	*Anthochortus* + *Willdenowia*	60.00
6.	Lanariaceae	33.33
7.	Bruniaceae	30.00
8.	Heleophrynidae	25.00
9.	*Agapanthus*	17.65
10.	Promeropidae	13.63
11.	*Bradypodion*	13.04
12.	Grubbiaceae + Curtisiaceae	10.00
13.	*Tulbaghia*	6.67
14.	*Malacothrix typica*	4.04
15.	*Afroedura*	3.60
16.	*Grielum*	2.56
17.	Achariaeae	2.08
18.	*Platysaurus*	0.00
19.	*Rhoptropus*	0.00
20.	*Rhoptropella*	0.00
21.	*Narudasia*	0.00
22.	*Petromus typicus*	0.00
23.	Greyiaceae	0.00
24.	*Stangeria*	0.00
25.	Welwitschiaceae	0.00
26.	*Moringa ovalifolia*	0.00
27.	*Nectaropetalum*	0.00

OGUs included in unit A9:

KNYS - Knysna
OBRG - Overberg
WFYN - Western Fynbos

Table C1.10: Unit A10 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A10: (CL%)
1.	Bruniaceae	32.00
2.	*Bradypodion*	21.73
3.	*Anthochortus* + *Willdenowia*	16.00
4.	*Malacothrix typica*	15.15
5.	Achariaeae	11.25
6.	*Tulbaghia*	11.11
7.	Grubbiaceae + Curtisiaceae	10.67
8.	*Afroedura*	8.65
9.	Promeropidae	8.18
10.	Lanariaceae	5.00
11.	*Agapanthus*	2.35
12.	*Grielum*	1.54
13.	*Petromus typicus*	1.33
14.	*Platysaurus*	0.74
15.	Heleophrynidae	0.00
16.	*Rhoptropus*	0.00
17.	*Rhoptropella*	0.00
18.	*Narudasia*	0.00
19.	Geissolomataceae	0.00
20.	Greyiaceae	0.00
21.	Roridulaceae	0.00
22.	*Stangeria*	0.00
23.	Welwitschiaceae	0.00
24.	*Moringa ovalifolia*	0.00
25.	*Nectaropetalum*	0.00
26.	Nivenioideae	0.00
27.	*Hypocalyptus*	0.00

OGUs included in unit A10:

MHVD - Mesic Highveld
SBRG - Sneeuberg
LKRR - Lower Karoo Region
NQLD - Namaqualand
RVHT - Roggeveld-Hantam

Table C1.11: Unit A11 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A11: (CL%)
1.	Promeropidae	9.09
2.	*Platysaurus*	7.40
3.	Grubbiaceae + Curtisiaceae	6.67
4.	*Afroedura*	5.41
5.	*Tulbaghia*	4.44
6.	*Agapanthus*	2.94
7.	Heleophrynidae	0.00
8.	*Bradypodion*	0.00
9.	*Rhoptropus*	0.00
10.	*Rhoptropella*	0.00
11.	*Narudasia*	0.00
12.	*Malacothrix typica*	0.00
13.	*Petromus typicus*	0.00
14.	Bruniaceae	0.00
15.	Geissolomataceae	0.00
16.	Lanariaceae	0.00
17.	Greyiaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	Welwitschiaceae	0.00
21.	*Moringa ovalifolia*	0.00
22.	*Anthochortus* +*Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Achariaeae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A11:

WBCB - Waterberg-Central Bushveld
MUCT - Munyati-Chitungwiza

Table C1.12: Unit A12 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A12: (CL%)
1.	*Platysaurus*	33.33
2.	Grubbiaceae + Curtisiaceae	30.00
3.	*Afroedura*	24.32
4.	Promeropidae	2.02
5.	Greyiaceae	0.85
6.	Heleophrynidae	0.00
7.	*Bradypodion*	0.00
8.	*Rhoptropus*	0.00
9.	*Rhoptropella*	0.00
10.	*Narudasia*	0.00
11.	*Malacothrix typica*	0.00
12.	*Petromus typicus*	0.00
13.	Bruniaceae	0.00
14.	Geissolomataceae	0.00
15.	Lanariaceae	0.00
16.	Roridulaceae	0.00
17.	*Stangeria*	0.00
18.	Welwitschiaceae	0.00
19.	*Agapanthus*	0.00
20.	*Moringa ovalifolia*	0.00
21.	*Anthochortus* +*Willdenowia*	0.00
22.	*Nectaropetalum*	0.00
23.	*Tulbaghia*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A12:

SNMP - Southern Mopane
CHMN - Chimanimani
SINH - Save-Inhambane
LPSR - Limpopo-Serowe
LPBH - Limpopo-Banhine
BUZI - Buzi
TTZB - Tete-Zambezi
RNDE - Runde
NYGN - Nyangani

Table C1.13: Unit A13 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A13: (CL%)
1.	*Platysaurus*	11.11
2.	Promeropidae	0.00
3.	Heleophrynidae	0.00
4.	*Bradypodion*	0.00
5.	*Afroedura*	0.00
6.	*Rhoptropus*	0.00
7.	*Rhoptropella*	0.00
8.	*Narudasia*	0.00
9.	*Malacothrix typica*	0.00
10.	*Petromus typicus*	0.00
11.	Bruniaceae	0.00
12.	Geissolomataceae	0.00
13.	Lanariaceae	0.00
14.	Greyiaceae	0.00
15.	Grubbiaceae + Curtisiaceae	0.00
16.	Roridulaceae	0.00
17.	*Stangeria*	0.00
18.	Welwitschiaceae	0.00
19.	*Agapanthus*	0.00
20.	*Moringa ovalifolia*	0.00
21.	*Anthochortus* + *Willdenowia*	0.00
22.	*Nectaropetalum*	0.00
23.	*Tulbaghia*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A13:

MINH - Northern Maputaland-Inhambane
QMZB - Quelimane-Zambezi
MTMW - Matandwe-Mwabvi

Table C1.14: Unit A14 and characteristic lineages at stage one of cluster analysis (Figure 4.3)

	Lineage:	A14: (CL%)
1.	*Platysaurus*	11.11
2.	*Tulbaghia*	6.67
3.	*Afroedura*	3.60
4.	Promeropidae	0.00
5.	Heleophrynidae	0.00
6.	*Bradypodion*	0.00
7.	*Rhoptropus*	0.00
8.	*Rhoptropella*	0.00
9.	*Narudasia*	0.00
10.	*Malacothrix typica*	0.00
11.	*Petromus typicus*	0.00
12.	Bruniaceae	0.00
13.	Geissolomataceae	0.00
14.	Lanariaceae	0.00
15.	Greyiaceae	0.00
16.	Grubbiaceae +Curtisiaceae	0.00
17.	Roridulaceae	0.00
18.	*Stangeria*	0.00
19.	Welwitschiaceae	0.00
20.	*Agapanthus*	0.00
21.	*Moringa ovalifolia*	0.00
22.	*Anthochortus* + *Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit A14:

NXSP - Naxi Salt Pan
MTPO - Matopo
MACH - Mafungabusa-Chizarira

Appendix C2:

Table C2.1: Unit B1 and characteristic lineages at stage two of cluster analysis (Figure 4.4)

	Lineage:	B1: (CL%)
1.	*Grielum*	38.46
2.	*Rhoptropella*	26.67
3.	*Petromus typicus*	21.33
4.	*Malacothrix typica*	15.15
5.	*Platysaurus*	11.85
6.	*Narudasia*	10.00
7.	*Tulbaghia*	7.11
8.	Bruniaceae	2.00
9.	*Bradypodion*	0.87
10.	*Afroedura*	0.54
11.	Promeropidae	0.00
12.	Heleophrynidae	0.00
13.	*Rhoptropus*	0.00
14.	Geissolomataceae	0.00
15.	Lanariaceae	0.00
16.	Greyiaceae	0.00
17.	Grubbiaceae + Curtisiaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	Welwitschiaceae	0.00
21.	*Agapanthus*	0.00
22.	*Moringa ovalifolia*	0.00
23.	*Anthochortus* + *Willdenowia*	0.00
24.	*Nectaropetalum*	0.00
25.	Nivenioidea	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit B1:

UPKR - Upper Karoo
FRCN - Fish River Canyon
HBRG - Hunsberge
WKLH - Western Kalahari
KLHS - Kalahari Steppe

Table C2.2: Unit B2 and characteristic lineages at stage two of cluster analysis (Figure 4.4)

	Lineage:	B2: (CL%)
1.	*Rhoptropus*	90.00
2.	Welwitschiaceae	81.00
3.	*Moringa ovalifolia*	67.50
4.	*Petromus typicus*	66.67
5.	*Narudasia*	45.00
6.	*Malacothrix typica*	30.30
7.	*Grielum*	27.69
8.	*Afroedura*	9.73
9.	*Tulbaghia*	8.00
10.	*Rhotropella*	3.33
11.	Promeropidae	0.00
12.	Heleophrynidae	0.00
13.	*Bradypodion*	0.00
14.	*Platysaurus*	0.00
15.	Bruniaceae	0.00
16.	Geissolomataceae	0.00
17.	Lanariaceae	0.00
18.	Greyiaceae	0.00
19.	Grubbiaceae + Curtisiaceae	0.00
20.	Roridulaceae	0.00
21.	*Stangeria*	0.00
22.	*Agapanthus*	0.00
23.	*Anthochortus* + *Willdenowia*	0.00
24.	*Nectaropetalum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit B2:

FHRV - Fish River
NKLT - Naukluft
SNMB - Sandy Namib
BBRG - Brandberg
RNMB - Rocky Namib
WHAS - Windhoek-Auas
CNST - Central Namibian Steppe
TSBE - Tsumbe
NGSN - Namibian Grassy Savanna
ANKR - Angolan Nama-Karoo

Table C2.3: Unit B3 and characteristic lineages at stage two of cluster analysis (Figure 4.4)

	Lineage:	B3: (CL%)
1.	*Malacothrix typica*	11.15
2.	*Tulbaghia*	10.10
3.	*Moringa ovalifolia*	3.41
4.	*Bradypodion*	0.79
5.	Welwitschiaceae	0.46
6.	Grubbiaceae + Curtisiaceae	0.15
7.	Promeropidae	0.00
8.	Heleophrynidae	0.00
9.	*Platysaurus*	0.00
10.	*Afroedura*	0.00
11.	*Rhoptropus*	0.00
12.	*Rhoptropella*	0.00
13.	*Narudasia*	0.00
14.	*Petromus typicus*	0.00
15.	Bruniaceae	0.00
16.	Geissolomataceae	0.00
17.	Lanariaceae	0.00
18.	Greyiaceae	0.00
19.	Roridulaceae	0.00
20.	*Stangeria*	0.00
21.	*Agapanthus*	0.00
22.	*Anthochortus* + *Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in B3:

KLHS - Kalahari Savanna
DHVD - Dry Highveld
ORKR - Orange River Karoo
KNWD - Kanye-Werda
GBRN - Gaborone
CKLH - Central Kalahari
ENGS - Eastern Namibian Grassy Savanna
ODWG - Odangwa
CBNG - Cubango
CUNE - Cunene
OKDL - Okavango Delta
SWSP - Sowa Salt Pan

MGSP - Makgadikgadi Salt Pan
CITO - Cuito
ZMBK - Zambezian Baikaieae
ZMGF - Zambezian Flooded Grasslands
CHBE - Chobe
ZMMB - Zambezian Miombo
ZMMM - Zambezian Mopane-Miombo
LINH - Limpopo-Inhambane
PINH - Pomene-Inhambane
NMLI - Namuli

Table C2.4: Unit B4 and characteristic lineages at stage two of cluster analysis (Figure 4.4)

	Lineage:	B4: (CL%)
1.	*Bradypodion*	86.96
2.	Achariaeae	80.00
3.	*Agapanthus*	75.29
4.	Promeropidae	65.68
5.	Heleophrynidae	60.00
6.	Greyiaceae	55.38
7.	Grubbiaceae + Curtisiaceae	54.00
8.	*Tulbaghia*	44.44
9.	*Afroedura*	43.78
10.	Bruniaceae	40.50
11.	*Stangeria*	25.00
12.	*Anthochortus* + *Willdenowia*	25.00
13.	Lanariaceae	20.00
14.	*Nectaropetalum*	15.00
15.	Nivenioideae	15.00
16.	*Hypocalyptus*	15.00
17.	*Malacothrix typica*	12.27
18.	Geissolomataceae	10.00
19.	Roridulaceae	10.00
20.	*Platysaurus*	6.67
21.	*Grielum*	1.54
22.	*Petromus typicus*	0.33
23.	*Rhoptropus*	0.00
24.	*Rhoptropella*	0.00
25.	*Narudasia*	0.00
26.	Welwitschiaceae	0.00
27.	*Moringa ovalifolia*	0.00

OGUs included in unit B4:

SMPL - Southern Maputaland
PTCB - Pondoland-Southern Transkei Coastal Belt
ABCB - Albany Coastal Belt
WBSP - Wolkberg-Soutpansberg
NMPE - Northern Mpumalanga Escarpment
NMLV - Northern Middleveld
SMLV - Southern Middleveld
KDME - KZN-Drakensberg-Mpumalanga Escarpment
DBRG - Drakensberg
NTMD - Natal-Transkei Midlands
NLCB - Natal Coastal Belt
ATWB - Amatola-Winterberg

KNYS - Knysna
OBRG - Overberg
WFYN - Western Fynbos
MHVD - Mesic Highveld
SBRG - Sneeuberg
LKRR - Lower Karoo Region
NQLD - Namaqualand
RVHT - Roggeveld-Hantam

Table C2.5: Unit B5 and characteristic lineages at stage two of cluster analysis (Figure 4.4)

	Lineage:	B5: (CL%)
1.	*Platysaurus*	62.96
2.	Grubbiaceae + Curtisiaceae	23.73
3.	*Afroedura*	22.89
4.	Promeropidae	6.68
5.	*Tulbaghia*	3.27
6.	Greyiaceae	0.45
7.	*Agapanthus*	0.35
8.	Heleophrynidae	0.00
9.	*Bradypodion*	0.00
10.	*Rhoptropus*	0.00
11.	*Rhoptropella*	0.00
12.	*Narudasia*	0.00
13.	*Malacothrix typica*	0.00
14.	*Petromus typicus*	0.00
15.	Bruniaceae	0.00
16.	Geissolomataceae	0.00
17.	Lanariaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	Welwitschiaceae	0.00
21.	*Moringa ovalifolia*	0.00
22.	*Anthochortus* + *Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalytpus*	0.00
27.	Achariaeae	0.00

OGUs included in unit B5:

WBCB - Waterberg-Central Bushveld
MUCT - Munyati-Chitungwiza
SNMP - Southern Mopane
CHMN - Chimanimani
SINH - Save-Inhambane
LPSR - Limpopo-Serowe
LPBH - Limpopo-Banhine
BUZI - Buzi
TTZB - Tete-Zambezi
RNDE - Runde
NYGN - Nyangani
MINH - Northern Maputaland-Inhambane

QMZB - Quelimane-Zambezi
MTMW - Matandwe-Mwabvi
NXSP - Naxi Salt Pan
MTPO - Matopo
MACH - Mafungabusa-Chizarira

Appendix C3:

Table C3.1: Unit C1 and characteristic lineages at stage three of cluster analysis (Figure 4.4)

	Lineage:	C1: (CL%)
1.	*Petromus typicus*	87.11
2.	*Grielum*	62.05
3.	*Rhoptropus*	60.00
4.	Welwitschiaceae	54.00
5.	*Malacothrix typica*	45.45
6.	*Moringa ovalifolia*	45.00
7.	*Rhoptropella*	20.00
8.	*Tulbaghia*	14.81
9.	*Afroedura*	8.82
10.	*Narudasia*	5.33
11.	*Platysaurus*	3.95
12.	Bruniaceae	0.67
13.	*Bradypodion*	0.29
14.	Promeropidae	0.00
15.	Heleophrynidae	0.00
16.	Geissolomataceae	0.00
17.	Lanariacea	0.00
18.	Greyiaceae	0.00
19.	Grubbiaceae + Curtisiaceae	0.00
20.	Roridulaceae	0.00
21.	*Stangeria*	0.00
22.	*Agapanthus*	0.00
23.	*Anthochortus* + *Willdenowia*	0.00
24.	*Nectaropetalum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit C1:

UPKR - Upper Karoo
FRCN - Fish River Canyon
HBRG - Hunsberge
WKLH - Western Kalahari
KLHS - Kalahari Steppe
FHRV - Fish River
NKLT - Naukluft
SNMB - Sandy Namib

BBRG - Brandberg
RNMB - Rocky Namib
WHAS - Windhoek-Auas
CNST - Central Namibian Steppe
TSBE - Tsumbe
NGSN - Namibian Grassy Savanna
ANKR - Angolan Nama-Karoo

Table C3.2: Unit C2 and characteristic lineages at stage three of cluster analysis (Figure 4.4)

	Lineage:	C2: (CL%)
1.	*Malacothrix typica*	11.16
2.	*Tulbaghia*	10.10
3.	*Moringa ovalifolia*	3.41
4.	*Bradypodion*	0.79
5.	Promeropidae	0.00
6.	Heleophrynidae	0.00
7.	*Platysaurus*	0.00
8.	*Afroedura*	0.00
9.	*Rhoptropus*	0.00
10.	*Rhoptropella*	0.00
11.	*Narudasia*	0.00
12.	*Petromus typicus*	0.00
13.	Bruniaceae	0.00
14.	Geissolomataceae	0.00
15.	Lanariaceae	0.00
16.	Grubbiaceae + Curtisiaceae	0.00
17.	Greyiaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	Welwitschiaceae	0.00
21.	*Agapanthus*	0.00
22.	*Anthochortus* + *Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalyptus*	0.00
27.	Achariaeae	0.00

OGUs included in unit C2:

KLHS - Kalahari Savanna
DHVD - Dry Highveld
ORKR - Orange River Karoo
KNWD - Kanye-Werda
GBRN - Gaborone
CKLH - Central Kalahari
ENGS - Eastern Namibian Grassy Savanna
ODWG - Odangwa
CBNG - Cubango
CUNE - Cunene

OKDL - Okavango Delta
SWSP - Sowa Salt Pan
MGSP - Makgadikgadi Salt Pan
CITO - Cuito
ZMBK - Zambezian Baikaieae
ZMGF - Zambezian Flooded Grasslands
CHBE - Chobe
ZMMB - Zambezian Miombo
ZMMM - Zambezian Mopane-Miombo
LINH - Limpopo-Inhambane
PINH - Pomene-Inhambane
NMLI - Namuli

Table C3.3: Unit C3 and characteristic lineages at stage three of cluster analysis (Figure 4.5)

	Lineage:	C3: (CL%)
1.	*Bradypodion*	86.96
2.	Achariaeae	80.00
3.	*Agapanthus*	75.29
4.	Promeropidae	65.68
5.	Heleophrynidae	60.00
6.	Greyiaceae	55.38
7.	Grubbiaceae + Curtisiaceae	54.00
8.	*Tulbaghia*	44.44
9.	*Afroedura*	43.78
10.	Bruniaceae	40.50
11.	*Stangeria*	25.00
12.	*Anthochortus* + *Willdenowia*	25.00
13.	Lanariaceae	20.00
14.	*Nectaropetalum*	15.00
15.	Nivenioideae	15.00
16.	*Hypocalytpus*	15.00
17.	*Malacothrix typica*	12.27
18.	Geissolomataceae	10.00
19.	Roridulaceae	10.00
20.	*Platysaurus*	6.67
21.	*Grielum*	1.54
22.	*Petromus typicus*	0.33
23.	*Rhoptropus*	0.00
24.	*Rhoptropella*	0.00
25.	*Narudasia*	0.00
26.	Welwitschiaceae	0.00
27.	*Moringa ovalifolia*	0.00

OGUs included in unit C3:

SMPL - Southern Maputaland
PTCB - Pondoland-Southern Transkei Coastal Belt
ABCB - Albany Coastal Belt
WBSP - Wolkberg-Soutpansberg
NMPE - Northern Mpumalanga Escarpment
NMLV - Northern Middleveld
SMLV - Southern Middleveld
KDME - KZN-Drakensberg-Mpumalanga Escarpment
DBRG - Drakensberg
NTMD - Natal-Transkei Midlands

NLCB - Natal Coastal Belt
ATWB - Amatola-Winterberg
KNYS - Knysna
OBRG - Overberg
WFYN - Western Fynbos
MHVD - Mesic Highveld
SBRG - Sneeuberg
LKRR - Lower Karoo Region
NQLD - Namaqualand
RVHT - Roggeveld-Hantam

Table C3.4: Unit C4 and characteristic lineages at stage three of cluster analysis (Figure 4.5)

	Lineage:	C4: (CL%)
1.	*Platysaurus*	69.96
2.	Grubbiaceae + Curtisiaceae	23.73
3.	*Afroedura*	22.89
4.	Promeropidae	6.68
5.	*Tulbaghia*	3.27
6.	Greyiaceae	0.45
7.	*Agapanthus*	0.35
8.	Heleophrynidae	0.00
9.	*Bradypodion*	0.00
10.	*Rhoptropus*	0.00
11.	*Rhoptropella*	0.00
12.	*Narudasia*	0.00
13.	*Malacothrix typica*	0.00
14.	*Petromus typicus*	0.00
15.	Bruniaceae	0.00
16.	Geissolomataceae	0.00
17.	Lanariaceae	0.00
18.	Roridulaceae	0.00
19.	*Stangeria*	0.00
20.	Welwitschiaceae	0.00
21.	*Moringa ovalifolia*	0.00
22.	*Anthochortus* + *Willdenowia*	0.00
23.	*Nectaropetalum*	0.00
24.	*Grielum*	0.00
25.	Nivenioideae	0.00
26.	*Hypocalytpus*	0.00
27.	Achariaeae	0.00

OGUs included in unit C4:

WBCB - Waterberg-Central Bushveld
MUCT - Munyati-Chitungwiza
SNMP - Southern Mopane
CHMN - Chimanimani
SINH - Save-Inhambane
LPSR - Limpopo-Serowe
LPBH - Limpopo-Banhine
BUZI - Buzi
TTZB - Tete-Zambezi
RNDE - Runde

NYGN - Nyangani
MINH - Northern Maputaland-Inhambane
QMZB - Quelimane-Zambezi
MTMW - Matandwe-Mwabvi
NXSP - Naxi Salt Pan
MTPO - Matopo
MACH - Mafungabusa-Chizarira

Appendix C4:

Table C4.1: Unit D1, the whole southern Africa and characteristic lineages (stage four of the cluster analysis) (Figure 4.6)

	Lineages:	D1: (CL%)
1.	*Tulbaghia*	60.81
2.	*Afroedura*	50.00
3.	*Malacothrix typica*	44.60
4.	Grubbiaceae + Curtisiaceae	40.54
5.	*Platysaurus*	36.49
6.	*Bradypodion*	31.08
7.	Promeropidae	29.73
8.	*Agapanthus*	22.97
9.	Achariaeae	21.62
10.	*Petromus typicus*	20.27
11.	Greyiaceae	17.57
12.	*Grielum*	17.57
13.	Heleophrynidae	16.22
14.	*Moringa ovalifolia*	16.22
15.	Bruniaceae	13.51
16.	Welwitschiaceae	13.51
17.	*Rhoptropus*	12.16
18.	*Narudasia*	10.81
19.	*Stangeria*	6.76
20.	*Anthochortus* + *Willdenowia*	6.76
21.	Lanariaceae	5.41
22.	*Rhoptropella*	4.05
23.	*Nectaropetalum*	4.05
24.	Nivenioideae	4.05
25.	*Hypocalyptus*	4.05
26.	Geissolomataceae	2.70
27.	Roridulaceae	2.70