Redefining the Griqualand West Centre of Endemism

AW Frisby
25474014

Dissertation submitted in fulfilment of the requirements for the degree *Magister Scientiae* in Botany at the Potchefstroom Campus of the North-West University

Supervisor: Prof SJ Siebert
Co-supervisor: Mr DP Cilliers

May 2016

DECLARATION

I declare that the work presented in this Masters dissertation is my own work, that it has not been submitted for any degree or examination at any other university, and that all the sources I have used or quoted have been acknowledged by complete reference.

Signature of the Student:…………………………………………………………

Signature of the Supervisor:………………………………………

ABSTRACT

The Griqualand West Centre (GWC) of plant endemism in the Northern Cape was defined and described in 2001 according to geological features and limited floristic data. Approximately 40 plant species were proposed to be endemic to the GWC in an area larger than Lesotho and similar in size to provinces such as KwaZulu-Natal and Mpumalanga. As these political areas each contain one or more centres of endemism with hundreds of endemics, the existence of a GWC could be questioned considering its large size and few endemics. To test for the presence of the GWC, data regarding the plant species present in the region and their distributions were sourced from the Plants of Southern Africa database, literature surveys and herbaria with specimens collected from the region. After mapping the species distributions, 24 plant species were found to be restricted to the Griqualand West region. The disjunct distributions of two near-endemic taxa indicated a link between the GWC and two other centres of plant endemism, namely Gariep and Sekhukhuneland. Based on the distributions of species deemed to be floristic elements of the Griqualand West region, links were identified with both the Nama-Karoo and Savanna biomes. When the total distributions of all GWC endemic and near-endemic species are considered, the resulting boundaries of the GWC are extensive, covering an area even larger than the existing unresolved boundaries. Thus, this study proposed the concept of ‗core area‘ when assessing large centres with few endemic species. In this method, distant outlier populations (>100 km) of endemic or near-endemic species are discarded during the demarcation of the Centre. The proposed boundaries of the GWC by means of concept of core area differs from the 2001 borders in two ways, namely that the duneveld in the northern and north-western section of the GWC is not included in the new boundaries and that it is extended eastwards towards Kimberley to include thornveld. Two GWC endemics may be edaphic specialists, having only been recorded on soils rich in calcium, namely *Nuxia gracilis* (near-endemic) and *Rennera stellata*. The floristic patterns in Griqualand West were identified with cluster analysis. Resulting floristic clusters were compared to the extent of various abiotic variables to infer links with the flora. As previous studies have suggested, geology was a major factor dividing the flora of Griqualand West according to areas dominated by siliciclastic rock, limestone and dolomite, mafic and felsic formations, and schists. However, topography and climate also had a major influence on the flora, with divisions on similar geology being ascribed to mean rainfall and temperature or geomorphology (plateau, mountain or valley). A number of GWC endemics were restricted to three of the floristic clusters present within the core area boundaries, which allowed the description of three sub-centres of endemism, namely the Northern Ghaap Plateau and Kuruman Hills, Southern Kalahari and Langeberge, and Southern Ghaap Plateau and Kimberley-Prieska valley sub-centres.

Key words: centre of endemism; climate; endemic; floristic; geology; Griqualand West; near-endemic; topography

ACKNOWLEDGEMENTS

I would like to thank the following people and institutions for their contribution to my dissertation:

- My parents and sister for their constant support;
- My supervisors, Prof. SJ Siebert and Mr. D Cilliers for their guidance and support;
- Prof. AE van Wyk for sharing his knowledge of Griqualand West and its flora;
- Fellow students that helped with fieldwork and data collection, including M Andriessen, D Komape, L Jabar, N van Staden and L Darlow;
- Dr. S Ellis for assistance with statistical analysis;
- The department of Botany at the North West University, Potchefstroom;
- Idawa Mine management and private land owners in Griqualand West for allowing access to their properties for botanical collections;
- Herbarium staff at the following herbaria: A.P. Goossens Herbarium (PUC), McGregor Museum Herbarium (KMG), H.G.W.J. Schweickerdt Herbarium (PRU), South African National Parks Herbarium (KSAN), National Museum Herbarium (NMB), Geo Potts Herbarium (BLFU) and Pretoria National Herbarium (PRE);
- The North-West University for financial support.

TABLE OF CONTENTS

Chapter 3: Griqualand West study area 22

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

1.1 Background and Rationale

Human activities including agriculture (Tilman 1999), mining (Bridge 2004), urbanization (Liu *et al*. 2011), and human-mediated climate change (Adger *et al*. 2007), to name but a few, are having increasingly detrimental effects on the environment. It is of paramount importance that the short-sighted destruction of life-sustaining ecosystem services is reduced dramatically in the near future (Alexander *et al*. 1997). In terrestrial ecosystems, plants are the primary producers (Lieth 1973) and are therefore a key component in the functioning of said ecosystems. The importance of conserving plants and the ecosystems of which they are a basal part is severely understated (Myers 1988; 1990).

In various parts of the world, plant taxa with highly restricted distributions have been identified and placed on lists such as the Red data list of southern African plants (Hilton-Taylor 1996), so as to aid their conservation. Red data lists provide guidelines for why and where conservation efforts should be concentrated (Golding 2002). These plant taxa may require focussed conservation efforts as they are, or could easily become, threatened with extinction (Golding 2002). Identifying areas where there is a high density of such taxa is an important step in their conservation. A Centre of Plant Endemism is a geographical region in which many plant taxa with highly restricted total distributions (endemics) co-occur (van Wyk & Smith 2001). Identifying Centres of Plant Endemism may greatly aid plant conservation efforts by allowing specific regions to be actively conserved (Wilson *in* van Wyk & Smith 2001).

Efforts to identify Centres of Plant Endemism have been undertaken on most continents including South America (e.g. Nelson *et al*. 1990), North America (e.g. Estill & Cuzan 2001), Asia (e.g. López-Pujol *et al*. 2011), Europe (e.g. Tribsch 2004), Australasia (e.g. Crisp *et al*. 2001), Africa (e.g. Linder 2001) and various island chains (e.g. Bramwell 1976). When considering that up to 20% of earth‘s flowering plants are still undescribed (Joppa *et al*. 2011), it is likely that Centres of Plant Endemism are yet to be identified in various parts of the globe.

In southern Africa, various centres of endemism have been proposed. Many of these centres are still only vaguely defined. Van Wyk & Smith (2001) represents the most comprehensive overview of Centres of Plant Endemism in the region. In this publication, 18 centres were proposed, one of which is the Griqualand West Centre (GWC) of Plant Endemism. This is an example of a centre that remains vaguely defined, as its proposal is based on limited plant distribution records and the exceptional geology of the region– a factor known to be linked to plant endemism (see Chapter 2).

The lack of relevant floristic information for the region makes a more accurate definition of the GWC, its borders, endemics and its conservation impossible.

Despite the limited botanical research in the GWC (Wilman 1946), the floristic diversity of this region is undisputed. John Acocks, during his botanical survey of South Africa in the mid-20th century, collected more species in a sampling point in Griqualand West than at any other point in the country (Acocks 1988). The complex geology of this region is expected to be a large contributing factor resulting in the presence of endemic taxa (Wyk & Smith 2001). Van Wyk & Smith (2001) also proposed that many plant taxa in the GWC may remain undescribed, some of which could have highly restricted ranges and therefore be of special conservation significance.

As so little is known about the GWC and its poor conservation status, with only two official nature reserves (Witsand Nature Reserve and Mokala National Park), its ecosystems and biodiversity could become threatened by uninformed development decisions. The extraordinary geology of the area has resulted in parts of this centre being destroyed or disturbed through mining activities (van Wyk & Smith 2001). Thus, the mining activity represents the greatest threat to the biodiversity of the GWC, with the possibility that a number of edaphic specialist species may be under threat.

The strong mining presence in the area emphasizes the need to identify the endemic plant species and delimit the boundaries of the GWC, which will enable informed decisions to be made on how to best conserve the remaining natural habitats in the region and to protect its ecosystems.

1.2 Layout and approach

This dissertation is divided into six chapters. The Introduction (Chapter 1) provides background for the study and states the rationale. This chapter also presents the principal aims and hypotheses of the study. The Literature Review (Chapter 2) provides the phytogeographical context by discussing examples of plant endemism on a variety of geologies and briefly outlining some of the methods commonly used to identify centres of plant endemism. Chapter 3 describes the GWC Study Area in terms of its anthropogenic and geological histories, and provides maps outlining the major abiotic variables of the region and its vegetation. Endemic and Near-endemic Taxa of the Griqualand West Centre of Endemism (Chapter 4) considers the GWC endemic and near-endemic species and presents, with evidence, the GWC endemics and near-endemics and redefines its borders. Floristic Patterns of Griqualand West (Chapter 5) identifies floristic patterns in the Griqualand West and links the floristic patterns and endemic taxa distributions to abiotic variables. Synopsis and Future Prospects (Chapter 6) discusses the major findings and how the aims of the study have been met, discussues potential threats to the GWC and suggests conservation priorities, and proposes further research.

1.3 Hypotheses and principal aims

The three main aims of this study were to:

- Gather floristic data to identify GWC endemic plant taxa by means of a spatial assessment;
- Redefine the GWC boundaries based on the collective distributions of endemic taxa;
- Assess relationships between floristic sub-centres of endemism, endemics and abiotic variables.

The principle aims of this study are based on two hypotheses, namely:

> i) Van Wyk & Smith (2003) and Mucina & Rutherford (2006) refers to a centre of endemism in Griqualand-West. If a centre of endemism is present in this region, then a number of species will be endemic to the area demarcated as such.
> ii) Van Wyk & Smith (2003) and Mucina & Rutherford (2006) links the majority of proposed endemics to the geology. If the endemicity is a consequence of the rock types present, then the endemics will be restricted to a specific geology or combinations of geological types.

1.4 Objectives

The objectives of this study were to:

- Collect all available distribution records of potential GWC endemics.
- Collect substrate information of all potential GWC endemics.
- Identify GWC endemic, near-endemics and floristic element species based on known distributions and the broad GWC borders of van Wyk & Smith (2001).
- Assess and modify the borders for the GWC.
- Identify regions within the GWC where there is a high density of endemics.
- Create a presence-absence matrix for all species present in the study area.
- Identify floristic clusters in the study area.
- Identify characteristic and diagnostic species for each floristic cluster.
- Identify links between floristic clusters and abiotic variables of the study area.
- Describe the characteristics of floristic clusters in the study area based on abiotic variables.

- Identify sub-centres of endemism based on floristic clusters that are within the GWC core area borders.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A number of phytogeographic (study of plant distributions) concepts and definitions must be considered to understand the concept of plant endemism. Part of this review explores important terms associated with plant endemism specifically.

Various methods may be employed to identify regions with high levels of plant endemism. As with all studies of nature, the scale at which observations are made greatly influences the manner in which results are interpreted. Thus, certain methods may be more or less appropriate depending on the nature of the study area and the desired outcome. This review provides an overview of some of the most commonly used approaches when attempting to identify and classify areas of with high levels of plant endemism.

Griqualand West has a highly varied geology and it is expected that edaphic specialist species will be present in the region (van Wyk & Smith 2001). A broad overview is given of local (southern African) and global endemism on substrates that are prevalent in Griqualand West so as to illustrate the possibility of similar substrate-related endemism in said region.

2.2 Floristic concepts

An endemic taxon is defined as a taxon which is limited in its range to a specific geographical area (Kruckeberg & Rabinowitz 1985). These endemic taxa are often the characterising elements of the floristic region of which they are a part (van Wyk & Smith 2001). It is important to note that the size of the geographical area referred to in the definition may take on any size. To illustrate this point, consider that all species on earth are endemic to the planet. This is not very helpful to differentiate between phytogeographic patterns and for this reason the geographical area referred to in the definition of an endemic taxon is usually relatively small. A concept related to endemism is that of the floristic element. This term refers specifically to a taxon which has a geographical range which coincides with that of endemic species of a centre of endemism, but is distributed beyond the boundaries of the centre (White 1979). A floristic element of a phytogeographical region is identified as such by having its main distribution in said phytogeographical region.

White (1983) defined a Regional Centre of Endemism (RCE) as a phytochorion which has more than 50% of its species confined to it and a total of more than 1000 endemic species. If this definition is followed, the resulting RCE most often covers a large geographical area, which, given the available resources and current land utilisation practices, is of little use for conservation purposes (van Wyk & Smith 2001).

A Centre of Plant Endemism (CPE) is considered to be an area of relatively small size (smaller than that of a RCE) which harbours a unique assemblage of species and infraspecific taxa, some of which are endemic species or near-endemics (a species with a restricted range also marginally present in an adjacent area of smaller size than the area in which it is most numerous (White 1983)). A CPE is ranked hierarchically below the level of RCE. Thus, a number of CPE's may fall within the borders of a RCE.

Another well-known classification involving plant endemism is the ‗hotspot' concept (Myers 1988; 1990). A hotspot is a region with exceptional concentrations of species with high levels of endemism (at least 1 500 endemic plant species). Crucially, to be classified as a hotspot, the region must face a severe threat of destruction, having already lost at least 75% of its original extent (Myers 1990). This classification method, as with White (1983), is of greater application for larger scales, specifically on a global scale (van Wyk & Smith 2001).

A Centre of Plant Diversity (CPD), is similar to a CPE, but should not to be confused with it. The former is a term coined by the WWF/IUCN (WWF & IUCN 1994-1997) and refers to an area that is of high conservation value in terms of protecting the highest number of plant species, many of which are endemics. If sufficient endemics are present in a CPD, it may be considered a Centre of Plant Endemism and Diversity (CPED (SABONET 2005)). That is, a CPD can also be a CPE. However, unlike a CPE, a CPED can also be classified as an Important Plant Area (IPA) (Anderson 2002) that is important for site-based (small scale) conservation planning. However, not all CPED's are IPA's (SABONET 2005). It must be noted that a CPED is not part of a classification hierarchy such as is the case with RCE's and CPE's. This is because a CPED is not bound by the borders of a RCE and may violate its borders. A CPD should also not be confused with the term Centre of Diversity which is applied in biogeography and systematics to refer to the centre of origin of a specific plant species (Acquaah 2007).

2.3 Methods to identify CPD's and CPE's

2.3.1 Intuitive discernment

In southern Africa, a number of databases in which distribution records of plant taxa are aggregated and are available for use in scientific research as well as to the interested layman. These databases include, among others, Plants of southern Africa: an online checklist (PRECIS) and the African Plant database (TROPICOS). Visual investigations of the recorded distributions of plant species are sufficient to identify regions with a pattern of co-occurring plant species with restricted distribution ranges. This was largely the method followed by van Wyk & Smith (2001) in their identification of centres of plant endemism for southern Africa. This method is known as intuitive discernment (Rosen 1988), and has been both heavily criticized (Webb 1965) and soundly defended (White 1983). It is of my opinion that this method is acceptable to utilise under the following three conditions: i) The datasets used are not deficient (that is, the regions in question are well collected); ii) the discerned patterns are subjected to subsequent analysis, and iii) it is appreciated that due to human disturbance and changing environmental conditions, a given data point may not represent current reality.

2.3.2 Species area curves

One commonly used method to identify CPD‘s and CPE‘s makes use of the species-area curve (Cain 1938). In this method, the number of species present are counted as area incrementally increases and plotted on a graph with unit area as the independent variable. Thus, the number of species present in any geographical region may be extrapolated for a specific unit area. The value obtained may then be compared to the corresponding value for surrounding regions. Although simple, this method would be impractical due to labour and time related constraints, owing to the required sample size. Thus, the species area-curve data are often subjected to transformation and sorting. Species-area data may be subjected to double-logarithmic transformation and also divided based on aridity of sample sites (Cowling *et al*. 1998). By doing this, differences in species diversity distribution resulting from community variation and a number of major climatic variables are accounted for, potentially reducing error rates. Ultimately, this allows vastly different and often widely separated floras to be statistically compared, and floristically diverse regions to be identified with greater confidence.

2.3.3 Gap analysis

Gap analysis (Scott *et al.* 1993) utilises programes such as GIS (ESRI, 2011) to identify areas with high biodiversity that are currently not formally protected. This approach informs the establishment of new reserves and/or instigates changes in land management practices so that vulnerable species and/or vegetation types may be conserved (Scott *et al.* 1993). The identification of ‗gaps‘ is done by considering an array of both biotic and abiotic variables (Scott *et al.* 1993). GIS (ESRI 2011) allows various digital maps to be overlaid. Examples of some layers that may be used include, among others, rainfall averages, year-round temperature averages and extremes, topography, vegetation units, individual species distributions, substrate distributions, and degree of human-induced habitat degradation in the form of fragmentation, pollution and transformation for a variety of purposes (Scott *et al.* 1993).

An advantage of gap analysis is that it is less restricted by funding constraints than some fieldwork-intensive methods (Scott *et al.* 1993). A further advantage is that various filters may be employed so as to visualise the level of association between a given number of variables, thus allowing certain variables to be discarded and others to be included depending on the desired level of resolution. A simple filter that may be employed is to locate areas of high species richness by locating areas of ‗maximum overlap‘ (Scott *et al.* 1993). This is achieved by using recorded species distributions as the only variable.

There are, however, a number of drawbacks associated with gap analysis. These drawbacks are mainly associated with inaccuracies that may result from poor resolution of available datasets, as well as the unavailability of datasets for potentially important variables. An example of inaccuracy resulting from low data resolution is the resulting inability to account for the presence of species occurring in small, sparsely distributed habitats (Scott *et al*. 1993) such as seepage (Stohlgren *et al*. 1997) and anomalous geological features (Boneschans *et al*. 2015), to name but a few. Additionally, poor sampling effort may result in underestimates of species distributions through failure to identify significant associations between a given species and an associated variable, such as a preferred substrate. In acknowledgment of the potential drawbacks of the method, Scott *et al.* (1993) state that ―field verification of gap analysis maps and recommendations at specific sites (at a scale more detailed than that used to verify regional gap analysis) is essential prior to any conservation or biodiversity management action". Stohlgren *et al*. (1997) address many of the potential inaccuracies of the method by increasing the resolution of the data, as well as further eliminating bias. This is largely achieved by improving sampling techniques, key among which is the reduction of the minimum mapping unit size and by employing double sampling techniques for accurate stratification of homogenous and heterogeneous vegetation units (Stohlgren *et al.* 1997). However, despite improved methodology, Stohlgren *et al*. (1997) note that habitat types of conservation importance are not always accounted for following gap analysis, emphasising the need for caution.

2.3.4 Parsimony analysis of endemicity

Parsimony Analysis of Endemicity (PAE) (Rosen 1988) is a method that classifies areas (localities or quadrats) according to their shared taxa, resulting in a hierarchical classification of the geographical units. This method has been applied to large data-sets and over large geographical areas. As an example, Saiz *et al*. (2013) used PAE to analyse floristic distribution records (79 194 records) to successfully identify areas of high endemism in the Iberian Peninsula and the Balearic Islands, an area of 585 000 km^2.

PAE requires the study area to be divided into areas (grids) of equal or similar size and a list of taxa for each grid is compiled. In the case of Saiz *et al*. (2013), each grid had the dimensions of 50 x 50 km. However, this grid size can be altered depending on the level of resolution desired or to accommodate the nature of the available data set. It is important to note that certain grids can be excluded due to a higher than desired threshold of a particular cover type such as agricultural land, regions lying outside the study area or in the ocean (Saiz *et al*. 2013). The taxa present in each grid can be considered as the characters and thus grids are compared based on similarities of the taxa present (Saiz *et al*. 2013).

Following the division of the data into grids, cluster analysis is undertaken to group the data based on similarity by using any one of a variety of computer programs. Various cluster algorithms can be selected for the analysis, including the Unweighted Pair Group Method using Arithmetic Averages (UPGMA) and the Jaccard index. UPGMA has been shown to perform particularly well when used for biogeographical regionalization purposes (Legendre & Legendre 1998).

Parsimony analysis is then done under maximum parsimony to group grids based on overall similarity. Areas of endemism can then be identified by locating groups of grids that were found to be distinct from others due to the presence of at least two taxa with restricted distributions (Saiz *et al*. 2013). Single grids found to be distinct due to the presence of two or more exclusive taxa are also recognised as areas of endemism (Saiz *et al*. 2013).

PAE is a useful method, particularly when attempting to understand and visualize large-scale biodiversity patterns, such as on the regional scale. However, one key necessity of this method is access to a complete data set. PAE may produce distorted results that are of little use when the amount of data available for each grid is not relatively similar. Thus, extensive sampling efforts may be required in data-deficient areas prior to utilising PAE.

2.3.5 Floristic data collation and collection

The above described methods have, at least in part, been devised so as to minimise manual labour and to yield results as fast as possible. However, if time and labour is not a constraint, by far the best method to use in identifying CPD‘s and CPE‘s is to sample a region systematically, preferably over a number of seasons. By using this method, very little subjectivity is required and the downfalls of statistical analysis using models may be avoided.

Areas to be targeted for floristic surveys should be determined by collating all available data and thereby identifying areas that are poorly sampled. Once data-deficient regions have been identified, they may be visited and specimens collected of all (preferably fertile) plants. Areas that are in some way unique, climatically, geologically or otherwise may be specifically targeted for collection efforts. Specimens can then be expertly identified and a species list for the region created. The levels of endemism and diversity can then be accurately calculated which may or may not support the regions recognition as a CPE or CPD.

As an example, the Sneeuberg Centre of Endemism (Eastern Cape, South Africa) was identified using this intense sampling method (Clark *et al*. 2009). The fieldwork was done over a period of four years and encompassed a total of 18 collection trips (Clark *et al*. 2009). Over 5000 plant specimens were collected and identified by taxonomists, yielding 1195 species, eight of which were new to science (Clark *et al*. 2009). The Sneeuberg Centre was shown to have 33 (2.8 %) endemic and 13 (1.1 %) near-endemic species (Clark *et al*. 2009). The results obtained through this method allowed some clarification of the greater Albany Centre (van Wyk & Smith 2001) of which the Sneeuberg Centre is a part.

2.4 Edaphic endemism

2.4.1 Introduction

The geology of an area is represented by the rock types present. These rocks, also known as the parent material (Brady & Weil 2008), undergo both chemical and physical weathering by Earth‘s atmosphere and microbes, a process which ultimately yields soils. Thus, the type of soil that is formed is largely dependent on the nature of the rock from which it originated (Boneschans *et al*. 2015). Land plants, with the exception of epiphytes, are dependent on soils for physical support, air, water, temperature moderation, and protection from toxins and accessibility to nutrient elements (Brady & Weil 2008). Plants, in turn, also modify soils in various ways including root action and root exudates (Jenny 1941). The close relationship between plants and soils means that speciation is often driven by geology and edaphic conditions (Kruckeberg & Rabinowitz 1985). As suggested by Gankin & Major (1964) in their *refuge* model, endemic species are often restricted to a soil type that excludes the regionally dominant flora due to a disadvantage such as poor nutrient availability. Thus, species endemic to a soil type have a genetic advantage that allows them to better survive and reproduce on anomalous soil types (Gankin & Major 1964).

A species restricted to a specific soil type will over time become so adapted to the prevailing conditions that it can no longer survive on surrounding soil types, even in the absence of competition (Meyer 1986). Such species may be considered “edaphic specialists” or “edaphic endemics” (Hopper *et al*. 1990). There is a trend of higher levels of substrate-specific endemics on unfertile soils (Cowling & Holmes 1992). Nutrient uptake by edaphic endemics on unfertile soils may rely on microsymbiotic nutrient uptake (Cowling *et al*. 1990). Wild (1968) points out that edaphic specialists exist in an island-like habitat due to the restrictions imposed on the potential for plant migrations. Given the variety of geologies present in the GWC, this review will consider the available literature regarding endemism on the major substrate types present in the GWC. Particular attention is given to edaphic specialist plant species. The location of each geology and substrate type and the respective formation histories are outlined in Chapter 3.

2.4.2 Ironstone and Banded Iron Formation

Ironstone, as referred to in this review, alludes to sedimentary rocks rich in iron. Other rock types may also be rich in iron, but as sedimentary ironstone is the prominent type present in the GWC, particularly in the Asbestos Mountains, only literature associated with this type is discussed here. Plant species endemic to ironstone and its related substrates have been identified in many parts of the world. In south-east Brazil, the so-called “Iron Quadrangle” represents an area of around 7 200 km^2 and is one of the most well studied geological features on earth (Jacobi *et al*. 2007; Jacobi & do Carmo 2008). This region is home to an exceptionally diverse flora, including several plant species which are endemic to soils derived from ironstone (Jacobi *et al*. 2007; Jacobi & do Carmo 2008). Two examples of such species are *Arthrocereus glaziovii* (Cactaceae) and *Ditassa monocoronata* (Apocynaceae) (Jacobi *et al*. 2007; Jacobi & do Carmo 2008). Additionally, there are plant communities in this region which are typically only associated with ironstone outcrops (Jacobi & do Carmo 2008). Ironstone habitats are very poorly conserved in Brazil, and are under considerable threat from the iron-ore industry (Jacobi & do Carmo 2008).

In South-western Australia, banded-iron formations (BIF) are structurally and compositionally different from the surrounding habitats and exhibit high levels of endemism and species turnover (Gibson *et al*. 2010; Gibson *et al*. 2012). Various BIF endemic plant species have been identified (Yates *et al*. 2011), including among others, *Acacia karina* (Nevill *et al*. 2010), *Acacia woodmaniorum* (Fabaceae) (Millar *et al*. 2013), *Banksia nivea* ssp *uliginosa* (Proteaceae), *Darwinia ferricola* (Myrtaceae), *Grevillea brachystylis* subsp. *australis* (Proteceae), *Lambertia orbifolia* (Soorae 2010) (Fig. 1a), *Pityrodia iphthima* (Lamiaceae) (Shepard 2007) and five endangered species of genus *Tetratheca* (Elaeocarpaceae) (Butcher *et al*. 2007; Butcher & Kruass 2009). Poot & Lambers (2003) showed that two *Hakea* (Proteaceae) species endemic to ironstone are able to survive in the shallow and xeric ironstone soils due to various root system characteristics including disproportionately long roots, which emphasises the role of ironstone in plant speciation. As in

Brazil, a number of vegetation types are unique to ironstone in south-western Australia (Markey & Dillon 2008). The ironstone flora of Australia is also under severe threat due to mining activities (Yates *et al*. 2011).

Limited literature is available regarding ironstone endemism in Africa. One species known to have a preference for iron-rich substrates including BIF is *Euphorbia barnardii* (Euphorbiaceae) (Knowles & Witkowski 2000) (Fig 1b), a serpentine endemic in the Sekhukhuneland Centre of Endemism (Limpopo, South Africa).

2.4.3 Calcium-rich substrates

In the GWC, dolomite, limestone and calcrete (calcareous tufa) are all present (van Wyk & Smith 2001). All three afore-mentioned substrates are particularly prominent on the Ghaap Plateau (van Wyk & Smith 2001). Dolomite is an anhydrous carbonate mineral rich in calcium and magnesium, predominantly $CaMg(CO_3)_2$ (Anthony *et al*. 2003). The term dolomite also refers to sedimentary carbonate rock, which is composed predominantly of the dolomite mineral (Anthony *et al*. 2003). Limestone is a sedimentary rock rich in calcium and composed of the minerals calcite and aragonite (calcium carbonate: $CaCO_3$) (Boynton 1966). It consists predominantly of skeletal fragments of marine organisms. Calcrete also known as Hardpan is calcium-rich duricrust, a hardened layer in or on soil (Dixon & McLaren 2009). It is formed when any terrestrial material is cemented or replaced by calcium carbonate ($CaCO_3$), often in arid or semi-arid environments as a result of climatic fluctuations (Dixon & McLaren 2009).

Calcium-rich substrates are a common feature in many places around the world, covering an estimated 20 million km^2 which is around 13% of the total land surface on earth (Yaalon 1988). This is largely due to the ever-changing topography of earth‘s surface, with many now exposed regions having once been below sea-level and thus subjected to accumulating sediments of marine origin. Following emergence from ancient seas, calcium-rich substrates provide an edaphic niche which may be colonised by plants. Plant species endemic to such substrates have been noted in various regions, contributing in some cases disproportionately high numbers of endemic species to the local flora (Cowling & Hilton-Taylor 1997). Vegetation types confined to calcium rich bedrocks are often characterized by high species richness, and are often home to rare and red-listed plant species (Reinhardt *et al*. 2013). Kelly (1922) divided plants in relation to their affinity to calcium-rich substrates into three groups, namely calciphile (Ca-loving), calcifuge (Ca-hating), and indifferent. Species in the calciphile category are of relevance to this study. Examples of plant endemism will be discussed below for each of the calcium-rich substrates present in the GWC.

2.4.3.1 Calcrete

Plant species restricted to calcrete make a significant contribution to the exceptionally diverse Cape floristic region (Low & Berry 2007). The Saldanha Peninsula is home to a number of plant species that are restricted to calcrete systems (Low & Berry 2007), which are prominent in the region. Many of these species are highly endangered and have consequently been placed on the Red Data List (Golding 2002). The calcrete and calcareous sand flora of the region includes 374 calcrete and calcareous sand endemics (Low & Berry 2007). Many of these are rare and endangered, including *Afrolimon capense* (Plumbaginaceae) (Fig. 1c), *Cephalophyllum rostellum* (Aizoaceae), *Helichrysum cochleariforme, Helichrysum tricostatum* (Asteraceae) and *Limonium acuminatum* (Plumbaginaceae). The unique flora of the Saldanha Peninsula is largely due to the calcrete presence which has partly driven plant speciation in the region (Boucher & Rode 1997). Cowling (1983) also noted a high concentration of narrow endemic species occurring on calcareous soils in south-eastern Cape. There are also various fauna endemic to calcrete such as the snake *Bitis armata* which is only found in calcareous fynbos (Mouton 2008). In coastal Eastern Cape, *Syncarpha recurvata* (Asteraceae) is restricted to soft, shallow calcrete sands on calcrete ridges where it faces a variety of threats including calcrete mining for cement production, urban expansion and over-exploitation in the cut-flower industry (Swart 2006).

2.4.3.2 Limestone

In northern Vietnam, the Ha Long Bay World Heritage site is a renowned limestone-rich landscape (Qin *et al*. 2012) which takes the form of many small islands (Fig. 1d). Numerous endemic plant species are known from these limestone islands, including taxa in the Balsaminaceae, Euphorbiaceae, Gesneriaceae, and Urticaceae (Qin *et al*. 2012). Examples of limestone endemics are *Impatiens verrucifer* (Balsaminaceae) and *Triadica rotundifolium* (Euphorbiaceae) (Qin *et al*. 2012). The limestone islands and ourcrops are also home to endemic fauna including two primate species (*Trachypithecus delacouri* and *T. poliocephalus*) (Tuyet 2001).

In the Agulhas Plain in the Cape floristic region (Western Cape, South Africa), 17% (110 taxa) of the plant species occurring on limestone are strict limestone endemics (Cowling *et al*. 1994). Also in the Cape floristic region, the Hagelkraal area and De Hoop Nature Reserve are home to a number of limestone endemic plant species (Willis *et al*. 1996). The De Hoop Nature Reserve is a 'hotspot' for limestone endemic species richness (Willis *et al*. 1996). Within this region, germination rates of certain limestone endemic species were shown to be higher in limestone soils (Mustart & Cowling 1993). Thus, limestone soils must have properties that promote germination in species adapted to grow in said soils. *Annesorhiza calcicola* (Apiaceae) is an example of a limestone endemic from the

Cape region which is known to occur on only a few limestone outcrops on the Saldanha peninsula (Magee & Manning 2010).

In east Africa, limestone endemics have also been recorded. An example is *Diplolophium boranense* (Apiaceae) which occurs on limestone ridges in southern Somalia (Bidgood & Vollesen 2006).

In Middle Tennessee, USA, *Echinacea tennesseensis* (Asteraceae) (Fig. 1e) is endemic to limestone cedar glades (Walck *et al*. 1999). *Talinum calcaricum* (Portulacaceae) is also endemic to limestone cedar glades of middle Tennessee and north Alabama (Ware & Pinion 1990). In central Arizona, four rare limestone endemic species occur, including the endangered shrub *Purshia subintegra* (Rosaceae), which occurs on limestone outcrops in four disjunct populations (Maschinski *et al*. 2004; Maschinski *et al*. 2006). In the Middle Arkansas Valley in Colorado, species endemic to limestone soils are also present, an example of which is *Oxybaphus rotundifolius* (Nyctaginaceae) (Kelso *et al*. 1996).

In southern and central China, limestone outcrops are particularly prominent in the Yunnan and Guangxi Provinces. The vegetation types occurring on limestone in these regions are diverse and rich in endemic taxa, owed largely to the greatly varied edaphic and topographic conditions associated with limestone outcrops (Zhu *et al*. 2003). Zhu *et al*. (2003) identified 1394 taxa occurring on limestone, of which 141 occur only on limestone. This represents around 10% of the limestone flora. Examples of limestone endemic species in this region include *Amoora calcicola* (Meliaceae), *Celtis philippensis* var. *wightii* (Celtidaceae) and *Pistacia weinmannifolia* (Anacardiaceae) (Zhu *et al*. 2003). In Hunan Province (Fig. 1f) located in Southwest China, 68 plant species have been identified as limestone endemics (Yutan 1999).

In North Canterbury, New Zealand, *Heliohebe maccaskillii* (Plantaginaceae) is a threatened species endemic to limestone cliffs (Norton & Molloy 2009). *Oreomyrrhis basicola* (Apiaceae) is another limestone endemic from limestone habitats in the North Canterbury region (Heenan & Molloy 2006).

In the Iberian Peninsula, Spain, *Campanula arvatica* subsp. *adsurgens* (Campanulaceae) and *Petrocoptis grandiflora* (Caryophyllaceae) (Fig. 1g) are among the plant taxa endemic to the limestone rock faces of the region (Guitian *et al*. 1994).

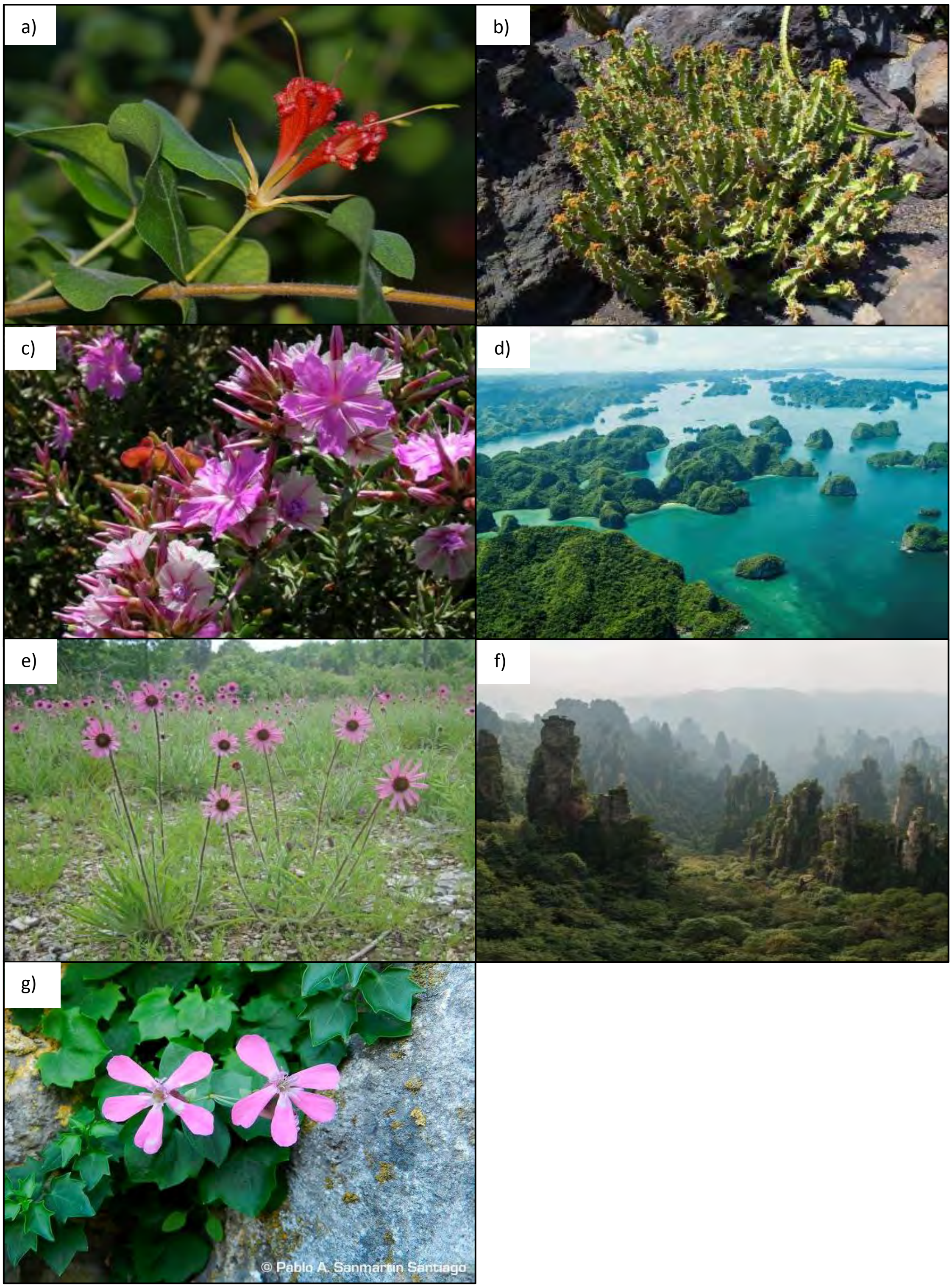


Figure 1: a) *Lambertia orbifolia* (Proteaceae)–an ironstone endemic from south-western Australia (Photo: www.flikr.com. (Russel Cumming)), b) *Euphorbia barnardii* (Euphorbiaceae)–an ironstone endemic in Limpopo, South Africa (Photo: www.commons.wikimedia.org), c) *Afrolimon capense* (Plumbaginaceae)–a calcrete endemic in the Saldanha Peninsula, South Africa (Photo: www.redlist.sanbi.org (N.A. Helme)), d) Aerial view of the limestone-rich Ha Long Bay, Vietnam (Photo: www.travelalltogether.com), e) *Echinacea tennesseensis* (Asteraceae)–a limestone glade endemic from Tennessee, USA (Photo:www.missouribotanicalgarden.com), f) Limestone pinnacles in Hunan Province, China (Photo: www.en.wikipedia.org), g) *Petrocoptis grandiflora* (Caryophyllaceae)–a limestone cliff endemic from northern Spain (Photo: www.arkive.org (Pablo A. Sanmartin Santiago)).

In Slovakia, numerous plant species are endemic to limestone, including *Daphne arbuscula* (Thymelaeaceae), *Erysimum wahlenbergii* (Brassicaceae) and *Onosma tornensis* (Boraginaceae) (Gollasova *et al*. 2002).

In tropical ecosystems, limestone outcrops are also regarded as ―hotspots” (see 2.2) due to the large number of endemic plants and animals they support (Clements *et al*. 2006). In West Malaysia, limestone outcrops (also referred to as karsts) harbour around 1220 karst-associated plant species, 11% of which are strict limestone endemics (Chin 1977). The flora of this region is under severe threat from limestone quarrying (Clements *et al*. 2006). *Begonia sandsiana* (Begoniacece) is another tropical limestone endemic, occurring on limestone karsts on the southern escarpment of Papua New Guinea (Takeuchi 2013).

From the above examples, it is clear that limestone often harbours unique floras in many parts of the world and in a variety of plant families. Some families have a large number of limestone endemics. A good example of this is the Apiaceae. The presence of surface limestone does not, however, guarantee the presence of endemic species. An example of this is the Barrens in south-western Australia. Here, only low levels of endemism were recorded on limestone (Cowling *et al*. 1994). This may be due to the low incidence of limestone in this region. Thus, limited surface limestone may have hampered the development of a limestone flora in Western Australia (Cowling *et al*. 1994).

2.4.3.3 Dolomite

Gazania lanata (Asteraceae) is endemic to dolomite ‗lenses‘ near the town of Robertson in the Cape floristic region, South Africa (Magee *et al*. 2011). *Pearsonia callistoma* (Fabaceae) is a small herbaceous plant endemic to dolomitic substrates in the Wolkberg Centre of endemism in northern South Africa (Campbell-Young & Balkwill 2000). Mathews *et al*. (1993) identified 32 species that are endemic or near-endemic to the dolomitic outcrops of the Chuniespoort Formation on South Africa‘s north-eastern escarpment. Dolomite grassland endemics are known in the heavily-populated Gauteng province, an example being *Habenaria mossii* (Orchidaceae) (Pfab *et al*. 2002).

In Bullitt and Jefferson Counties, Kentucky, USA, *Leavenworthia exigua* var. *laciniata* (Brassicaceae) occurs primarily on dolomite glades (also recorded on limestone glades (Loehle *et al*. 2006)). The Ketona dolomite glades in eastern USA are a region of significant botanical diversity (Allison & Stevens 2001). Multiple dolomite endemics are present, including *Castilleja kraliana* (Orobanchaceae), *Coreopsis grandiflora* var. *inclinata* (Asteraceae), *Dalea cahaba* (Fabaceae) and *Erigeron strigosus* var. *dolomiticola* (Asteraceae), to name but a few (Allison & Stevens 2001). In the interior highlands of the USA, *Scutellaria bushii* (Lamiaceae) is endemic to dolomite outcrops (Zollner *et al*. 2005).

In the Iberian Peninsula, Spain, *Jurinea pinnata* (Asteraceae) is part of the regions' dolomite-endemic flora (Salmerón-Sánchez *et al*. 2014). In the Baetic ranges of Spain, outcrops of dolomite are relatively common and are home to a ‗peculiar' flora with a large proportion of endemic species (Medina-Cazorla *et al*. 2010). The high levels of endemism on dolomitic substrates in the region are attributed to the highly stressful physicochemical conditions associated with dolomite (Mota *et al*. 2008). Around 144 species were identified by Mota *et al*. (2008) to have an affinity to dolomite, some of which occur strictly on dolomite.

Draba ladina (Brassicaceae) is a narrow endemic occurring in the Swiss Alps, predominantly in dolomite crevices (Widmer & Baltisberger 1999). *Soldanella minima* (Primulaceae) is another species endemic to high European mountain ranges occurring on dolomite (Zhang *et al*. 2001). Also in Europe, *Linum dolomiticum* (Linaceae) (Fig. 2a) is a rare species restricted to a few dolomite outcrops in Hungary (Dobolyi 2003).

2.4.4 Quartzite

In South Africa, the Wolkberg Centre of Endemism is located on the north-eastern Drakensberg escarpment and is home to numerous endemic plant species, many of which are restricted to quartzite-derived soils (Campbell-Young & Balkwill 2000). In this region, Mathews *et al*. (1993) identified 81 taxa as endemic or near-endemic to quartzitic substrates, which represent 71% of the endemic species of the region. Ten endemic species belong to the genus *Helichrysum* (Asteraceae) (van Wyk & Smith 2001). In the Soutpansberg Mountains in northern South Africa, most of the 45 endemic taxa occur solely on nutrient poor quartzites or the closely related substrate sandstone (Hahn 2010), an example of which is *Aloe hahnii* (Asphodelacece) (Klopper & Smith 2009). In the Cape floristic region, the majority of the world-famous fynbos flora is endemic to soils derived from quartzite (Cowling 1983). In the Knersvlakte Centre of Endemism, located in the north-eastern corner of the Western Cape Province, South Africa, 39 plant species are found growing amongst quartz pebbles (Rhind 2010). In this region each separate quartz field has a unique flora (Rhind 2010). Endemic species include, among many others, *Argyroderma crateriforme*, *A. subulatum* and *Oophytum nanum*, (Mesembryanthemaceae) (van Wyk & Smith 2001). Although many of these species may not be physiologically dependent on the quartz pebbles, many have adapted to be camouflaged between the white pebbles (Wiens 1978) and are thus dependent on the quartz for protection from herbivory. There are a number of endemics restricted to the quartzitic Magaliesberg and Witwatersrand ranges and surrounding areas. Examples of such quartzite endemics include

Aloe peglerae (Asphodelaceae), *Ceropegia decidua* (Apocynaceae), *Delosperma purpureum* (Fig. 2b) and *D. vogtsii* (Aizoaceae) (Pfab *et al*. 2002).

In the Chimanimani Mountains in Zimbabwe, the infertile quartzites harbour many highly localised endemic species, numbering 41 following a survey in 1963 (Wild *et al*. 1963). This number increased to 55, as identified by Mapaura (2002). *Olea chimanimani* (Oleaceae) is an example of a Chimanimani quartzite endemic (Green & Kupicha 1979).

In Madagascar, *Pentachlaena latifolia* (Sphaerosepalaceae) is endemic to quartzite substrates in the Ibity and Antealabe massifs, and represents one of only a few species belonging to this Madagasy endemic family (Schatz *et al*. 1999).

In the Barrens, southwestern Australia, local endemism on quartzite was found to be near 18%, which was the highest value for any substrate in the region (Cowling *et al*. 1994).

In Europe, the species *Carex cretica* (Cyperaceae) and *Lathyrus neurolobus* (Fabaceae) are among the endemic species occurring in the quartzitic Aegean wetlands in western Crete, Greece (Bergmeier & Abrahamczyk 2007). The afore-mentioned species are under threat due to exploitation of spring waters (Bergmeier & Abrahamczyk 2007).

The *campo rupestre* vegetation type in south-eastern Brazil occurs on quartzite-derived substrates and is a significant centre of floristic diversity and endemism (Alves & Kolbek 1994). In this region many quartzite outcrops harbour endemic species which are often endemic to only one outcrop (Alves & Kolbek 1994). Species in the family Velloziaceae are prominent endemics of the region, with 194 species endemic to the vegetation overlying quartzite (Alves & Kolbek 1994). *Aylthonia tomentosa* and *Vellozia kolbekii* are examples of the regions quartzite-endemic Velloziaceae (Alves & Kolbek 1994). *Vellozia compacta* (Velloziaceae) is near-endemic to quartzite outcrops in the south-eastern Brazilian rupestrian fields, occurring on only one other substrate (ferruginous soil) in a disjunct population (Lousada *et al*. 2013). The Apocynaceae also have many endemic species occurring in the region, with around 18 endemic species (Rapini *et al*. 2002), *Mandevilla rubra* and *M. semirii* as two examples (de Sales *et al*. 2006). *Syagrus glaucescens* (Arecaceae) is another species restricted to the quartzitic rupestrian fields of the southern Espinhaço Range, in Minas Gerais, Brazil (Miola *et al*. 2011).

Also in South America, the Guayana region which extends through Venezuela, the Guayanas, northern Brazil and south-east Colombia, is one of the most significant biodiverse and endemic-rich regions in the world (Rull 2005). The region is famous for the flat-topped, isolated and elevated *tepuis* (Fig. 2c) also known as Table Mountains or collectively as Pantepui, which consist largely of quartzites (Rull 2005). The genus *Chimantaea* (Asteraceae) is an example of a taxon endemic to three specific tepuis (Nogué *et al*. 2013). The Pantepui is home to over 2 300 species, 33% of which are endemic (Rull 2005). The larger *tepuis* may have local endemism levels of up to 54% (Rull 2005).

2.4.5 Sandy substrates

In north-central South Africa, the broad vegetation unit, namely Kalahari Duneveld (Mucina & Rutherford 2006) is home to a large number of plant species endemic to deep Aeolian sands. The unique flora, which occurs over parts of Botswana, Namibia and north-central South Africa, includes endemic taxa often referred to as ‗Kalahari endemics" (Mucina & Rutherford 2006). Examples of Kalahari endemics include *Acacia haematoxylon*, *A. luederitzii* var. *luederitzii* (Mimosaceae), *Anthephora argentea* (Poaceae), *Helichrysum arenicola* (Asteraceae), *Hermannia burchellii* (Malvaceae), *Kohautia ramosissima* (Rubiaceae), *Megaloprotachne albescens* (Poaceae), *Neuradopsis austro-africana* (Neuradaceae), *Orbea knobelii* (Apocynaceae), *Stipagrostis amabilis* (Poaceae) and *Tridentea marientalensis* subsp. *marientalensis* (Asclepiadaceae) (Mucina & Rutherford 2006). Within the Kalahari Duneveld vegetation unit, and also in the Griqualand-West Centre, lies the Witsand Reserve which is home to endemic plant species including *Pterothrix tecta* (Asteraceae) (MacDonald 1981). There are also endemic invertebrates such as the butterfly *Anthene lindae* and *Tuxentius melaena* subsp. *griqua* (Terblanche & Taylor 2000).

In the Maputuland Centre of Endemism extending along the east coast of South Africa, southern Mozambique and eastern Swaziland, many of the 230+ endemic and near-endemic plant species occur on the infertile sandy soils of marine origin (van Wyk 1996). Of particular interest in this region is the plant community known as Sand Forest, which is a rare and species-rich tropical dry forest occurring on ancient coastal sand dunes harbouring many Maputuland endemics (van Wyk & Smith 2001). Endemic species occurring on sandy substrates include *Brachychloa schiemanniana* (Poaceae), *Crinum acuale* (Amaryllidaceae) (Fig. 2d) and *Helichrysopsis septentrionale* (Asteraceae) (van Wyk & Smith 2001) and *Warneckea parvifolia* (Melastomataceae) (Stone & Ntetha 2013).

Located on the coastal plain of Namaqualand, South Africa, the Western Cape Strandveld vegetation type occurs on sands of marine origin and is home to a number of local endemics (Mucina & Rutherford 2011). Endemic species occurring on deep sand include, among others, *Gladiolus carmineus* (Iridaceae), *Lampranthus salteri* (Aizoaceae) (Mucina & Rutherford 2006), *Stoeberia utilis* (Aizoaceae) (Rhind 2010), *Thesium litoreum* (Santalaceae) (Mucina & Rutherford 2006) and *Wooleya farinosa* (Aizoaceae) (Rhind 2010).

In North America, *Cirsium pitcheri* (Asteraceae) is an example of a species endemic to the dune ecosystems of the Great Lakes (Fant *et al*. 2014). Also in North America, the Athabasca sand dunes in central Canada are home to nine (Lamb & Guedo 2012) sand dune endemic plants, namely *Achillea millefolium* var. *megacephala* (Asteraceae), *Armeria maritima* ssp. *interior* (Plumbaginaceae), *Deschampsia mackenzieana* (Poaceae), four *Salix* (Salicaceae) species (Cooper & Cass 2001), *Stellaria arenicola* (Caryophyllaceae) (Purdy *et al*. 1994) and *Tanacetum huronense* var. *floccosum* (Asteraceae) (Karpan & Karpan 1998). In California, USA, the Eureka Dunes (Fig. 2e) are home to narrow endemic species including *Astragalus lentiginosus* var. *micans* (Fabaceae), *Oenothera avita* ssp. *eurekensis* (Onagraceae) and *Swallenia alexandrae* (Poaceae) (Pavlik & Barbour 1988; Pavlik 1989). In the upper Snake River Plain of central Idaho, USA, *Astragalus oniciformis* (Fabaceae) is an example of the narrow endemic flora occurring on the region‘s aeolian sand deposits (Alexander *et al*. 2004). *Bidens cabopulmensis* (Asteraceae) is restricted to the coastal sand dunes of Baja California Sur in Mexico (De la Luz & Medel-Narváez 2013).

In Bahia, eastern Brazil, *Maytenus psammopliila* (Celastraceae) is endemic to sandy soils of dunes in *caatinga*, a semi-arid vegetation type (Biral & Lombardi 2013). Also in Brazil, numerous endemic species occur on white quartzitic sand in the Cerrado Biome, including *Cnidoscolus quercifolius*, *C. urnigerus* (Euphorbiaceae) (Sátiro & Roque 2008), and *Tocoyena* subsp. (Rubiaceae) (Delprete 2008). In Peru, tropical white sand forests are world-renowned for their high levels of endemism (Fine *et al*. 2010). Fine *et al*. (2010) identified 114 species that are endemic to the white sands and identified the region as an important contributor to the overall diversity of the Amazon rainforest.

In eastern Mongolia, *Corispermum elongatum* (Amaranthaceae) is among the endemic flora of both the fixed and mobile sand dunes of the region and is an important soil stabilizer (He *et al*. 2009).

The sand dunes and associated sandy habitats of the European seashores have a large percentage of endemic species, with as much as 25% of the flora restricted to only one province or county (van der Maarel & van der Maarel-Versluys 1996). *Hieracium eriophorum* (Asteraceae) (Fig. 2f) is an example of the afore-mentioned flora, occurring only on the coastal sand dunes of south-west France (Frey *et al*. 2012). The coastal sand dunes of Epirus, Greece, harbour a unique flora, including two sand dune endemics (Spanou *et al*. 2006).

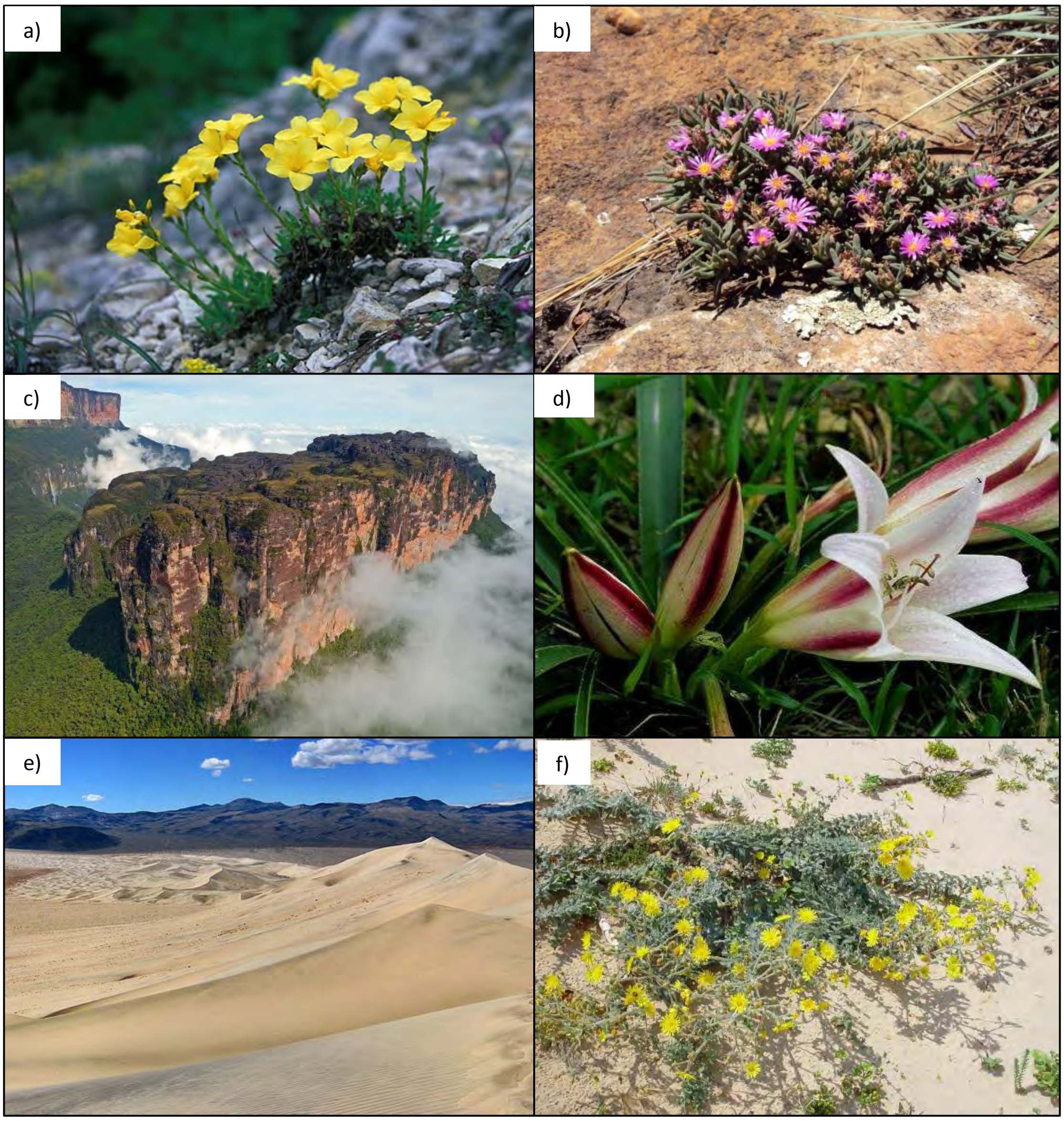


Figure 2: a) *Linum dolomiticum* (Linaceae)–a dolomite from Hungary (Photo: www.dinpi.hu), b) *Delosperma purpureum* (Aizoaceae)–a quartzite endemic from Gauteng, South Africa (Photo: www.ispotnature.org (Georg Fritz)), c) Aerial view of a quartzitic *tepui (Photo:* www.philippekok.com), d) *Crinum acuale* (Amaryllidaceae)–a sand forest endemic from KwaZulu-Natal, South Africa (Photo: www.plantzafrica.com), e) The Eureka Sand Dunes in California, USA (www.summitpost.org), f) *Hieracium eriophorum* (Asteraceae)–a coastal sand dune endemic from South-West France (Photo: www.fr.ch).

CHAPTER 3: GRIQUALAND WEST STUDY AREA

3.1 History

Griqualand West (Fig. 3) is a geographical region of around 40 000 km^2 and is named after the Khoekhoe people inhabiting this area, namely the Griqua (van Wyk & Smith 2001). The Griqua were semi-nomadic tribes with a diverse heritage including Dutch, Tswana, Khoekoe and Khoesan people (Penn 2005). Many Griqua people still live in Griqualand although they are no longer semi-nomadic.

Griqualand West was inhabited by Khoisan people from at least the Late Iron Age (Coon & Hunt 1965). Evidence of their former presence is still visible in the form of rock art which is common in the region (Fig. 4). Following the arrival of Europeans in southern Africa, the region has been the stage for many disputes and conflicts including widespread raiding, land-ownership battles between the Griqua, British and Boers, a rapid influx of foreigners following the discovery of diamonds in 1867, a temporary stint as an official British colony, annexure by the Cape Colony and eventual integration into what is today the Northern Cape province of South Africa (Giliomee & Mbenga 2007).

Throughout the history of the region, the indigenous people have been manipulated, ultimately losing their land (Penn 2005). This had over time lead to a loss of cultural identity. Languages are threatened with extinction and indigenous knowledge of the land is being lost (Anderson & Harrison 2006). Many Griqua communities have a close association with plants (Pienaar 2009) which is maintained by nature reserves and sharing of plant knowledge, particularly medicinal plants (Fig. 5).

3.2 Study area

The area of study encompasses the geographical region of Griqualand West in north-central South Africa, primarily in the Northern Cape Province, but also extending into parts of the North-West and Free State Provinces (Fig. 6). It covers an extensive geographical area (99 000 km^2), larger than the province of KwaZulu-Natal (94 361 km^2). The location of the study area was determined by the borders proposed for the Griqualand West Centre (GWC) by van Wyk & Smith (2001) which in turn were derived from the complex geology of Griqualand West. Based on preliminary data regarding the distributions of potentially endemic plant species, a set of 218 quarter-degree grids (QDG‘s) were defined as the greater Griqualand West study area (GWSA) for the purpose of this study (Fig. 7).

Figure 3: Landscape of Griqualand West, as seen from a BIF hill near the town of Danielskuil. (Photo: AW Frisby)

Figure 4: Koisan rock art on a BIF rock overhang in southern Griqualand West. (Photo: AW Frisby)

Figure 5: *Hoodia gordonii*, seen here growing on ironstone near the town of Prieska, is renowned for its medicinal uses, particularly as a weight loss product owing to its appetite suppressing properties. (Photo: AW Frisby)

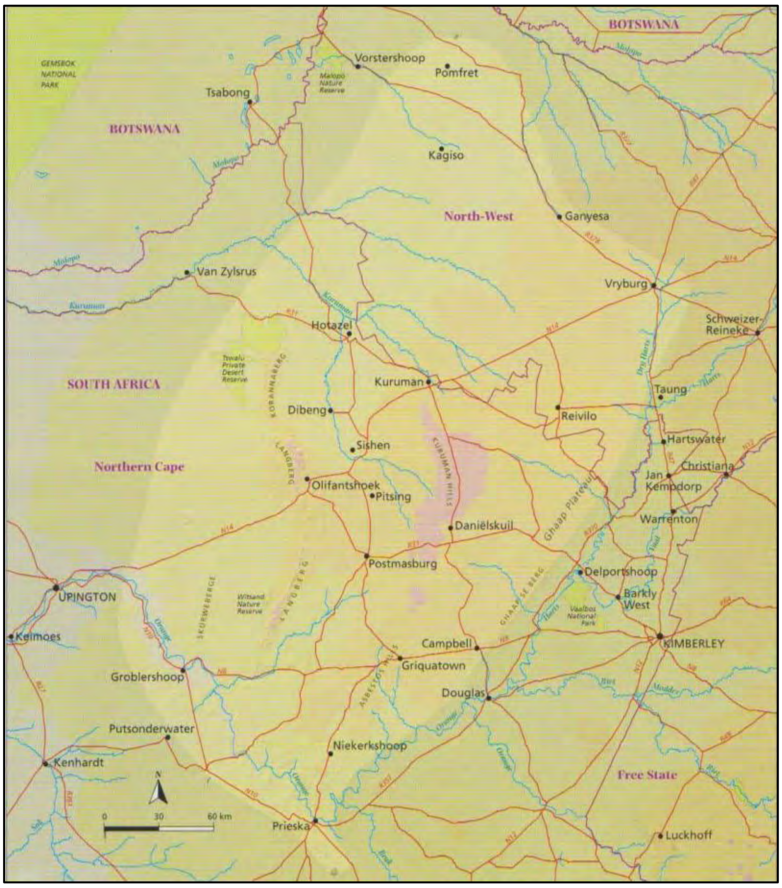


Figure 6: The GWC (light shaded area) as proposed by van Wyk & Smith (2001).

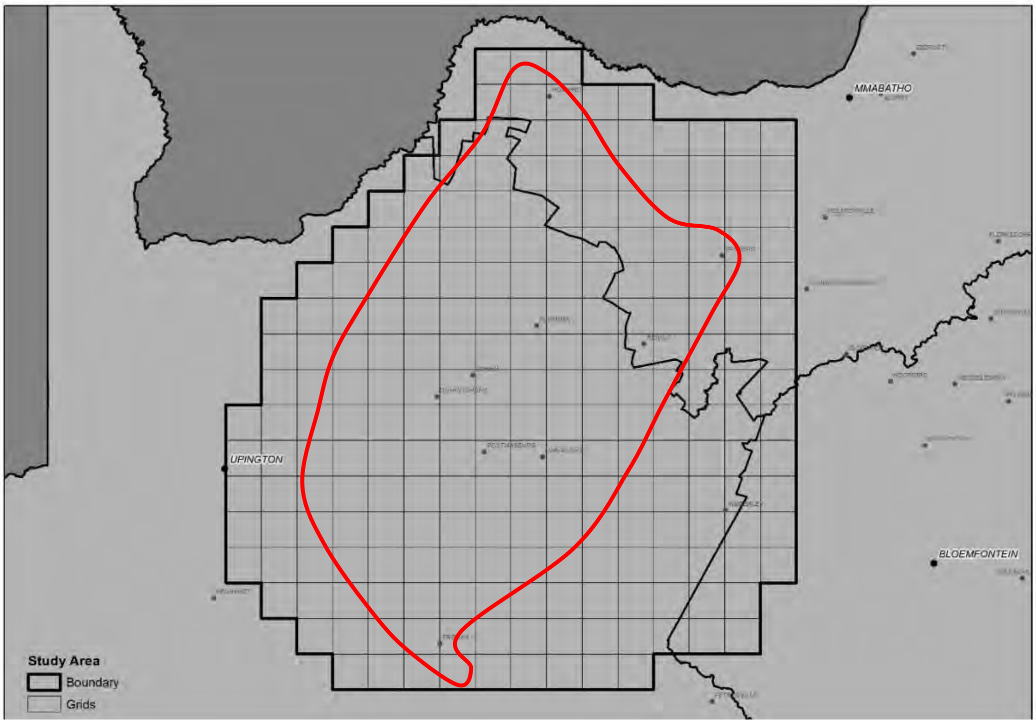


Figure 7: Grids represent the greater Griqualand West Study Area (GWSA). Proposed GWC borders (van Wyk & Smith 2001) are indicated in red.

3.3 Topography and hydrology

The topography of the Griqualand West region is greatly varied, including undulating landscapes with higher and lower-lying areas (Fig. 8). The eastern-central section of the GWSA is a relatively flat plateau approximately 130 km wide and 280 km long, known as the Ghaap Plateau (van Wyk & Smith 2001). It slopes up gently from the eastern escarpment at 1 100 m rising to around 1 450m at its western extreme at the foot of the Kuruman Hills (Acocks 1988), with a maximum altitude of ± 1 530 m asl in the north.

The western-central section of the GWSA has a number of mountain ranges and hills cutting through the region from north to south, including the Langeberge, Korannaberge, Kuruman Hills, Asbestos Hills, Doringberge and the Skurweberge (van Wyk & Smith 2001).

The longest of these ranges in the GWSA are the Langeberge stretching some 160 km (Fig. 9) and reaching a maximun altitude of ± 1 800 m a.s.l. The Korannaberg is a low rising set of hills (± 1 300 m a.s.l.) that are effectively a northerly extension of the Langeberge, extending some 30km.

The Kuruman Hills are the the highest (1 835+ m a.s.l.) in the GWSA, extending around 90 km from north to south between the towns of Kuruman in the north and Danielskuil in the south. The Abestos Hills are a range of low hills (± 1 200 m a.s.l.) that extend northwards for 50 km from just north of Griquatown. The Doringberge (Fig. 10) are particularly prominent (± 1 300 m a.s.l.) around the town of Prieska. The Skurweberge are a set of small hills (± 1 200 m a.s.l.) north of Groblershoop, extending about 20 km from north to south. West of the Skurweberge and Doringberge, towards the towns of Upington to the west and Pomfret to the north, is relatively flat section (± 1 000 m a.s.l.) of the GWSA, dominated by Kalahari sands. The southeast of the GWSA is also relatively flat with numerous small hills and rises (± 1 100 m a.s.l.), with occasional Kalahari sands.

The GWSA, being a semi-arid region, has few perennial rivers (Fig. 11). By far the most prominent is the Orange River (Fig. 12), which forms the southern and south-western boundary of the GWSA. In the east, the Harts River drains the Ghaap Plateau through a number of eastward flowing tributaries including the Dry Harts River. The Riet River joins the Harts River which then flows into the Orange River just west of the town Douglas. The western Ghaap is drained by a number of small tributaries that ultimately flow into the larger westward flowing Kuruman River which joins the Molopo River and ultimately the Orange River downstream from Augrabies Falls. Due to the scarce and erratic rainfall of the GWSA, many smaller tributaries remain dry for many months, or in extreme droughts, years at a time.

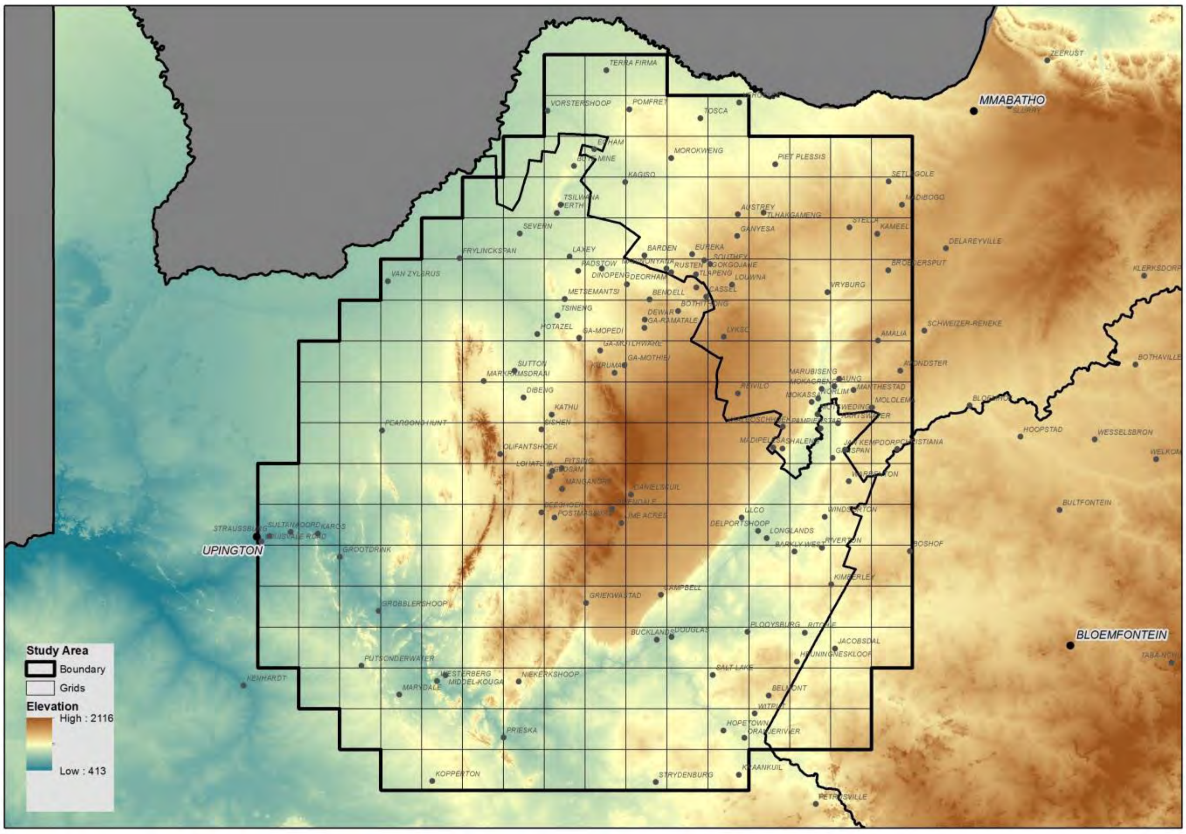


Figure 8: Topography of the GWSA.

Figure 9: Quartzitic Langeberge looking north near Witsand Nature Reserve. (Photo: AW Frisby).

Figure 10: Distant hills of the most south-eastern extent of the Doringberge near the town of Prieska, which consist of Banded Iron Formation. (Photo: AW Frisby).

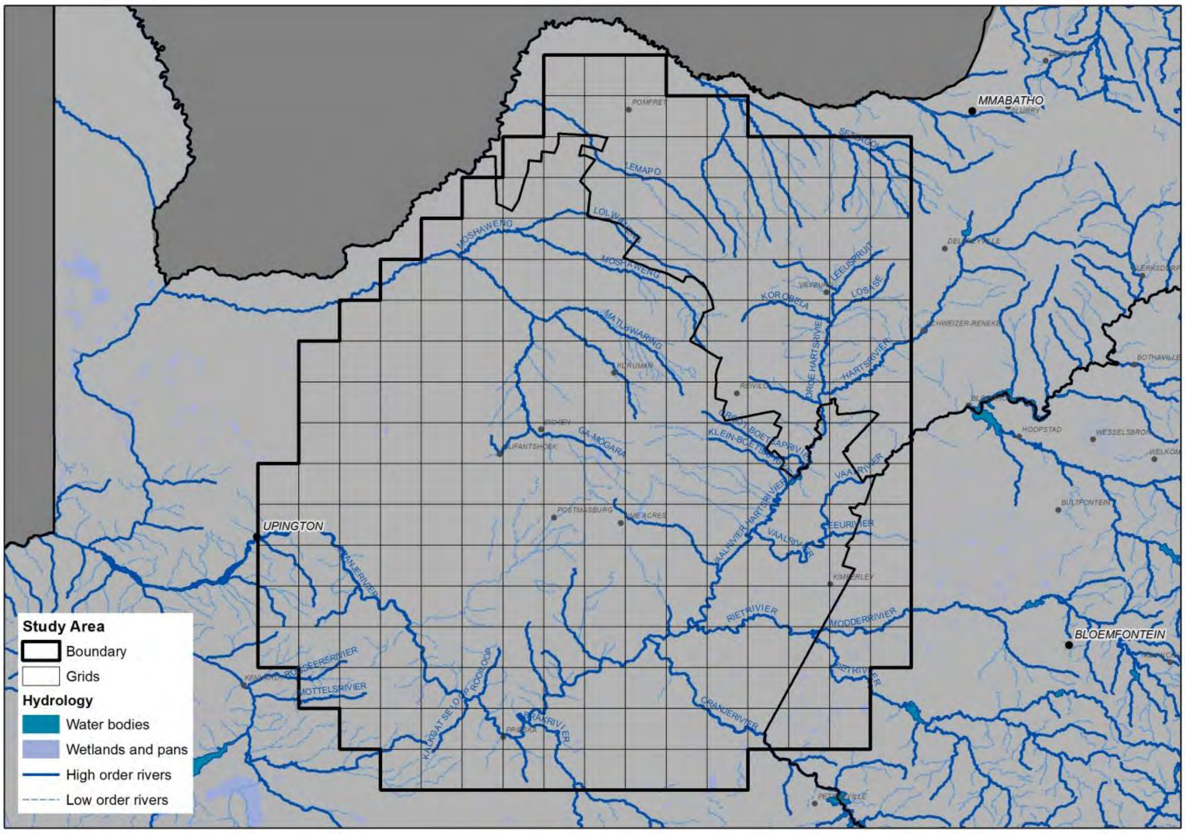


Figure 11: Rivers and drainage basins of the GWSA.

3.4 Geology

The geology of Griqualand West is diverse and complex (Fig. 13), consisting of igneous, sedimentary and metamorphic rocks comprised of an array of parent materials. The geology is representative of much of southern Africa‘s formations, including rocks from the earliest precursor continents of what later formed the Super-continent of Pangaea and later Africa. Griqualand West has economically important deposits of iron (Hälbich *et al*. 1993), manganese (De Villiers 1983) and lime (Altermann & Wotherspoon 1995). The region also has economically important deposits of asbestos (Fig. 14), but no mines remain active due to a drop in global demand owing to health risks. As a result, the GWSA has a strong mining industry, with some of South Africa‘s largest and most active iron mines, such as Sishen Iron Ore Mine (Fig. 15). There are also a number of active lime mines including Idwala Mine near Danielskuil (Fig. 16).

3.4.1 Ventersdorp Supergroup

The Ventersdorp Supergroup consists of igneous lava‘s that were deposited between 2 714 and 2 665 mya following the collision between the Kaapvaal Craton and the Zimbabwe Craton. Today rocks of this formation are present on the eastern extreme of the GWSA north of Kimberley (McCarthy & Rubidge 2005).

3.4.2 Transvaal Supergroup

The Transvaal Supergroup consists of layers of sedimentary rock deposited in a shallow sea some 2 600 m.y.a. The deposits once covered an extensive expanse, covering most of the then Kaapvaal Craton (McCarthy & Rubidge 2005). Subsequent erosion has, however, left outcrops only in the Griqualand West region of the Northern Cape, a small part of southern Botswana and parts of northern South Africa. The Transvaal Supergroup is divided into subgroups, two of which are prominent features of the GWSA.

The first of these subgroups is the Griqualand West Sequence, also known as the Ghaap Group (Altermann & Hälbich 1990). The Ghaap Group is comprised of Calcium-rich sediments including limestone and dolomite (Altermann & Hälbich 1990). These sediments give rise to shallow, black, turfy and highly alkaline soils, and dark brown to red and more sandy soils respectively (Jenny 1941). The majority of the Ghaap Groups‘ modern day extent is exposed as the Ghaap Plateau (Figs. 17 & 18) which is comprised mainly of dolomite (Fig. 19). The Ghaap Plateau is a vast, elevated expanse that forms the most prominent geological feature in the GWSA.

Figure 12: The Orange River near the town of Groblershoop. (Photo: AW Frisby)

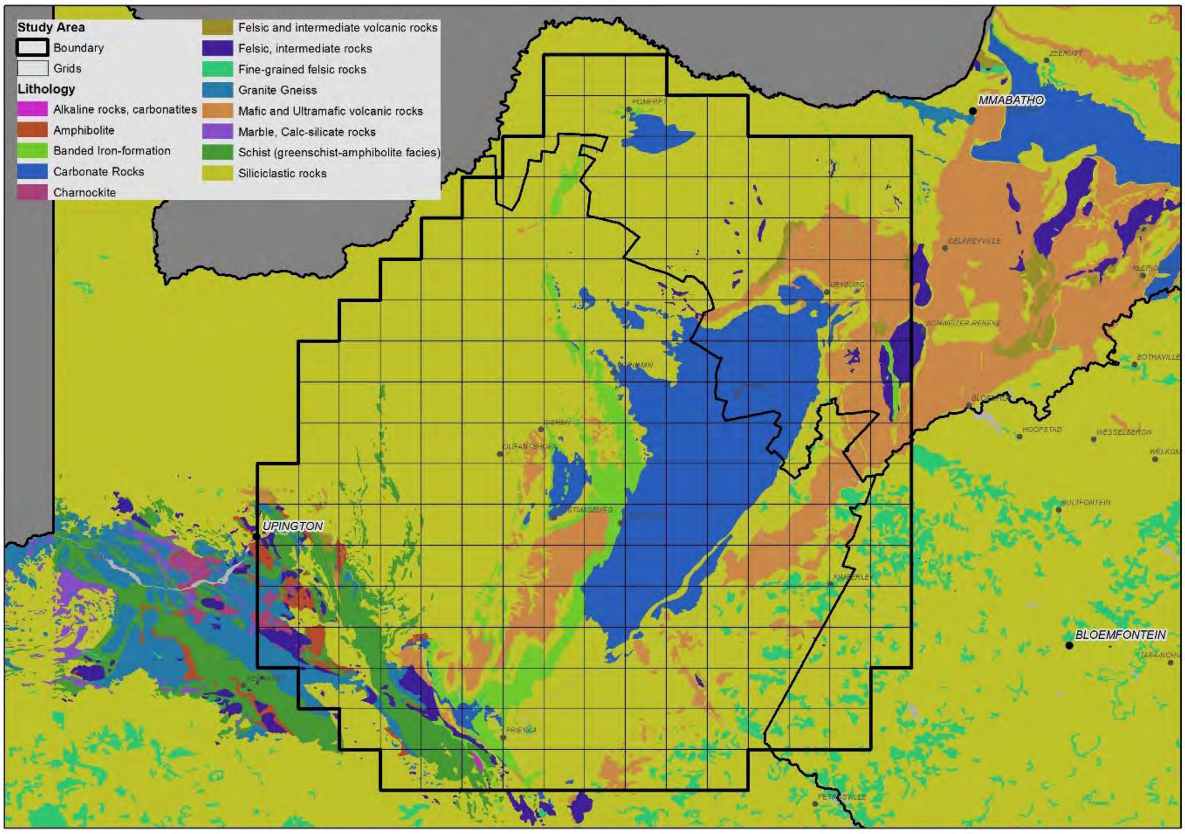


Figure 13: Geology of the GWSA.

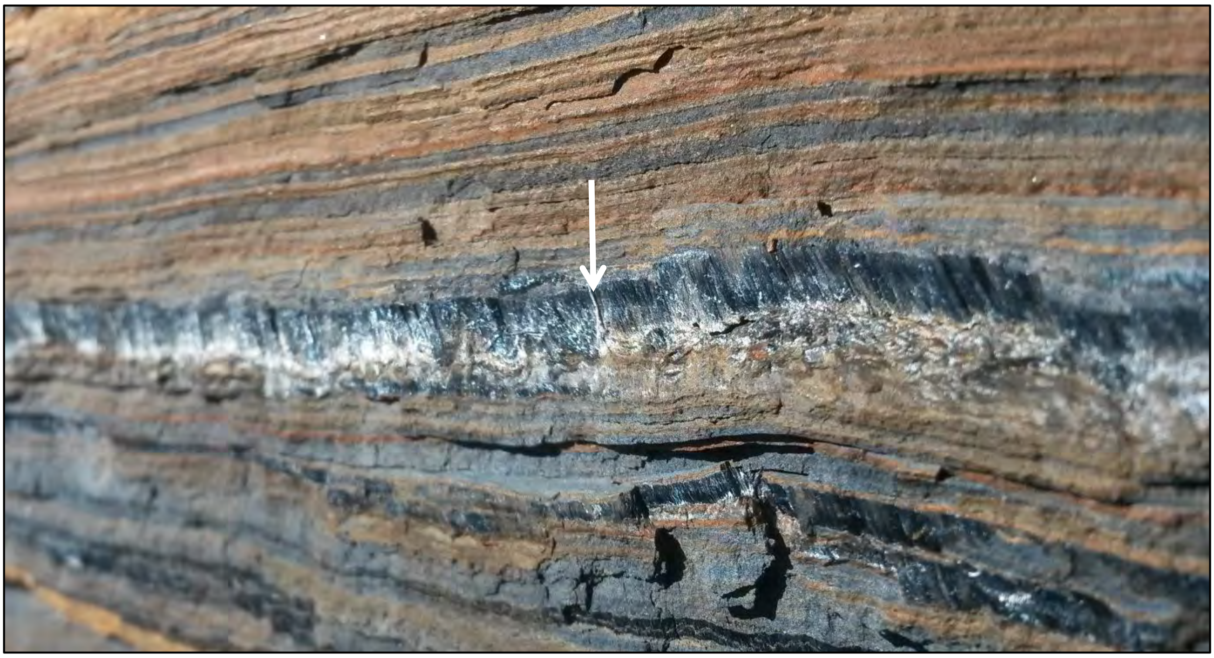


Figure 14: Asbestos imbedded in Banded Iron Formation in the Doringberge near Prieska. The asbestos strip is in the center of the image indicated by a white arrow. (Photo: AW Frisby)

Figure 15: Sishen Iron Ore Mine. One of the largest open-cast mines in the world. (Photo: www.angloamerican.com)

Figure 16: Mining pit at Idwala Lime Mine near the town of Danielskuil. (Photo: L Jabar)

Figure 17: Exposed dolomite on the Ghaap Plateau near a seasonal pan, near Griquatown. (Photo: AW Frisby)

Figure 18: *Avonia albissima* growing in calcium rich soil on the Ghaap Plateau, near Campbell. (Photo: AW Frisby)

Figure 19: Dolomite with interspersed Kalahari sand near Griquatown. (Photo: AW Frisby)

The second subdivision of the greater Transvaal Supergroup present in the GWC is the Postmasburg Group which consists of iron and manganese ore deposits (Gutzmer *et al*. 1996). Within the Postmasburg Group subdivision, the Asbestos Hills subgroup consists of ironstone (Banded Iron Formations) (Fig. 20) and lavas which today form the Asbestos and Kuruman Hills (Grobbelaar *et al*. 1995). The Doringberge which are primarily banded iron formation are also the part of the Postmasburg Group.

3.4.3 Waterberg Supergroup

The Waterberg Supergroup was deposited around 1 800 mya and was the result of widespread rifting caused by the Ubendian event when the Kaapvaal-Zimbabwe Craton collided with the Congo Craton (McCarthy & Rubidge 2005). The rocks of this group were deposited by undulating rivers on a vast plain which at one point may have covered much of the Craton (McCarthy & Rubidge 2005). The sediment forming this supergroup appears to have originated from the northern parts of the Craton and consist mainly of sandstones with occasional mudstone deposits (McCarthy & Rubidge 2005). Much of this group has eroded or is covered by later sediments. In the GWSA, rocks of this group are present near the north-western border near Van Zylsrus, although not common, being hidden by aoelian Kalahari sands.

3.4.4 Olifantshoek Supergroup

The Olifantshoek Supergroup consists of clastic sediments rich in quartzites (Eglington 2006), limestones, dolomites and mudstones which were also deposited in shallow marine conditions around 1 900 m.y.a. (McCarthy & Rubidge 2005). The rocks of the Olifantshoek Supergroup are intensely folded due to the Ubendian event (McCarthy & Rubidge 2005). The north-south trending Langeberg consisting primarily of resistant quartzites are the most prominent component of the folded Olifantshoek Supergroup.

Figure 20: *Adromiscus* sp. growing on Banded Iron Formation in the Asbestos Hills near Danielskuil. (Photo: AW Frisby)

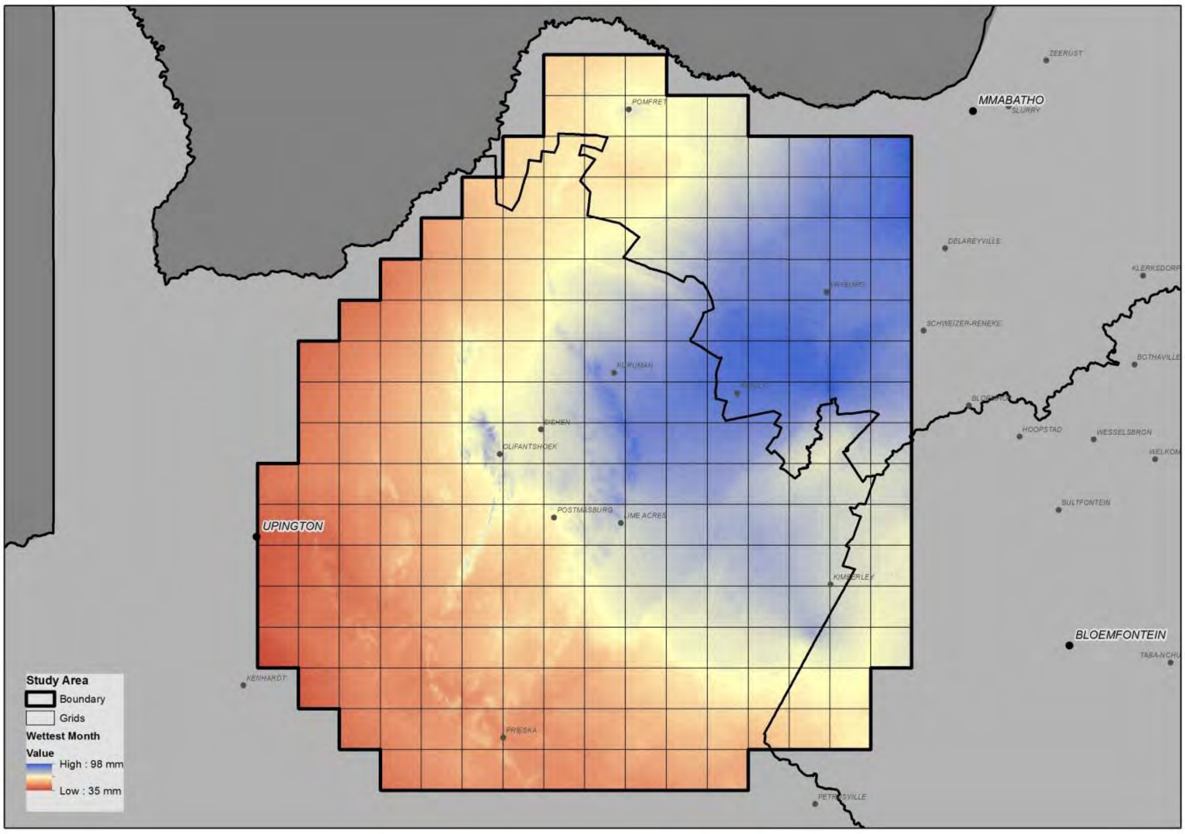


Figure 21: Mean rainfall for the wettest month in the GWSA.

3.4.5 Aeolian sands

In the northern, western and south-western parts of the GWSA the inter-montane valleys are filled-in with red, relatively deep aeolian Kalahari sand (van Wyk & Smith 2001). As the name suggests, this sand originated in the Kalahari and has over time been blown south and accumulated in depressions between the mountains, hills and koppies. This deep sand reaches high temperatures during the summer months and has poor water retention.

3.5 Climate

3.5.1 Rainfall

The climate of the GWSA is semi-arid. Semi-arid climates are characterised by sparse yearly rainfall and low productivity (Fischer & Turner 1978). The rainfall in the GWSA is highly erratic and varies from 250 to 450 mm annually falling mainly in the summer months (van Wyk & Smith, 2001). Water is thus the limiting factor for the plant life of semi-arid regions (Wiegand *et al*. 1995). Higher mean rainfall patterns for the wettest month (Fig. 21), driest month (Fig. 22) and annually (Fig. 23) roughly correspond with higher lying regions, most notably the Ghaap Plateau.

3.5.2 Temperature

The mean annual temperature of the GWSA is around 18°C (van Wyk & Smith 2001). Mean maximum and minimum temperature of higher lying areas in the GWSA are cooler than surrounding areas in both summer (Fig. 24) and in winter (Fig. 25). The mountain ranges and most prominently, the Ghaap Plateau, appear to have a cooler climate distinct from the greater GWSA.

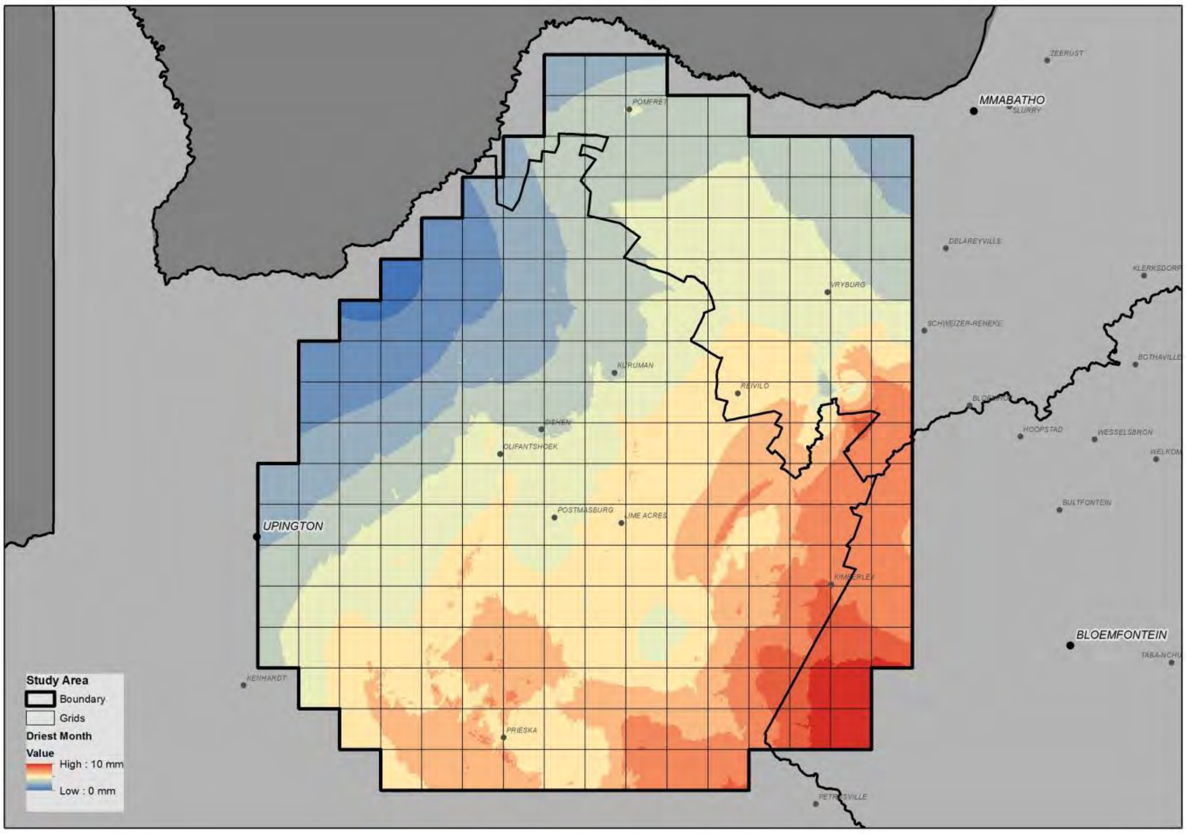


Figure 22: Mean rainfall for the driest month in the GWSA. On this map red represents areas of high rainfall. On this map blue indicates areas of low rainfall and red areas of high rainfall.

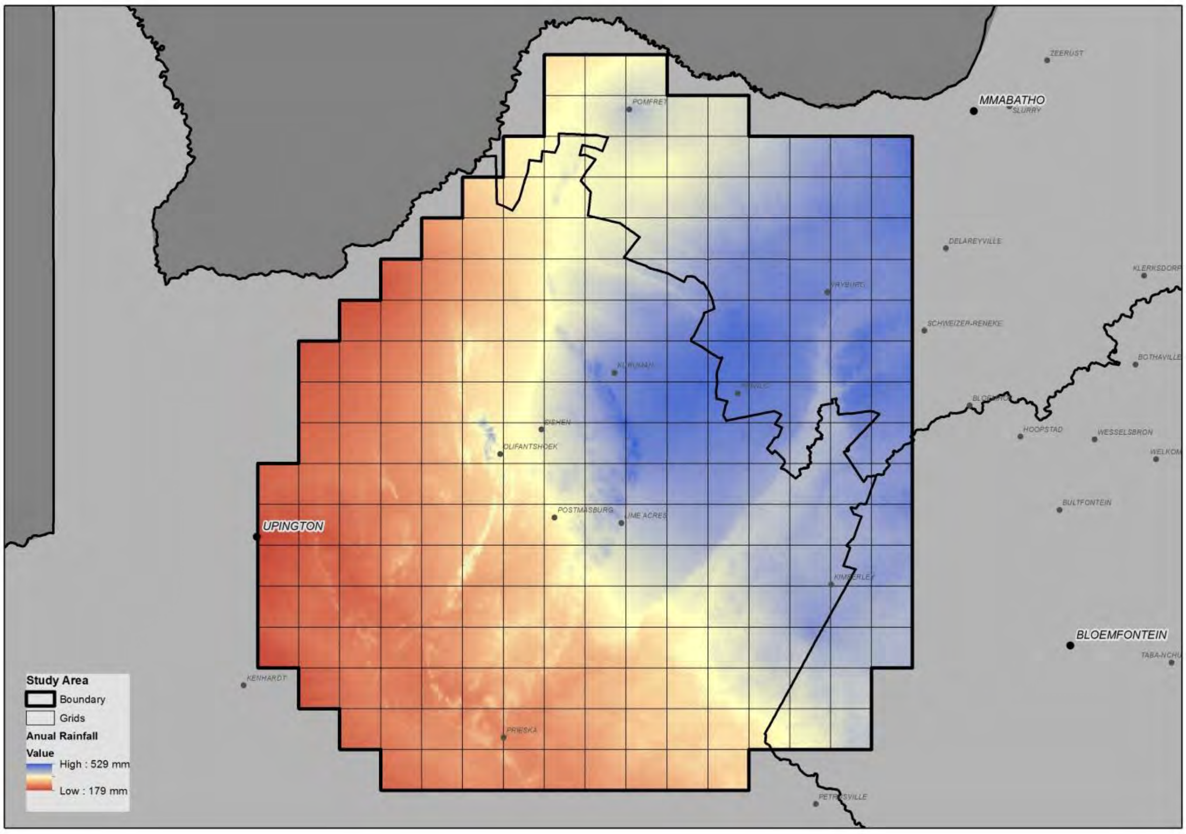


Figure 23: Mean annual rainfall of the GWSA.

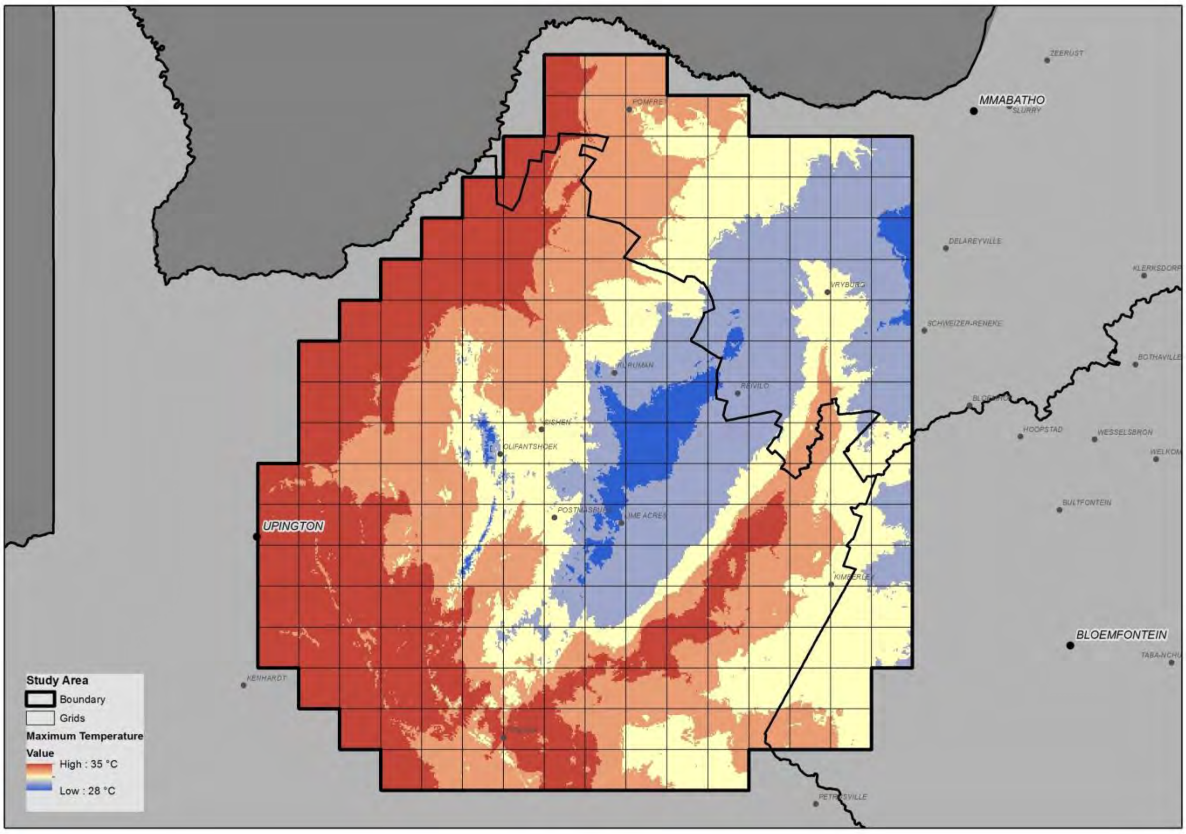


Figure 24: Mean maximum temperatures of the GWSA.

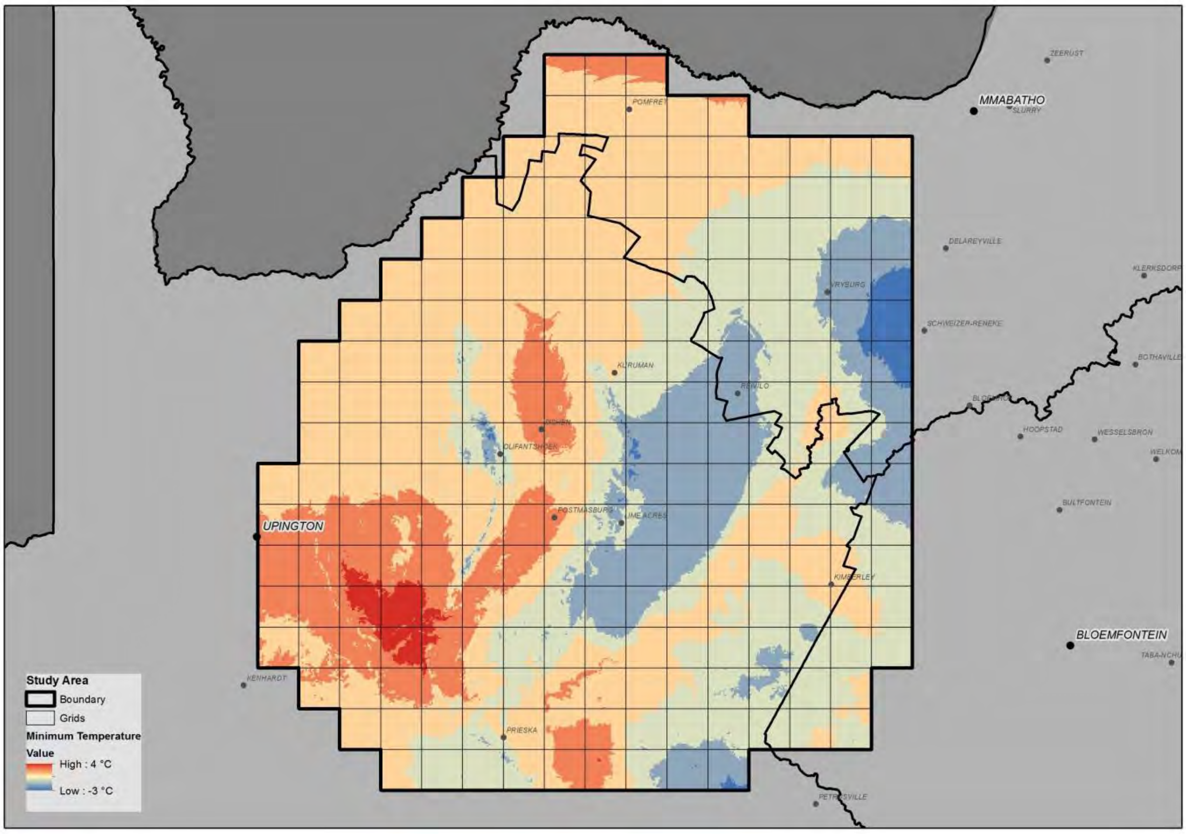


Figure 25: Mean minimum temperatures of the GWSA.

3.6 Vegetation

3.6.1 Biomes

The GWSA is located within the Savanna Biome (Fig. 26), although some parts of the GWSA extend in another biome, namely the Nama-Karoo Biome. The GWSA has low to moderate to moderate vegetation index (NDVI) (Fig. 27). The Savanna Biome is characterised by an herbaceous ground layer dominated by grasses (Poaceae) and an upper layer comprising of woody vegetation. The ratio and height of the respective layers determine the next level of subdivisions which include Shrubveld, Woodland and Bushveld (Rutherford & Westfall 1986). The major macroclimatic traits that characterize the Savanna Biome are seasonality of precipitation and a thermal regime with low incidence of frost (Mucina & Rutherford 2006). The savanna of South Africa represents the southernmost extension of Africa‘s most widespread biome (Mucina & Rutherford 2006). It covers approximately 399 600 km^2 of South Africa and 12 900 km^2 of Swaziland (Mucina & Rutherford 2006).

3.6.2 Veld types

Acocks (1988) placed the Griqualand West area in a broad veld type named Kalahari Thornveld. Within this veld type two main subdivisions were recognised, namely Kalahari Thornveld Proper and Vryburg Shrub Bushveld (Acocks 1988). Within the Kalahari Thornveld Proper there were four further subdivisions, namely North-eastern Form, Eastern Form, Central Form and Western Form (Acocks 1988). Within the Vryburg Shrub Bushveld four subdivisions were recognized, namely *Tarchonanthus* veld of the Ghaap Plateau, Mixed *Tarchonanthus* veld of the Asbestos and Kuruman Hills, Mixed *Tarchonanthus—Rhus—Croton* Veld of the Langeberg and Mixed *Tarchonanthus* Thornveld of the Kimberley plains and koppies (Acocks 1988). The Vryburg Shrub Bushveld and its four subdivisions were, according to Acocks (1988), the main veld types covering the Griqualand West area.

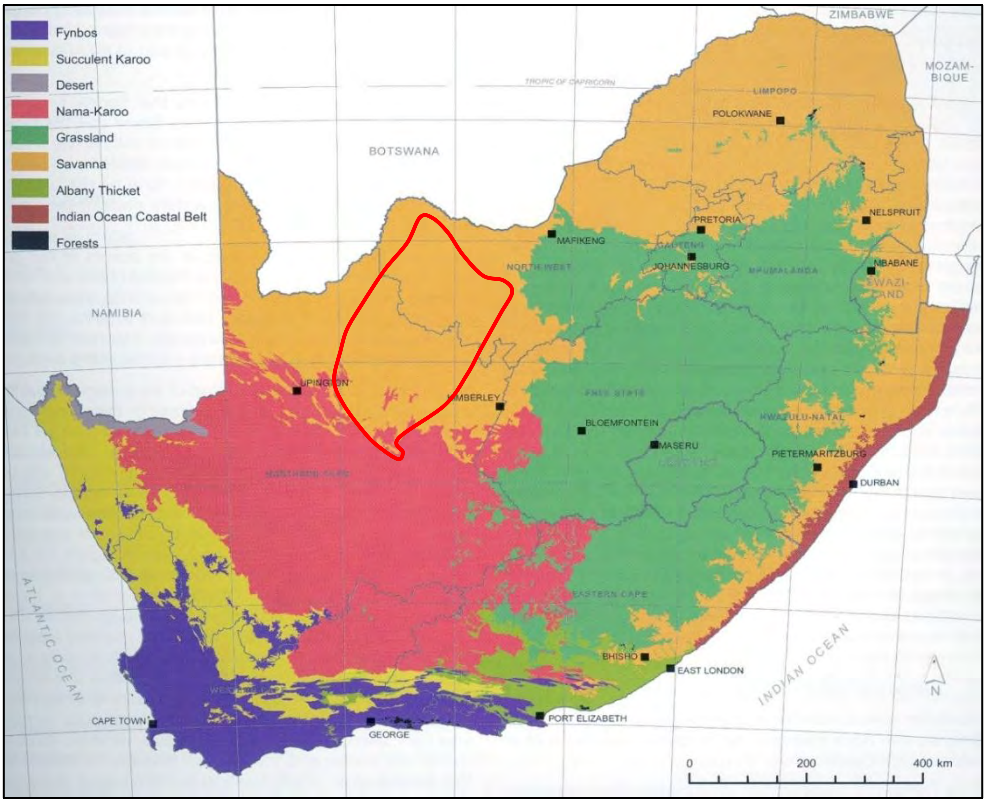


Figure 26: Biomes of southern Africa. Rutherford & Westfall (1986). Proposed GWC borders (van Wyk & Smith 2001) are indicated in red.

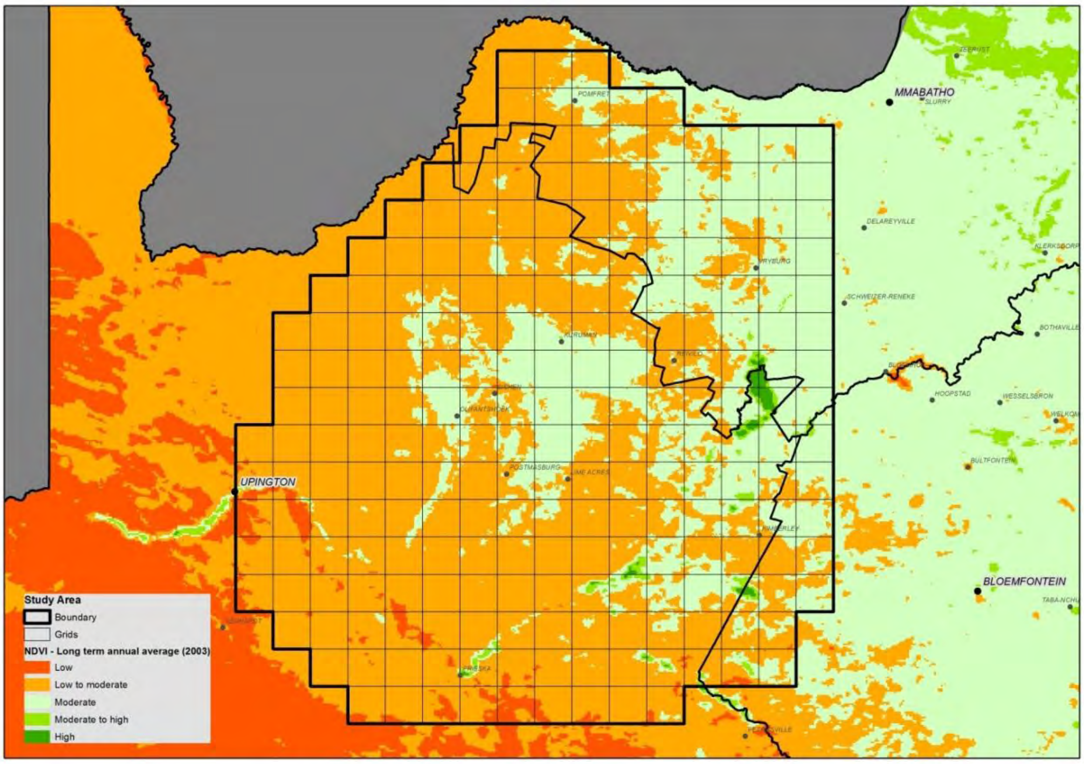


Figure 27: Vegetation index (NDVI) of the GWSA.

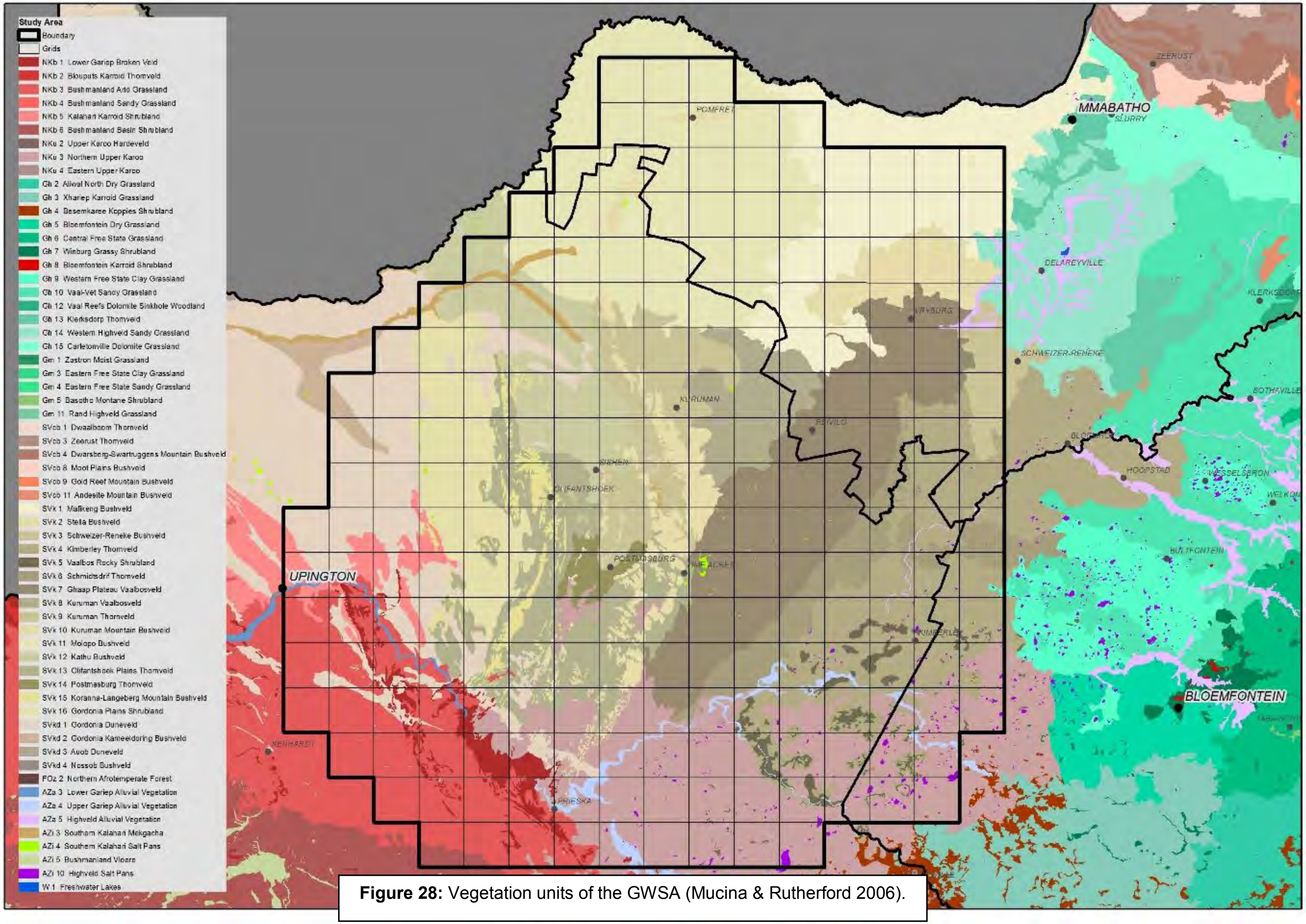


Figure 28: Vegetation units of the GWSA (Mucina & Rutherford 2006).

3.6.3 Vegetation types

Low & Rebelo (1996) identified two main vegetation types for the Griqualand West region, namely Kalahari Mountain Bushveld and Kalahari Plateau Bushveld. The former covered the mountainous western extent of Griqualand West and the latter covered the eastern plateau (Ghaap Plateau) (Low & Rebelo 1996).

3.6.4 Vegetation units

More recently, Mucina & Rutherford (2006) classified the Griqualand West region broadly under the Eastern Kalahari Bushveld Bioregion. Within this broad classification, Mucina & Rutherford (2006) identified a complex of vegetation units (Fig. 28), namely Mafikeng Bushveld (SVk1), Stella Bushveld (SVk2), Kimberley Thornveld (SVk4), Vaalbos Rocky Shrubland (SVk5), Schmidtsdrif Thornveld (SVk6), Ghaap Plateau Vaalbosveld (SVk7), Kuruman Vaalbosveld (SVk8), Kuruman Thornveld (SVk9), Kuruman Mountain Bushveld (SVk10), Molopo Bushveld (SVk11), Kathu Bushveld (SVk12), Olifantshoek Plains Thornveld (SVk13), Postmasburg Thornveld (SVk14), Koranna-Langeberg Mountain Bushveld (SVk15) and Gordonia Plains Scrubland (SVk16). A small portion of the Gordonia Duneveld (SVkd1) veld type, which is a part of the Kalahari Duneveld Bioregion, is also present within the GWC (Mucina & Rutherford 2006). There are also small pockets of Nama-Karoo vegetation in southern and western parts of the GWSA (van Wyk & Smith 2001), namely Northern Upper Karoo vegetation (NKu3), Lower Gariep Broken Veld (NKb1) and Bushmanland Arid Grassland (NKb3) (Mucina & Rutherford 2006). Additionally, two Inland Saline vegetation types are present in the GWSA, namely Southern Kalahari Mekgacha (AZi3) and Southern Kalahari Salt Pans (AZi4).

3.7 Flora

It was first proposed that Griqualand West may have a unique flora by Maria Wilman and fellow botanists interested in the region in the 1940‘s (Wilman 1946). A project was initiated to extensively investigate the Griqualand West flora, but the outbreak of World War II in 1939 made the work impossible due to high publication costs (Wilman 1946). Instead of investigating the flora, only a preliminary check list of plant species present in Griqualand West could be produced (Wilman 1946).

Acocks (1953) produced a list of 302 species in a single survey in the Asbestos Hills (Banded Iron formation), the highest number of species recorded at any of the many sampling points taken by him to produce his renowned map and publication on Veld Types of South Africa. Concurrently, some of the vegetation types in the GWSA are known to be exceptionally rich in plant species (van Wyk & Smith 2001).

A number of plant taxa have been proposed as endemic to the GWC by authors including van Wyk & Smith (2001) and Mucina & Rutherford (2006). The former predicted >40 GWC endemics (van Wyk & Smith 2001). Mucina & Rutherford (2006) identified GWC 16 endemics linked to specific vegetation units. However, as the endemic status of these taxa had not been tested, they shall be referred to as antecedent endemics.

Eight vegetation units Eastern Kalahari Bushveld Bioregion are restricted to the GWSA. Postmasburg Thornveld (SVk14) has two antecedent GWC endemics, namely *Digitaria polyphylla* and *Euphorbia bergii* (Mucina & Rutherford, 2006), but no endemic species were known to be restricted to this vegetation unit. Kuruman Thornveld (SVk9) is home to antecedent GWC endemic species *Blepharis marginata*, *Chorchorus pinnatipartitus*, *Digitaria polyphylla*, and *Gnaphalium englerianum*, the last being endemic to this vegetation unit (Mucina & Rutherford, 2006). Ghaap Plateau Vaalbosveld (SVk7) is home to a number of antecedent GWC endemics including *Blepharis marginata*, *Calobota cuspidosa*, *Corchorus pinnatipartitus*, *Digitaria polyphylla*, *Euphorbia wilmaniae*, *Nuxia gracilis* (near-endemic), *Prepodesma orpenii*, *Putterlickia saxatilis*, *Tarchonanthus obovatus*, and *Rennera stellata*, the last of which is suspected to be endemic to this vegetation unit (Mucina & Rutherford, 2006). Stella Bushveld (SVk2) and Kuruman Vaalbosveld (SVk8) has no GWC endemic species (Mucina & Rutherford, 2006).

Olifantshoek Plains Thornveld (SVk13) harbors a number of antecedent GWC endemics including *Amphiglossa tecta*, *Calobota cuspidosa*, *Justicia puberula*, *Putterlickia saxatilis*, *Sutera griquensis* and *Tarchonanthus obovatus* (Mucina & Rutherford, 2006). *Amphiglossa tecta* is suspected to be endemic to this vegetation unit (Mucina & Rutherford, 2006). Koranna-Langeberg Mountain Bushveld (SVk15) has two antecedent GWC endemics recorded, namely *Digitaria polyphylla* and *Justicia puberula* (Mucina & Rutherford, 2006). Kuruman Mountain Bushveld (SVk10) has a number of antecedent GWC endemics, namely *Calobota cuspidosa*, *Digitaria polyphylla, Euphorbia planiceps, Euphorbia wilmaniae, Justicia puberula, Sutera griquensis* and *Tarchonanthus obovatus* (Mucina & Rutherford, 2006). *Euphorbia planiceps* is suspected to be endemic to this vegetation unit (Mucina & Rutherford, 2006).

It is worth noting that of the eight vegetation units restricted to the GWSA, six were known to harbor GWC antecedent endemics (Table 1) (Mucina & Rutherford, 2006). In contrast, the savanna vegetation units also present in the GWSA, but not restricted to it, have minimal records of antecedent GWC endemics (Table 1).

Table 1: Savanna vegetation units of the Eastern Kalahari Bushveld Bioregion containing antecedent GWC endemic taxa according to Mucina & Rutherford (2006). Vegetation units highlighted in green are endemic to the GWSA. Vegetation units highlighted in blue are not endemic to the GWSA. SVK1, Mafikeng Bushveld; SVK2, Stella Bushveld; SVK3, Schweizer-Reneke Bushveld; SVK4, Kimberley Thornveld; SVK5, Vaalbos Rocky Shrubland; SVK6, Schmidtsdrif Thornveld; SVK7, Ghaap Plateau Vaalbosveld; SVK8, Kuruman Vaalbosveld; SVK9, Kuruman Thornveld; SVK10, Kuruman Mountain Bushveld; SVK11, Molopo Bushveld; SVK12, Kathu Bushveld; SVK13, Olifantshoek Plains Thornveld; SVK14, Postmasburg Thornveld; SVK15, Koranna-Langeberge Mountain Bushveld.

Veg Map Code	*Blepharis marginata*	*Corchorus pinnatipartitus*	*Euphorbia bergii*	*Euphorbia planiceps*	*Euphorbia wilmaniae*	*Digitaria polyphylla*	*Gnaphalium englerianum*	*Justicia puberula*	*Calobota cuspidosa*	*Lithops aucampiae* subsp. *aucampiae*	*Putterlickia saxatilis*	*Prepodesma orpenii*	*Rennera stellata*	*Sutera griquensis*	*Tarchonanthus obovatus*	*Amphiglossa tecta*	No antecedent GWC endemics
🟦 SVK1																	x
🟩 SVK2																	x
🟦 SVK3																	x
🟦 SVK4	x		x							X							
🟦 SVK5																	x
🟦 SVK6	x											x					
🟩 SVK7	x	x			x	x			x		x	x	x		x		
🟩 SVK8																	x
🟩 SVK9	x	x				x	x										
🟩 SVK10				x	x	x		x	x					x	x		
🟦 SVK11																	x
🟦 SVK12																	x
🟩 SVK13				x				x	x		x				x	x	
🟩 SVK14			x			x											
🟩 SVK15						x		x									
🟦 SVK16																	x

The flora of the GWSA appears to be influenced by at least one category of substrate, namely calcium rich substrates. This is evident when considering that several calcicole species (species adapted to grow on calcium-rich substrates) are widespread in the arid regions of southern Africa and is centered in the GWC of Van Wyk and Smith (2001). That is, they are most abundant in the GWSA. Examples include *Bergia anagaloides*, *Eragrostis macrochlamys* var. *wilmaniae*, *Erucrastrum griquense*, *Justicia thymifolia*, *Lotononis crumaniana* and *Salvia namaensis* (van Wyk & Smith, 2001).

White (1983) named the floristic region, in which the GWSA is located, the Kalahari-Highveld Regional Transition Zone (Fig. 29). The Kalahari component of this zone‘s flora is expected to be associated with the aoelian sand which characterizes the Kalahari Desert. As there is a strong aeolian sand component in the GWSA, particularly in the eastern and north-eastern parts, its flora should too be expected to have a strong Kalahari element. Similarly, the GWSA is expected to also have a strong Highveld flora component. Both the Kalahari and Highveld floras‘ contribution to the GWSA is expected to be predominantly herbaceous.

The majority of the antecedent GWC endemics appear to be derived from the Zambezian and Karoo-Namib Regional Centers of Endemism (van Wyk & Smith, 2001). It is predicted that one species known to be near-endemic the GWC and the Sekhukhuneland Centre of Endemism (SKC), namely *Nuxia gracilis* (Siebert, 2001), displays a widely disjunct distribution between the two centers because of the presence of Ca-rich substrates and arid conditions in both (van Wyk & Smith, 2001). There is also an apparent ancient link between the GWC and the Eastern Cape Province to the south that is inferred by considering the GWC endemic, *Putterlickia saxatilis* (van Wyk & Smith, 2001). Three other species in the genus *Putterlickia* are bound to centres of endemism (Fig. 30) along the coastal Eastern Cape (Jordaan *et al*. 2015).

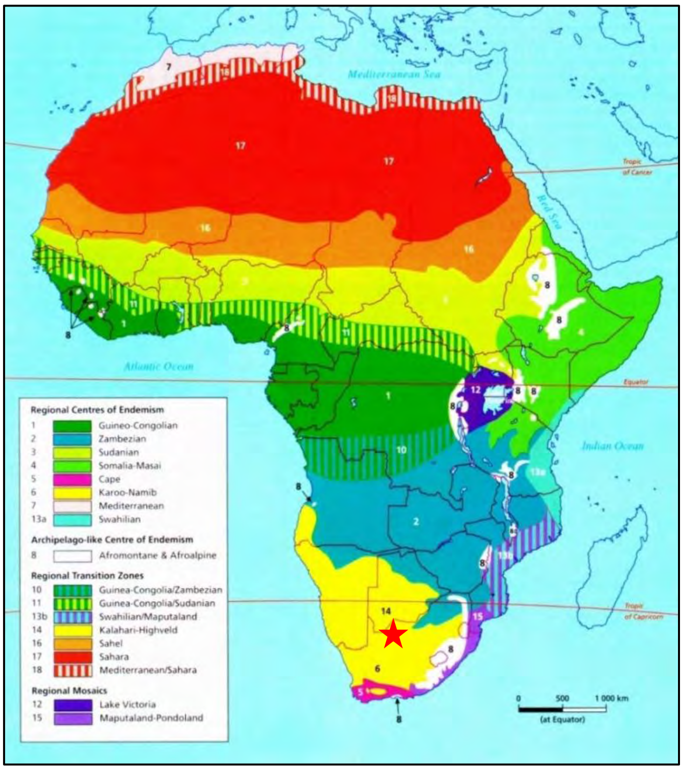
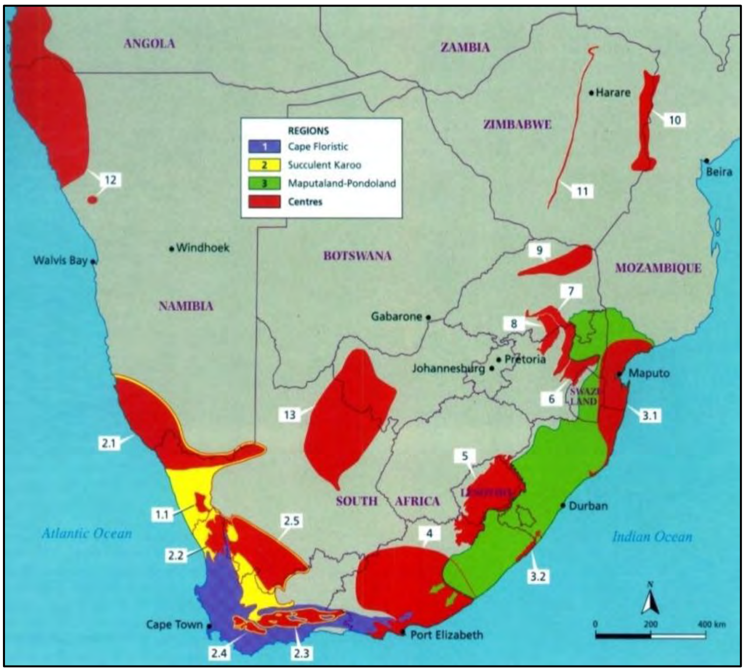


Figure 29: Phytogeographical regions of Africa (White, 1983). The location of the GWSA is indicated by a red star.



1. Cape Floristic Region (CFR)
   - 1.1 Kamiesberg Centre (KBC)
2. Succulent Karoo Region (SKR)
   - 2.1 Gariep Centre (GC)
   - 2.2 Knersvlakte Centre (KVC)
   - 2.3 Little Karoo Centre (LKC)
   - 2.4 Worcester-Robertson Karoo Centre (WRKC)
   - 2.5 Hantam-Roggeveld Centre (HRC)
3. Maputaland-Pondoland Region (MPR)
   - 3.1 Maputaland Centre (MC)
   - 3.2 Pondoland Centre (PC)
4. Albany Centre (AC)
5. Drakensberg Alpine Centre (DAC)
6. Barberton Centre (BC)
7. Wolkberg Centre (WC)
8. Sekhukhuneland Centre (SKC)
9. Soutpansberg Centre (SC)
10. Chimanimani-Nyanga Centre (CIC)
11. Great Dyke Centre (GDC)
12. Kaokoveld Centre (KOC)
13. Griqualand West Centre (GWC)

Figure 30: Regions and centers of plant endemism in southern Africa (van Wyk & Smith, 2001). The GWC is labeled number 13.

CHAPTER 4: ENDEMIC AND NEAR-ENDEMIC TAXA OF THE GRIQUALAND WEST CENTRE OF ENDEMISM

4.1 Introduction

For the purpose of this study, a centre of plant endemism is defined as a geographical region in which many plant taxa (endemics) with highly restricted total distributions co-occur (van Wyk & Smith 2001). The Griqualand West Centre of Endemism (GWC) was identified as one of 18 centres of endemism in southern Africa by Van Wyk and Smith (2001). Of these, the GWC remains the most poorly studied and vaguely defined, its current boundaries based on geological features and very limited empirical floristic data.

Despite the lack in knowledge, the floristic diversity of the region is undisputed. John Acocks, during his botanical survey of South Africa in the mid-20th century, collected more species per unit area in Griqualand West than at any other point in the country (Acocks 1988). The complex geology of this region is expected to be a contributing factor resulting in the large number of species occurring in the region. Van Wyk and Smith (2001) predicted that many edaphic specialist plant taxa of the GWC remain undescribed, some of which could be rare and threatened endemic species of conservation significance.

The extraordinary geology of the area, which includes ultramafic rock types and heavy metal-containing soils (Johnson *et al*. 2006), has resulted in large parts of the GWC being disturbed by mining activities (van Wyk & Smith 2001). Although large areas are still intact, it remains poorly conserved and threatened by uninformed development decisions.

A detailed floristic survey of the GWC is required to identify the priority areas for conservation. As a first step towards achieving this goal, this study aims to make adjustments to the borders of the GWC to more accurately reflect the core distribution area of its endemics and thereby improving its value for conservation planning and targeted research initiatives. The objectives of this study were to identify the endemic and near-endemic taxa of the GWC, assess the level of endemicity and to combine the distributions (base maps) of these taxa to revise the boundaries of the GWC.

4.2 Materials and Methods

4.2.1 Classification of endemic and near-endemic taxa

Plant taxa potentially endemic or near-endemic to the Griqualand West region were identified from Wilman (1946), van Wyk & Smith (2001), Acocks (1988), Mucina & Rutherford (2006) and Germishuizen & Meyer (2003). Additionally, the Flora of southern Africa (e.g. Codd 1985) was consulted to identify plant taxa with small distributions in the Griqualand West region. A list of 16 potentially endemic taxa was constructed for further assessment with herbarium records.

Distribution data was obtained for each of the potential endemic and near-endemic taxa from PRECIS (Pretoria National Herbarium Computerized Information System) and herbaria with specimens collected in the Griqualand West region. The A.P. Goossens Herbarium (PUC), McGregor Museum Herbarium (KMG), South African National Parks Herbarium (KSAN), National Museum Herbarium (NMB), Geo Potts Herbarium (BLFU) and Pretoria National Herbarium (PRE) were consulted. Fuzzy Gazetteer (2000) was used to clarify descriptive locality records. GPS records were limited and therefore the quarter-degree-grid (QDG: 675 km^2) system was used for mapping purposes (Robertson & Barker 2006). Additionally, all information regarding the substrate and geology on which the herbarium specimens were found when collected was recorded.

Once all available locality data were collected for each of the potential endemic and near endemic taxa, the distribution of each species was mapped with ArcGIS (ESRI 2011). Intuitive discernment (Rosen 1988) was used to assess the resulting distribution maps and identify taxa endemic to the Griqualand West region. Species were regarded as endemic if their distributions were centered over the GWC boundaries proposed by van Wyk & Smith (2001). These boundaries were based on underlying geology and used as a reference position for the GWC. Distributions beyond these boundaries did not disqualify endemicity.

Near-endemic species were also identified through intuitive discernment. A near-endemic was defined as a taxon with a distribution centered over the GWC boundaries proposed by van Wyk & Smith (2001), but with a population or populations disjunct to those in Griqualand West. Near-endemicity is implied if the disjunct population(s) occurred in another proposed or recognized centre of plant endemism.

Floristic elements were also considered. These taxa had to have a high density of records from the Griqualand West region, but otherwise had to be sparsely distributed elsewhere in southern Africa. Overlays of their distributions on a quarter-degree-grid were used to identify floristic links to the GWC.

All taxa with distributions adjudged to not belong to one of the three afore-mentioned categories were discarded. Hence, mapping criteria (Fig. 31) had to be used to distinguish between the three categories of taxa, namely endemic taxa, near-endemic taxa and floristic elements.

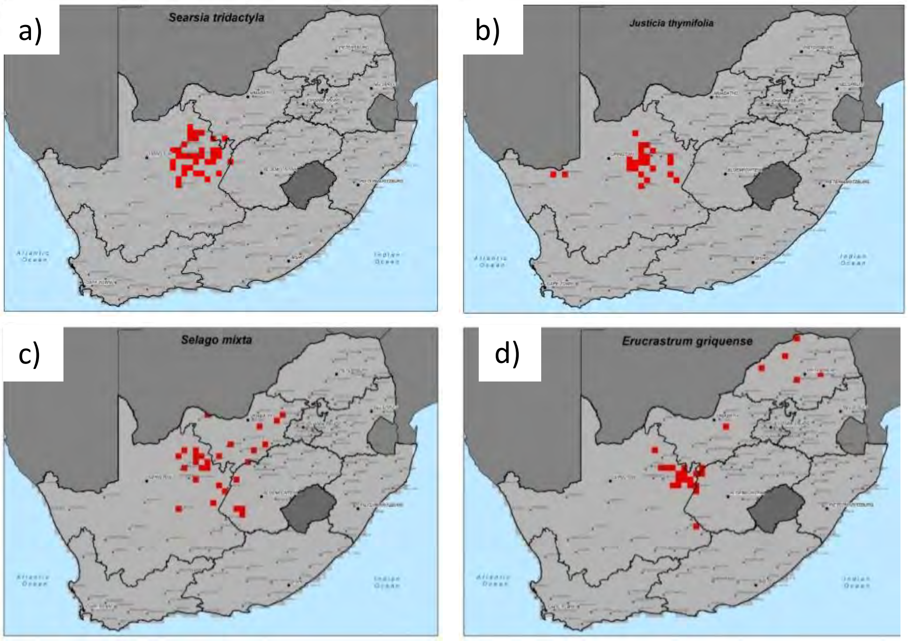


Figure 31: Mapping criteria. a) Endemic: centered and restricted distribution in Griqualand West; b) Near-endemic: distribution shared between Griqualand West and another recognized centre of endemism (Gariep Centre in this case); c) Widespread and not endemic (would be discarded); and d) Floristic element: widespread with a clear clustering in Griqualand West, but sparse occurrences beyond its boundaries.

4.2.2 Mapping the GWC boundary

The distributions of the identified endemic and near endemic taxa were overlaid to create a quarter-degree-grid map. Outer grids were taken as the outer border of the GWC. The resulting borders were further refined by excluding grids in which there were less than three records of endemic or near-endemic species. It was assumed that where two or less endemics were present in a grid that they would be limited to areas bordering the GWC and that most of the grid would not harbour the appropriate habitat. This size reduction allowed for more accurate demarcation of the core area of the GWC in which the density of endemic species was the highest. Outer grids were again taken as the outer border of the GWC.

4.2.3 Species-area correlations

Surface area and total number of species and endemics of the GWC were compared with the 18 other southern African centers of endemism (van Wyk & Smith, 2001). The relationship between total number of species and the number of endemic species was tested for all the 18 centers, by utilizing Spearman‘s rank correlation coefficient. As there was a large correlation, it was possible to do a weighted regressions using STATISICA (StatSoft, 2001) for all 18 centers by comparing the total number of species vs. the number of endemics. This was done for both the untransformed and the natural log (ln) transformed data.

4.3 Results

A literature review yielded 86 taxa that were potentially endemic or near endemic to the GWC (Table 2). Thirty three of these taxa were discarded due to unfitting distributions or a lack of data, 27 taxa were found to be floristic elements of the GWC and 24 taxa were found to be endemic to the GWC. Two taxa were found to be near-endemic to the GWC.

Table 2: Taxa considered during the screening process for GWC endemics and near-endemics. Justifications are based on herbarium records as available on 30 January 2014.

Species	Synonym	Family	Classification	Justification
Agrostis griquensis Stapf	NA	Poaceae	Floristic element	Distribution extends as far east as Bloemfontein. Centred in GWC.
Aizoon asbestinum Schltr.	NA	Aizoaceae	Discarded	Wide distribution extending from GWC to southern Namibia.
Amphiglossa tecta (Brusse) Koekemoer	*Pterothrix tecta* Brusse	Asteraceae	GWC endemic	One locality at Witsand in western GWC.
Antimima lawsonii (L.Bolus) H.E.K.Hartmann	*Ruschia lawsonii* (L.Bolus)	Aizoaceae	GWC endemic	Restricted to GWC.
Barleria media C.B.Clarke	NA	Acanthaceae	GWC endemic	Restricted to GWC.
Bergia anagaloides E.Mey. Ex Fenzl	*Bergia alsinoides* Friedr.-Holzh.	Elatinaceae	Discarded	Very widespread in South Africa and Namibia.
Blepharis marginata (Nees) C.B.Clarke	*Acanthodium marginatum* Nees	Acanthaceae	GWC endemic	Restricted to central GWC.
Boscia foetida Schinz subsp*. foetida*	*Boscia rautanenii* Schinz	Capparaceae	Discarded	Widespread in Gariep region and Namibia.
Brachiaria dura Stapf var. *pilosa* J.G.Anderson	NA	Poaceae	GWC endemic	Restricted to GWC.
Brachystelma canum R.A.Dyer	NA	Apocynaceae	Discarded	Too far east of GWC.
Brachystelma dimorphum R.A.Dyer subsp*. dimorphum*	NA	Apocynaceae	Discarded	Too far east of GWC in Free State Province.
Calobota cuspidosa (Burch.) Boatwr. & B.-E.van Wyk	*Lebeckia macrantha* Harv.	Fabaceae	GWC endemic	Restricted to GWC.
Calobota psiloloba (E.Mey.) Boatwr. & B.-E.van Wyk	*Lebeckia psiloloba* (E.Mey.) Walp.	Fabaceae	Discarded	Not present in GWC.
Carex burchelliana Boeckeler	NA	Cyperaceae	Floristic element	Outlier population in eastern North-West Province Centred in GWC.
Cineraria exilis DC.	NA	Asteraceae	GWC endemic	Restricted to GWC. Known only from type specimen.
Convolvulus boedeckerianus Peter	NA	Convolvulaceae	Discarded	Widespread in central South Africa.
Corchorus pinnatipartitus Wild	NA	Malvaceae	Floristic element	Also occurs in southern Botswana, centred in GWC.
Crotalaria griquensis L.Bolus	NA	Fabaceae	Floristic element	Wide distribution in central South Africa.

Dicoma kurumanii S.Ortiz & Netnou	NA	Asteraceae	GWC endemic	Restricted to GWC.
Digitaria polyphylla Henrard	NA	Poaceae	Floristic element	Distribution extends too far west, centred in GWC.
Ebracteola wilmaniae (L.Bolus) Glen	*Ruschia wilmaniae* (L.Bolus) L.Bolus *var. wilmaniae*	Aizoaceae	Floristic element	Distribution extends too far east, centred in GWC.
Eragrostis macrochlamys Pilg. var. *wilmaniae* (C.E.Hubb. & Schweick.) De Winter	*Eragrostis macrochlamys* Pilg. p.p.	Poaceae	Floristic element	Also present in central Namibia and western Botswana, centred in GWC.
Eriocephalus ericoides (L.f.) Druce subsp. *griquensis* M.A.N.Müll.	*Eriocephalus ericoides* (L.f.) Druce p.p.	Asteraceae	GWC endemic	Restricted to GWC.
Erucastrum griquense (N.E.Br.) O.E.Schulz	*Diplotaxis griquensis* (N.E.Br.) Sprague	Brassicaceae	Floristic element	Widespread in central and north-western South Africa, centred in GWC.
Euphorbia bergii A.C.White, R.A.Dyer & B.Sloane	NA	Euphorbiaceae	Floristic element	Extends too far into Free State Province, centred in GWC.
Euphorbia duseimata R.A.Dyer	NA	Euphorbiaceae	Floristic element	Also in Namibia, centred in GWC.
Euphorbia inornata N.E.Br.	*Euphorbia crassipes* Marloth	Euphorbiaceae	Discarded	Sunken into *E. crassipes* Marloth.
Euphorbia planiceps A.C.White, R.A.Dyer & B.Sloane	*Euphorbia wilmaniae* Marloth	Euphorbiaceae	Discarded	Sunken into *E. wilmaniae* Marloth.
Euphorbia rectirama N.E.Br.	*Euphorbia spartaria* N.E.Br.	Euphorbiaceae	Discarded	Sunken into *E. spartaria* N.E.Br.
Euphorbia wilmaniae Marloth	*Euphorbia planiceps* A.C.White, R.A.Dyer & B.Sloane	Euphorbiaceae	Floristic element	Wide distribution in South Africa, centred in GWC.
Galenia portulacacea Fenzl	NA	Aizoaceae	Discarded	Wide distribution.
Gnaphalium englerianum (O.Hoffm.) Hilliard & B.L.Burtt	*Amphidoxa engleriana* O.Hoffm.	Asteraceae	GWC endemic	Restricted to GWC.
Halopeplis amplexicaulis (Vahl) Ung.-Sternb. ex Ces., Pass. & Gibelli	NA	Chenopodiaceae	Discarded	Cosmopolitan species.
Helichrysum spiciforme DC.	NA	Asteraceae	Floristic element	Also present in southern Namibia, centred in GWC.
Hereroa wilmaniae L.Bolus	*Hereroa uncipetala* (N.E.Br.) L.Bolus	Aizoaceae	GWC endemic	Restricted to GWC.
Indigofera damarana Merxm. & A.Schreib.	*Indigofera wilmaniae* Baker f. ex J.B.Gillett	Fabaceae	Floristic element	Also occurs in Namibia, centred in GWC.
Ipomoea suffruticosa Burch.	*Turbina suffruticosa* (Burch.) A.Meeuse	Convolvulaceae	Floristic element	Widely distributed in southern Africa, centred in GWC.

Jamesbrittenia albiflora (I.Verd.) Hilliard	*Sutera albiflora* I.Verd.	Scrophulariaceae	Floristic element	Distribution extends too far east and south. Partially centred in GWC.
Justicia puberula (Immelman) Immelman	*Justicia parvibracteata* Immelman	Acanthaceae	GWC endemic	Restricted to GWC.
Justicia thymifolia (Nees) C.B.Clarke	*Adhatoda thymifolia* Nees	Acanthaceae	GWC near-endemic	Main population restricted to GWC. Marginally present in Gariep Centre.
Listia minima (B.-E.van Wyk) B.-E.van Wyk & Boatwr.	NA	Fabaceae	Discarded	Unresolved taxon
Listia subulata (B.-E.van Wyk) B.-E.van Wyk & Boatwr.	NA	Fabaceae	Discarded	Unresolved taxon
Lithops aucampiae subsp. *aucampiae* var. *aucampiae* (de Boer) D.T.Cole	NA	Aizoaceae	Discarded	Variety no longer recognised.
Lithops aucampiae subsp. *aucampiae* var. *koelemanii* (de Boer) D.T.Cole	NA	Aizoaceae	Discarded	Variety no longer recognised.
Lithops aucampiae L.Bolus subsp. *euniceae* (de Boer) D.T.Cole	NA	Aizoaceae	GWC endemic	Restricted to GWC.
Lithops bromfieldi L.Bolus	*Lithops bromfieldii* L.Bolus var. *glaudinae* (de Boer) D.T.Cole	Aizoaceae	GWC endemic	Restricted to GWC.
Lithops lesliei (N.E.Br.) N.E.Br. subsp. *burchellii* D.T.Cole	*Lithops lesliei* (N.E.Br.) N.E.Br. p.p.	Aizoaceae	GWC endemic	Restricted to GWC.
Lotononis burchellii Benth.	NA	Fabaceae	Floristic element	Widespread, centred in GWC.
Lotononis crumanina Burch. ex Benth.	NA	Fabaceae	Floristic element	Wide distribution in central South Africa, centred in GWC.
Lotononis linearifolia B.-E.van Wyk	NA	Fabaceae	Discarded	Distribution in Namibia unknown. Should be investigated further as a potential near-endemic taxon.
Maytenus ilicina (Burch.) Loes.	*Gymnosporia ilicina* (Burch.) Davison	Celastraceae	GWC endemic	Restricted to GWC.
Melhania transvaalensis Szyszyl.	NA	Malvaceae	Discarded	Marginally present in GWC, centred in Limpopo Province.
Mestoklema copiosum N.E.Br. ex Glen	NA	Aizoaceae	Floristic element	Present in Eastern Cape, Northern Cape and Free State Provinces, centred in GWC.
Monechma districhotrichum (Lindau) P.G.Mey.	*Justicia distichotrichum* Lindau	Acanthaceae	Discarded	Also widespread in southern Namibia.
Nananthus aloides (Haw.) Schwantes	*Aloinopsis aloides* (Haw.) Schwantes	Aizoaceae	Discarded	Widespread in central South Africa.

Nerine frithii L.Bolus	NA	Amaryllidaceae	Discarded	Centred in North-West Province.
Nerine hesseoides L.Bolus	NA	Amaryllidaceae	Discarded	Present too far west of GWC.
Nolletia annetjieae P.P.J.Herman	NA	Asteraceae	Discarded	Taxon no longer recognised.
Nuxia gracilis Engl.	*Lachnopylis gracilis* (Engl.) C.A.Sm.	Buddlejaceae	GWC near-endemic	Present in GWC and Sekhukhuneland Centre.
Pentzia oppositifolia Magee	NA	Asteraceae	Floristic element	Present too far east of GWC, centred in GWC.
Petalidium parvifolium C.B.Clarke ex Schinz	*Petalidium wilmaniae* Oberm.	Acanthaceae	Discarded	Mainly in Gariep region including southern Namibia.
Pharnaceum viride Adamson	NA	Molluginaceae	Floristic element	Also present in Soutpansperg (Limpopo), Western Cape and Gariep region. Centred in GWC.
Phyllobolus amabilis Gerbaulet & Struck	NA	Aizoaceae	GWC endemic	Restricted to GWC.
Prepodesma orpenii (N.E.Br.) N.E.Br.	*Nananthus orpenii* N.E.Br.	Aizoaceae	GWC endemic	Restricted to GWC.
Putterlickia pyracantha (L.) Szyszyl.	*Catha campestris* (Eckl. & Zeyh.) C.Presl	Celastraceae	Discarded	Very widespread.
Putterlickia saxatilis (Burch.) M.Jordaan	*Gymnosporia saxatilis* (Burch.) Davison	Celastraceae	GWC endemic	Restricted to GWC.
Rennera stellata P.P.J.Herman	NA	Asteraceae	GWC endemic	Restricted to GWC.
Ruschia griquensis (L.Bolus) Schwantes	*Mesembryanthemum griquense* L.Bolus	Aizoaceae	Discarded	Very widespread in central South Africa.
Salsola atrata Botsch.	*Salsola globulifera* Fenzl	Chenopodiaceae	GWC endemic	Restricted to GWC.
Salsola humifusa A.Brückn.	NA	Chenopodiaceae	Floristic element	Distribution extends too far south and east. Centred in GWC.
Salvia namaensis Schinz	*Salvia burchellii* N.E.Br.	Lamiaceae	Discarded	Widespread in central South Africa and Western Cape. Also occurs in southern Namibia.
Searsia tridactyla (Burch.) Moffett	*Rhus tridactyla* Burch.	Anacardiaceae	GWC endemic	Restricted to GWC.
Selago mixta Hilliard	*Walafrida paniculata* (Thunb.) Rolfe	Scrophulariaceae	Floristic element	Distribution extends too far into North-West Province. Centred in GWC.
Septulina ovalis (E.Mey. ex Harv.) Tiegh.	*Loranthus ovalis* E.Mey. ex Harv.	Loranthaceae	Discarded	Not present in GWC. Only in Gariep Centre.
Sesbania notialis J.B.Gillett	NA	Fabaceae	Floristic element	Distribution extends too far to the east. Centred in GWC.
Stachys burchelliana Launert	*Stachys burchellii* Benth.	Lamiaceae	Floristic element	Present in southern Namibia (outside of Gariep Centre). Centred in GWC.
Stapelia arnotii N.E. Br.	NA	Apocynaceae	Discarded	Taxon no longer recognised.
Stapelia hursita L. var. *gariepensis* (Pillans) Bruyns	*Stapelia gariepensis* Pillans	Apocynaceae	Discarded	Only present in Gariep region.

Stapelia rubiginosa Nel	NA	Apocynaceae	Discarded	Not present in GWC, only in Gariep Centre.
Stapelia similis N.E.Br.	*Stapelia juttae* Dinter	Apocynaceae	Discarded	Not present in GWC.
Sutera griquensis Hiern	*Sutera burchellii* Hiern	Scrophulariaceae	Floristic element	Also present in central Free-State Province and central North-West Province. Centred in GWC.
Tarchonanthus obovatus DC.	NA	Asteraceae	GWC endemic	Restricted to GWC.
Thesium dumale N.E.Br.	NA	Santalaceae	GWC endemic	Restricted to northern GWC.
Titanopsis calcarea (Marloth) Schwantes	*Titanopsis fulleri* Tischer	Aizoaceae	Floristic element	Widely distributed in central GWC.
Trachyandra burkei (Baker) Oberm.	*Anthericum burkei* Baker	Asphodelaceae	Discarded	Also present in southern Botswana.
Triaspis hypericoides (DC.) Burch. subsp. *hypericoides*	NA	Malpighiaceae	Floristic element	Also present in Limpopo, Gauteng and Mpumalanga. Centred in GWC.

4.3.1 GWC endemic and near-endemic taxa

The following 26 taxa described below conformed to the mapping criteria for endemic categories. The distributions of all 26 taxa were roughly centred on the GWC boundaries of van Wyk & Smith (2001).

4.3.1.1 *Amphiglossa tecta* (Brusse) Koek.

Pterothrix tecta F.Brusse in Bothalia 20: 67 (1990), syn. nov. Type: Northern Cape, 2822 (Glen Lyon): Hay Dist., Witsand, some 70 km SW of Postmasburg, (–CB), 1989-11-26, Brusse 5629 (PRE, holo.!; AD, B, BAF, BH, BM, BOL, BR, BRI, C, CAN, CANB, COI, E, EA, G, GH, GRA, HBG, J, K!, L, LD, LG, LISU, LMA, M, MEL, MO, NBG!, NH, NSW, NU, O, P, R, S!, SRGH, U, UC, UPS!, US, W, WAG!, WIND, Z, iso.)

Amphiglossa tecta (Asteraceae) (Fig. 32a) is a perennial shrub of up to 600 mm in height. It is aromatic (camphor odour) and produces white to pale mauve flowers with golden bracts from November (summer) to July (winter). It is known from one small locality (Fig. 35a) where it grows in sand basins among white Kalahari sand dune outliers just west of the Langeberg at Witsand. The entire known population is protected within Witsand Nature Reserve. It is classified as critically endangered (von Staden 2011).

4.3.1.2 *Antimima lawsonii* (L.Bolus) H.E.K.Hartmann

Mesembryanthemum lawsonii L.Bolus in Annals of the Bolus Herbarium 4: 85 (1927a). *Ruschia lawsonii* (L.Bolus) L.Bolus: 219 (1950) Type: Lawson 18551 (BOL, holo.!).

Antimima lawsonii (Aizoaceae) (Fig. 32b) is a perennial succulent of up to 250 mm in height. It produces deep to bright pink flowers in spring (September). It is a habitat specialist and has a narrow distribution in Griqualand West (Fig. 35b) occurring on limestone-derived soils (Hartman 1998). It is classified as rare (Klak & Raimondo 2006).

4.3.1.3 *Barleria media* C.B.Clarke

Barleria media C.B.Clarke in Flora Capensis, V, I, 51 (1901). Bechuanaland: Batlaros, Kuruman, leg. Silk 240 (Kimberley Museum, Transvaal Museum). Kalahari Region: Bechuanaland; on the rocks at Chue Vley, Burchell, 2386!

Barleria media (Acanthaceae) (Fig. 32c) is a perennial herb of up to 100 mm in height and produces mauve flowers in June. This species occurs in the northern parts of Griqualand West (Fig. 35c). No substrate data is available for this species barring that it occurs in rocky areas such as mountains and koppies. It is classified as least concern (Cholo 2006).

4.3.1.4 *Blepharis marginata* (Nees) C.B.Clarke

Blepharis marginata (Nees) C.B.Clarke in Thiselton-Dyer, Flora Capensis 5: 29 (1901); Obermeyer, Ann. Transv. Mus. 19: 117, (1937); Wilman, Prelim. Checklist Fl. Pl. Griqualand West: 218 (1946); Welman, Mem. Bot. Surv. S. Afr. 62: 659 (1993). Type: South Africa, Burchell 1902 (G-DC, holotype, not seen; K, isotype !).
Acanthodium marginatum Nees in DC., Prodr. 11: 275 (1847).

Blepharis marginata (Acanthaceae) (Fig. 32d) is a perennial dwarf shrub or herb of up to 100 mm in height. It produces light blue flowers in autumn (April). It occurs in central Griqualand West in a north-westerly band from Kimberley across the Ghaap Plateau (calcium rich substrates predominantly limestone (Vollesen 2000)) to Sishen (Fig. 35d) where ironstone is prominent. It is categorised as least concern (Kamundi 2006).

4.3.1.5 *Brachiaria dura* var. *pilosa* J.G.Anderson

Brachiaria dura var. *pilosa* J.G.Anderson in Kirkia I: 104 (1961). Leistner 1372; sand-dunes at Witsand, Acocks 2168; foot of dunes, Esterhuysen 2269 (PRE, holo.).

Brachiaria dura var. *pilosa* (Poaceae) (Fig. 32e) is a perennial graminoid of up to 1.3 m in height. It flowers at various times during the year, possibly depending on rainfall. Inflorescences are yellowish with bright orange anthers and purple stamens with black seed. It has a narrow distribution in Griqualand West (Fig. 35e), occurring in the hot and semi-arid western part. It is locally abundant on the white sand dunes in the Witsand area. It is classified as data-deficient (Victor & Fish 2005).

4.3.1.6 *Calobota cuspidosa* (Burch.) Boatwr. & B.-E.van Wyk

Calobota cuspidosa (Burch.) Boatwr. & B.-E.van Wyk in South African Journal of Botany 75: 546–556 (2009).
Calobota cuspidosa (Burch.) Boatwr. and B-E.VanWyk, comb. nov. *Spartium cuspidosum* Burch., Trav. S. Africa 1: 348 (1822). Type—South Africa, Northern Cape, between ‗Gatikamma' and ‗Klaarwater' [now Griquatown], Burchell 1697 (K!).
Lebeckia macrantha Harv. in Harv. and Sond., Fl. Cap. 2: 83–84 (1862), syn. nov. Type—South Africa, without precise locality, ‗Zooloo country', Miss Owen s.n. (TCD, photo!).

Calobota cuspidosa (Fabaceae) (Fig. 32f) is a perennial shrub of up to 2.5 m in height. Branches end in short spines. It may flower in most months of the year, producing yellow flowers in abundance. It is widespread in Griqualand West (Fig. 35f) occurring on a variety of substrates including limestone, dolomite, aeolian sand, quartzite and chert. It is classified as least concern (Foden & Potter 2005).

4.3.1.7 *Cineraria exilis* DC.

Cineraria exilis DC. in Prodr. 6: 305. 1838. Type: near source of source of the Moshaweng River, 27 Sept. 1812, Burchell 2274 (holotype G-DC!; isotype K!). *C. exilis* included in recent *Cineraria* revision (Cron *et al*. 2006) under ‗Species excluded from the genus'.

Cineraria exilis (Asteraceae) (Fig. 32g) is a perennial herb. It is known only from the type specimen collected in 1812 near the source of the Moshaweng River in the Kuruman district (Fig. 35g). It is classified as data-deficient and is taxonomically problematic (Cron *et al*. 2008).

4.3.1.8 *Dicoma kurumanii* S.Ortiz & Netnou

Dicoma kurumanii S.Ortiz & Netnou in Botanical Journal of the Linnean Society 147(4), 509–513. Typus: South Africa, Northwest Province, Kuruman District, top of Ga Mhana Peak, 11.ii.1886, Marloth 1103 (Holotypus NBG; Isotypi K, PRE).

Dicoma kurumanii (Asteraceae) (Fig. 32h) is a perennial dwarf shrub of around 200 mm in height. Its inflorescences have a straw colour (Ortiz & Netnou 2005), produced in February. This species has a narrow distribution in Griqualand West (Fig. 35h), known from only one locality near the town of Kuruman. No substrate data is available for this species. It is classified as least concern (Foden & Potter 2005). This status probably requires reassessment due to the narrow distribution of the species.

4.3.1.9 *Eriocephalus ericoides* (L.f.) Druce subsp. *griquensis* M.A.N.Müll.

Eriocephalus ericoides (L.f.) Druce in Supplement to Botanical Exchange Club of the British Islands for 1916: 622 (1917); Merxm.: 61 (1967). Type: Cape Province, exact locality unknown. Collector unknown (LINN 983.5, holo., microfiche!; WIND, photo.!).
Tarchonanthus ericoides L.f.: 360 (1782).
subsp. *griquensis* M.A.N.Müller, subsp. nov., *E. ericoidi* (L.f.) Druce subsp. *ericoidi* affinis sed foliis permanenter velutinus differt.

Eriocephalus ericoides subsp. *griquensis* (Asteraceae) (Fig. 32i) is a perennial shrub of up to 1 m in height. The inflorescences of this taxon are yellow and appear in the rainy season, usually January to April, but also July to August if winter rain falls (Hilliard 1983). It is widespread in Griqualand West (Fig. 35i), growing on a variety of substrates including red Kalahari sand dunes as well as calcium rich substrates including limestone and calcrete. It is classified as least concern (Foden & Potter 2005). The typical subspecies occurs south of the GWC and also in central Namibia (Hilliard 1983).

4.3.1.10 *Gnaphalium englerianum* (O.Hoffm.) Hilliard & B.L.Burtt

Gnaphalium englerianum (O.Hoffm.) Hilliard & B.L.Burtt in Botanical Journal of the Linnean Society. 82: 193 (1981); Hillard in Bot. J. Linn. Soc. 82: 282 (1981). Type: Cape, Kachun, near Kuruman, 1 200 m, Feb. 1886, Marloth 1004 (E; PRE; SAM, iso.!.).
Amphidoxa engleriana O. Hoffm. in Bot. Jb. 10: 274 (1989).

Gnaphalium englerianum (Asteraceae) (Fig. 33a) is a silvery grey perennial herb of up to 100 mm in height. The inflorescence has snow-white bracts in February. It has a restricted distribution in Griqualand West (Fig. 36a), having only been recorded on the banks of the Hol River near the town of Rievilo in the North-West province. Its collection locality suggests that the species may have an affinity for moist environments. It may be an extreme variant of *G. filagopsis* Hilliard & Burtt (Hilliard 1983). It is classified as least concern (Kamundi & Victor 2005). Due to its restricted distribution, this classification should be reassessed.

4.3.1.11 *Hereroa wilmaniae* L.Bolus

Hereroa wilmaniae L.Bolus in Hartman (2001): Illustrated handbook of succulent plants, Aizoaceae, F-Z: 56-62. NM 1929: 82 Lectotype: Wilman 17264 (chosen from two syntypes, BOL!) = *Prepodesma uncipetala* N.E.Br. GC 1931: 389 = *H. uncipetala* (N.E.Br.) L.Bolus NM 1938: 135 T Pole Evans 6891 (K!) = *H. wilmaniae* L.Bolus var. *langebergenesis* L.Bolus NM 1929: 82 T Wilman 17352 (BOL!).

Hereroa wilmaniae (Aizoaceae) (Fig. 33b) is a perennial succulent of up to 100 mm in height. It produces pink flowers in spring and summer (August to December). The flowers may be moth pollinated as they open at night. The species occurs in the southern half of Griqualand West (Fig. 36b) and has been recorded primarily on quartzite derived soils with a few records from river alluvium and calcareous soil. It is categorised as data-deficient (Burgoyne *et al*. 2005).

4.3.1.12 *Justicia puberula* (Immelman) Immelman

Justicia puberula (Immelman) Immelman (1995): Flora of southern Africa 30, 3, 1: 18-46. Type: Cape Province, 11 miles nort-north-west of Olifantshoek, in Toto Mountains, kloof, in rock crevices and under shrubs, Tölken & Schlieben 1176 (PRE, holo.!).
J. parvibracteata Immelman in Bothalia 16: 39 (1986a) non Léonard in Standley: 1231 (1938).

Justicia puberula (Acanthaceae) (Fig. 33c) is a perennial herb or dwarf shrub of up to 500 mm in height. It produces white flowers with purple spots in the throat of the corolla. It flowers in summer from February to March. The species is primarily found in the north-western and western parts of Griqualand West (Fig. 36c). It has only been recorded from sandy soil patches among ironstone and in one case from a sandy area among quartzite. It is classified as least concern (Kamundi 2006).

4.3.1.13 *Justicia thymifolia* (Nees) C.B. Clarke

Justicia thymifolia (Nees) C.B. Clarke in Dyer, Flora Capensis 5, 1: 64 (1901); Wilman: 222 (1946). Types: northern Cape Province, Hay Division, between Griquatown and Spuigslang, Burchell 1702 (K, lecto., here designated, photo. in PRE!); northern Cape Province, Orange River, Lichtenstein s.n. (B- W, microfiche in PRE!). *Adahotoda thymifolia* Nees: 392 (1847).

Justicia thymifolia (Acanthaceae) (Fig. 33d) is a perennial shrub or dwarf shrub of up to 1.5 m in height (Baden *et al*. 1995). It produces cream flowers in winter (July). It is widespread in Griqualand West (Fig. 36d), occurring on a variety of substrates including red aeolian sand, quartzite, ironstone and dolomite, especially on rocky hill slopes (Baden *et al*. 1995). It is considered as near-endemic to Griqualand West as it also occurs in another centre of endemism, namely the Gariep Centre, although only in South Africa and not crossing into Namibia. It is classified as least concern (Kamundi 2006).

4.3.1.14 *Lithops aucampiae* L.Bolus subsp. *euniceae* (de Boer) D.T.Cole

Lithops aucampiae L.Bolus subsp. *euniceae* (de Boer) D.T.Cole in Hartman (2001): Illustrated handbook of succulent plants, Aizoaceae, F-Z: 56-62. 1988: 220 = *L. aucampiae* var. *euniceae* De Boer 1966: 54 T Cole 48 (PRE) = *L. aucampiae* L.Bolus var. *fluminalis* D.T.Cole NCSJ 1970: 8= *L. aucampiae* L.Bolus ssp. *euniceae* (De Boer) D.T.Cole var. *fluminalis* D.T.Cole 1988: 104 T Cole 54 (PRE).

Lithops aucampiae subsp. *euniceae* (Aizoaceae) (Fig. 33e) is a perennial succulent of up to 10 mm in height. It produces yellow flowers from February to April. It is restricted to the south-eastern corner of Griqualand West (Fig. 36e) where it is known to occur on fined-grained sandstone (Hartman 2001). This species is a member of the so called –stone plants” that are notoriously difficult to locate in their natural habitats. It is classified as vulnerable as the two known localities are threatened by illegal dumping (Victor & Hammer 2005).

4.3.1.15 *Lithops bromfieldii* L. Bolus

Lithops bromfieldii L.Bolus in Hartman (2001): Illustrated handbook of succulent plants, Aizoaceae, F-Z: 56-62. NM 1934: 452 T Bromfield 2286/33 (BOL) = *L. glaudinae* De Boer 1960: 129 = *L. bromfieldii* L.Bolus var. *glaudinae* (De Boer) D.T.Cole Excelsa 1973: 50 T Cole 116 (PRE) = *L. insularis* L.Bolus NM 1937: 75 = *L. bromfieldii* L.Bolus var. *insularis* (L.Bolus) Fearn 1970: 92 T Wilmot 1353/34 (BOL) = *L. mennellii* L.Bolus NM 1937: 75 = *L. bromfieldii* L.Bolus var. *mennellii* (L.Bolus) Fearn 1970: 92 T Mennell 645/34 (BOL) = *L. rooi* Haage 1937: 16 nomen nudum = *L. rouxii* J. Oesterreich 1937: 100 nomen nudum = *L. upingtonensis* L.Bolus in litt. Nomen nudum.

Lithops bromfieldii (Aizoaceae) (Fig. 33f) is a low-growing perennial succulent. It produces yellow flowers (Hartman 2001) in late winter (August). Flowers open in the late afternoon. This species has a restricted distribution range in Griqualand West (Fig. 36f), known to occur in only a few locations in the west of the region. This distribution corresponds roughly with the region‘s southern extreme of quartzite outcrops where it has only been recorded occurring on quartzite-related substrates. This species is a member of the so called –stone plants” that are notoriously difficult to locate in their natural habitats. Thus, the distribution of this species may be wider than indicated in the distribution map below. It is classified as least concern (Victor 2005). Due to the restricted distribution and popularity of the genus with collectors, this status should be reviewed.

4.3.1.16 *Lithops lesliei* (N.E.Br.) N.E.Br. subsp. *burchellii* D.T.Cole

Lithops lesliei (N.E.Br.) N.E.Br. subsp. *burchellii* D.T.Cole in Hartman (2001): Illustrated handbook of succulent plants, Aizoaceae, F-Z: 56-62. 1988: 217 T Cole 302 (PRE).

Lithops lesliei subsp. *burchellii* (Aizoaceae) (Fig. 33g) is a low-growing perennial succulent. Flowers are whitish grey tinged with cream or yellow or pinkish beige (Hartman 2001). This species has a restricted distribution range in the GWC (Fig. 36g), known from only ten localities in south-western Griqualand West. As another member of the –stone-plants”, the difficulty involved in finding it in habitat may mean that the distribution may be wider than indicated in the map below. It has been recorded growing on calcareous soils between quartzite pebbles and jaspilite (Hartman 2001). It is threatened by illegal collection for the medicinal plant trade and is classified as near threatened (Victor 2005).

4.3.1.17 *Maytenus ilicina* (Burch.) Loes.

Celastrus ilicinus, Burch. in Burchell's Trav. i. 340 ; DC. Prod. ii, 7. Asbestos hills at Blaaubosch Poort, Dist. Hay, Wilman 1327 in Herb. Bolus ! and in Nat. Herb. Pretoria ! Asbestos Hills; Marloth 4909 in Herb. Bolus ! Marloth 2076 in Herb. Marloth ! Asbestos Mountains, Griqualand West, Burchell 1163 ! 2037 in Herb. Kew !

Maytenus ilicina (Celastraceae) (Fig. 33h) is a perennial shrub or tree of up to 3 m in height. It produces green flowers in March. It has a wide distribution in Griqualand West (Fig. 36g) and occurs on a variety of substrates including calcareous soils, ironstone and quartzite. It is classified as least concern (Archer & Victor 2005). This taxon may be discarded in an upcoming revision (Archer 2015: pers. comm.).

4.3.1.18 *Nuxia gracilis* Engl.

Nuxia gracilis Engl .in Engler, Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeographie 10: 243. 1888; Prain & Cummings in Fl. Cap. 4(1): 1040. 1909; Verdoorn in Fl. S. Afr. 26: 151. 1963. Type: S. Africa: Cape Province: Hay District, Klein Boetsap, Marloth 980 (holotype not seen, destroyed in B; lectotype: PRE; isotypes: K, PRE). Homotypic synonym: *Lachnopylis gracilis* (Engl.) C.A. Smith, Kew Bull. 1930: 24 1930.

Nuxia gracilis (Stilbaceae) (Fig. 33i) is a perennial shrub of up to 4 m in height. It produces white to cream flowers in summer (November and December) that are sweet scented (Leeuwenberg 1975). This species occurs on the eastern edge of the Ghaap Plateau in Griqualand West (Fig. 36i). This species is restricted to calcareous soils in the vicinity of perennial or seasonal water sources such as stream and river banks. It is considered near-endemic to Griqualand West as it also occurs in another centre of endemism, namely the Sekhukhuneland Centre in north-eastern South Africa where it is also restricted to calcareous soils near water courses. It is classified as least concern (Victor 2005).

4.3.1.19 *Phyllobolus amabilis* Gerbaulet & Struck

Phyllobolus amabilis Gerbaulet & Struck in Hartman (2001): Illustrated handbook of succulent plants, Aizoaceae, F-Z: 56-62 1996: 25 T Hammer 1405 (BOL!).

Phyllobolus amabilis (Aizoaceae) (Fig. 34a) is a perennial succulent of up to 100 mm in height. It produces cream-yellow flowers (Hartman 2001) in spring (September). It has a highly restricted distribution (Fig. 37a), known from only one locality near Prieska in the southern extreme of Griqualand West. No substrate data is available for this species barring that it favours rocky sites (Hartman 2001). It is classified as rare (Raimondo & Cholo 2008).

4.3.1.20 *Prepodesma orpenii* (N.E. Br.) N.E. Br.

Prepodesma orpenii (N.E. Br.) N.E. Br. in Hartman (2001): Illustrated handbook of succulent plants, Aizoaceae, F-Z: 56-62. 1931: 389 = *M. orpenii* N.E.Br. GC 1921: 303 = *Aloinopsis orpenii* (N.E.Br.) L.Bolus SAG 1929: 288 = *Nananthus orpenii* (N.E.Br.) NM 1938: 133 T Pole Evans 6910 (K!) = *Rabiea tersa* N.E.Br. GC 1931: 54 = *Nananthus tarsus* (N.E.Br.) G.D. Rowley NCSJ 1978: 6 T Pole Evans 7623 (K!).

Prepodesma orpenii (Aizoaceae) (Fig. 34b) is a perennial succulent of up to 50 mm in height. It has bright yellow flowers appearing between February and September. The flowers open in the afternoon to late evening. This species occurs in much of central Griqualand West (Fig. 37b), having only been collected on calcareous and loamy soils (Hartman 2001) including limestone and calcrete. It is classified as least concern (Burgoyne 2006).

4.3.1.21 *Putterlickia saxatilis* (Burch.) Jordaan

Gymnosporia saxatalis, Davidson in Bothalia 2: 289–346.
Celastrus saxatalis Burch., Burchell's Trav. 11, 264. Type: Asbestos mountains, Griqualand West: Burchell 1671! 2027 in Herb. Kew! Griqualand West Burchell 2158 in Herb. Kew! Near Hamapery, Bechuanaland. Burchell 2487 in Herb. Kew!

Putterlickia saxatilis (Celastraceae) (Fig. 34c) is a perennial shrub of up to 2 m in height. It has cream-coloured flowers and red fruit appearing in winter (June). This species occurs in most parts of Griqualand West (Fig. 37c) on a variety of substrates including ironstone, quartzite, dolerite, dolomite and manganese-rich rock. The rest of the genus is confined to the moist eastern coastal parts of southern Africa (Jordaan & van Wyk 1998). It is classified as least concern (Archer & Victor 2005).

4.3.1.22 *Rennera stellata* P.P.J.Herman

Rennera stellata P.P.J.Herman in Botanical Journal of the Linnean Society (1999), 129: 367–377. Type. 2824 (Kimberley): South Africa, Northern Cape, Koopmansfontein Agricultural Research Station (-AA), Herman 1482 (PRE, holotypus, B, BM, C, E, G, J, K, KMG, M, MO, NBG, NMB, NY, P, PRU, S, UPS, WAG, WIND, Z, isotypus).

Rennera stellata (Asteraceae) (Fig. 34d) is a small perennial herb of 100 mm in height. It produces yellow flowers (Herman 1999) from summer (January) to autumn (April). It is known to occur in the north-western parts of Griqualand West (Fig. 37d) in seasonally waterlogged pans on calcrete (Herman 1999). It is classified as vulnerable due to habitat loss and habitat degradation through trampling by cattle (von Staden & Herman 2006).

4.3.1.23 *Salsola atrata* Botsch.

Salsola atrata Botsch. in Botanicheskii Zhurnal 58: 819 (1973). Type: South Africa, Boschjemansland, Bitterfontein, Kalkstein, Zeyher 1448 (LE, holotype; K, W, isotypes).
S. globulifera Fenzl in Mém, Acad. Sci. Pétersb. VII. 27(8): 12 (1880).

Salsola atrata (Amaranthaceae) (Fig. 34e) is a perennial dwarf shrub of up to 350 mm in height. It produces very small, pale yellow flowers in spring and summer (October to November). It has a restricted distribution in Griqualand West (Fig. 37e) (Botschantzev 1974), occurring in the region of the town Reivilo in the North-West province. No substrate data has been recorded for this species. However, as it is known distribution is on the Ghaap Plateau which is dominated by calcareous substrates. It is classified as least concern (Kamundi 2005).

4.3.1.24 *Searsia tridactyla* (Burch.) Moffett

Rhus tridcatyla Burch., Travels in the interior of southern Africa 1: 340 (1822) ‗*R. tridactyle*'; DC.: 71 (1825); G. Don: 74 (1832); Sond: 516 (1825); Engl.: 446 (1883); Diels: 590, 641 (1898); Engl.: 217 (1921). Type: Northern Cape, Asbestos Mountains, 27.9.1811, Burchell 1667 (K, holo.!; BOL!, iso.).
Toxicidendron tridactylum (Burch.) Kuntze: 154 (1891).
Rhus ciliata sensu Schonl.: 82 (1930) p.p., et auct. mult., non Licht. ex Schult.

Searsia tridactyla (Anacardiaceae) (Fig. 34f) is a perennial shrub or tree of up to 4 m in height. Branches are spine-like. It produces small yellow-green flowers in summer (December to March). It is widespread in most parts of Griqualand West (Fig. 37f) and occurs on a wide variety of substrates including dolomite, calcrete, ironstone, quartzite and sandy substrates. The extent of occurrence of the species can be considered as the most typical for the GWC. It is classified as least concern (Foden & Potter 2005).

4.3.1.25 *Tarchonanthus obovatus* DC.

Tarchonanthus obovatus DC., Prodromus 5: 431 (1836), Herman & Condy: 108, t. 2180 (2001). Type: South Africa, Bechuanaland Division (?Northern Cape), Klipfontein, Burchell 2155 (G-DC, holo.; K!–PRE).

Tarchonanthus obovatus (Asteraceae) (Fig. 34g) is a perennial shrub or tree of up to 2 m in height. The female plant produces greenish-white flowers during the cold seasons (between March and August) and fruit with a prominent white and fluffy pappus. The male flowers are small and brown. It is widespread in Griqualand West (Fig. 37g) and occurs on ironstone, limestone (Herman 2002), quartzite, calcrete and sand overlying dolerite. It is classified as least concern (Foden & Potter 2005).

4.3.1.26 *Thesium dumale* N.E. Br.

Thesium dumale N.E. Br. in Burtt Davy, Flowering Plants and Ferns of Transvaal part 2: xxxiii and 461 (1932). Type locality uncertain, possibly Vryburg div. in the NW Province of South Africa.

Thesium dumale (Santalaceae) (Fig. 34h) is a perennial herb and hemi-parasite of up to 200 mm in height. It produces small, green-white flowers from November to February. It only occurs in northern Griqualand West (Fig. 37h). No information on substrate preferences has been recorded for this species. It is classified as least concern (Foden & Potter 2005).

Figure 32: a) Herbarium specimen (Brusse F 5629, S) of *Amphiglossa tecta* (plants.jstor.org); b) *Antimima lawsonii* in habitat (www.ispotnature.org); c) Herbarium specimen (Silk E 240, PRE) of *Barleria media*; d) Herbarium specimen (Shaw J 59, K) of *Blepharis marginata* (plants.jstor.org); e) Herbarium specimen (Esterhuysen E 2269, K) of *Brachiaria dura* var. *pilosa* (plants.jstor.org); f) Herbarium specimen (Aucamp 939, KMG) of *Calobota cuspidosa*; g) Herbarium specimen (Burchell 2274, K) of *Cineraria exilis* (plants.jstor.org); h) Herbarium specimen (Burchell 2179, K) of *Dicoma kurumanii* (plants.jstor.org) and i) *Eriocephalus ericoides* subsp. *griquensis* in habitat (www.ispotnature.org).

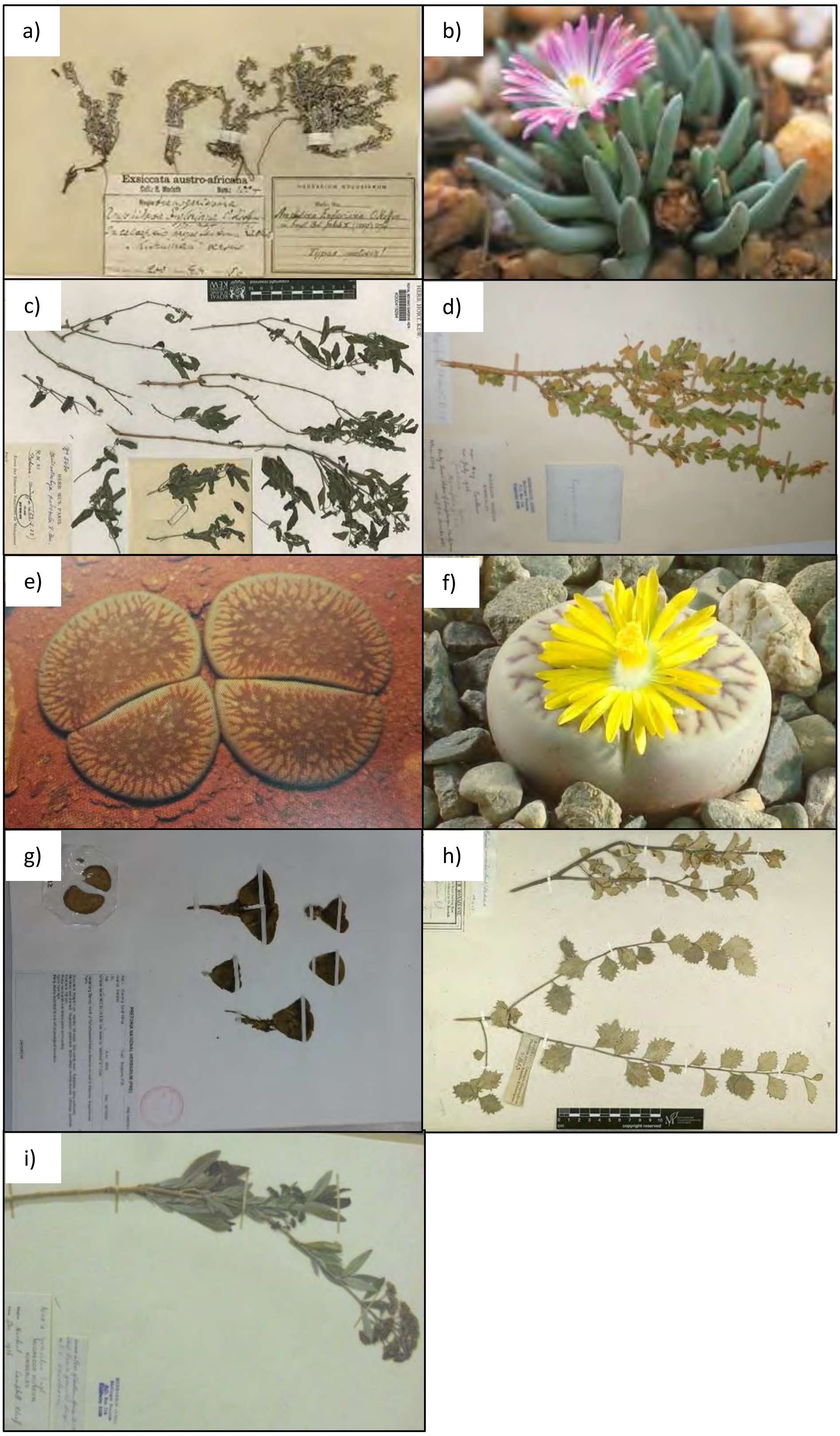


Figure 33: a) Herbarium specimen (Marloth 1004, BOL) of *Gnaphalium englerianum*; b) *Hereroa wilmaniae* in habitat (www.ispotnature.org); c) Herbarium specimen (Unknown collector 5430, K) of *Justicia puberula*. (plants.jstor.org); d) Herbarium specimen (Acocks 485, KMG) of *Justicia thymifolia*; e) *Lithops aucampiae* subsp. *euniceae* in habitat (Photo: D. T. Cole 1979 C 48, PRE); f) *Lithops bromfieldii* in cultivation (www.flikr.com); g) Herbarium specimen (Burgoyne 9612, PRE) of *Lithops lesliei* subsp. *burchellii*; h) Herbarium specimen (Burchell 1663, M) of *Maytenus ilicina* and i) Herbarium specimen (Acocks 1428, KMG) of *Nuxia gracilis*.

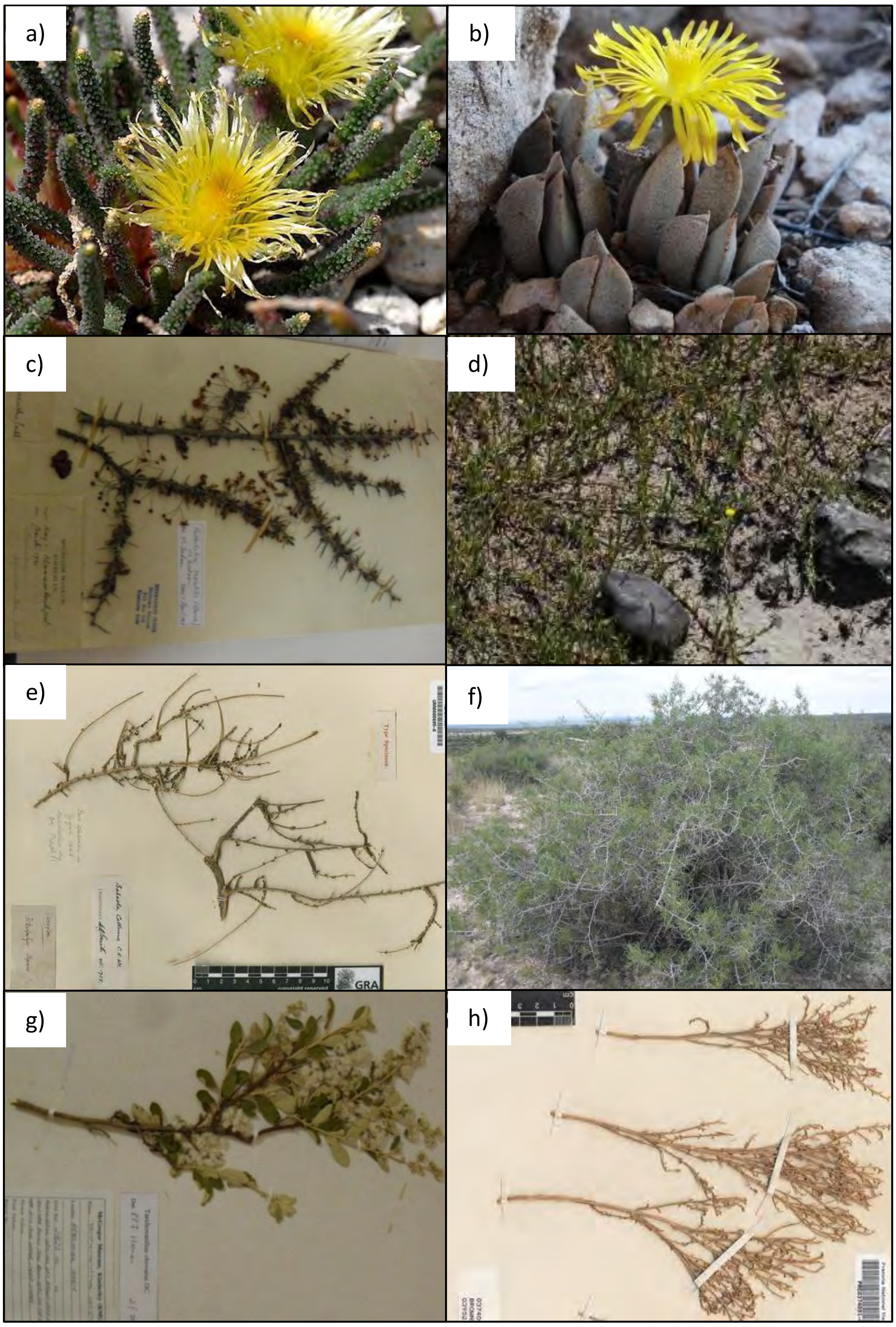


Figure 34: a) *Phyllobolus amabilis* in habitat (www.ispotnature.org); b) *Prepodesma orpenii* in habitat (www.ispotnature.org); c) Herbarium specimen (Wilman M 1315, KMG) of *Putterlickia saxatilis*; d) *Rennera stellata* in habitat (Photo: R Terblanche); e) Herbarium specimen (Zeyher 1448, GRA) of *Salsola atrata* (plants.jstor.org); f) *Searsia tridactyla* in habitat; g) Herbarium specimen (Gubb AA 4361, KMG) of *Tarchonanthus obovatus*; and h) Herbarium specimen (Brown N 6985, PRE) of *Thesium dumale* (plants.jstor.org).

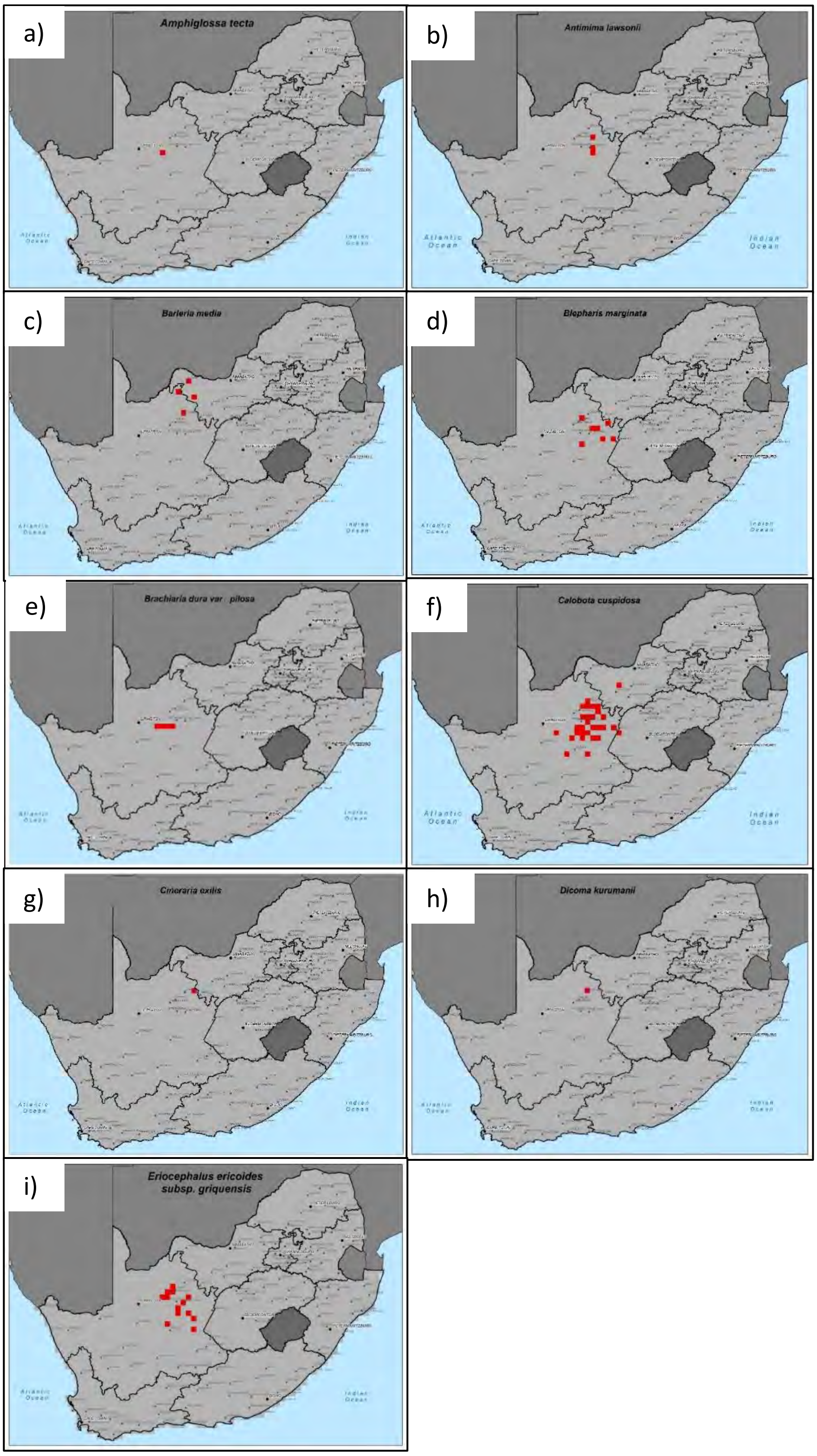


Figure 35: Global distribution of a) *Amphiglossa tecta*; b) *Antimima lawsonii*; c) *Barleria media*; d) *Blepharis marginata*; e) *Brachiaria dura* var. *pilosa*; f) *Calobota cuspidosa*; g) *Cineraria exilis*; h) *Dicoma kurumanii* and i) *Eriocephalus ericoides* subsp. *griquensis*.

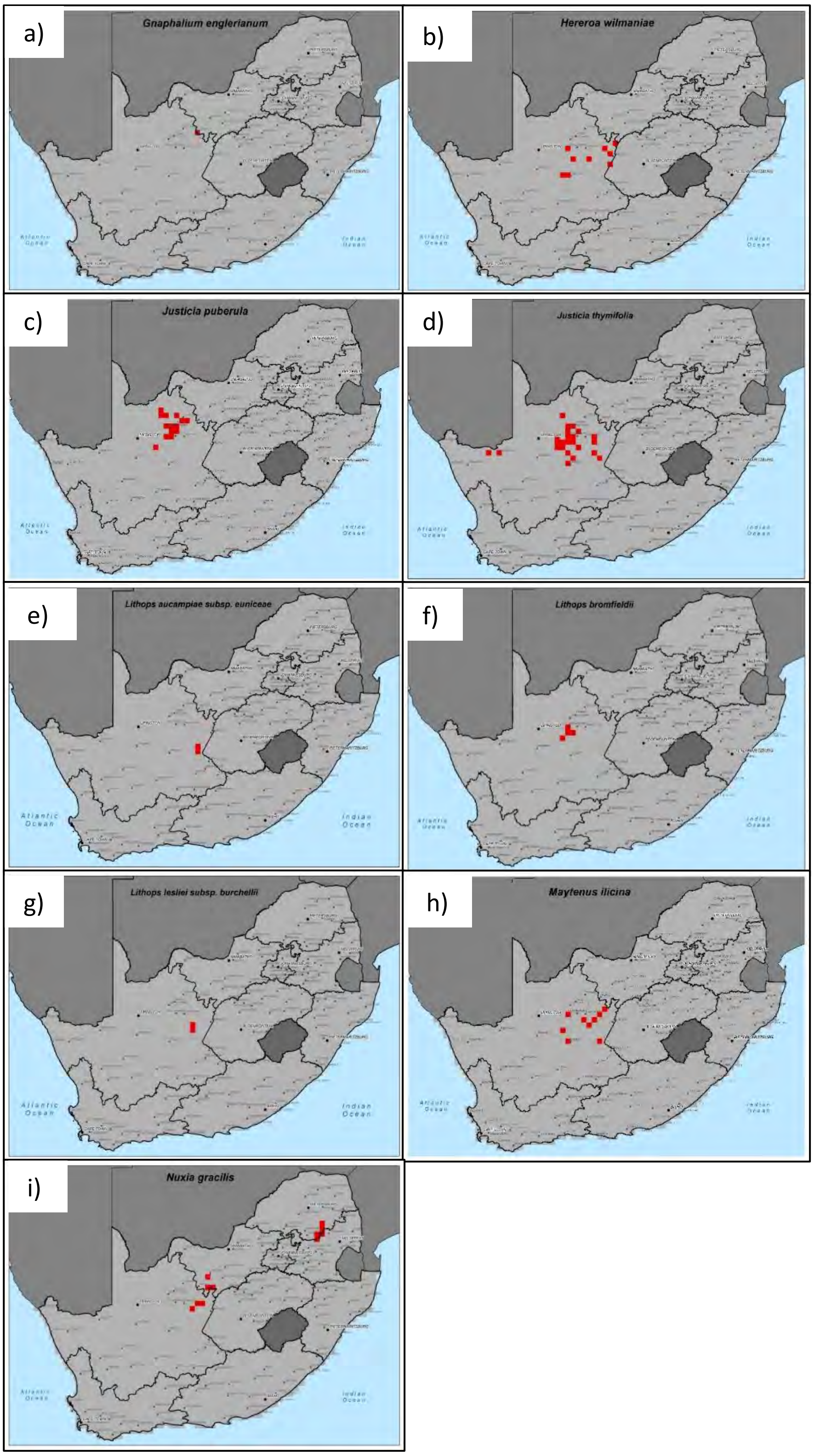


Figure 36: Global distribution of a) *Gnaphalium englerianum*; b) *Hereroa wilmaniae*; c) *Justicia puberula* (near endemic); d) *Justicia thymifolia*; e) *Lithops aucampiae* subsp. *euniceae*; f) *Lithops bromfieldii*; g) *Lithops lesliei* subsp. *burchellii*; h) *Maytenus ilicina* and i) *Nuxia gracilis* (near endemic).

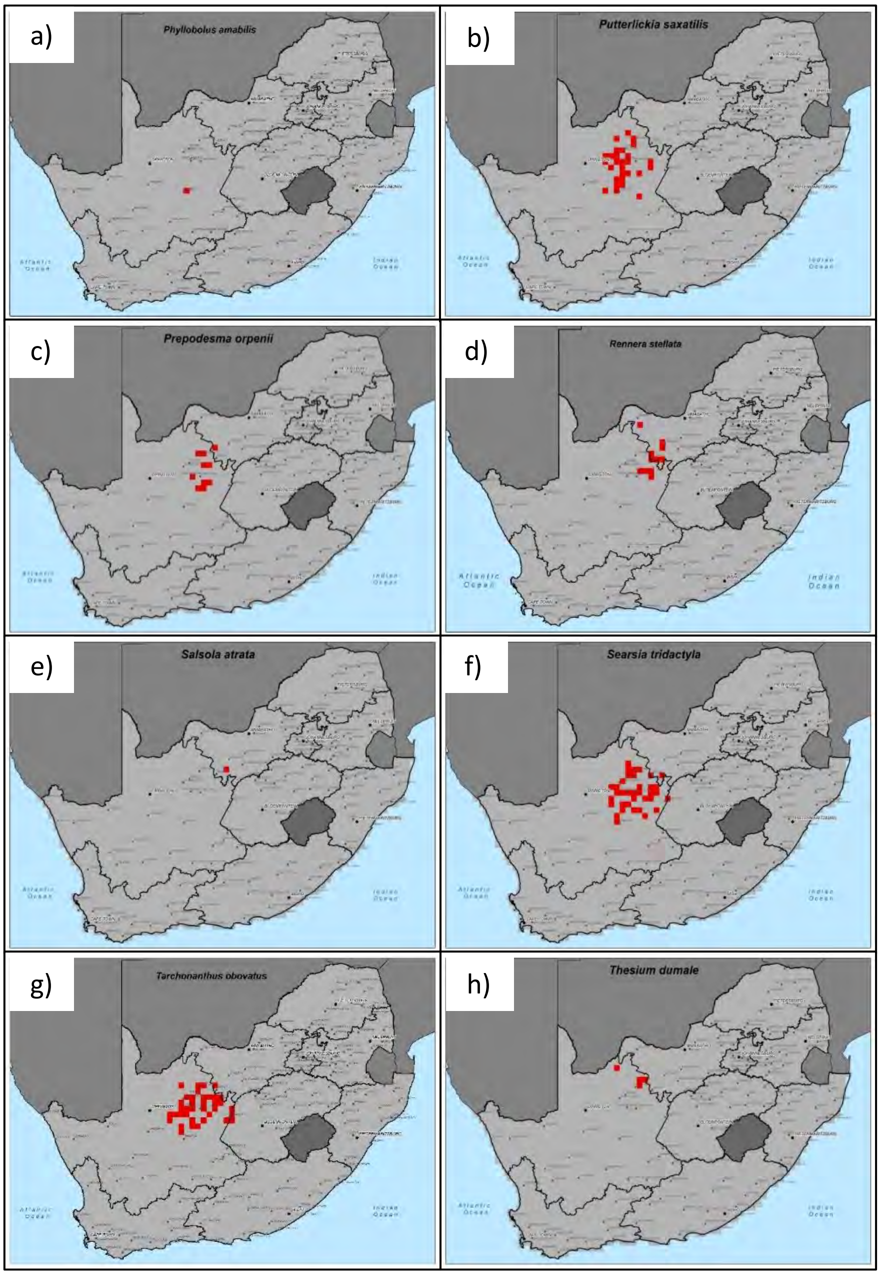


Figure 37: Global distribution of a) *Phyllobolus amabilis*; b) *Putterlickia saxatilis*; c) *Prepodesma orpenii*; d) *Rennera stellata*; e) *Salsola atrata*; f) *Searsia tridactyla*; g) *Tarchonanthus obovatus* and h) *Thesium dumale*.

4.3.2 GWC floristic links

When all the total distributions of the GWC endemic, near-endemic and floristic element taxa (Table 2) are overlayed, the resulting distribution pattern (Fig. 38) indicates a floristic link between the GWC region and the Nama-Karoo and Savanna Biomes. These links are inferred based on the distributions, primarily of the floristic element taxa and the regions into which the majority extend. This is to be expected as the GWC is located primarily in the Savanna Biome but is also in close proximity to the Nama-Karoo Biome to the West and South-West. Thus, the flora of the GWC is strongly influenced by taxa from these two biomes.

4.3.2.1 Nama-Karoo

The eight floristic element taxa associated with the Nama-Karoo Biome and their growth forms (grass, forb or woody) are as follows: *Aizoon asbestinum* (succulent forb); *Digitaria polyphylla* (grass); *Eragrostis macrochlamys* var. *wilmaniae* (grass); *Euphorbia wilmaniae* (succulent forb); *Indigofera damarana* (forb); *Pharnaceum viride* (forb); *Stachys burchelliana* (forb); *Titanopsis calcarea* (succulent forb). The Poaceae appear to contribute the most (2) floristic element taxa from this biome.

Only one GWC endemic has a distribution that is restricted to this biome, namley *Lithops aucampiae* subsp. *euniceae*.

4.3.2.2 Savanna

The 17 floristic element taxa associated with the Savanna Biome and their growth forms (grass, forb or woody) are as follows: *Carex burchelliana* (forb); *Corchorus pinnatipartitus* (forb); *Crotalaria griquensis* (forb); *Ebracteola wilmaniae* (forb); *Erucastrum griquense* (forb); *Euphorbia bergii* (succulent forb); *Euphorbia duseimata* (succulent forb); *Helichrysum spiciforme* (forb); *Ipomoea suffruticosa* (forb); *Lotononis crumanina* (forb); *Pentzia oppositifolia* (forb); *Selago mixta* (forb); *Sesbania notialis* (forb); *Stachys burchelliana* (forb); *Sutera griquensis* (forb); *Triaspis hypericoides* subsp. *hypericoides (forb); Jamesbrittenia albiflora (forb).* The Scrophulariaceae and the Fabaceae contribute the most floristic element taxa with three species each. Euphorbiaceae and Asteraceae both contribute two floristic element species.

23 Of the GWC endemics have distributions restricted to this biome. The outlier poulation of the near-endemic *Justicia thymifolia* may be restricted to a small patch of savanna in the Gariep region.

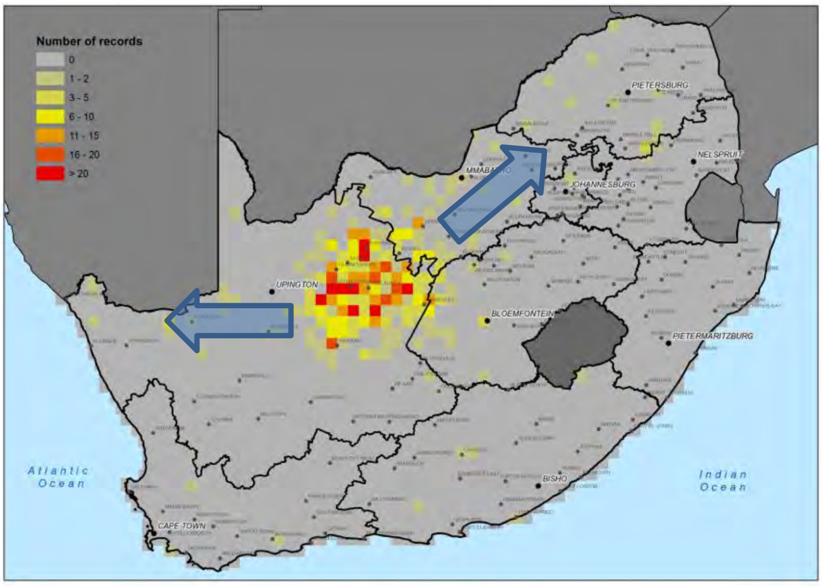


Figure 38: Combined distribution of GWC endemic, near-endemic and floristic element taxa. The arrow on the left indicates an inferred floristic link between GWC flora and the Nama Karoo Biome. The arrow on the right indicates an inferred link between the GWC flora and the Savanna Biome. (Compare to Fig. 26).

4.3.3 GWC boundaries

Following the identification of the GWC endemic (24) and near-endemic (2) species and the overlaying of all their distributions (without floristic elements) new borders for the GWC are proposed (Fig. 39). The boundaries were fitted to the outer boundaries of the grid cluster in which GWC endemics were present.

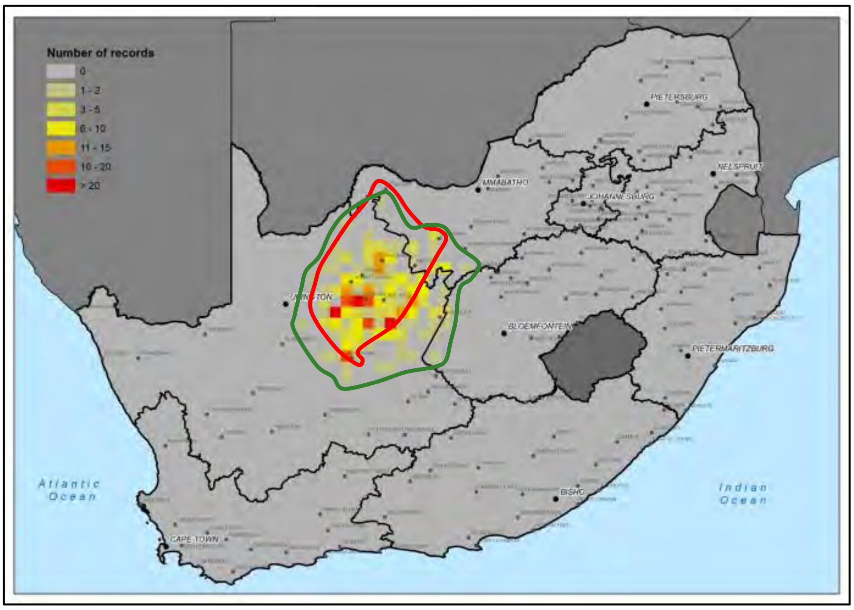


Figure 39: GWC boundaries: Combined distribution of GWC endemic and near-endemic species (26 taxa). The green polygon that encircles the total distribution of the afore-mentioned species. The red polygon represents the boundaries of the GWC as proposed by Van Wyk & Smith (2001).

As the area within the new GWC borders proposed in Figure 39 was found to cover a very extensive area, larger than the borders proposed by van Wyk & Smith (2001), the new GWC borders were further refined by excluding grids in which there were less than three records of endemic or near-endemic taxa. The resulting borders (also the result of combining the outer edges of all identified grids (see 4.2.2)) represents the ‗core area‘ of the GWC (Fig. 40) which is supported by the presence of the 26 endemic species.

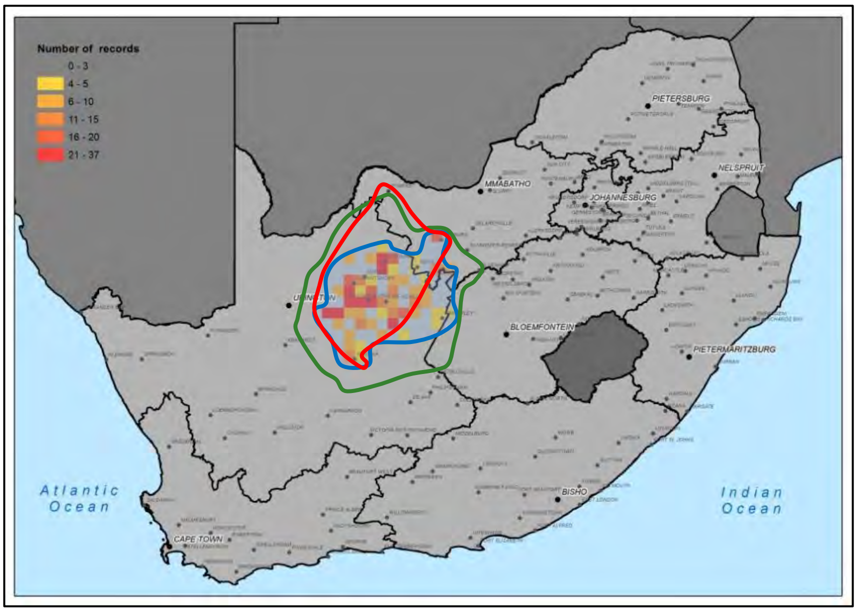


Figure. 40: Core grids of the GWC (blue-shaded polygon) based on the occurrence of endemic and near-endemic species. Core grids have more than two records of endemic species. Green polygon represents the GWC boundaries based on the occurrence of at least one endemic plant species per quarter-degree-grid. Red polygon represents the GWC borders as proposed by van Wyk & Smith (2001).

4.3.4 GWC species-area correlations

A strong correlation (greater than 0.5) was found for the variables, total number of species and total number of endemic species. The residual value for the GWC for the untransformed data (Fig. 41) was not larger than 2 and is therefore not an outlier value for number of endemic taxa per total number of species on a 95% confidence interval. The residual value for the GWC for the natural log transformed data (Fig. 42) was also below 2 and therefore shows the GWC to not be an outlier value for number of endemic taxa per total number of species on a 95% confidence interval.

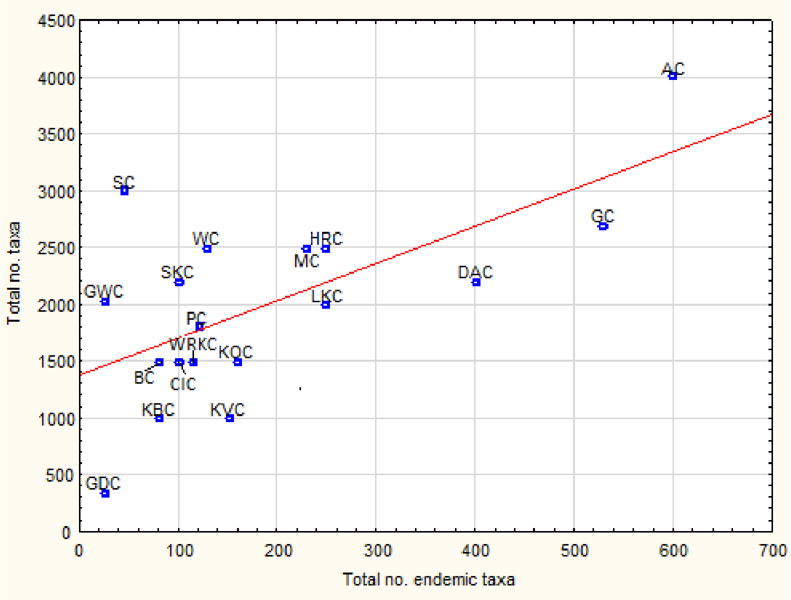


Figure 41: Weighted regression for the 18 (van Wyk & Smith, 2001) centres of endemism. The Centres are abbreviated as follows: Kamiesberg Centre (KBC); Gariep Centre (GC); Knersvlakte Centre (KVC); Little Karoo Centre (LKC); Worcester-Robertson Karoo Centre (WRKC); Hantam-Roggeveld Centre (HRC); Maputoland Centre (MC); Pondoland Centre (PC); Albany Centre (AC); Drakensberg Alpine Centre (DAC); Barberton Centre (BC); Wolkberg Centre (WC); Sekhukhuneland Centre (SKC); Soutpansberg Centre (SC); Chimanimani-Nyanga Centre (CIC); Great Dyke Centre (GDC); Kaokoveld Centre (KOC) and Griqualand West Centre (GWC).

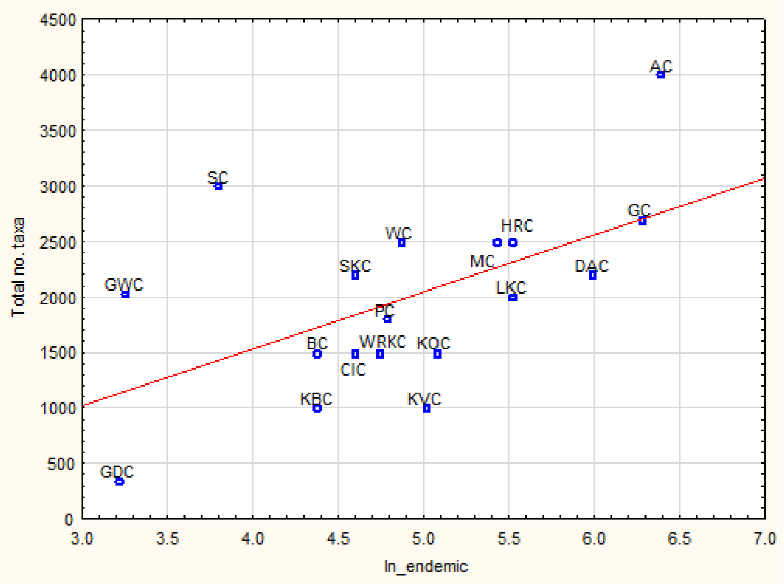


Figure 42: Weighted regression for the 18 (van Wyk & Smith, 2001) centres of endemism using the natural log (ln) transformation. The Centres are abbreviated as follows: Kamiesberg Centre (KBC); Gariep Centre (GC); Knersvlakte Centre (KVC); Little Karoo Centre (LKC); Worcester-Robertson Karoo Centre (WRKC); Hantam-Roggeveld Centre (HRC); Maputoland Centre (MC); Pondoland Centre (PC); Albany Centre (AC); Drakensberg Alpine Centre (DAC); Barberton Centre (BC); Wolkberg Centre (WC); Sekhukhuneland Centre (SKC); Soutpansberg Centre (SC); Chimanimani-Nyanga Centre (CIC); Great Dyke Centre (GDC); Kaokoveld Centre (KOC) and Griqualand West Centre (GWC).

4.4 Discussion

4.4.1 GWC endemism

The Asteraceae and Aizoaceae both contribute the most endemic species (seven each) to the GWC. These two families are the two largest in southern Africa (Koekemoer *et al*. 2013). The Acanthaceae contributes four endemic species. This family is the 15th largest in southern Africa, and so having four GWC endemics is notable. The Celastraceae contributes two endemics which is also notable as the Celastraceae is not one of the 20 largest families in southern Africa. The Amaranthaceae, Anacardiaceae, Santalaceae, Poaceae, Fabaceae and Stilbaceae each contribute one endemic species to the GWC. Some of the GWC endemics are very rare, known from only a small region or a few localities such as *Amphiglossa tecta*, *Dicoma kurumanii*, *Gnaphalium englerianum*, *Lithops aucampiae* subsp. *euniceae, Lithops lesiei* subsp. *burchellii*, *Phyllobolus amabilis* and *Salsola atrata*. There are also a number of GWC endemics that are widely distributed throughout most of the centre. These include *Calobota cuspidosa*, *Putterlickia saxatilis*, *Searsia tridactyla* and *Tarchonanthus obovatus*, all of which are woody trees or shrubs. The two near-endemics, namely *Justicia thymifolia* and *Nuxia gracilis*, indicate links with two other centers of endemism, namely the Gariep and Sekhukhuneland Centres respectively. Seven of the 24 endemic species are succulent, comprising 29% of the endemics. This is lower than the 32.5% predicted by van Wyk & Smith (2001).

It was predicted by van Wyk & Smith (2001) that the GWC would harbor more than 40 endemic taxa, representing a total of 2.2 % of the approximate 1 800 taxa present within the GWC. Thus, the 26 taxa found to be endemic or near-endemic to the GWC accounts for 1.4% of the total flora, which is a lower than expected. This figure represents the lowest percentage of endemism of any of the 18 centres of endemism recognized in southern Africa. The percentage endemism of the GWC is comparable only with the Soutpansberg Centre (SC) with its 45 endemic taxa totaling 1.5 % of its total flora (van Wyk & Smith, 2001). However, the SC has a much smaller total surface area (7 000 km^2) when compared to the GWC (99 000 km^2). The GWC is by size ranked the second largest centre while the SC is the tenth largest of the 18.

Low levels of endemism for the GWC required further comparison with the other 18 centres (van Wyk & Smith, 2001) to determine whether its recognition as a centre be maintained or not.

Weighted regressions suggest that the GWC has a level of endemism that is within the norm for the 18 (van Wyk & Smith, 2001) centers in southern Africa when considering number of endemics and total flora.

It is worth noting that the Soutpansberg Centre (SC) proved to be the only outlier center for number of endemic taxa per total number of species on a 95% confidence interval, for both the untransformed (Fig. 41) and natural log transformed (Fig. 42) data. Thus, the SC has less endemic species per total number of species than would be expected for its total flora when compared to the norm for the other 17 centers in southern Africa. As the SC is the only centre with a level of endemism comparable to that of the GWC, the finding that the SC is a negative (less endemic species than the trend) outlier further highlights the low level of endemism for the GWC.

One crucial consideration regarding the low level of endemism of the GWC is the severe lack of botanical collections made in this region as of 30 January 2014 (Figure 43). It is clear that the GWC is severely under-collected, with many QDG's having less than 30 taxa collected and also a number without a single collected specimen. As interest in the region increases and botanical collections are increased, it is likely that more endemic taxa that are as of yet uncollected and even undescribed, will be found. Additionally, some taxa may require closer taxonomic scrutiny, with distinct infra-specific taxa still unrecognized.

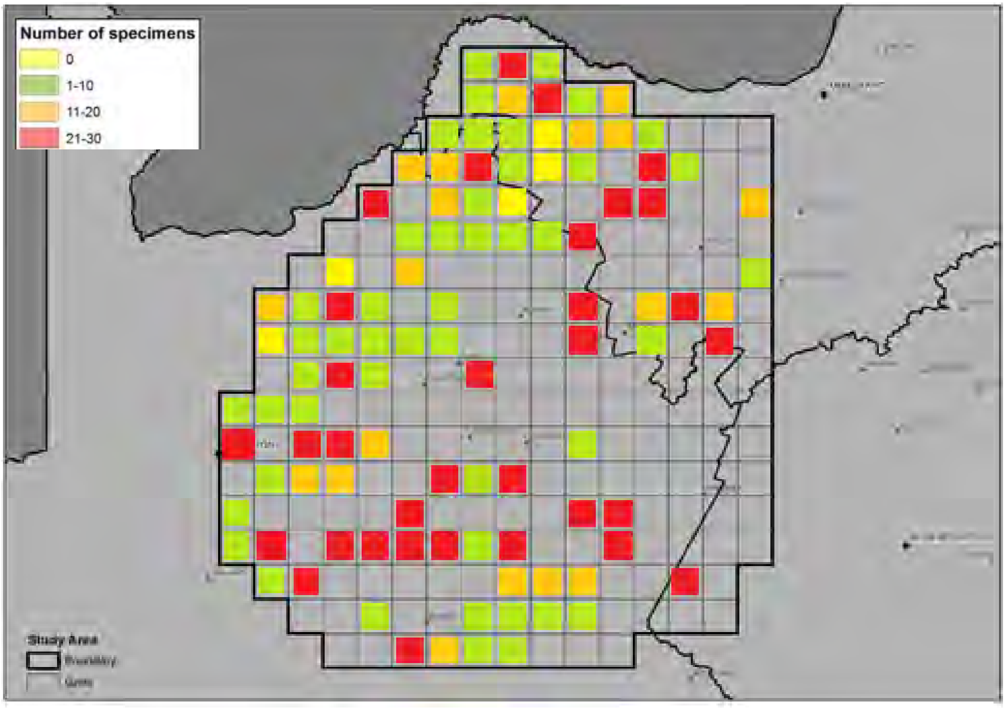


Figure 43: Collection effort in GWSA as of January 2014 based on data collected for this study. Grids that are not coloured have more than 30 specimens recorded.

The relative aridity of the GWC (250-450 mm annually) should not be a reason for the low number of endemic taxa, as a number of arid centres of endemism are recognized for southern Africa, including the nearby Gariep Centre (GC) (0-300 mm annually), Knersvlakte Centre (KVC) (50-125 mm annually), Little Karoo Centre (LKC) (125-300 mm annually), Worcester-Robertson Karoo Centre (WRKC) (125-350 mm annually), Hantam-Roggeveld Centre (HRC) (150-250 mm annually) and the Kaokoveld Centre (KOC) (100-350 mm annually), all of which have higher levels of endemism than the GWC. The Gariep Centre (GC), which is one of the most arid centres in southern Africa has the highest level of endemism of all 18 centres at 20.7% (van Wyk & Smith, 2001). Thus, aridity may promote speciation in some regions and discourage it in others. These statistics suggest that an array of variables, both environmental and historical factors should be considered when trying to identify drivers of plant adaptation and isolation, as the degree that various variables influence a flora may vary from region to region (Crisp *et al*. 2001).

As highlighted by Kruckeberg & Rabinowitz (1985), geology and substrates play a major role in plant speciation. Endemic taxa are often restricted to a soil type that excludes the regionally dominant flora due to a disadvantage such as poor nutrient availability. Thus, species endemic to a soil type have a genetic advantage that allows them to better survive and reproduce on anomalous soil types (Gankin & Major 1964). A species restricted to a specific soil type will over time become so adapted to the prevailing conditions that it can no longer survive on surrounding soil types, even in the absence of competition (Meyer 1986). Such species may be considered ‗edaphic specialists‘ or ‗edaphic endemics‘ (Hopper *et al*. 1990). The diverse geology of the GWC was predicted to harbor a number of edaphic specialists (van Wyk & Smith 2001). However, of the 26 endemic and near-endemic species, nine show a preference to soils rich in calcium. Of these, three species, namely *Euphorbia planiceps*, *Nuxia gracilis* and *Rennera stellata* appear to be edaphic specialists, having only been recorded occurring on Ca-rich soils. The substrate which supports the most endemic and near-endemic species is Ca-rich rocks and soils (Fig. 44a), which includes calcrete, dolomite and limestone. Much of the Ca-rich rock in the GWC is located on the Ghaap Plateau, which forms the central region (according to the borders proposed by this study) of the GWC. Based on current data, the majority (81.1%) of endemic and near-endemic species occur on rocks or substrates that are of sedimentary origin (Fig. 44b). Given these preliminary statistics, the diverse geology of the GWC and the low total number of endemic taxa in the GWC, the level of influence that geology alone has on the presence of endemic plant species in the region is questionable. Hence, much of the species identified as endemic to Griqualand West by this study have distributions that violate the boundaries proposed by van Wyk & Smith (2001), as these boundaries were only used as a reference for the region and based on only the geology.

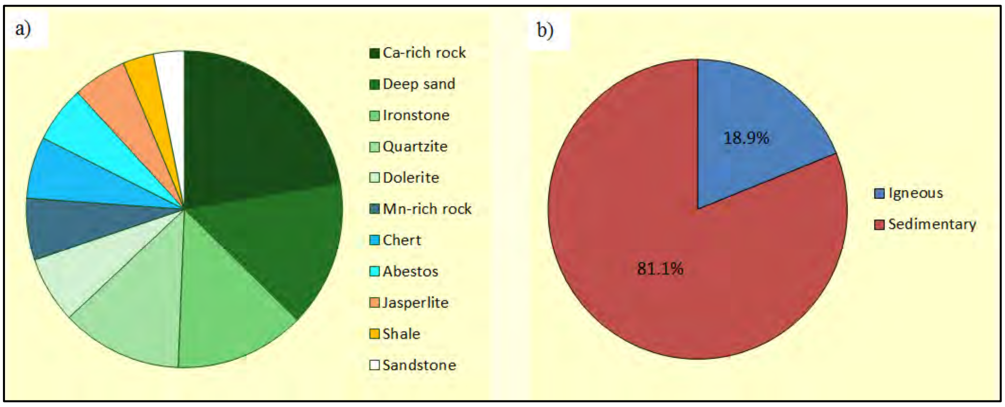


Figure 44: Preferences of GWC endemic and near-endemic taxa for a) various substrates (the proportion of mean number of occurrence records); and b) sedimentary or igneous origin.

It is possible that there are other factors other than the diverse geology of the region that have affected endemism in the flora of the GWC. Firstly, the flora of the GWC might be relatively young when compared to the flora of more diverse centres of endemism. Sufficient time is one of the main factors allowing speciation to occur (Willis 1922). Key to this concept is long-term stability of a region. This hypothesis predicts that a changing environment is too unstable for species to adapt, become specialized and undergo speciation (Hua & Wiens 2013). There is, however, no evidence in the literature that the flora of the GWC is young. Secondly, species endemism is often determined by the richness of the surrounding species pool (Caley 1997; Vetaas *et al*. 2002; Zobel *et al*. 2011). However, a larger species pool does not always mean that there will be more endemic taxa, as is evidenced by the SC of plant endemism with a total flora of around 3000 taxa but with only 1.5 % endemism (van Wyk & Smith 2001). The GWC also has a relatively large species pool totaling around 2075 species.

One of the greatest factors creating instability in an environment is a changing climate. Thus, the GWC may have been subjected to greater climatic variations than other centres, which would have hindered speciation (Hua & Wiens 2013) and the subsequent presence of many endemic taxa. The GWC is located close to the transition zone between summer and winter rainfall. This zone may have been subjected to shifting over time, resulting in some degree of climatic instability. Thus, despite the very diverse geology of the region, speciation rates may be or may have been low owing to regular climatic changes. Indeed the climate of the southern African interior has been shown to have changed dramatically over the last 25 000 years (Holmgren *et al* 2003), with significant climatic oscillations that affected vegetation distributions, particularly over the last 6500 years (Lee-Thorp *et al*. 2001).

The GWC is one of only a few centres in southern Africa that is not associated with the escarpment (Fig. 45). The escarpment in South Africa has many climatic zones associated with aspect and altitude and other phenomena such as rain shadows (Killick 1978). These climatic zones represent niches which can be occupied by a large number of species in relatively small areas. The low level of endemism in the GWC compared to other centres that are linked to the escarpment may be due to the relative lack of topographical and therefore stable microclimatic and microhabitat heterogeneity. Furthermore, mountainous regions, such as are associated with the escarpment, may to some degree act as areas of long term climatic stability as taxa may migrate with relative ease up and down a mountain as its preferred climatic zone shifts (Pauli *et al*. 2003). Through this process long term climatic stability may be simulated in a small geographical area, which allows sufficient time for speciation to occur and thus a higher number of endemic taxa to exist in the region.

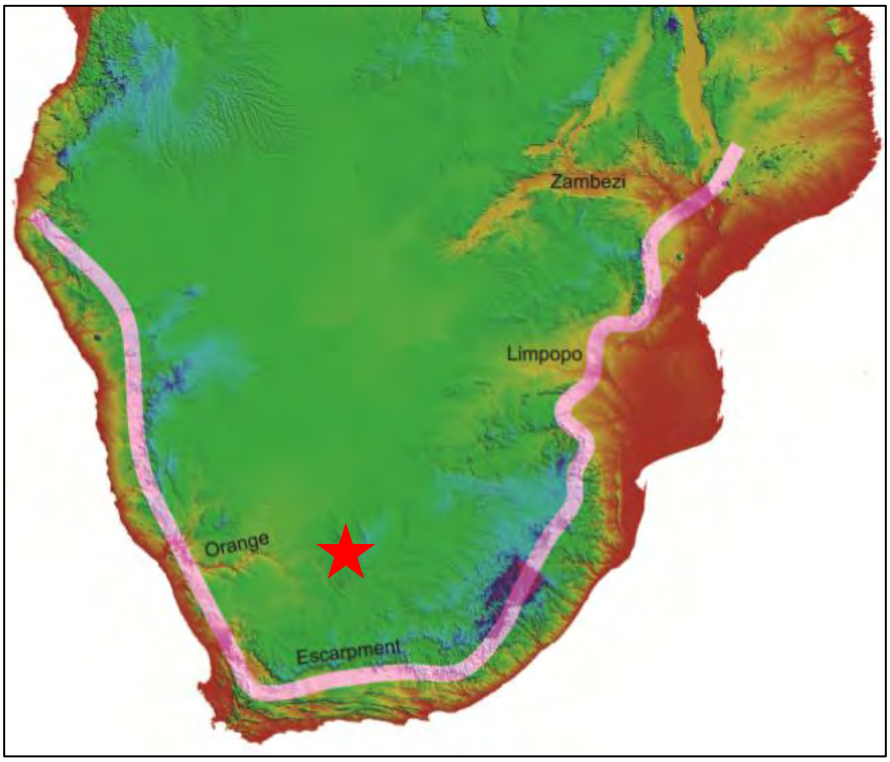


Figure 45: The southern African escarpment (Hahn, 2006). Location of the GWC is indicated by a red star.

4.4.2 GWC boundaries

The borders proposed by this study are comparable to those proposed by van Wyk & Smith (2001), with two major exceptions, namely an extension of the southern and south-western boundaries and an extension of the eastern boundaries (Fig. 39). The major town of Kimberley is included within the new boundaries (Fig. 39).

These new boundaries are, however, very extensive, covering an area even greater than the unresolved boundaries predicted by van Wyk & Smith (2001). If conservation is the ultimate goal for the identification of centres of endemism, a smaller and more defined area may be of more use to conservationists. This study therefore proposes the concept of ‗core area' when working with large centres with few endemic species (Fig. 40). Distant outlier populations (>100 km) of otherwise relatively widespread endemic or near-endemic species are discarded during the demarcation of the centre. The proposed boundaries of the GWC by means of core area differ from van Wyk & Smith (2001) in two ways. Firstly, their proposed northern and north-western section of the GWC is not included in the new boundaries. This is to be expected considering the prevalence of quaternary sediments (aeolian sand) in this area which mainly harbor Kalahari endemics. Thus, towns including Hotazel, Ganyesa, Kagiso and Pomfret are no longer within the borders of the GWC core area. Secondly, the core area now contains the town of Kimberley which is an extension of the eastern boundary proposed by van Wyk & Smith (2001).

The extension of the GWC boundaries proposed by van Wyk & Smith (2001) which was based primarily on geological features may indicate that the regions flora is not as influenced by geology alone as was first hypothesized. Rather, a combination of factors including geology and climate may be contributing to the presence of endemics.

4.5 Conclusion

Twenty-four endemic and two near-endemic taxa were identified following an extensive literature review and intuitive discernment based on known distributions. The GWC was shown to have a low level of endemicity (1.4%), particularly when compared to the other 17 southern African centres recognised by van Wyk & Smith (2001). The distribution patterns of 26 endemic and near-endemic species demarcate a common territory which confirms the presence of a centre of plant endemism in the region, as proposed by van Wyk & Smith (2001).

The borders proposed by this study differ to those proposed by van Wyk & Smith (2001) as the southern, south-western and eastern boundaries are all extended (Fig. 39). The major town of Kimberley is included within the new boundaries. To address the scale issue associated with such a large centre of endemism with few endemics, a core area concept was proposed to attempt to combine those parts of the study area where the endemics are most abundant. The GWC core area (Fig. 40) excludes the northern and north-western section of the GWC as proposed by van Wyk & Smith (2001). The town of Kimberley is included within the GWC core area boundaries.

As the GWC is still under collected (Fig. 43), the GWC core area (Fig. 40) is a region that should be the focus of future botanical collections due to the apparent density of endemic taxa in this region and the associated conservation implications. As more data becomes available the areas of conservation concern, such as the relatively densely populated Kimberley region may become apparent, at which point conservation strategies may be devised and implemented to conserve the GWC flora and associated ecosystems.

CHAPTER 5: FLORISTIC PATTERNS OF GRIQUALAND WEST

5.1 Introduction

The flora of Griqualand West has been poorly studied, owed largely to the lack of botanical collecting in the region. The recognition of a centre of plant endemism in Griqualand West, namely the Griqualand West Centre (GWC) by van Wyk & Smith (2001), highlighted the need to further investigate the flora of the region. The description of the GWC by van Wyk & Smith (2001) was based broadly on the complex geology of the region and the known association of endemic plant species with serpentines (Morrey *et al*. 1989), dolomites (Mathhews *et al*. 1993) and ultramafics (Siebert *et al*. 2001) elsewhere.

However, the extent to which geology has influenced the flora of Griqualand West and the number of endemics is unknown (Frisby *et al*. 2015). Other abiotic factors which are known to have a strong influence on the flora of a geographical area must also be considered as potential floristic drivers for the region. Examples include, among others, climate (Duever *et al*. 1994; Pyšek *et al*. 2005; Wang *et al*. 2009), soil (Beadle 1966) and topography (Moeslund *et al*. 2013; Webb *et al*. 1999). Knowledge of the regions' floristic patterns and the abiotic drivers thereof may contribute towards an understanding of the evolutionary history of the regions' flora, aid its conservation by contributing towards informed land-use decisions (Pressey *et al*. 2000) and lend insight into the potential effects of climate change on its flora (Loarie *et al*. 2008). The aim of this study was to identify and describe floristic patterns within the Griqualand West region and to identify links between these patterns and their potential abiotic drivers. Furthermore, this study also explored links between the GWC core area endemics (see chapter 4) and the observed floristic patterns, with the aim to identify sub-centres of endemism. Sub-centres indicate areas of higher endemism in the region and are priority areas to focus conservation actions.

5.2 Materials and method

5.2.1 Data collection and preparation

Species lists were obtained for the quarter-degree grids (QDGs) of the GWSA (Fig. 7; Chapter 3) from PRECIS (Pretoria National Herbarium Computerized Information System). This data was supplemented with additional specimen records for potential endemic and near-endemic species (Mucina & Rutherford 2006; van Wyk & Smith 2001) obtained from herbaria with collections from the Griqualand West region (see Chapter 4). These herbaria included the A.P. Goossens Herbarium (PUC), McGregor Museum Herbarium (KMG), H.G.W.J. Schweickerdt Herbarium (PRU), South African National Parks Herbarium (KSAN), National Museum Herbarium (NMB), Geo Potts Herbarium (BLFU) and Pretoria National Herbarium (PRE). All data was captured at species level and distribution resolution of QDGs. Fuzzy Gazetteer (2000) was used to clarify descriptive locality records of specimens and linking these to QDGs. The original species-level data was modified into two additional datasets, namely genus- and family-level, by combining all species occurrences into genera and combining all genera occurrences into their respective families. Alien taxa were excluded from all datasets as such taxa are not subject to all the same ecological pressures as the indigenous flora, which may result in alien distribution patterns that do not coincide with the greater floristic patterns, such as biomes (Hugo *et al*. 2012).

As the GWSA was poorly collected many quarter-degree grids had few species records, with some having had no species recorded as of yet. With such ‗gaps‘ in the database an analysis of the floristic patterns in the GWSA would not be possible. Such incomplete sampling often results in false records of species absence and thus results in biased biodiversity estimations (Kurzweg 2011). To address this problem, the ‗Centroid Grid profile‘ of Kurzweg (2011) was adopted in an attempt to improve the species resolution of poorly collected QDGs. The Centroid Grid profile strengthens under-collected QDG‘s in poorly collected regions by extrapolating species occurrences from three adjacent QDG‘s with the most similar vegetation units (Kurzweg 2011). Thus, the entire species lists of the three adjacent grids with the most similar vegetation are included in the Centroid Grid. Kurzweg (2011) found the Centroid Grid profile to be an acceptable means to counter the bias in plant diversity data at the QDG level by i) strengthening under-sampled grids and ii) visibly ‗smoothing‘ out the gaps between under-and well-collected grids. It must be noted that the centroid grid method makes an assumption that neighbouring QDGs with similar vegetation composition will share similar plant species and that adjacent grids will, therefore, give information on species not yet sampled, but which are likely to be encountered in that grid (Kurzweg 2011).

The criteria for selecting adjacent grids were as follows:

- Three of eight QDG‘s surrounding a centroid grid (Fig. 46) were chosen subjectively by visually analysing their vegetation unit cover (Mucina and Rutherford 2006) (Fig. 26).
- A first elimination of surrounding QDG‘s took place by discarding those containing vegetation units not found in the centroid grid and then choosing the three QDGs with vegetation unit cover most closely resembling that of the centroid grid.

- In cases where more than five grids contained a vegetation type not present in the centroid grid, the grids containing <10% of such vegetation types were selected.
- In some cases, it was not possible to select three adjacent grids without violating the previous criterion. In such cases a grid with the corresponding vegetation unit cover not more than two grids away from the centroid grid was selected.

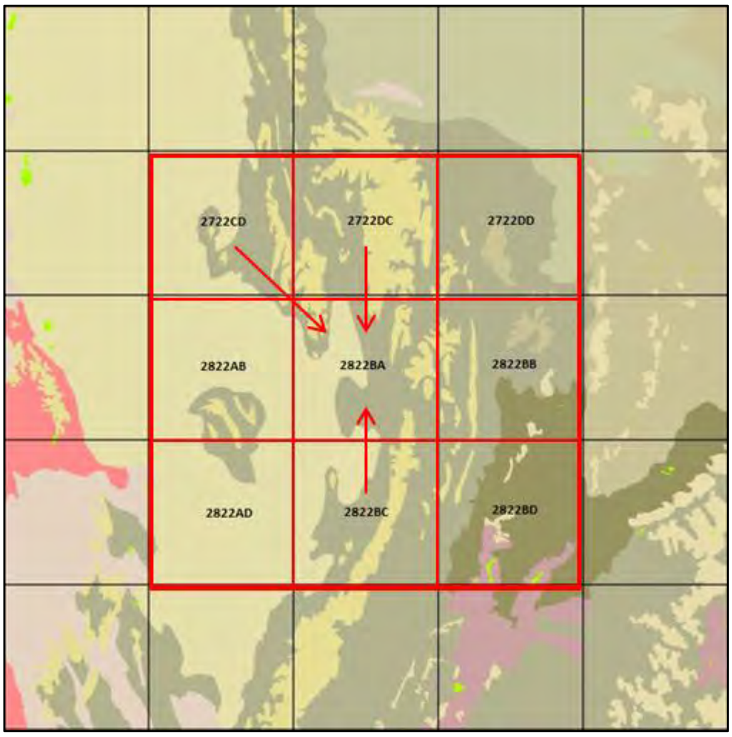


Figure 46: Centroid Grid profile. In this example, 2822 BA is the centroid grid. The three adjacent grids most similar to 2822 BA based on vegetation unit (Mucina & Rutherford 2006) cover were: 2722 CD, 2722 DC and 2822 BC.

The centroid grid profile was applied to the original data. The resulting species, genus and family level datasets were hereafter referred to as transformed data. Matrices were constructed for the original and transformed data using PyScriptor (free, open source).

5.2.2 Data analysis

To assess the effect that transformation by the Centroid Grid profile has on the data, PRIMER 6 software (2006) was used for NMDS ordination analysis of both the original and transformed data. A fourth root transformation was performed on both the original and transformed data sets and the Bray-Curtis distance measure was applied using 100 restarts.

To identify floristic patterns in the GWSA, cluster analysis was performed on the transformed data using STATISTICA 8 software (2007). The Ward linkage was used for cluster creation (Ward 1963). The number of clusters that should be created from the data was chosen. Thus, for each data hierarchy, namely species, genus and family-level, cluster numbers varying from 2 to 6 were created, resulting in five levels of resolution.

The Sørensen–Dice index (Dice 1945; Sørensen 1948) was used to measure the similarity between the clusters. This index has been shown to be suited to ecological data (Looman & Campbell 1960) as it retains sensitivity even in heterogeneous datasets and gives less weight to outliers (McCune *et al*. 2002).

ArcGIS (ESRI 2011) was used to visually depict the results of the cluster analysis in the form of floristic cluster maps. These clusters were visually compared to maps of the major abiotic variables in the GWSA (Fig. 47), so as to determine the number of clusters that are supported on all three data hierarchies by the abiotic variables of the GWSA. PAST (Hammer *et al*. 2001) was used to perform analysis of similarity (ANOSIM) on all data hierarchies, the results of which are given in terms of R- and p-values.

For each of the data hierarchies, the key taxa for the constituent phytochoria (highest cluster resolution) were identified. Two types of key taxa were considered, namely characteristic and diagnostic taxa. Taxa were considered characteristic if they were only recorded for a single cluster and not from any others. Taxa were considered diagnostic if they show high constancy within a cluster, but also occur in other clusters where they might also exhibit high constancy. Constancy refers to how regularly a taxon was recorded for a cluster and translates as the number or percentage of QDG‘s in a cluster that a given taxon occurs in. Characteristic taxa were identified by determining which taxa were present only in a single cluster. In clusters where numerous characteristic taxa were present, those with high constancy were chosen for the description of the floristic clusters. Diagnostic taxa were identified as those taxa with a constancy of more than 60%, i.e. the most abundant in the cluster. In clusters with many diagnostic taxa, highest constancies were taken for qualification and this selection was done for three growth forms, namely grasses, forbs and woody taxa. The GWC endemics and near-endemics present in each cluster were also identified.

Links between the GWC and the GWSA floristic clusters were inferred by stacking the GWC core area over the phytochoria. Phytochoria with GWC endemic species restricted to its clusters only, were identified as sub-centres of endemism for the GWC.

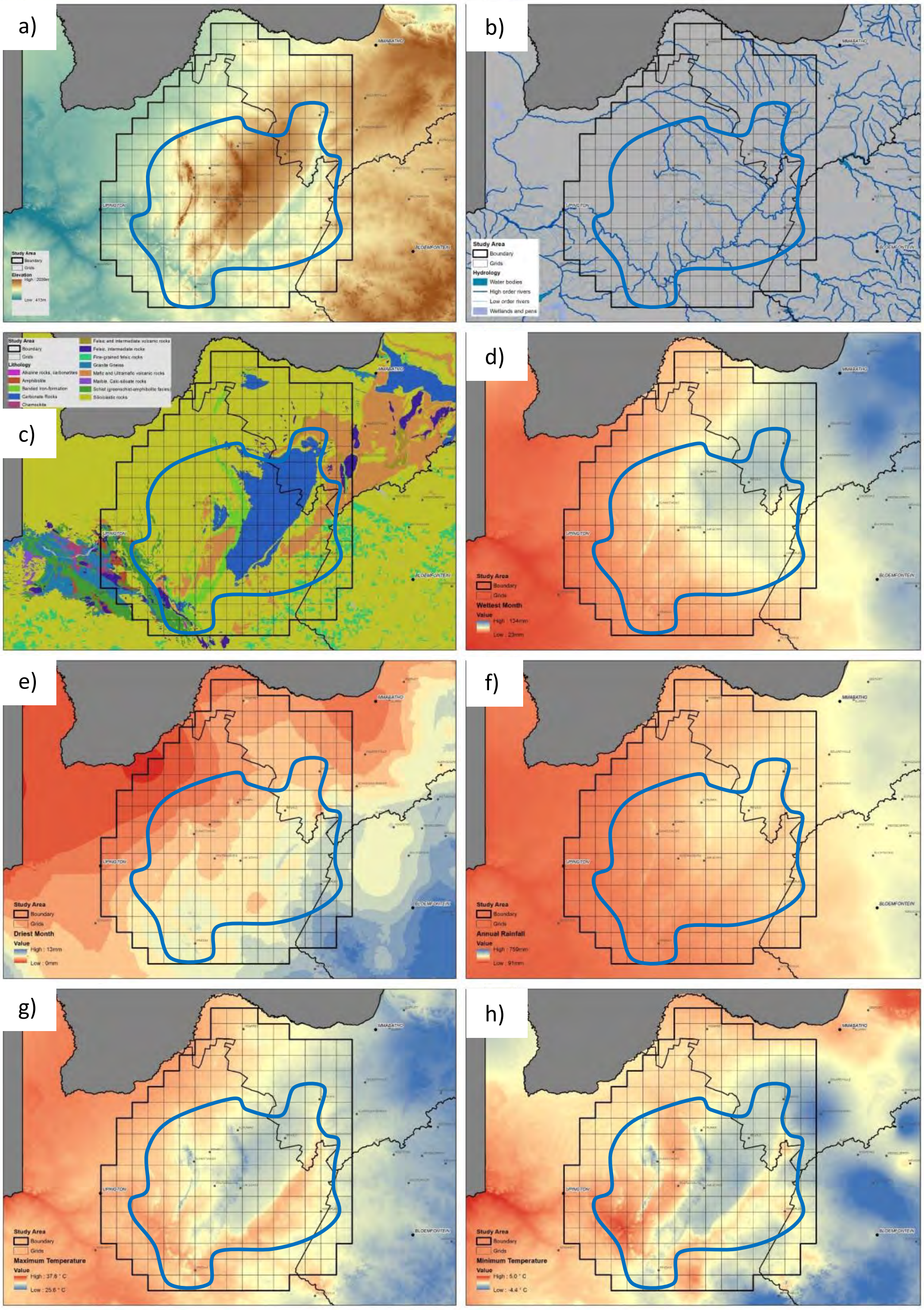


Figure 47: Maps of abiotic variables in GWSA: a) topography, b) hydrology, c) geology, d) mean rainfall in wettest month, e) mean rainfall in driest month, f) mean annual rainfall, g) mean maximum temperatures, and h) mean minimum temperatures. The borders of the GWC core area are indicated in blue.

5.3 Results

5.3.1 Ordination analysis

The NMDS ordination plots for the original and transformed data sets (Fig. 46) indicate that the centroid grid profile altered the distribution of the data to a large extent, as the transformed data showed greater clustering than the original data. The number of taxa added to each QDG of the GWSA by means of the centroid grid profile approach is indicated in the Appendix. The average number of taxa added to a given grid was 130, and this improved the average species coverage from 61 to 190 per QDG. It must be noted that the 2D stress values of the transformed data NMDS ordination plots were all less (<0.2) than those of the original data (>0.2). Hence, the transformed data provided a better correspondence than the original data, but neither the original nor the transformed data had 2D stress values representing a good correspondence for the NMDS ordination plots (= or <0.05).

No clear clusters were visually evident for the ordination plots of both the untransformed and transformed data (Figs.48b, d, f), possibly due to the large number of grids being compared and the collection bias that persisted despite the transformation (Appendix). Thus, ordination analysis of the GWSA QDG‘s could not demarcate any floristic patterns in the GWSA, but supported the application of the centroid grid profile.

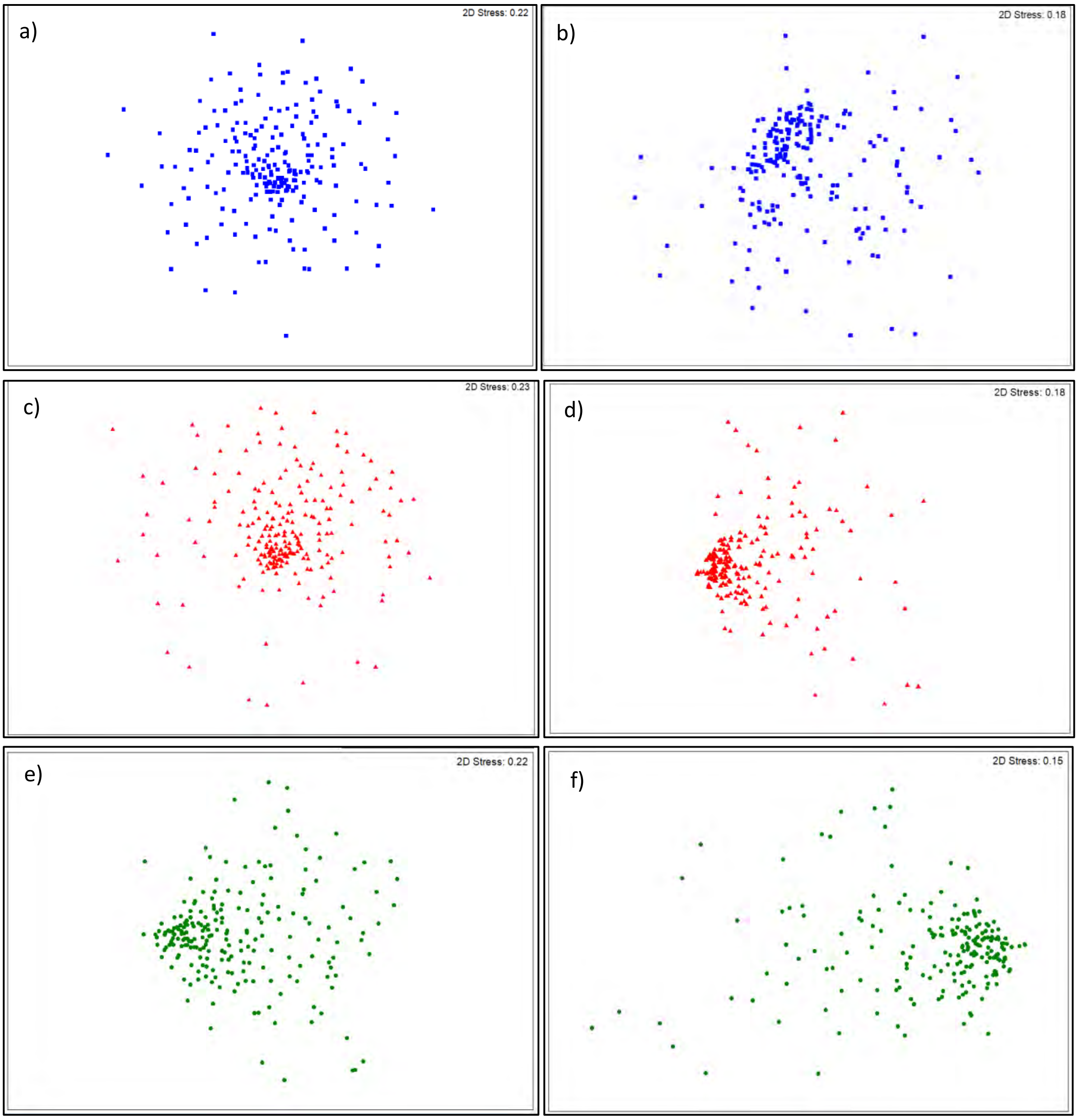


Figure 48: Ordination plots of QDGs a) original and b) transformed species-level data, c) original and d) transformed genus-level data, and e) original family- and f) transformed family-level data. The 2D stress values are reported for each ordination plot in the top right hand corners.

5.3.2 Cluster analysis and key taxa

Cluster analysis of the transformed species-level data (Fig. 49) yielded floristic distribution maps with non-fragmented clusters of varying sizes, each representing hypothetical phytochoria at six different levels of hierarchical resolution. The clusters based on genus- (Fig. 50) and family-level data (Fig. 51) did not vary substantially from those of the species-level data. For this reason the results of the genus- and family-level data are given as support for the results of the species-level data, and not discussed further in detail. Also for this reason, only the characteristic and diagnostic taxa of the constituent clusters based on species-level data are provided, excluding the characteristic and diagnostic taxa of the genus- and family-level data.

The clusters of all hierarchical resolutions, the hierarchies of which are indicated in Figure 52, were named based on the abiotic variables by which each was characterised and/or the general geographic region in which it occurs, as follows:

Cluster 1: Flora of siliclastic rocks in arid areas
- Cluster 1.1: Variant 1
- Cluster 1.2: Variant 2

Cluster 2: Flora of Griqualand-West
  - Cluster 2.1: Northern Ghaap Plateau and Kuruman Hills
  - Cluster 2.2: Southern Griqualand-West
    - Cluster 2.2.1: Mafic, ultramafic and felsic areas
      - Cluster 2.2.1.1: Southern Kalahari and Langeberge
      - Cluster 2.2.1.2: Southern Ghaap Plateau and Kimberley-Prieska valley
    - Cluster 2.2.2: Orange River valley schists

For the sake of brevity, only the six constituent (lowest cluster resolution) (Fig. 49a) and the two base clusters (highest cluster resolution) (Fig. 49e) are discussed and referred to, excluding clusters at intermediate levels of resolution (Figs. 49b, c, d). The results of cluster analysis for the genus- (Fig. 50) and family-level data (Fig. 51) are given in support of the species-level cluster results.

The ANOSIM results of for species-, and family-level data (Table 3) show significant dissimilarity between clusters at all resolution levels (R-value>0.5 and p<0.0001). This was not always the case for the genus-level data (Table 3).

The key species (characteristic and diagnostic species) and the GWC endemics occurring in each of the six constituent clusters (Fig. 49a) were found to be as follows:

Cluster 1.1: Flora of siliclastic rocks in arid areas–variant 1

Characteristic taxa

Boophone disticha (Geophyte); *Cotula turbinata* (Forb); *Dischisma spicatum* (Forb); *Lampranthus otzenianus* (Succulent); *Lessertia diffusa* (Herb); *Osteospermum grandiflorum* (Woody); *Pteronia divaricata* (Woody).

Diagnostic taxa

Grass: *Aristida congesta* subsp. *congesta*; *Eragrostis lehmanniana* var. *lehmanniana*; *Schmidtia kalahariensis*; *S. pappophoroides*; *Stipagrostis obtusa*; *Stipagrostis uniplumis* var. *uniplumis*; *Trianthema parvifolia* var. *parvifolia.*
Forb: *Bulbostylis hispidula* subsp. *pyriformis*; *Cyperus margaritaceus* var. *margaritaceus*.
Woody: *Vachellia haematoxylon*; *Searsia tenuinervis*.

GWC endemic taxa

Barleria media (Forb)*; Calobota cuspidosa* (Woody)*; Eriocephalus ericoides* subsp. *griquensis* (Woody)*; Gnaphalium englerianum* (Forb)*; Justicia puberula* (Forb)*; J. thymifolia* (Forb)*; Nuxia gracilis* (Woody)*; Putterlickia saxatilis* (Woody)*; Rennera stellata* (Forb)*; Salsola atrata* (Forb)*; Searsia tridactyla* (Woody)*; Thesium dumale* (Forb).

Cluster 1.2: Flora of siliclastic rocks in arid areas–variant 2

Characteristic taxa

Chamaecrista capensis var. *flavescens* (Forb); *Digitaria tricholaenoides* (Grass); *Selago welwitschii* var. *holubii* (Forb).

Diagnostic taxa

Grass: *Aristida stipitata* subsp. *spicata*; *Eragrostis pallens*.
Forb: *Erlangea misera*; *Geigeria burkei* subsp. *burkei* var. *zeyheri*; *Ipomoea ommanneyi; Nidorella hottentotica; Oxygonum dregeanum* subsp. *canescens* var. *canescens.*

Woody: *Vachellia hebeclada* subsp. *hebeclada*; *Dichrostachys cinerea* subsp. *africana* var. *setulosa; Terminalia sericea.*

GWC endemic taxa

Rennera stellata (Forb).

Cluster 2.1: Flora of northern Ghaap Plateau and Kuruman Hills

Characteristic taxa

Bergia pentheriana (Forb)*; Clematis brachiata* (Forb)*; Crotalaria distans* subsp. *distans* (Forb); *Dyschoriste transvaalensis* (Woody); *Hirpicium bechuanense* (Woody)*; Indigastrum costatum* subsp. *macrum* (Forb)*; Limeum sulcatum* var. *gracile* (Forb)*; Tephrosia lupinifolia* (Forb).

Diagnostic taxa

Grass: *Aristida congesta* subsp*. congesta; Cymbopogon pospischilii; Digitaria eriantha; Eragrostis lehmanniana* var. *lehmanniana; Eragrostis trichophora; Melinis repens* subsp. *repens; Sporobolus fimbriatus.*

Forb: *Bulbostylis burchellii; Leucas capensis.*

Woody: *Diospyros lycioides* subsp. *lycioides; Searsia ciliata.*

GWC endemic taxa

Antimima lawsonii (Succulent)*; Barleria media* (Forb)*; Blepharis marginata* (Forb)*; Calobota cuspidosa* (Woody)*; Cineraria exilis* (Forb)*; Dicoma kurumanii* (Forb)*; Eriocephalus ericoides* subsp. *griquensis* (Woody)*; Gnaphalium englerianum* (Forb)*; Hereroa wilmaniae* (Succulent)*; Justicia puberula* (Forb)*; J. thymifolia* (Forb)*; Maytenus ilicina* (Woody)*; Nuxia gracilis* (Woody)*; Prepodesma orpenii* (Succulent)*; Putterlickia saxatilis* (Woody)*; Rennera stellata* (Forb)*; Salsola atrata* (Forb)*; Searsia tridactyla* (Woody)*; Tarchonanthus obovatus* (Woody)*; Thesium dumale* (Forb).

Cluster 2.2.1.1: Flora of southern Kalahari and Langeberge

Characteristic taxa

Brachiaria dura var. *pilosa* (Grass)*; Euryops multifidus* (Woody)*; Lithops bromfieldii* (Succulent)*; Lotononis parviflora* (Forb)*; Psiadia punctulata* (Woody).

Diagnostic taxa

Grass: *Eragrostis lehmanniana* var. *lehmanniana; Eragrostis trichophora; Stipagrostis ciliata var. capensis.*

Forb: *Helichrysum zeyheri; Justicia thymifolia; Monechma divaricatum.*

Woody: *Vachellia haematoxylon; Putterlickia saxatilis; Tarchonanthus obovatus.*

GWC endemic taxa

Blepharis marginata (Forb)*; Brachiaria dura* var. *pilosa* (Grass)*; Calobota cuspidosa* (Woody)*; Eriocephalus ericoides* subsp. *griquensis* (Woody)*; Hereroa wilmaniae* (Succulent)*; Justicia puberula* (Forb)*; J. thymifolia* (Forb)*; Lithops bromfieldii* (Succulent)*; Maytenus ilicina* (Woody)*; Phyllobolus amabilis* (Succulent)*; Prepodesma orpenii* (Succulent)*; Putterlickia saxatilis* (Woody)*; Rennera stellata* (Forb)*; Searsia tridactyla* (Woody)*; Tarchonanthus obovatus* (Woody).

Cluster 2.2.1.2: Flora of southern Ghaap Plateau and the Kimberley-Prieska valley

Characteristic taxa

Amellus tridactylus subsp. *tridactylus* (Forb); *Conyza scabrida* (Woody); *Galenia exigua* (Woody); *Lasiopogon glomerulatus* (Forb); *Osyris lanceolata*; *Pteronia sordida* (Woody).

Diagnostic taxa

Grass: *Aristida adscensionis; Aristida congesta* subsp. *congesta; Enneapogon desvauxii; Eragrostis echinochloidea; Eragrostis lehmanniana* var. *lehmanniana; Tragus racemosus*.

Forb: *Geigeria filifolia; Gnidia polycephala; Pentzia calcarea.*

Woody: *Grewia flava; Lycium cinereum.*

GWC endemic taxa

Amphiglossa tecta (Woody shrub)*; Antimima lawsonii* (Succulent)*; Blepharis marginata* (Forb)*; Calobota cuspidosa* (Woody)*; Eriocephalus ericoides* subsp. *griquensis* (Woody)*; Hereroa wilmaniae* (Succulent)*; Justicia thymifolia* (Forb)*; Lithops aucampiae* subsp. *euniceae* (Succulent)*; L. lesliei* subsp*. burchellii* (Succulent)*; Maytenus ilicina* (Woody)*; Nuxia gracilis* (Woody)*; Phyllobolus amabilis* (Succulent)*; Prepodesma orpenii* (Succulent)*; Putterlickia saxatilis* (Woody)*; Searsia tridactyla* (Woody)*; Tarchonanthus obovatus* (Woody).

Cluster 2.2.2: Flora of Orange River valley schists

Characteristic taxa

Albuca cooperi (Geophyte); *Berkheya spinosissima* subsp. *spinosissima* (Woody)*; Cheilanthes deltoidea* subsp. *deltoidea* (Geophyte); *Haworthia nigra* var. *diversifolia* (Succulent)*; Indigofera pechuelii* (Woody)*; Manulea schaeferi* (Forb)*; Tetragonia reduplicata* (Succulent)*; Tulbaghia tenuior* (Forb).

Diagnostic taxa

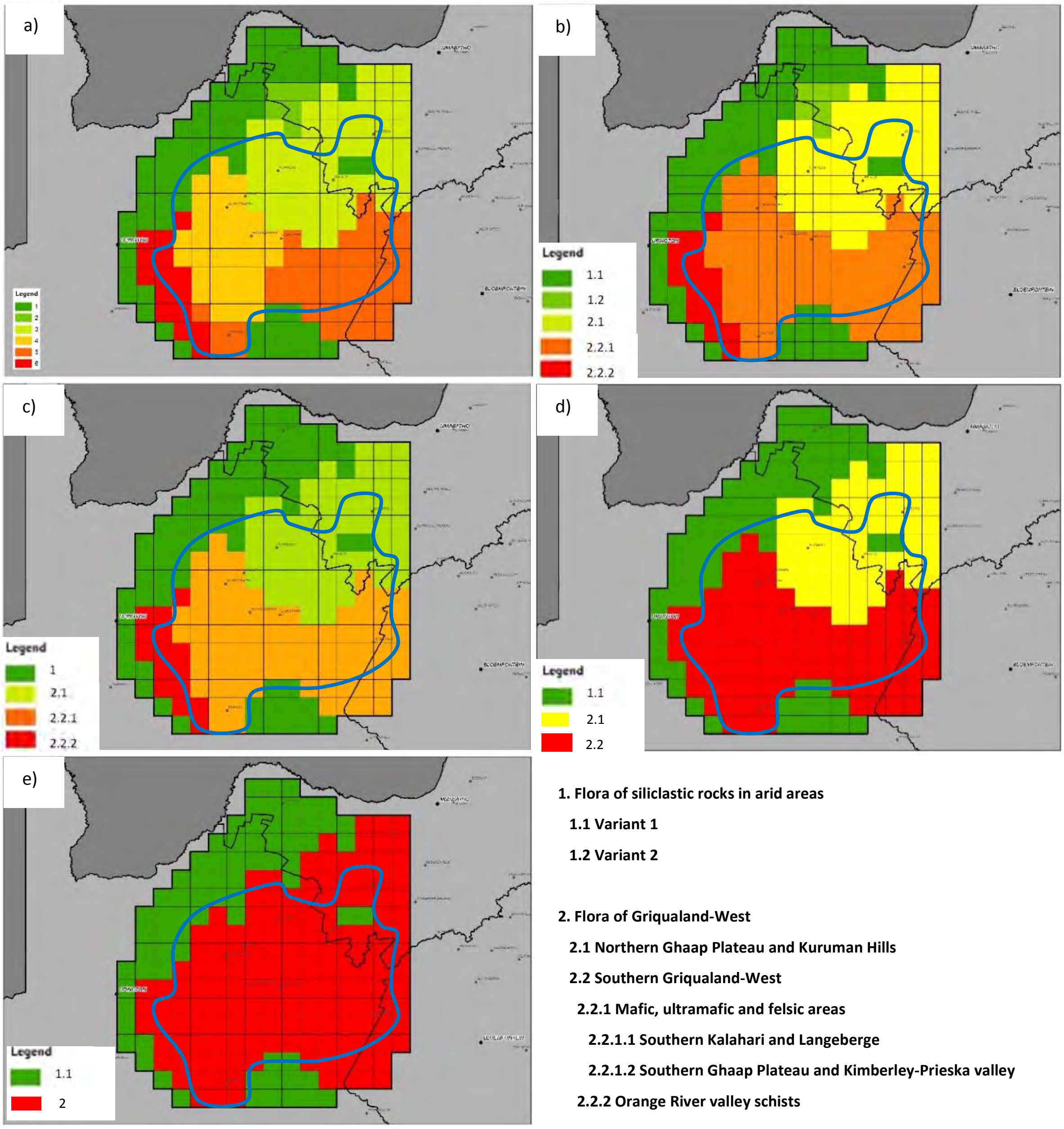
Grass: *Aristida adscensionis; Eragrostis echinochloidea; Stipagrostis obtusa; Tragus berteronianus.*

Forb: *Aptosimum spinescens; Barleria lichtensteiniana; Leobordea platycarpa*.

Woody: *Lycium cinereum; Searsia pendulina*.

GWC endemic taxa

Calobota cuspidosa (Woody)*; Hereroa wilmaniae* (Succulent)*; Justicia puberula* (Forb)*; J. thymifolia* (Forb)*; Putterlickia saxatilis* (Woody)*; Tarchonanthus obovatus* (Woody).



- **1. Flora of siliclastic rocks in arid areas**
  - **1.1 Variant 1**
  - **1.2 Variant 2**

- **2. Flora of Griqualand-West**
  - **2.1 Northern Ghaap Plateau and Kuruman Hills**
  - **2.2 Southern Griqualand-West**
    - **2.2.1 Mafic, ultramafic and felsic areas**
      - **2.2.1.1 Southern Kalahari and Langeberge**
      - **2.2.1.2 Southern Ghaap Plateau and Kimberley-Prieska valley**
    - **2.2.2 Orange River valley schists**

Figure 49: Results of cluster analysis of the GWSA species-level data. a) data clustering with six groups, b) five groups, c) four groups, d) three groups and e) two groups. Each colour represents a different cluster. The legend on each indicates the numerical name given to each cluster. The names of each cluster are provided in the bottom right corner of the Figure. The borders of the GWC core area are indicated in blue.

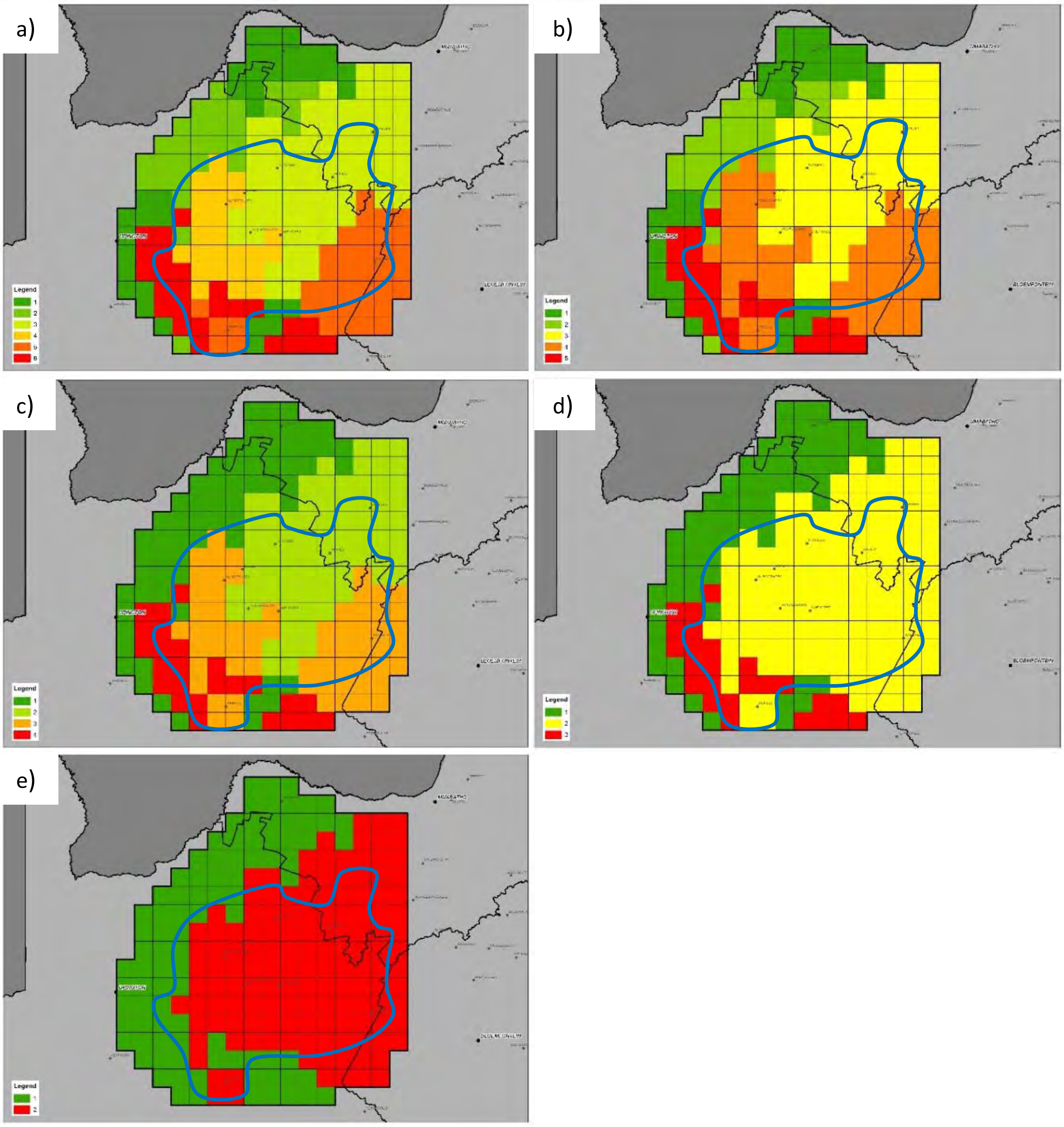


Figure 50: Results of cluster analysis for the GWSA genera-level data. a) data clustering with six groups, b) five groups, c) four groups, d) three groups and e) two groups. Each colour represents a different cluster. The legend on each indicates the numerical name given to each cluster. These results were similar to the species level data and is provided here as support for Figures 49 and 52. The borders of the GWC core area are indicated in blue.

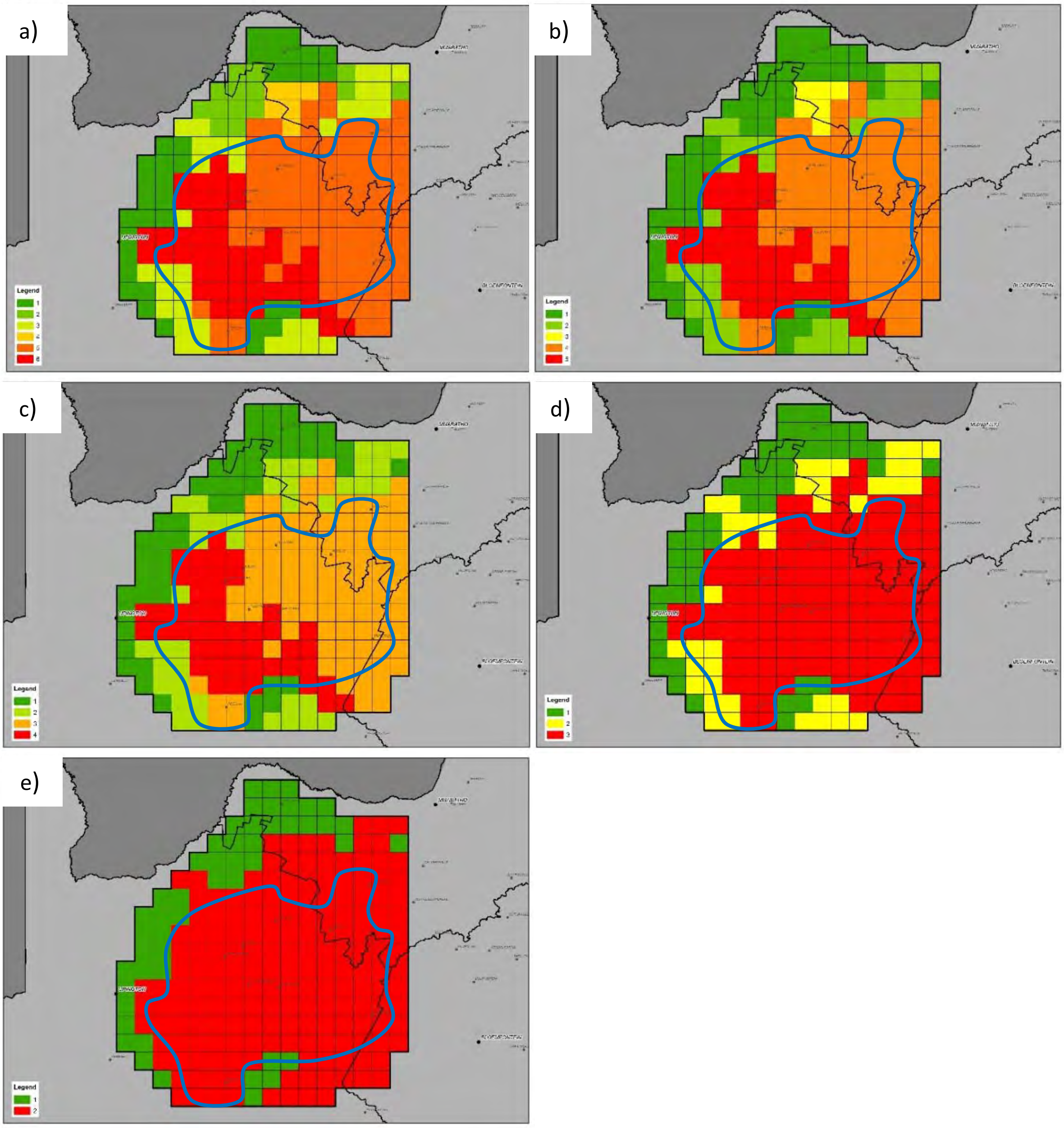


Figure 51: Results of cluster analysis for the GWSA family-level data. a) data clustering with six groups, b) five groups, c) four groups, d) three groups and e) two groups. Each colour represents a different cluster. The legend on each indicates the numerical name given to each cluster. These results were similar to the species level data and is provided here as support for Figures 49 and 52. The borders of the GWC core area are indicated in blue.

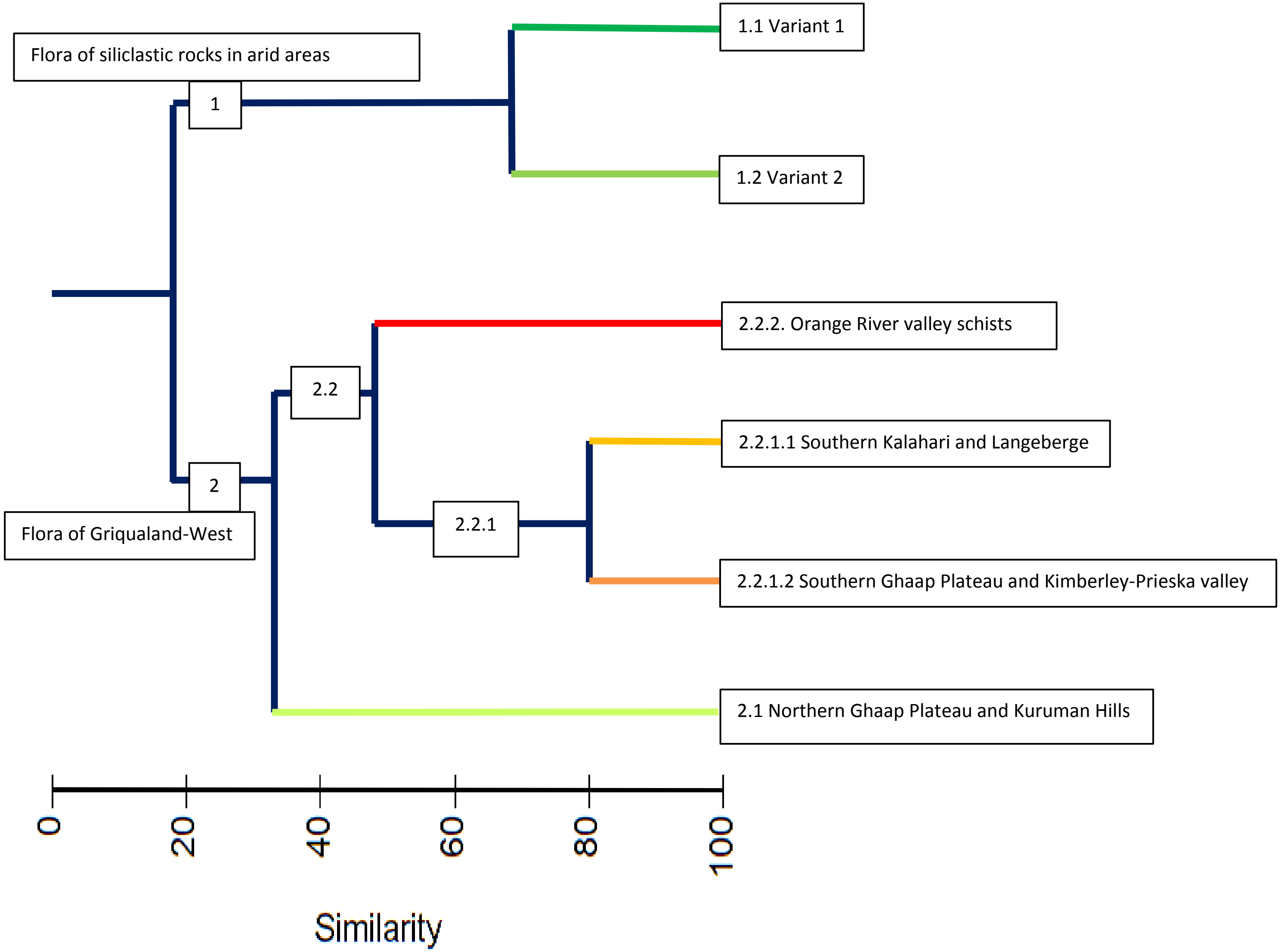


Figure 52: Dendrogram indicating the relatedness between the six clusters (Fig. 47a) of the species-level data based on the Sørensen–Dice index of similarity. The numerical names of all clusters are provided. Only the names of the two base clusters and the six constituent clusters are provided. The similarity % for all clusters may be inferred using the scale provided.

Table 3: R-value at p</= 0.0001 for species-, genus- and family-level datasets following ANOSIM analyses

Dataset	No. of clusters	R-value
Species	6	0.622
	5	0.6297
	4	0.5353
	3	0.5425
	2	0.5949
Genus	6	0.496
	5	0.7538
	4	0.4502
	3	0.5706
	2	0.5396
Family	6	0.6548
	5	0.6547
	4	0.6547
	3	0.6437
	2	0.5757

5.4 Discussion

5.4.1 Constituent clusters

The six constituent clusters (Fig. 49a), all of which are based on species-level data, are briefly discussed below.

5.4.1.1 Flora of siliclastic rocks in arid areas–variant 1 (cluster 1.1)

This floristic cluster is characterised by a low-lying topography and is dominated by siliclastic rocks and has a high incidence of aoelian Kalahari sands. A small isolated cluster (two QDG's) occurs in eastern parts of the GWSA. This may be the result of a nearby valley characterised by more arid, hotter conditions as well as more siliclastic rocks. The mean rainfall in the wettest month is low, at around 30 mm and in the driest month is very low, with large parts receiving no rain at all. The mean annual rainfall is around 80 mm per year indicating its aridity. Large parts of this cluster have high mean maximum temperatures of 35°C. The mean minimum temperatures vary from 0-5°C. This cluster has a number of rivers, particularly in its northern parts, the most prominent of which is the Moshaweng River. Twelve GWC endemics have extended ranges from the GWC core area into this cluster.

5.4.1.2 Flora of siliclastic rocks in arid areas–variant 2 (cluster 1.2)

This is the smallest of the six constituent floristic clusters identified for the GWSA. It has a low-lying topography and is dominated by siliclastic rocks and has a high incidence of aoelian Kalahari sands. The mean rainfall in the wettest month is low, at around 30 mm and in the driest month is very low at around 5 mm per year. The mean annual rainfall is 80 mm per year. This cluster has high mean maximum temperatures of 35°C. The mean minimum temperatures vary from 0-5°C. This cluster has a number of rivers passing through it including the Moshaweng and Lemapo Rivers. Many of the diagnostic species of this floristic cluster are often associated with pans such as *Erlangea misera* and *Nidorella hottentotica.* Only one GWC endemic, namely *Rennera stellata*, is present in this cluster. The identification of *Dichrostachys cinerea* subsp. *africana* as a diagnostic taxon may indicate bush encroachment in the region, a potential reason for this clusters differentiation from cluster 1.1.

5.4.1.3 Flora of northern Ghaap Plateau and Kuruman Hills (cluster 2.1)

This floristic cluster is characterised by a high-lying plateau (Ghaap Plateau), which is comprised of carbonate rocks, and a set of hills (Kuruman Hills) comprised of banded iron formation. It occurs in the north-eastern section of the GWSA. The mean rainfall in the wettest month is around 100 mm and in the driest month is low at around 5 mm. The mean annual rainfall is around 520 mm per year. This cluster has the lowest mean maximum temperatures in the GWSA at 30°C. The mean minimum temperature is 0-3°C, of which the coldest parts are associated with the more elevated Kuruman Hills. Many tributaries of larger rivers originate within the Ghaap Plateau interior at the centre of this cluster. Twenty of the 26 GWC endemics are present in this cluster, the highest number for all clusters.

5.4.1.4 Flora of southern Kalahari and Langeberge (cluster 2.2.1.1)

This floristic cluster is characterised by mountainous terrain, most prominently the quartzitic Langeberge. This cluster has low-lying areas surrounding the Langeberge which are dominated by siliclastic rocks with a high incidence of Kalahari sand. The mean rainfall in the wettest month varies from 25 mm in lower-lying areas and 80 mm on the Langeberge. The mean rainfall in the driest month is around 5 mm. The mean annual rainfall for this cluster varies from 200 mm in the lower-lying areas to 400 mm in the Langeberge. The mean maximum temperature varies between 30°C in lower-lying areas to 28°C in the Langeberge. The mean minimum temperatures vary from 4°C in lower-lying areas to -3°C in the

Langeberge. No major rivers flow through this cluster, barring the Orange River which forms its south-western boundary. Fifteen GWC endemics are present in this cluster, two of which, namely *Tarchonanthus obovatus* and *Putterlickia saxatilis* are diagnostic woody taxa for the cluster. Two GWC endemics are characteristic taxa of the cluster, namely *Brachiaria dura* var. *pilosa* and *Lithops bromfieldii*.

This cluster corresponds with large parts of the Southern Kalahari geomorphic province (a land area with a specific combination of physical, climatic, tectonic influences that determines the characteristics of surrounding areas, particularly in terms of hydrology (Dollar *et al*. 2007)) described by Partridge *et al*. (2010).

5.4.1.5 Flora of southern Ghaap Plateau and Kimberley-Prieska valley (cluster 2.2.1.2)

This floristic cluster is characterised by the southern half of the high-lying Ghaap Plateau and a low lying valley extending from the town of Prieska eastwards towards Kimberley along the eastern Ghaap Plateau escarpment (Kimberley-Prieska valley). The part of this cluster occurring in and around Prieska is narrowly disjunct from the rest of the cluster. The southern Ghaap Plateau consists of carbonate rocks whereas the low-lying valley is characterised by siliclastic rocks with a high incidence of Kalahari sand. There is also a patchwork of mafic, ultramafic and schist rocks in the cluster. The mean rainfall in the wettest month varies from 80 mm on the Ghaap Plateau to 30 mm in the Prieska area. The mean rainfall in the driest month varies from 5-10 mm. The mean annual rainfall varies from around 400 mm in the Kimberley area to 190 mm in the Prieska area. The valley adjacent to the eastern Ghaap Plateau escarpment receives an intermediate amount of rainfall annually, at around 250 mm. The mean maximum temperatures vary from cooler conditions in the southern Ghaap Plateau at around 30°C, to more hotter conditions in the Kimberley-Prieska valley at around 35°C. The mean minimum temperatures vary from -2°C on the southern Ghaap Plateau to 1°C in the Kimberley-Prieska valley. This cluster has major rivers flowing through it, including the Orange, Harts and Vaal Rivers. The floristic link between the southern Ghaap Plateau to this cluster as opposed to cluster 2.1 (Northern Ghaap Plateau and Kuruman Hills) may potentially be explained by the more arid conditions in the of the former, which results in a stronger link to the more arid and lower-lying Kimberley-Prieska valley. Sixteen GWC endemics are present in this cluster.

5.4.1.6 Flora of Orange River valley schists (cluster 2.2.2)

This floristic cluster is characterised by the low-lying river valley with a variety of geologies including granite gneiss, marble and schists, the last of which is dominant. The mean rainfall in the wettest month is low at around 30 mm and in the driest month is around 5 mm. The mean annual rainfall is around 250 mm. The mean maximum temperature is around 35°C and the mean minimum temperature is 0-4°C. The Orange River is a dominant feature of this cluster. Six GWC endemics are present in this cluster.

5.4.2 Base clusters

The two base clusters (Fig. 49e) of the species-level data showed the best correspondence with the abiotic variables under consideration, and clearly separate the Griqualand-West flora from that of the more aeolian Kalahari.

5.4.2.1 Flora of siliclastic rocks in arid areas (cluster 1)

This floristic cluster roughly corresponds with regions in the GWSA that are characterised low-lying topography (Fig. 53a) and siliclastic rocks (Fig. 53b) with a high incidence of Kalahari sands. These results are similarly supported by the clusters based on genus- and family-level data (Figs. 54 and 55). The mean rainfall in the wettest month is low at around 30 mm and in the driest month is very low, varying from 0 to 2 mm. The mean annual rainfall of this cluster varies from 180 mm in the western GWSA to around 500 mm in the vicinity of Pomfret. The mean maximum temperature varies between 30 and 35°C. The mean minimum temperature is around 0°C. Some of the characteristic species of this cluster are typical Kalahari species associated with aoelian sands, such as *Searsia tenuinervis.* Some of the dominant species (based on number of grids in which a species is present) include the grasses *Eragrostis lehmanniana* var. *lehmanniana* and *Stipagrostis uniplumis* var. *uniplumis*, the forbs *Bulbostylis hispidula* subsp. *pyriformis*, *Geigeria ornativa* subsp. *ornativa*, *Gnidia polycephala* and *Hermannia tomentosa*, and the trees *Vachellia erioloba* and *V. haematoxylon*.

5.4.2.2 Flora of Griqualand-West (cluster 2)

This floristic cluster roughly corresponds with regions in the GWSA that are characterised by higher rainfall, cooler temperatures and more elevated topography (Fig. 53a) than floristic cluster 1. The mean rainfall in the wettest month varies from 98 mm in the Langeberge and Kuruman Hills to 35 mm in the vicinity of Prieska. The mean rainfall in the driest month varies between 0-5 mm. The mean annual rainfall varies between 579 mm in the Langeberge and Kuruman Hills to 179 mm around Prieska. The mean maximum temperature varies between 28°C in the Langeberge and the Ghaap Plateau interior, to 35°C around Prieska and the Orange River Valley, and the mean minimum temperatures varies between -3°C in the Langeberge and Kuruman Hills to 4°C in the Orange River valley. This cluster corresponds roughly with the interior parts of the GWSA which has a wide variety of geologies (Fig. 53b), most prominently the carbonate rocks of the Ghaap Plateau, mafic and ultramafic volcanic rocks and BIF. The cluster shows a strong link between the Kimberley-Prieska valley and the Southern Ghaap Plateau. This supports the endemicity assessment that proposes the inclusion of the Kimberley area in the Griqualand-West concept. These results are similarly supported by the clusters based on genus- and family-level data (Figs. 54 and 55). Some of the dominant species (based on number of grids in which species is present) for this cluster include the grasses *Aristida congesta* subsp*. congesta; Digitaria eriantha; Eragrostis curvula*, the forbs *Leucas capensis; Monechma divaricatum; Pentzia calcarea*, and the trees *Lycium cinereum; Searsia ciliata; Searsia tridactyla; Tarchonanthus obovatus*.

The flora of Griqualand-West is therefore a combination of three distinct areas. The most prominent is the moister, high-lying northern Ghaap Plateau with its limestone and dolomite, and the Kuruman Hills consisting of banded ironstone. The second is the quartzitic Langeberg-Korannaberg with the extension of the Kalahari into the low-lying valleys between and around these mountains, including the Skurweberg and Asbestos Hills (BIF). And then there is the Orange River valley which consists of the Vaal-Harts-Orange valley between Kimberley and Prieska, including the southern Ghaap Plateau and the Orange River valley from west of Prieska to east of Upington.

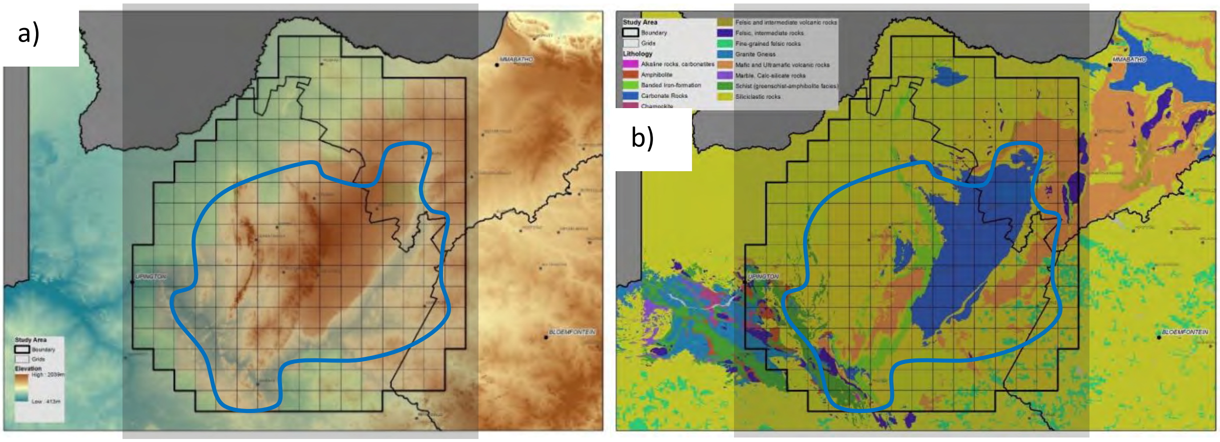


Figure 53: Base floristic clusters based on species-level data compared to a) topography and b) geology of the GWSA. Shaded green indicates the extent of the Flora of siliclastic rocks and the shaded orange the Flora of Griqualand-West. The borders of the GWC core area are indicated in blue.

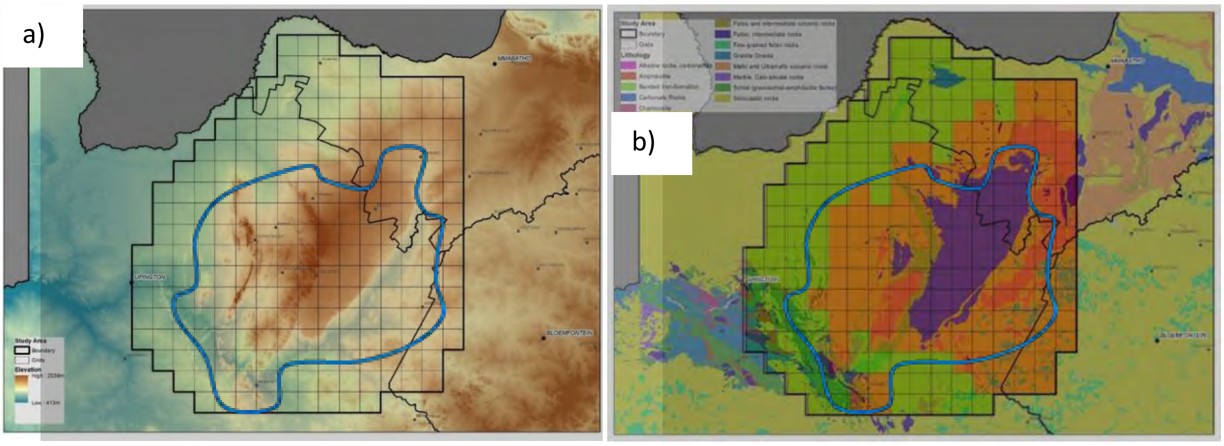


Figure 54: Base floristic clusters based on genus-level data compared to a) topography and b) geology of the GWSA. Shaded green indicates the extent of the Flora of siliclastic rocks and the shaded orange the Flora of Griqualand-West. The borders of the GWC core area are indicated in blue.

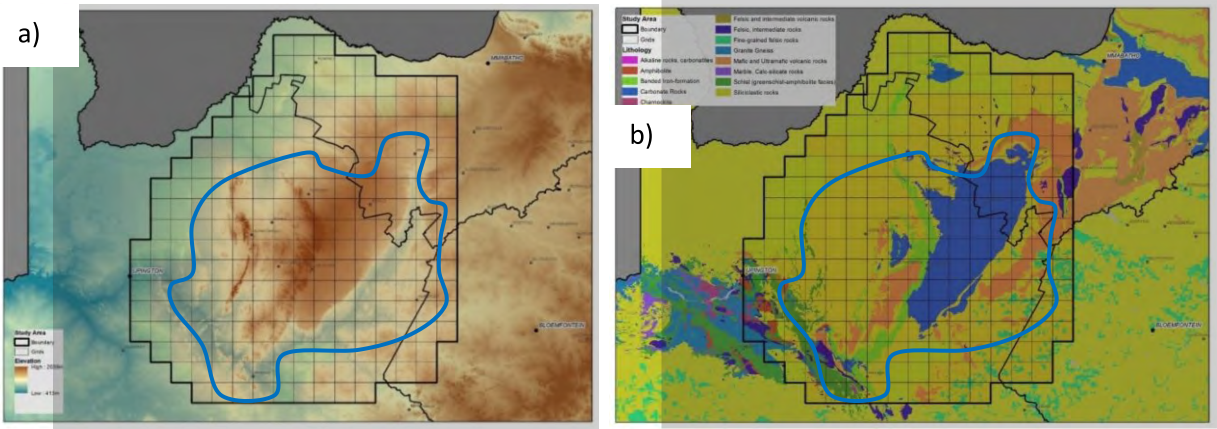


Figure 55: Base floristic clusters based on family-level data compared to a) topography and b) geology of the GWSA. Shaded green indicates the extent of the flora of siliclastic rocks and the shaded orange the flora of Griqualand-West. The borders of the GWC core area are indicated in blue.

5.5 GWC endemics associated with floristic clusters

In chapter 4, 26 plant taxa were proposed as endemic to the GWC boundaries within the GWSA (Figs. 39 and 40). The GWC endemics are all recognized at species level. No families and genera are endemic to the GWC. Thus, only constituent floristic clusters based on species-level data (Fig. 49a) corresponding with the GWC core area (Fig. 40) were analysed for the presence of endemics.

5.5.1 Flora of siliclastic rocks in arid areas (cluster 1)

This cluster has no GWC endemics restricted to it. This result emphasises the link between the presence of GWC endemics, non-siliclastic rocks and elevated topography.

5.5.2 Flora of Griqualand West (cluster 2)

This cluster contains within its boundaries the vast majority of the GWC endemics. The 15 GWC endemics restricted to this floristic cluster are as follows:

Amphiglossa tecta, *Antimima lawsonii*, *Blepharis marginata*, *Brachiaria dura* var. *pilosa*, *Cineraria exilis*, *Dicoma kurumanii*, *Gnaphalium englerianum*, *Hereroa wilmaniae*, *Lithops aucampiae* subsp. *euniceae*, *L. bromfieldii*, *L. lesliei* subsp. *burchellii*, *Maytenus ilicina*, *Phyllobolus amabilis, Prepodesma orpenii*, and *Tarchonanthus obovatus*. This represents 63 % of the GWC endemics. The remaining eleven endemics occur primarily in floristic cluster 2, but with a few occurrences in floristic cluster 1. An example of such an endemic is *Rennera stellata* (Figs. 34d and 37d).

The high number of GWC endemics associated with cluster 2 is supported by the rough visual correspondence between this cluster and the GWC core area (Fig. 56). Thus, the link between cluster 2 and the GWC endemics further emphasizes the influence that topography and geology has on the flora of the GWC.

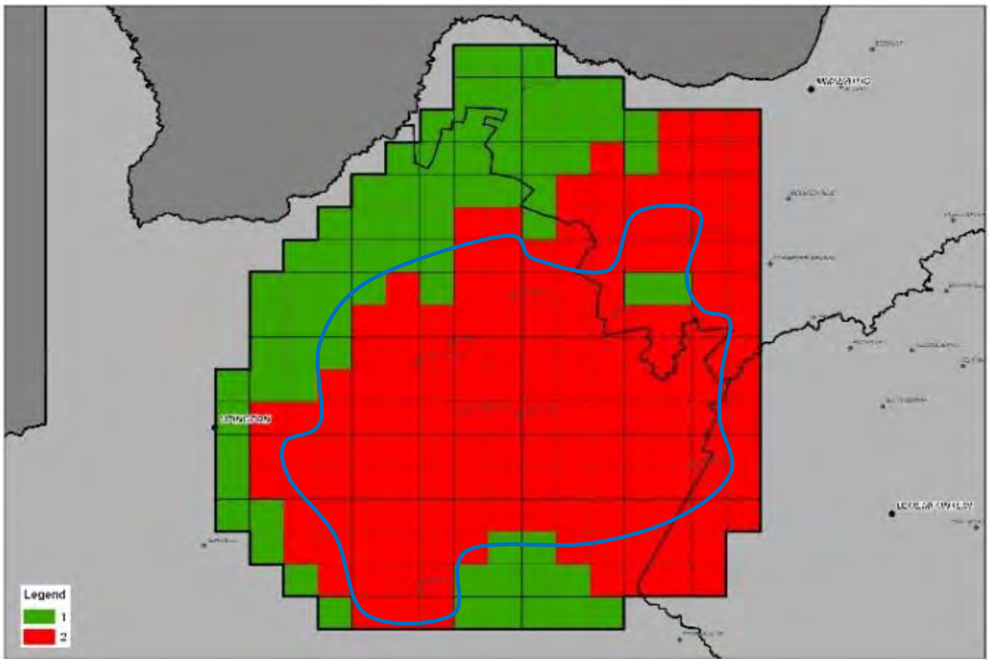


Figure 56: Base floristic clusters of species level data compared to the GWC core area which is indicated by the blue polygon.

5.6 Sub-centres of endemism within the GWC core area

As the GWC core area falls within floristic cluster 2 (Flora of Griqualand West), it is possible to identify sub-centres of endemism (Fig. 57) by considering the constituent floristic clusters (Fig. 49a) of floristic cluster 2 and the endemics that are restricted to each.

5.6.1 Northern Ghaap Plateau and Kuruman Hills sub-centre

Floristic cluster 2.1 (Flora of northern Ghaap Plateau and Kuruman Hills) has five GWC endemics restricted to it, namley *Antimima lawsonii* (Figs. 32b and 35b), *Cineraria exilis* (Figs. 32g and 35g), *Dicoma kurumanii* (Figs. 32h and 35h), *Gnaphalium englerianum* (Figs. 33a and 36a) and the near-endemic *Nuxia gracilis* (Figs. 33j and 36j). In total, 20 GWC endemics are present in this sub-centre.

5.6.2 Southern Kalahari and Langeberge sub-centre

Floristic cluster 2.2.1.1 (Flora of southern Kalahari and Langeberge) has three GWC endemics restricted to it, namely *Amphiglossa tecta* (Figs. 32a and 35a), *Brachiaria dura* var. *pilosa* (Figs. 32e and 35e) and *Lithops bromfieldii* (Figs. 33f and 36f). In total, 15 GWC endemics are present in this sub-centre.

5.6.3 Southern Ghaap Plateau and Kimberley-Prieska valley sub-centre

Floristic cluster 2.2.1.2 (Flora of southern Ghaap Plateau and the Kimberley-Prieska valley) has three GWC endemics restricted to it, namely *Lithops lesliei* subsp. *burchellii* (Figs. 33g and 36g), *L. aucampiae* subsp. *euniceae* (Figs. 33e and 36e) and *Phyllobolus amabilis* (Figs. 34a and 37a). In total, 16 GWC endemics are present in this sub-centre.

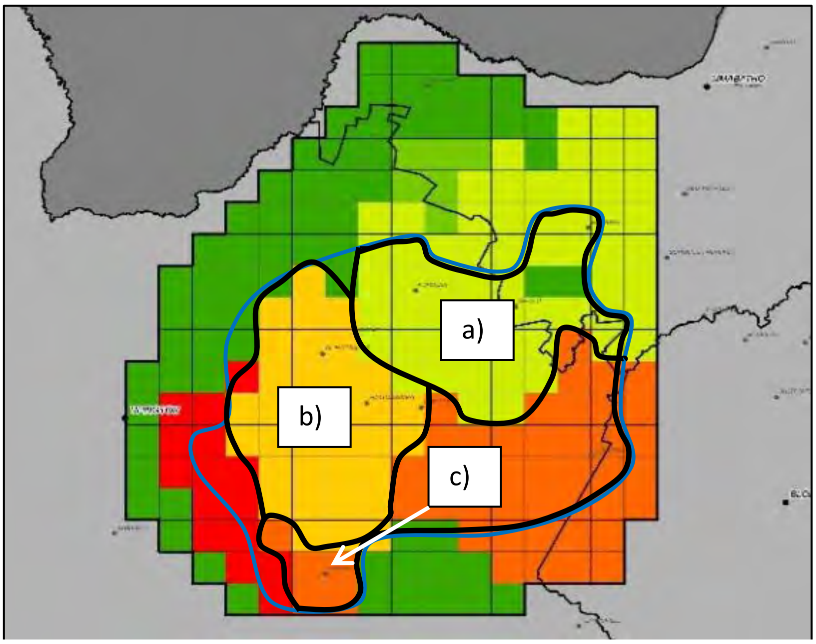


Figure 57: Floristic clusters based on species level data compared to the GWC core area which is indicated by the blue polygon. The black polygons represent the borders of the three sub-centres of endemism and are as follows: a) Northern Ghaap Plateau and Kuruman Hills sub-centre, b) Southern Kalahari and Langeberge sub-centre and c) Southern Ghaap Plateau and Kimberley-Prieska valley sub-centre.

5.6 Conclusion

The use of the Centroid grid profile requires that the results be considered as preliminary as this method extrapolates species distributions on a coarse scale due to the size of a QDG (25 x 27 km). Further sampling should be conducted to verify the presence of taxa in grids in which they were extrapolated to occur. As more floristic exploration is undertaken in Griqualand West more accurate data will become available including GPS coordinates and more species records which may support the recognition of more floristic clusters within the GWSA.

As predicted by van Wyk & Smith (2001), geology appears to be a factor influencing the flora of Griqualand West. However, the rough correspondence between the hypothetical floristic clusters and geology indicates that topography in addition, may also be influencing the floristic patterns of the GWSA. It must be noted that the geology of the GWSA is closely associated with its topography which, in turn, is also associated with rainfall and temperature. The topography comprises a high-lying plateau, mountains and river valleys. The higher lying plateau and mountains have a cooler climate, with the plateau having higher rainfall. The river valleys are drier and hotter.

The link between the borders of the GWC core area and the Griqualand-West floristic cluster which is characterised by elevated topography and heterogeneous, non-siliclastic geology, emphasises the role that the afore-mentioned abiotic variables has in harbouring range-restricted species. The constituent floristic clusters occurring within the GWC core area borders have a number of GWC endemics restricted within its borders. Their presence allowed the identification of three sub-centres of endemism in the GWC core area, namely the Northern Ghaap Plateau and Kuruman Hills sub-centre, the Southern Kalahari and Langeberge sub-centre, and the Southern Ghaap Plateau and Kimberley-Prieska valley sub-centre.

CHAPTER 6: SYNOPSIS AND FUTURE PROSPECTS

6.1 Introduction

This study has highlighted the uniqueness of the Griqualand West region, particularly in terms of its flora. This study floristically defines the Griqualand West Centre of endemism (GWC) based on the collective distributions of a number of species, many of which are very rare and/or under threat of extinction.

The principle findings of this study are discussed below, together with a brief discussion of some future studies that may be conducted in the region, and potential threats to the flora of the GWC.

6.2 Principle findings

6.2.1 GWC borders and endemism

The hypothesis that a centre of plant endemism (Mucina & Rutherford 2006; van Wyk & Smith 2001) is present in the Griqualand West region, namely the GWC, is supported through the identification of 24 endemic and two near-endemic species. However, the GWC has a low level of endemicity (1.4% of total flora), particularly when compared to the other 17 southern African centres recognised by van Wyk & Smith (2001).

The borders proposed by this study differ to those proposed by van Wyk & Smith (2001) as the southern, south-western and eastern boundaries are all extended with the major town of Kimberley now included within the GWC boundaries. These proposed shifts were based on the collective distributions of all GWC endemic and near-endemic species. An additional definition of the GWC boundaries are proposed to address the scale issue associated with such a large centre of endemism with few endemics. The GWC ‗core area' concept combines those parts of the study area where the endemics are most abundant. The GWC core area borders exclude the northern and north-western section of the GWC as proposed by van Wyk & Smith (2001), as most endemics occur rarely in these areas, whereas more occurrences per QDG were recorded for the Kimberley which is included within the GWC core area boundaries.

Floristic links between the flora of the GWC and two biomes (Savanna and Nama-Karoo) were identified based on the collective distributions of the GWC floristic element species.

One and 23 GWC endemics were restricted to the Nama-Karoo and Savanna biomes respectively.

The GWC is still under-collected and should be targeted for botanical exploration, particularly in regions known to be rich in endemics, such as the rocky and mountainous areas in the GWC core area.

6.2.2 Floristic regions of Griqualand West and sub-centres of endemism

The hypothesis that the endemicity of the GWC is a consequence of the rock types present (van Wyk & Smith 2001) is supported through the correlation between the GWC core area borders and floristic clusters that are associated with the unique geology and topography of Griqualand West. A number of GWC endemics are restricted to floristic clusters within the GWC core area, which made it possible to identify three sub-centres of endemism. These sub-centres of endemism are the Northern Ghaap Plataeau and Kuruman Hills sub-centre, the Southern Kalahari and Langeberg sub-centre and the Southern Ghaap Plateau and Kimberley-Prieska valley sub-centre.

It must be noted that the use of the Centroid grid profile (due to the under-collected status of the region) requires that the results be considered as preliminary. Further thorough sampling should be conducted to verify the presence of taxa within grids in which they were extrapolated to occur.

The correlation between endemism and the unique geology and elevated topography of the floristic region highlights the importance of conserving the elevated, rocky regions in Griqualand West.

6.3 Future studies

6.3.1 Botanical collections

A major limitation of this study was the lack of botanical collection that has been conducted in the GWC. Crucial to future investigations into the distribution of GWC endemics, floristic regions or boundaries is a significant increase in botanical collections. Based on the known presence of endemics, it is possible that there may be other, as of yet unknown plant species present in the GWC that is yet to be collected and described. Furthermore, some infraspecific taxa of otherwise known taxa may be yet to be collected and identified as unique to the GWC.

Another limitation of this study was the very coarse resolution of the available data. The vast majority of the currently available plant distribution records for the GWSA are only available at quarter-degree grid (QDG) level. Thus, future botanical collections in the region should include GPS coordinates for all specimens which will allow more accurate distribution mapping to be done.

6.3.2 Edaphic specialist species

The link found in this study between the GWC flora and the regions' unique geology warrants more investigation, particularly concerning edaphic specialist species. The prevalence of calcium-, iron- and manganese-rich soils holds the possibility of future studies investigating the physiological characteristics of species restricted to such soils, and how such substrates have influenced plant speciation and distribution patterns (van Wyk & Smith 2001). As suggested by van Wyk & Smith (2001), the remaining manganese-rich outcrops should be explored for potential manganese hyperaccumulators, as have been identified in various other parts of the world (Bidwell *et al*. 2002; Brooks *et al*. 1981; Fernando *et al*. 2006; Li *et al*. 2007; Memon & Yatazawa 1984; Min *et al*. 2007; Xue *et al*. 2004; Yang *et al*. 2008). Additionally, life forms including bryophytes, lichens and soil algae should be collected and documented on all of the regions unique geologies as there may be rare, endemic or species new to science on these substrates.

6.3.3 Fauna

To effectively conserve a region, all the various aspects of an ecosystem should be investigated and conserved, including the fauna. There are a number of threatened animal species with distributions at least in part in the GWC. These include two reptiles (Black Spitting Cobra (*Naja nigricincta woodii*) and Beaked Blind Snake (*Typhlops schinzii*)), six bird species Black Harrier (*Circus maurus*), Kori Bustard (*Ardeotis kori*), Martial Eagle (*Polemaetus bellicosus*), Ludwig's Bustard (*Neotis ludwigii*), Lanner Falcon (*Falco biarmicus*), Sclater's Lark (*Spizocorys sclateri*)) (Hoare 2006) and two butterfly species (*Anthene lindae* and *Tuxentius melaena* subsp. *griqua*) (Terblanche & Taylor 2000). Knowledge of other threatened invertebrates occurring in the GWC are poor, as no official published threatened species lists exist for any invertebrates (Hoare 2006). There exists a strong possibility that numerous undescribed insects occur in the GWC, many of which may have a strong association with environmental variables of the GWC, such as species adapted to the white substrates of the Ghaap Plateau (Fig. 58).

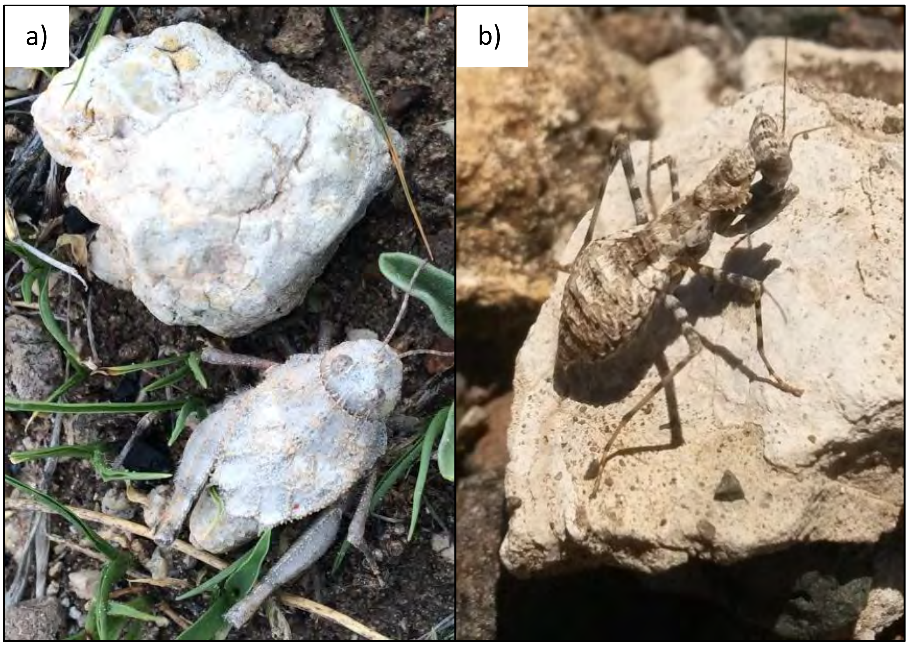


Figure 58: a) Stone Grasshopper (*Trachypetrella* subsp.) and b) praying mantis subsp. nymph, both mimicking the limestone substrate on Ghaap Plateau. (Photos: AW Frisby).

6.3.4 Scale of centres of endemism

The current definitions of a centre of endemism do not consider scale. This forces a biogeographer to employ subjective methods to define the borders of a centre of endemism, which is undesirable. The problem is that as a larger and larger area is considered, more and more species will inevitably be endemic to the area. As a result, even very large areas with comparatively few endemics can be considered a centre of endemism under current definitions. This problem was emphasized by this study, with the GWC found to be one of the largest centres in southern Africa but with the lowest level of endemicity.

This problem may potentially be addressed by a number of approaches. Firstly, a threshold ratio of number of endemic species to total surface area can be decided upon, below which a region should not be considered as a centre of endemism. Another approach would be to create ranks for centres of endemism based on level of endemicity which would allow differentiation between centres with high levels of endemism and those with low levels.

One reason that scale has as of yet not been considered as part of the definition for a centre of endemism is that ultimately all species should be considered as important and worth conserving, whether it is restricted to centre of endemism or not. Thus the size and number of endemics present in a centre should not influence the importance of conserving it.

6.4 Threats to the GWC

6.4.1 Bush encroachment

Bush encroachment is the increase of woody plant abundance (O‘ Connor & Crow 1999). *Senegalia mellifera* (Fabaceae) is an indigenous shrub/small tree that is known to be an encroacher-species in semi-arid environments (Joubert *et al*. 2008). The GWC, with its semi-arid climate is no exception to this (van Wyk & Smith 2001), with large areas of land having been invaded by this species, particularly in southern half of the GWC. One of the biggest problems of bush encroachment is a loss of biodiversity (Wigley *et al*. 2009), which could seriously threaten many of the already scarce endemics. Various factors (Ward 2005) may have led to this problem in the GWC, with improper rangeland management, including overgrazing (Walter 1964) and the suppression of fire (Trollope 1974), common contributing factors.

To address this problem, legislation should be put in place that makes carrying capacity assessments compulsory, for all types of farmers, including game farming (which is prevalent in the GWC). A regular fire regime should be determined and encouraged, an effort that may help prevent bush encroachment by *S. mellifera*. Systematic removal of thick stands of *S. mellifera* should be undertaken in such a way that further environmental degradation (such as excessive soil disturbance) does not occur. It is important that the chosen methods of encroaching plants be ecologically responsible, economically justifiable (Smit 1998) and in accordance with legislative laws.

6.4.2 Mineral and natural gas mining

The strong mineral mining presence in the GWC has caused an unknown amount of damage to the flora of the region. However, thanks to legislation, various laws now protect the land on and surrounding mines, and crucially entail that environmental impact assessments EIA‘s be done prior to any mining. This must be done so as to comply with the National Environmental Management Act (No. 107 of 1998) (NEMA) and the Mineral and Petroleum Resources Development Act (No. 28 of 2002) (MPRDA). Laws particular to mining activities (MPRDA No. 28 of 2002) include that the holder of a mining permission\right\permit:

- must consider, investigate, assess and communicate the impact of their activities on the environment comprehensibly.
- must, as far as is reasonably practicable, rehabilitate the environment to its natural or predetermined state, or to a land use which conforms to the generally accepted principle of sustainable development.

- is responsible for environmental damage, pollution or ecological degradation as a result of reconnaissance, prospecting or mining operations which may occur inside and outside the boundaries of the areas to which such right, permission or permit relates.

- must ensure that mining operations will take place within the framework of national environmental management policies, norms and standards.

If these laws such as the above examples continue to be enforced on a national and provincial level, the threat of the mining presence to the GWC and its endemic plants in particular, is greatly reduced.

Natural gas mining through hydraulic fracturing is another threat to the GWC, particularly the southern parts of the centre (Fig. 59), where a Technical Cooperation Permit (TCP) has been granted to a gas company. This permit allows the applicant to do a desktop study, acquire seismic data from other sources including the Agency, etc.; but does not include any prospecting or exploration activities (MPRDA section 77(1)). In the northern parts of the GWC, another area is under application for a gas exploration, but has of yet not been approved.

Various concerns about the effect of hydraulic fracturing on the environment has been raised, particularly the risk of ground water pollution (Vidic *et al*. 2013) and a lowering of the water table (Healy 2007) which could contribute to droughts. These and other negative aspects of hydraulic fracturing could potentially negatively affect the flora of the GWC and threaten the survival of some GWC endemics. However, as with mineral mining, hydraulic fracturing activities must also comply with the National Environmental Management Act (No.

107 of 1998) (NEMA) and the Mineral and Petroleum Resources Development Act (No. 28 of 2002) (MPRDA) and in so doing reduces the threat of hydraulic fracturing to the GWC flora.

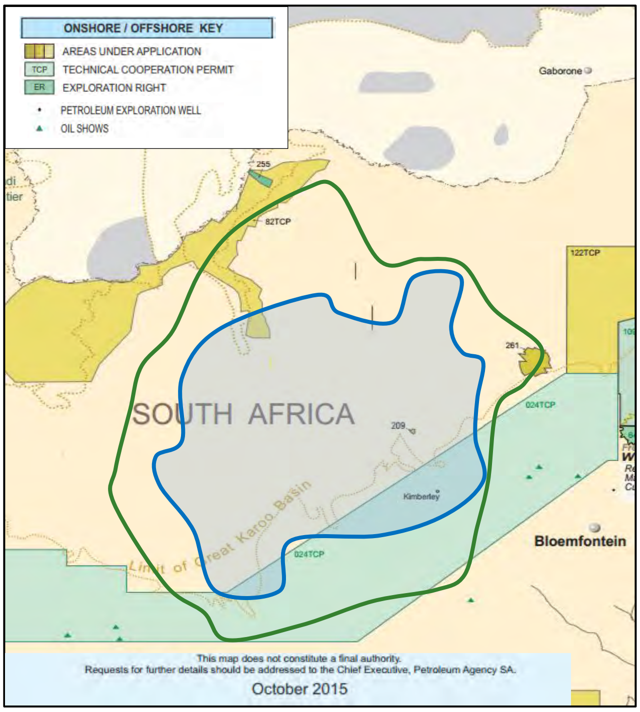


Figure 59: Map of proposed hydraulic fracturing areas in the Griqualand West region. The green and blue polygons represent the borders of the GWC and GWC core areas respectively. Map source: www.petroleumagencysa.com.

6.4.3 Climate change

Various aspects of climate change have been predicted to have adverse effects on the world‘s flora. One of the adverse consequences of climate change on plants is the inferred range shifts predicted by numerous models (Thuiller 2004). Due to the dependence of plants on their substrate, the predicted range shifts may, in part, only be possible if the substrate required by the plant is present in the regions were climate will become favorable. In the case of edaphic specialist species, such as some of the GWC endemics (*Nuxia gracilis* and *Rennera stellata*), such range shifts may be impossible due to substrate requirements. Thus, in place of range shifts only range reductions (Midgley *et al*. 2003) can occur, a prospect predicted to negatively impact endemic plant species in regions of the world (Loarie *et al*. 2008). In California, it is predicted that 66% of the 2387 endemic plant species will experience >80% reductions in their total range within the next 100 years (Loarie *et al*. 2008). Such trends may lead to the eventual extinction of many plant species (Dullinger *et al*. 2012), the first of which to go extinct likely to be the already range-restricted plants such as the GWC endemics. To address the problem of potential extinctions due to the inability to naturally migrate to areas where all habitat requirements are met, some authors have suggested human-assisted colonisation of threatened species to potentially distant locations deemed to meet its habitat requirements (Hoegh-Guldberg *et al*. 2008). This strategy can be considered for the future conservation of GWC endemics identified to be under severe threat of extinction through the effects of climate change.

REFERENCES

Acocks JPH (1988) Veld Types of South Africa: Memoirs of the Botanical Survey of South Africa No. 57. Botanical Research Institute, Pretoria.

Acquaah G (2007) Principles of plant genetics and breeding. Blackwell Publishing, Oxford.

Adger N, Aggarwal P, Agrawala S, Alcamo J, Allali A, Anisimov O, Arnell N, Boko M, Canziani O, Carter T, Casassa G, Confalonieri U, Cruz RV, Alcaraz E, Easterling W, Field C, Fischlin A, Fitzharris BB, García CG, Hanson C, Harasawa H, Hennessy K, Huq S, Jones R, Bogataj LK, Karoly D, Klein R, Kundzewicz Z, Lal M, Lasco R, Love G, Lu X, Magrín G, Mata LJ, McLean R, Menne B, Midgley G, Mimura N, Mirza MQ, Moreno J, Mortsch L, Niang-Diop I, Nicholls R, Nováky B, Nurse L, Nyong A, Oppenheimer M, Palutikof J, Parry M, Patwardhan A, Lankao PR, Rosenzweig C, Schneider S, Semenov S, Smith J, Stone J, van Ypersele J, Vaughan D, Vogel C, Wilbanks T, Wong PP, Wu S, Yohe G (2001) Climate change 2007: Impacts, adaptation and vulnerability. Intergovernmental Panel on Climate Change, Brussels.

Alexander JA, Liston A, Popovich SJ (2004) Genetic diversity of the narrow endemic *Astragalus oniciformis* (Fabaceae). *American Journal of Botany* **91**: 2004–2012.

Alexander S, Ehrlich PR, Goulder L, Lubchenco J, Matson PA, Mooney HA, Woodwell GM (1997) Ecosystem services: benefits supplied to human societies by natural ecosystems Vol. 2. Ecological Society of America, Washington.

Allison JR, Stevens TE (2001) Vascular flora of Ketona dolomite outcrops in Bibb County, Alabama. *Castanea* **66**: 154–205.

Altermann W, Hälbich IW (1990) Thrusting, folding and stratigraphy of the Ghaap Group along the southwestern margin of the Kaapvaal Craton. *South African Journal of Geology* **93**: 553–566.

Altermann W, Wotherspoon JM (1995) The carbonates of the Transvaal and Griqualand West sequences of the Kaapvaal craton, with special reference to the Lime Acres limestone deposit. *Mineralium Deposita* **30**: 124–134.

Anderson S (2002) Identifying important plant areas. Plantlife International, London.

Anderson GD, Harrison KD (2006) Language hotspots: linking language extinction, biodiversity, & human knowledge base. *Living Tongues Institute for Endangered Languages Occasional Papers Series* **1**: 1–11.

Anthony JW, Bideaux RA, Bladh KW, Nichols MC (2003) Handbook of Mineralogy: Borates, Carbonates, Sulfates 5. Mineral Data Publishing, Tuscon (AZ).

Alves RJV, Kolbek J (1994) Plant species endemism in savanna vegetation on table mountains (Campo Rupestre) in Brazil. *Vegetatio* **113**: 125–139.

Archer RH (2015) Taxonomic status of *Maytenus ilicina.* 2nd November, SANBI (Pretoria).

Archer RH, Victor JE (2005) *Maytenus ilicina* (Burch.) Loes. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Archer RH, Victor JE (2005) *Putterlickia saxatilis* (Burch.) M.Jordaan. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Archer RH, von Staden L, Victor JE (2005) *Euphorbia wilmaniae* Marloth. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/28.

Baden C, Balkwill K, Getliffe NFM, Immelman KL, Manning JC, Munday J (1995) Acanthaceae-Justiciinae. *Flora of Southern Africa* **30** Part 3, Fascicle 1. National Botanical Institute, Pretoria.

Beadle NCW (1966) Soil phosphate and its role in molding segments of the Australian flora and vegetation, with special reference to xeromorphy and sclerophylly. *Ecology* **47**: 992–1007.

Bergmeier E, Abrahamczyk S (2007) Ecology and distribution of the Aegean wetland endemics *Carex cretica* and *Lathyrus neurolobus*. *Nova Hedwigia Beihefte* **131**: 207.

Bharucha FR, Meher-Homji VM (1965) On the floral elements of the semi-arid zones of India and their ecological significance. *New Phytologist* **64**: 330–342.

Bidgood S, Vollesen K (2006) A new species of *Diplolophium* (Apiaceae) from Ethiopia. *Kew Bulletin* **61**: 239–242.

Bidwell SD, Woodrow IE, Batianoff GN, Sommer-Knudsen J (2002) Hyperaccumulation of Manganese in the rainforest tree *Austromyrtus bidwillii* (Myrtaceae) from Queensland, Australia. *Functional Plant Biology* **29**: 899–905.

Biral L, Lombardi JA (2013) A New Species of *Maytenus* (Celastraceae) from Bahia, Brazil, and Neotypification of *Maytenus boaria*. *Harvard Papers in Botany* **18**: 129–132.

Boatwright JS, Tilney PM, van Wyk BE (2009) The generic concept of *Lebeckia* (Crotalarieae, Fabaceae): reinstatement of the genus *Calobota* and the new genus *Wiborgiella*. *South African Journal of Botany* **75**: 546–556.

Boneschans RB, Coetzee MS, Siebert SJ (2015) A geobotanical investigation of the Koedoesfontein Complex, Vredefort Dome, South Africa. *Australian Journal of Botany* **63**: 324–340.

Botschantzev V (1974) A synopsis of *Salsola* (Chenopodiaceae) from south and south-west Africa. *Kew Bulletin* **29**: 597–614.

Boucher C, Rode E (1997) Alpha Saldanha cement project. Specialist report 2: flora. Botany Department, University of Stellenbosch, Stellenbosch.

Boynton RS (1966) Chemistry and technology of lime and limestone. Interscience Publishers, New York.

Brady NC, Weil RR (2008) The nature and properties of soils. Prentice-Hall Inc., New Jersey.

Bramwell D (1976) The endemic flora of the Canary Islands: distribution, relationships and phytogeography. Springer, Netherlands.

Bridge G (2004) Contested terrain: mining and the environment. *Annual Review of Environment and Resources* **29**: 205–259.

Brooks RR, Trow JM, Veillon JM, Jaffré T (1981) Studies on Manganese-accumulating *Alyxia* species from New Caledonia. *Taxon* **30**: 420–423.

Burgoyne PM (2006) *Mestoklema copiosum* N.E.Br. ex Glen. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/30.

Burgoyne PM (2006) *Prepodesma orpenii* (N.E.Br.) N.E.Br. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Burgoyne PM, Raimondo D, Daniels F (2005) *Hereroa wilmaniae* L.Bolus. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Butcher R, Byrne M, Crayn DM (2007) Evidence for convergent evolution among phylogenetically distant rare species of *Tetratheca* (Elaeocarpaceae, formerly Tremandraceae) from Western Australia. *Australian Systematic Botany* **20**: 126–138.

Butcher PA, Krauss SL (2009) Development of microsatellites from the rare ironstone endemic, *Tetratheca paynterae* ssp. *paynterae* and cross-species amplification. *Molecular ecology resources* **9**: 386–389.

Cain SA (1938) The Species-Area Curve. *American Midland Naturalist* **19**: 573–581.

Caley MJ (1997) Local endemism and the relationship between local and regional diversity. *Oikos* **79**: 612–615.

Campbell NA, Reece JB, Urry LA, Cain ML, Wasserman SA, Minorsky PV, Jackson RB (2008) Biology, 8th edition. Pearson, Boston.

Campbell-Young GJ, Balkwill K (2000) A new species of *Pearsonia* (Fabaceae) from dolomites in Northern Province, South Africa. *Nordic Journal of Botany* **20**: 547–555.

Cawood FT (2004) The Mineral and Petroleum Resources Development Act of 2002: a paradigm shift in mineral policy in South Africa. *Journal-South African Institute of Mining and Metallurgy* **104**: 53–64.

Chin SC (1977) The limestone hill flora of Malaya. *Gardens' Bulletin Singapore* **30**: 165–219.

Cholo F (2006) *Barleria media* C.B.Clarke. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/30.

Clark VR, Barker NP, Mucina L (2009) The Sneeuberg: a new centre of floristic endemism on the Great Escarpment, South Africa. *South African Journal of Botany* **75**: 196–238.

Clements R, Sodhi NS, Schilthuizen M, Ng PK (2006) Limestone karsts of Southeast Asia: imperilled arks of biodiversity. *Bioscience* **56**: 733–742.

Coon CS, Hunt EE (1965). The living races of man. *Human Biology* **39**: 330–333.

Cooper RL, Cass DD (2001) Comparative evaluation of vessel elements in *Salix* subsp. (Salicaceae) endemic to the Athabasca sand dunes of northern Saskatchewan, Canada. *American journal of botany* **88**: 583–587.

Cowling RM (1983) Phytochorology and vegetation history in the south-eastern Cape, South Africa. *Journal of Biogeography* **10**: 393–419.

Cowling RM, Hilton-Taylor C (1997) Phytogeography, flora and endemism. *In* Cowling RM, Richardson DM, Pierce SM (1997) Vegetation of southern Africa. Cambridge University Press, Cambridge.

Cowling RM, Holmes PM (1992) Endemism and speciation in a lowland flora from the Cape Floristic Region. *Biological Journal of the Linnean Society* **47**: 367–383.

Cowling RM, Lombard AT (2002) Heterogeneity, speciation/extinction history and climate: explaining regional plant diversity patterns in the Cape Floristic Region. *Diversity and Distributions* **8**: 163–179.

Cowling RM, Rundel PW, Desmet PG, Esler KJ (1998) Extraordinary high regional-scale plant diversity in southern African arid lands: subcontinental and global comparisons. *Diversity and Distributions* **4**: 27–36.

Cowling RM, Samways MJ (1994) Predicting global patterns of endemic plant species richness. *Biodiversity Letters* **2**: 127–131.

Cowling RM, Straker CJ, Deignan MT (1990) Does microsymbiont-host specificity determine plant species turnover and speciation in Gondwanan shrublands? A hypothesis. *South African Journal of Science* **86**: 118–120.

Cowling RM, Witkowski ETF, Milewski AV, Newbey KR (1994) Taxonomic, edaphic and biological aspects of narrow plant endemism on matched sites in mediterranean South Africa and Australia. *Journal of Biogeography* **21**: 651–664.

Crisp MD, Laffan S, Linder HP, Monro A (2001) Endemism in the Australian flora. *Journal of Biogeography* **28**: 183–198.

Cron GV, Balkwill K, Knox EB (2006) *Bolandia* (Senecioneae, Asteraceae): a new genus endemic to southern Africa. *Novon* **16**: 224–230.

Cron GV, Victor JE, von Staden L (2008) *Cineraria exilis* DC. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

de la Luz JLL, Medel-Narváez A (2013) A new species of *Bidens* (Asteraceae: Coreopsidae) from Baja California Sur, Mexico. *Acta Botanica Mexicana* **103**: 119–126.

de Sales MF, Kinoshita LS, Simões AO (2006) Eight new species of *Mandevilla* Lindley (Apocynaceae, Apocynoideae) from Brazil. *Novon: A Journal for Botanical Nomenclature* **16**: 112–128.

Davison JD (1927) Celastraceae R.Br. *Bothalia* **2**: 289–346.

De Villiers JE (1983) The managanese deposits of Griqualand West, South Africa: some mineralogic aspects. *Economic Geology* **78**: 1108–1118.

Delprete PG (2008) Revision of *Tocoyena* (Rubiaceae: Gardenieae) from the states of Goiás and Tocantins and a new species endemic to white-sand areas in the Brazilian cerrado. *Journal of the Botanical Research Institute of Texas* **2**: 983–993.

Dice LR (1945) Measures of the amount of ecologic association between species. *Ecology* **26**: 297–302.

Dixon JC, McLaren SJ (2009) Duricrusts: Geomorphology of desert environments. Springer Netherlands.

Dobolyi K (2003) Phytosociological evaluation and multivariate analysis of the habitat of Linum dolomiticum Borbás (Linceae) I. *Studia Botanica Hungarica* **34**: 111–112.

Dollar ESJ, James CS, Rogers KH, Thoms MC (2007) A framework for interdisciplinary understanding of rivers as ecosystems. *Geomorphology* **8**: 147–162.

Duever MJ, Meeder JF, Meeder LC, McCollom JM (1994) The climate of south Florida and its role in shaping the Everglades ecosystem *in* Everglades: The ecosystem and its restoration. St. Lucie Press, Florida.

Dullinger S, Gattringer A, Thuiller W, Moser D, Zimmermann NE, Guisan A, Willner W, Plutzar C, Leitner M, Mang T, Caccianiga M, Dirinböck T, Ertl S, Fischer A, Lenoir J, Svenning J, Psomas A, Schmatz DR, Silc U, Vittoz P, Hülber, K (2012) Extinction debt of high-mountain plants under twenty-first-century climate change. *Nature Climate Change* **2**: 619–622.

Eglington BM (2006) Evolution of the Namaqua-Natal Belt, South Africa: a geochronological and isotype geochemical review. *Journal of African Earth Sciences* **46**: 93–111.

Escudero A, Somolinos RC, Olano J, Rubio A (1999) Factors controlling the establishment of *Helianthemum squamatum*, an endemic gypsophile of semi-arid Spain. *Journal of Ecology* **87**: 290–302.

ESRI (2011). ArcGIS Desktop: Release 10. Environmental Systems Research Institute: Redlands.

Estill JC, Cruzan MB (2001) Phytogeography of rare plant species endemic to the southeastern United States.*Castanea* **66**: 3–23.

Fant JB, Havens K, Keller JM, Radosavljevic A, Yates ED (2014) The influence of contemporary and historic landscape features on the genetic structure of the sand dune endemic, *Cirsium pitcheri* (Asteraceae). *Heredity* **112**: 519–530.

Fernando DR, Batianoff GN, Baker AJ Woodrow IE (2006) In vivo localization of Manganese in the hyperaccumulator *Gossia bidwillii* (Benth.) N. Snow & Guymer (Myrtaceae) by cryo-SEM/EDAX. *Plant, Cell and Environment* **29**: 1012–1020.

Fine PV, García-Villacorta R, Pitman NC, Mesones I, Kembel SW (2010) A floristic study of the White-Sand Forests of Peru. *Annals of the Missouri Botanical Garden* **97**: 283–305.

Fischer RA, Turner NC (1978) Plant productivity in the arid and semiarid zones. *Annual Review of Plant Physiology* **29**: 277–317.

Foden W, Potter L (2005) *Calobota cuspidosa* (Burch.) Boatwr. & B.-E.van Wyk. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/30.

Foden W, Potter L, (2005) *Dicoma kurumanii* S.Ortiz & Netnou. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Foden W, Potter L (2005) *Eriocephalus ericoides* (L.f.) Druce subsp. *griquensis* M.A.N.Müll. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/28.

Foden W, Potter L, (2005) *Searsia tridactyla* (Burch.) Moffett. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29

Foden W, Potter L (2005) *Tarchonanthus obovatus* DC. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Foden W, Potter L (2005) *Thesium dumale* N.E.Br. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Frey DJ, Haag CR, Kozlowski G, Tison J, Mraz P (2012) High genetic and morphological diversity despite range contraction in the diploid *Hieracium eriophorum* (Asteraceae) endemic to the coastal sand dunes of south-west France. *Botanical Journal of the Linnean Society* **169**: 365–377.

Frisby AW, Siebert SJ, Cilliers D, van Wyk AE (2015) Redefining the Griqualand West Centre of plant endemism. *South African Journal of Botany* **98**: 178.

Gankin R, Major J (1964) *Arctostaphylos myrtifolia*, its biology and relationship to the problem of endemism. *Ecology* **45**: 792–808.

Gibson N, Meissner R, Markey AS, Thompson WA (2012) Patterns of plant diversity in ironstone ranges in arid south western Australia. *Journal of Arid Environments* **77**: 25–31.

Gibson N, Yates CJ, Dillon R (2010) Plant communities of the ironstone ranges of South Western Australia: hotspots for plant diversity and mineral deposits. *Biodiversity and Conservation* **19**: 3951–3962.

Giliomee H, Mbenga M (2007) New history of South Africa. Tafelberg Publishers, Cape Town.

Golding JS (2002) *Southern African plant red data lists*. SABONET, Pretoria.

Gollasova K, Kmetova E, Michalkova E, Mraz P, Mrazova V (2002) Endemic plant species 1: 3 000 000. Slovakia: Ministry of Environment of the Slovak Republic, Slovak Environmental Agency Banska Bystrica.

Green PS, Kupicha FK (1979) Notes on the genus *Olea*. *Kew Bulletin* **34**: 69–75.

Grobbelaar WS, Burger MA, Pretorius AI, Marais W, van Niekerk IJM (1995) Stratigraphic and structural setting of the Griqualand West and the Olifantshoek Sequences at Black Rock, Beeshoek and Rooinekke Mines, Griqualand West, South Africa. *Mineralium Deposita* **30**: 152–161.

Guitian J, Sanchez JM., Guitian P (1994) Pollination ecology of *Petrocoptis grandiflora* Rothm.(Caryophyllaceae); a species endemic to the north-west part of the Iberian Peninsula. *Botanical Journal of the Linnean Society* **115:** 19–27.

Gutzmer J, Beukes NJ (1996) Karst-hosted fresh-water Paleoprotezoic manganese deposits, Postmasburg, South Africa. *Economic Geology* **91**: 1435–1454.

Hahn N (2010) Floristic diversity of the Soutpansberg, Limpopo Province, South Africa. Doctoral thesis, University of Pretoria, Pretoria.

Hälbich IW, Scheepers R, Lamprecht D, van Deventer JL, De Kock NJ (1993) The Transvaal-Griqualand West banded iron formation: geology, genesis, iron exploitation. *Journal of African Earth Sciences (and the Middle East)* **16**: 63–120.

Hammer Ø, Harper DAT, Ryan PD (2001) Past: paleontological statistics software package for education and data analysis. *Palaeontologia Electronica* **4**: 1–31.

Hartmann HE (2002) Illustrated handbook of succulent plants: Aizoaceae F-Z. Springer, Berlin.

Hartmann HEK (1998) New combinations in *Antimima* (Ruschioideae, Aizoaceae) from southern Africa. *Bothalia* **28**: 67–82.

He YH, Zhao H, Liu XP, Zhao XY, Zhang TH, Drake S (2009) Reproductive allocation of *Corispermum elongatum* in two typical sandy habitats. *Pakistan Journal of Botany* **41**: 1685–1694.

Healy D (2007) Hydraulic Fracturing or ―Fracking”: A short summary of current knowledge and potential environmental impacts. A small scale study for the Environmental Protection Agency (Ireland) under the Science, Technology, Research and Innovation for the Environment (STRIVE) Programme.

Heenan PB, Molloy BPJ (2006) A new species of *Oreomyrrhis* (Apiaceae) from southern South Island, New Zealand, and comparison of its limestone and ultramafic habitats. *New Zealand Journal of Botany* **44**: 99–106.

Herman PPJ (1999) Synopsis of the genus *Rennera* Merxm. (Asteraceae, Anthemideae) with the description of a new species from South Africa. *Botanical journal of the Linnean Society* **129**: 367–377.

Herman PPJ (2002) Revision of the *Tarchonanthus camphoratus* complex (Asteraceae-Tarchonantheae) in southern Africa. *Bothalia* **32**: 21–28.

Hilliard OM (1983) Asteraceae, Gnaphaliinae (first part). *Flora of southern Africa* **33** Part 7, Fascicle 2. National Botanical Institute, Pretoria.

Hoare D (2006) Ecological investigation of the proposed ESKOM sub-station extension at Garona, Northern Cape. Tswelopele Environmental Services (Pty) Ltd., Randburg.

Hoegh-Guldberg O, Hughes L, McIntyre S, Lindenmayer DB, Parmesan C, Possingham HP, Thomas CD (2008) Assisted colonization and rapid climate change. *Science* **321**: 345–346.

Holling CS (1973) Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* **4**: 1–23.

Holmgren K, Lee-Thorp JA, Cooper GR, Lundblad K, Partridge TC, Scott L, Scott L, Sithaldeen R, Tyson, PD (2003) Persistent millennial-scale climatic variability over the past 25 000 years in Southern Africa. *Quaternary Science Reviews* **22**: 2311–2326.

Hua X, Wiens JJ (2013) How does climate influence speciation? *The American Naturalist* **182**: 1–12.

Jacobi CM, do Carmo FF, Vincent RC, Stehmann JR (2007) Plant communities on ironstone outcrops: a diverse and endangered Brazilian ecosystem. *Biodiversity and Conservation* **16**: 2185–2200.

Jacobi CM, Fonseca do Carmo F (2008) The contribution of ironstone outcrops to plant diversity in the Iron Quadrangle, a threatened Brazilian landscape. *A Journal of the Human Environment* **37**: 324–326.

Jenny H (1941) Factors of soil formation. McGraw-Hill, New York.

Johnson MR, Anhauesser CR, Thomas RJ (2006) The Geology of South Africa. Geological Society of South Africa, Johannesburg.

Joppa LN, Roberts DL, Pimm SL (2011) How many species of flowering plants are there? *Proceedings of the Royal Society B: Biological Sciences* **278**: 554–559.

Jordaan M, Boon RG, van Wyk AE (2015) *Putterlickia neglecta* (Celastraceae), a new species from southern Africa. *Phytotaxa* **208**: 217–224.

Jordaan M, van Wyk AE (1998) Systematic studies in subfamily Celastroideae (Celastraceae) in southern Africa: the genus *Putterlickia*. *South African Journal of Botany* **64**: 322–329.

Joubert DF, Rothauge A, Smit GN (2008) A conceptual model of vegetation dynamics in the semiarid highland savanna of Namibia, with particular reference to bush thickening by *Acacia mellifera*. *Journal of Arid Environments* **72**: 2201–2210.

Kamundi DA (2006) *Blepharis marginata* (Nees) C.B.Clarke. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/28.

Kamundi DA (2006) *Justicia puberula* Immelman. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Kamundi DA (2006) *Justicia thymifolia* (Nees) C.B.Clarke. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/06/01.

Kamundi DA (2005) *Salsola atrata* Botsch. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Kamundi DA, Victor JE (2005) *Gnaphalium englerianum* (O.Hoffm.) Hilliard & B.L.Burtt. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/28.

Karpan R, Karpan A (1998) Northern sandscapes–exploring Saskatchewan‘s Athabasca Sand Dunes. Parkland Publishing, Regina.

Kelley AP (1922) Plant indicators of soil types. *Soil Science* **13**: 411–424.

Kenrick P, Crane PR (1997) The origin and early evolution of plants on land. *Nature* **389:** 33–39.

Killick DJB (1978) Further data on the climate of the Alpine Vegetation Belt of eastern Lesotho. *Bothalia* **12**: 567–572.

Kirchner JW (2002) The Gaia hypothesis: fact, theory, and wishful thinking. *Climatic change* **52**: 391–408.

Kirchner JW (2003) The Gaia hypothesis: conjectures and refutations. *Climatic Change* **58**: 21–45.

Klak C, Raimondo D (2006) *Antimima lawsonii* (L.Bolus) H.E.K.Hartmann. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Klopper RR, Smith GF (2009) Asphodelaceae: Alooideae. *Aloe hahnii*, a new species in the Section Pictae, in the Soutpansberg Centre of Endemism, Limpopo Province, South Africa. *Bothalia* **39**: 98–100.

Knowles L, Witkowski ETF (2000) Conservation biology of the succulent shrub, *Euphorbia barnardii*, a serpentine endemic of the Northern Province, South Africa. *Austral Ecology* **25**: 241–252.

Koekemoer M, Steyn HM, Bester SP (2013) Guide to plant families of southern Africa. South African National Biodiversity Institute, Pretoria.

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift* **15:** 259–263.

Kruckeberg AR, Rabinowitz D (1985) Biological aspects of endemism in higher plants. *Annual Review of Ecology and Systematics* **16**: 447–479.

Lamb EG, Guedo DD (2012) The distribution, abundance, and environmental affinities of the endemic vascular plant taxa of the Athabasca Sand Dunes of northern Saskatchewan. *Ecoscience* **19**: 161–169.

Lee-Thorp JA, Holmgren K, Lauritzen SE, Linge H, Moberg A, Partridge Tyson PD (2001) Rapid climate shifts in the southern African interior throughout the mid to late Holocene. *Geophysical Research Letters* **28**: 4507–4510.

Leeuwenberg AJM (1975) The Loganiaceae of Africa: 14. A revision of *Nuxia* Lam. *Meded. Landbouwhogesch. Wageningen* **78**: 1–80.

Legendre P, Legendre L (1998). Numerical Ecology: Second English Edition, Developments in Environmental Modelling 20. Elsevier, Amsterdam.

Li MS, Luo YP, Su ZY (2007) Heavy metal concentrations in soils and plant accumulation in a restored Manganese mineland in Guangxi, South China. *Environmental pollution* **147**: 168–175.

Lieth H (1973) Primary production: terrestrial ecosystems. *Human ecology* **1**: 303–332.

Linder HP (2001) Plant diversity and endemism in sub-Saharan tropical Africa. *Journal of Biogeography* **28**: 169–182.

Liu Y, Yao C, Wang G, Bao S (2011) An integrated sustainable development approach to modeling the eco-environmental effects from urbanization. *Ecological Indicators* **11**: 1599–1608.

Loarie SR, Carter BE, Hayhoe K, McMahon S, Moe R, Knight C, Ackerly DD (2008) Climate change and the future of California's endemic flora. *PLoS ONE* **3**: 1–10.

Loehle C (2006) Endemic plant distributions in eastern North America: implications for conservation. *Journal of Forestry* **104**: 415–418.

Looman J, Campbell JB (1960) Adaptation of Sorensen's K (1948) for estimating unit affinities in prairie vegetation. *Ecology* **41**: 409–416.

López-Pujol J, Zhang FM, Sun HQ, Ying TS, Ge S (2011) Centres of plant endemism in China: places for survival or for speciation? *Journal of Biogeography* **38**: 1267–1280.

Lousada JM, Lovato MB, Borba EL (2013) High genetic divergence and low genetic variability in disjunct populations of the endemic *Vellozia compacta* (Velloziaceae) occurring in two edaphic environments of Brazilian campos rupestres. *Brazilian Journal of Botany* **36**: 45–53.

Lovelock JE, Margulis L (1974) Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis. *Tellus* **26**: 2–10.

Low AB, Berry M (2007) Proposed reverse osmosis plant for the transnet iron ore handling facility, Saldanha: botanical assessment: COASTEC.

Low AB, Rebelo AG (1996) Vegetation of South Africa, Lesotho and Swaziland. Department of Environmental Affairs & Tourism, Pretoria.

MacDonald I (1981) Witsand–a mirage in the red Kalahari. *African Wildlife* **35**: 29–31.

Magee AR, Boatwright, JS, Mucina L (2011) *Gazania lanata* and *G. splendidissima*: Two new species of Asteraceae (tribe Arctotideae) from the Greater Capensis, with an updated key for the genus. *South African Journal of Botany* **77**: 86–93.

Magee AR, Manning JC (2010) *Annesorhiza calcicola* (Apiaceae), a new limestone endemic species from the Western Cape Province of South Africa. *South African Journal of Botany* **76**: 139–141.

Mapaura A (2002) Endemic plant species of Zimbabwe. *Kirkia* **18**: 117–149.

Markey A, Dillon S (2008) Flora and vegetation of the banded iron formations of the Yilgarn Craton: the central Tallering Land System. *Conservation Science of Western Australia* **7**: 121–149.

Maschinski J, Baggs JE, Sacchi CF (2004) Seedling recruitment and survival of an endangered limestone endemic in its natural habitat and experimental reintroduction sites. *American Journal of Botany* **91**: 689–698.

Maschinski J, Baggs JE, Quintana-Ascencio PF, Menges ES (2006) Using population viability analysis to predict the effects of climate change on the extinction risk of an endangered limestone endemic shrub, Arizona cliffrose. *Conservation Biology* **20**: 218–228.

Matthews WS, van Wyk AE, Bredenkamp GJ (1993) Endemic flora of the north-eastern Transvaal escarpment, South Africa. *Biological Conservation* **63**: 83–94.

McCarthy T, Rubidge B (2005) The story of earth and life: a southern African perspective on a 4.6-billion-year journey. Struik Nature, Cape Town.

McCune B, Grace JB, Urban DL (2002) Analysis of ecological communities: Vol. 28. MjM software design, Gleneden Beach, OR.

Medina-Cazorla JM, Garrido-Becerra JA, Mendoza-Fernández A, Pérez-García FJ, Salmerón E, Gil C, Mota Poveda JF (2010) Biogeography of the Baetic ranges (SE Spain): a historical approach using cluster and parsimony analyses of endemic dolomitophytes. *Plant Biosystems* **144**: 111–120.

Meissner R, Caruso Y (2008a) Flora and vegetation of the banded ironstone formation of the Yilgarn Craton: Koolanooka and Perenjori Hills. *Conservation Science Western Australia* **7**: 73–88.

Meissner R, Caruso Y (2008b) Flora and vegetation of the banded ironstone formation of the Yilgarn Craton: Mt Gibson. *Conservation Science Western Australia* **7**: 105–120.

Memon AR, Yatazawa M (1984) Nature of Manganese complexes in Manganese accumulator plant *Acanthopanax sciadophylloides*. *Journal of Plant Nutrition* **7**: 961–974.

Meyer SE (1986) The ecology of gypsophile endemism in the eastern Mojave Desert. *Ecology* **67**: 1303–1313.

Midgley GF, Hannah L, Millar D, Thuiller W, Booth A (2003) Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation* **112**: 87–97.

Millar MA, Coates DJ, Byrne M (2013) Genetic connectivity and diversity in inselberg populations of *Acacia woodmaniorum*, a rare endemic of the Yilgarn Craton banded iron formations. *Heredity* **111:** 437–444.

Min Y, Meizhen T, Aoyama I (2007) Accumulation and uptake of Manganese in a hyperaccumulator *Phytolacca americana*. *Minerals Engineering* **20**: 188–190.

Miola DT, Freitas CR, Barbosa M, Fernandes GW (2011) Modeling the spatial distribution of the endemic and threatened palm shrub *Syagrus glaucescens* (Arecaceae). *Neotropical Biology and Conservation* **6**: 78–84.

Moeslund JE, Arge L, Bøcher PK, Dalgaard T, Ejrnæs R, Odgaard MV, Svenning JC (2013) Topographically controlled soil moisture drives plant diversity patterns within grasslands. *Biodiversity and conservation* **22**: 2151–2166.

Morrey DR, Balkwill K, Balkwill MJ (1989) Studies on serpentine flora: preliminary analyses of soils and vegetation associated with serpentine rock formations in the southeastern Transvaal. *South African Journal of Botany* **55**: 171–177.

Mota JF, Medina-Cazorla JM, Navarro FB, Pérez-García FJ, Pérez-Latorre A, Sánchez-Gómez P, Merlo ME (2008) Dolomite flora of the Baetic ranges glades (south Spain). *Flora-Morphology, Distribution, Functional Ecology of Plants* **203**: 359–375.

Mouton P (2008). Proposed Ankerlig-Omega Transmission Power Line: Terrestrial Fauna Environmental Impact Assessment Report.

Mucina L, Rutherford MC (2006) The vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute, Pretoria.

Mustart PJ, Cowling RM (1993) The role of regeneration stages in the distribution of edaphically restricted fynbos Proteaceae. *Ecology* **74**: 1490–1499.

Myers N (1988) Threatened biotas: "hot spots" in tropical forests. Environmentalist **8**: 187–208.

Myers N (1990) The biodiversity challenge: expanded hot-spots analysis. *Environmentalist* **10**: 243–256.

Nelson BW, Ferreira CA, da Silva MF, Kawasaki ML (1990) Endemism centres, refugia and botanical collection density in Brazilian Amazonia. *Nature* **345**: 714–716.

Nevill PG, Anthony JM, Krauss SL (2010) Isolation and characterization of microsatellite markers for the banded ironstone endemic *Acacia karina* (Leguminosae: Mimosaceae) and cross-species amplification with *A. stanleyi* and *A. jibberdingensis*. *Conservation Genetics Resources* **2**: 321–323.

Nisbet EG, Cann JR, Van Dover CL (1995) Origin of photosynthesis. *Nature* **373**: 479.

Nogué S, Rull V, Vegas-Vilarrúbia T (2013) Elevational gradients in the neotropical table mountains: patterns of endemism and implications for conservation. *Diversity and Distributions* **19**: 676–687.

Norton DA, Molloy BPJ (2009) *Heliohebe maccaskillii* (Plantaginaceae) – a new rank for a threatened limestone endemic, North Canterbury, New Zealand. *New Zealand Journal of Botany* **47**: 405–409.

O'Connor TG, Crow VRT (1999 Rate and pattern of bush encroachment in Eastern Cape savanna and grassland. *African Journal of Range and Forage Science* **16**: 26–31.

Ortiz S, Netnou NC (2005) A new species of *Dicoma* (Asteraceae, Mutisieae) from South Africa. *Botanical Journal of the Linnean Society* **147**: 509–513.

Partridge TC, Dollar ESJ, Moolman J, Dollar LH (2010) The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists. *Transactions of the Royal Society of South Africa* **65**: 1–47.

Pauli H, Gottfried M, Dirnböck T, Dullinger S, Grabherr G (2003) Assessing the long-term dynamics of endemic plants at summit habitats. Springer, Berlin.

Pavlik BM (1989) Phytogeography of sand dunes in the Great Basin and Mojave Deserts. *Journal of Biogeography* **16**: 227–238.

Pavlik BM, Barbour MG (1988) Demographic monitoring of endemic sand dune plants, Eureka Valley, California. *Biological Conservation* **46**: 217–242.

Penn N (2005) The forgotten frontier: colonist and Khoisan on the Cape's northern frontier in the 18th century. Juta and Company Ltd., Cape Town.

Pfab MF, Victor JE, van Wyk BE (2002) Threatened plants of Gauteng, South Africa. *South African Journal of Botany* **68**: 370–375.

Pienaar A (2009) The Griqua‘s apprentice: ancient healing arts of the Karoo. Random House Struik, Cape Town.

Poot P, Lambers H (2003) Are trade-offs in allocation pattern and root morphology related to species abundance? A congeneric comparison between rare and common species in the south-western Australian flora. *Journal of Ecology* **91**: 58–67.

Pressey RL, Hager TC, Rya KM, Schwarz J, Wall S, Ferrier S, Creaser PM (2000) Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. *Biological Conservation* **96**: 55–82.

PRIMER 6 version 1.1.15 (2012) PRIMER-E Ltd., United Kingdom.

Purdy BG, Bayer RJ, Macdonald SE (1994) Genetic variation, breeding system evolution, and conservation of the narrow sand dune endemic *Stellaria arenicola* and the widespread *S. longipes* (Caryophyllaceae). *American Journal of Botany* **81**: 904–911.

Pyšek P, Jarošík V, Kropáč Z, Chytrý M, Wild J, Tichý L (2005) Effects of abiotic factors on species richness and cover in Central European weed communities. *Agriculture, ecosystems & environment* **109**: 1–8.

Qin XS, Zhang RJ, Xing FW (2012) A study on the flora and vegetation of Cat Dua Island, northeastern Vietnam. *Pakistan Journal of Botany* **44**: 1229–1232.

Raimondo D, Cholo F (2008) *Phyllobolus amabilis* Gerbaulet & Struck. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29

Rapini A, De Mello-Silva R, Kawasaki ML (2002) Richness and endemism in Asclepiadoideae (Apocynaceae) from the Espinhaço Range of Minas Gerais, Brazil–a conservationist view. *Biodiversity & Conservation* **11**: 1733-1746.

Raven JA, Allen JF (2003) Genomics and chloroplast evolution: what did cyanobacteria do for plants*? Genome Biology* **4**: 209.

Raven JA, Edwards D (2001) Roots: evolutionary origins and biogeochemical significance. *Journal of Experimental Botany* **52**: 381–401.

Reinhardt S, Odland A, Pedersen A (2013) Calciphile alpine vegetation in Southern Norway: importance of snow and possible effects of climate change. *Phytocoenologia* **43**: 207–223.

Rhind PM (2010) Plant Formations in the Western Cape BioProvince. Not published.

Rosen BR (1988a) Biogeographic patterns: a perceptual overview. In Myers AA, Giller PS. Analytical biogeography pp. 23-55, Chapman & Hall, London.

Rosen BR (1988b) From fossils to earth history: applied historical biogeography. In Myers AA, Giller PS. Analytical biogeography: an integrated approach to the study of animal and plant distributions, pp. 437–481, Chapman & Hall, New York.

Rull V (2005) Biotic diversification in the Guayana Highlands: a proposal. *Journal of Biogeography* **32**: 921–927.

Rutherford MC, Westfall RH (1986) Biomes of southern Africa: an objective categorization. *Memoirs of the Botanical Survey of South Africa* **54**: 1–98.

RSA (Republic of South Africa) (1998) National Environmental Management Act (Act No. 107 of 1998). *Government Gazette, South Africa 401*(19519).

SABONET (2005) Newsletter of the Southern African Botanical Diversity Network. Volume 9 No. 2.

Saiz M, Carlos J, Donato M, Katinas L, Crisci JV, Posadas P (2013) New insights into the biogeography of south-western Europe: spatial patterns from vascular plants using cluster analysis and parsimony. *Journal of Biogeography* **40**: 90–104.

Salmerón-Sánchez E, Martínez-Nieto MI, Martínez-Hernández F, Garrido-Becerra JA, Mendoza-Fernández AJ, de Carrasco CG, Mota JF (2014) Ecology, genetic diversity and phylogeography of the Iberian endemic plant *Jurinea pinnata* (Lag.) DC.(Compositae) on two special edaphic substrates: dolomite and gypsum. *Plant and Soil* **374**: 233–250.

Sátiro LN, Roque N (2008) The family Euphorbiaceae on the sand dunes of the middle São Francisco River, Bahia State, Brazil. *Acta Botanica Brasilica* **22**: 99–118.

Schatz GE, Lowry PP, Wolf AE (1999) Endemic families of Madagascar. A synoptic revision of Sphaerosepalaceae. *Adansonia* **21**: 107–123.

Scott JM, Davis F, Csuti B, Noss R, Butterfield B, Groves C, Anderson H, Caicco S, D'Erchia F, Edwards TC, Ulliman J, Wright RG (1993) Gap Analysis: a geographic approach to protection of biological diversity. *Wildlife Monographs* **123**: Biological Diversity 3–41.

Shepherd KA (2007) *Pityrodia iphthima* (Lamiaceae), a new species endemic to banded ironstone in Western Australia, with notes on two informally recognised *Pityrodia*. *Nuytsia* **17**: 347–352.

Siebert SJ (1998) Ultramafic substrates and floristic patterns in Sekhukhuneland, South Africa. MSc. thesis, University of Pretoria, Pretoria.

Siebert SJ, van Wyk AE, Bredenkamp GJ (2001) Endemism in the flora of ultramafic areas of Sekhukhuneland, South Africa. *South African Journal of Science* **97**: 529–532.

Smit GN (1998) Management of rangeland in southern Africa with special reference to bush enchroachment. Unpublished paper presented at the Master Farmer day on the farm Waldorf, Otawi, Namibia, 15th April 1998.

Soorae PS (2010) Global re-introduction perspectives: Additional case studies from around the globe. IUCN/SSC Re-introduction Specialist Group & Environment Agency, Abu Dhabi.

Sørensen T (1948) A method of establishing groups of equal amplitude in plant sociology based on similarity of species and its application to analyses of the vegetation on Danish commons. *Kongelige Danske Videnskabernes Selskab* **5**: 1–34.

Spanou S, Verroios G, Dimitrellos G, Tiniakou A, Georgiadis T (2006) Notes on flora and vegetation of the sand dunes of western Greece. *Willdenowia-Annals of the Botanic Garden and Botanical Museum Berlin-Dahlem* **36**: 235–246.

STATISTICA version 11 (2012) Computer software. StatSoft Inc., United States

Stohlgren TJ, Coughenour MB, Chong GW, Binkley D, Kalkhan MA, Schell LD, Buckley DJ, Berry JK (1997) Landscape analysis of plant diversity. *Landscape Ecology* **12**: 155–170.

Stone RD, Ntetha NA (2013) *Warneckea parvifolia* (Melastomataceae–Olisbeoideae), a new -sand-forest” endemic from northeastern KwaZulu-Natal (South Africa) and southernmost Mozambique, and a phylogenetic analysis of eastern and southern African representatives of *Warneckea*. *South African Journal of Botany* **88**: 317–325.

Swart PA (2006) Horticultural propagation of the threatened species, *Syncarpha recurvata* (L.f.) B.Nord. Unpublished MSc. thesis, Nelson Mandela Metropolitan University.

Takeuchi W (2013) *Begonia sandsiana* sp. nov. (Begoniaceae), a remarkable calciphile from the southern karst of Papua New Guinea. *Phytotaxa* **138**: 31–38.

Terblanche RF, Taylor JC (2000) Notes on the butterflies of Witsand: a unique terrestrial island in the Northern Cape Province, South Africa—with special reference to two red data book butterfly species. *Metamorphosis* **11**: 122–131.

Thuiller W (2004) Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology* **10**: 2020–2027.

Tilman D (1999) Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proceedings of the National Academy of Sciences* **96**: 5995–6000.

Tribsch A (2004) Areas of endemism of vascular plants in the Eastern Alps in relation to Pleistocene glaciation. *Journal of Biogeography* **31**: 747–760.

Trollope WSW (1974) Role of fire in preventing bush encroachment in the Eastern Cape. *Proceedings of the Annual Congresses of the Grassland Society of Southern Africa* **9**: 67–72.

Tuyet D (2001) Characteristics of karst ecosystems of Vietnam and their vulnerability to human impact. *Acta Geologica Sinica (English Edition)* **75**: 325–329.

van der Maarel E, van der Maarel-Versluys M (1996) Distribution and conservation status of littoral vascular plant species along the European coasts. *Journal of Coastal Conservation* **2**: 73–92.

van Wyk A.E (1996) Biodiversity of the Maputuland Centre. In van der Maesen LJG, van der Burgt XM, van Medebach de Rooy JM. The biodiversity of African plants, pp. 198–207, Kluwer Academic Publishers, Dordrecht.

van Wyk AE, Smith GF (2001) Regions of floristic endemism in southern Africa: A review with emphasis on succulents. Umdaus Press, Hatfield.

Vetaas OR, Grytnes JA (2002) Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography* **11**: 291–301.

Vollesen K (2000) *Blepharis* (Acanthaceae), a taxonomic revision. Royal Botanic Gardens, Kew, London.

von Staden L, Herman PPJ (2006) *Rennera stellata* P.P.J.Herman. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

von Staden L (2011) *Amphiglossa tecta* (Brusse) Koekemoer. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/28.

Vane-Wright RI, Humphries CJ, Williams PH (1991) What to protect? Systematics and the agony of choice. *Biological Conservation* **55**: 235–254.

Victor JE (2005) *Lithops bromfieldii* L.Bolus. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Victor JE (2005) *Lithops lesliei* (N.E.Br.) N.E.Br. subsp. *burchellii* D.T.Cole. National Assessment: Red List of South African Plants version 2015.1. Accessed on 2015/11/09.

Victor JE (2005) *Nuxia gracilis* Engl. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/06/01.

Victor JE Fish L (2005) *Brachiaria dura* Stapf var. *pilosa* J.G.Anderson. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/29.

Victor JE, Hammer SA (2005) *Lithops aucampiae* L.Bolus subsp. *euniceae* (de Boer) D.T.Cole. National Assessment: Red List of South African Plants version 2014.1. Accessed on 2015/05/30.

Vidic RD, Brantley SL, Vandenbossche JM, Yoxtheimer D, Abad JD (2013) Impact of shale gas development on regional water quality. *Science* **340**(6234).

Walck JL, Baskin JM, Baskin CC (1999) Relative competitive abilities and growth characteristics of a narrowly endemic and a geographically widespread *Solidago* species (Asteraceae). *American Journal of Botany* **86**: 820–828.

Walter H (1964) Productivity of vegetation in arid countries: the savannah problem and bush encroachment after overgrazing. *The Ecology of Man in the Tropical Environment* **4**: 221–229.

Wang X, Fang J, Sanders NJ, White PS, Tang Z (2009) Relative importance of climate vs local factors in shaping the regional patterns of forest plant richness across northeast China. *Ecography* **32**: 133–142.

Ward JH (1963) Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association* **58**: 236–244.

Ward D (2005) Do we understand the causes of bush encroachment in African savannas? *African Journal of Range and Forage Science* **22**: 101–105.

Ware S, Pinion G (1990) Substrate adaptation in rock outcrop plants: eastern United States *Talinum* (Portulacaceae). *Bulletin of the Torrey Botanical Club* **117**: 284–290.

Webb DA (1965) Some difficulties in the establishment of phytogeographical divisions. *Revue Roumaine de Biologie, Série de Botanique* **10**: 33–41.

Webb EL, Stanfield BJ, Jensen ML (1999) Effects of topography on rainforest tree community structure and diversity in American Samoa, and implications for frugivore and nectarivore populations. *Journal of Biogeography* **26**: 887–897.

Weiß C (2007) StatSoft, Inc., Tulsa, OK.: STATISTICA, Version 8. *AStA Advances in Statistical Analysis* **91**: 339–341.

White F (1979) The Guineo-Congolian Region and its relationships to other phytochoria. *Bulletin du Jardin botanique national de Belgique / Bulletin van de Nationale Plantentuin van België* **49**: 11–55.

White F (1983) The vegetation of Africa: a descriptive memoir to accompany the Unesco/AETFAT/UNSO vegetation map of Africa. Natural Resources Research XX. Unesco, Paris.

White F (1993) The AETFAT chorological classification of Africa: history, methods and applications. *Bulletin du Jardin Botanique National de Belgique* **62**: 225–281.

Widmer A, Baltisberger M (1999) Molecular evidence for allopolyploid speciation and a single origin of the narrow endemic *Draba ladina* (Brassicaceae). *American Journal of Botany* **86**: 1282–1289.

Wiegand T, Milton SJ Wissel C (1995) A simulation model for a shrub ecosystem in the semiarid Karoo, South Africa. *Ecology* **76:** 2005–2221.

Wiens D (1978) Mimicry in plants. *In* MacIntyre RJ, Clegg MT (1978) Evolutionary Biology. Springer, USA.

Wigley BJ, Bond, WJ, Hoffman MT (2009) Bush encroachment under three contrasting land-use practices in a mesic South African savanna. *African Journal of Ecology* **47**: 62–70.

Wild H (1968) Phytogeography of South Central Africa. *Kirkia* **6**: 197–222.

Wild H, Brenan JPM, Meikle RD, Peterson B, Cannon JFM (1963). The endemic species of the Chimanimani Mountains and their significance. *Kirkia* **4:** 125–157.

Willis JC (1922) Age and area. Cambridge University Press, Cambridge.

Willis CK, Lombard AT, Cowling RM, Heydenrych BJ, Burgers CJ (1996) Reserve systems for limestone endemic flora of the Cape lowland fynbos: iterative versus linear programming. *Biological Conservation* **77**: 53–62.

Wilman M (1946) Preliminary check list of flowering plants and ferns of Griqualand West (Southern Africa). Deighton Bell, Cambridge.

WWF & IUCN (1994-1997) Centres of plant diversity. A guide and strategy for their conservation. 3 Volumes. IUCN Publications Unit, Cambridge.

Xue SG, Chen YX, Reeves RD, Baker AJ, Lin Q, Fernando DR (2004) Manganese uptake and accumulation by the hyperaccumulator plant *Phytolacca acinosa* Roxb. (Phytolaccaceae). *Environmental Pollution* **131**: 393–399.

Yaalon DH (1988) Calcific horizon and calcrete in aridic soils and paleosols: progress in last twenty years. *Soil Science Society of America Agronomy Abstracts*. Cited in Wright and Tucker (1991).

Yang SX, Deng H, L, MS (2008) Manganese uptake and accumulation in a woody hyperaccumulator, *Schima superba*. *Plant, Soil and Environment* **54**: 441–446.

Yates CJ, Gibson N, Pettit NE, Dillon R, Palmer R (2011) The ecological relationships and demography of restricted ironstone endemic plant species: implications for conservation. *Australian Journal of Botany* **59**: 692–700.

Yutan YX (1999) Primary study of limestone endemic plants in Hunan Province. *Journal of Central South Forestry University* **2**: 34.

Zhang LB, Comes HP, Kadereit JW (2001) Phylogeny and quaternary history of the European montane/alpine endemic *Soldanella* (Primulaceae) based on ITS and AFLP variation. *American Journal of Botany* **88**: 2331–2345.

Zhu H, Wang H, Li BG, Sirirugsa P (2003) Biogeography and floristic affinities of the limestone flora in Southern Yunnan, China. *Annals of the Missouri Botanical Garden* **90**: 444–465.

Zobel M, Otto R, Laanisto L, Naranjo-Cigala A, Pärtel M, Fernández-Palacios JM (2011) The formation of species pools: historical habitat abundance affects current local diversity. *Global Ecology and Biogeography* **20**: 251–259.

Zollner D, MacRoberts MH, MacRoberts BR, Ladd D (2005) Endemic vascular plants of the Interior Highlands, USA. *SIDA, Contributions to Botany* **21**: 1781–1791.

ONLINE REFERENCES

- Fuzzy Gazetteer (2000): isodp.hof-university.de.
- Map of proposed hydrauclic fracturing sites in South Africa: www.petroleumagencysa.com.
- Photo of a quartzitic *tepui*: www.philippekok.com.
- Photo of *Afrolimon capense*: www.redlist.sanbi.org (N.A. Helme).
- Photo of *Crinum acuale*: www.plantzafrica.com.
- Photo of *Delosperma purpureum*: www.ispotnature.org (Georg Fritz).
- Photo of *Echinacea tennesseensis*: www.missouribotanicalgarden.com.
- Photo of *Eriocephalus ericoides* subsp. *griquensis*: www.ispotnature.org.za.
- Photo of *Euphorbia barnardii*: www.commons.wikimedia.org.
- Photo of Ha Long Bay, Vietnam: www.travelalltogether.com.
- Photo of *Hieracium eriophorum*: www.fr.ch.
- Photo of *Lambertia orbifolia*: www.flikr.com (Russel Cumming).
- Photo of limestone pinnacles in Hunan Province, China: www.en.wikipedia.org.
- Photo of *Linum dolomiticum*: www.dinpi.hu.
- Photo of: *Petrocoptis grandiflora*: www.arkive.org (Pablo A. Sanmartin Santiago).
- Photo of Sishen Iron ore mine: www.angloamerican.com.
- Photo of the Eureka Sand Dunes in California, USA: www.summitpost.org.
- Python Software Foundation: www.python.org.

APPENDIX

Table 3: Number of original taxa present in each of the GWSA QDG's, taxa added per grid and transformed centroid grid profile data.

	Number of taxa		
QDG	Original data	Added	Adjusted data
2523CA	1	45	46
2523CB	27	14	41
2523CC	6	30	36
2523CD	14	26	40
2523DA	7	34	41
2523DC	25	20	45
2523DD	7	30	37
2524CC	12	13	25
2622BB	2	29	31
2622BC	11	48	59
2622BD	17	11	28
2622CB	22	39	61
2622CC	59	61	120
2622CD	59	55	114
2622DA	34	33	67
2622DB	16	43	59
2622DC	5	62	67
2622DD	5	41	46
2623AA	2	52	54
2623AB	2	15	17
2623AC	23	20	43
2623AD	8	56	64
2623BA	1	9	10
2623BB	17	1	18
2623BC	0	59	59
2623BD	0	53	53
2623CA	8	20	28
2623CB	0	59	59
2623CC	6	217	223
2623CD	7	216	223
2623DA	51	15	66
2623DB	222	91	313
2623DC	7	55	62
2623DD	25	240	265
2624AA	11	35	46
2624BB	116	19	135
2624BC	1	110	111
2624BD	83	50	133
2624CA	21	293	314
2624CB	25	69	94
2624CC	51	59	110
2624CD	67	320	387
2624DA	33	130	163
2624DB	82	72	154
2624DC	338	64	402
2624DD	45	365	410
2625AA	0	204	204
2625AC	66	0	66
2625CA	12	174	186
2625CC	52	261	313
2721BB	32	15	47
2721BC	17	0	17
2721BD	7	29	36
2721DA	0	17	17
2721DB	1	7	8
2721DC	0	0	0
2721DD	6	13	19
2722AA	0	48	48
2722AB	42	12	54
2722AC	22	6	28
2722AD	5	74	79
2722BA	12	88	100
2722BB	65	16	81
2722BC	67	13	80
2722BD	5	79	84
2722CA	2	47	49
2722CB	6	134	140
2722CC	26	72	98
2722CD	0	120	120
2722DA	3	159	162

	Number of taxa		
QDG	Original data	Added	Adjusted data
2624AB	3	33	36
2624AC	102	209	311
2624AD	24	29	53
2624BA	32	118	150
2723AB	122	354	476
2723AC	110	195	305
2723AD	346	144	490
2723BA	57	162	219
2723BB	62	245	307
2723BC	80	81	161
2723BD	27	129	156
2723CA	79	164	243
2723CB	121	122	243
2723CC	24	189	213
2723CD	51	217	268
2723DA	57	207	264
2723DB	32	94	126
2723DC	175	137	312
2723DD	178	93	271
2724AA	230	79	309
2724AB	201	50	251
2724AC	54	56	110
2724AD	16	60	76
2724BA	30	265	295
2724BB	119	36	155
2724BC	27	31	58
2724BD	12	151	163
2724CA	33	135	168
2724CB	5	129	134
2724CC	41	231	272
2724CD	82	119	201
2724DA	90	105	195
2724DB	24	208	232
2724DC	30	364	394
2724DD	103	297	400
2725AA	6	125	131
2725AC	72	82	154
2725CA	103	62	165
2725CC	267	53	320
2821AB	9	9	18
2821AD	24	19	43
2821BA	9	19	28

	Number of taxa		
QDG	Original data	Added	Adjusted data
2722DB	6	157	163
2722DC	113	162	275
2722DD	153	123	276
2723AA	141	335	476
2821CD	8	37	45
2821DA	5	210	215
2821DB	13	160	173
2821DC	75	71	146
2821DD	63	100	163
2822AA	36	133	169
2822AB	61	70	131
2822AC	27	54	81
2822AD	11	171	182
2822BA	84	95	179
2822BB	28	334	362
2822BC	71	194	265
2822BD	123	187	310
2822CA	22	174	196
2822CB	86	151	237
2822CC	43	72	115
2822CD	93	122	215
2822DA	115	165	280
2822DB	30	267	297
2822DC	19	278	297
2822DD	160	131	291
2823AA	41	270	311
2823AB	126	76	202
2823AC	197	193	390
2823AD	146	199	345
2823BA	134	65	199
2823BB	43	136	179
2823BC	51	107	158
2823BD	8	199	207
2823CA	8	362	370
2823CB	27	269	296
2823CC	164	135	299
2823CD	46	120	166
2823DA	86	74	160
2823DB	41	196	237
2823DC	133	106	239
2823DD	24	277	301
2824AA	132	47	179

	Number of taxa		
QDG	Original data	Added	Adjusted data
2821BB	4	15	19
2821BC	100	36	136
2821BD	25	111	136
2821CB	32	26	58
2824BB	176	315	491
2824BC	109	382	491
2824BD	57	417	474
2824CA	170	218	388
2824CB	128	601	729
2824CC	24	281	305
2824CD	50	264	314
2824DA	309	420	729
2824DB	538	180	718
2824DC	185	544	729
2824DD	168	529	697
2825AA	81	168	249
2825AC	45	128	173
2825CA	137	484	621
2825CC	31	260	291
2921AB	0	17	17
2921BA	29	8	37
2921BB	59	63	122
2921BC	4	5	9
2921BD	22	113	135
2921DB	0	6	6
2922AA	28	93	121
2922AB	25	154	179
2922AC	68	74	142
2922AD	50	375	425
2922BA	27	113	140
2922BB	33	266	299
2922BC	60	109	169
2922BD	84	111	195
2922CA	80	62	142
2922CB	9	133	142
2922CC	0	51	51
2922CD	51	36	87
2922DA	371	52	423
2922DB	104	355	459
2922DC	24	364	388
2922DD	14	374	388
2923AA	13	286	299

	Number of taxa		
QDG	Original data	Added	Adjusted data
2824AB	64	141	205
2824AC	88	144	232
2824AD	239	297	536
2824BA	275	292	567
2923BB	124	40	164
2923BC	12	11	23
2923BD	14	201	215
2923CA	8	19	27
2923CB	2	28	30
2923CC	6	16	22
2923CD	6	56	62
2923DA	3	87	90
2923DB	6	92	98
2923DC	53	37	90
2923DD	44	60	104
2924AA	20	249	269
2924AB	129	69	198
2924AC	37	193	230
2924AD	51	91	142
2924BA	104	65	169
2924BB	25	144	169
2924BC	18	151	169
2924BD	42	127	169
2924CA	107	108	215
2924CB	94	132	226
2924CC	28	43	71
2924DA	50	193	243
2924DB	176	73	249
2925AA	44	142	186
Mean	60.5	129.6	190.1