The relevance of the Greater Cederberg Biodiversity Corridor (GCBC)

for reptile conservation

by

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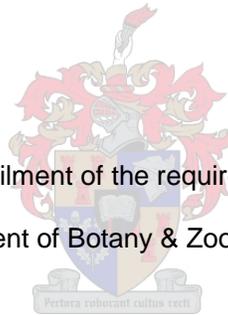
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March 2008

Declaration:

I, the undersigned, hereby declare that the work contained in this thesis is my own original

work and that I have not previously in its entirety or in part submitted it at any university for

a degree.

Signature: _____   **Date:** _____

Abstract

The Greater Cederberg Biodiversity Corridor (GCBC) is a large-scale conservation corridor situated in the south-western region of South Africa. Delineation of the GCBC was largely based on by vegetation data. The relevance of the GCBC for the conservation of the reptilian fauna in the area south of 31°S and west of 21°E is assessed in the present study. This entailed determining the GCBC's coverage of regional reptile diversity patterns and assessing its potential conservation significance during possible climate induced changes in reptile distributions.

Reptile species point distribution data from the preliminary (2007) SARCA (South African Reptile Conservation Assessment) database was used. Under-representation of the Tankwa Karoo in the dataset required a field survey of this region. Additionally, the biogeographical influence of the arid Tankwa Karoo Basin on the distribution of reptiles in the south-western districts of South Africa was investigated. Turnover across the Basin is high, species richness is lower than in surrounding mountainous areas and there are no species endemic to the area. The Tankwa Karoo Basin acts as a dispersal barrier for many reptile species occurring in the surrounding more mesic areas. At the same time, the ranges of a number of typical northern, arid adapted species extend southward along the Tankwa Plains. A number of species range extensions in the region are reported.

Patterns of endemism, species richness and turnover were plotted from the point distribution data at quarter and eighth degree square resolution. Extensive sampling bias towards reserves and populated areas is apparent from the reptile species richness plots. This pattern is more pronounced for snakes than lizards. Reptile richness is particularly high along the north-south section of the Cape Fold Mountains and also relatively high along the south-western coast, peaking in the Lambert's Bay area. The majority of the 20 reptile species endemic to the study area are associated with one of two identified centres

of endemism: the Greater Cederberg area, or the narrow coastal zone stretching from the Lambert's Bay area to the Cape Peninsula. An additional third set of endemics comprised of melanistic forms restricted to a number of different refugia, notably, Landroskop, the Cape Peninsula, Sladanha-Langebaan region, Piketberg Mountains and a confined area along the western section of the Cape Fold Mountains. Species richness and endemism patterns co-vary within the study area.

Biotic regions were identified through hierarchical clustering of grid cells according to shared species occurrences. A Northern, Southern, Central and Western biotic region was identified. Classification tree methodology (CART) and Canonical Correspondence Analysis (CCA) were used to characterise defined biotic regions in terms of selected environmental variables. Four sets of species assemblages are described on the basis of these biotic regions – two major and two minor ones. Of the major assemblages the Northern assemblage can be described as an arid zone one and the Southern assemblage as a mesic zone one. The minor Central assemblage, comprising mainly rock-dwelling forms, represent evolutionary leftovers as a result of climate change induces cycles of contraction and expansion of arid and mesic faunas. The other minor one, the West Coast assemblage could be considered a sub-assemblage of the Northern one, with particular adaptation to the coastal climate. Environmental characterisation of the biotic regions reveals that these groupings are supported by an environmental signal. The contiguity of four distinct sets of reptiles, each with its own set of environmental requirements, in this relatively small geographic area clearly indicates that the south-western region of South Africa is biogeographically complex.

The GCBC incorporates the largely coinciding centres of endemism and richness along the West Coast and the greater Cederberg area. Although the centre of endemism for melanistic reptile forms, in the Saldanha-Langebaan area, falls just south of the GCBC boundary, the Corridor fulfils the requirements for effective conservation of reptiles in the

area to a large degree. The north-south dispersal pathways provided by the Corridor along the Cape Fold Mountains is believed to be adequate to buffer climate change effects, however there is concern about its ability to contribute to the persistence of the assemblage associated with the narrow coastal zone in the west.

Uittreksel

Die Groter Cederberg Biodiversiteit Korridor (GCBK) is 'n grootskaalse bewaringskorridor wat in die suid-westelike deel van Suid-Afrika geleë is. Die grense van GCBK is gebasseer op plantegroei data. In die huidige studie word die betekenis van die GCBK vir die bewaring van die reptiel fauna in die gebied suid van 31°S en wes van 21°O assesseer. Die mate waartoe die GCBK die patrone van reptieldiversiteit in die streek inkorporeer, asook die korridor se potensiaal om voorsiening te maak vir reptiel verspreidingsgebiede wat moontlik as gevolg van potensiële omgewingsverandering kan verskuif.

Die beskikbare puntverspreidingsdata van die voorlopige (2007) SARCA (South African Reptile Conservation Assessment) databasis is gebruik. Swak verteenwoordiging van die Tankwa Karoo in die datastel het 'n veldopname van die gebied genoodsaak. Verder is die biogeografiese invloed van die ariede Tankwa Karoo Kom op die verspreidingspatrone van reptiele in die suid-westelike deel van Suid-Afrika ook ondersoek. Die spesie omset van beide Noord na Suid en Wes na Oos oor die Tankwa is hoog, die spesierykheid is aansienlik laer as in die omringende bergagtige gebiede en daar is geen spesies wat endemies is tot die Tankwa Karoo nie. Die Tankwa Karoo Kom dien as 'n barieêre teen spreiding vir sommige reptielspesies wat in die omringende gematigde gebiede voorkom. Terselfdertyd reik die verspreidings van 'n aantal tipiese droogte aangepasde spesies vanuit die noorde suidwaarts langs die Tankwa Vlaktes. Nuwe verspredingsrekords wat 'n paar spesies se gebiede uitbrei word ook raporteer.

Die puntverspreidingsdata is geruik om die patrone van endemisme, spesierykheid en omset op kwart- en agtstegraad resolusie te plot. Spesierykheid kaarte toon 'n duidelike neiging tot deegliker opnames in reservate en bewoonde gebiede. Hierdie patroon is

meer opmerklik vir slange as akkedisse. Reptielrykheid is besonders hoog langs die noord-suid as van die Kaapse Plooiberge en ook relatief hoog langs die suid-wes kus met 'n maksimum in die Lambertsbaai omgewing. Die meerderheid van die 20 reptielspesies wat endemies is aan die studie area is met een van twee geïdentifiseerde sentrums van endemisme geassosieer: die Groter Cederberg area óf die nou kussone wat vanaf Lambertsbaai tot Kaappunt strek. 'n Derde stel endemiese spesies wat uit melanistiese vorme bestaan, is beperk tot 'n aantal refugia, naamlik, Landroskop, Kaappunt, Saldanha-Langebaan omgewing, Piketberg berge en 'n beperkte area langs die westelike dele van die Kaapse Plooiberge. Spesierykheid en endemisme patrone stem grootliks ooreen binne die studie area.

Roosterselle is op grond van gedeelde spesiesamestellings met behulp van 'n hieragiese groeperingsmetode (Incremental Sum of Squares) gegroepeer. Vier bio-areas, nl. 'n Noordelike-, Suidelike-, Sentrale en Westelike bio-area is identifiseer. Klassifikasieboom metodologie (Classification and Regression Trees, CART) asook Kanoniese Annalises (Cannonical Correspondence Annalysis, CCA) is gebruik om hierdie geografiese areas in terme van 'n aantal omgewingsveranderlikes te karakteriseer. Vier spesieversamelings, twee groter en twee kleiner versamelings, is in ooreenstemming met hierdie vier areas geïdentifiseer. Die Noordelike en Suidelike spesieversamelings is die groteres en kan beskryf word as die faunas van onderskeidelik 'n ariede en gematigde sone. Die kleiner Sentrale versameling bestaan hoofsaaklik uit rots-lewende spesies en mag die evolusionêre oorblyfsels verteenwoordig van ariede en gematigde faunas waarvan die verspreidings herhaaldelik as gevolg van klimaatsveranderingsiklusse uitgebrei en gekrimp het. Die Weskus versameling is ook 'n kleiner een en kan as 'n sub-versameling van die Noordelike een beskou word, maar spesifiek tot die kus klimaat aangepas. Die klassifikasie van hierdie bio-areas word ondersteun deur die analiese van die omgewingsveranderlikes. Die feit dat vier kenmerkende versamelings reptiele, elk met sy

besondere omgewingsvereistes, in hierdie relatief klein geografiese area ontmoet, dui daarop dat die suid-westelike deel van Suid-Afrika biogeografies kompleks is.

Die GCBK inkorporeer die grootliks ooreenstemmende sentrums van endemisme en rykheid wat langs die Weskus en in die groter Cederberg area voorkom. Alhoewel die sentrum van melanistiese endemiese spesies, in die Saldanha-Langebaan omgewing, net buite die grense van die Korridor val, voldoen die GCBK grootliks aan die vereistes vir die effektiewe bewaring van reptiele in die gebied. Die voorsiening van noord-suid verspreidingsweë langs die Kaapse Plooiberge binne die Korridor word beskou as voldoende om die gevolge van klimaatsverandering te buffer. Daarinteen is daar kommer oor die vermoeë van die GCKB om 'n doeltreffende bydrae te maak tot die voortbestaan van die spesieversameling wat met die nou kussone langs die Weskus geassosieer is.

Acknowledgements

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Chapter 1

General background and introduction

1.1.   PROBLEM STATEMENT

The southern African sub-region boasts a total of more than 500 described reptile species, a figure that is constantly increasing with the current rate at which new scientific descriptions are produced (Marais & Alexander 2007). In addition, the sub-continent also has a high level of reptile endemism (Harrison 2005). Within the subcontinent, South Africa has the richest diversity of reptiles and is globally ranked as having the third richest lizard fauna after Australia and Mexico (Branch 2005).

The Western Cape Province of South Africa contains approximately 40% of the total number of reptile species in the country (Baard & de Villiers 2000). The Western Cape reptile fauna comprise of 92 lizard, 41 snake, 11 terrestrial tortoise and one freshwater terrapin species (Baard & de Villiers 2000). There is also a high level of endemism in the Western Cape with 17 lizard species, two snake species and two terrestrial tortoise species restricted to the province (Baard & de Villiers 2000). Furthermore, the Western Cape Province features the highest terrestrial tortoise (chelonian) diversity in the world with eight species (11 taxa when subspecies are included) out of the 40 species recognised worldwide, found here (Baard & de Villiers 2000).

The Greater Cederberg Biodiversity Corridor (GCBC) is a large-scale conservation corridor recently (2005) demarcated in the south-western region of South Africa. It incorporates

coastal, lowland, as well as mountainous areas, and spans the boundary between the Succulent Karoo and Fynbos biomes. Although various ecological processes and biological patterns were taken into consideration, the delineation of the GCBC boundaries was largely based on data on diversity and importance of vegetation in the region (Low *et al*. 2004; Barodien, 2005). This practice of using floristic diversity and importance as surrogate and signal for faunal diversity is often implemented in conservation planning (Turpie & Crowe 1994; Cowling *et al.* 2003; Lombard *et al.* 2003).

One of the fundamental functional aims of conservation corridors can be summarised as making provision for current and long-term ecosystem dynamics, as well as for the persistence of biological patterns and processes of an area (Hess & Fisher 2001; Rouget *et al.* 2006). The maintenance and restoration of landscape connectivity along its north-south and east-west axes is therefore an integral objective of the GCBC (Anon 2004) since such areas could act as ecological buffer zones in the face of inevitable climate change by allowing biota space in which to track these changes (Hannah *et al*. 2002). However, as is the case with many corridors, the GCBC carries some measure of uncertainty with regards to how effective it may prove to be (Hannah *et al.* 2002), because bioclimatic models of spatial distributions of biota and regional models of future climate change did not play a role during the planning phase of the GCBC. It begs the question whether biota in the Corridor would have the ability to react in accordance with, and at the required pace of the changing climate.

It is the particular aim of the present work to research the relevance of the Greater Cederberg Biodiversity Corridor for the conservation of the reptilian fauna of the region. Because reptiles are ectothermic and a group with relatively low vagility they are expected to be particularly vulnerable to the effects of climate change (Gibbons *et al*. 2000). Not only is the conservation of present distribution and diversity patterns considered, but also the possible

value of the GCBC as buffer zone for reptile range shifts during climate change. This thesis contributes to one of the final research goals set for the SCARCE project (Survey of Cederberg Amphibians and Reptiles for Conservation and Ecotourism), which is to investigate the conservation significance of the GCBC for reptiles. The SCARCE initiative is a four-year project, funded by the Critical Ecosystems Partnership Fund (CEPF) and is aimed at generating information on the herpetofauna of the GCBC in order to augment conservation decision-making and implementation.

1.2.   THE APPROACH TO THE PROBLEM

There are two main components to the approach of establishing the Corridor's relevance for reptile conservation:

1. Determining to what extent the defined planning unit (GCBC) incorporates reptile diversity.
2. Determining the large-scale correlation of reptile distribution patterns with current environmental and climatic variables.

Diversity patterns need to be known before the degree of reptile diversity coverage can be established. Therefore, to achieve the first objective, the regional patterns of three elements of diversity (endemism, species richness and species turnover) were computed, mapped and characterised. The second objective, environmental analysis of species distribution patterns, was performed on a multiple species basis. This entailed firstly to search for and define distinct biotic regions and associated reptile species assemblages. These regions were subsequently characterised in termsof a number of selected environmental variables. Such information may prove to be valuable to asses whether habitat provided by the GCBC would prove to be adequate for reptile assemblages in which to track potential climate change events.

1.3.   THE STUDY AREA

In order to investigate the regional significance of the GCBC for reptile conservation, it was deemed relevant to define and consider a study area which goes beyond the borders of the Corridor. The selected area of interest is the region south of 31° latitude and west of 21° longitude, i.e., the south-western region of South Africa (Figure 1.1). The western part of the Western Cape Province as well as the adjacent southern sections of the Northern Cape Province (Roggeveld and northern Tanqua Karoo), are included in the defined study area
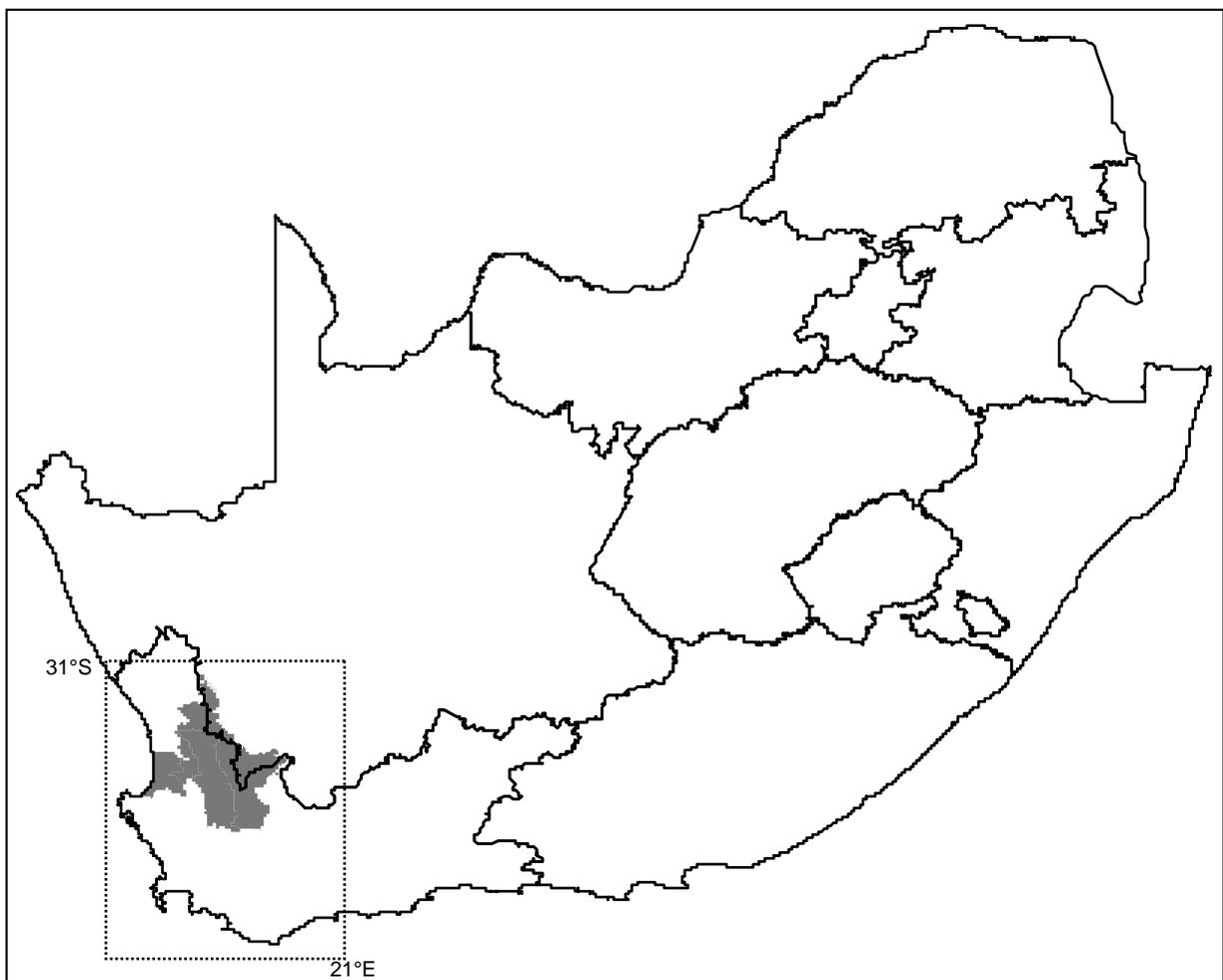
Figure 1.1:   Map of South Africa indicating the study area, south of 31°S and west of 21°E, (indicated by the dotted line) and the extent and location of the Greater Cederberg Biodiversity Corridor (grey shaded area).

Two of the 25 global biodiversity hotspots identified to aid in conservation prioritisation (Mittermeier *et al.* 1998; Myers *et al.* 2000), namely the Cape Floristic Region and the Succulent Karoo, are represented in the study area. These global biodiversity hotspots are defined as areas with extraordinary high levels of endemism which have suffered, and still are under threat of severe habitat loss (Myers *et al.* 2000).

1.4.   THE DATA

1.4.1. Species data

The dataset of species distribution records used in this study was obtained from the preliminary South African Reptile Conservation Assessment (SARCA) database in July 2007. The four year SARCA project (2005-2009), jointly lead by the South African Biodiversity Institute (SANBI) and the University of Cape Town's Avian Demography Unit (ADU), is aimed at compiling and generating distribution data of reptiles in South Africa, Swaziland and Lesotho. These data will ultimately be used to create a distribution atlas and Red Data Book, for the reptiles of the specified region, which will partially replace the currently outdated *South African Red Data List for Reptiles and Amphibians* by Branch (1988). A large portion of the records in this database were contributed by various museums as well as scientific- and academic institutes across the country. A large amount of data was also contributed by the SCARCE project of which the current study formed a part. An inherent feature of the data is therefore that records originate from sightings and specimen collections compiled over a number of years with no standard sampling strategy.

On closer inspection of the dataset which was extracted from the SARCA database, it was noted that the Tankwa Karoo region was grossly underrepresented. It was therefore deemed necessary to conduct a systematic survey of this under-sampled region to supplement the dataset.

Only specific (and not sub-specific) data were considered in this thesis. The resultant dataset consists of a total of 5473 records representing 122 species (76 lizards; 38 snakes; eight chelonians – see Appendix A). It should be noted that the final dataset consists of presence-only data. The limitations of presence-only data are acknowledged. However, it is a common attribute of data obtained from natural history collections (Graham *et al.* 2004; Pearce & Boyce 2006) and acquiring true presence/absence data for a study of this geographical extent is very difficult. Presence-only data are commonly used in species distribution and diversity studies (e.g., Guisan & Hofer 2003; Slatyer *et al.* 2007) and with caution, sober interpretation and the correct statistical techniques this type of records can be very useful (Guisan & Zimmerman 2000; Loiselle *et al.* 2003; Pearce & Boyce 2006).

The distribution records are all geo-referenced and were translated from point data to a regular grid with the GIS software package ArcView 3.2 (ESRI), following the methods of Guisan & Hofer (2003). The distribution data were aggregated in this way at two grid resolutions namely, quarter degree squares (QDS) and eighth degree squares (EDS), based on the South African National Grid System. This method basically generated two presence/absence datasets from the presence-only data which could be used in subsequent analyses. It is further acknowledged that the area of QDSs and EDSs is dependent on latitude, but in terms of my study area, this effect is negligible. It should also be noted that coastal cells, which often represent a smaller area than inland cells, were included in the analyses. It was decided not to disregard these cells on account of their smaller land surface area because that would result in the complete absence or severe under representation of a number of species with a coastal distribution (especially along the West Coast).

An inherent limitation of distribution data is the issue of false presences and absences. One should aim to minimise both of these types of error within the data as far as possible, but also

determine which will have the least negative effect for a particular analysis (Loiselle *et al.* 2003; Brotons *et al.* 2004). Occurrence or presence-only data are often characterised by many false absences – if there is no record for a species at a particular locality it could either indicate that the species does not occur there, or that it does occur there and has just never been recorded officially, or that the area has never been surveyed. In turn, range maps (often based on expert opinion) and minimum convex polygons generated from occurrence data typically include many false presences and are often a substantial over-estimation of species' distributions (Burgman & Fox 2003; Woinarski *et al.* 2005). The approach of generating a new presence/absence dataset from the occurrence dataset, as described in the previous paragraph, was therefore considered the most conservative trade-off between the two extremes.

1.4.2. Environmental data

All environmental data were obtained via the Department of Geology, Geography & Environmental Studies, University of Stellenbosch. These data were harvested at both QDS and EDS resolution as an average value for each grid cell based on data from Schulze's (1997) *South African Atlas of Agrohydrology and –climatology*, departmental databases (A. Van Niekerk unpublished data) as well as the South African Weather Service's WB42 dataset (refer to Chapter 4 for a detailed discussion of the particular variables as well as their derivation and the sources from which they were obtained).

1.5.   OVERVIEW OF CHAPTERS

In Chapter 2, the biogeographical influence of the Tankwa Karoo Basin on reptile distribution in south-western South Africa is discussed. Significant new distribution records that resulted from the survey of the basin are also highlighted. Chapter 3 describes species richness, endemism and turnover patterns for reptiles in the area south of 31° latitude and west of 21°

longitude, i.e., the south-western region of South Africa. In Chapter 4, biotic regions and associated reptile assemblages in the south-western region of South Africa are discussed and the environmental variables that best describe these biotic regions are identified. In Chapter 5 the relevance of the Greater Cederberg Biodiversity Corridor for reptile conservation is evaluated in terms of the results obtained in this study.

Chapter 2

The biogeographical influence of the Tankwa Karoo Basin on reptile distribution in the south-western region of South Africa

2.1.   INTRODUCTION

2.1.1   Problem statement

The Tankwa Karoo Basin is an arid basin in the south-western part of South Africa, between the Swartruggens and Cederberg Mountains in the west and the Roggeveld Escarpment in the east (Figure 2.1). In the south-east it is isolated from the Moordenaars Karoo by the Koedoesberge and Klein Roggeveld Mountains. The basin is drained by the Tankwa and Doring Rivers and their tributaries.
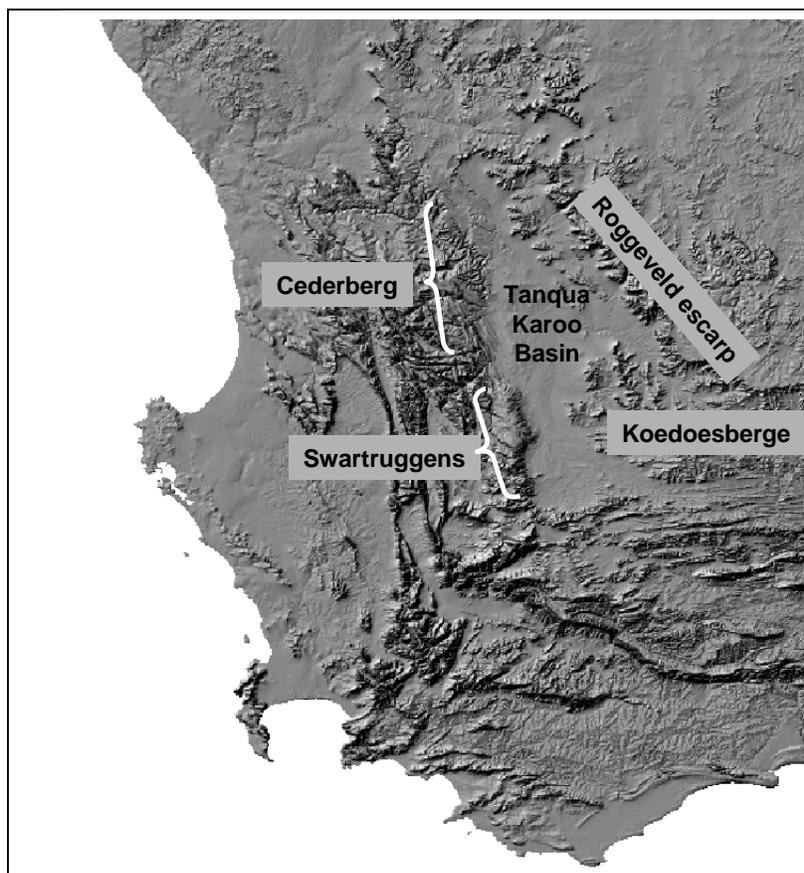
Figure 2.1. The Tankwa Karoo Basin and surrounding mountains.

The Tankwa Karoo Basin is part of the Rainshadow Valley Karoo Bioregion, one of the six bioregions constituting the Succulent Karoo Biome (Mucina *et al.* 2006a). Mean annual precipitation in the basin is extremely low, ranging from 70-110 mm. With the absence of the influence of coastal fog, the basin is one of the driest areas in the Succulent Karoo Biome and for most of the year rather resembles a desert landscape (Mucina *et al.* 2006a) (Figure 2.2). The biogeographical significance of this apparently inhospitable stretch of land has not been determined for any faunal group. The potential capacity of the basin to act as a dispersal barrier or dispersal corridor, for example, is unknown. The aim of this study was to investigate the biogeographical influence of the Tankwa Karoo Basin on the distribution of reptiles in south-western South Africa. Such knowledge is important for effective conservation planning, particularly in the light of global climate change.

The Greater Cederberg Biodiversity Corridor (GCBC) is a large-scale conservation corridor that was recently demarcated in the Greater Cape Floristic Region of South Africa. The west-to-east corridor section of the GCBC spans the Tankwa Karoo Basin in the vicinity of the Tankwa Karoo National Park (Figure 2.3). Specialist mapping of reptile distributions was conducted during the planning phase of the GCBC to facilitate in the delineation of the boundaries of this regional planning unit (Anon 2005). The aforementioned study revealed an extreme paucity in reptile distribution data for the Tankwa Karoo Basin, clearly visible in a plot of reptile distribution records in the current SARCA database (Figure 2.4). The biogeographical analysis of the Tankwa Karoo Basin therefore first required a detailed reptile survey before any analyses could be conducted.

The results of this study would allow an evaluation of the relevance of the GCBC for reptile conservation, particularly the relevance of the eastern corridor section that spans the Tankwa Karoo Basin. The new reptile records for the basin will also contribute to the South African Reptile Conservation analysis which is currently in progress.

Figure 2.2. The arid Tankwa plains.
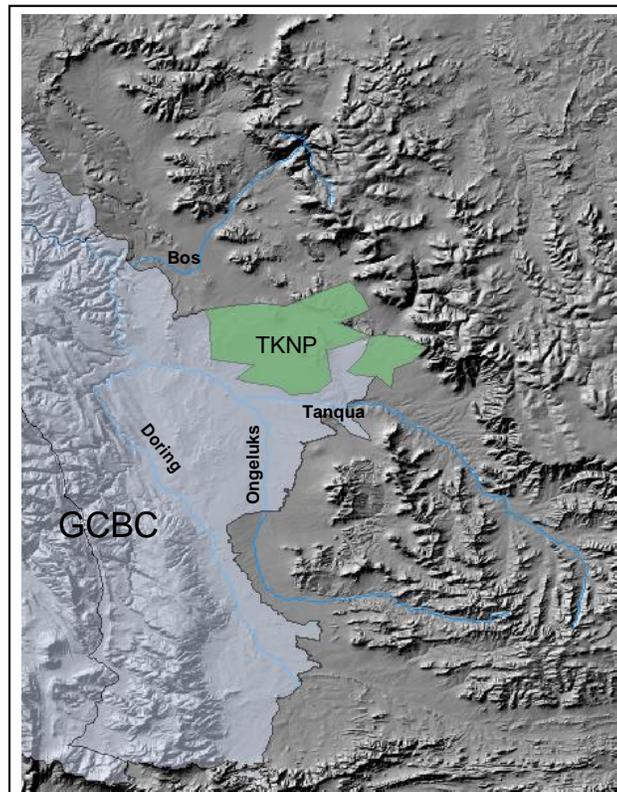
Figure 2.3. The Greater Cederberg Biodiversity Corridor (GCBC) and Tankwa Karoo National Park (TKNP) relative to the Tanqua Karoo Basin.
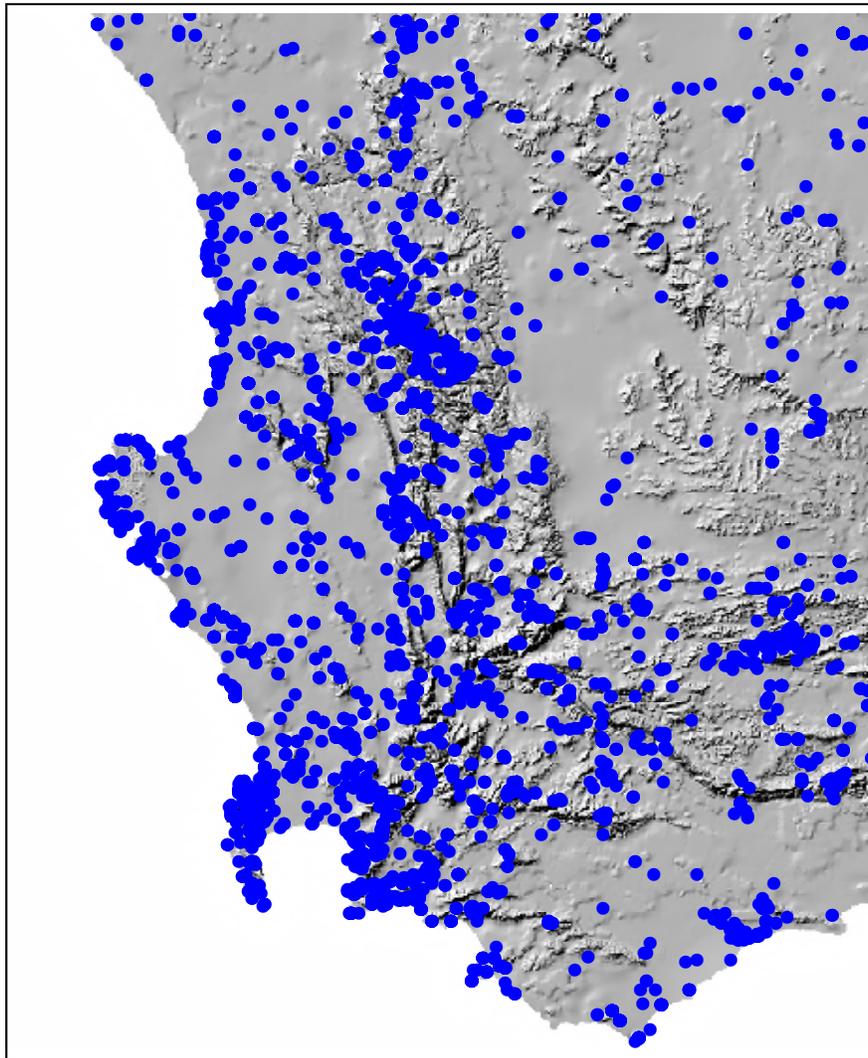
Figure 2.4. Reptile distribution records in the SARCA database for the area south of 31⁰S

and west of 21⁰E, showing the paucity in data for the Tankwa Karoo Basin.

2.1.2. Vegetation and climate

The Rainshadow Valley Karoo Bioregion encompasses 14 vegetation types, five of which occur in the Tankwa Karoo Basin (Figure 2.5). The vegetation unit dominating the Tankwa Basin is Tanqua Karoo (SKv 5) and is embedded with patches of the azonal inland saline vegetation, Tanqua Wash Riviere (AZi 7), along the alluvial floors and sheet-wash plains of the Tankwa and Doring Rivers and their tributaries (Mucina *et al.* 2006a; Mucina *et al.* 2006b). The eastern sections of the Swartruggens Mountains (bordering the Tankwa Basin in the west) are characterized by Swartruggens Quartzite Karoo (SKv 2) vegetation which extends from Karoopoort in the south to the Doring River canyon in the north (Mucina *et al.* 2006a). From the Doring River canyon northwards to the Hantam region the vegetation type changes to Agter-Sederberg Shrubland (Skv 3) (Mucina *et al.* 2006a). In the south-eastern part of the Tankwa Basin, Koedoesberge-Moordenaars Karoo (SKv 3) replaces Tankwa Karoo (SKv 5) vegetation on the foothills of the low Koedoesberge and Pienaarsfontein se Berg mountain ranges (Mucina *et al.* 2006a). The vegetation on the higher elevations of these mountains is described as Central Mountain Shale Renosterveld (FRs 5) (Rebelo *et al.* 2006) which is a vegetation type of the Karoo Renosterveld Bioregion of the Fynbos Biome (Rutherford *et al.* 2006).

The Mean Annual Precipitation (MAP) values for all the vegetation types of the Tankwa Karoo Basin are listed in Table 2.1. The MAP of the vegetation units bordering on Tanqua Karoo (SKv 5) are all above 200 mm. Although the MAP for Tankwa Karoo and its associated azonal vegetation, Tanqua Wash Riviere (AZi 7), is indicated as slightly above 160 mm, the region has a high spatial variability of precipitation (Mucina *et al*. 2006a). Long-term precipitation data collected at three localities within the unit show that the MAP ranges from 72 mm in the central part (Elandsvlei on the Tankwa River) to 111 mm and 112 mm, respectively, in the south (Spes Bona on the Doring River) and the north (Reenen on the Wolf River) of the unit. With the absence of the influence of coastal fog, Tanqua Karoo (Skv 5) is one of the driest forms of the Succulent Karoo Biome (Mucina *et al.* 2006a).
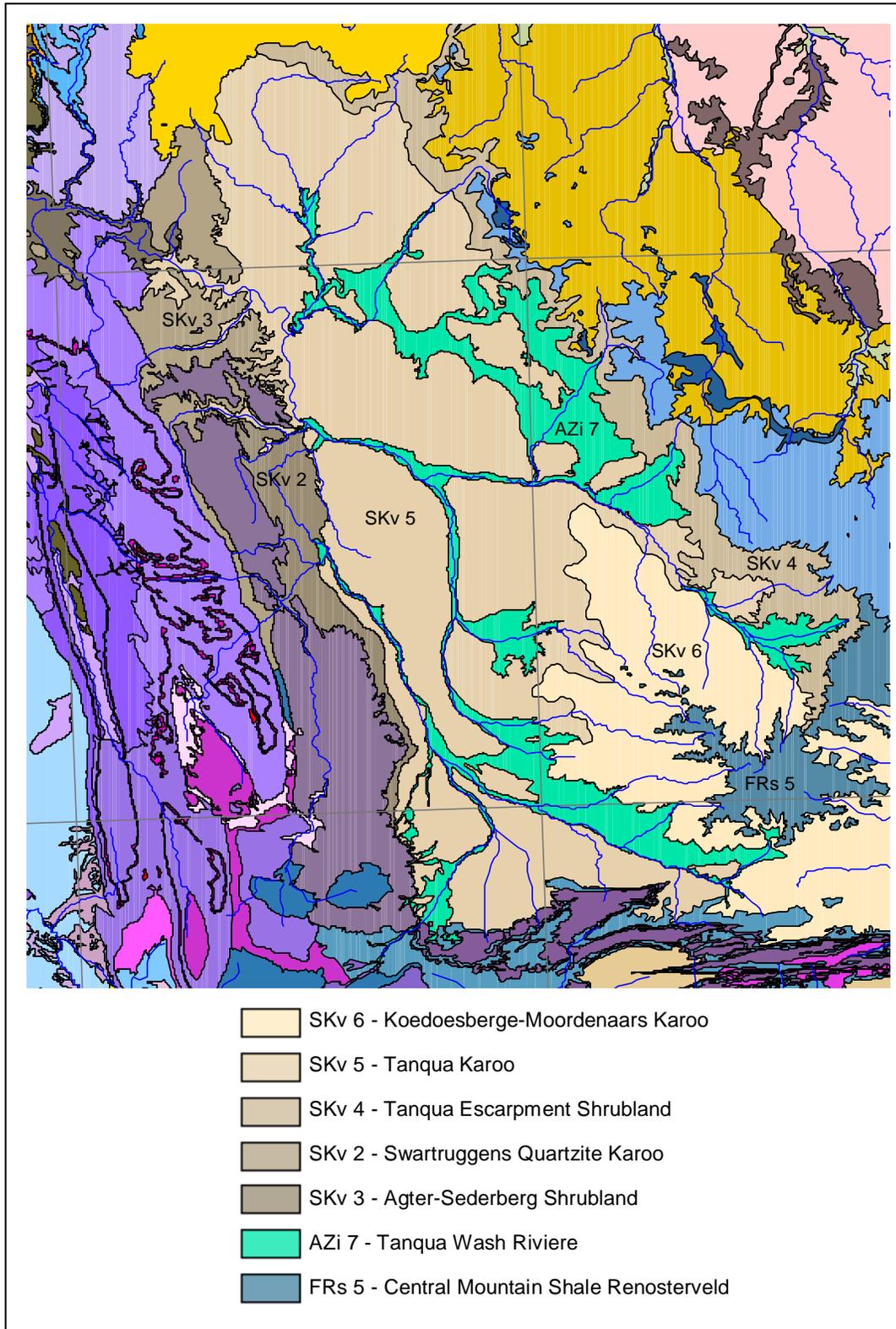
Figure 2.5. Vegetation map for the Tankwa Karoo Basin (Mucina *et al*. 2005; Mucina *et al*. 2006c).

2.1.3. Conservation status

The Succulent Karoo has been used as small livestock grazing fields for centuries (Milton *et al.* 1997), but due to the extremely arid summers, utilization in the Tankwa Karoo Basin is mainly limited to four to five months during the winter season (Rubin 1998). Land-use in the Tankwa Karoo National Park has also predominantly focused on small livestock grazing with limited evidence of historical cultivation efforts (Freitag-Ronaldson *et al.* 2006). Since agricultural production is very low in the Tankwa Basin, only a small portion of land has been transformed, although some areas have been heavily overgrazed and are invaded by alien plants (Mucina *et al.* 2006a). The conservation status of all the units comprising the Tankwa Karoo Basin is classified as 'Least threatened' by Mucina *et al.* (2006a), according to the scale of categories in Golding (2002).

Table 2.1. The vegetation types of the Tankwa Karoo Basin and adjacent mountainous areas, with associated Mean Annual Precipitation (MAP) and Mean Annual Temperature (MAT) values (Mucina *et al.* 2006a & b).

Code	Vegetation Type	MAP	MAT
SKv 2	Swartruggens Quartzite Karoo	208 mm	16.5 °C
SKv 3	Agter-Sederberg Shrubland	257 mm	16.8 °C
SKv 4	Tanqua Escarpment Shrubland	274 mm	15.8 °C
SKv 5	Tanqua Karoo	163 mm	17.4 °C
SKv 6	Koedoesberge-Moordenaars Karoo	206 mm	15.8 °C
AZi 7	Tanqua Wash Riviere	162 mm	17.3 °C
FRs 5	Central Mountain Shale Renosterveld	288 mm	14.6 °C

2.2. METHODS

2.2.1. Selection of sampling localities

The Tankwa survey was implemented with the intent that sampled areas should be representative of the whole region and also that a maximum number of species be detected. The sampling effort was limited by the accessibility of the region since the largest part of the region is privately owned land and can only be accessed via private roads. Selection of particular sampling localities was therefore largely governed by the ability to identify and contact landowners, and subsequently being granted permission to conduct a survey on their property. However, the overall selection was directed by the condition that sampling localities should be spaced out throughout the length and breadth of the region, with the additional requirement that the sampling effort within each vegetation unit (as defined in Mucina & Rutherford 2006) should be roughly proportional to the size of each of these units within the total area. These localities are mapped in Figure 2.6 and a list of all the surveyed localities, along with a general GPS and the date when visited is supplied in Table 2.2.
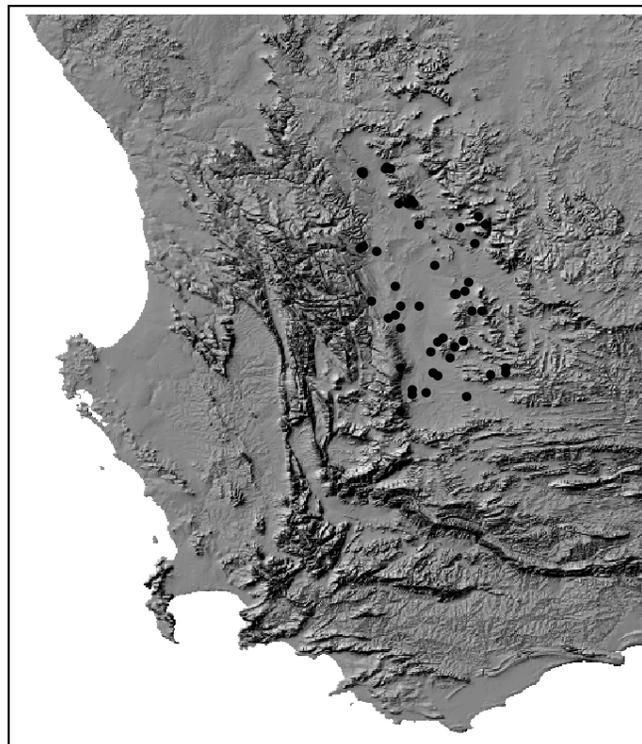
Figure 2.6. Distribution of survey localities in Tankwa Karoo Basin.

Table 2.2. List of Tankwa Karoo survey localities with general GPS coordinates (in decimal degrees) and the date visited. TKNP = Tankwa Karoo National Park; DDS = decimal degrees south; DDE = decimal degrees east

Locality	Date	DDS	DDE
N'Wardouw	April 2006	-32.92805	19.71393
Driefontein	April 2006	-32.79258	19.90777
Rietfontein	April 2006	-32.85412	19.87083
Kareekloof A	June 2006	-33.16743	19.70970
Kareekloof B	June 2006	-33.04903	19.77253
Perdebergkoppies	June 2006	-33.07677	19.77755
Fonteinskop	June 2006	-33.06283	19.84968
Bizansgat	June 2006	-32.82715	19.99570
Pienaarsfontein	June 2006	-32.78317	20.04620
Spitskoppe	June 2006	-32.77863	19.93620
Hangklip	June 2006	-32.88010	19.97583
Rooivlak	August 2006	-32.63941	20.08693
Isle of Sky A	August 2006	-32.48699	20.07005
Isle of Sky B	August 2006	-32.52442	20.05347
Klappieshoek	August 2006	-32.63304	20.14570
Bantamsfontein	September 2006	-32.97043	20.18242
Klipbanksfontein A	September 2006	-32.95917	20.26780
Klipbanksfontein B	September 2006	-32.92867	20.26915
Kareekolk A	September 2006	-32.95657	19.88315
Kareekolk B	September 2006	-32.97245	19.91285
Patatsrivier road	September 2006	-33.08143	20.05958
Blaauwboschkolk	November 2006	-32.65482	19.68177
Groote Kapels Fontein	November 2006	-32.61098	19.80812
Klipkraal	November 2006	-32.67185	19.65268
Tandschoonmaak	November 2006	-32.60718	19.71670
Elandsdrift	November 2006	-32.58477	19.55790
Paulshoek - TKNP	March 2007	-32.27940	20.10888
Elandsberg - TKNP	March 2007	-32.20083	20.02910
Langkloof - TKNP	March 2007	-32.17723	20.15618
Gannaga Pass - TKNP	March 2007	-32.13230	20.12555
Varschfontein - TKNP	March 2007	-32.18088	19.81300
Gansfontein	April 2007	-32.72222	19.71250
Elandsvlei A	June 2007	-32.29983	19.51330
Elandsvlei B	June 2007	-32.32323	19.59118
Oudebaaskraal	June 2007	-32.39609	19.88704
Vaalfontein	June 2007	-32.54960	20.00973
Vaalfontein	June 2007	-32.54977	19.99615
Papkuil	July 2007	-32.50383	19.68838
Witkloof A	July 2007	-32.04580	19.76772
Witkloof B	July 2007	-32.06913	19.78370
Kleinhoek	July 2007	-31.88193	19.65842
Kalkgat	July 2007	-31.90228	19.51112

2.2.2. Survey method

Surveys were conducted by actively searching for reptiles sheltering underneath vegetation and rocks or within crevices. This method allows one to cover a large area and a variety of different retreat sites. Active searches were also conducted during night time to ensure maximum detection of species. Animals were caught by hand or small noose where necessary for accurate identification. The GPS coordinates, of the point where each animal was encountered, were recorded.

A maximum of two voucher specimens of each species encountered were collected from each location. Voucher specimens were preserved using standard preservation methods: Sacrificed individuals were fixated with 10% formaldehyde and preserved in 70% alcohol. All specimens were catalogued and entered in the Ellerman Collection of the University of Stellenbosch. Sight records were also entered into the database. Specimens from the Northern Cape Province were collected and exported under the permits (No. 0450/06 and No. 4457/06), issued to P. le F. N Mouton and A. Meyer, by the Northern Cape Nature Conservation Board. In the Western Cape Province, specimens were collected under the permit held by P. le F. N Mouton (No. 001-201-00016) issued by CapeNature for the SCARCE project.

2.2.3. Species turnover

Species turnover between the Tankwa Karoo Basin and the surrounding areas was simply expressed as the proportion of species lost and gained from one area to the other (see Koleff *et al*. 2003 for a list of beta diversity measures). The proportion was calculated by dividing the number of species unique to both the focal (*c*) and the neighbouring (*b*) area with the sum of (c), (b) and (*a*) – the number of species shared by the two areas. The resultant turnover value ranges between zero (no turnover) and one (complete turnover, no shared species). For the comparison of the Tankwa Karoo Basin with the larger Cederberg area and Roggeveld Escarp & Plateau respectively, the aggregated species occurrence data of transects of adjacent quarter degree square (QDS) cells in each region

were considered (Figure 2.7a). In each region a transect of five adjacent QDS cells were selected.   However, since the low species richness of the Roggeveld Plateau is considered to be an effect of sampling bias relative to the grid block coinciding with the Williston area (see Chapter 3), it was decided to add the data from that particular cell to the Roggeveld transect for the comparison of species composition. It is acknowledged that it is preferable not to use unequal areas when calculating beta diversity, but it was considered necessary in the present instance since comparing unequally sampled areas could result in diversity values which do not reflect reality. Furhtermore, two blocks of four adjoining QDS cells were selected just south and just north of the Tankwa Basin and compared with a transect of four QDS cells within the basin for the investigation of species compositional turnover across the north-south axis of the region (Figure 2.7b).

a)   b)
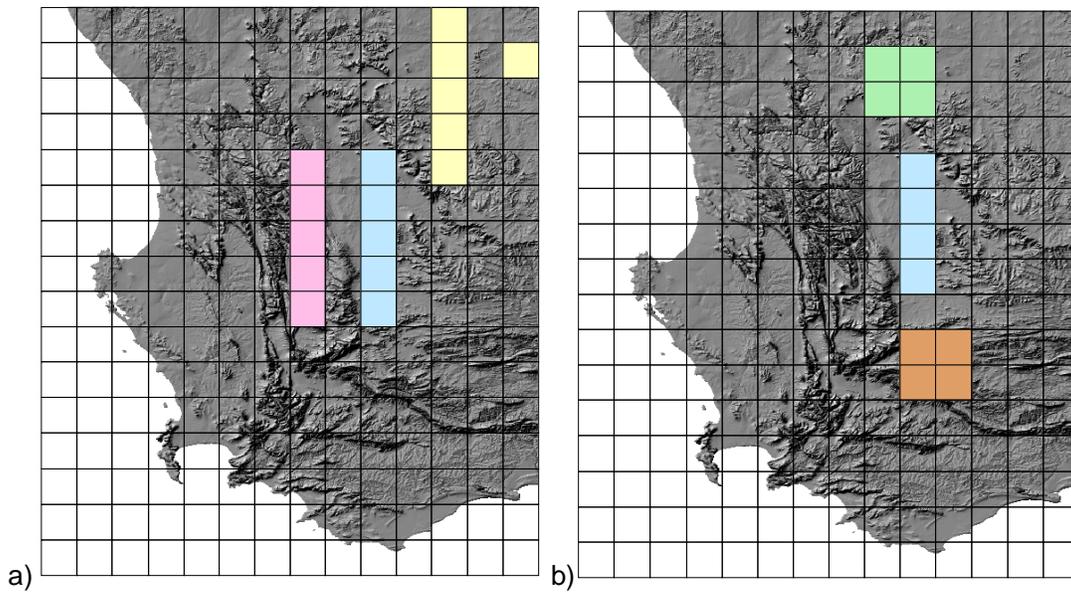
Figure 2.7. Species occurrence data for the following QDS cells were aggregated to calculate the species compositional turnover (beta diversity) between a) the larger Cederberg area (pink), Tankwa Karoo Basin (blue) and the Roggeveld Escarpment & Plateau (yellow) as well as b) the Tankwa Basin (blue) and the areas north (Hantam area) and south (Bonteberg area) thereof (green and orange shaded areas respectively).

2.3.   RESULTS

2.3.1. Species distributions

A total of 38 species (24 lizards, 11 snakes, three chelonians) were recorded during the survey of the Tankwa Karoo Basin (Table 2.3). A list of the collected voucher specimens and recorded observations, accompanied their location and GPS-coordinates, is presented in Appendix B. The survey generated distribution data for five quarter degree squares which previously had no reptile distribution records, for one which previously had only a single record and for one which previously had only three records. At the finer resolution (eighth degree square) data were generated for 16 cells for which no data were recorded previously, for five cells which previously had only one record and for one which previously had only two records.

The species distribution ranges of the 38 reptiles species recorded during the Tankwa surveys are represented in Figures 2.8(a)-(x), 2.9(a)-(k) and 2.10(a)-(c) – lizards, snakes and tortoises, respectively, in alphabetical order. It should be noted that for many species these distributions represent only a portion of their entire range. In many cases therefore, what may look like a substantial range expansion by the addition of records from the Tankwa survey (yellow shaded records) in fact only fills a gap in the recorded distribution – e.g. *C. bibronii*, *Bitis arietans* and *Naja nivea.* Although there are no records in the north-eastern section of the study area, these three species are widespread in South Africa (*C. bibronii*) and southern Africa (*B. arietans* and *N. nivea*) and have a number of records outside of the study area. There are eight species, however, which should be mentioned in terms of new records which extend their existing recorded distribution ranges: *Chondrodactylus angulifer; Cordylus cataphractus, Goggia lineata, Pachydactylus kladeroderma, Trachylepis occidentalis, Bitis caudalis* and *Naja n. woodi.*

Table 2.3. Reptile species list of reptile species recorded in the Tankwa survey.

Taxon Name	English Name
Lizards	
Agama atra	Southern Rock Agama
Agama hispida	Spiny Agama
Chondrodactylus angulifer	Giant Ground Gecko
Chondrodactylus bibronii	Bibron's Tubercled Gecko
Cordylosaurus subtessellatus	Dwarf Plated Lizard
Cordylus cataphractus	Armadillo Girdled Lizard
Cordylus polyzonus	Karoo Girdled Lizard
Goggia hexapora	Cedarberg Dwarf Leaf-toed Gecko
Goggia lineata	Striped Dwarf Leaf-toed Gecko
Meroles knoxii	Knox's Desert Lizard
Microacontias lineatus lineatus	Striped Legless Skink
Nucras tessellata	Western Sandveld Lizard
Pachydactylus capensis	Cape Thick-toed Gecko
Pachydactylus formosus	Rough Thick-toed Gecko
Pachydactylus geitje	Ocellated Thick-toed Gecko
Pachydactylus kladeroderma	Thin-skinned Thick-toed Gecko
Pachydactylus mariquensis	Marico Thick-toed Gecko
Pachydactylus weberi	Weber's Thick-toed Gecko
Pedioplanis laticeps	Cape Sand Lizard
Pedioplanis lineoocellata	Spotted Sand Lizard
Trachylepis capensis	Cape Skink
Trachylepis occidentalis	Western Three-striped Skink
Trachylepis sulcata	Western Rock Skink
Trachylepis variegata	Variegated Skink
Snakes	
Bitis arietans	Puff Adder
Bitis caudalis	Horned Adder
Bitis rubida	Red Adder
Dipsina multimaculata	Dwarf Beaked Snake
Lamprophis guttatus	Spotted House Snake
Leptotyphlops gracilior	Slender Thread Snake
Naja nigricollis woodi	Black Spitting Cobra
Naja nivea	Cape Cobra
Psammophis notostictus	Whip Snake
Rhinotyphlops lalandei	Delelande's Beaked Blind Snake
Chelonians	
Chersina angulata	Angulate Tortoise
Homopus signatus	Speckled Padloper
Psammobates tentorius	Tent Tortoise
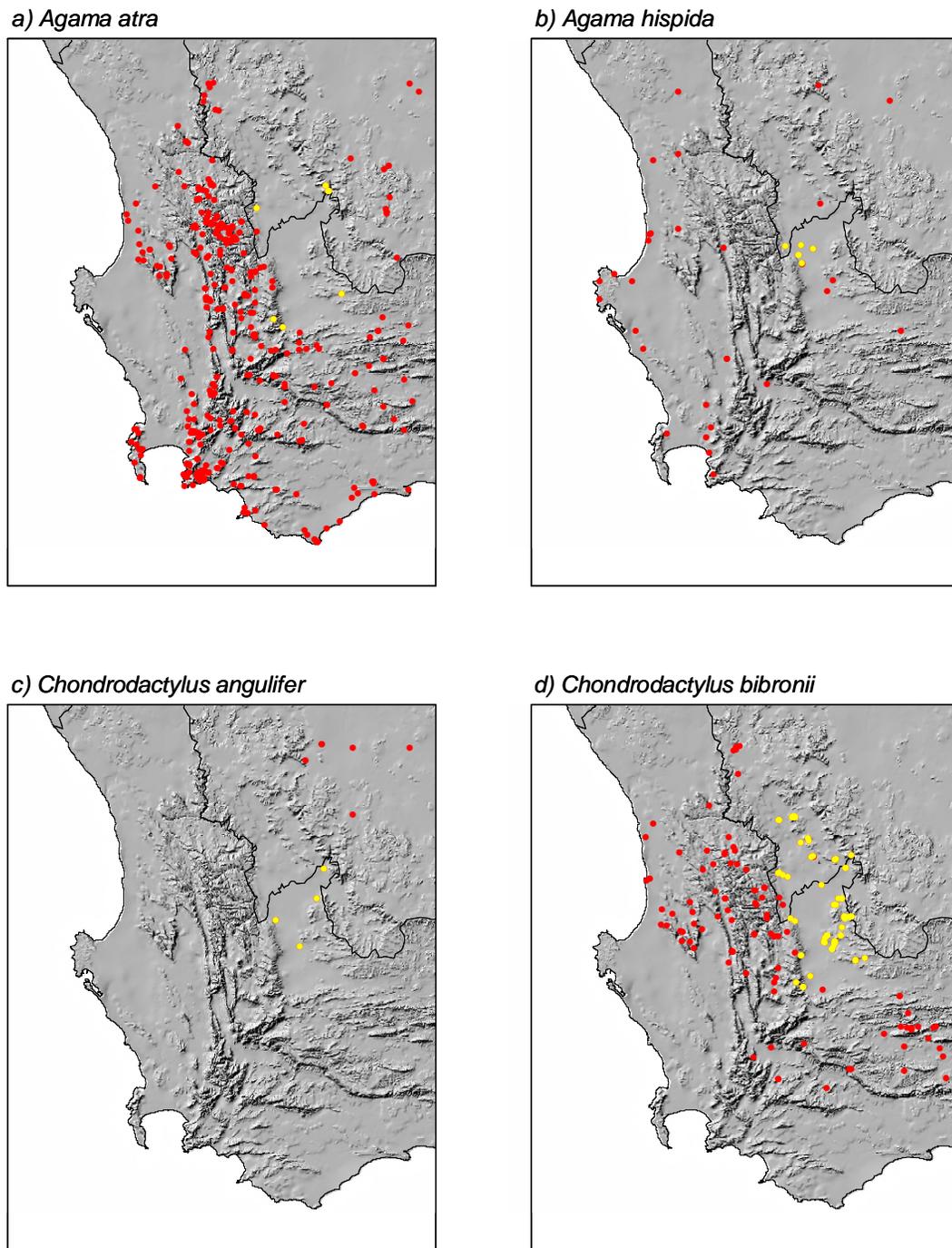
Figure 2.8 (a)-(d).   Distribution records for a) *Agama atra*, b) *Agama hispida,* c) *Chondrodactylus angulifer* and d) *Chondrodactylus bibronii* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

e) Cordylosaurus subtessellatus

f) Cordylus cataphractus

g) Cordylus polyzonus
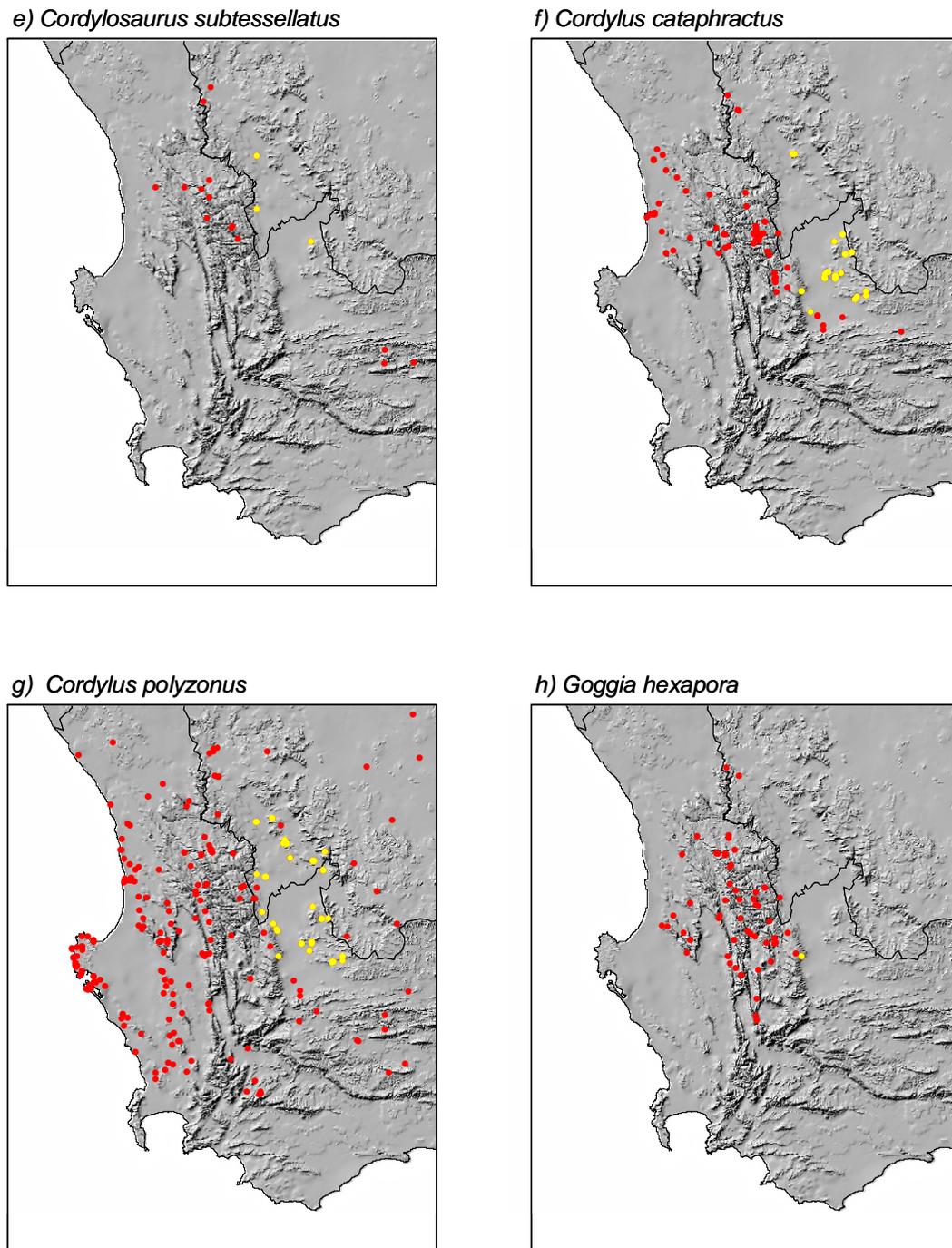
h) Goggia hexapora

Figure 2.8 (e)-(h). Distribution records for e) *Cordylosaurus subtessellatus*, f) *Cordylus cataphractus,* g) *Cordylus polyzonus* and h) *Goggia hexapora* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

i) Goggia lineata

j) Meroles knoxii

k) Microacontias lineatus

l) Nucras tessellata
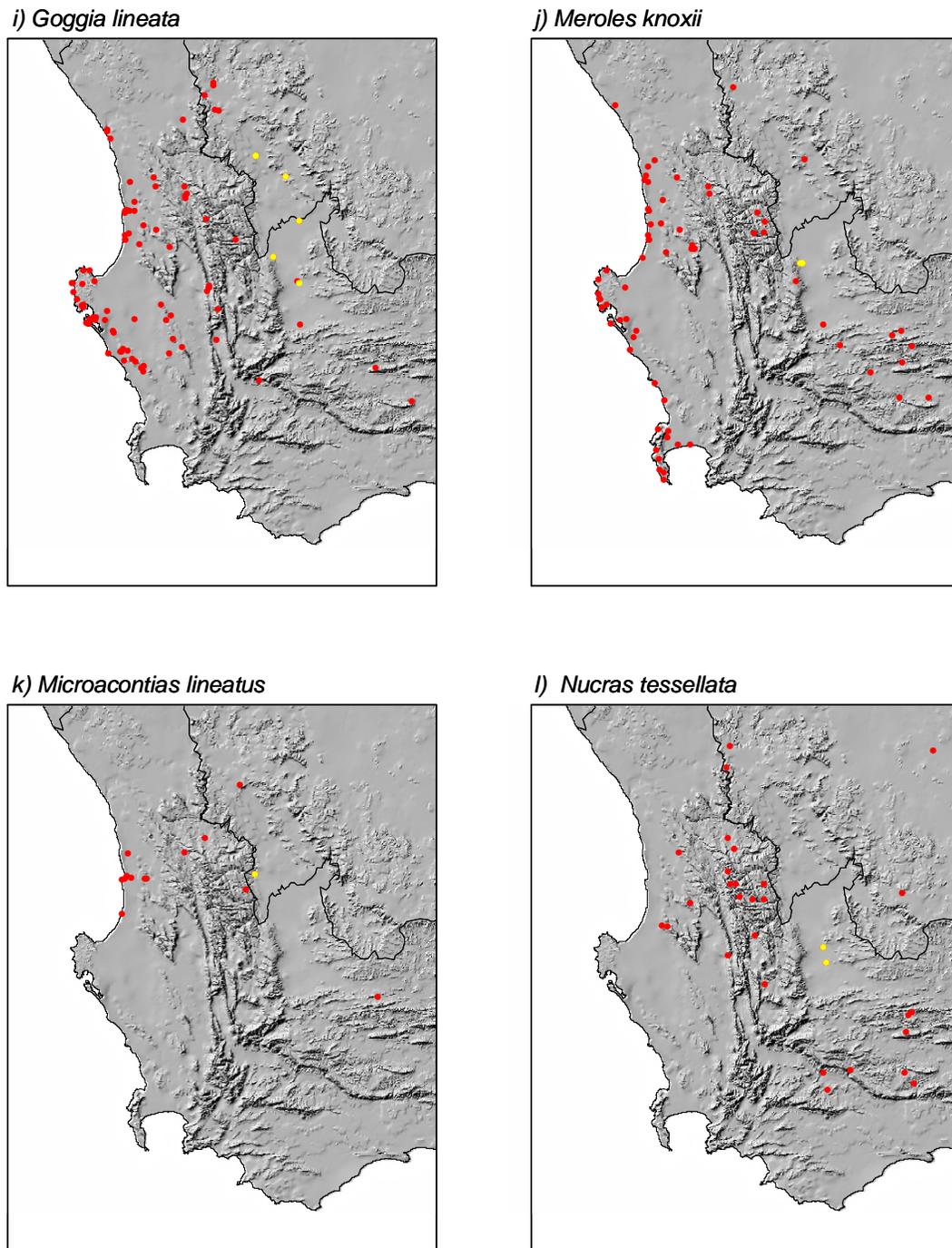
Figure 2.8 (i)-(l).   Distribution records for i) *Goggia lineata*, j) *Meroles knoxii,* k) *Microacontias lineatus* and l) *Nucras tessellata* within the relevant study area.   Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

m) Pachydactylus capensis

n) Pachydactylus formosus

o) Pachydactylus geitje

p) Pachydactylus kladeroderma
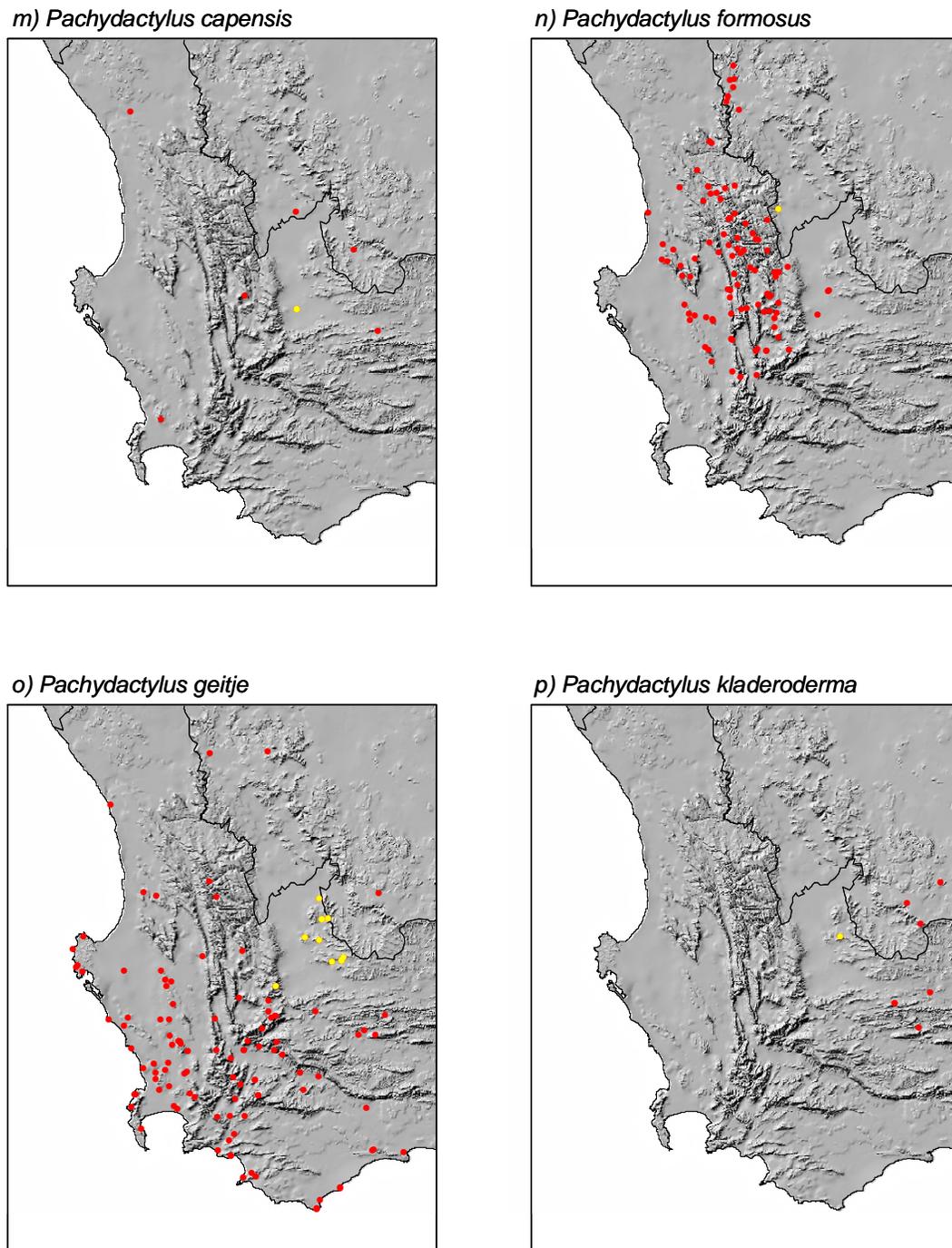
Figure 2.8 (m)-(p). Distribution records for m) *Pachydactylus capensis*, n) *Pachydactylus formosus,* o) *Pachydactylus geitje* and p) *Pachydactylus kladeroderma* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

q) Pachydactylus mariquensis

r) Pachydactylus weberi

s) Pedioplanis laticeps

t) Pedioplanis lineoocellata
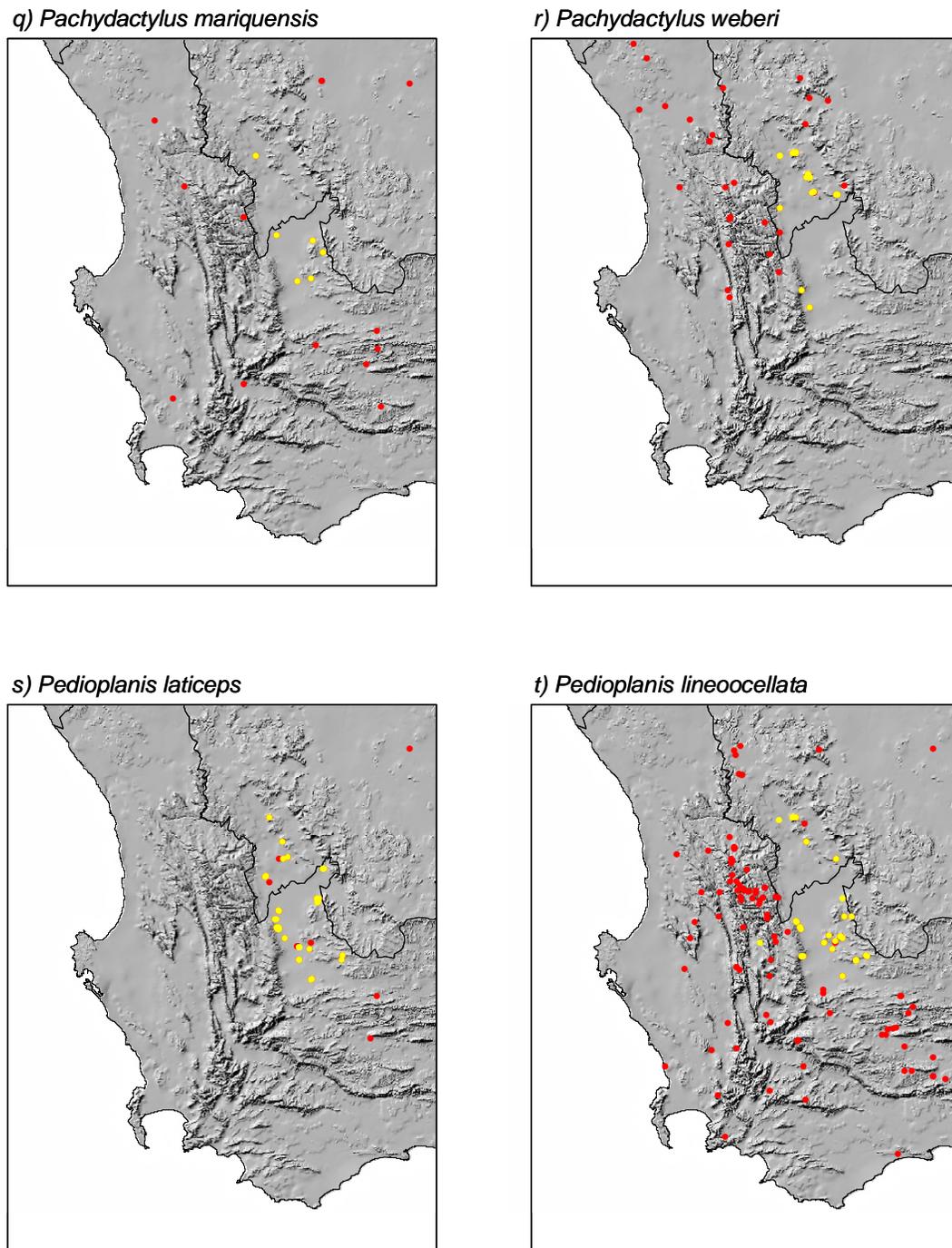
Figure 2.8 (q)-(t). Distribution records for q) *Pachydactylus mariquensis*, r) *Pachydactylus weberi,* s) *Pedioplanis laticeps* and t) *Pedioplanis lineoocellata* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

u) Trachylepis capensis

v) Trachylepis occidentalis

w) Trachylepis sulcata

x) Trachylepis variegata
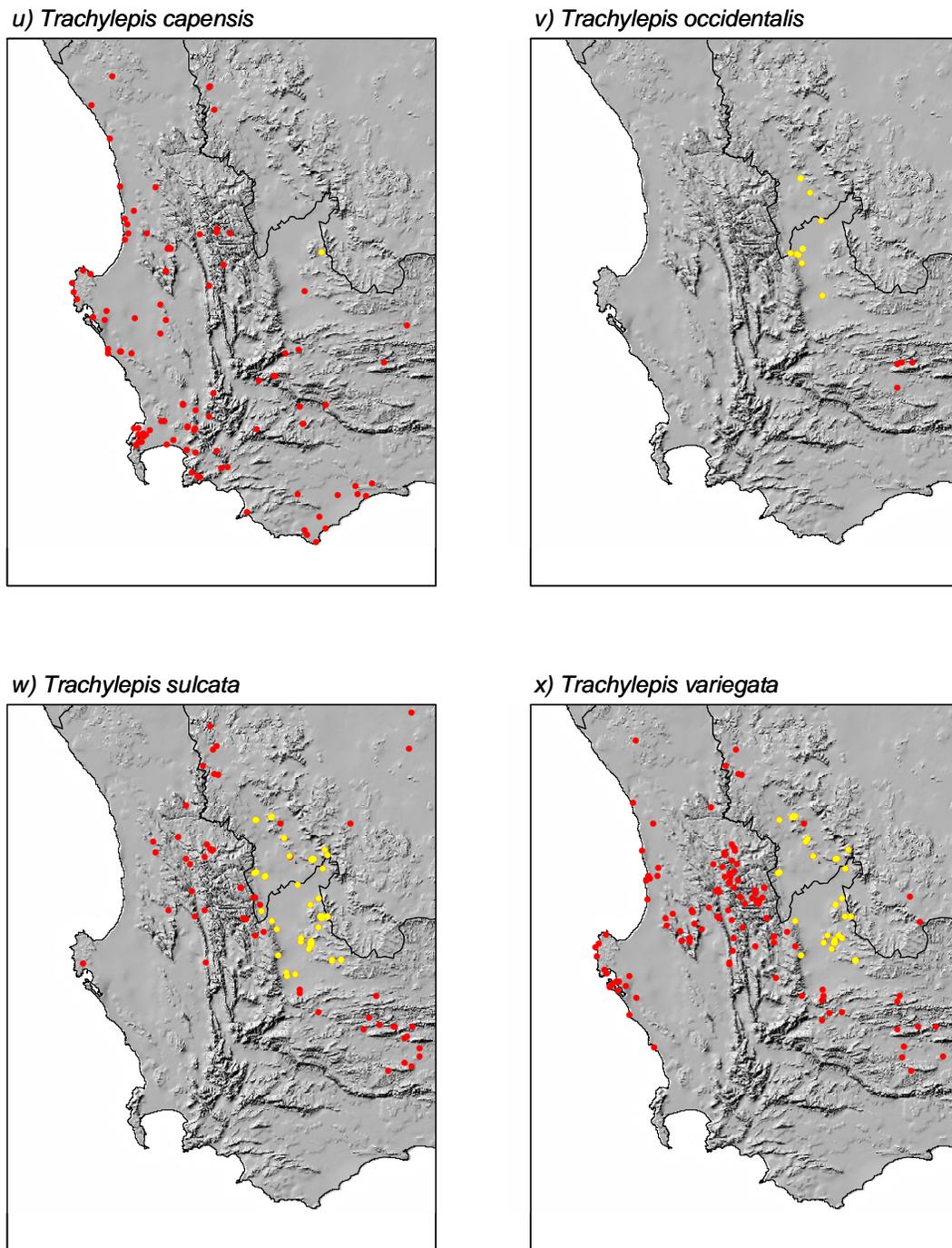
Figure 2.8 (u)-(x).   Distribution records for u) *Trachylepis capensis*, v) *Trachylepis occidentalis,* w) *Trachylepis sulcata* and x) *Trachylepis variegata* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

a) Bitis arietans

b) Bitis caudalis

c) Bitis rubida

d) Dipsina multimaculata
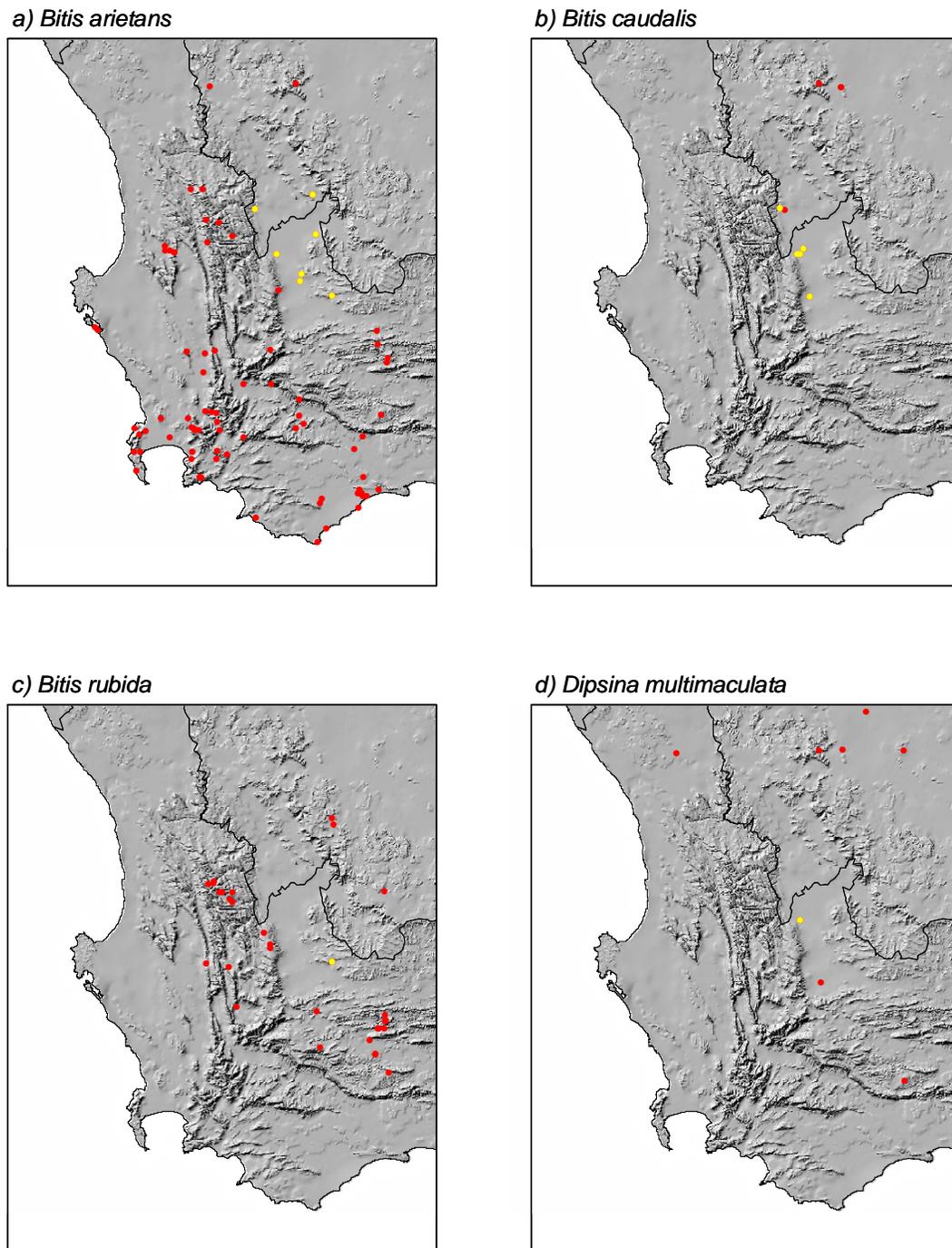
Figure 2.9 (a)-(d). Distribution records for a) *Bitis arietans*, b) *Bitis caudalis,* c) *Bitis rubida* and d) *Dipsina multimaculata* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

e) Lamprophis guttatus
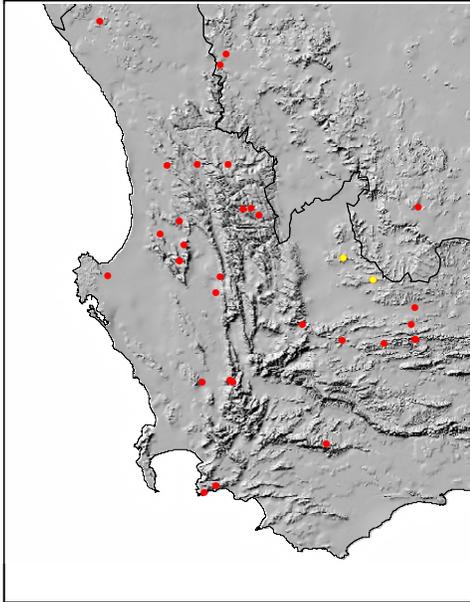
f) Leptotyphlops gracilior
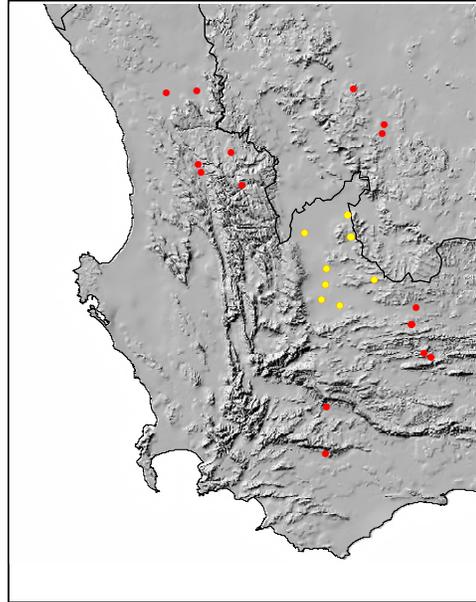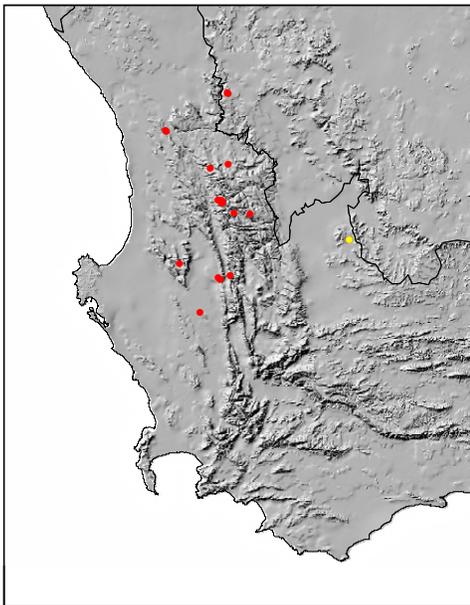
g) Naja n. woodi

h) Naja nivea
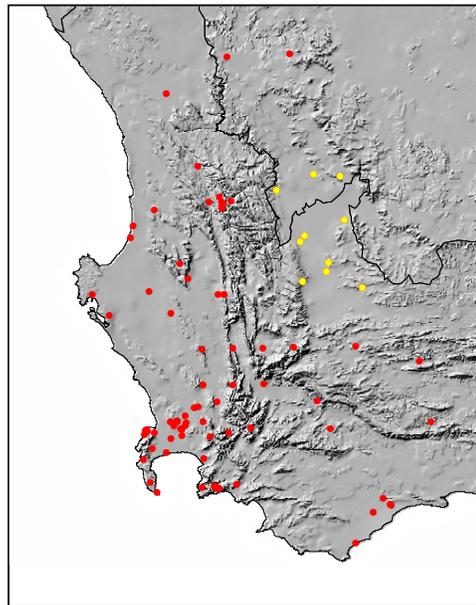
Figure 2.9 (e)-(h).   Distribution records for e) *Lamprophis guttatus*, f) *Leptotyphlops gracilior*, g) *Naja n. woodi* and h) *Naja nivea* within the relevant study area.   Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

i) Psammophis notostictus   *j) Rhinotyphlops lalandei*
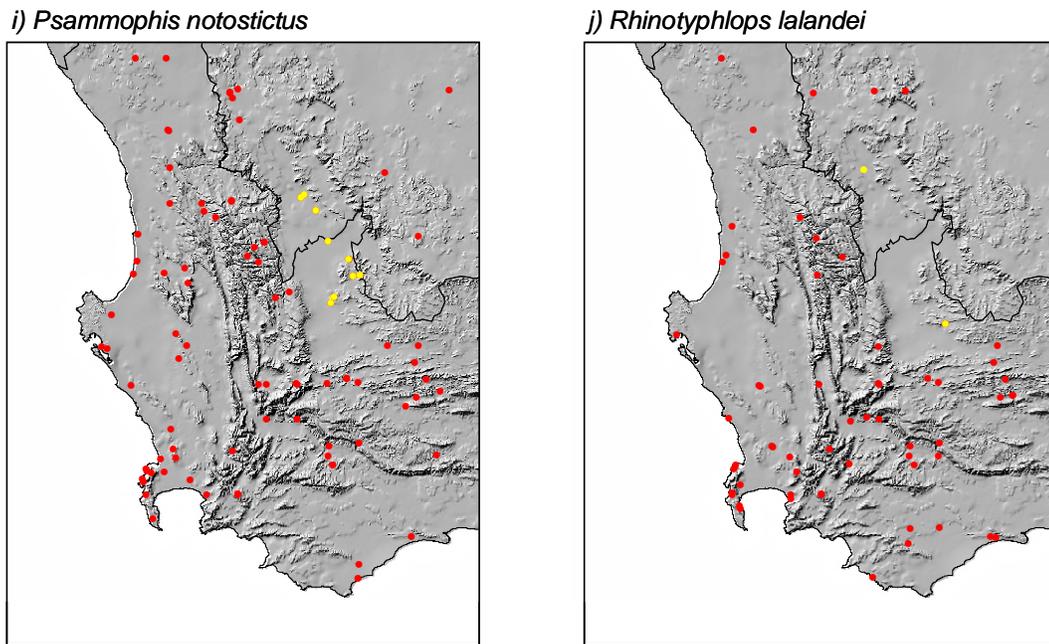
Figure 2.9 (i)-(j). Distribution records for i) *Psammophis notostictus* and j) *Rhinotyphlops lalandei* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

a) Chersina angulata
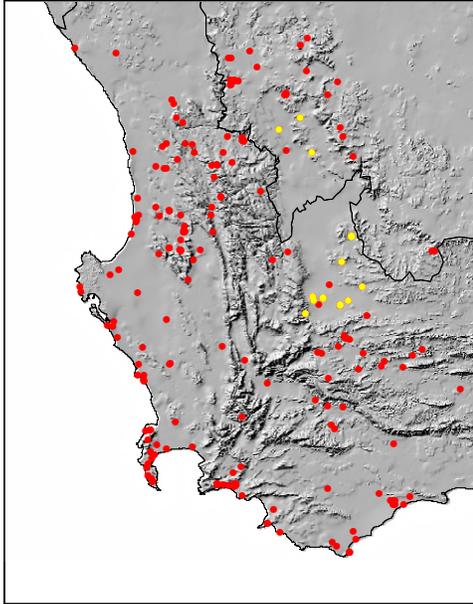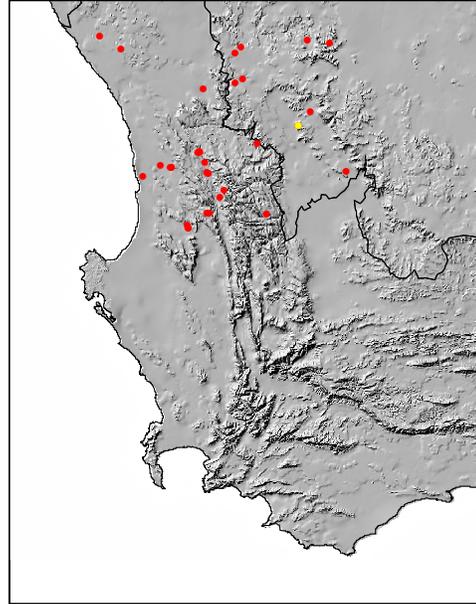
b) Homopus signatus

c) Psammobates tentorius
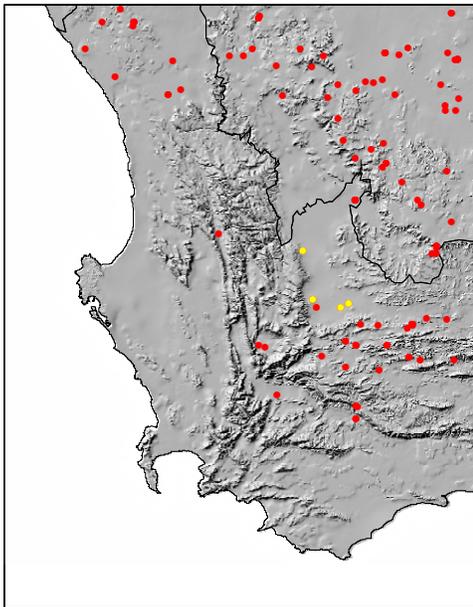
Figure 2.10 (a)-(c). Distribution records for a) *Chersina angulata*, b) *Homopus signatus* and c) *Psammobates tentorius* within the relevant study area. Records obtained from the SARCA database are shaded red while the records from the Tankwa survey are shaded in yellow.

2.3.2. Species turnover

The β-values indicating the proportion of species losses and gains between the Tankwa Basin and the larger Cederberg area to the west and between the Tankwa Basin and the Roggeveld escarpment and plateau to the east are presented in Table 2.4. In both cases the turnover is high. Species turnover between the Cederberg and Roggeveld areas is exceptionally high. Forty five species were recorded in the Cederberg transect, 30 in the Tankwa transect and 24 for the Roggeveld escarpment and plateau. The species unique to or shared between two or all three of the different transects are summarised in Table 2.6.

The corresponding β-values and species lists indicating turnover across the north/south axis of the Tankwa Basin are presented in Tables 2.5 and 2.7 respectively. Similar to the west-east axis, turnover along the north-south axis is also high. The species richness for the relevant transects for the southern, northern and Tankwa regions respectively are 37, 23 and 25 species each.

In Figure 2.11 shematic representations of the numbers of shared species between a) the Cederberg, Tankwa Basin and Roggeveld, and b) the Tankwa Basin and the areas emmediately south and north of it.
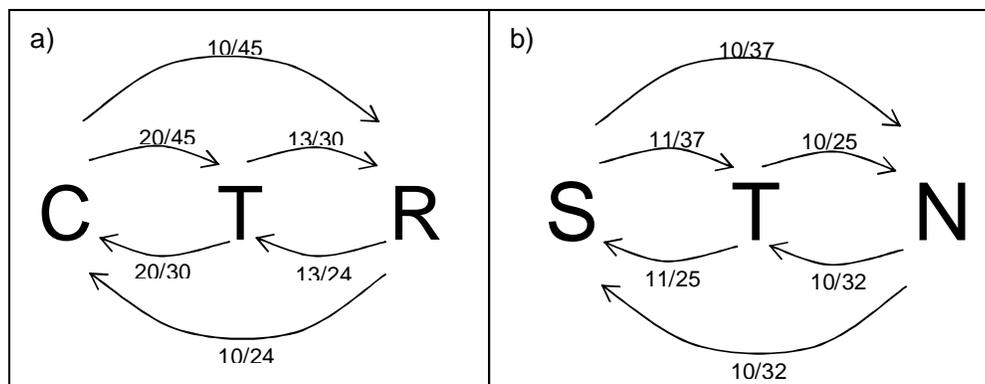
Figure 2.11. Schematic diagram of number of shares species between a) Cederberg (C), Tankwa (T) and Roggeveld (R), and b) the areas south (S) and north (N) of the Tankwa Basin (T).

Table 2.4. Species turnover (β) between the Tankwa Karoo Basin, the greater Cederberg area in the west, and the Roggeveld escarpment and plateau in the east, was calculated by dividing the number of species unique to both the focal (*c*) and the neighbouring (*b*) area with the sum of (c), (b) and (*a*) – the number of species shared by the two regions. β-values range between a minimum of zero (no turnover) and a maximum of one (complete turnover).

	a	b	c	β
Tankwa vs Roggeveld	13	11	17	0.68
Tankwa vs Cederberg	20	25	10	0.64
Roggeveld vs Cederberg	10	35	14	0.83

Table 2.5. Species turnover (β) between the Tankwa Karoo Basin, the Hantam area in the north, and the Bontberg area in the south, was calculated by dividing the number of species unique to both the focal (*c*) and the neighbouring (*b*) area with the sum of (c), (b) and (*a*) – the number of species shared by the two regions. β-values range between a minimum of zero (no turnover) and a maximum of one (complete turnover).

	a	b	c	β
Tankwa vs South	11	26	14	0.78
Tankwa vs North	10	12	15	0.73
South vs North	10	12	27	0.80

Table 2.6. Summary of the reptile species unique to or shared between three transects in respectively the larger Cederberg area (C), the Tankwa Basin (T) and the Roggeveld escarpment & plateau (R) (refer to Appendix A for full species names).

C	T	R	C & T	T & R	C, T & R	C & R
A. australis	B. caudalis	A. aculeata	B. arietans	A. hispida	C. polyzonus	A. atra
A. porphyreus	N. nivea	C. namaquensis	C. angulata	C. angulifer	N. tessellata	A. lubricus
B. atropos	T. occidentalis	D. scabra	C. bibronii	D. multimaculata	P. lineoocellata	L. capensis
B. gutturale		M. suborbitalis	C. cataphractus	H. boulengeri	P. mariquensis	P. purcelli
B. rubida		P. garrulus	C. subtessellatus	L. gracilior	P. notostictus	
C. mclachlani		P. namaquensis	G. lineata	P. laticeps	T. sulcata	
D. typus		R. schinzi	M. knoxii	P. tentorius		
G. hexapora			P. capensis			
G. microlepidota			P. formosus			
H. signatus			P. geitje			
L. guttatus			P. rhombeatus			
L. rufulus			P. weberi			
M. lineatus			T. capensis			
N. woodi			T. variegata			
P. burchelli						
P. microlepidotus						
Ps. capensis						
R. lalandei						
T. beetzii						
T. homalocephala						
T. montana						

Table 2.7. Summary of the reptile species unique to or shared between three transects in respectively the Tankwa Basin (T) and the regions just to the south (S) and north (N) of the basin (refer to Appendix A for full species names).

S	T	N	S & T	N & T	N & S	N, S & T
A. meleagris	*C. bibronii*	*B. cornuta*	*P. mariquensis*	*A. hispida*	*A. lubricus*	*B. arietans*
A. atra	*C. subtessellatus*	*D. multimaculata*	*P. notostictus*	*B. caudalis*	*L. capensis*	*C. angulata*
A. australis	*C. cataphractus*	*H. boulengeri*	*T. capensis*	*C. angulifer*	*P. tentorius*	*C. polyzonus*
B. rubida	*G. lineata*	*H. signatus*	*T. sulcata*	*P. weberi*	*R. lalandei*	*N. nivea*
B. gutturale	*L. gracilior*	*H. lacteus*	*T. variegata*			*P. geitje*
C. cordylus	*N. tessellata*	*L. nigricans*				*P. lineoocellata*
G. typicus	*P. capensis*	*P. cana*				
H. areolatus	*P. formosus*	*S. sexlineatus*				
L. aurora	*P. laticeps*					
L. fiskii	*T. occidentalis*					
L. guttatus						
L. rufulus						
M. knoxii						
P. maculata						
P. oculatus						
P. burchelli						
P. subrufa						
P. rhombeatus						
P. microlepidotus						
T. homalocephala						
T. gularis						
T. montana						

2.4. DISCUSSION

2.4.1. Distribution records

The reptile fauna of the sparsely vegetated, slightly undulating plains of the intramountain Tankwa Karoo Basin is largely limited to terrestrial and burrowing forms. Species richness is lower than in the surrounding mountainous areas to the North, West and South of the Basin. Low species richness is to be expected for a homogeneous area such as the Tankwa Karoo Basin. There are no endemic species and the reptile fauna contains elements from all surrounding areas.

With the general paucity of rocky habitats in the Tankwa Basin it is to be expected that rock-dwelling reptiles will be less well represented. Yet, wherever the plain is interrupted by isolated dolerite buffs or slightly elevated ridges, a complement of rock-dwelling forms typical of the surrounding mountainous areas, were present, typically the Karoo Girdled Lizard (*Cordylus polyzonus* – Figure 2.8g), the Karoo Skink (*Trachylepis sulcata* – Figure 2.8w), the Variegated Skink (*Trachylepis variegata* – Figure 2.8x) and Bibron's Gecko (*Chondrodactylus bibronii* – Figure 2.8d*).* The Southern Rock Agama (*Agama atra* – Figure 2.8a), on the other hand, is notably absent in the Tankwa Basin and is restricted to the surrounding mountains. Branch (1998) gives the range of *A. atra* as occurring throughout the Western Cape and most of the Northern and Eastern Cape. This is a gross over-estimation of its true range as it is clearly absent from the western coastal lowlands and from the Tankwa Karoo Basin. Its absence from the south-western coastal areas north of the Cape Peninsula has also been noted by Oelofsen *et al.* (1987).

The presence of *C. bibronii* on man-made structures throughout the basin, in many cases surrounded by vast stretches of rock-less habitat, highlights the unique dispersal ability of this rock-dwelling lizard. Likewise, the presence of the Armadillo Lizard (*Cordylus cataphractus* – Figure 2.8f) on the Perdebergkoppies, two small tillite outcrops surrounded by vast stretches of unsuitable habitat, was very unexpected.

The Cape Sand Lizard (*Pedioplanis laticeps* – Figure 2.8s) is the dominant species on the Tankwa plains. Branch (1998) gives the range of this species as central Karoo and it is clear that the Tankwa Karoo Basin provides a north-south dispersal corridor for this species. It co-occurs with the Spotted Sand Lizard (*P. lineoocellata pulchella* – Figure 2.8t) on the plains, but there appears to be distinct habitat partitioning between the two. *Pedioplanis l. pulchella* appears to prefer rockier habitat, while *P. laticeps* prefers the gravel plains with minimal vegetation cover. In the west, Knox's Desert Lizard (*Meroles knoxii* – Figure 2.8j) marginally enters the Tankwa Basin where it co-occurs with the two Sand Lizard species, but is restricted to sand habitat. The Southern Spiny Agama (*Agama hispida* – Figure 2.8b) is also abundant in the central parts of the Tankwa Karoo Basin.

The range of the Giant Ground Gecko (*Chondrodactylus angulifer* – Figure 2.8c) is depicted by Branch (1998) as reaching as far south as an imaginary east-west line through Saldanha and Piketberg. The SARCA database, which is the most comprehensive database for southern African lizards, however, contains no records for this species south of 32° S within the study area. The range given by Branch (1998) therefore appears to be grossly over-estimated. It is, however, clear that the arid Tankwa Karoo Basin serves as a southward dispersal corridor for this species. The four distribution records for *C. angulifer* are the first records for the Tankwa region and are also the most southerly records for this species in the study area. The ranges of terrestrial geckos, notably the Striped Dwarf Leaf-toed Gecko (*Goggia lineata* – Figure 2.8i), Marico Thick-toed Gecko (*Pachydactylus mariquensis* – Figure 2.8q) and Cape Thick-toed Gecko (*P. capensis* – Figure 2.8m) do not appear to be influenced by the arid Tankwa Karoo Basin. One exception is the Ocellated Thick-toed Gecko (*P. geitje*) which appears to be absent from the Tankwa plains. As far as rock-dwelling geckos are concerned, the basin clearly acts as a dispersal barrier for the Rough Thick-toed Gecko (*P. formosus* – Figure 2.8n)*,* Thin-skinned Thick-toed Gecko (*P. kladeroderma* – Figure 2.8p) and Cedarberg Dwarf Leaf-toed Gecko (*G. hexapora* – Figure 2.8h).

In contrast to the Giant Ground Gecko (*C. angulifer*), of which the range extends southwards along the whole breadth (west to east) of the basin, the Horned Adder (*Bitis caudalis* – Figure 2.9b) and Bushmanland Tent Tortoise (*Psammobates tentorius verroxii*), also two essentially northern forms in the study area, appears to have southern range extensions only along the western side of the basin. *Psammobates t. tentorius* appears to be restricted to a narrow east to west zone in the southern part of the basin. One would expect a contact zone (or zone of intergradation) between these two subspecies in the south-western area of the basin.

There were only four previous records for the Western Three-striped Skink (*Trachylepis occidentalis*)*,* within the study area, located closely together in the Anysberg region (Figure 2.8v).   Although this species has a widespread distribution stretching from northern Namibia through the central karroid regions of the Northern Cape Province down to the Anysberg (Branch 1998), it has never been recorded in the Tankwa Karoo Basin. The new records reported here therefore extends this species' recorded range to the west.

The Tankwa distribution records reported here for the Armadillo Girdled Lizard (*Cordylus cataphractus*), Striped Dwarf Leaf-toed Gecko (*Goggia lineata*) and Black Spitting Cobra (*Naja nigricollis woodi*) (Figure 2.9g) extend the known distribution ranges of these three species in an easterly direction. The new *N. n. woodi* record is more than 75 km east of previous records.   The record for the Thin-skinned Thick-toed Gecko (*Pachydactylus kladeroderma*) on the slopes of the Pienaarsfontein se Berg mountain range extends the recorded distribution range of this gecko species to the west. This is a rock-dwelling species with a relatively restricted distribution from the inland Great Escarpment on the Nuweveldberg to the southern Cape Fold Mountains (Branch 1998). The new record is more than 60 km SW and 70 km NW from the two SARCA database records nearest to it and extends the range in a westerly direction by approximately 45 km.

2.4.2. Species turnover

The method of comparing species composition, and subsequently determining species turnover across the Tankwa Karoo Basin, by means of transects/blocks composed from adjacent QDS grid cells was chosen in order to avoid 1) the problem of arbitrarily defining the limits of the regions, and 2) comparing areas of unequal size with each other. As mentioned, an exception was made in the case of the Roggeveld escarpment & plateau, for which an additional cell was included since the area is severely under sampled.

From the diagram in Figure 2.11a it is clear that where nearly half of the Cederberg species is also in the Tankwa only a quarter are shared with the Roggeveld. Fully two thirds of the Tankwa species are shared with Cederberg and just more that a third also occur in the Roggeveld. More than half of the Roggeveld species also occur in the Tankwa and just a litte less than half of the Roggeveld species are also recorded in the Cederberg transect. Along the north-south (Figure 2.11b) axis of the Basin less than a third of the southern species are recorded in the Tanwka and the area noth of it. Less than half of the species recorded in the Tankwa occur in either the areas north and south of it. The area north of the Tankwa shares just a little bit less than a third of the species recorded for the region with the Tankwa Basin transect species and the southern transect.

Species turnover along both the west-east and north-south axes across the Tankwa Basin is high, a clear indication of the biogeographical influence of the Tankwa Karoo Basin on reptile distribution. The arid basin clearly forms a dispersal barrier for many species occurring in the more mesic surrounding areas. In the west and the south, the Cederberg/Swartruggens/Tankwa Karoo Basin and Bonteberg area-Tankwa Karoo Basin transitions also mark the transition between the Fynbos and the Succulent Karoo Biomes. It is clear that the major transition vegetation coincides with a major transition in reptile species composition. In the east and north the transition is less clearly demarcated, all areas falling within the Succulent Karoo Biome. The observation that the Tankwa Karoo Basin has higher species richness than the less arid Hantam area in the north is

interesting and can probably be explained by the fact that several species from the Cederberg/Swartruggens and Roggeveld areas marginally enter the Tankwa Karoo Basin, but are absent in the Hantam area.

The summary lists (Tables 2.6 and 2.7) of species unique to or shared between regions are a useful aid to inspect the compositional differences between the areas. It should be mentioned that these can not be considered absolute lists and should only be regarded as a first step in the characterisation of the species assemblages concerned. Because of the nature of the dataset (point distribution) and the fact that for some species only a portion of their entire distribution ranges are included in the study area, as well as the fact that only a limited number of cells from a particular region were included in the analyses, some species are not represented in all the relevant regions they occur in.

The significance of the Tankwa Karoo as a dispersal conduit in future climate change scenarios will be difficult to assess without knowledge of how rainfall patterns will change in the basin. Taking into account the greater number of shared species between the areas east and west of the basin than between areas north and south of the basin, west-east connectivity across the basin is from a conservation point of view probably more important than north-south connectivity. The Tankwa Karoo National Park, as part of the Greater Cederberg Biodiversity Corridor, already spans the basin along the west-east axis. Since agricultural production is very low in the Tankwa Basin, only a small portion of land has been transformed, although some areas have been heavily overgrazed and are invaded by alien plants (Mucina *et al.* 2006a). Should north-south connectivity become an issue, additional conservation areas would probably not be required.

In summary, the results of this study show that the Tankwa Karoo Basin acts as a dispersal barrier for many reptile species occurring in the surrounding more mesic areas. At the same time, it acts as a southward dispersal corridor for several species, notably *Chondrodactylus angulifer, Trachylepis occidentalis, Bitis caudalis, Dipsina multimaculata*

and *Psammobates tentorius verroxii*. It contains no unique elements and its reptile fauna

can best be described as transitional.

Chapter 3

Reptile diversity patterns in the south-western region of South Africa

3.1.   INTRODUCTION

3.1.1. Problem statement

South Africa and in particular the Western and Northern Cape Provinces, is renowned for its reptile diversity and endemism (Hilton-Taylor & Le Roux 1991; Bauer 1993; Baard *et al*. 1999; Baard & de Villiers 2000). The latter two provinces also harbour two of the world's 25 recognised biodiversity hotspots (Myers *et al*. 2000), namely the Succulent Karoo and the Cape Floristic Region. Two measures which are commonly used to describe the biological diversity of a region are species richness (or alpha diversity) and species turnover (or beta diversity). Information on these diversity components and endemism are useful to direct conservation prioritisation strategies (Kier & Barthlott 2001; Slatyer *et al.* 2007). Although information on each of these measures by themselves can make a considerable contribution during conservation planning, their impact may increase substantially when regarded in combination (Orme *et al.* 2005; Brooks *et al.* 2006; Lamoreux *et al.* 2006). For example, putting conservation focus largely on areas of high richness might only ensure the preservation of a large number of widespread and/or common species whilst centres of endemism may be left unattended. Furthermore, conserving mainly areas of endemism may in turn lead to expending effort (time and funding) which may not produce long-term success. The objective should therefore rather be to locate areas where some of these properties of diversity can be conserved simultaneously and/or to devise a reserve system which would, as a whole, be representative of the different components of diversity.

A number of authors have investigated the coincidence of species richness and endemism patterns within, as well as the spatial correlation of these phenomena between taxa, at various geographical scales. A study by Kerr (1996) on the species richness and endemism patterns of four taxa (Mammalia, *Lasioglossum*, Plusinae and Papilionidae) in North America indicated that richness and endemism patterns were generally matching within taxa, but not between taxa. A continental scale analysis of endemism in the Australian flora (Crisp *et al.* 2001) found that in general centres of endemism coincide with centres of species richness. However, in another study by Slatyer *et al.* (2007), which investigated endemism and species richness in Australian Anura, regions identified to be significant in terms of endemism differed from those identified for their species richness value. Furthermore, Slatyer *et al.* (2007) also showed that endemism patterns between the three main anuran families differed. The global geographical distribution of hotspots of species richness, threat and endemism of breeding birds were found to be incongruent (Orme *et al.* 2005). In contrast, Lamoreux *et al.* (2006) state that global richness as well as endemism patterns between amphibians, reptiles, birds and mammals are correlated significantly. They do, however, report that the correlation between richness and endemism patterns is weak.

For the south-western region of South Africa, reptile endemism has until now only been discussed to the degree of general statements regarding the relatively high number of endemic species occurring in the (largely congruent) Western Cape Province and the Cape Floristic Region respectively. Twenty one reptile species are described as endemic to the Western Cape Province (Baard & De Villiers 2000) (17 lizards, two snakes and two tortoises), and Baard *et al.* (1999) mention that 19% of the reptile species occurring in the Cape Floristic Region are endemics. It has, however, never been investigated whether any distinct pattern exists, i.e., overlap in the ranges of these endemic species. Identifying such possible centres of endemism is very important from a conservation point

of view to aid in the identification of priority areas (Simmons *et al.* 1998; Kier & Barthlott 2001; Crisp *et al.* 2001; Slatyer 2007).

3.1.2. Terminology

In his article on the relationship between area and endemism, Anderson (1994) points out that one of the major problems encountered when dealing with the phenomenon of endemism, is of a semantic nature. The terms 'endemic' and 'endemism' are used with different meanings in various disciplines and even within the zoogeographical literature several distinct definitions have been implemented. Consequently, if not clearly defined, these terms may become vague concepts which could easily be misinterpreted.

For the purpose of this thesis the commonly used definition, that *a species is considered as an endemic to a particular area if it occurs only in that area* (Anderson 1994; Crisp *et al.* 2001), was adopted. This definition inherently implies that a clearly defined limited area should be specified. Sometimes there is also an additional condition that the area should be 'small', but as pointed out by Crisp *et al.* (2001) endemism is a scale-dependant phenomenon and the classification of a species' distribution range as 'small' is dependant on the geographical extent of the area under consideration. There are, however, methods available which have been developed to obviate the problem of defining a minimum range-size threshold to determine which species are endemics and which are not (Crisp *et al.* 2001; Linder 2001a; Slatyer, 2007) (see section 3.2.2).

It is also important to realise the difference between "areas of endemism" and "centres of endemism" when dealing with the subject of endemism. Although there are many different opinions and definitions in the literature on what should be defined as an "area of endemism" (Anderson 1994; Hausdorf 2002; Szumik *et al.* 2002) it is generally recognized by the coinciding distribution ranges of two or more endemic taxa (Crisp 2001; Laffan & Crisp 2003). A "centre of endemism" is an area where a larger number of endemic

species than expected relative to the surrounding landscape occurs (Crisp 2001; Laffan & Crisp 2003). Biogeographers and ecologists are interested in these areas for different reasons. Biogeographers aim to explain how evolutionary processes shaped the location and ranges of species' distributions either by restriction through a unique combination of ecological factors, or by a history of vicariance events and subsequent speciation in isolation (Crisp *et al.* 2001; Hausdorf 2002; Laffan & Crisp 2003). In turn, ecologists are interested in identifying such areas for the conservation value they may hold – these habitats and the associated species often represent a significant component of the biodiversity of a region (Jetz *et al.* 2004) and are commonly vulnerable due to rarity and/or threat (Fjeldså 1994; Gaston 1994; Myers *et al.* 2000).

3.1.3. Objectives

In terms of the objective of the present study to investigate the importance of the Greater Cederberg Biodiversity Corridor for reptile conservation, it was considered relevant to determine to what degree different diversity components correlate. This chapter is therefore devoted to characterising reptile distribution patterns in the area south of 31° latitude and west of 21° longitude in terms of endemism, species richness and turnover. A further objective was to evaluate the quality of the reptile distributional data currently available for south-western South Africa.

3.2.   METHODS

An inherent challenge when working with any dataset originating from natural history collections, such as the present one, is the incidence of false-absences, which are abundant when working with presence-only point distributions (Graham *et al.* 2004), as well as false-presences which occur with the creation of generalised range maps and/or minimum convex polygons (Burgman & Fox 2003). In order to minimise both of these errors and since the focus of the present study is on large-scale regional patterns it was

decided to translate the presence-only point distributions to quarter degree- and eighth degree square grid resolutions.

3.2.1. Species richness

The most direct way of representing species richness or alpha diversity (α) is by a simple count per unit area (Whittaker 1972). It is one of the most commonly used measures of diversity in the literature (Lennon 2001). Therefore, for this study, richness maps were generated at both quarter degree square (QDS) and eighth degree square (EDS) resolution for the entire reptile dataset as well as for snakes and lizards separately by adding up in each case the relevant number of species which have been recorded within each grid cell. The resultant richness count values were then mapped with the GIS programme ArcView 3.2 (ESRI) which resulted in easily interpretable graphical representations of the species richness patterns.

3.2.2. Endemism

Three methods were used to map the reptile endemism patterns in the study area at both QDS and EDS resolutions. The first and most simple approach was to consider only species which are endemic (100% of their range within study area) to the defined study area and subsequently creating a map depicting merely the number of endemic species which have been recorded within each cell.

Weighted endemism (WE) (Crisp *et al.* 2001; Linder 2001a; Slatyer *et* al. 2007) is a method which is implemented to avoid the use of an arbitrary region or a range-size threshold in the definition of endemic species. It is essentially a grid-based method which incorporates all species present in the study area with each species contributing a certain weight to a cell in which it occurs according to a continuous weighting function. A species' weight is determined by calculating the inverse of its range – i.e. the inverse of the number of cells in which it occurs (Crisp *et al.* 2001; Linder 2001a; Slatyer *et al.* 2007).

Therefore, a species occurring in only a few cells will contribute a much higher weighted endemism score to a particular cell than another species with a very wide distribution range. The individual weights of all species present in a cell are then summed to obtain the WE score for each cell and therefore cells with the highest total WE score should represent areas where many range-restricted species are present (Linder 2001a).

Because weighted endemism has been found to be correlated with species richness patterns (Crisp *et al.* 2001; Linder 2001a) another index termed corrected weighted endemism (CWE) has been derived simply by dividing the weighted endemism score by the total count of species (richness) in a cell (Crisp *et al.* 2001; Linder 2001a). One caveat is that both WE and CWE have been found to be sensitive to sampling bias to some degree (Linder 2001a; Slatyer *et al.* 2007). It was therefore decided to exclude from these analyses those species (with extensive distribution ranges) for which distribution records are severely deficient as well as species of which the ranges just enter the study area and which are subsequently only recorded in a few cells along the periphery of the study area. Such species would falsely contribute a high weighting value to cells. Maps depicting the resultant WE and CWE scores were generated in ArcView 3.2 (ESRI). The natural breaks method (which is recommended for data which are unevenly distributed) was used to classify the grid cells into six classes which are represented in graduated colours, the darker the hue of a cell the higher WE or CWE score it represents.

3.2.3. Turnover

The spatial turnover or change in the identities of species, i.e., species replacement, is called beta diversity (β) or species turnover and represents an essential component of the spatial pattern of biodiversity (Whittaker 1972; Koleff *et al.* 2003). The beta diversity measure chosen to calculate the species turnover for reptiles in the chosen study area is called β_{sim} and was formulated by Lennon *et al.* (2001) who based it on the original formulation of Simpson (1943).

Koleff *et al.* (2003) conducted a comparative review of a subset of 24 of the numerous measures which have been applied in the literature to investigate beta diversity patterns. They encourage the use of matching components which introduces a standard by which different methods can be compared and they subsequently re-expressed the original formulations in terms of these matching components. In order to clarify the concept of matching components, consider two equal-area quadrates – a 'focal quadrate' and a 'neighbouring quadrate'. Matching components are defined as *a*, *b*, and *c* where *a* is the total number of species occurring in both the focal and neighbouring quadrates, *b* is the number of species occurring only in the neighbouring quadrate and *c* is the number of species occurring only in the focal quadrate. Re-expressed in terms of these matching components the β_{sim} diversity index is as follows:

$$\beta_{sim} = \frac{\min(b,c)}{\min(b,c) + a}$$

This particular index was chosen because it has the property of measuring species gain and loss – it focuses more on compositional differences than on differences in species richness (Koleff *et al.* 2003). This was regarded as an important factor to take into consideration since there is a danger that one could just end up rediscovering local richness gradients (Lennon *et al.* 2001) and species richness is considered independently in another section of this chapter. Furthermore, Lennon *et al.* (2001) empirically verified that β_{sim} adjusts for richness gradients between adjacent quadrates and is therefore not influenced by local differences in richness.

The analysis of beta diversity patterns was conducted by means of the grid system – at both QDS and EDS resolutions. At each resolution turnover was calculated on a 3 x 3 cell neighbourhood basis. The matching components, *a*, *b* and *c*, of all cells with data were used to calculate individual values of β_{sim} for each focal- vs. neighbouring quadrate combination. These values were subsequently averaged to obtain the final beta-diversity score for each focal cell. The β_{sim} values range between a minimum of zero (no turnover

between focal cell and neighbourhood) and a maximum of one (complete turnover / no shared species between focal cell and neighbourhood).

3.3. RESULTS AND DISCUSSION

3.3.1. Species richness

The quarter degree square (QDS) resolution is regarded to be a better representation of actual species distribution patterns, however, a number of aspects regarding the dataset are especially apparent in the EDS maps. Species richness patterns, at both QDS and EDS resolutions, for reptiles, lizards and snakes are depicted in Figures 3.1, 3.2 and 3.3, respectively. Richness patterns are highly congruent between the two resolutions. The focus of this thesis is on regional-scale diversity patterns and therefore description and discussion of patterns will mainly be limited to QDS resolution.

Extensive sampling bias in the study area is immediately obvious from the species richness plot for reptiles depicted in Figure 3.1. Cells containing nature conservation areas (Figure 3.4) almost invariably have high species counts, reflecting more intensive surveying in these areas. A Man-Whitney U Test which compared the richness values of reserve cells with that of non-reserve cells proved that this bias in the data is significant at QDS resolution for the datasets of all reptiles combined (n_{res} = 59; $n_{non-res}$ = 115; U = 1362; p < 0.0001), lizard species only (n_{res} = 59; $n_{non-res}$ = 115; U = 1474; p < 0.0001) as well as snake species only (n_{res} = 59; $n_{non-res}$ = 115; U = 1507; p < 0.0001).

Cell FB in the north of the study area (Figure 3.1), for example, contains the Oorlogskloof Nature Reserve near Nieuwoudtville, Cell LJ the Anysberg Nature Reserve, Cell ML the Boosmansbos Nature Reserve, Cell LN the De Hoop Nature Reserve, and Cell IL the Vrolijkheid Nature Reserve (Figure 3.4). Cells with high species counts along the north-south axis in the centre of the study area (Figure 3.1) correspond with a range of reserves along the Cape Fold Mountains, including the Cederberg Wilderness Area in the north,

and the Grootwinterhoek Wilderness Area, Hawequa, Hottentots Holland Reserves, the Kogelberg Biosphere Reserve in the south as well as the Table Mountain National Park in the south-west (Figure 3.4). The large number of empty cells in the north-eastern part of the study area relative to the south-western part, particularly evident for snakes (Figure 3.3), further highlights acute sampling bias in the data. It is clear that the species richness plot for reptiles depicted in Figure 3.1 should be interpreted with great caution.

Relative to lizards, snakes are notoriously difficult to find. One would expect that during short surveys most of the lizard species present at a locality may be recorded, but only a small fraction of the snake species. It is therefore to be expected that the inflated species counts for reserves relative to surrounding areas are mainly due to snake records accumulated over time. The species richness plot for lizards (Figure 3.2) indeed shows less 'reserve inflated' cells than the plot for snakes (Figure 3.3) and should therefore be a closer approximation of the true diversity pattern. It must be pointed out that for lizards there is still a very prominent reserve effect visible in the data and caution in the interpretation of patterns is still needed.

From Figure 3.2a it is apparent that in the study area, lizard species richness is high along the Cape Fold Mountains, but with a north to south decline in numbers along the north-south section of the mountains. This is evident when comparing well-sampled areas from the north and south. Cells EF and FF, representing the Cederberg Wilderness Area in the north, have a high species count of 22-27 species, while Cells EM and FM, representing the Landdroskop area in the Hottentots Holland Mountains (Hottentots Holland Nature Reserve) have a relatively low count of only 6-10 species. Numerous studies have been conducted in the Landdroskop area and the lizard fauna is well known (see, e.g., Mouton 1987; Mouton & Van Wyk 1990, 1995; Du Toit 2001; Costandius & Mouton 2006; Costandius *et al.* 2006). There are, for example, no less than seven gecko species present in the Cederberg Wilderness area and only one in the Landdroskop area (Mouton

pers. com.). The ranges of several 'southern' species (e.g., *Tetradactylus tetradactylus*, *T. seps*, *Cordylus cordylus*, *Pseudocordylus microlepidotus*, *P. capensis*, *Trachylepis homalocephala*, and *Afrogecko porphyreus*, to name but a few, extend quite a way northwards along the Cape Fold Mountains. Several 'northern' species present in the Cederberg area, drop out towards the south. It is clear that the Cederberg area contains elements of both 'southern' and 'northern' lizard assemblages (see Chapter 4), while the Landdroskop area harbours only a 'southern' assemblage.   The high rainfall in the extreme south-western areas may render conditions less suitable for reptiles in this area. High rainfall in the south-west and resultant low solar radiation during late winter/spring when food availability peaks in the winter rainfall area, for example, has been advanced as possible reasons for *C. cataphractus* not to occur further south than Piketberg (Cell DH) (Mouton *et al.* 2008).

Judging by the high species counts recorded in the Anysberg (Cell LJ) and Boosmansbos (Cell ML) areas, there is probably a similar decline in lizard species richness in the study area from east to west along the southern ranges of the Cape Fold Mountains. Because of poor sampling in the mountainous areas immediately west of Anysberg and Boosmansbos, the decline is not as apparent as along the northern ranges of the Cape Fold Mountains.

It is clear from Figure 3.2a that cells for which high lizard species counts were recorded are, with one exception, montane areas. This is in line with one of the popular hypotheses put forward to explain spatial variability in species richness, namely that of habitat heterogeneity (Currie 1991).   Elevation variability or topographic heterogeneity is commonly used as a surrogate for habitat heterogeneity under the assumption that an area with high topographic relief has high spatial variability in mesoscale climate and therefore harbours a larger number of different habitats (Rodríguez *et al.* 2005). Kerr & Packer (1997) showed topographic relief to be a determinant of mammal species richness

and Rodríguez *et al.* (2005) found evidence of elevation variability driving reptile richness variation.

Low species richness for lizards recorded in the south-western coastal lowland area, south of the Piketberg Mountains and west of the Cape Fold Mountains (Swartland area) is probably not a sampling artefact. Although this area has almost completely been transformed for agricultural purposes (Rouget *et al.* 2006), patches of natural habitat still remain and these have been extensively surveyed by Oelofsen *et al.* (1987). This lowland area originally comprised renosterveld (Mucina & Rutherford 2006), a habitat type generally not high in lizard richness (Baard 1990).

Several areas along the south-western coast show higher richness than adjacent inland areas and in the Lambert's Bay area (Cells CF, CG, CH), species counts are particularly high for a lowland area. The coastal zone is charaterised by a rich burrowing reptile fauna, the Cape Legless Skink (*Acontias meleagris*), Striped Legless Skink (*Microacontias lineatus*), Coastal Legless Skink (*M. litoralis*), Cape Dwarf Burrowing Skink (*Scelotes caffer*), Gronovi's Dwarf Burrowing Skink (*S. gronovii*), Kasner's Dwarf Burrowing Skink (*S. kasneri*), Bloubergstrand Dwarf Burrowing Skink (*S. sexlineatus*), Cuvier's Blind Legless Skink (*Typhlosaurus caecus*), although there are also several other species for which the ranges are restricted to the coast such as the Namaqua Dwarf Chameleon (*Bradypodion occidentale*), Austen's gecko (*Pachydactylus austeni*) and Large-scaled girdled lizard (*Cordylus macropholis*). The coastal zone from the Cape Peninsula to just north of Lambert's Bay has been well sampled and the recorded species counts are probably a true reflection of species richness along the coast. The Langebaan-Saldanha area acts as a refugium for melanistic lizard species and populations (Cordes & Mouton 1996) and once the taxonomic status of some of the melanistic populations has been resolved (see, e.g., Mouton *et al.* 2002) the species count for this area may rise.

Sampling in the southern coastal lowland areas appears to have been poor (see Figure 3.2b) and it would be premature to conclude that richness is low along this section of the coast.   Likewise low richness in the north-eastern part of the study area is likely a sampling artefact.   In summary, the species richness pattern that emerges from the available data for lizards in the study area is that richness is high along the Cape Fold Mountains and higher in the northern and eastern sections than in the south-western sections of the mountains.   There is also relatively high diversity along the south-western coast, peaking in the Lambert's Bay area.   It is, however clear that low data quality is a major problem, precluding any firm conclusions.

The observed richness plot for snakes in the study area (Figure 3.3a) differs substantially from that recorded for lizards.   There are relatively high snake counts in the area from the Cape Peninsula to Stellenbosch (Cells CL, DL, EL).   This is also the most densely populated area in the Western Cape and it could be that these relatively high figures reflect a high incidence of snake reporting by the public.   The highland-lowland dichotomy in richness is, however, less apparent in snakes than in the case of lizards. The diet of snakes (ranging from snails and slugs, insect larvae, lizards, birds, eggs to small mammals (Branch 1998; Marais 2004)) is much more varied than that of lizards (mostly insects (Branch 1998)) and one would expect that the environmental factors determining the ranges of species will be much more varied in the case of snakes.   The poor quality of the data in the case of snakes precludes any firm conclusions regarding species richness patterns in the study area.

There is a huge discrepancy in the number of empty cells at EDS level for lizards and snakes in the data set (see Fig. 3.2b and Fig. 3.3b). For snakes, 53 % of the cells are empty and for lizards 36 %.   For both lizards and snakes the paucity in data increases towards the north-eastern inland areas, but the paucity is much more apparent in the case of snakes.   The data show that collecting has been done in some areas but that these

surveys were of too short a duration to capture local snake presence. These two plots highlight the severe reptile data deficiency for large parts of the study area.

The long absence of an up-dated distribution atlas for reptiles, which could be used as a scientific reference, is probably in part to blame for the poor quality of the available data. This forces researchers to rely heavily on popular field guides such as that of Branch (1998), Marais (2004) and Boycott & Bourquin (2000). In these books species distributions are depicted in the form of generalised range maps, not reflecting the known records within the range. Workers in the field using the field guide tend to report only those records that extend the ranges of species and not those that may fill gaps within the depicted ranges. This problem will partly be rectified by the publication of the new *Red Data Book for Reptiles for South Africa, Lesotho and Swaziland*, in which species distributions will be depicted in QDS-format (similar to the Atlas and Red Data Book of the frogs of South Africa, Lesotho and Swaziland by Minter *et al*. 2004) . It is, however, important that future field guides also use EDS- or QDS-format distribution maps like those in Tolley & Burger (2007).

The second reason for the poor quality of the data is probably also the lack of a permanent reporting avenue whereby the general public can report sight records of reptiles. Digital photography opens many possibilities for the public to report sightings without having to kill or handle the animals. Both SCARCE (www.sun.ac.za/capeherp) and SARCA (www.saherps.net/sarca) had tremendous success with their websites and inviting photographic contributions from the public. It is of paramount importance that a similar but more permanent reporting avenue be created in order to sustain public interest and participation.

A good example of the impact that public participation can have in biodiversity surveys is the success of the first Southern African Bird Atlas Project (SABAP1 1986-1991) and

projects which developed from it (Harrison *et al*. in press). Continued public participation was maintained by the launch of a number of ongoing, focussed projects (such as Coordinated Waterbird Counts (CWAC); Birds In Reserves Project (BIP) and Coordinated Avi-faunal Roadcounts (CAR)) (Harrison *et al*. 1996) and is set forth with the current, follow-up Southern African Bird Atlas Project (SABAP2) (Harrison *et al.* in press).
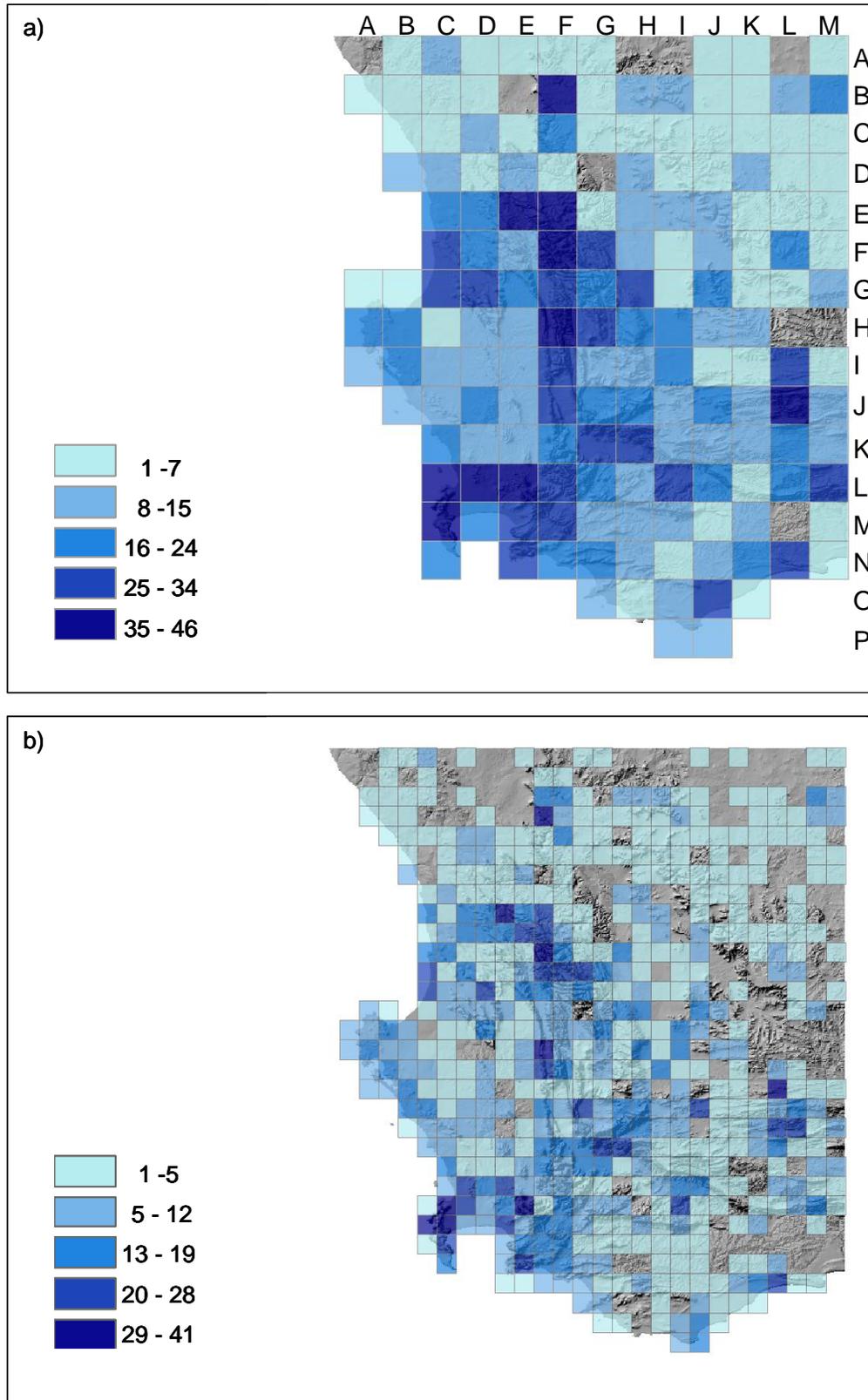
Figure 3.1. Species richness patterns for all reptile species at a) QDS and b) EDS resolutions.
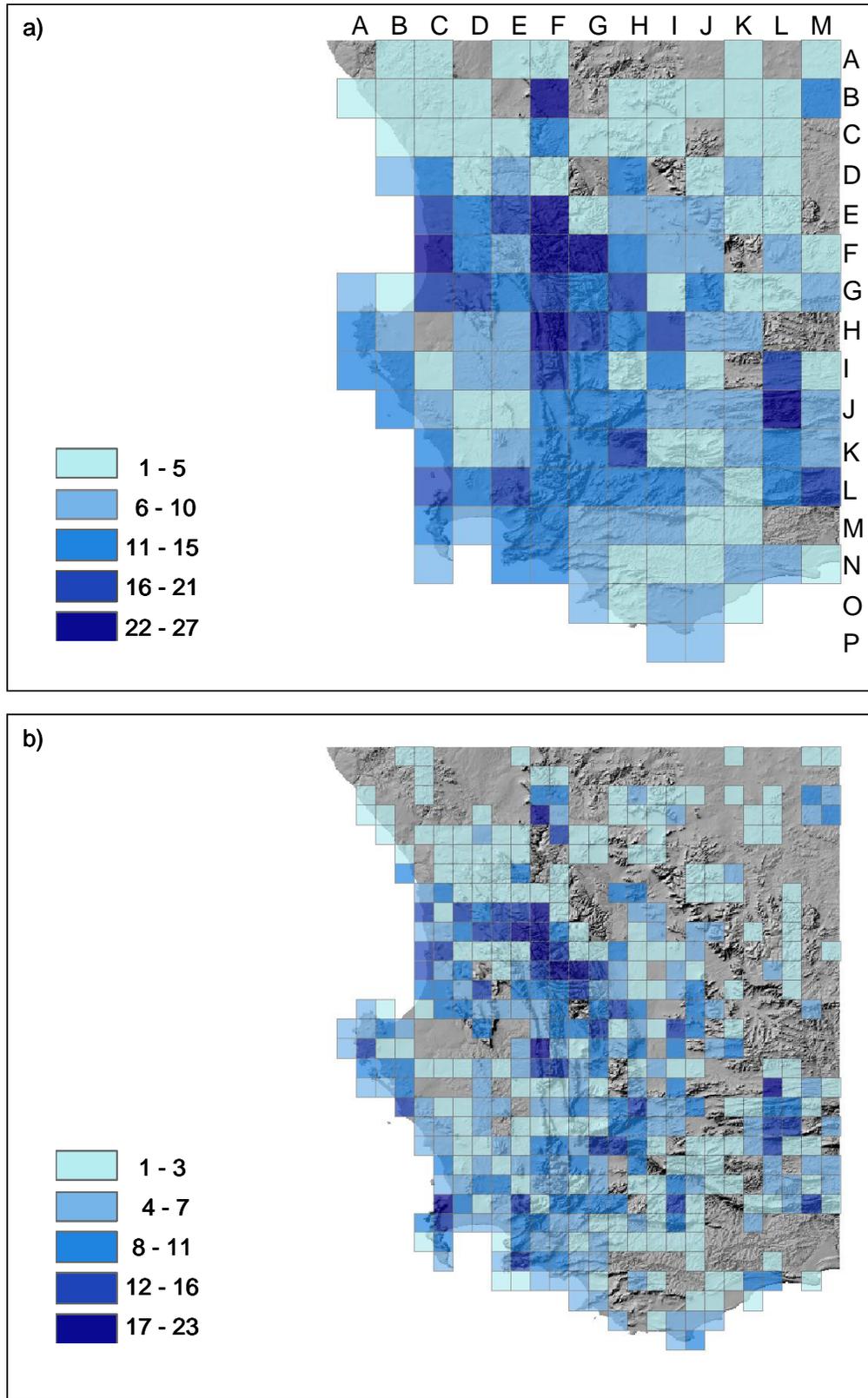
Figure 3.2. Species richness patterns for lizard species only, at both a) QDS and b) EDS resolutions.
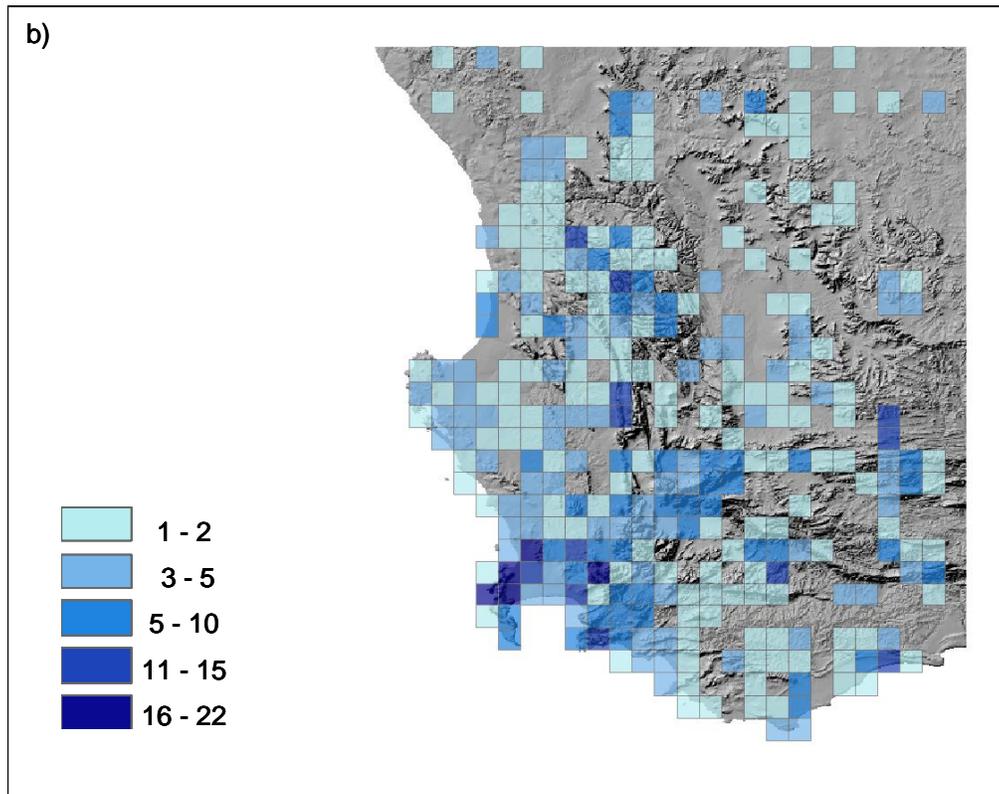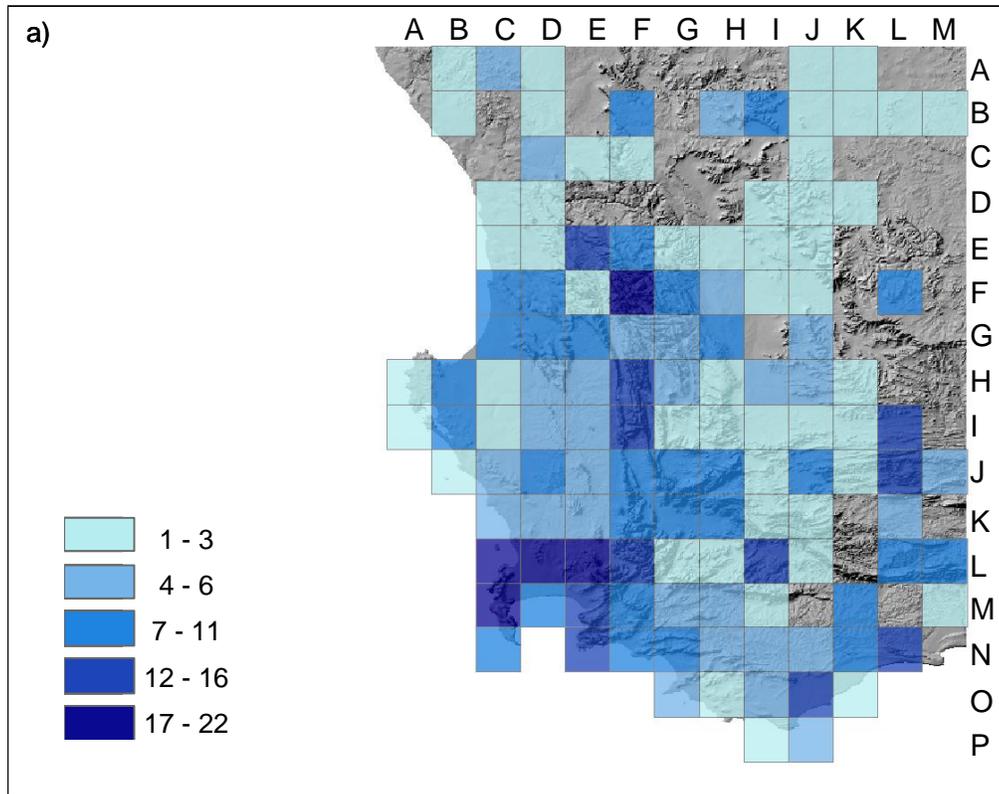
Figure 3.3. Species richness patterns for snake species only, at both a) QDS and b) EDS resolutions.
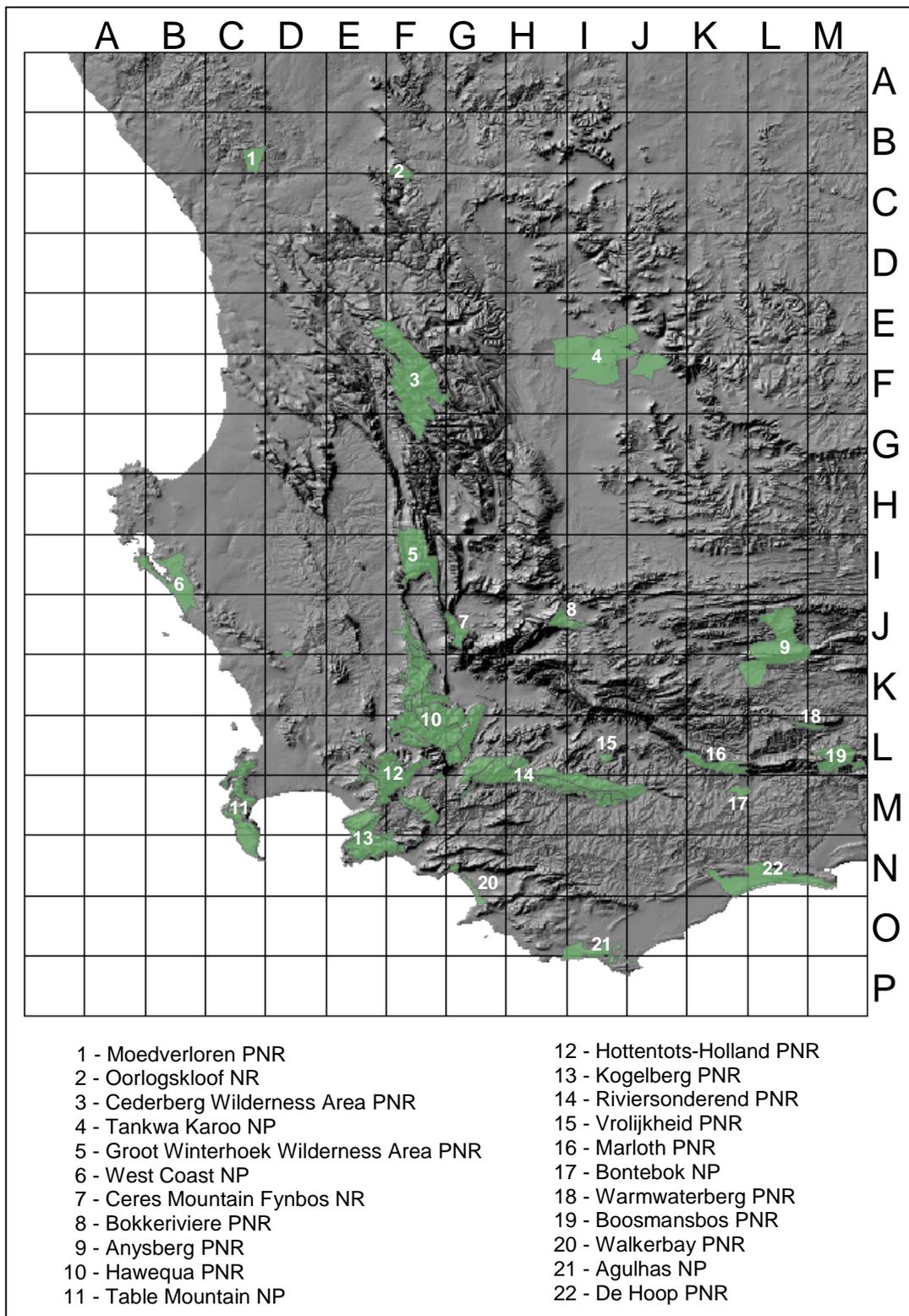
Figure 3.4. Provincial nature reserves (PNR) and national Parks (NP) in the study area are depicted as green shaded areas on the map. (PNR = Provincial Nature Reserve; NP = National Park)

1 - Moedverloren PNR
2 - Oorlogskloof NR
3 - Cederberg Wilderness Area PNR
4 - Tankwa Karoo NP
5 - Groot Winterhoek Wilderness Area PNR
6 - West Coast NP
7 - Ceres Mountain Fynbos NR
8 - Bokkeriviere PNR
9 - Anysberg PNR
10 - Hawequa PNR
11 - Table Mountain NP
12 - Hottentots-Holland PNR
13 - Kogelberg PNR
14 - Riviersonderend PNR
15 - Vrolijkheid PNR
16 - Marloth PNR
17 - Bontebok NP
18 - Warmwaterberg PNR
19 - Boosmansbos PNR
20 - Walkerbay PNR
21 - Agulhas NP
22 - De Hoop PNR

3.3.2. Endemism

There are eighteen reptile species with distribution ranges entirely contained within the study area. Daniels *et al.* (2004) pointed out that two populations of one of these species, Oelofsen's Girdled Lizard (*Cordylus oelofseni*), should actually be designated as distinct species. A total of 20 reptile species (Table 3.1) are thus considered endemic to the study area according to currently available distribution records. Figure 3.5 shows the recorded point distributions of the endemic species in relation to each other. Some species, for instance *Pseudocordylus nebulosus* and the three populations of the *C. oelofseni* complex can be termed narrow endemics whilst others, such as the Karoo Gecko (*Pachydactylus formosus* and Slender Thread Snake (*Leptotyphlops gracilior*), are substantially more widespread.

The patterns of endemism obtained via the three different methods for all reptile species combined are depicted in Figures 3.6 and 3.7 for the two resolutions, QDS and EDS, respectively. Because 16 of the 20 endemics are lizard species, weighted endemism (WE) and corrected weighted endemism (CWE) results are provided separately for lizards at QDS (Fig 3.8) and EDS (Fig 3.9) resolution.

The patterns of species richness and weighted endemism are significantly positively correlated (QDS: Spearman r = 0.96, p < 0.05; EDS: Spearman r = 0.93, p < 0.05). The correlation between species richness and corrected weighted endemism (CWE) is significant and positive (QDS: Spearman r = 0.52, p < 0.05; EDS: Spearman r = 0.27, p < 0.05), but the correlation is not as strong as for species richness and weighted endemism.

The corrected weighted endemism method was developed to correct for the possible confounding effect which species richness patterns may have on the identification of centres of endemism and represents the average degree of endemism of the species recorded in an area (Crisp *et al.* 2001; Slatyer *et al.* 2007). Therefore, according to the

CWE method, the grid cells corresponding to the species rich Cederberg Mountains only have average values as centres of endemism. Slatyer *et al.* (2007) tested the CWE method in their study on the patterns of endemism and richness in the Australian Anura. However these authors decided against CWE for two reasons: 1) it measures a different aspect of endemism from which they intended, and 2) unlike the high correlation between richness and WE (r = 0.87) which was sighted as a reason for implementing CWE by Linder *et al.* (2001a), the correlation between richness and WE (r = 0.55) was relatively low. The correlation between reptile species richness and WE endemism patterns (r = 0.93, QDS) is relatively high in the present study area and therefore it was also decided to implement CWE. However, similar to Slatyer *et al.* (2007) it was found that this measure generates high endemism scores in some poorly sampled areas and in particular where widespread species are poorly sampled.

In contrast to the case of species richness plots, the data appear to be sufficient to capture the basal patterns of reptile endemism in the study area. The plot of the number of study area endemics present per cell clearly shows that the north-south section of the Cape Fold Mountains harbours the most study area endemics (Figure 3.6a). When range size is brought in as a factor in describing endemism, several other areas beside the greater Cederberg area are highlighted. The weighted endemism plot for lizards (Figure 3.8a) shows that the lizard species endemic to the greater Cederberg area (e.g., *Goggia microlepidota*, *G. hexapora*, *P. formosus*, *Australolacerta australis*, *Cordylus mclaclani*), which can be considered the first set of endemic species in the study area, all have relatively large ranges and that those with very restricted ranges occur scattered over a larger area. The Landdroskop area in the Hottentots Holland Mountains (Cells EM and FM) harbours two endemic species with restricted ranges, i.e., an undescribed *Cordylus* species closely related to *C. oelofseni* (Daniels *et al.* 2004) and *Pseudocordylus nebulosus.* The range of *P. nebulosus* is given as less than 11 km^2 (Costandius *et al.* 2006). Both are melanistic species restricted to areas of high cloud cover and orographic

fog (Mouton & Van Wyk 1995; Costandius *et al.* 2006). Taking the low species richness recorded for the two Landdroskop cells into account, the presence of two endemic species with small ranges in this area becomes even more significant (corrected weighted endemism, Figure 3.8b).

Several other refugia for melanistic species and populations have been identified in the study area. *Cordylus niger* is restricted to the Cape Peninsula and the Saldanha-Langebaan area where there is a high incidence of mist associated with the upwelling of cold water in the Atlantic Ocean (Badenhorst *et al.* 1992). *Cordylus oelofseni* occurs as a few small, isolated populations along the western section of the Cape Fold Mountains, from Piekenierskloof near Citrusdal to the Obiekwa Mountains near Tulbagh (Mouton & Van Wyk 1990). Another undescribed melanistic species closely related to *C. oelofseni* occurs in the Piketberg Mountains (Mouton & Van Wyk 1990; Daniels *et al.* 2004). These melanistic species with restricted ranges add significantly to the recorded endemism in the study area. It is, however, clear that they are relics from a previous period with very specific climatic conditions (high incidence of fog and cloud cover) and that they survive today in refugia where these conditions are still present today (Mouton & Oelofsen 1988, Daniels *et al.* 2004). It is to be expected that these melanistic endemics will be restricted to a number of different refugia and not a single one. The underlying evolutionary process responsible for this set of endemics is thus distinctly different from that describing other sets of endemics in the study area.

A third set of endemics is comprised of burrowing lizards restricted to the West Coast, from the Lambert's Bay area in the north to the Cape Peninsula in the south. *Scelotes gronovii* and *S. kasneri* occur in the Lambert's Bay area and the recently described *S. montispectus* (Bauer *et al.* 2003) from the Blouberg Nature Reserve, just north of the Cape Peninsula. All three burrowing lizards are restricted to the narrow coastal zone with its sand substrate and very specific climatic conditions associated with the cold Atlantic

Ocean. Looking at the coastal zone in a broader context, there are quite a number of species that are restricted to the narrow coastal zone, from the Gariep River in the north to the Cape Peninsula in the south (see Branch 1998), making the coastal zone a distinct area of endemism in South Africa. Besides the three burrowing species already mentioned, several of these West Coast endemics occur in the study area (e.g., *Bradypodion occidentale*, *Pachydactylus austeni*, *Cordylus macropholis*). Clearly, the West Coast endemics form a distinct set of endemics in the study area.

Besides the three sets of endemics mentioned so far, there are a few outliers, notably *Bradypodion pumilum* endemic to the south-western part of the study area, and *Cordylus minor* endemic to the extreme eastern part of the study area (Matjiesfontein to Komsberg). *Afroedura hawequensis*, endemic to the Cape Fold Mountains from Wellington to Villiersdorp (Mouton et al. 1987) can probably be added to the greater Cederberg set of endemics.

Of the four remaining endemic reptile species, i.e. three snake and one tortoise species, the Southern Adder (*Bitis armata*) data are too limited to allow assignment of *B. armata* to any set of endemics. It is currently known from the Agulhas plain near Hermanus, but an isolated population has also been recorded from near Langebaan on the West Coast (Branch 1998). Although its range extends slightly more to the east than those of other Greater Cederberg endemics, *Leptotyphlops gracilior* can probably be included in this group. Likewise, the only endemic tortoise in the study area, *Psammobates geometricus*, can be included in the Greater Cederberg set of endemics. Historically, it had a much wider distribution on the coastal lowlands, reaching as far south as the Helderberg Basin (Baard & Mouton 1993). *Psammophis leightoni* has been only recorded in the south-western part of the study area. Lack of data does not allow a clear perspective of its range.

Richness and endemism patterns for reptiles in the study area (south of 31°S and west of 21°E) are spatially correlated at both levels of resolution. The discovery of this relationship can be very useful information for the identification of priority areas for conservation (Orme *et al.* 2005; Brooks *et al.* 2006; Lamoreux *et al.* 2006). It implies that conservation actions targeted at the protection of centres of reptile endemism will by consequence also incorporate areas with high reptile species richness and *vice versa*. A study on scorpion distribution and diversity in southern Africa (Prendini 2005) shows a very similar pattern of correlation between hotspots of endemism and richness in the south-western region of South Africa. Furthermore these patterns are also highly congruent with that reported for reptiles in the present study – high richness and endemism along the topographically diverse Cape Fold Mountains.

Table 3.1. List of reptilian species with distribution ranges limited to within the study area. (CFM = Cape Fold Mountains)

Species	Family	Lifestyle	Area
Afroedura hawequensis	Gekkonidae	Rupiculous	CFM - Hawekwa Mountains in the north to Stettyn Mountains in the south
Australolacerta australis	Lacertidae	Rupiculous	Greater Cederberg area from Clanwilliam south through Olifantsrivier Mountains, Skurweberge & Hex River Mountains
Bitis armata	Viperidae	Terrestrial	Agulhas Plain near Hermanus with isolated population near Langebaan
Bradypodion pumilum	Chameleonidae	Arboreal	south-western Western Cape
Cordylus mclachlani	Cordylidae	Rupiculous	From Calvinia District in Hantam south to Cederberg and Swartruggens Mountains
Cordylus minor	Cordylidae	Rupiculous	Restricted area in Komsberg Pass on Roggeveld Escarpment
Cordylus niger	Cordylidae	Rupiculous	Cape Peninsula & Saldanha
Cordylus oelofseni (Landroskop)	Cordylidae	Rupiculous	Landroskop: Hottentots-Holland Mountains
Cordylus oelofseni (Olifantsrivier)	Cordylidae	Rupiculous	Olifantsrivier Mountains from Piekenierskloof Pass (north) to Oubikwa Mountains (south)
Cordylus oelofseni (Piketberg)	Cordylidae	Rupiculous	Piketberg & Platberg Areas
Goggia hexapora	Gekkonidae	Rupiculous	Greater Cederberg area, Olifantsrivier Mountains & Piketberg
Goggia microlepidota	Gekkonidae	Rupiculous	Greater Cederberg area, Grootwinterhoek & Swartwuggens Mountains
Leptotyphlops gracilior	Leptotyphlopidae	Fossorial	Greater Cederberg area through Tanqua Basin and Roggeveld Escarp & Plateau
Pachydactylus formosus	Gekkonidae	Rupiculous	From Nieuwoudtville in north to Bainskloof in South, West Coast to Tanqua Basin
Psammobates geometricus	Testudinidae	Terrestrial	Isolated resnosterveld habitats on the western Cape lowlands
Psammophis leightoni	Colubridae	Terrestrial	South-western coast from the Sandveld to Melkbosstrand area
Pseudocordylus nebulosus	Cordylidae	Rupiculous	Landroskop in the Hottentots-Holland Mountains
Scelotes gronovii	Scincidae	Fossorial	Lambert's Bay area on the West Coast
Scelotes kasneri	Scincidae	Fossorial	Lambert's Bay area on the West Coast
Scolotes montispectus	Scincidae	Fossorial	South-west Coast in the Blouberg area

Figure 3.5. Point distribution records of reptile species endemic to the study area (south of 31°S and west of 21°E).
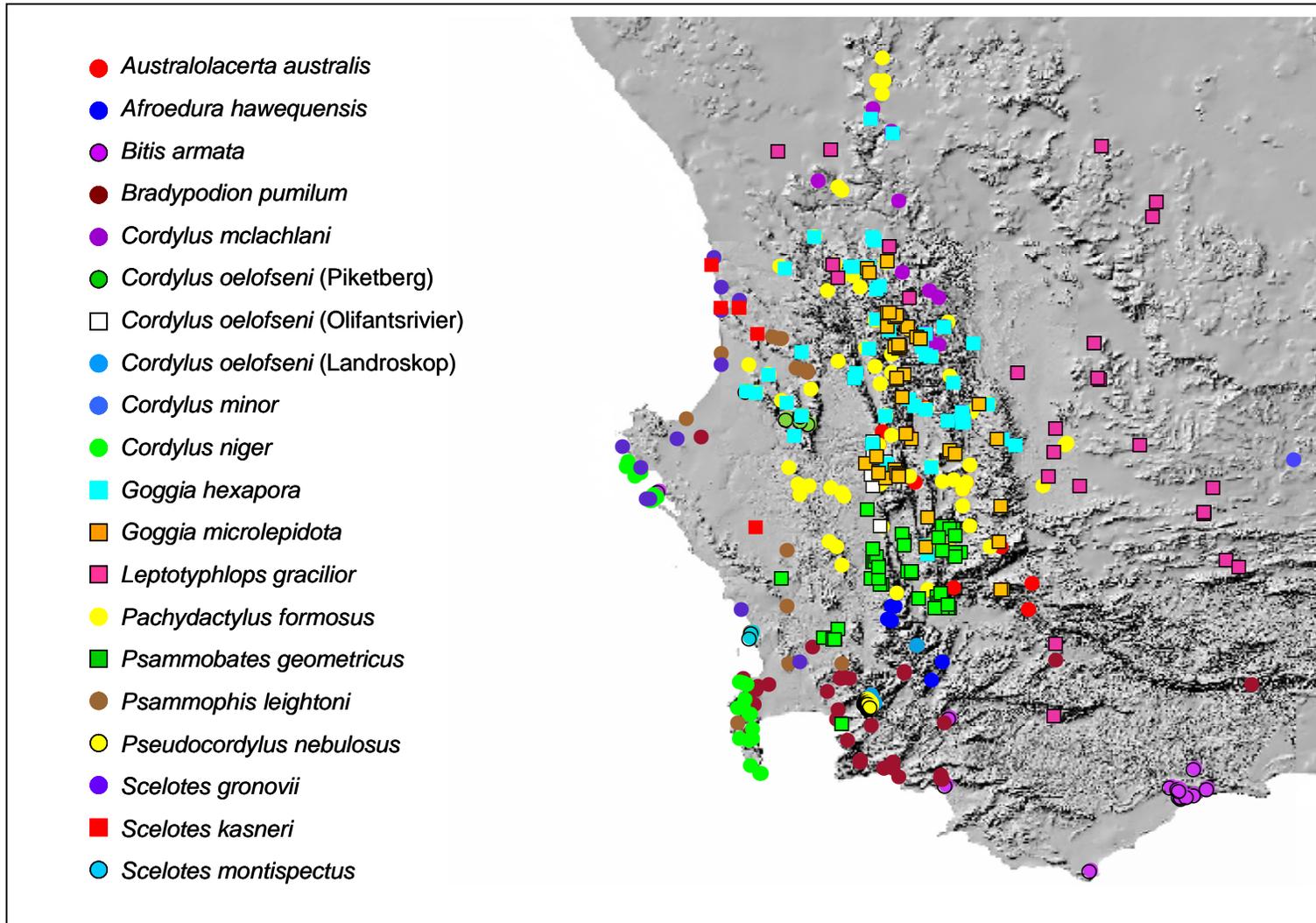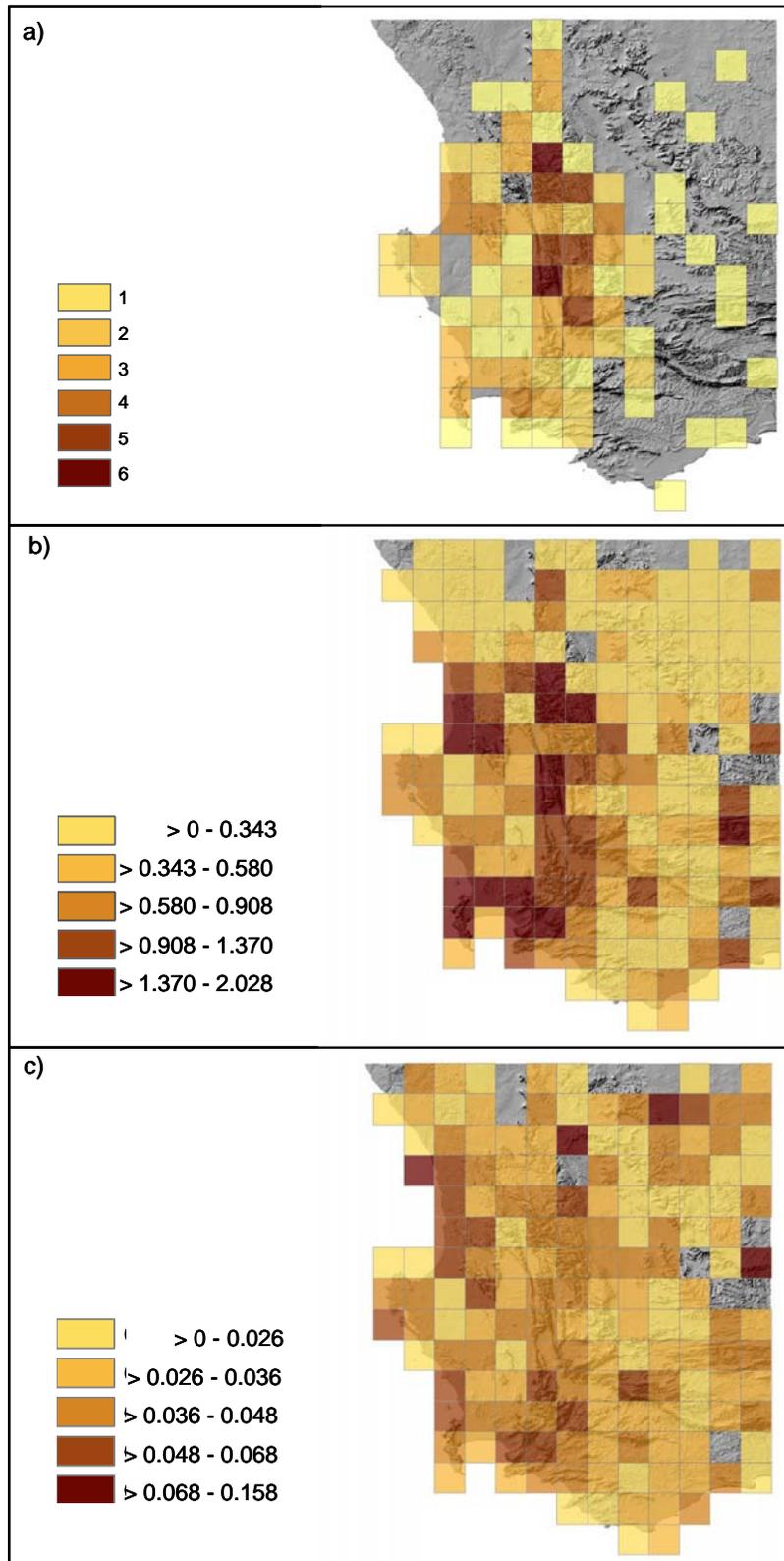
Figure 3.6. a) Endemism count, b) Weighted endemism and c) Corrected weighted endemism patterns of all reptiles at QDS resolution.
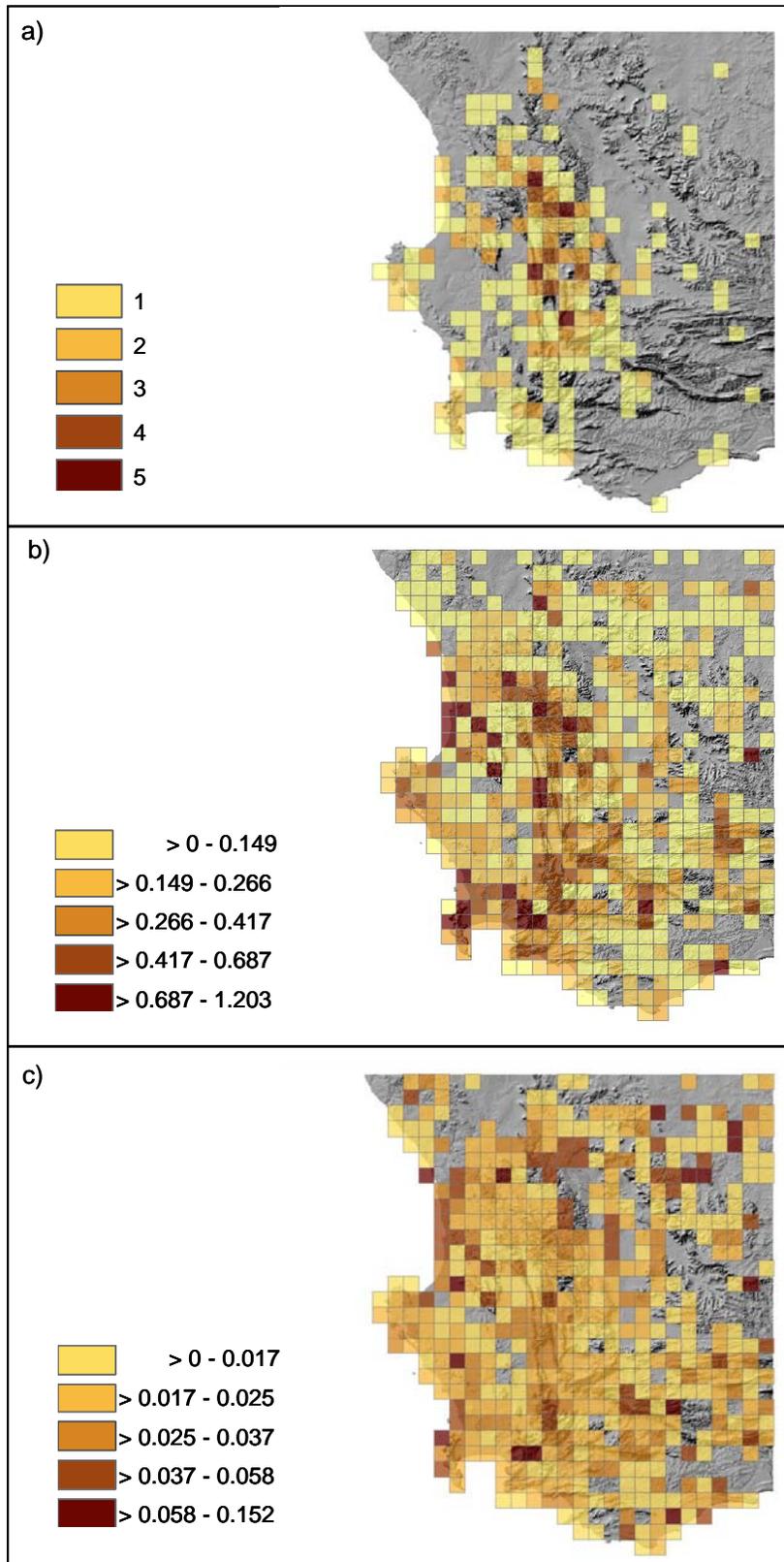
Figure 3.7. a) Endemism count, b) Weighted endemism and c) Corrected weighted endemism patterns of all reptiles at EDS resolution.
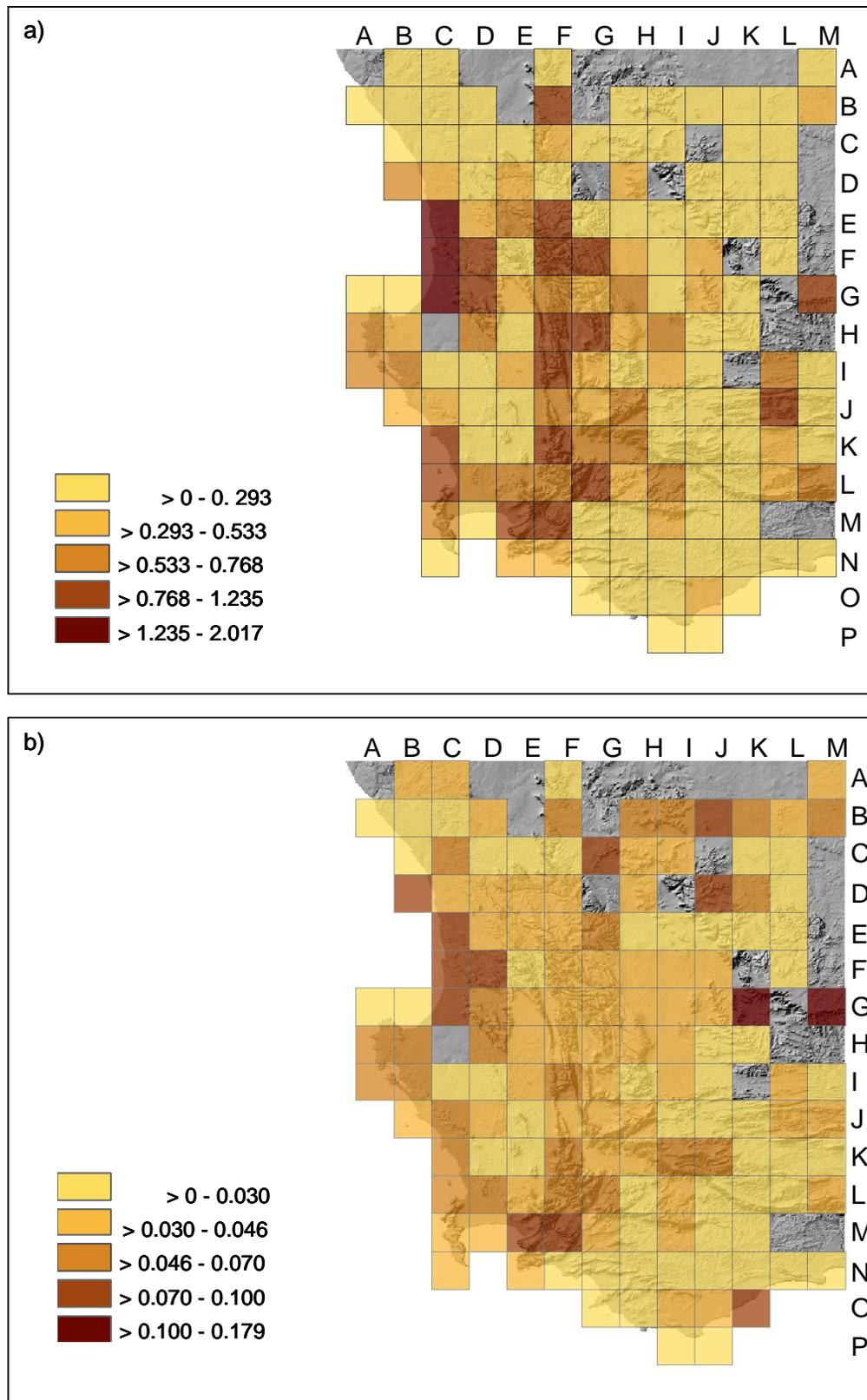
Figure 3.8. a) Weighted endemism (WE) and b) Corrected weighted endemism (CWE) patterns for lizard species only, at QDS resolution.
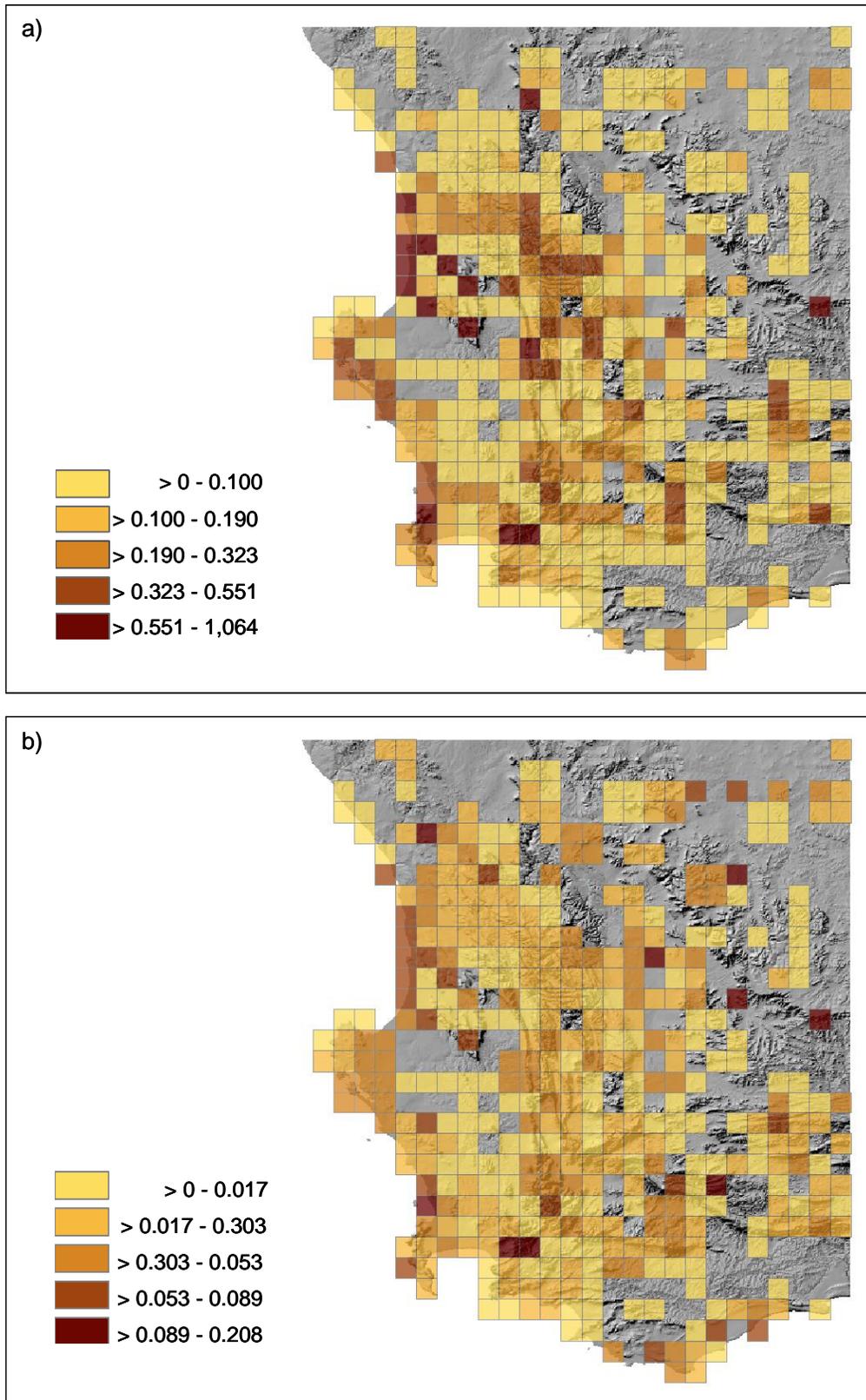
Figure 3.9. a) Weighted endemism (WE) and b) Corrected weighted endemism (CWE) patterns for lizard species only, at EDS resolution

3.3.3. Species turnover

The species turnover patterns for reptiles in the study area, at both QDS and EDS resolutions, are depicted in Figure 3.4. Beta-diversity, as formulated by Lennon *et al.* (2001), was found to be significantly negatively correlated with species richness (at QDS-resolution: Spearman r = 0.539 p < 0.05). This negative correlation is apparent when comparing the beta-diversity plot (Figure 3.4) with the reptile species richness plot (Figure 3.1). Areas of low species richness in the study area have more spatial turnover in species (high beta diversity scores). According to Lennon *et al.* (2001), who reported a similar pattern in their study on the geographical structure of British bird distributions, this implies that areas of low species richness tend to have relatively more random mixtures of species than areas of high species richness.

The discussion of how representative distribution data are for different regions within the present study area, revealed that the low species richness reported for some areas may be an artefact of sampling bias. It should therefore be noted that these are also the areas (Overberg, Northern Sandveld and the north-eastern section of the study area) for which, on average, the highest β-diversity scores are reported. However the pattern of negative correlation between species richness and turnover patterns persists when only the sub-sections of the study area for which distribution data are regarded to be fairly exhaustive are considered (i.e. the area corresponding to the study area of Oelofsen *et al.* 1987).

High species turnover indicate transition zones which are characteristically either gradual or sharp discontinuities which correlate with boundaries or contact zones between different communities or species assemblages (Lennon *et* al. 2001; Van Rensburg *et al.* 2004). Therefore it is often indicative of population or species distribution range edges. The significance of high species turnover zones for conservation of species diversity is uncertain. Although the conservation of peripheral populations could potentially prove important (Channell & Lomolino 2000), Gaston *et al.* (2001) warn against the danger of a

conservation network which represents species only from marginal areas within their ranges. Conservation sites which are selected on the basis of maximising beta-diversity may not be adequate for the long-term persistence of marginal species (Gaston *et al.* 2001). A more detailed discussion of the pattern of species turnover in terms of species composition follows in Chapter 4.

The low quality of the reptile data for the study area probably called for a different approach in determining species richness and turnover. A possible solution could be to derive species ranges through the application of α-hulls. Alpha-hulls are generalisations of minimum convex polygons and are an explicit means of excluding discontinuities within a species range (Burgman & Fox 2003). The bias in determining range extent is much less with α-hulls than with convex hulls (Burgmann & Fox 2003). The polygons derived with this method could then, similarly as in the present study, be translated to a grid system from which species richness and turnover patterns could subsequently be derived. It is predicted that species richness and turnover patterns would be more gradual and accurate if species ranges rather were to be used, which could lead to more robust interpretation of patterns.
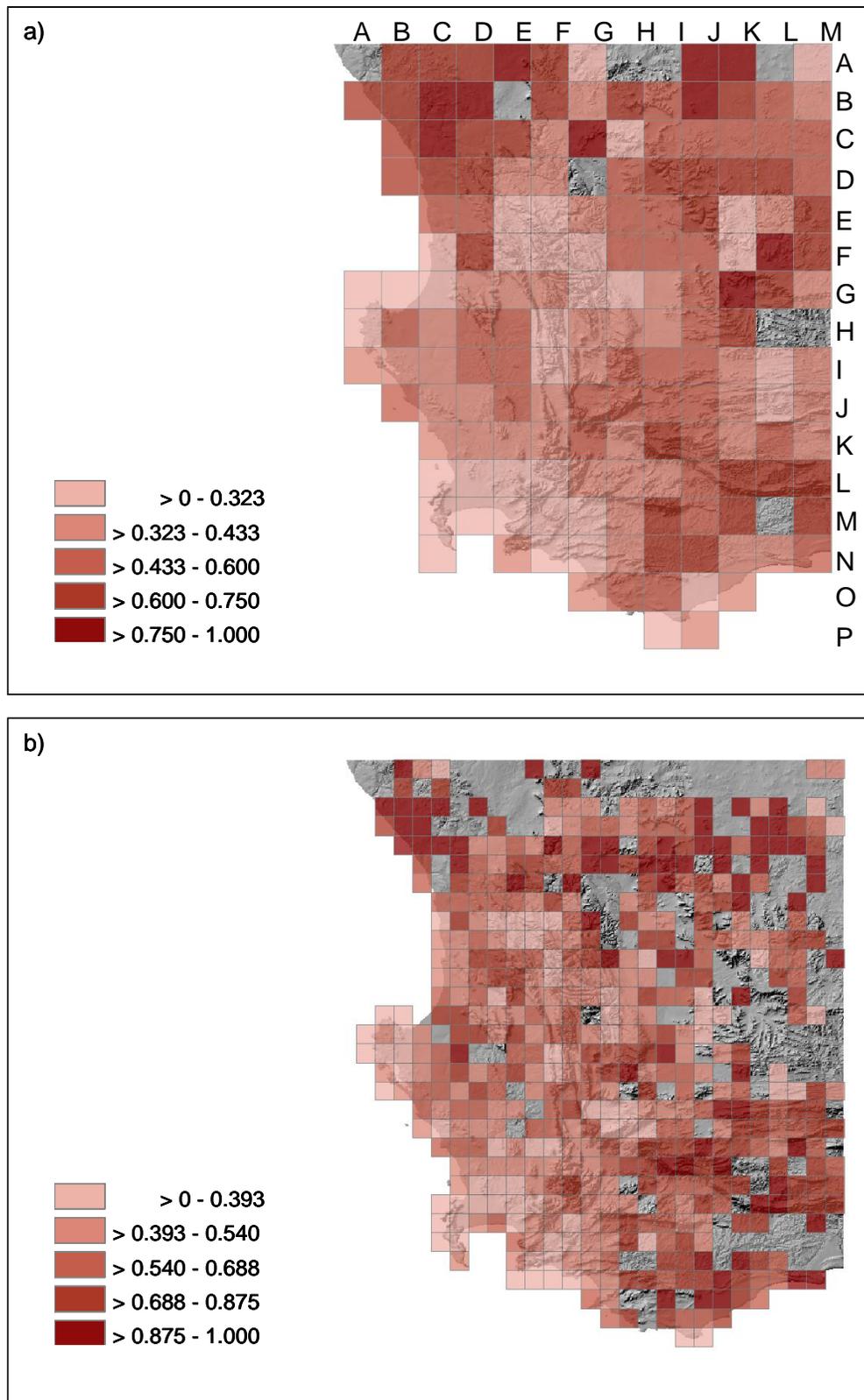
Figure 3.10. Species turnover (β-diversity) patterns according to β_{sim} values for both a) QDS and b) EDS resolutions.

Chapter 4

Identification and environmental characteristics of reptile biotic regions and assemblages in the south-western region of South Africa

4.1.   INTRODUCTION

4.1.1. Background and problem statement

The earth has experienced significant and rapid climate changes on time scales of decades to millennia (Zachos *et al*. 2001). It has long been recognized that species distribution limits are related to climate variables (Salisbury 1926; Good 1931) and that, to the extent that dispersal and resource availability allow, species will track the shifting climate and likewise shift their distributions (Vrba 1985; Walther *et al.* 2002). In the process some species are likely to be threatened with extinction while others will thrive.

The assemblages of species in ecological communities do not only reflect interactions with the abiotic environment, but also among organisms. We may therefore expect that rapid climatic change or extreme climatic events can also alter community composition (Walther *et al.* 2002**)**. In the Sonoran Desert of the south-western United States, for example, recent increases in woody shrub density, extinction of previously common animal species and increases in formerly rare animal species have been attributed to regional climatic shifts (Brown *et al*. 1997).

Like other ectotherms, reptiles are heavily influenced by environmental conditions and direct climatic effects on development, spatial distribution, and species interactions are apparent. Because reptiles cannot regulate their body temperatures physiologically like mammals and birds the thermal environment is of particular importance. Temperature not only influences daily activity, but also growth, timing and frequency of reproduction and

other life history characteristics (Huey 1982; Hutchison & Dupre 1992). The majority of amphibians require temporary or permanent water bodies for reproduction, and rainfall patterns directly affects their distribution (Duelman & Trueb 1986). Reptiles and amphibians should thus be more vulnerable to climate change than birds and mammals.

Low dispersal ability may make reptiles and amphibians even more vulnerable to climate change. The ability of species to track climate changes will depend on their ability to disperse, as well on the existence of suitable pathways for dispersal. Evidence that current reptile distributions in Europe display high levels of non-equilibrium with current climate is a strong indication that dispersal may indeed be lower for reptiles than for other groups of terrestrial vertebrates and plants (exluding amphibians) (Araujo *et al.* 2006). Although dispersal ability may vary substantially within taxa (Smith & Green 2005), the generally low dispersal ability of reptiles and amphibians is reflected in higher rates of endemism in comparison with other terrestrial vertebrate or plant groups in Europe (Williams *et al.* 2000), and can explain why major faunal regions in Europe are determined more by the location of three glacial refugia than by current climate gradients. Results therefore suggest that responses of plant and bird species to climate change are more likely to be accurately forecasted by models correlating present-day distributions with climate, and that reptile and amphibian species will be least capable of shifting distributions, making them most vulnerable to rapid environmental changes (Araujo & Pearson 2005).

The Western and Northern Cape Provinces of South Africa are particularly rich in reptiles (Branch 1998). The latter two provinces also harbour two of the world's 25 recognised biodiversity hotspots (Myers *et al.* 2000), namely the Succulent Karoo and the Cape Floristic Region. The Greater Cederberg Biodiversity Corridor (GCBC), a large-scale conservation corridor, was recently (2005) demarcated in the region and spans the boundary between Succulent Karoo and Fynbos biomes (and thus the corresponding two

hotspots). Although various ecological processes and biological patterns were taken into consideration, the delineation of the GCBC boundaries was largely underpinned by vegetation data (Low *et al.* 2004; Barodien, 2005).   The fundamental aim of the conservation corridor will be to make provision for current and long-term ecosystem dynamics, as well as for the persistence of biological patterns and processes of the area (Hess & Fisher 2001; Rouget *et al.* 2006). In the face of inevitable climate change it should also allow biota space in which to track these changes (Hannah *et al.* 2002). As is the case with many corridors, the GCBC carries some measure of uncertainty with regards to how effective it may prove to be for different taxa (Hannah *et al.* 2002). The relevance of the GCBC for the conservation of the regions' rich herpetofauna, for example, is still uncertain.

Besides the usefulness of information on species richness (alpha diversity), species turnover (beta diversity) and endemism patterns in directing conservation prioritisation strategies (Kier & Barthlott 2001; Slatyer *et al.* 2007), knowledge of groups or assemblages of species with similar environmental needs may be just as important. While modelling individual species can provide a good basis for considering the particular needs of selected species in conservation planning, it may not be the most effective way of addressing spatial pattern in biodiversity as a whole (Ferrier *et al.* 2002). The latter might often be addressed more effectively by integrating spatial modelling with numerical classification techniques designed to analyse patterns within large datasets. The aim of the present study was to identify possible reptile assemblages in the south-western districts of South Africa and to find the best environmental descriptors of the geographical area associated with each assemblage.

The first step was to identify biotic regions within the study area. In accordance with Sans-Fuentes & Ventura (2000), biotic regions are defined as areas with largely similar biotas. In other words, these regions are classified by the shared distribution ranges of a

number of different species. This practice of classifying geographical areas by biotic similarity is a popular research tool which is often implemented to study the processes directing differences in faunal composition and is applied at various spatial scales (Welsh 1994; Williams *et al.* 1999). Conservation studies and actions also benefit from area classification since it often produces classes or groupings which are easily communicated and interpreted and can serve as pragmatic surrogates which facilitate management decisions when species-level information is deficient or unavailable (Welsh 1994; Williams *et al.* 1999; Ferrier *et al.* 2002).

4.1.2. Environmental Data

In Austin (2002) and Araujo & Pearson (2005) it is argued that the negligence of ecological knowledge during the study of functional relationships between species distributions and climatic/environmental factors can have a limiting effect on analyses. Environmental factors can be considered as either direct, indirect or resource predictors of distribution (Austin 1980). Factors should therefore be selected because of the direct effect it may have on reptiles' daily activity (e.g. temperature, solar radiation, cloud cover; incidence of fog), or an indirect effect it could have on its productivity by influencing, for example, prey abundance.

Temperature

Temperature is of direct life-history importance to reptiles – whose extent of activity and productivity are primarily dependent on environmental heat. Huey (1982) mentions that reptile distributions may be influenced in particular by minimum and maximum temperatures, and it was shown that distribution limits of restricted range reptiles in Switzerland are largely determined by temperature related factors (Guisan & Hofer 2003). Both annual and seasonal mean minimum and maximum temperatures were included in the present analysis.

Solar radiation

Reptiles are known to make use of heliothermic basking during thermoregulation. The amount of solar radiation received on earth, and the presence of clouds and fog which is influences it (Schulze 1997), are therefore highly relevant for reptile activity, metabolism and reproduction.

Precipitation

Precipitation is proposed to be of indirect significance to reptile distributions through the effect it has on reptile's productivity, reproduction and food abundance. For example, lizards are generally insectivorous and the abundance of insects is influenced by precipitation (Cumming & Bernard 1997). Rainfall has been shown to influence the activity and timing of egg laying in the Angulate tortoise, *Chersina angulata* (Ramsay *et al.* 2002; Hofmeyr *et al.* 2004).

Altitude

Although altitude is not a factor that is of direct physiological importance to the animals, it strongly correlates with a number of climatic factors of importance, such as temperature, occurrence of frost, precipitation, incidence of fog and the like. Altitudinal zonation is a common phenomenon in plants and animals and reptiles are known often to be limited to certain altitudes (Fischer & Lindenmayer 2005). Furthermore, the standard deviation of altitude within each cell can be used as a measure of the topographic heterogeneity (Crisp *et al.* 2001) – a surrogate for habitat variability.

4.2.   METHODS

4.2.1. Identification of biotic regions

Biotic regions were identified by subjecting the cells of both the QDS and EDS grids to an agglomerative hierarchical clustering method. With this method no *a priopri* specification of the number of clusters (i.e., assemblages) expected, is required. The objects (in this

case grid cells) are fused into groups/clusters on the basis of their similarity (Han 2001), i.e., the shared occurrence of different reptile species. The sorting strategy used was minimum incremental sum of squares (ISS; also known as Ward's Method) using chord distance (for the binary data) as dissimilarity coefficient. Calculations were performed with the program package Syntax 2000 (Podani 2001). The chord distance normalizes the data allowing the grid cells with different levels of alpha diversity (species counts) to be compared without generating distortions.

The number of biotic regions was determined *a posteriori* by calculating the optimal number of clusters for each of the two hierarchies – the level within each hierarchy where the separation of groups of grid cells is most strongly supported – following the methods of Podani (1997) using Syntax 5.02 (Podani 1994).

4.2.2. Species Assemblages

Distinct species assemblages that are largely associated with a particular biotic region were identified. The species ranges reported in the preliminary SARCA data and the generalised range maps in the field guide by Branch (1998) were considered during the assignment of species to assemblages.   Species were assigned to particular assemblages on the basis of shared/(substantial congruence in) distribution ranges. However care was taken not to force these classifications. For instance, a species with a 'blanket' distribution (i.e. expansive ranges covering the entire or majority of the study area) does not make a unique contribution to any one assemblage.

4.2.3. Environmental Data

The environmental variables considered to be of ecological importance and which were therefore used to characterise the environmental envelopes of biotic regions, are listed in Table 4.1. Refer to Appendix C for details on the calculation of certain variables.

Table 4.1.   List of selected climate- and environmental variables. The seasons are defined as follows: Spring = September to November; Summer = December to February; Autumn = March to May; Winter = June to August.

Abbreviation	Variable Description	Unit	Source
P	Mean Annual Precipitation	mm	Schulze, 1997
PV	Variation in Annual Precipitation	%	Schulze, 1997
PS*	Precipitation Seasonality	%	Schulze, 1997
SpringP	Mean spring median precipitation	mm	Schulze, 1997
SummerP	Mean summer median precipitation	mm	Schulze, 1997
AutumnP	Mean autumn median precipitation	mm	Schulze, 1997
WinterP	Mean winter median precipitation	mm	Schulze, 1997
T	Mean Annual Temperature	°C	Schulze, 1997
TN	Mean Annual Minimum Temperature	°C	Schulze, 1997
TX	Mean Annual Maximum Temperature	°C	Schulze, 1997
SpringTN	Mean Spring Minimum Temperature	°C	Schulze, 1997
SummerTN	Mean Summer Minimum Temperature	°C	Schulze, 1997
AutumnTN	Mean Autumn Minimum Temperature	°C	Schulze, 1997
WinterTN	Mean Winter Minimum Temperature	°C	Schulze, 1997
SpringTX	Mean Spring Maximum Temperature	°C	Schulze, 1997
SummerTX	Mean Summer Maximum Temperature	°C	Schulze, 1997
AutumnTX	Mean Autumn Maximum Temperature	°C	Schulze, 1997
WinterTX	Mean Winter Maximum Temperature	°C	Schulze, 1997
SpringS	Mean Spring Solar radiation	$MJ.m^{-2}.day^{-1}$	Schulze, 1997
SummerS	Mean Summer Solar radiation	$MJ.m^{-2}.day^{-1}$	Schulze, 1997
AutumnS	Mean Autumn Solar radiation	$MJ.m^{-2}.day^{-1}$	Schulze, 1997
WinterS	Mean Winter Solar radiation	$MJ.m^{-2}.day^{-1}$	Schulze, 1997
FOG*	Annual incidence of foggy days	days	Van Niekerk, pers. comm.
CLO*	Annual incidence of cloudy days	octas	Van Niekerk, pers. comm.
CI*	Continentality Index	N/A	Van Niekerk, pers. comm.
SAI*	Summer Aridity Index	N/A	Van Niekerk, pers. comm.
ALT	Altitude	m	Van Niekerk, pers. comm.
ALT_SD	Standard deviation of Altitude	m	Van Niekerk, pers. comm.
VegCount	Number of vegetation types in cell	N/A	Van Niekerk, pers. comm.

* Refer to Appendix B for detail on the calculation of these variables/indexes

4.2.4. Data Analyses

Two methods, Classification & Regression Trees (CART) as well as Canonical Correspondence Analysis (CCA), were implemented to explore the relationships between biotic regions and the selected variables. Both of these methods are well suited for the analysis of complex ecological data, results are represented graphically and are easily interpretable (Palmer 1993; De'Ath & Fabricius 2000). The following software packages were used for the respective methods: STASTISTICA 7.1 (StatSoft Inc. 2006) for the Classification & Regression Trees analyses and CANOCO for Windows 4.52 (ter Braak & Šmilauer 2002) for the Canonical Correspondence Analyses.

Classification tree analysis

With this method the variation of a single response variable is explained by one or a combination of explanatory variables via a set of hierarchical decision rules which repeatedly split the data into more homogeneous groups (De'Ath & Fabricius 2000). The response variable can either be of a categorical (classification trees) or a continuous (regression trees) nature, whilst the explanatory variables can be categorical and/or continuous. In the present study the response variable was categorical (the four biotic regions – as defined above) and the explanatory variables were the selected continuous climate variables (se Table 4.1 for the list of the variables).

The result is graphically represented as a tree with a root node, representing the undivided data, at the top with the branches and leaves underneath. Each branch represents a split in the dataset and each leaf or terminal node represents one of the final groups. The basic aim is to divide/classify the data in such a way that the homogeneity within each final group (terminal node) is maximised. This homogeneity of the terminal nodes is represented in terms of their impurity, which for classification trees is defined in terms of the proportions, c, of responses in each category. There are three common criteria used to calculate impurity for classification trees (De'Ath & Fabricius 2000). The

criterion used in the present study is the Gini index ($1 - \Sigma\ c^2$), which typically splits off the largest category into a separate group. A general feature of methods which use a splitting criterion is that multiple trees of different sizes are generated; leaving one with the problem of determining which tree is the 'best'. De'Ath & Fabricius (2000) discuss a number of different commonly used methods distinguish between the trees.   In the present analysis the optimal tree was selected by cross-validation.

Canonical correspondence analysis (CCA)

Canonical Correspondence Analysis (CCA), a constrained ordination method of multivariate analysis of ecological data (Lepš & Šmilauer 2003), was implemented using CANOCO 4.52 (ter Braak & Šmilauer 2002). CCA rather than generalized linear modelling (GLM) was chosen because all species can be analysed simultaneously and this method performs well even with data where there are many absences (Guisan *et al.* 1999). Furthermore, Palmer (1993) showed through simulation studies that CCA is robust to noise and skew. CCA also performs well even with complex sampling designs and highly inter-correlated variables (Palmer 1993).

Automatic forward selection was used to reduce the data set by selecting the variables that explain the variation in the data the best. The number of selected variables were further limited by specifying $K = 7$ in order to reduce the individual variance inflation factors (VIF) to less than 20 (ter Braak & Šmilauer 2002). A variable with a large VIF value is almost perfectly correlated with the other variables and therefore does not make a unique contribution to the regression equation (ter Braak & Šmilauer 2002).

4.3.   RESULTS AND DISCUSSION

4.3.1. Biotic Regions and Species Assemblages

The ISS-clustering technique used in this study shows that the study area (south of 31ºS and west of 21ºE) can be partitioned into four biotic regions on the basis of shared

occurrence of reptile species (Figure 4.1). The regions include a Southern region, a Western Region, a Central Region, and a North-eastern Region. Although there are a few outlier cells, the four regions are geographically well defined. The outliers are caused by the limited data available for a number of species with wide distributions, particularly snakes. The Western, Southern and Central biotic regions largely fall within the Fynbos biome as defined by Rutherford *et al.* 2006, while the North-eastern biotic region spans the Succulent Karoo and Nama-Karoo biomes (Rutherford *et al.* 2006).

The biotic regions (Figure 4.1) echo the pattern of species turnover recorded for the study area (Chapter 3, Figure 3.10a). The boundaries between the Western, Southern and Central biotic regions appear to coincide with areas of higher species turnover between the three areas of low turnover. The areas of low turnover correspond to the central areas of the biotic regions. The boundary between the Central and North-eastern biotic regions is more diffuse than the other contact zones.

For assignment of individual reptile species to biotic regions, particularly in the case of those species for which limited data were available for the study area, generalised maps depicting species ranges in a southern African context, were consulted (e.g., Branch 1998; Marais 2004; Tolley & Burger 2007). On the basis of the biotic regions identified, reptiles occurring in the study area can be partitioned into four corresponding assemblages, two major ones and two minor ones. A Southern assemblage and a Northern assemblage constitute the two major ones and a West Coast assemblage and a Central assemblage the two minor ones (Table 4.2). Some species have a blanket distribution in the study area and cannot be assigned to any of the four assemblages (Table 4.2). There are considerably more snakes than lizards with blanket distributions. This is probably also true for South Africa as the whole; snakes in general tend to have larger ranges than lizards (see, e.g., Branch 1998; Marais 2004). Three species cannot be assigned with confidence to any of the assemblages and are listed as Intermediate in

Table 4.2. The Angulated Tortoise, *Chersina angulata,* has a broad coastal distribution from the Gariep River in the north to East London in the east, with inland extensions at places (Branch 1998) and, although not having a blanket distribution in the study area, is extensively represented in at least three of the biotic regions identified. Both the Robertson Dwarf Chameleon (*Bradypodion gutterale*) and the Spotted House Snake (*Lamprophis guttatus*) have ranges that straddle an imaginary east-west line separating the geographical areas associated with the Northern and Southern assemblages. The Thin-skinned Thick-toed Gecko (*Pachydactylus kladeroderma*) can also not be assigned with confidence to any of the assemblages. Seven species only marginally occur in the study area, one in the north and five in the east, and do not fit in any of the assemblages identified in the study area. It is clear that these species belong to assemblages that largely occur outside the current study area. They are therefore considered peripheral species (Table 4.2). The Southern Adder, *Bitis armata* occurs on the Agulhas plain on the South Coast, but there is also an isolated population in the Langebaan area (Branch 1998). Since several other 'southern' species have range extensions up to Langebaan (e.g., the Black Girdled Lizard (*Cordylus niger*), Cape Girdled Lizard (*Cordylus cordylus*), Marbled Leaf-toed Gecko (*Afrogecko porphyreus*), Cape Legless Skink (*Acontias meleagris*), Silvery Dwarf Burrowing Skink (*Scelotes bipes*), Red-sided Skink (*Trachylepis homalocephala*)), the Southern Adder, *Bitis armata*, is assigned to the Southern assemblage.

The Southern assemblage contains distinctly more snakes than the Northern assemblage (38% of saurians vs. only 22%). Another distinct feature of the snake component of the Southern assemblage is that all species, with the exception of *Bitis armata*, have extensive eastern distributions extending in a narrow band along the south coast of South Africa to the west (Branch 1998; Marais 2004). Sundevall's Shovel-snout (*Prosymna sundevalli*), Spotted Skaapsteker (*Psammophylax rhombeatus*) and Spotted Harlequin Snake (*Homoroselaps lacteus*) have similar distributions, but because the westward

distributional band is broader than in the other species, they are listed as species with blanket distributions in the study area (Table 4.2). As with snakes, there are a number of lizard species in the Southern assemblage with extensive eastern distributions extending along the southern districts of South Africa to the west (e.g., the Cape Legless Skink (*Acontias meleagris*), Red-sided Skink (*Trachylepis homalocephala*), Delalande's Sandveld Lizard (*Nucras lalandii*), Burchell's Sand Lizard (*Pedioplanis burchelli*), Yellow-throated Plated Lizard (*Gerrhosaurus flavigularis*), Cape Grass Lizard (*Chamaesaura anguina*), and Cape Girdled Lizard (*Cordylus cordylus*)) (Branch 1998). While *B. armata* is the only south-western snake representative in the Southern assemblage, there are several distinctly south-western lizard species in this assemblage (e.g., the Black Girdled Lizard (*Cordylus niger*), Oelofsen's Girdled Lizard (*C. oelofseni*), Cape Dwarf Chameleon (*Bradypodion pumilum*), Hawequa Flat Gecko (*Afroedura hawequensis*)*,* and Cloud Lizard (*Pseudocordylus nebulosus*)). Another interesting feature of the Southern assemblage is that it contains considerably fewer geckos than the Northern assemblage (12% of all lizards vs. 33%), but more cordylids (38% of all lizards vs. 13%). For the other lizard families, the numbers of species in the two assemblages are comparable.

In a way the Northern assemblage is the mirror image of the Southern assemblage in that the majority of the species have extensive north-western distributions stretching from Namibia down into South Africa and then some distance eastwards into the interior, but avoiding the south-western and southern coastal areas (see Branch 1998). The West Coast assemblage is characterised by a high number of fossorial and terrestrial species associated with sand substrates (Table 4.2). There are no rock-dwelling lizards in this assemblage and all the burrowing forms are scincid lizards. The Central assemblage is comprised mostly of lizards. The majority of species have restricted ranges and are endemic to the study area.
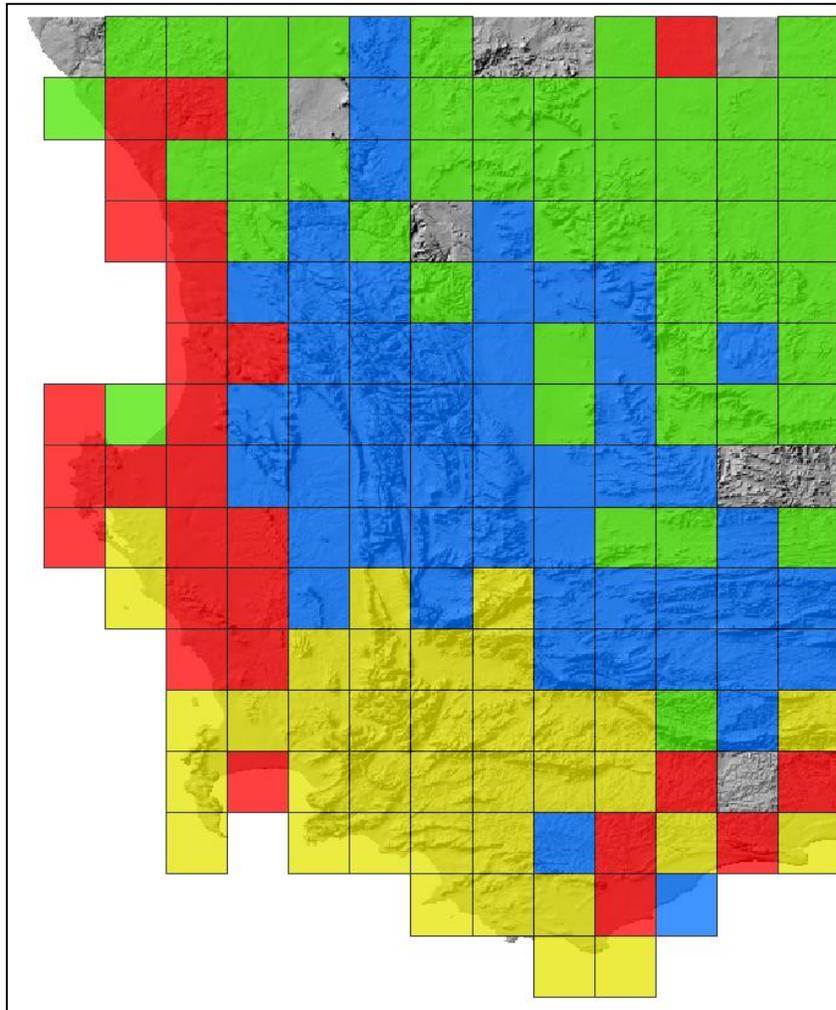
Figure 4.1.   The four biotic regions which were identified through agglomerative hierarchical clustering are represented by groups of QDS cells of different colours. The regions are named as follows: North-eastern biotic region (NE) = green; Central biotic region (C) = blue; Western biotic region (W) = red and Southern biotic region (S) = yellow.

Table 4.2. Reptile species assemblages identified in the study area (south of 31ºS and west of 21ºE). See Appendix A for full species names. (Table continues on next page)

Southern	Western	Central	Northern	Intermediate	Blanket	Peripheral
Lizards	Lizards	Lizards	Lizards	Lizards	Lizards	Lizards
A. meleagris	M. lineatus	A. australis	T. occidentalis	B. gutturale	T. capensis	B. ventrale
S. bipes	M. litoralis	C. mclachlani	T. variegata	P. kladeroderma	P. l. pulchella	C. peersi
S. caffer	T. caecus	Ps. capensis	T. sulcata		A. atra	G. hewitti
T. homalocephala	S. sexlineatus	G. hexapora	M. suborbitalis	Snakes		G. rupicola
N. lalandii	S. gronovii	G. microlepidota	N. tessellata	L. guttatus	Snakes	P. maculatus
P. burchelli	S. kasneri	P. formosus	N. livida		R. lalandei	P. oculatus
G. flavigularis	S. montispectus		P. laticeps	Chelonians	L. capensis	
C. anguina	M. ctenodactylus	Snakes	P. namaquensis	C. angulata	P. cana	Snakes
C. cordylus	M. knoxii	L. gracilior	G. typicus		P. sundevallii	B. inornata
C. niger	C. macropholis		C. subtessellatus		P. rhombeatus	
C. oelofseni	P. austeni	Chelonians	C. polyzonus		P. notostictus	
C. coeruleopunctatus	P. labialis	P. geometricus	C. cataphractus		D. scabra	
Cordylus sp. nov.	B. occidentale		C. minor		H. lacteus	
Cordylus sp. nov.			A. hispida		N. nivea	
Ps. microlepidotus	Snakes		A. aculeata		B. arietans	
Ps. nebulosus	B. cornuta		C. namaquensis			
A. hawequensis	N. n. woodi		G. lineata		Chelonians	
A. porphyreus	P. leightoni		P. mariquensis		P. subrufa	
P. geitje			P. capensis			
T. tetradactylus	Chelonians		P. s. purcelli			
T. seps	H. signatus		P. weberi			
T. gularis			P. garrulus			
T. montana			C. angulifer			
B. pumilum			C. bibronii			

Southern	Western	Central	Northern	Intermediate	Blanket	Peripheral
Snakes *L. nigricans* *L. rufulus* *L. aurora* *L. fuscus* *L. inornatus* *L. capense* *D. lutrix* *A. multimaculatus* *P. crucifer* *C. hotamboeia* *D. typus* *H. haemachatus* *B. atropos* *B. armata* *C. rhombeatus* Chelonians *H. areolatus*			Snakes *T. beetzi* *B. rubida* *B. caudalis* *L. fiskii* *R. schinzi* *A. lubricus* *D. multimaculata* Chelonians *H. femoralis* *H. boulengeri* *P. tentorius*			

4.3.2. Environmental characterisation of biotic regions

The classification tree analysis predicts the four reptile biotic regions by selected environmental/climatic variables (Figure 4.2). There are four terminal nodes (leaves) in the tree. Each of the splits (branches) is labelled with the split variable and its values which determine the split. Each terminal node is described by a histogram of the proportion of each category (biotic regions) within the node. The number of observations, N, within each group are also shown on each node.

On the first split the data are divided into two groups according to the splitting criterion that the mean summer solar radiation (Summer_S) is either $\leq$ 32.482 $MJ.m^{-2}.day^{-1}$ or > 32.482 $MJ.m^{-2}.day^{-1}$. The group with Summer_S $\leq$ 32.482400 $MJ.m^{-2}.day^{-1}$ is then further split into two groups according to the variability of precipitation (PV) within each QDS (either $\leq$ 31.28 % or > 31.28 %). The group for which Summer_S > 32.482 $MJ.m^{-2}.day^{-1}$ is split by the mean solar radiation during winter months (Winter_S) being either $\leq$ 13.709 $MJ.m^{-2}.day^{-1}$ or > 13.709 $MJ.m^{-2}.day^{-1}$. Detailed categorised histograms of the four terminal nodes are depicted in Figure 4.3. These histograms indicate what proportion of cells, for which a certain set of decision rules are true, belong to a particular biotic region.

Although the three variables, Summer_S; PV and Winter_S, feature within the final (or best) tree, they should not be mistaken to be the ultimate explanatory variables of the biotic regions. The predictor importance values of all the environmental variables are presented in Table 4.3. According to this table the variability of precipitation (PV) is the best explanatory variable of the different biotic regions and all other variables are then ranked accordingly.

Figure 4.2.   The dendrogram resulting from the classification tree analysis (CART) of biotic regions in terms of environmental variables at a QDS resolution. The colours in the legend indicate the different biotic regions and correspond to those in Figure 4.1.
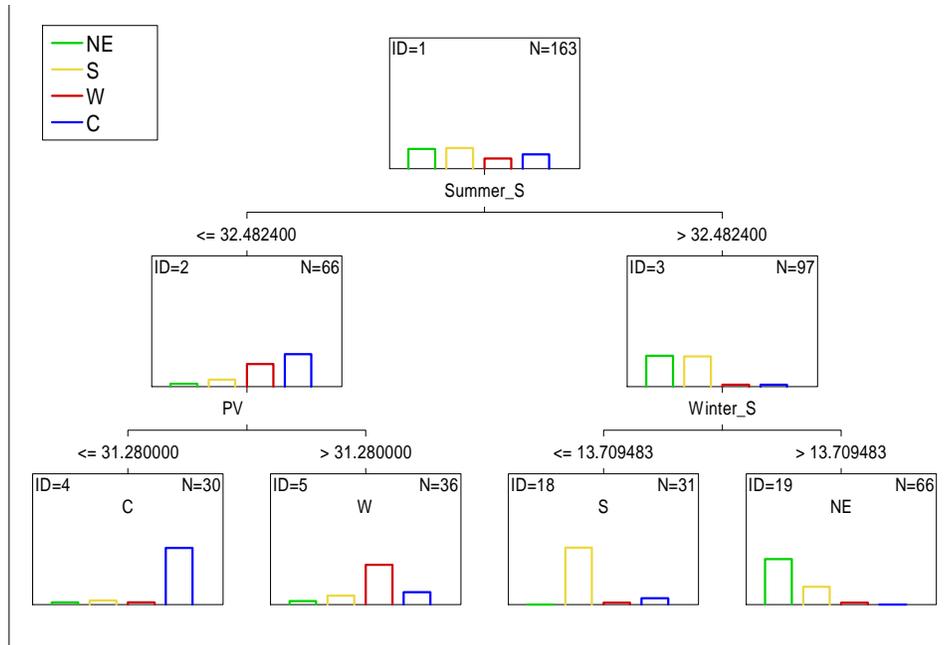
Figure 4.3.   Categorised histograms corresponding to the terminal nodes of the dendrogram in Figure 4.2. Codes below bars match to the relevant biotic regions, while percentages in parenthesis indicate the proportion of the total number of QDS cells. The percentage of cells from each biotic region appears above each bar.
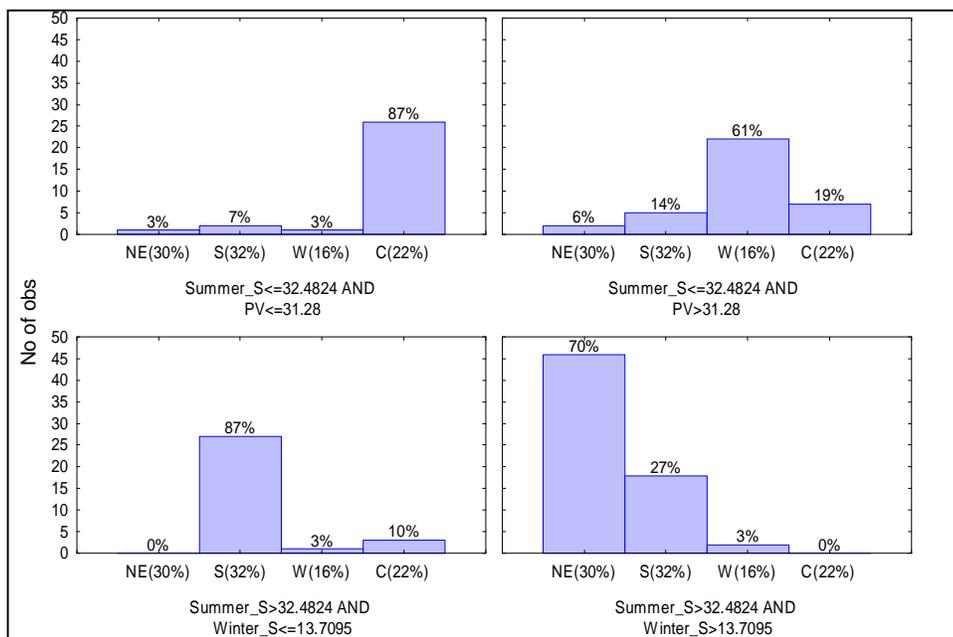
Table 4.3. Variable rank and importance values of the climatic- and environmental variables used to characterise the four biotic regions via the classification tree method (CART).

	Variable rank	Importance
PV	100	1.000000
ALT_SD	87	0.872735
P	81	0.814637
SpringP	81	0.811756
WinterS	81	0.806954
WinterTN	79	0.789882
SpringS	76	0.760642
ALT	72	0.721676
AutumnTN	72	0.718892
SummerTN	71	0.711553
AutumnS	69	0.687510
CI	68	0.677928
T	68	0.678566
SummerP	68	0.684824
SummerTX	68	0.678064
SummerS	68	0.678311
TN	67	0.667388
WinterP	64	0.642990
SpringTN	61	0.608580
Veg count	60	0.600814
FOG	59	0.590394
SAI	58	0.582270
SpringTX	57	0.567249
AutumnP	54	0.541279
TX	52	0.522781
AutumnTX	51	0.505539
CLO	43	0.426186
WinterTX	42	0.418722
PS	40	0.395656

Figures 4.4 and 4.5 show the ordering of individual QDS grid cells, along the major axes of variation revealed by the CCA ordination.   The eigenvalues (the measure of the explanatory power of an ordination axis, ranging between 0 and 1) for the first, second and third axes are 0.391, 0.207 and 0.183, respectively. Using forward selection, seven variables were foun to be most informative.   These variables are: annual incidence of cloudy days (CLO), the summer aridity index (SAI), seasonality of precipitation (PS), standard deviation of altitude (ALT_SD), the continentality index (CI), the average minimum summer temperature (Summer_TN) and the average maximum spring temperature (Spring_TX).

The discrepancy between the CART and CCA analyses in terns of identifying the variables of greatest importance (information value) goes on the account of the different strategies underlying both techniques.   CART uses each variable sequentially (and repeatedly) to test how well it predicts the pre-defined classes (in this case: four reptile biotic regions). Each variable is used in al subsequent steps (after each split of the data) and could therefore feature more than once as the best explanatory variable. In contrast to this, the effect of the combined influence of all variables is investigated with CCA. In CCA the number of explanatory variables are reduced by excluding 'redundant' variables (i.e. those which are highly correlated with one or more other variables – see section 4.2.4) and reporting only those which explain the variance in the data in a unique way.

Spatial separation (in the expected ordination space of axes 1 and axes 2) of the four groups of objects, representing the four biotic regions, became evident in the CCA analysis. This indicates that there is a strong environmental signal (due to the constrained nature of involving environmental variables in the ordination) associated with these groups. For example, Precipitation variability (PV) and Mean Annual Precipitation (P), the variables with the highest and third highest explanatory power (Table 4.3), respectively, are important for the southern and northern areas of the studied region, respectively. The

southern area is characterised by significantly higher mean annual rainfall (P) (ANOVA: F = 45.416, p ≤ 0.01) and significantly less year-to-year variability in rainfall patterns (PV) (ANOVA: F= 57.332, p ≤ 0.01) than the northern area (see Figure 4.6a+b). The regional patterns of both P and PV in South Africa (Schulze 1997) correlate with the regional distribution patterns of a number of reptile species which are assigned to the Southern assemblage (Table 4.2), i.e. extensive eastern ranges that extends in a narrow band along the south coast of South Africa to the west.

The individual 'environmental envelopes' of the four biotic regions can be described as follows from the CART analysis: The North-eastern Biotic Region shows the highest levels of mean solar radiation, within the study area, during summer and winter months (summer_S = 35.68 MJ.m^{-2}.day^{-1}; winter_S = 14.40 MJ.m^{-2}.day^{-1}; see Figure 4.6c+d). The level of mean summer solar radiation (summer_S = 34.04 MJ.m^{-2}.day^{-1}) for the Central Biotic Region is also high, but significantly lower (Bonferroni test: MS = 4.4673, df = 159.00 p ≤ 0.001) than that of the Northern-eastern Biotic Region, and it has intermediate levels of mean winter solar radiation (mean winter_S = 13.47 MJ.m^{-2}.day^{-1}, which significantly differs from that of the North-eastern Biotic Region (Bonferroni test: MS = 0.39851, df = 159.00; p ≤ 0.001)). Both the Western- and Southern Biotic Regions are recognised by intermediate to low levels of mean summer solar radiation (mean summer_S = 29.70 MJ.m^{-2}.day^{-1} and 29.19 MJ.m^{-2}.day^{-1} respectively). The difference in summer_S is insignificant for these two regions, but they are distinguished from each other by a significant difference in the annual variability in precipitation (mean PV = 34.77 % for the Western Biotic Region while mean PV = 31.28% for the Southern Biotic Region (Bonferroni test: MS = 9.5093, df = 159.00, p ≤ 0.001); see Figure 4.6c). The low levels of solar radiation of the Southern- and Western biotic regions are related to the fact that the highest annual incidence of overcast days (Figures 4.5 and 4.6e) (related to high annual precipitation) and fog (Figure 4.6f), respectively, occur in these biotic regions.

It is clear from the analysis that the south-western region of South Africa is a biogeographically complex area in that four distinct sets of reptiles, each with its own set of environmental requirements, interface here in a relatively small geographical area. It is expected that the four reptile assemblages will show vastly different responses to climate change and that conservation strategies in the region will be tested to the limit. It is clear that the two main assemblages can be described as an arid zone one and a mesic zone one. The West Coast assemblage can be probably considered a sub-assemblage of the Northern assemblage, but with particular adaptations to the coastal climate. The coastal climate is characterised by a high incidence of fog and copious dewfalls resulting from the cold, upwelled waters of the Benguela Current (Cowling *et al.* 1999; Desmet & Cowling 1999). The Central assemblage, which is mainly comprised of rock-dwelling species with restricted ranges, may represent some evolutionary leftovers of cycles of contraction and expansion of the arid and mesic faunas in response to global climate change. The Greater Cederberg Area, because of its high topographic heterogeneity, may have distinct refugial qualities in this regard.

Figure 4.4. Canonical Correspondence Analysis graph depicting the results for Axis1 (horizontal) and Axis2 (vertical): The four biotic regions are represented by different colours (Yellow = Southern; Red = Western, Blue = Central and Green = North-eastern). Forward selected environmental variables are represented by the arrows. (ALT_SD: standard deviation of altitude; CI: Continentality Index; CLO: Number of cloudy days; PS: Seasonality of rainfall; SAI: summer aridity index; Spring_TX: Mean maximum spring temperature; Summer_TN: Mean minimum summer temperature.)
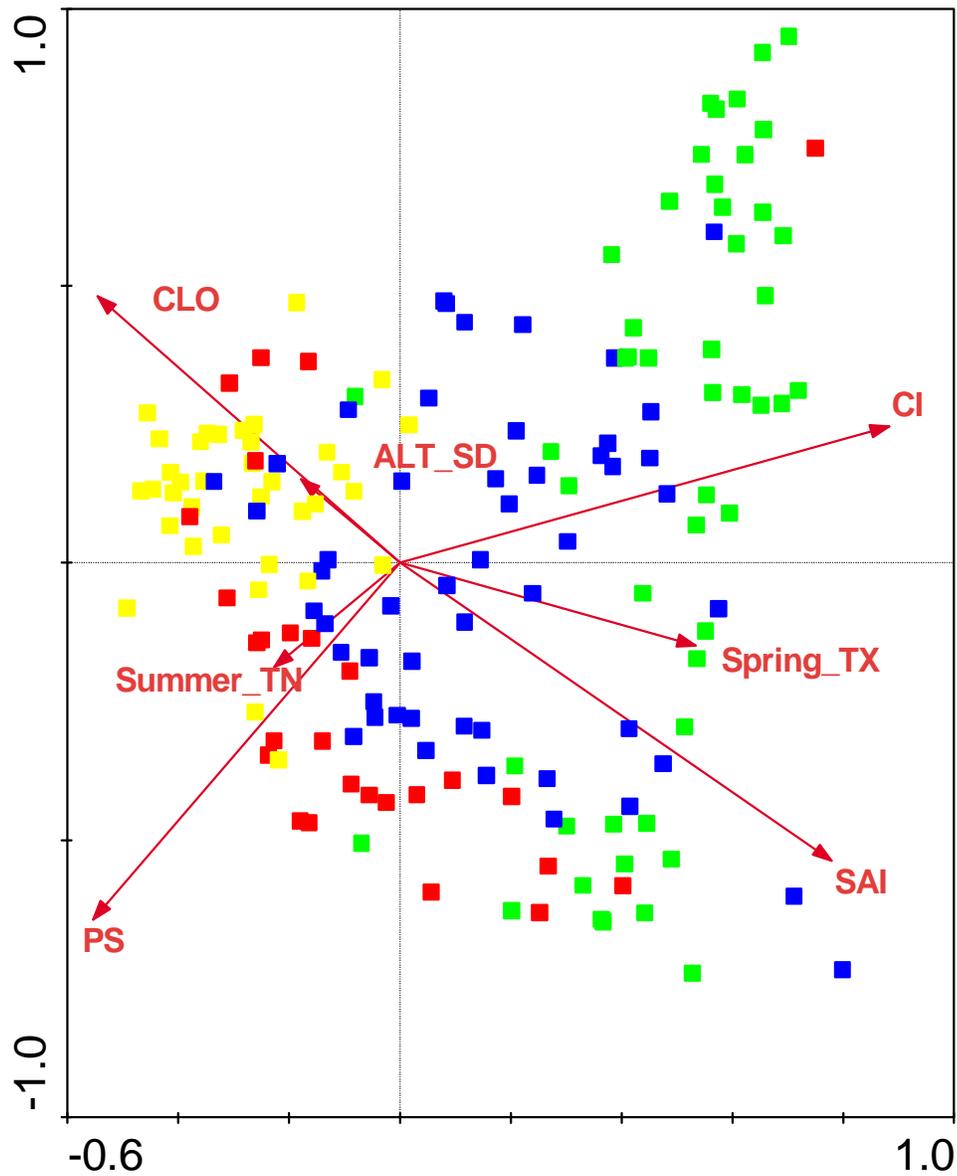
Figure 4.5. Canonical Correspondence Analysis graph depicting the results for Axis1 (horizontal) and Axis3 (vertical): The four biotic regions are represented by different colours (Yellow = Southern; Red = Western, Blue = Central and Green = North-eastern). Forward selected environmental variables are represented by the arrows. (ALT_SD: standard deviation of altitude; CI: Continentality Index; CLO: annual incidence of cloudy days; PS: Seasonality of rainfall; SAI: summer aridity index; Spring_TX: Mean maximum spring temperature; Summer_TN: Mean minimum summer temperature.)
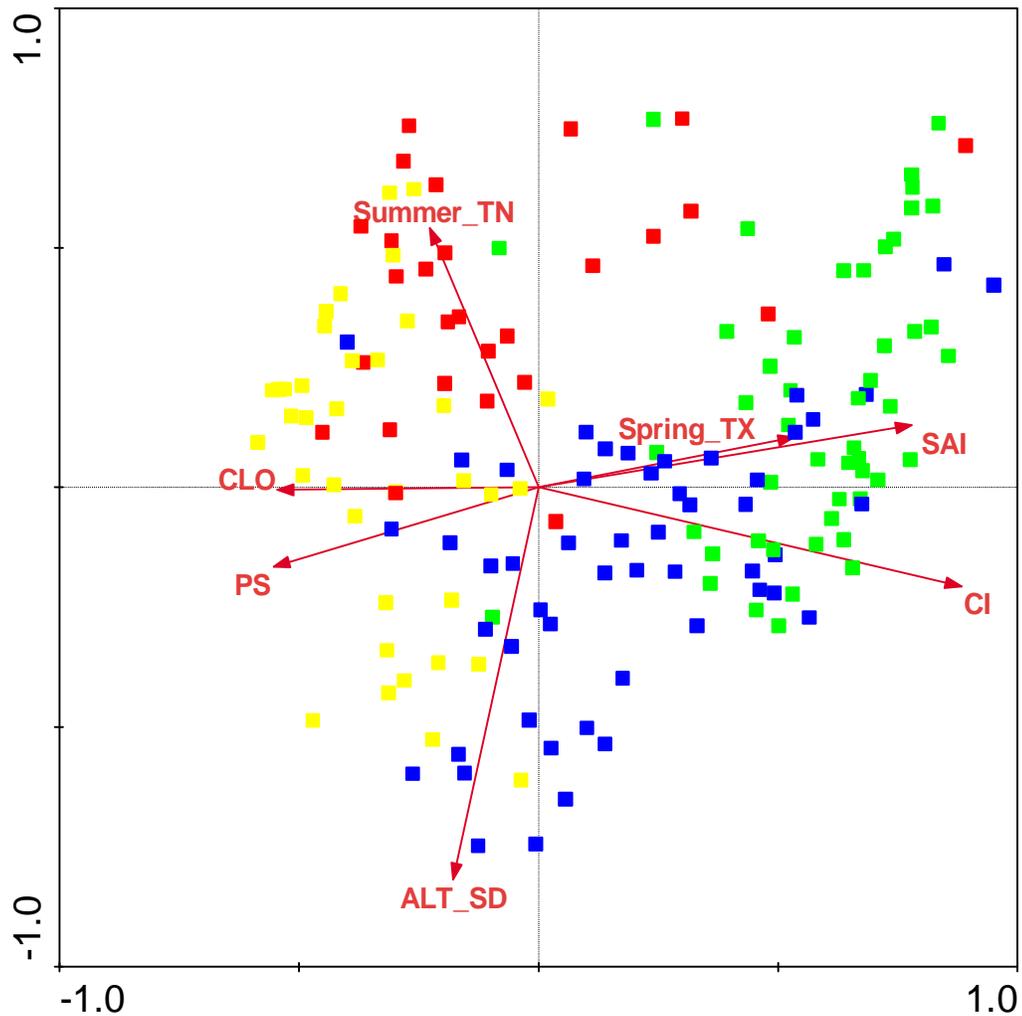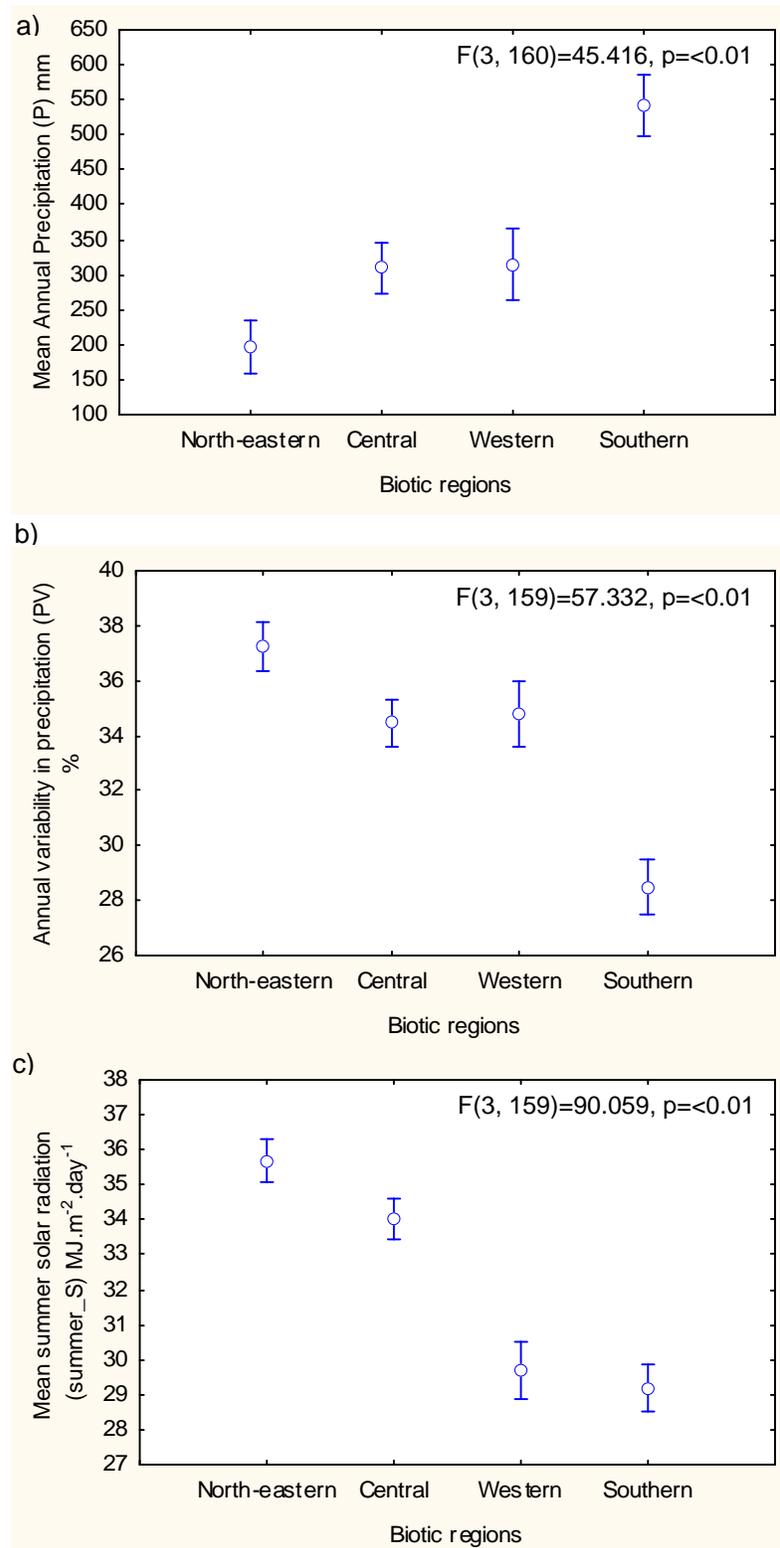
Figure 4.6 (a)-(c). LS Means of analyses of variation (ANOVA) between biotic regions for a) mean annual precipitation (P), b) annual variability in precipitation (PV), and c) mean summer solar radiation (summer_S). Vertical bars denote 95% confidence intervals
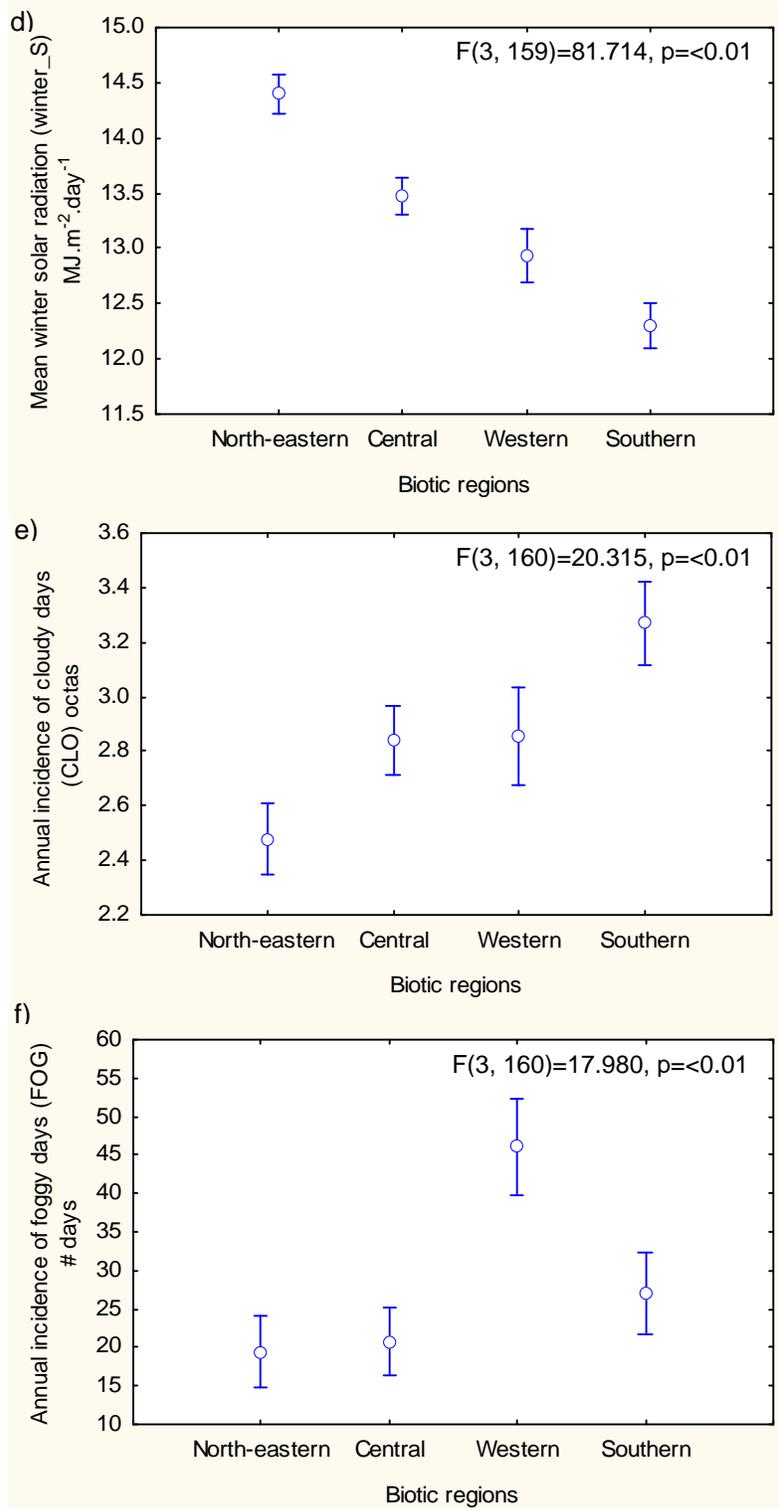
Figure 4.6 (d)-(f). LS Means of analyses of variation (ANOVA) between biotic regions for

d) mean winter solar radiation (winter_S), e) annual incidence of cloudy days (CLO), and

f) annual incidence of foggy days (FOG). Vertical bars denote 95% confidence intervals

Chapter 5

The relevance of the Greater Cederberg Biodiversity Corridor for reptile conservation

5.1.   INTRODUCTION

Because resources to address intensifying anthropogenic threats to biodiversity are usually limited, geographic priorities must be established so that these resources and effort can be allocated to areas with high biodiversity value (Ceballos *et al.* 1998; Olson & Dinerstein 1998). In most cases, lack of high-quality species distribution data has made it difficult to identify priority areas with confidence (Williams & Gaston 1994). There is also frequently a difference of opinion among conservationists over which aspects of biodiversity are most important in setting priorities.

Species richness and endemism are two measures which are commonly used to describe the biological diversity of a region and are useful to direct conservation prioritisation strategies (Kier & Barthlott 2001; Slatyer *et al.* 2007). Some authors have emphasized species richness, while others argue that areas of high endemism should be targeted most (Prendergast *et al.* 1993; Kerr 1997; Ceballos *et al.* 1998). It is today generally accepted that, although information on each of these measures by themselves can make a considerable contribution during conservation planning, their impact may increase substantially when regarded in combination (Orme *et al.* 2005; Brooks *et al.* 2006; Lamoreux *et al.* 2006). Priorities set on the basis of species richness alone may not successfully conserve areas of high endemism, which are clearly important to biodiversity conservation at any scale. Data on endemism are typically less available

than data on species richness, and patterns of endemism are thus less well understood (Bibby 1992; Kerr 1997).

The use of indicator taxa, i.e., well-studied groups of organisms whose biodiversity patterns can be used as surrogates for other taxa or for overall biodiversity patterns, has become popular in recent years (e.g., Pearson & Cassola 1992; Scott *et al*. 1993; Daily & Ehrlich 1996; Carroll & Pearson 1998; Van Jaarsveld *et al*. 1998; Ricketts *et al*. 1999). The usefulness of indicator taxa has been evaluated in several studies and the results are of a mixed nature. It became apparent that the utility of this conservation tool depends on the taxon selected and the scale of the analysis (Weaver 1995).

5.2.   THE GREATER CEDERBERG BIODIVERSITY CORRIDOR (GCBC)

The GCBC encompasses an area of roughly 1.8 million hectares in the Western Cape, South Africa (Fig. 5.1) (Anon 2005). It also includes two global biodiversity hotspots, namely the Cape Floristic Region and the Succulent Karoo (Anon 2005). The Cape Floristic Region Biodiversity Hotspot is a Mediterranean-type system which is located at the south-western tip of South Africa (CEPF 2001). The Succulent Karoo Biodiversity Hotspot stretches from southern Namibia through the north-western region of South Africa into the south-western part of the country where it is meets the CFR (Driver *et al*. 2003). It is the only arid ecosystem to be recognised as a global biodiversity hotspot (Driver *et al*. 2003).

The GCBC is regarded as a 'regional planning unit' aimed at maintaining and restoring connectivity between protected areas and reserves within the defined area as well as implementation of sustainable land-use throughout the region so as to ensure long-term

preservation of the landscape and its processes (Anon 2005). In other words, the GCBC is designed to provide suitable habitat not only for the fauna and flora in it, but also for sustainable human activities, and through its connectivity also serve a conduit function for present and future movement (dispersal) patterns of plants and animals.

Many GIS data layers (such as protected areas, important bird areas and wetlands, landcover & habitat transformation, the spatial component of ecological processes, and expert mapping of significant bird, herpetofauna, fish, insect, plant and mammal areas) were incorporated during the delineation of the GCBC boundary (Barodien 2005). However, vegetation data, such as 1999 C.A.P.E Irreplaceability (CPU 2003) and the new Vegetation Map of South Africa, Lesotho and Swaziland (Mucina & Rutherford 2004; Mucina *et al.* 2005) were of primary consideration during this process (Barodien 2005).
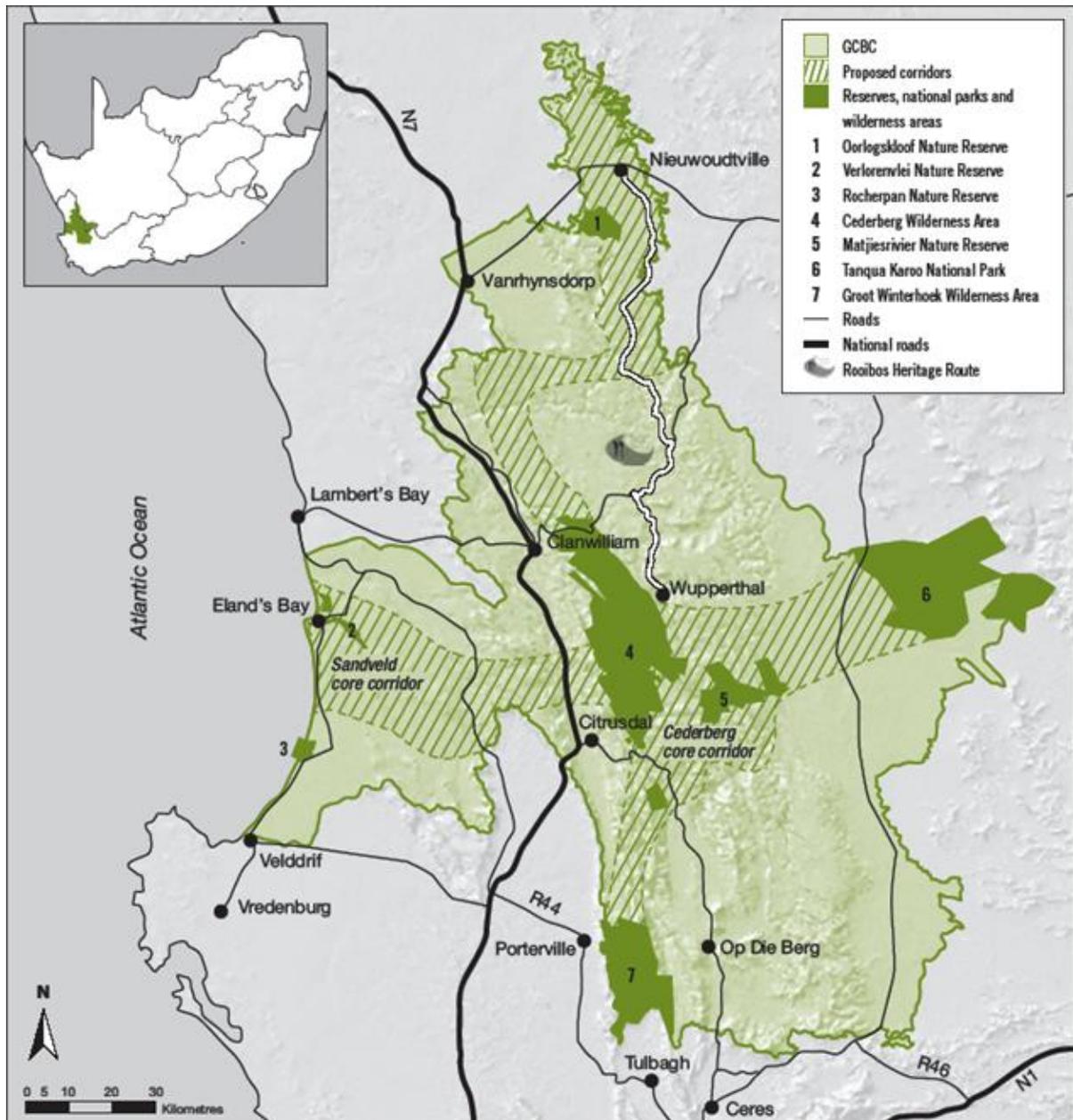
Figure 5.1. The Greater Cederberg Biodiversity Corridor extends from Niewoudtville in

the north to the Grootwinterhoek in the south, Elandsbaai in the west and the Tanqua

Karoo National Park in the east.

5.3. CORRIDORS AND CONSERVATION IN THE GREATER CAPE FLORISTIC REGION (GCFR)

South Africa has made an international commitment to the conservation and sustainable development of its rich diversity of plants, animals and habitats (Hens & Nath 2003; Balmford 2005). Intense conservation focus has therefore been directed at both the Succulent Karoo and the CFR hotspots in South Africa during the last decade (e.g., Cowling *et al.* 1999, 2003; Desmet *et al.* 1999; Pressey *et al.* 2003). Examples of major projects which have been initiated are: 1) the Succulent Karoo Ecosystem Plan (SKEP) which started in January 2002 with the design of a comprehensive framework whereby the implementation of conservation actions in the Succulent Karoo is currently directed (Driver *et al.* 2003), and 2) the Cape Action Plan for People and the Environment (CAPE) which is a 20-year implementation programme which followed from the Cape Action Plan for the Environment – a 2-year project which commenced late in 1998 and was designed to develop a strategy and action plan for sustained conservation of the biodiversity contained in the Cape Floristic Region (Cowling *et al.* 2003; Younge & Fowkes 2003).

An approach which is increasingly implemented to advance the overwhelming task of reducing loss of biodiversity is to focus conservation efforts at environmental patterns, processes and habitats (i.e. ecosystem conservation) rather than attempting to preserve biological diversity through traditional single species conservation (Franklin 1993; Cowling & Heijnis 2001; Sergio *et al.* 2003). This is achieved by designing and managing large-scale conservation corridors, which incorporate a number of important biological patterns and processes at a landscape scale. (Rozdilsky *et al.* 2001; Rouget *et al.* 2006). The Greater Cederberg Biodiversity Corridor (GCBC) is one of three such landscape scale conservation strategies in the Western Cape Province of South Africa,

initiated and implemented by the Cape Action Plan for People and the Environment (CAPE). The other two are the Gouritz and Baviaanskloof Mega-reserves.

The idea behind mega-reserves and corridors is not merely to serve as an immediate spatial environment for plants and animals to remain, but ultimately to provide for possible future changes in spatial requirements in order for them to persist. It is thus very important to determine the relevance of a particular corridor for the long-term conservation of its constituent biota.

5.4.   SPECIES RICHNESS AND ENDEMISM

Despite the distinct sampling bias in the data, clear patterns of reptile species richness were observed for south-western South Africa, south of 31ºS and west of 21ºE (see Chapter 3). Based on the lizard data (Figure 3.2a), there is an area of high species richness along the northern section of the Cape Fold Mountains, from Oorlogskloof near Niewoudtville in the north, down to the Grootwinterhoek Mountains in the south. A minor area of species richness has also been noted along the West Coast, immediately west of the montane area of species richness (Figure 3.2a). Both these areas of richness fall well within the boundaries of the GCBC as delineated at present (Figure 5.1). In fact, the montane area of richness coincides with the core area of the GCBC. Our finding that two major reptile assemblages, a southern and a northern one (see Chapter 4), meet in the Cederberg area, probably explains the high species richness of this area.

Three main sets of endemic species have been identified for the study area (see Chapter 3). The main set comprises a number of species that can be described as Greater Cederberg endemics and the related area of endemism corresponds with the

montane area of species richness. There is also a coastal set of endemics of which the spatial confines coincide with the coastal area of species richness. The GCBC therefore captures both richness and endemism of reptiles in the area. However, the south-western Cape region also harbors a third set of endemics, namely a set of relict melanistic lizard species (Mouton & Oelofsen 1988; Mouton *et al.* 2002; Daniels *et al.* 2004). In South Africa, the phenomenon of melanism in lizards is largely unique to the south-western districts and these melanistic species are considered of high conservation importance (Baard *et al.* 1999). The range of at least one melanistic species falls within the GCBC, namely that of Oelofsen's Girdled Lizard *Cordylus oelofseni* (Mouton & Van Wyk 1990). An undescribed melanistic girdled lizard species occurs in the Piketberg and Platberg areas which fall marginally within the GCBC. In the Saldanha-Langebaan area, melanistic populations of the Karoo Girdled Lizard (*Cordylus polyzonus*) and the Cape Legless Skink (*Acontias meleagris*) occur in sympatry with populations of the Black Girdled Lizard, *Cordylus niger* (Cordes & Mouton 1996). There is a distinct possibility that the melanistic populations of the first two species may soon be described as new species (see Mouton et al. 2002), making this area a distinct centre of endemism for melanistic reptiles. The GCBC could have contributed more significantly to the conservation of this melanistic assemblage by the inclusion of the Saldanha-Langebaan area in the western corridor section, i.e., by extending the corridor southward along the coast to at least the Saldanha-Langebaan area (Figure 5.2).
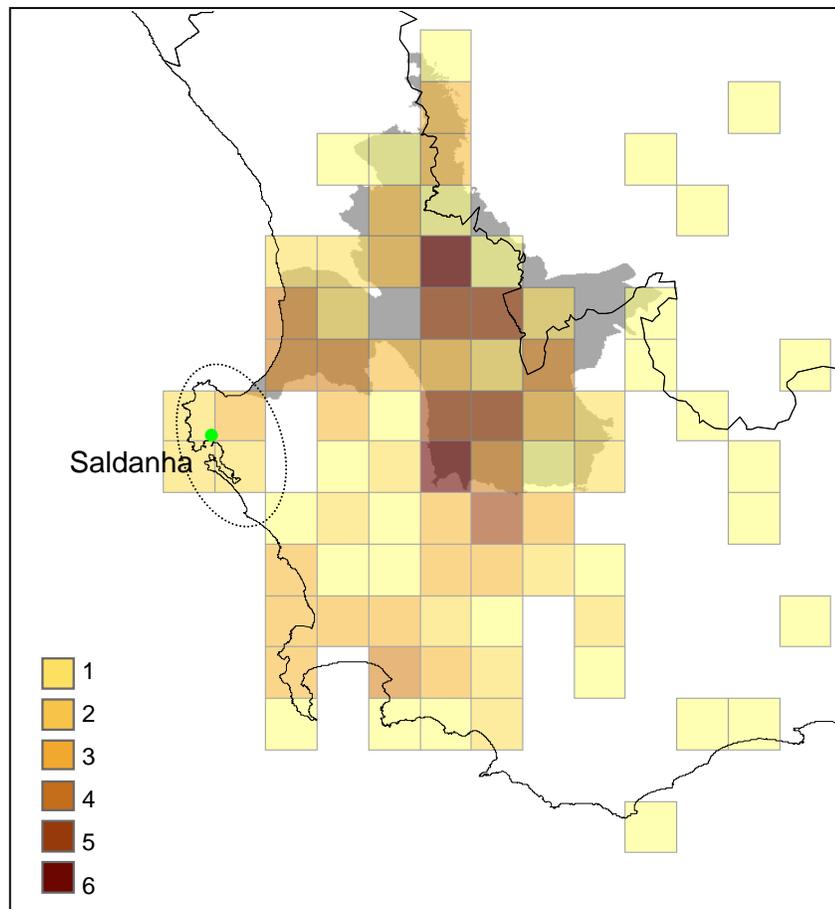
Figure 5.2. The incorporation of QDS endemism patterns by the GCBC (grey shaded area). Inclusion of the suggested area in the Saldanha-Langebaan region (dotted line) would include a set of melanistic endemic lizards which is currently falls outside the corridor's borders.

One major shortcoming of the GCBC towards reptile conservation appears to be its limited potential in the conservation of coastal species. A distinct West Coast reptile assemblage has been identified in the study area (Chapter 4) and the geographical range of this assemblage is a narrow coastal band, from the Gariep River down to the Cape Peninsula. This coastal zone is under immense development pressure. Furthermore, it is unknown how this assemblage will react to climate change. A north-

south dispersal corridor along the coast may be extremely important for this species assemblage. Extending the corridor along the coast to at least the Saldanha-Langebaan area and also to some distance north of Lambert's Bay, will probably considerably increase the potential effectiveness of the GCBC in reptile conservation.

There is at least one endemic reptile species, which contributes to the Greater Cederberg area of endemism, but of which the range falls just outside the borders of the GCBC. The Geometric Tortoise (*Psammobates geometricus*), listed as Endangered in IUCN Red Data lists (Baard *et al.* 1999), occurs in four isolated geographical areas, i.e., the Ceres Valley, the Worcester-Tulbagh Valley, and the Klapmuts and Agtergroenberg (north of Wellington) areas (Baard 1993; Baard & Mouton 1993). It is clear that the GCBC cannot make any contribution to the conservation of this threatened species.

5.5   THE GCBC AND CLIMATE CHANGE

The reptile fauna of the south-western districts of South Africa can be partitioned into four distinct assemblages, three of which can be described as arid zone assemblages and one, the Southern assemblage, as a mesic zone one (see Chapter 4). The current distribution patterns of the constituent species of the Northern and Southern assemblages suggest that climate tracking mainly takes place along a north-south axis. Inland, the GCBC amply provides for north-south dispersal. The north-south section of the corridor largely follows the Cape Fold Mountains and habitat disturbance will always remain low. There is no distinct west-east dispersal activity obvious from the reptile data and the west-east corridor section of the GCBC is probably of lesser importance for reptiles as a long-term dispersal route.

Although changes in sea level may force west-east dispersal of species in the coastal assemblage, a north-south dispersal route must be considered important as the constituent species probably also comprise arid and mesic-adapted species. It is expected that coastal species will track west-east shifts in the coastline and at the same time shift their ranges north or south in tracking climate changes. It is an open question whether the GCBC sufficiently provides for dispersal along the coast.

In summary, the GCBC fulfils the requirements for effective conservation of reptiles in the area to a large degree. It encompasses the main areas of species richness and endemism. It probably provides sufficient north-south dispersal pathways along the north-south section of the Cape Fold Mountains to buffer the effects of climate change on reptile distributions. The only concern is that it makes little provision for north-south dispersal along the coast.

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Appendix A

Latin Name	Common Name
Lizards	
Acontias meleagris	Cape Legless Skink
Afroedura hawequensis	Hawequa Flat Gecko
Afrogecko porphyreus	Marbled Leaf-toed Gecko
Agama aculeata	Ground Agama
Agama atra	Southern Rock Agama
Agama hispida	Spiny Agama
Australolacerta australis	Southern Rock Lizard
Bradypodion gutturale	Little Karoo Dwarf Chameleon
Bradypodion occidentale	Namaqua Dwarf Chameleon
Bradypodion pumilum	Cape Dwarf Chameleon
Bradypodion ventrale	Eastern Cape Dwarf Chameleon
Causus rhombeatus	Common Night Adder
Chamaeleo namaquensis	Namaqua Chameleon
Chamaesaura anguina	Cape Grass Lizard
Chondrodactylus angulifer	Giant Ground Gecko
Chondrodactylus bibronii	Bibron's Gecko
Cordylosaurus subtessellatus	Dwarf Plated Lizard
Cordylus cataphractus	Armadillo Girdled Lizard
Cordylus coeruleopunctatus	Blue-Spotted Girdled Lizard
Cordylus cordylus	Cape Girdled Lizard
Cordylus macropholis	Large-scaled Girdled Lizard
Cordylus mclachlani	McLachlan's Girdled Lizard
Cordylus minor	Dwarf Girdled Lizard
Cordylus niger	Black Girdled Lizard
Cordylus oelofseni	Oelofsen's Girdled Lizard
Cordylus peersi	Peers' Girdled Lizard
Cordylus polyzonus	Karoo Girdled Lizard
Gerrhosaurus flavigularis	Yellow-throated Plated Lizard
Gerrhosaurus typicus	Namaqua Plated Lizard
Goggia hewitti	Hewitt's Dwarf Leaf-toed Gecko
Goggia hexapora	Cedarberg Dwarf Leaf-toed Gecko
Goggia lineata	Striped Leaf-toed Gecko
Goggia microlepidota	Small-scaled Leaf-toed Gecko
Goggia rupicola	Namaqua Dwarf Leaf-toed Gecko
Meroles ctenodactylus	Smith's Desert Lizard
Meroles knoxii	Knox's Desert Lizard
Meroles suborbitalis	Spotted Desert Lizard
Microacontias lineatus	Striped Legless Skink
Microacontias litoralis	Coastal Legless Skink
Nucras lalandii	Delalande's Sandveld Lizard
Nucras livida	Karoo Sandveld Lizard
Nucras tessellata	Striped Sandveld Lizard
Pachydactylus austeni	Austen's Gecko
Pachydactylus capensis	Cape Gecko
Pachydactylus formosus	Karoo Gecko
Pachydactylus geitje	Ocellated Gecko
Pachydactylus kladeroderma	Thin-skinned Thick-toed Gecko
Pachydactylus labialis	Western Cape Gecko

Latin Name	Common Name
Lizards (continued)	
Pachydactylus maculatus	Spotted Gecko
Pachydactylus mariquensis	Marico Thick-toed Gecko
Pachydactylus oculatus	Golden Spotted Gecko
Pachydactylus serval purcelli	Western Spotted Gecko
Pachydactylus weberi	Weber's Thick-toed Gecko
Pedioplanis burchelli	Burchell's Sand Lizard
Pedioplanis laticeps	Cape Sand Lizard
Pedioplanis lineoocellata pulchella	Spotted Sand Lizard
Pedioplanis namaquensis	Namaqua Sand Lizard
Pseudocordylus capensis	Graceful Crag Lizard
Pseudocordylus microlepidotus	Dwarf Crag Lizard
Pseudocordylus nebulosus	Cloud Lizard
Ptenopus garrulus	Common Barking Gecko
Scelotes bipes	Silvery Dwarf Burrowing Skink
Scelotes caffer	Cape Dwarf Burrowing Skink
Scelotes gronovii	Gronovi's Dwarf Burrowing Skink
Scelotes kasneri	Kasner's Dwarf Burrowing Skink
Scelotes montispectus	Bloubergstrand Dwarf Burrowing Skink
Scelotes sexlineatus	Striped Dwarf Burrowing Skink
Tetradactylus seps	Short-legged Seps
Tetradactylus tetradactylus	Common Long-tailed Seps
Trachylepis capensis	Cape Skink
Trachylepis homalocephala	Red-sided Skink
Trachylepis occidentalis	Western Three-striped Skink
Trachylepis sulcata	Western Rock Skink
Trachylepis variegata	Variegated Skink
Tropidosaura gularis	Cape Mountain Lizard
Tropidosaura montana	Common Mountain Lizard
Typhlosaurus caecus	Cuvier's Blind Legless Skink
Snakes	
Amplorhinus multimaculatus	Many-Spotted Snake
Aspidelaps lubricus	Coral Snake
Bitis arietans	Puff Adder
Bitis armata	Southern Adder
Bitis atropos	Berg Adder
Bitis caudalis	Horned Adder
Bitis cornuta	Many-horned Adder
Bitis inornata	Plain Mountain Adder
Bitis rubida	Red Adder
Crotaphopeltis hotamboeia	Herald Snake
Dasypeltis scabra	Common Egg Eater
Dipsina multimaculata	Dwarf Beaked Snake
Dispholidus typus	Boomslang
Duberia lutrix	Common Slug Eater
Hemachatus haemachatus	Rinkhals
Homoroselaps lacteus	Spotted Harlequin Snake
Lamprophis aurora	Aurora House Snake

Latin Name	Common Name
Snakes (continued)	
Lamprophis capensis	Brown House Snake
Lamprophis fiskii	Fisk's House Snake
Lamprophis fuscus	Yellow-bellied House Snake
Lamprophis guttatus	Spotted House Snake
Lamprophis inornatus	Olive House Snake
Leptotyphlops gracilior	Slender Thread Snake
Leptotyphlops nigricans	Black Thread Snake
Lycodonomorphus rufulus	Common Brown Water Snake
Lycophydion capense	Cape Wolf Snake
Naja nigricollis woodi	Black Spitting Cobra
Naja nivea	Cape Cobra
Prosymna sundevallii	Sundevall's Shovel-snout
Psammophis crucifer	Cross-marked Grass Snake
Psammophis leightoni	Forkmarked Sand Snake
Psammophis notostictus	Karoo Whip Snake
Psammophylax rhombeatus	Spotted Skaapsteker
Pseudaspis cana	Mole Snake
Rhinotyphlops lalandei	Delalande's Beaked Blind Snake
Rhinotyphlops schinzi	Schinz's Beaked Blind Snake
Telescopus beetzi	Namib Tiger Snake
Chelonians	
Chersina angulata	Angulate Tortoise
Homopus areolatus	Parrot-Beaked tortoise
Homopus boulengeri	Karoo Boulenger's Padloper
Homopus femoralis	Greater Padloper
Homopus signatus	Speckled Padloper
Pelomedusa subrufa	Marsh Terrapin
Psammobates geometricus	Geometric Tortoise
Psammobates tentorius	Tent Tortoise

Appendix B

Taxon Name	USEC# nr.	DDS	DDE	Type*	Locality
Agama atra	H6101	32.300	19.513	S	Elandsvlei
Agama atra		32.132	20.126	O	Gannaga Pas - TKNP
Agama atra	H5936	33.135	19.652	S	Kareekloof
Agama atra	H6034	32.955	20.267	S	Klipbanksfontein
Agama atra	H6074	32.177	20.156	S	Langkloof - TKNP
Agama atra		32.175	20.152	O	Langkloof - TKNP
Agama atra		33.202	19.732	O	R355 fork
Agama hispida	H6044	32.655	19.682	S	Blaauwboschkolk
Agama hispida	H6045	32.655	19.682	S	Blaauwboschkolk
Agama hispida		32.585	19.558	O	Elandsdrift
Agama hispida	H6083	32.722	19.713	S	Gansfontein
Agama hispida		32.715	19.708	O	Gansfontein
Agama hispida	H6047	32.611	19.808	S	Groote Kapels Fontein
Agama hispida	H6058	32.582	19.701	S	Tandschoonmaak
Bitis caudalis		32.646	19.690	O	Blaauwboschkolk
Bitis caudalis	H6156	32.298	19.518	S	Elandsvlei
Bitis caudalis	H6063	32.648	19.666	S	Klipkraal
Bitis caudalis	H6038	32.967	19.770	S	R355 S of Perdebergkoppies
Bitis caudalis		32.607	19.717	O	Tandschoonmaak
Bitis rubida	H6039	32.968	20.178	S	Bantamsfontein
Chersina angulata		32.816	20.003	O	Bizansgat
Chersina angulata		33.062	19.852	O	Fonteinskop
Chersina angulata		33.063	19.848	O	Fonteinskop
Chersina angulata		31.902	19.511	O	Kalkgat
Chersina angulata		33.169	19.710	O	Kareekloof
Chersina angulata		32.987	20.176	O	Klipbanksfontein
Chersina angulata		33.117	19.991	O	Near Rietpoort
Chersina angulata		33.081	20.060	O	Patatsrivier road
Chersina angulata		33.049	19.773	O	R355 N of Kareekloof turnoff
Chersina angulata		33.077	19.778	O	R355 N of Kareekloof turnoff
Chersina angulata		32.863	19.888	O	Rietfontein
Chersina angulata		32.639	20.089	O	Rooivlak
Chersina angulata		32.639	20.085	O	Rooivlak
Chersina angulata		32.644	20.088	O	Rooivlak
Chersina angulata		31.824	19.680	O	Soutpan Road
Chersina angulata		33.111	19.996	O	Between Toorberg & Vaalkloof
Chersina angulata		32.066	19.776	O	Witkloof
Chondrodactylus angulifer	H6061	32.655	19.682	S	Blaauwboschkolk
Chondrodactylus angulifer	H6060	32.500	20.038	S	Isle of sky
Chondrodactylus angulifer	H6157	32.275	20.110	S	Paulshoek - TKNP
Chondrodactylus angulifer	H5928	32.856	19.894	S	Rietfontein
Chondrodactylus bibronii		32.970	20.182	O	Bantamsfontein
Chondrodactylus bibronii	H6025	32.965	20.187	S	Bantamsfontein

#USEC = University of Stellenbosch Ellerman Collection;* S = Specimen; O = Observation

Taxon Name	USEC[#] nr.	DDS	DDE	Type*	Locality
Chondrodactylus bibronii	H5941	32.827	19.996	S	Bizansgat
Chondrodactylus bibronii		32.827	19.996	O	Bizansgat
Chondrodactylus bibronii		32.832	20.001	O	Bizansgat
Chondrodactylus bibronii		32.818	20.001	O	Bizansgat
Chondrodactylus bibronii		32.830	19.997	O	Bizansgat
Chondrodactylus bibronii		32.846	19.990	O	Bizansgat
Chondrodactylus bibronii	H5919	32.824	19.905	S	Driefontein
Chondrodactylus bibronii		32.826	19.908	O	Driefontein
Chondrodactylus bibronii		32.793	19.908	O	Driefontein
Chondrodactylus bibronii		32.205	20.010	O	Elandsberg - TKNP
Chondrodactylus bibronii		32.201	20.011	O	Elandsberg - TKNP
Chondrodactylus bibronii		32.302	19.501	O	Elandsvlei
Chondrodactylus bibronii	H6100	32.300	19.513	S	Elandsvlei
Chondrodactylus bibronii		32.324	19.585	S	Elandsvlei
Chondrodactylus bibronii	H6106	32.314	19.549	S	Elandsvlei
Chondrodactylus bibronii	H5957	32.882	19.975	S	Hangklip
Chondrodactylus bibronii		32.880	19.977	O	Hangklip
Chondrodactylus bibronii		32.881	19.978	O	Hangklip
Chondrodactylus bibronii	H5999	32.500	20.038	S	Isle of sky
Chondrodactylus bibronii		32.502	20.067	O	Isle of sky
Chondrodactylus bibronii		32.504	20.068	O	Isle of sky
Chondrodactylus bibronii	H6118	31.905	19.518	S	Kalkgat
Chondrodactylus bibronii		31.902	19.511	O	Kalkgat
Chondrodactylus bibronii		33.122	19.651	O	Kareekloof
Chondrodactylus bibronii		33.167	19.711	O	Kareekloof
Chondrodactylus bibronii	H5937	33.167	19.710	S	Kareekloof
Chondrodactylus bibronii	H5989	32.630	20.147	S	Klappieshoek/Rooivlak
Chondrodactylus bibronii		32.633	20.146	O	Klappieshoek/Rooivlak
Chondrodactylus bibronii		32.636	20.147	O	Klappieshoek/Rooivlak
Chondrodactylus bibronii		32.639	20.095	O	Klappieshoek/Rooivlak
Chondrodactylus bibronii		31.879	19.643	O	Kleinhoek
Chondrodactylus bibronii		31.883	19.649	O	Kleinhoek
Chondrodactylus bibronii		31.884	19.631	O	Kleinhoek
Chondrodactylus bibronii		31.880	19.656	O	Kleinhoek
Chondrodactylus bibronii		31.882	19.658	O	Kleinhoek
Chondrodactylus bibronii	H6032	32.955	20.267	S	Klipbanksfontein
Chondrodactylus bibronii	H6053	32.670	19.644	S	Klipkraal
Chondrodactylus bibronii		32.638	19.608	O	Klipkraal
Chondrodactylus bibronii		32.175	20.152	O	Langkloof - TKNP
Chondrodactylus bibronii		32.918	19.696	O	N'Wardouw
Chondrodactylus bibronii		32.924	19.701	O	N'Wardouw
Chondrodactylus bibronii		32.396	19.887	S	Oudebaaskraal
Chondrodactylus bibronii	H6066	32.273	20.105	S	Paulshoek - TKNP
Chondrodactylus bibronii		32.783	20.046	O	Pienaarsfontein
Chondrodactylus bibronii	H5946	32.782	20.045	S	Pienaarsfontein

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Taxon Name	USEC# nr.	DDS	DDE	Type*	Locality
Chondrodactylus bibronii	H5933	33.077	19.778	S	Rooifontein
Chondrodactylus bibronii		32.640	20.086	O	Rooivlak
Chondrodactylus bibronii	H5973	32.639	20.089	S	Rooivlak
Chondrodactylus bibronii	H5976	32.641	20.091	S	Rooivlak
Chondrodactylus bibronii		32.647	20.088	O	Rooivlak
Chondrodactylus bibronii		32.647	20.090	O	Rooivlak
Chondrodactylus bibronii		32.645	20.090	O	Rooivlak
Chondrodactylus bibronii		32.634	20.140	O	Rooivlak
Chondrodactylus bibronii		32.779	19.938	O	Spitskoppe
Chondrodactylus bibronii	H5954	32.779	19.936	S	Spitskoppe
Chondrodactylus bibronii	H5956	32.779	19.936	S	Spitskoppe
Chondrodactylus bibronii		32.782	19.936	O	Spitskoppe
Chondrodactylus bibronii		32.550	20.010	O	Vaalfontein
Chondrodactylus bibronii		32.550	19.996	O	Vaalfontein
Chondrodactylus bibronii	H6079	32.181	19.813	S	Varschfontein - TKNP
Chondrodactylus bibronii		32.189	19.795	O	Varschfontein - TKNP
Chondrodactylus bibronii		32.044	19.766	O	Witkloof
Chondrodactylus bibronii	H6143	32.075	19.699	S	Witkloof
Chondrodactylus bibronii		32.066	19.776	O	Witkloof
Cordylosaurus subtessellatus	H6107	32.296	19.515	S	Elandsvlei
Cordylosaurus subtessellatus	H6122	31.905	19.518	S	Kalkgat
Cordylosaurus subtessellatus	H6150	32.550	19.996	S	Vaalfontein
Cordylus cataphractus	H6026	32.965	20.187	S	Bantamsfontein
Cordylus cataphractus	H5940	32.827	19.996	S	Bizansgat
Cordylus cataphractus		32.827	19.996	O	Bizansgat
Cordylus cataphractus		32.816	20.001	O	Bizansgat
Cordylus cataphractus		32.815	20.002	O	Bizansgat
Cordylus cataphractus		32.806	20.002	O	Bizansgat
Cordylus cataphractus	H5663	32.824	19.905	S	Driefontein
Cordylus cataphractus		32.793	19.908	O	Driefontein
Cordylus cataphractus		32.826	19.908	O	Driefontein
Cordylus cataphractus	H6001	32.499	20.067	S	Isle of sky
Cordylus cataphractus		32.502	20.067	O	Isle of sky
Cordylus cataphractus		32.630	20.147	O	Klappieshoek/Rooivlak
Cordylus cataphractus	H5991	32.630	20.148	S	Klappieshoek/Rooivlak
Cordylus cataphractus		32.633	20.146	O	Klappieshoek/Rooivlak
Cordylus cataphractus		31.883	19.649	O	Kleinhoek
Cordylus cataphractus	H6128	31.884	19.631	S	Kleinhoek
Cordylus cataphractus	H6033	32.959	20.268	S	Klipbanksfontein
Cordylus cataphractus		32.989	20.174	O	Klipbanksfontein
Cordylus cataphractus	H6036	32.929	20.269	S	Klipbanksfontein
Cordylus cataphractus	H5923	32.924	19.700	S	N'Wardouw
Cordylus cataphractus		32.924	19.700	O	N'Wardouw
Cordylus cataphractus	H5949	32.788	20.047	S	Pienaarsfontein
Cordylus cataphractus	H5938	33.077	19.778	S	Rooifontein

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Taxon Name	USEC[#] nr.	DDS	DDE	Type*	Locality
Cordylus cataphractus	H5980	32.646	20.088	S	Rooivlak
Cordylus cataphractus		32.647	20.088	O	Rooivlak
Cordylus cataphractus		32.647	20.090	O	Rooivlak
Cordylus cataphractus	H5953	32.779	19.936	S	Spitskoppe
Cordylus cataphractus		32.779	19.936	O	Spitskoppe
Cordylus cataphractus		32.779	19.936	O	Spitskoppe
Cordylus cataphractus		32.779	19.936	O	Spitskoppe
Cordylus cataphractus		32.778	19.936	O	Spitskoppe
Cordylus cataphractus	H6158	32.550	19.996	S	Vaalfontein
Cordylus polyzonus	H6027	32.971	20.183	S	Bantamsfontein
Cordylus polyzonus		32.967	20.185	O	Bantamsfontein
Cordylus polyzonus		32.965	20.187	O	Bantamsfontein
Cordylus polyzonus	H5942	32.828	19.996	S	Bizansgat
Cordylus polyzonus		32.815	20.002	O	Bizansgat
Cordylus polyzonus		32.819	20.000	O	Bizansgat
Cordylus polyzonus		32.201	20.029	O	Elandsberg - TKNP
Cordylus polyzonus		32.209	20.024	O	Elandsberg - TKNP
Cordylus polyzonus		32.205	20.010	O	Elandsberg - TKNP
Cordylus polyzonus		32.204	20.012	O	Elandsberg - TKNP
Cordylus polyzonus		32.585	19.558	O	Elandsdrift
Cordylus polyzonus	H6152	32.298	19.516	S	Elandsvlei
Cordylus polyzonus	H6102	32.323	19.591	S	Elandsvlei
Cordylus polyzonus		32.324	19.585	O	Elandsvlei
Cordylus polyzonus	H6075	32.132	20.126	S	Gannaga Pas - TKNP
Cordylus polyzonus	H6087	32.722	19.697	S	Gansfontein
Cordylus polyzonus		32.714	19.689	O	Gansfontein
Cordylus polyzonus	H5958	32.881	19.975	S	Hangklip
Cordylus polyzonus		31.905	19.518	O	Kalkgat
Cordylus polyzonus	H6123	31.902	19.511	S	Kalkgat
Cordylus polyzonus	H5992	32.631	20.148	S	Klappieshoek/Rooivlak
Cordylus polyzonus		31.880	19.656	O	Kleinhoek
Cordylus polyzonus	H6145	31.882	19.658	S	Kleinhoek
Cordylus polyzonus		32.959	20.268	O	Klipbanksfontein
Cordylus polyzonus	H6037	32.925	20.271	S	Klipbanksfontein
Cordylus polyzonus		32.925	20.274	O	Klipbanksfontein
Cordylus polyzonus	H6050	32.674	19.652	S	Klipkraal
Cordylus polyzonus	H5922	32.924	19.701	S	N'Wardouw
Cordylus polyzonus	H6065	32.279	20.109	S	Paulshoek - TKNP
Cordylus polyzonus		32.273	20.105	O	Paulshoek - TKNP
Cordylus polyzonus	H5969	32.640	20.086	S	Rooivlak
Cordylus polyzonus	H5979	32.643	20.088	S	Rooivlak
Cordylus polyzonus	H6108	32.550	20.010	S	Vaalfontein
Cordylus polyzonus	H6082	32.181	19.814	S	Varschfontein - TKNP
Cordylus polyzonus		32.044	19.766	O	Witkloof
Cordylus polyzonus	H6129	32.070	19.747	S	Witkloof

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Taxon Name	USEC# nr.	DDS	DDE	Type*	Locality
Cordylus polyzonus		32.066	19.776	O	Witkloof
Cordylus polyzonus		32.070	19.783	O	Witkloof
Cordylus polyzonus		32.069	19.784	O	Witkloof
Cordylys polyzonus	H5921	32.825	19.906	S	Driefontein
Cordylys polyzonus		32.826	19.909	O	Driefontein
Dipsina multimaculata	H6062	32.646	19.690	S	Blaauwboschkolk
Goggia hexapora		32.924	19.700	O	N'Wardouw
Goggia lineata	H6125	31.902	19.511	S	Kalkgat
Goggia lineata	H6126	31.902	19.511	S	Kalkgat
Goggia lineata	H6049	32.672	19.653	S	Klipkraal
Goggia lineata	H6149	32.396	19.887	S	Oudebaaskraal
Goggia lineata	H5930	32.863	19.888	S	Rietfontein
Goggia lineata	H6134	32.066	19.776	S	Witkloof
Homopus signatus		31.884	19.631	O	Kleinhoek
Homopus signatus cafer		32.201	20.013	O	Elandsberg - TKNP
Lamprophis guttatus	H6020	32.932	20.281	S	Klipbanksfontein
Lamprophis guttatus	H5947	32.783	20.041	S	Pienaarsfontein
Leptotyphlops gracilior	H5961	33.062	19.852	S	Fonteinskop
Leptotyphlops gracilior	H6007	32.487	20.071	S	Isle of sky
Leptotyphlops gracilior	H6008	32.487	20.071	S	Isle of sky
Leptotyphlops gracilior	H6017	32.957	19.883	S	Kareekolk
Leptotyphlops gracilior	H5998	32.641	20.097	S	Klappieshoek/Rooivlak
Leptotyphlops gracilior	H6023	32.933	20.281	S	Klipbanksfontein
Leptotyphlops gracilior		32.863	19.888	O	Rietfontein
Leptotyphlops gracilior		32.639	20.089	O	Rooivlak
Leptotyphlops gracilior		32.607	19.717	O	Tandschoonmaak
Leptotyphlops gracilior	H6041	33.111	19.996	O	Between Toorberg & Vaalkloof
Meroles knoxii	H6092	32.715	19.688	S	Gansfontein
Meroles knoxii		32.715	19.708	O	Gansfontein
Meroles knoxii	H6095	32.715	19.710	S	Gansfontein
Microacontias lineatus lineatus	H6155	32.302	19.501	S	Elandsvlei
Naja nigricollis woodi		32.639	20.089	O	Rooivlak
Naja nivea		32.607	19.717	O	Tandschoonmaak
Naja nivea		32.189	19.795	O	Varschfontein - TKNP
Nucras tessellata	H6040	32.972	19.913	S	Kareekolk
Nucras tessellata	H5659	32.856	19.894	S	Rietfontein
Pachydactylus capensis	H5963	33.062	19.854	S	Fonteinskop
Pachydactylus capensis	H5964	33.062	19.854	S	Fonteinskop
Pachydactylus formosus	H6148	32.302	19.501	S	Elandsvlei
Pachydactylus geitje	H6018	32.968	20.177	S	Bantamsfontein
Pachydactylus geitje	H6004	32.487	20.070	S	Isle of sky
Pachydactylus geitje	H5934	33.146	19.668	S	Kareekloof
Pachydactylus geitje	H5995	32.633	20.147	S	Klappieshoek/Rooivlak
Pachydactylus geitje		32.960	20.267	O	Klipbanksfontein
Pachydactylus geitje	H6035	32.955	20.267	S	Klipbanksfontein

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Taxon Name	USEC# nr.	DDS	DDE	Type*	Locality
Pachydactylus geitje		32.933	20.281	O	Klipbanksfontein
Pachydactylus geitje	H5952	32.800	20.062	S	Pienaarsfontein
Pachydactylus geitje	H5978	32.642	20.089	S	Rooivlak
Pachydactylus geitje		32.644	20.088	O	Rooivlak
Pachydactylus geitje	H5955	32.779	19.936	S	Spitskoppe
Pachydactylus kladeroderma	H5951	32.775	20.038	S	Pienaarsfontein
Pachydactylus mariquensis	H5960	32.833	19.994	S	Bizansgat
Pachydactylus mariquensis	H6124	31.902	19.511	S	Kalkgat
Pachydactylus mariquensis	H5997	32.639	20.096	S	Klappieshoek/Rooivlak
Pachydactylus mariquensis	H6114	32.504	19.688	S	Papkuil
Pachydactylus mariquensis	H5932	32.854	19.871	S	Rietfontein
Pachydactylus mariquensis	H6149	32.550	20.010	S	Vaalfontein
Pachydactylus weberi	H6073	32.201	20.011	S	Elandsberg - TKNP
Pachydactylus weberi	H6098	32.300	19.513	S	Elandsvlei
Pachydactylus weberi	H6119	31.905	19.518	S	Kalkgat
Pachydactylus weberi	H6120	31.905	19.518	S	Kalkgat
Pachydactylus weberi		31.884	19.631	O	Kleinhoek
Pachydactylus weberi		31.880	19.656	O	Kleinhoek
Pachydactylus weberi		31.882	19.658	O	Kleinhoek
Pachydactylus weberi	H6070	32.201	20.029	S	Paulshoek - TKNP
Pachydactylus weberi	H5935	33.049	19.773	S	R355 N of Kareekloof turnoff
Pachydactylus weberi	H6077	32.181	19.813	S	Varschfontein - TKNP
Pachydactylus weberi	H6078	32.181	19.813	S	Varschfontein - TKNP
Pachydactylus weberi		32.189	19.795	O	Varschfontein - TKNP
Pachydactylus weberi	H6151	32.046	19.768	S	Witkloof
Pachydactylus weberi	H6144	32.044	19.766	S	Witkloof
Pachydactylus weberi	H6136	32.070	19.747	S	Witkloof
Pachydactylus weberi	H6135	32.069	19.784	S	Witkloof
Pachydactylus weberi	H6130	32.069	19.784	S	Witkloof
Pachydactylus weberi	H5924	32.924	19.700	S	N'Wardouw
Pedioplanis l. pulchella		32.970	20.182	O	Bantamsfontein
Pedioplanis l. pulchella	H6024	32.966	20.187	S	Bantamsfontein
Pedioplanis l. pulchella	H5944	32.828	19.329	S	Bizansgat
Pedioplanis l. pulchella		32.814	20.003	O	Bizansgat
Pedioplanis l. pulchella	H5662	32.825	19.905	S	Driefontein
Pedioplanis l. pulchella	H6072	32.201	20.013	S	Elandsberg - TKNP
Pedioplanis l. pulchella	H6089	32.722	19.697	S	Gansfontein
Pedioplanis l. pulchella	H6090	32.714	19.689	S	Gansfontein
Pedioplanis l. pulchella	H6091	32.714	19.689	S	Gansfontein
Pedioplanis l. pulchella	H5959	32.881	19.978	S	Hangklip
Pedioplanis l. pulchella	H6002	32.503	20.071	S	Isle of sky
Pedioplanis l. pulchella	H6146	31.902	19.511	S	Kalkgat
Pedioplanis l. pulchella	H5996	32.633	20.147	S	Klappieshoek/Rooivlak
Pedioplanis l. pulchella	H6138	31.882	19.646	S	Kleinhoek
Pedioplanis l. pulchella	H6140	31.885	19.633	S	Kleinhoek

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Taxon Name	USEC# nr.	DDS	DDE	Type*	Locality
Pedioplanis l. pulchella	H6141	31.882	19.658	S	Kleinhoek
Pedioplanis l. pulchella	H6021	32.933	20.281	S	Klipbanksfontein
Pedioplanis l. pulchella		32.923	20.275	O	Klipbanksfontein
Pedioplanis l. pulchella		32.674	19.652	O	Klipkraal
Pedioplanis l. pulchella	H6051	32.671	19.648	S	Klipkraal
Pedioplanis l. pulchella	H5926	32.925	19.701	S	N'Wardouw
Pedioplanis l. pulchella	H5927	32.925	19.701	S	N'Wardouw
Pedioplanis l. pulchella		32.928	19.714	O	N'Wardouw
Pedioplanis l. pulchella		33.081	20.060	O	Patatsrivier road
Pedioplanis l. pulchella	H5948	32.787	20.039	S	Pienaarsfontein
Pedioplanis l. pulchella	H5950	32.788	20.047	S	Pienaarsfontein
Pedioplanis l. pulchella		32.799	20.066	O	Pienaarsfontein
Pedioplanis l. pulchella	H5968	32.639	20.085	S	Rooivlak
Pedioplanis l. pulchella		32.779	19.940	O	Spitskoppe
Pedioplanis l. pulchella	H6132	32.068	19.751	S	Witkloof
Pedioplanis laticeps	H6059	32.789	19.754	S	R355 road
Pedioplanis laticeps		33.111	19.996	O	Between Toorberg & Vaalkloof
Pedioplanis laticeps	H6048	32.646	19.690	S	Blaauwboschkolk
Pedioplanis laticeps	H6104	32.323	19.591	S	Elandsvlei
Pedioplanis laticeps	H6105	32.324	19.585	S	Elandsvlei
Pedioplanis laticeps	H6084	32.722	19.713	S	Gansfontein
Pedioplanis laticeps	H6085	32.722	19.713	S	Gansfontein
Pedioplanis laticeps	H6086	32.722	19.697	S	Gansfontein
Pedioplanis laticeps	H6096	32.714	19.689	S	Gansfontein
Pedioplanis laticeps	H6094	32.715	19.710	S	Gansfontein
Pedioplanis laticeps	H5965	32.882	19.974	S	Hangklip
Pedioplanis laticeps	H6000	32.499	20.040	S	Isle of sky
Pedioplanis laticeps	H6003	32.503	20.071	S	Isle of sky
Pedioplanis laticeps	H6005	32.524	20.053	S	Isle of sky
Pedioplanis laticeps	H6011	32.524	20.053	S	Isle of sky
Pedioplanis laticeps	H6012	32.524	20.053	S	Isle of sky
Pedioplanis laticeps	H6013	32.524	20.053	S	Isle of sky
Pedioplanis laticeps	H6016	32.957	19.883	S	Kareekolk
Pedioplanis laticeps	H6015	32.957	19.883	S	Kareekolk
Pedioplanis laticeps	H6142	31.885	19.633	S	Kleinhoek
Pedioplanis laticeps	H6031	32.958	20.266	S	Klipbanksfontein
Pedioplanis laticeps	H6022	32.923	20.274	S	Klipbanksfontein
Pedioplanis laticeps	H6057	32.647	19.667	S	Klipkraal
Pedioplanis laticeps	H6042	33.117	19.991	S	Near Rietpoort
Pedioplanis laticeps		32.275	20.104	O	Paulshoek - TKNP
Pedioplanis laticeps	H6068	32.274	20.113	S	Paulshoek - TKNP
Pedioplanis laticeps		32.276	20.116	O	Paulshoek - TKNP
Pedioplanis laticeps	H6069	32.275	20.110	S	Paulshoek - TKNP
Pedioplanis laticeps	H5931	32.863	19.888	S	Rietfontein
Pedioplanis laticeps	H5660	32.863	19.888	S	Rietfontein

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Taxon Name	USEC# nr.	DDS	DDE	Type*	Locality
Pedioplanis laticeps	H5661	32.863	19.888	S	Rietfontein
Pedioplanis laticeps	H6055	32.588	19.710	S	Tandschoonmaak
Pedioplanis laticeps	H6056	32.582	19.701	S	Tandschoonmaak
Pedioplanis laticeps	H6080	32.186	19.793	S	Varschfontein - TKNP
Pedioplanis laticeps		32.201	19.753	O	Varschfontein - TKNP
Pedioplanis laticeps		32.186	19.793	O	Varschfontein - TKNP
Pedioplanis laticeps	H6133	32.066	19.746	S	Witkloof
Psammobates sp.		32.863	19.888	O	Rietfontein
Psammobates t. veroxii		33.049	19.773	S	R355 N of Kareekloof turnoff
Psammobates tentorius		33.111	19.996	O	Between Toorberg & Vaalkloof
Psammobates tentorius		32.717	19.693	O	Gansfontein
Psammobates tentorius		33.081	20.060	O	Patatsrivier road
Psammophis notostictus	H5929	32.824	19.905	S	Driefontein
Psammophis notostictus	H6009	32.524	20.053	S	Isle of sky
Psammophis notostictus	H6006	32.524	20.053	S	Isle of sky
Psammophis notostictus	H5993	32.633	20.146	S	Klappieshoek/Rooivlak
Psammophis notostictus	H6154	32.396	19.887	S	Oudebaaskraal
Psammophis notostictus	H5977	32.642	20.089	S	Rooivlak
Psammophis notostictus		32.782	19.936	O	Spitskoppe
Psammophis notostictus	H6081	32.186	19.793	S	Varschfontein - TKNP
Psammophis notostictus		32.096	19.677	O	Witkloof
Psammophis notostictus	H6153	32.075	19.699	S	Witkloof
Rhinotyphlops lalandei	H6019	32.968	20.178	S	Bantamsfontein
Rhinotyphlops sp.		31.907	19.519	O	Kalkgat
Trachylepis capensis	H5972	32.639	20.087	S	Rooivlak
Trachylepis occidentalis	H6046	32.655	19.682	S	Blaauwboschkolk
Trachylepis occidentalis	H6093	32.719	19.709	S	Gansfontein
Trachylepis occidentalis	H6097	32.956	19.884	S	Kareekolk
Trachylepis occidentalis		32.648	19.666	O	Klipkraal
Trachylepis occidentalis	H6054	32.638	19.608	S	Klipkraal
Trachylepis occidentalis	H6112	32.396	19.887	S	Oudebaaskraal
Trachylepis occidentalis		32.607	19.717	O	Tandschoonmaak
Trachylepis occidentalis	H6127	32.186	19.793	S	Varschfontein - TKNP
Trachylepis occidentalis	H6115	32.075	19.699	S	Witkloof
Trachylepis occidentalis	H6116	32.075	19.699	S	Witkloof
Trachylepis sp.		32.863	19.888	O	Rietfontein
Trachylepis sulcata	H6029	32.970	20.182	S	Bantamsfontein
Trachylepis sulcata		32.967	20.185	O	Bantamsfontein
Trachylepis sulcata		32.827	19.996	O	Bizansgat
Trachylepis sulcata	H5945	32.816	20.001	S	Bizansgat
Trachylepis sulcata		32.832	20.001	O	Bizansgat
Trachylepis sulcata		32.846	19.990	O	Bizansgat
Trachylepis sulcata		32.845	19.995	O	Bizansgat
Trachylepis sulcata	H5966	32.833	19.994	S	Bizansgat
Trachylepis sulcata	H5920	32.824	19.905	S	Driefontein

#USEC = University of Stellenbosch Ellerman Collection; * S = Specimen; O = Observation

Taxon Name	USEC[#] nr.	DDS	DDE	Type*	Locality
Trachylepis sulcata		32.793	19.908	O	Driefontein
Trachylepis sulcata	H6071	32.201	20.029	S	Elandsberg - TKNP
Trachylepis sulcata		32.209	20.024	O	Elandsberg - TKNP
Trachylepis sulcata		32.205	20.010	O	Elandsberg - TKNP
Trachylepis sulcata		32.204	20.012	O	Elandsberg - TKNP
Trachylepis sulcata		32.585	19.558	O	Elandsdrift
Trachylepis sulcata		32.302	19.501	O	Elandsvlei
Trachylepis sulcata	H6099	32.300	19.515	S	Elandsvlei
Trachylepis sulcata	H6103	32.323	19.591	S	Elandsvlei
Trachylepis sulcata		32.324	19.585	O	Elandsvlei
Trachylepis sulcata	H5962	33.063	19.850	S	Fonteinskop
Trachylepis sulcata		32.132	20.126	O	Gannaga Pas - TKNP
Trachylepis sulcata	H6088	32.722	19.697	S	Gansfontein
Trachylepis sulcata		32.882	19.975	O	Hangklip
Trachylepis sulcata	H6010	32.501	20.066	S	Isle of sky
Trachylepis sulcata	H6014	32.722	20.066	S	Isle of sky
Trachylepis sulcata	H6121	31.905	19.518	S	Kalkgat
Trachylepis sulcata		31.902	19.511	O	Kalkgat
Trachylepis sulcata	H5990	32.630	20.147	S	Klappieshoek/Rooivlak
Trachylepis sulcata		32.636	20.147	O	Klappieshoek/Rooivlak
Trachylepis sulcata		32.639	20.095	O	Klappieshoek/Rooivlak
Trachylepis sulcata	H6139	31.883	19.649	S	Kleinhoek
Trachylepis sulcata		31.879	19.655	O	Kleinhoek
Trachylepis sulcata		31.882	19.658	O	Kleinhoek
Trachylepis sulcata	H6030	32.959	20.268	S	Klipbanksfontein
Trachylepis sulcata		32.958	20.266	O	Klipbanksfontein
Trachylepis sulcata		32.670	19.644	O	Klipkraal
Trachylepis sulcata		32.175	20.152	O	Langkloof - TKNP
Trachylepis sulcata		32.924	19.701	O	N'Wardouw
Trachylepis sulcata	H6113	32.396	19.887	S	Oudebaaskraal
Trachylepis sulcata	H6064	32.279	20.109	S	Paulshoek - TKNP
Trachylepis sulcata		33.049	19.773	O	R355 N of Kareekloof turnoff
Trachylepis sulcata	H5939	33.077	19.778	S	Rooifontein
Trachylepis sulcata	H5970	32.640	20.086	S	Rooivlak
Trachylepis sulcata	H5971	32.640	20.086	S	Rooivlak
Trachylepis sulcata	H5974	32.641	20.092	S	Rooivlak
Trachylepis sulcata		32.641	20.091	O	Rooivlak
Trachylepis sulcata	H5981	32.645	20.090	S	Rooivlak
Trachylepis sulcata	H5982	32.645	20.090	S	Rooivlak
Trachylepis sulcata	H5983	32.645	20.090	S	Rooivlak
Trachylepis sulcata	H5984	32.645	20.090	S	Rooivlak
Trachylepis sulcata	H5985	32.645	20.090	S	Rooivlak
Trachylepis sulcata	H5986	32.645	20.090	S	Rooivlak
Trachylepis sulcata	H5987	32.645	20.090	S	Rooivlak
Trachylepis sulcata	H5988	32.645	20.090	S	Rooivlak

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Taxon Name	USEC# nr.	DDS	DDE	Type*	Locality
Trachylepis sulcata	H6111	32.550	19.996	S	Vaalfontein
Trachylepis sulcata	H6076	32.181	19.813	S	Varschfontein - TKNP
Trachylepis sulcata	H6117	32.044	19.766	S	Witkloof
Trachylepis variegata	H6028	32.970	20.182	S	Bantamsfontein
Trachylepis variegata		32.971	20.183	O	Bantamsfontein
Trachylepis variegata		32.965	20.187	O	Bantamsfontein
Trachylepis variegata	H5943	32.828	19.996	S	Bizansgat
Trachylepis variegata		32.806	20.002	O	Bizansgat
Trachylepis variegata	H5967	32.833	19.994	S	Bizansgat
Trachylepis variegata		32.826	19.905	O	Driefontein
Trachylepis variegata		32.201	20.029	O	Elandsberg - TKNP
Trachylepis variegata		32.204	20.012	O	Elandsberg - TKNP
Trachylepis variegata		32.302	19.501	O	Elandsvlei
Trachylepis variegata		32.300	19.515	O	Elandsvlei
Trachylepis variegata		32.300	19.513	O	Elandsvlei
Trachylepis variegata		32.132	20.126	O	Gannaga Pas - TKNP
Trachylepis variegata		32.880	19.977	O	Hangklip
Trachylepis variegata		32.504	20.068	O	Isle of sky
Trachylepis variegata		31.905	19.518	O	Kalkgat
Trachylepis variegata	H5994	32.633	20.146	S	Klappieshoek/Rooivlak
Trachylepis variegata	H6137	31.879	19.643	S	Kleinhoek
Trachylepis variegata		31.884	19.631	O	Kleinhoek
Trachylepis variegata		31.879	19.655	O	Kleinhoek
Trachylepis variegata	H6052	32.671	19.648	S	Klipkraal
Trachylepis variegata	H5925	32.924	19.700	S	N'Wardouw
Trachylepis variegata	H6067	32.277	20.104	S	Paulshoek - TKNP
Trachylepis variegata		32.784	20.035	O	Pienaarsfontein
Trachylepis variegata		32.799	20.066	O	Pienaarsfontein
Trachylepis variegata	H5975	32.641	20.091	S	Rooivlak
Trachylepis variegata		32.778	19.936	O	Spitskoppe
Trachylepis variegata	H6109	32.550	20.010	S	Vaalfontein
Trachylepis variegata	H6110	32.550	20.010	S	Vaalfontein
Trachylepis variegata		32.180	19.816	O	Varschfontein - TKNP
Trachylepis variegata		32.046	19.768	O	Witkloof
Trachylepis variegata	H6131	32.070	19.747	S	Witkloof

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Appendix C

1.) Precipitation Seasonality (PS)

Percentage precipitation in April-Sept (inclusive) relative to total annual rainfall. A high PS value indicates a strong winter rainfall regime.

2.) Incidence of Fog (FOG) and cloudy (CLO) days

Fog and overcast days were calculated from the South African Weather Service's WB42 dataset of long term weather station data. An Inverse Distance Weighting (IDW) interpolator was used. The six nearest weather station data was considered for each cell and stations closer by was given an exponentionally (to the order of three) higher weight.

3.) Continentality Index (CI)

Calculated as follows:

$$K_G = 1.7 \frac{A}{\sin \varphi} - 20.4$$

where A is the difference between the mean temperatures of the hottest (Jan) and the coldest (July) months and $\varPhi$ is the latitude (Gorczyński 1920). A constant of 9 was added for scalability.

4.) Summer Aridity Index (SAI)

Calculated as the natural logarithmic of the mean precipitation of the four warmest months (Nov-Feb) (Rutherford & Westfall 1994). A constant of 9 was added for scalability.

References

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