

Ultramafic substrates and floristic patterns in Sekhukhuneland, South Africa

by

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Submitted in partial fulfilment of the requirements for the degree

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Co-supervisor: Prof. Dr. G.J. Bredenkamp

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**'The primary tactic in conservation must be to locate the world's hot spots
and to protect the entire environment they contain.'**

Edward O. Wilson (1992)

**I live to honour God, and I present this dissertation to Him, who thought it well to provide
me with opportunities I am certainly not worthy of.**

ABSTRACT

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Sekhukhuneland is an area of diverse geology and rich phytodiversity. This region harbours the world's largest reserves of chromium and platinum ore. A literature review of heavy metal soils is presented as introduction and motivation for this dissertation. Special attention was given to the effects of chromium on plants, due to its abundance in the Sekhukhuneland study area. Floristic elements of the Sekhukhuneland study area were determined by means of field work, herbarium studies and literature surveys. Approximately 50 endemic and 70 near-endemic taxa were identified for this region. Families such as Euphorbiaceae, Fabaceae, Liliaceae and Vitaceae proved the most prolific in endemic taxa. Distribution ranges for each of the floristic elements were mapped and analysed with a Geographical Information System. Plant distributions showed distinct floristic patterns within Sekhukhuneland, and links with other mountainous regions of the Northern Provinces of South Africa. Percentage surface cover of all the various geological substrates (predominantly Rustenburg Layered Suite and Transvaal Sequence) were calculated for each quarter degree grid in the study area. A correlation was found between the region's percentage endemism and percentage surface cover of ultramafic substrates. The ultramafic substrates, norite, anorthosite and pyroxenite, showed a significant positive correlation with percentage endemism. The high number of endemics and the endemic-ultramafic correlation in certain quarter degree grids, enabled the identification of focal areas of endemism in the study area. These focal areas of endemism support the status of Sekhukhuneland as an important Centre of Endemism.

Keywords: Sekhukhuneland, chrome, geology, ultramafic, endemism, phytodiversity, biodiversity savannah, phytogeography, phytochorion, Centre of Endemism.

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LIST OF ABBREVIATIONS

BIC	= Bushveld Igneous Complex
CBD	= Convention on Biological Diversity
GIS	= Geographical Information System
NP	= Northern Provinces of South Africa (Gauteng, North-West, Northern Province & Mpumalanga)
PRE	= National Herbarium, Pretoria
PRÉCIS	= Pretoria National Herbarium Computerised Information System
PRU	= H.G.W.J. Schweickerdt Herbarium, University of Pretoria
QDG	= Quarter Degree Grid
QDGs	= Quarter Degree Grids
RLS	= Rustenburg Layered Suite
SCE	= Sekhukhuneland Centre of Endemism
SSA	= Sekhukhuneland Study Area
TS	= Transvaal Sequence

CHAPTER 1

INTRODUCTION

1.1 Background

On 5 June 1992, at the United Nations Conference on Environment and Development (the Rio 'Earth Summit'), the Convention on Biological Diversity [CBD] was opened for signature (Davis *et al.* 1994). The CBD was inspired by the world community's growing commitment to sustainable development. It represents a dramatic step forward in the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the use of genetic resources.

What is biological diversity? Biological diversity, or **biodiversity**, is the sum of all species of animals, plants, fungi and micro-organisms, as well as the gene pool, evolutionary history and potential value of each species (Low & Rebelo 1996). In the light of this dissertation and its contribution to biodiversity studies, the individual uniqueness of infraspecific taxa can be added to the definition of biodiversity. Biodiversity is an integral part of ecosystems, ecological processes and landscapes, which is much appreciated (e.g. Kruger National Park) and needed (e.g. Maputaland) by a country's people.

The importance of plant diversity may be summarised as follows: humans and most other animals are almost totally dependent on plants, directly or indirectly, as a source of energy through their ability to convert the sun's energy via photosynthesis (Salisbury & Ross 1992). Tens of thousands of species of higher plants, and several hundred lower plants, are currently being used by humans for a wide diversity of purposes. To conserve and utilise this plant life sustainably, it is important to know what is being used and what should be conserved.

Knowledge of a region's phytodiversity forms the basis for understanding and managing its plant resources and environment. One of the main problems facing plant conservation in southern Africa, is the lack of sound information on which to base conservation strategies. Although only one manifestation of rarity, the endemic is the one that best fits the common notion of this concept (Kruckeberg & Rabinowitz 1985). The conservation of endemics that are threatened or endangered has therefore become a major concern shared by governments, conservation organisations, and individuals.

Endemic taxa are usually very rare plants with distinctive distribution patterns. The interpretation of endemism is, however, far from straightforward and the concept remains an enigmatic one, a precise scientific definition of 'endemic' proving elusive (Kruckeberg & Rabinowitz 1985). Endemic taxa also represent the geographical element which most naturally characterises the floristic uniqueness of a particular country or region (Stott 1981). Therefore, it is not surprising that their distribution patterns are often thought to contain a great deal of phytogeographical information which careful analysis will reveal and which will be of great value in interpreting the phytogeographical history of different regions and floras.

South-central Africa, that is the Republic of South Africa, Zimbabwe, Botswana, Zaire and Zambia, is one of the richest areas for heavy metals (especially copper, cobalt, chromium, nickel, platinum and uranium) in the world (Brooks & Malaisse 1985; Coetzee 1985; Nriagu & Nieboer 1988). The rocks of an area are widely accepted as the basis for the development of the area's soil (McVicar *et al.* 1991). Since edaphic factors are most commonly involved in showing the link between environments and endemic taxa (Kruckeberg & Rabinowitz 1985), the complex and contrasting lithology of the eastern Bushveld Igneous Complex [BIC] in Sekhukhuneland, provides an opportunity to assess both the influence of peculiar geological substrates on local endemics, as well as the regional specific endemism (floristic elements).

In an analysis by Matthews *et al.* (1993), the endemic seed plant flora of the North-Eastern Transvaal Escarpment is assessed in terms of the region's lithology. A total of at least 113 species and infraspecific taxa were recorded as endemic or near-endemic to the area. The area was proposed as a Centre of Endemism and is listed in Davis *et al.* (1994). This Centre of Endemism lies directly adjacent and to the east of the region assessed in this dissertation. When the location of the various botanical Centres of Endemism in South Africa are studied (Van Wyk & Van Wyk 1997), a rather peculiar pattern is evident - it seems as if the occurrence of one Centre is usually supported by the presence of adjacent Centres of a greater or lesser degree of endemism. Thus, the proximity of the Wolkberg Centre to Sekhukhuneland, raises the probability of a unique flora occurring in the study area.

1.2 Rationale and Motivation

In November 1995, South Africa signed the CBD and became a contracting party of the Convention. According to the preamble of the CBD (Geneva Executive Center 1994), the contracting parties need to become aware of the general lack of information and knowledge regarding biological diversity and of the urgent need to develop scientific, technical and institutional capacities to provide the basic understanding upon which to plan and implement appropriate measures.

Therefore, the main motivation for this study is to establish grounds for further, more intense research concerning biodiversity in Sekhukhuneland. The global shift towards the conservation of biodiversity and sustainable development has warranted further analyses into the occurrence and distribution of phytodiversity. This dissertation should be seen as a first attempt to determine certain fundamental aspects concerning the unknown phytodiversity of the study area.

The increasing pressure of development, and the increase in resource utilisation in Sekhukhuneland, necessitate the effective conservation of biodiversity, by means of collection and analysis of baseline floristic data, to prevent destruction of the rich biodiversity and exploitation of the natural resources. The motivation for this dissertation is partially a concern for the urgent need to highlight areas of prime botanical importance which is prone to rapid loss and degradation of natural ecosystems, and with the hope that these areas will receive adequate attention to ensure their conservation.

Sekhukhuneland is known for its heterogeneous geology in the form of the eastern Bushveld Igneous Complex. The Bushveld Igneous Complex is one of the main heavy metal resources in South Africa. When the localities of the main mineral resources of the Northern Provinces of South Africa (Coetzee 1985) is compared with the localities of the known and potential Centres of Endemism in the Northern Provinces of South Africa (Van Wyk & Van Wyk 1997), it is interesting to note how well these areas overlap. The endemics of Sekhukhuneland are situated upon the heavy metal soils of ultramafic substrates. Ultramafic soils of certain regions are known for their edaphic endemics (Wild 1970). Thus, the motivation of this dissertation is to some extent attributed to the unknown correlation which exist between geology and endemism.

This dissertation hopes to shed some light on the biodiversity of Sekhukhuneland, the distribution of endemics and the priority areas of the Sekhukhuneland Centre of Endemism. Therefore, basic information concerning the plant species, and especially the floristic diversity, endemics and floral-ultramafic associations of Sekhukhuneland, on the eastern Bushveld Igneous Complex of southern Africa, will be presented. Thus, the rationale and motivation for this study lies in the evaluation of Sekhukhuneland as a key potential site of diversity and to assess its status as a Centre of Endemism.

1.3 Approach and layout

The layout, or structure, of the dissertation is based on a primary theme and a few secondary themes. The primary theme of the study concerns ultramafic substrates and floristic patterns. This primary theme is presented by means of the secondary themes and is divided into three parts.

The first part of the layout is the **Introduction** (Chapter 1) and **A Review of Heavy Metal Soils** (Chapter 2). This is followed by the main part of the study which is further divided into two sections. The first section comprises the **Study Area** (Chapter 3), the **Methods** (Chapter 4) and certain aspects of the **Discussion and Additional Observations** (Chapter 5). The final part of the dissertation is the remaining aspects of the **Discussion and Additional Observations** (Chapter 5) and the **Conclusions** (Chapter 6).

A specific approach is followed in the dissertation. The approach is expressed as different themes, with each theme providing information in a specific order to adhere to the structure of the dissertation. The approach presents the three secondary themes in such a way as to contribute to the main idea, or primary theme, of the dissertation. The approach of the dissertation is described below:

<p>Introductory theme (Chapter 1 & 2)</p> <ol style="list-style-type: none"> (1) To motivate the study by means of background information; (2) To state the rationale and objectives of the study; (3) To explain the approach and layout; (4) To shortly introduce the hypothesis and aims of the study; (5) To present a literature review as an introduction to the primary theme of the study.
<p>Main Theme (Chapter 3, 4 & 5)</p> <ol style="list-style-type: none"> (1.1) To give a short historical overview of the region's people; (1.2) To define the borders of the Sekhukhuneland Study Area [SSA]; (1.3) To shortly discuss the SSA topography, climate, vegetation, flora and, especially, the geology; (1.4) To describe the methods which were used in the study; (2.1) To evaluate the endemism of the SSA; (2.2) To identify the focal points of endemism in the SSA; (2.3) To correlate the distribution patterns of the SSA with the geology.
<p>Concluding Theme (Chapter 5 & 6)</p> <ol style="list-style-type: none"> (1) To evaluate to what extent the objectives of the study have been met; (2) To suggest aspects needing further research in the SSA; (3) To conclude the study.

1.4 Hypothesis and principal aims

Potential areas of high biodiversity are recognisable by their peculiar history, climate, topography or edaphic factors (Stott 1981). ‘Peculiar’ means in this instance ‘strange’ or ‘rare’. The only environments that are strange or rare are heterogeneous environments. Sekhukhuneland is a region of heterogeneous topography, climate, history and geology. Therefore, the principle hypothesis of this dissertation is: **The Sekhukhuneland Study Area [SSA] is an area of high endemism, with floristic patterns which can be correlated with its heterogeneous geology.**

The first objective of this study is to compile a literature review on heavy metal soils. The second objective of the study is to establish which species are endemic or near-endemic to Sekhukhuneland. A deeper insight into the region’s endemism will shed light on the third objective, namely to determine the priority areas of high phytodiversity. The fourth objective is to try and relate the floristic patterns of the priority areas with the ultramafic substrates. These objectives are coupled to principal aims. The aims are special goals which have to be achieved before the objectives of the study can be met. The aims are as follows:

- To review the effects of heavy metal soils, and specifically chromium, on vegetation;
- To investigate whether chromium soils could facilitate hyperaccumulation and endemism;
- To discuss the geology of the Rustenburg Layered Suite [RLS] and other environmental heterogeneity;
- To compile a list of the plant taxa endemic or near-endemic to the SSA;
- To use GIS techniques to map the distribution of putative SSA endemics;
- To use GIS to correlate the distribution of SSA endemics and near-endemics with adjacent centres;
- To establish affinities between the SSA endemic elements and the ultramafic substrates;
- To establish whether Sekhukhuneland warrants recognition as a Centre of Endemism;
- To suggest topics for future research in the SSA; and
- To note any botanical aspects that might reflect on the biogeographical patterns in the SSA.

CHAPTER 2

A REVIEW OF HEAVY METAL SOILS

2.1 Introduction

The vegetation of the world's ultramafic substrates are renowned for their sharp boundaries and conspicuous physiognomical and floristic differences. From the Arctic tundra to the tropical rainforest, ultramafic substrates support a highly unusual flora distinguishable from its surroundings. Sometimes these vegetation anomalies are so pronounced that the geology can be mapped from the air by using the vegetation patterns alone (Brooks 1983).

Ultramafic rock formations contain less than 45% silica, almost no quartz or feldspar and consists mainly of ferromagnesian silicates, metal oxides and -sulphides, a high magnesium-calcium ratio, and high concentrations of elementary metals (MacVicar *et al.* 1991). Norite, anorthosite and pyroxinite are examples of ultramafic substrates.

Ultramafic soils (derived from ultramafic rock formations) have been recognised from their vegetation and floral cover for several hundred years, well before the edaphic reasons for the development of such vegetation had been established. In 1583, A. Caesalpino recognised the presence of an 'alyson' (*Alyssum bertolonii*) growing over 'black stones' of the Upper Tiber Valley in Tuscany (Brooks 1987). In more recent time (20th century) vegetation associated with heavy metal soils was first observed and studied by W. Robyns in 1932, but only years later, in 1960, did the enthusiasm of H. Wild stimulate many workers to conduct research in this field (Roberts & Proctor 1992). Subsequently work on this topic has been done all over the world in countries such as Canada and the United States in North America, Brazil and Cuba in South America, Sweden and Great Britain in Europe, Japan and India in Asia, Zimbabwe and the Democratic Republic of the Congo (Zaire) in Africa and New Caledonia in the Pacific Ocean (Brooks 1987).

Africa is one of the oldest and tectonically most stable of all the continents, and thus there are only six igneous intrusions in Africa which are of great significance for the deposition of ultramafic rocks (Coetzee 1985; Brooks 1987). Southern Africa is particularly renowned for the variation in its different types of ore (Wild 1974c; Brooks & Malaisse 1985; Nriagu & Nieboer 1988) and the high concentrations of different heavy metals occurring in its ultramafic rocks (Kent 1980; Coetzee 1985). Two of the ultramafic intrusions in Africa are located in southern Africa.

The Great Dyke is a intrusion that bisects Zimbabwe along a north-south line for some 500 km and which carries some of the world's greatest deposits of nickel and asbestos. The flora of ultramafic soils in Zimbabwe is well known and these studies have made an important contribution to our general understanding of the effects of toxic soils (Wild 1965; Wild 1974a; Wild 1974b; Wild 1974c; Werger *et al.* 1978; Brooks & Malaisse 1985; Brooks 1987; Nriagu & Nieboer 1988). Heavy metals such as copper and nickel create vegetation anomalies in Zimbabwe, in which the natural woodland or tree savannah vegetation is changed to bare grassy areas, or areas where the woody species are reduced from trees to shrubs or dwarf shrubs (stunting). These vegetation anomalies are created by soils containing lethal concentrations of heavy metals.

The second important intrusion in southern Africa is the Bushveld Igneous Complex [BIC], which was formed about 1 950 million years ago when it intruded into the older Precambrian gneiss (Visser *et al.* 1989). The surface area of the complex is about 65 000 km² with basic and ultramafic rocks occupying the outer circumference of the circular structure and dipping down towards the centre which is granitic at the surface and forms part of a saucer fed from a central volcanic pipe (Visser *et al.* 1989). The Bushveld Complex carries in its ultramafic layers the largest reserves of chrome and platinum metals in the world, accompanied by nickel and other base metals (Brooks 1998).

2.2 Background information

2.2.1 Minerals

A mineral is a chemical element produced as a result of the weathering of rock, with the weathered substance occurring as an ion deposit in the soil (Grobbelaar *et al.* 1987). Minerals are taken up by the roots of plants, and occasionally through the leaves (Salisbury & Ross 1992). Plants are dependent on certain minerals for their survival. Minerals which are essential for the survival of a plant, are known as **essential elements**. An essential element is determined by three criteria (Grobbelaar *et al.* 1987; Salisbury & Ross 1992):

- the plant must be dependent on the element for the completion of its life cycle;
- the element must form a part of an important molecule (e.g. chlorophyll);
- the element must have a direct influence on the plant; no other element must be able to fulfil its function.

There are 16 essential elements known in agriculture which are readily taken up by most plants. Three non-mineral (C, H, and O) and 13 mineral elements are recognised as essential elements (Grobbelaar *et al.* 1987). The essential elements can be divided into micro- and macro elements. A micro element is less essential than a macro element. If an element usually comprises less than 100

$\mu\text{g/g}$ of the plant dry weight, then it is a micro element (that is Mo, Cu, Zn, Mn, B, Fe and Cl) and if the element usually exceeds $100 \mu\text{g/g}$ of the plant dry weight, then it is a macro element (that is P, K, N, S, Ca and Mg) (Grobbelaar *et al.* 1987; Salisbury & Ross 1992).

Essential elements do sometimes occur at high concentrations in the soil. Under natural conditions macro elements are usually not toxic at high concentrations, whereas micro elements are (Burgoyne 1987). According to Salisbury & Ross (1992), toxicity of micro elements usually sets in at concentrations greater than $1\ 000 \mu\text{g/g}$ dry weight of the plant. If the concentration of an essential micro element is plotted against the growth of a specific plant, then a graph is created which displays plant growth as a function of the essential element (Figure 1). Plant growth can be divided into three phases:

- Phase 1: The essential element is at low concentrations in the soil. This means that the demand will be greater than the reserves (soil supply) of the element. This situation results in **proportional uptake** (straight line), where the plant's growth rate increases as the mineral concentration increases.
- Phase 2: The concentration of the essential element has increased past the demand for it. The luxurious phase is the concentration at which the plant has saturated its needs for the element. This situation is described as **luxurious uptake**. The zone of luxurious uptake indicates that the reserves (soil supply) of the element is greater than the demand for it. The plant's growth rate will therefore not increase as uptake increases, because the plant's need is already saturated.
- Phase 3: The concentration of the essential element (especially micro elements such as Cu, Zn and Fe) has reached high values that are lethal to the plant. The high values have exceeded the **critical zone** ($1\ 000 \mu\text{g/g}$ dry weight) where the plant was able to discharge the surplus of the element. Thus, the uptake exceeds the discharge, resulting in the accumulation of the element in the plant's cells. This situation is generally described as toxic, resulting in a decrease in growth rate and finally mortality.

Plant growth rate is dependent on phases one and two when micro and macro elements are taken up. The third phase applies when excessive amounts of certain micro elements are taken up. Any uptake beyond the critical zone ($1\ 000 \mu\text{g/g}$ dry weight) is excessive and toxic to the plant.

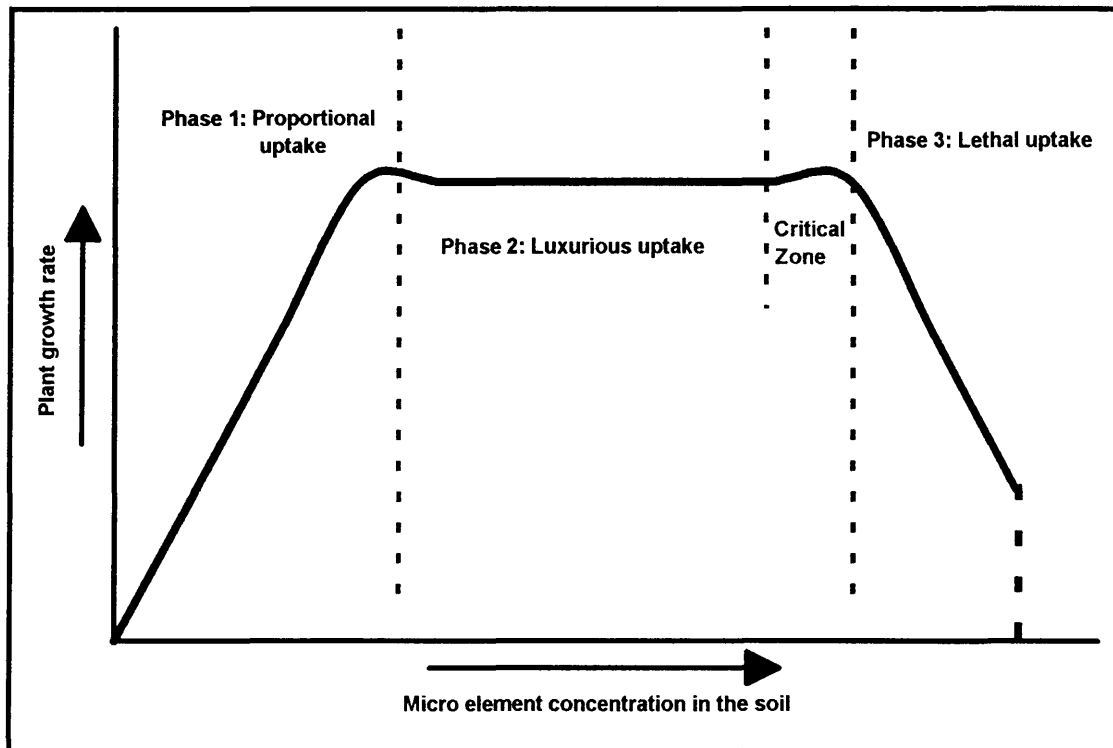


Figure 1 Plant growth rate as a function of the micro-element concentration in the soil (adapted from Brooks (1998)).

2.2.2 Heavy metals

There is a third aspect relevant to plant-soil interactions. Brooks & Yang (1984) found that relatively high nickel concentrations in plants were positively correlated with cobalt and chromium. These elements are typical of ultramafic soils (e.g. serpentine) and are known as heavy metal elements (Brooks 1987). Heavy metals are transition elements, e.g. manganese, iron, cobalt, nickel, copper, chromium, zinc, platinum, vanadium and titanium. These elements have densities greater than 5 000 kg m⁻³, hence the name 'heavy' metals (MacVicar *et al.* 1991). High concentrations (>1 000 µg/g) of these heavy metals and metals such as copper, iron and zinc (micro elements) are generally responsible for toxic soils.

The biological significance of heavy metals lies in the general toxicity of metals in relatively high doses to organisms. Metals have been used by humans as poisons for some time. The use of copper in Bordeaux mixture to prevent fungal attack upon grapevines (Agrios, cited in Wild (1978)), exemplifies the ability of metals to disrupt biological systems.

According to Nriagu & Nieboer (1988), heavy metals can disrupt biological systems in several ways. These include displacing essential elements from biomolecules, modifying the conformation of enzymes and blocking functional groups. These effects are due to the attraction of metal ions to oxygen, nitrogen and sulphur atoms — atoms that play important roles in the function of biological systems (Nriagu & Nieboer 1988).

An emphasis on dosage when discussing metal toxicity is important, as several metals are required by plants in at least some small quantity. These metals, e.g. Zn, Mg, Mn, and Cu, are generally accepted as essential plant nutrients (Salisbury & Ross 1992) and therefore are required for normal plant growth. One of the more interesting aspects, is the hyperaccumulation of nickel, the element hyperaccumulated by the greatest number of species (Brooks 1987). Nickel is not an essential nutrient for agricultural crops, which makes its uptake and hyperaccumulation by plants in nature very remarkable.

2.3 Hyperaccumulators

2.3.1 Introduction

Specific accumulation or rejection of any particular element by plants, is supported by the fact that geochemical associations in the substrate are not reflected in plant material (Brooks & Yang 1984). The mineral content of plants tends to be internally rather than externally controlled, because certain minerals may be essential elements for plant nutrition (Brooks & Malaisse 1985). Thus, the mineral

levels in plants tend to be constant and independent of the chemical composition of the substrate. Most plants have metal concentrations well below those of the soil in which they grow and it is only where very high concentrations occur in the substrate that the regulatory (exclusion) mechanism breaks down.

A peculiar feature of plant species growing on toxic soils is their ability to hyperaccumulate metals such as cobalt, copper and nickel in their tissues (Brooks & Yang 1984). In a study on the serpentine soils of Mpumalanga, Morrey *et al.* (1989) measured an average of 238 mg Cr/kg dry mass and 11 637 mg Ni/kg dry mass in the leaves of some plant species. It has been shown by Timperley *et al.* (1970) that heavy metal uptake by plants is a complicated process in which the content of an element in the plant remains constant irrespective of the concentration of this element in the soil via an exclusion mechanism. If the metal concentration in the substrate exceeds the critical zone, the plant's exclusion mechanism breaks down (Figure 2).

Metal uptake by plants is divided into a phase of selective uptake and a phase of proportional uptake. Heavy metal uptake is suppressed by means of the exclusion mechanism of selective uptake, when increased heavy metal concentrations are present in the soil (Figure 2). Proportional uptake occurs when high heavy metal concentrations are found in the soil and when the exclusion mechanism breaks down. Heavy metal uptake by the plant becomes proportional to the level in the soil, until a point is reached at which the plant is no longer able to tolerate the metal toxicity and dies.

2.3.2 Metallophytes

A metallophyte is a plant which is tolerant of heavy metal soils. The questions concerning metallophytes and heavy metal tolerance are closely connected to endemism and evolution. The preference shown by some plants for sites contaminated by heavy metals is a result of two possible factors: an acquired resistance to toxic ions, or a low tolerance to competition from other species outside contaminated sites. These factors can be coupled with palaeo- and neo-endemism. Neo-endemism involves a process whereby natural selection of metal-tolerant strains of 'plastic' species has allowed distinct metal-resistant forms to evolve in a relatively small number of generations. Palaeo-endemism involves relict populations of formerly widespread taxa which have now retreated to heavy metal soils because of competition pressure from other species.

Plant species growing on ultramafic substrates have developed special mechanisms to survive on soils with high concentrations of toxic heavy metals. These mechanisms prevent excessive uptake or poisoning by heavy metals during periods of exposure to high concentrations thereof. There are two

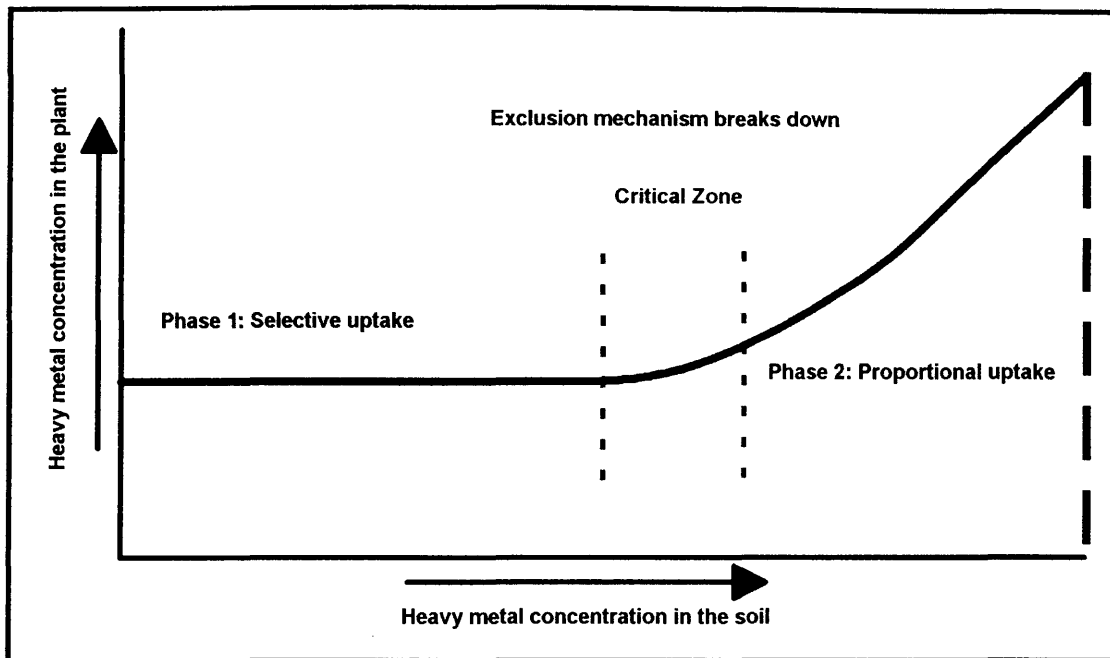


Figure 2 Heavy metal concentration in the plant as a function of heavy metal concentrations in the soil.

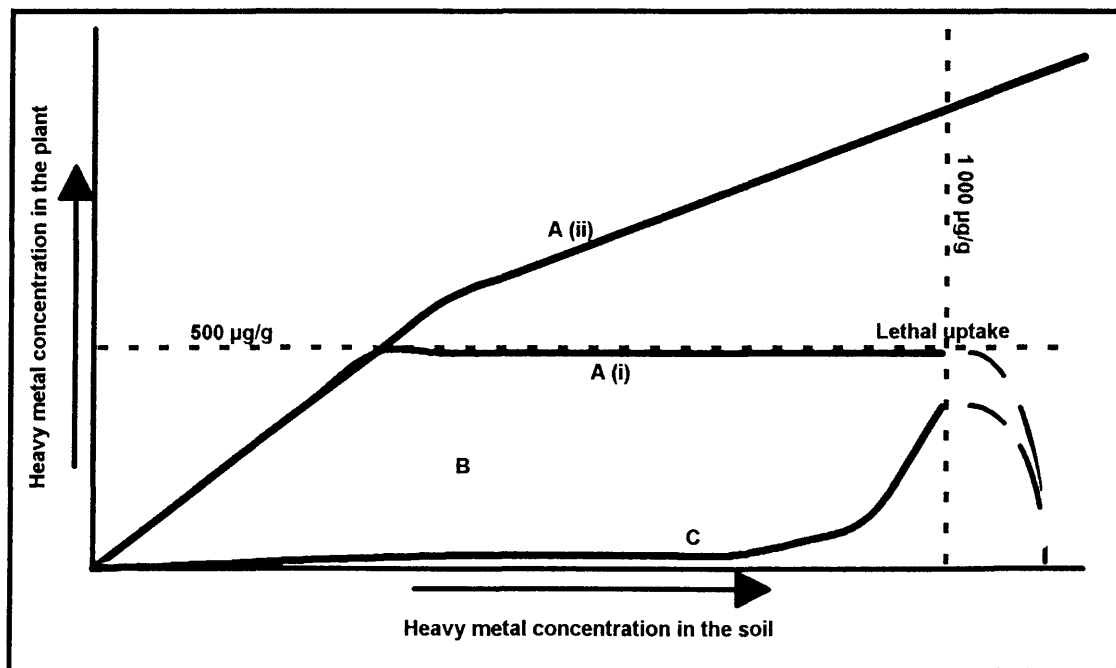


Figure 3 The heavy metal concentration in the plant as a function of the heavy metal concentration in the soil, for three groups of metallophytes (Baker 1981): A(i), Accumulators; A(ii), Hyperaccumulators; B, Indicators; C, Excluders of heavy metals. Heavy metal concentrations above 1 000 $\mu\text{g/g}$ in the soil and above 500 $\mu\text{g/g}$ in the plant are fatal to A(i), B and C.

mechanisms and three groups of metallophytes which are dependent on the relationship between the heavy metal concentration in the soil and that in the plant (Baker 1981) (Figure 3):

- The roots of adapted plants secrete unknown organic substances into the soil. These substances bind to the heavy metals/micro elements in the soil, thus preventing their uptake by the plants. Plants with this ability are known as **excluders**.

- ◆ **Excluders** are plants with the ability to suppress their metal uptake across a wide range of metal concentrations, but if the threshold value in the plant tissue is exceeded the excluding mechanism breaks down. An uncontrollable uptake will follow at a heavy metal concentration of 1 000 $\mu\text{g/g}$ in the soil, resulting in the death of the plant.

- Certain plants do not prevent the uptake of toxins, but rather store them in their tissues. Plants with this ability are known as **accumulators** and **indicators**.

- ◆ **Accumulators** are plants occurring on soils with either a low or high metal concentration. The plants accumulate the heavy metal in excess of the metal concentration in the soil. Such plants can accumulate between 100 and 500 $\mu\text{g/g}$ (dry weight) in their aerial parts or roots, depending on the metal concentration in the soil. Accumulators usually die at soil concentrations above 1 000 $\mu\text{g/g}$ (dry weight). **Hyperaccumulators** form part of this group, the difference being that these species accumulate more than 1 000 $\mu\text{g/g}$ (dry weight) of the heavy metal in their aerial parts or roots, even when occurring on the same soils as accumulators. High metal concentrations in the soil ($> 1\,000\ \mu\text{g/g}$) are not lethal to hyperaccumulators, as values of up to 12 000 $\mu\text{g/g}$ (dry weight) have been recorded in certain species. There are different methods of accumulation:

- Plants produce an excessive amount of unknown organic acids in their tissues. These organic compounds react with the toxic cations, resulting in stable metalo-organic compounds which suppress the toxicity of the heavy metal.

- Plants translocate the toxic metals to their leaves, where fire, herbivores or abscission ('abstriction') removes the leaves containing the toxins.

- Plants accumulate calcium as well as the toxins. Most heavy metals tend to be toxic at a pH of less than five. A high calcium (alkaline) concentration ensures a pH of five and higher.

- ◆ **Indicators** are plants with metal concentrations in their aerial parts or roots matching the concentration of the metal in the soil at either low or high metal concentrations. The plants die when the metal concentration in the soil becomes too high (usually above 1 000 $\mu\text{g/g}$ in the soils and 500 $\mu\text{g/g}$ in the plant (dry weight)).

Plants found on mineral deposits may be said to be **facultative** or **obligate** metallophytes (Brooks & Malaisse 1985). Facultative taxa will grow well in mineralised and 'normal' ground and clearly do not have a specific physiological requirement for this particular set of edaphic conditions. Wild

(1978) states that species which are strictly tied to toxic soils in one area but are found further afield in normal soils, are therefore physiological ecotypes. He interpreted these facultative taxa as relics of ancient floral movements surviving only in ecological refugia on toxic soils. These taxa represent the final stage in the production of palaeoendemic species.

Although the majority of the metallophytes of southern Africa are clearly facultative, there is a number of taxa which are confined to mineralised ground and which are clearly obligate (Wild 1978). Obligates may grow well in 'normal' soils, but they are very sensitive to fungal attack and it is probably this factor as well as their inability to withstand interspecific competition which restricts them to mineralised substrates (Brooks & Malaisse 1985). They are, nevertheless, still obligates even though their 'obligatory' property may be linked to low populations of fungi or other competing species. They are also physiological ecotypes, but they represent the intermediate stage in the production of neoendemic ecotypes or even species.

2.3.3 Hyperaccumulator species

A hyperaccumulator is a species that accumulates more than 1 000 $\mu\text{g/g}$ (dry weight) of a heavy metal in its tissue (Brooks 1987). The choice of a cut-off point at 1 000 $\mu\text{g/g}$ (dry weight) of a heavy metal for hyperaccumulators is not arbitrary, and is used, because Brooks (1987) observed that there is a marked gap between the highest average metal concentration in normal accumulators (500 $\mu\text{g/g}$) and the lowest value (1 000 $\mu\text{g/g}$) in hyperaccumulators. By using the 1 000 $\mu\text{g/g}$ cut-off point, a specific criterion is created by which hyperaccumulators may be identified. If a plant species tends to accumulate at values greater than 500 $\mu\text{g/g}$, but less than 1 000 $\mu\text{g/g}$, some individuals of a population will certainly have the potential to accumulate metal values above 1 000 $\mu\text{g/g}$ under certain conditions (Brooks & Malaisse 1985; Mesjasz-Przybylowicz *et al.* 1991). It has been found that certain species have the ability to accumulate metal values above 10 000 $\mu\text{g/g}$ (Morrey *et al.* 1989; Hughes & Noble 1991).

A list of the common hyperaccumulators recorded in southern Africa is supplied in Table 1. The list was compiled from the existing literature (Brooks & Yang 1984; Brooks & Malaisse 1985; Morrey *et al.* 1989) using the $\mu\text{g/g}$ units and applying the 1 000 $\mu\text{g/g}$ cut-off point. The list was compiled to indicate which families and, especially which genera, have members which are adapted to toxic soils. This list (Table 1) is an essential guideline to determine which taxa are likely to contain possible hyperaccumulators on other ultramafic substrates.

Table 1 Hyperaccumulators of selected heavy metals in southern Africa, with only values above 1 000 µg/g being supplied (Brooks & Yang 1984; Brooks & Malaisse 1985; Morrey *et al.* 1989)

Species	Highest concentration (µg/g dry weight)				
	Copper (Cu)	Cobalt (Co)	Chromium (Cr)	Nickel (Ni)	Iron (Fe)
Monocotyledons					
Commelinaceae					
<i>Commelina zigzag</i>	1 210	-	-	-	-
<i>Cyanotis longifolia</i>	-	4 200	-	-	-
Cyperaceae					
<i>Ascolepis metallorum</i>	1 200	-	-	-	-
<i>Bulbostylis mucronata</i>	5 700	2 130	-	-	-
Poaceae					
<i>Eragrostis racemosa</i>	2 800	-	-	-	-
<i>Rendlia cupricola</i>	1 560	-	-	-	-
Dicotyledons					
Acanthaceae					
<i>Barleria molensis</i>	-	-	-	-	1 500
<i>Blepharis acuminata</i>	-	-	-	1 815	-
Amaranthaceae					
<i>Pandiaka metallorum</i>	6 260	-	-	-	-
Anacardiaceae					
<i>Rhus wildii</i>	-	-	-	1 384	-
Caryophyllaceae					
<i>Silene cobalticola</i>	1 660	-	-	-	-
Asteraceae					
<i>Anisopappus davyi</i>	-	2 650	-	-	-
<i>Anisopappus hoffmanianus</i>	1 065	-	-	-	-
<i>Berkheya coddii</i>	-	-	-	11 637	-
<i>Dicoma niccolifera</i>	-	-	1 500	-	7 920
<i>Helichrysum serpentinicola</i>	-	-	-	-	1 230
<i>Vernonia petersii</i>	1 490	-	-	-	-
Convolvulaceae					
<i>Convolvulus ocellatus</i>	-	-	-	-	2 760
<i>Ipomoea alpina</i>	12 300	-	-	-	-
<i>Merremia xanthophylla</i>	-	-	-	1 378	1 710
Crassulaceae					
<i>Crassula vaginata</i>	-	1 405	-	-	-
Lamiaceae					
<i>Aeolanthus biformifolius</i>	3 920	2 820	-	-	-

Table 1 continued

Species	Highest concentration (µg/g dry weight)				
	Copper (Cu)	Cobalt (Co)	Chromium (Cr)	Nickel (Ni)	Iron (Fe)
Lamiaceae continued					
<i>Aeolanthus saxatilis</i>	-	1 000	-	-	-
<i>Haumaniastrum homblei</i>	-	2 010	-	-	-
<i>Haumaniastrum katangense</i>	2 140	2 240	-	-	-
<i>Haumaniastrum robertii</i>	1 960	10 200	-	-	-
Fabaceae					
<i>Crotalaria cobalticola</i>	-	3 010	-	-	-
<i>Pearsonia metallifera</i>	-	-	-	15 354	2 020
<i>Vigna dolomitica</i>	3 000	-	-	-	-
Scrophulariaceae					
<i>Alectra sessiliflora</i>	1 590	-	-	-	-
<i>Buchnera henriquesii</i>	3 520	1 510	-	-	-
<i>Lindernia damblonii</i>	-	1 000	-	-	-
<i>Lindernia perennis</i>	6 000	2 300	-	-	-
<i>Sopubia dregeana</i>	-	1 090	-	-	-
<i>Sutera fodina</i>	-	-	2 400	-	-
Tiliaceae					
<i>Triumfetta digitata</i>	1 060	-	-	-	-

2.4 Serpentine soils

2.4.1 Introduction

Serpentine is a hydrous magnesium silicate $Mg_6Si_4O_{10}(OH)_8$, i.e. a hydrothermally altered product of olivine ($(MgFe)_2SiO_4$) or pyroxene ($MgSiO_3$), with calcium being absent from the pure ultramafic mineral (Wild 1974a; Brooks 1987; Burgoyne 1987). Olivine and pyroxene contain high levels of nickel (Kent 1980). When these ores are exposed to the atmosphere, the inert olivine weathers into serpentine rich in nickel, but the pyroxene weathers into clay with high nickel concentrations (Prof. G. Cawthorn, pers. comm.). The pyroxene clays are less toxic than the serpentine (Wild 1974a). Serpentine is the most toxic soil in the sense of the abundance of heavy metals, followed by the basalts: pyroxenite, anorthosite and norite (Krauskopf 1967).

There are no species entirely confined to pyroxene clays, nevertheless the flora is ecologically very distinctive and the dwarfing of woody species is very characteristic (Wild 1974c). Wild (1974c) argues that the effect of the clay on the vegetation is primarily physical rather than chemical, perhaps due to the compaction of the surface. Another reason for the stunted vegetation might be ascribed to

the melanic or vertic A-horizons, to which rock formations like pyroxene give rise (MacVicar *et al.* 1991). These horizons form swollen clays in the wet season and shrunken clays in the dry season. The process breaks the plant roots, resulting in a ‘bonsai’ effect.

Serpentine soils are well known for their unusual vegetation and thus it has been well studied. Roberts & Proctor (1992) found that the grassland and savannah communities on the ultramafic soil (containing serpentine) of the Great Dyke in Zimbabwe, provide a dramatic structural and floristic contrast with the woodlands that occur on the adjacent granite, norite or pyroxenite. Wild (1965) found that the dominant species from the *Julbernardia globiflora-Brachystegia spiciformis* woodlands, are absent from the serpentines, indicating that the soils derived from norite and pyroxenite are markedly less toxic. Nevertheless, some herbaceous taxa occurring on norite and pyroxenite are usually confined to the serpentines, and thus appear to be intermediate between the ‘normal’ granite soils and the serpentine (Wild 1965).

2.4.2 The three serpentine factors

Soils derived from ultramafic serpentinitic rocks have been the subject of intensive study due to their well-documented infertility, or what is better known as the **serpentine factors** (Wild 1974a; Wild 1974b; Brooks & Yang 1984; Hughes & Noble 1991; Roberts & Proctor 1992). The serpentine phenomenon or ‘problem’, is created by a complicated interaction between various factors such as pH, soil chemistry and plant physiology. The ‘problem’ concerns the infertility of serpentine soils and is ascribed to any of three edaphic conditions, namely:

- high concentrations of magnesium which dominates the Mg/Ca ratio in the soil (Wild 1974a) and prevents the uptake of calcium by plants (Brooks 1987);
- the toxic effect of high concentrations of heavy metals such as nickel and cobalt (Wild 1974a);
- low levels of essential nutrients such as nitrogen, phosphorous, sulphur and potassium (Brooks & Yang 1984).

These three factors are probably the major cause of infertility in serpentine soils. These edaphic conditions are also interrelated and are complementary to each other.

Unfavourably low Ca/Mg ratios may influence the pH of the soil. Soil pH decreases as the Ca concentration of the soil decreases. According to Wild (1974a) and Brooks & Yang (1984), the lower the calcium content of the soil, the lower the pH, resulting in an increase in the toxicity of the heavy- and micro element levels. At a low pH the uptake of essential nutrients is suppressed through the antagonistic effect of high magnesium concentrations (Brooks & Yang 1984). A low calcium content

in serpentine due to a high Mg/Ca ratio is the direct cause of a calcium deficiency in plants (Brooks 1987). Deficiency of calcium in plants results in a lowered tolerance to toxins present in the soil.

The toxicity of heavy metals in the soil is dependant on the maintenance of high concentrations (Wild 1974a). Organic compounds may bind to the metals and remove it as a chelate complex or heavy rainfall may leach the metals from the soil (Brooks 1987). These factors do not suppress the toxicity of the heavy metals on serpentine, because of the insufficient rainfall and low productivity on serpentine. It should also be noted that a low pH will stimulate the release of metals from compounds in rocks, with this action inducing a higher toxicity in the soil (Brooks & Yang 1984).

Serpentine soils are described as infertile because of their unsuitability for successful crop cultivation (Burgoyne 1987). Brooks (1987) found that the low levels of nutrients in serpentine soils could be attributed to the well-drained character of serpentine and the lack of organic material due to the low productivity of serpentine. The well-drained soils result in the leaching of essential nutrients and the low productivity results in the deficiency of essential elements.

2.4.3 Serpentine tolerant flora

Unfavourable edaphic conditions on serpentine soils initiated the development of specialised (adapted) plants. Plants with adaptive mechanisms became very successful and survived on the serpentines. Endemic species developed on the serpentines through strict associations between the plants and the soil. According to Wild (1974b), heavy metals are toxic to many crop plants, but not so in the case of many tolerant indigenous species. The ability to evolve resistance to ultramafic soils is a widespread attribute amongst indigenous angiosperm families (Roberts & Proctor 1992). The specialised species on the serpentines are sparsely distributed and can be divided into two categories of facultative metallophytes (Wild 1978):

- plants which are adapted to survive on heavy metal soils and have the ability to exhibit their natural growth form;
- plants which are adapted to survive on heavy metal soils, but lack the ability to exhibit their natural growth form and exhibit dwarfism.

Wild (1965) regarded all the endemics on the serpentines of Zimbabwe as palaeoendemics, for these species have relatives which occur on non-ultramafic soils considerable distances away. Several of these endemics have their closest relatives in South Africa and it is suggested that they are the survivors of a previously more widespread extra-tropical Cape Flora (Wild 1965; Brooks 1987).

Plants occurring on serpentine soils in Zimbabwe contain several highly metalliferous species including the members of the following genera: *Barleria*, *Convolvulus*, *Cyphostemma*, *Dicoma*, *Euclea*, *Helichrysum*, *Indigofera*, *Merremia*, *Pearsonia*, *Rhus* and *Sutera* (Wild 1978; Roberts & Proctor 1992). The presence of families such as Proteaceae, Combretaceae and Anacardiaceae on serpentines (Wild 1965) shows that the tree life form is not necessarily excluded from developing serpentine tolerance.

Certain plants are known to accumulate nickel on the serpentine soils of the Barberton Sequence in northeastern South Africa. All these taxa belong to the Asteraceae (Morrey *et al.* 1989): these are *Berkheya coddii*, *B. zeyheri* subsp. *rehmannii* var. *rogersiana*, *Senecio coronatus* and *S. lydenburgensis*.

Plants occurring on highly toxic soils (3 700 µg/g dry weight copper and 1 900 µg/g dry weight cobalt) in the Democratic Republic of the Congo (Zaire), also contain several highly metalliferous species such as members of the genera: *Ascolepis*, *Bulbostylis*, *Eragrostis*, *Gladiolus*, *Icomum*, *Lobelia*, *Silene*, *Sopubia*, *Triumfetta* and *Vernonia* (Brooks & Malaisse 1985). Although far less work has been carried out on bryophytes as indicators of mineralization, it is known that the Shaba province of Zaire contains several species of copper-tolerant mosses of the following genera: *Brachytenium*, *Bryum*, *Pottia* and *Campylopus* (Brooks & Malaisse 1985).

2.5 Chromium

2.5.1 Introduction

Very little work has been done on the heavy metal flora of southern Africa and the tolerance of its component species to heavy metals (e.g. chromium). There is almost a total lack of published work for Botswana, Mozambique, Swaziland, Lesotho and the Republic of South Africa. This is not due to a lack of metalliferous or serpentiferous soils, since they are present in southern Africa (Roberts & Proctor 1992).

This section focuses on the potential toxicity of chromium in the soils of South Africa, because work on this metal and its associated vegetation is largely lacking. Hitherto no experimental/conclusive evidence has been supplied that chromium is to any degree responsible for the toxicity of ultramafic or any other soils in southern Africa. It is also noteworthy that there are no reliable records of any floras specifically adapted to chromium-rich soils anywhere on earth, though there are many adapted to nickel and/or cobalt (Brooks & Malaisse 1985; Brooks 1987; Brooks 1998). However, note that chromium accumulation was reported in *Sutera fodina*.

Chromium is the seventh most abundant element on earth, most of it residing in the earth's core and mantle (Coetzee 1985). In fact, Nriagu & Nieboer (1988) rank chromium as the 21st most abundant element and tenth most abundant metal in the surface of the earth's crust (especially in ultramafic rocks), ahead of other heavy metals such as nickel, copper, lead and zinc. Furthermore, chromium ranks fourth among the 29 elements of biological importance (Nriagu & Nieboer 1988).

According to Kent (1980) and Coetzee (1985), most of the world's chromite reserves (economically exploitable deposits) are located in southern Africa. The reserves of chromite ore in southern Africa (South Africa and Zimbabwe) account for 90% of the known world reserves, with South Africa contributing 70% (Coetzee 1985). The South African deposits are economically exploitable because the reefs run close to the surface in the eastern and western areas of the Bushveld Igneous Complex [BIC], to support a policy of open cast mining. The reefs are therefore exposed to environmental processes of weathering where the seams cut or underlie the surface.

Apart from nickel, chromium is the other mineral in ultramafic soils which is suspected of having toxic effects on vegetation (Wild 1965). The chromium content of 'normal' soils is in the order of 100 µg/g, whereas in ultramafic soils values of around 5 000 µg/g are common (Brooks 1987). The eastern rim of the Bushveld Complex, is a centre of endemism for genera such as *Euphorbia*, *Aloe*, *Rhoicissus* and *Rhus*. It is speculated that this endemism may be due to the presence of ultramafic rocks (A. E. van Wyk, pers. comm.).

Zimbabwe is well known for its toxic soils (serpentine) and the endemics on the Great Dyke. Serpentine endemics in Zimbabwe accumulate large amounts of heavy metals in their leaves (Wild 1974b). Wild (1974a) and Brooks & Malaisse (1985) believe that chromium does not play an important role in floristic changes on serpentine soils, since species tolerant to serpentine show no obvious changes in distribution and performance on varying chromium values. Where chromite seams outcrop on slopes, the chrome in the soil must be proportionately in greater quantity than in the intervening areas of serpentine between the seams and yet there is no visible difference in vegetation patterns as the seams are crossed (Wild 1974b). Wild (1974a) did find that varying nickel values seemed to be primarily responsible for well developed anomalies in serpentine tolerant vegetation. The fact that chrome can scarcely be toxic to many natural occurring plant species, does not however exclude the fact that cultivated species may be susceptible to chrome toxicity (Wild 1974a).

2.5.2 Chromitite and chromite

Chromium occurs in nature as the rock, chromitite. The origin of chromitite is associated with the BIC. Coetzee (1985) explains that the initial heave of the BIC magma was of pyroxenitic composition, from which magnesium rich pyroxene crystallised first, and with continuing crystal

settling the composition of the magma was changed, resulting in the crystallisation of chromite in seams. South Africa is known for its rich chromium-containing minerals in the ultramafic rocks of the BIC, with special mention of the reserves in the Merensky- and Bastard Reefs of the Bushveld Complex (Visser *et al.* 1989).

The BIC chromitite occurs as seams in the pyroxenite, norite and anorthosite geological units of South Africa (Visser *et al.* 1989). Extensive chromitite deposits, together with platinum, are confined mainly to the Critical Zone of the Rustenburg Layered Suite [RLS] of the Bushveld Complex. They occur as layers varying in thickness from less than a centimetre to more than two metres and can be continuous for up to a length of 100 metres below the surface (Brooks 1987).

The occurrence of chromitite in the BIC can be divided into a Western and an Eastern Belt (Coetzee 1985). The deposits of the Western Belt extend for about 200 km westward from Brits towards Rustenburg and then northwards, skirting the Pilanesberg on its western side and continuing with interruptions almost to the Crocodile River. The Eastern Belt commences near Draaikraal on the upper reaches of the Dwars River in the Lydenburg District and, continuing northwards, crosses the Steelpoort River near Steelpoort Station and then gradually swings north-westwards as far as Scheiding, a distance of about 120 km.

According to Coetzee (1985), chromitite occurs as layers of packed granules of **chromite** crystals, usually with diameters of about 0,5 mm. The associated gangue is mainly pyroxene, chrome-mica (fuchsite), some calcic feldspar and rarely serpentine-talc. The weathering of chromitite and the distribution of chromite into the soil is dependent on the interaction of parent material, time, climate, topography, fauna and flora (MacVicar *et al.* 1991).

Even though about 40 chromium-containing minerals are known, **the only ore mineral is chromite**. Chromite $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ is composed of the oxides of chrome and iron ($\text{Cr}_2\text{O}_3 = 68\%$ and $\text{FeO} = 32\%$) (Coetzee 1985). It shows considerable variation in composition and rarely conforms to the theoretical formula; the iron may be replaced by magnesium and the chromium by aluminium. The varieties containing little chromium (up to 14,6 % Cr_2O_3) are classed under picotite or chrome-spinel, $(\text{Mg,Fe})\text{O} \cdot (\text{Al,Cr})_2\text{O}_3$ (Coetzee 1985).

2.5.3 Uptake and translocation of chromium by higher plants

Outside of southern Africa there are no recorded cases of inordinate accumulation of chromium among vascular plants, but a chromium-accumulating bryophyte has been discovered in New Caledonia (Brooks & Malaisse 1985). The reluctance of vascular plants to accumulate chromium is

indeed so great that the chromium content of plant material is often used to assess the degree to which a plant sample has been contaminated by the surrounding soil (Brooks & Malaisse 1985).

Wild (1978) reported extraordinary concentrations of chromium in leaves of *Dicoma niccolifera* (estimated at 1 500 µg/g dry weight) and *Sutera fodina* (estimated at 2 400 µg/g dry weight). These plants were found near the Noro chrome mine on the Great Dyke. Brooks & Yang (1984) analysed the same taxa for chromium and other elements and have found concentrations of this element at least 20 times lower than those reported by Wild (1978). Therefore, it may be that the plant samples from the Noro chrome mine had been contaminated by wind-blown ore clinging to the stems and leaves of the plants.

Chromium, like most non-essential minerals, is not readily taken up by plants (Salisbury & Ross 1992). Although chromium might be very abundant in the soil, chromium remains relatively unavailable to plants (Wild 1974b). The accumulation of chromium is almost negligible when compared with the comparable figures for nickel shown in Table 2. The unavailability of chromium seems to explain why it is not toxic to the indigenous serpentine flora of Zimbabwe and why it induces no visible changes in plant communities or the distribution of individual species.

However, Wild (1974b) stated that high concentrations of chromium may become available and toxic to crop plants, but apparently not so in the case of many tolerant indigenous species. The ability to evolve resistance to ultramafic soils is a widespread attribute among angiosperm families (Table 1) (Roberts & Proctor 1992). Therefore, it seems that tolerance is a direct selective consequence of the presence of heavy metals and has a high heritability (Kruckeberg & Rabinowitz 1985). According to Kruckeberg & Rabinowitz (1985) populations in non-toxic environments may contain tolerant genotypes preadaptively, so natural variation in the capacity to withstand the metals is present in natural populations. In other words, it is not only the unavailability of chromium, but also the genetically inherited exclusion mechanisms within indigenous plants (Morrey *et al.* 1989), which are responsible for the lack in chromium toxicity.

Table 2 A soil analyses of serpentine (heavy metal contents in ppm) (Wild 1974b)

Location	Chrome		Nickel		Copper	
	Soil	Plant	Soil	Plant	Soil	Plant
Noro Chrome Mine	125 000	2	5 500	175	12,5	2
Tipperary Claims	15 500	2	9 375	273	33	2
Shamwari Deposit	530	0,3	50	5	10	0,25

Chromium may only be described as toxic if the soil chemistry is fully understood. Only recently Nriagu & Nieboer (1988) investigated chromium's behaviour in soil. There are two forms of

chromium in the soil, namely Cr (III) and Cr (IV) (Nriagu & Nieboer 1989). Cr (IV) is very soluble, but Cr (III) is much more stable and dominant in the soil. As a soluble anion, Cr (IV) readily penetrates cell membranes. By contrast, Cr (III) is only soluble at biological pH, when organically complexed in low molecular weight organic compounds (Nriagu & Nieboer 1989). Such an organic-Cr(III) compound in the soil probably does not penetrate plant membranes.

Thus, chromium is toxic when it is available to living organisms, but nowhere in previous studies has chromium been described as mobile and bio-available. There are three reasons why it was thought that chromium might not be mobile and bio-available in soils (Nriagu & Nieboer 1988):

- most forms of Cr (III) present in soils are low in solubility and reactivity and are oxidised to Cr (IV) only when environmental conditions are in a rather narrow and delicately balanced optimum;
- Cr (IV) is highly unstable in soils and thus the leaching, reduction and **plant uptake** of Cr (IV) is difficult to find or to follow in natural soils;
- soil analysts tend to dry and store soils before studying them, but this practice has hidden the chromium redox behaviour in the laboratory because, unlike moist field samples, dry soils, if long-stored, will not oxidise Cr (III) to Cr (IV).

The preceding reasons lead to the logical assumption that all chromium added to soils soon becomes permanently entrenched and unavailable as Cr (III), explaining why analysis of Cr (IV) in soil and water has not been included in the objectives of major studies of chromium uptake by plants. Not testing for Cr (IV) has stacked the odds against finding this mobile metal.

In studies inducing chromium uptake by plants, a linear relationship between soil Cr (IV) and root chromium content was found (Nriagu & Nieboer 1988). No correlation between soil Cr (IV) and chromium content of the aerial plant parts was found. This difference between root and shoot levels of chromium suggests that oxidation of Cr (III) enabled anionic Cr (IV) formed in the soil to move to the roots and be absorbed by them. After entering the roots, it appears that most of the Cr (IV) was reduced back to the stable Cr (III) at biological pH. The chromium was then retained by the roots in its insoluble form (Cr (III)) as part of a soluble organic complex that was not translocated to the above ground parts (Nriagu & Nieboer 1988). Thus, chromium is usually stored in the plant roots and not in the aerial parts of a plant.

Wherever Cr (III) is found in nature, it will be in close association with Al (III) and Fe (III). The atomic radii of chromium, aluminium and iron is 64, 67 and 54 pm respectively. Therefore, the ionic potentials of the trivalent ions are so similar, that substitution of one for another occurs in many mineral and organic structures (Nriagu & Nieboer 1988). Thus, the behaviour of organic and inorganic fractions of Cr (III) in soils are quite similar to that expected or found for aluminium and iron (Coetzee 1976). The movement of Cr (III) within spodic horizons appears to be the same as the

podsolization process of aluminium and iron (Coetzee 1985; MacVicar *et al.* 1991). Past research dealing with aluminium and iron should be helpful in predicting the mobility and solubility of Cr (III) in soils.

2.5.4 Chromium redox reactions

An understanding of the dynamic balance governing chromium redox is essential for explaining how plant roots and soil micro-organisms respond to absolute concentrations and relative levels of Cr (III) and Cr (IV) in their environments. Chromium can readily exist in both cationic (chromic (Cr^{3+})) and anionic (chromate (Cr^{6-})) forms. Cr (III) and Cr (IV) originate from the anionic form of chromite. Brooks (1987) suggests that the anionic form of chromium is more phytotoxic than the cationic state. Data have indicated that, at pH 7 (biological pH), chromate is indeed more capable than chromic in oxidising low-molecular-weight proteins (Brooks 1987).

Chromate is unstable at biologic pH values, but does not decompose as easily as expected, giving rise to Cr (III) (Nriagu & Nieboer 1988). Cr (III) undergoes oxidation to Cr (IV) during narrow environmental conditions. Oxidation of Cr (III) to Cr (IV) is determined by the interactions between soil pH, soil substance, soil moisture and soil microbes in natural soils (Nriagu & Nieboer 1988):

- Soil pH: Exchangeable Cr (III) is not oxidised to Cr (IV) in soils with pH greater than 5.
- Soil matter:
 - ◆ Inorganic substances: Oxidation of exchangeable Cr (III) is slow in soil horizons containing other heavy metals, due to their interference with manganese which is responsible for chromium oxidation;
 - ◆ Organic substances: The organic substances containing Cr (III) are negatively charged and are therefore repelled from the negatively charged manganese oxide surface, thus preventing oxidation.
- Soil moisture: Exchangeable Cr (III) needs to be transported to manganese to be oxidised to Cr (IV), but in dry soils no water film occurs as transport medium.
- Soil microbes: Microbes in the soil tend to facilitate the reduction of Cr (IV), rather than the oxidation of Cr (III).

Because oxidation so strikingly increases the mobility of chromium in soils and because oxidation is kinetically fast compared with reduction (Nriagu & Nieboer 1988), reduction of Cr (IV) can be expected to occur at an indefinitely later time and perhaps at some point far from its place of formation. Therein lies the possibility of chromite movement from reefs below the surface to the biological zone where it becomes accessible to plants. Areas around chrome mines are examples of potential chromium movement. Redox reactions, mediated by the atmosphere, could induce the

production of Cr (IV) and the movement of chromite, from the exposed chromite reefs, to the surrounding environment.

2.5.5 Chromium biochemistry

It may be said with some certainty that chromium is an element of which trace levels are required by plants, but when accumulated in excess, it becomes toxic. In this section, a very brief description will be given from Nriagu & Nieboer (1988), on what is known about the biological function of accumulated chromium during interactions with low-molecular-weight biomolecules, polynucleotides, enzymes and proteins.

Chromium is usually taken up from the soil as Cr (IV). In the plant root the Cr (IV) is reduced to Cr (III) at biological pH. Because Cr (IV) is an anion, it does not interact directly with biological ligands at biological pH and is reduced to the stable Cr (III). It must be noted that the biological half-life of Cr (III) in plant tissue is predicted to be minutes to hours. Thus, the toxicity of Cr (III) is very limited, the reason being that Cr (III) is speedily oxidised to the unstable Cr (IV)-organic complex by reductants in plant tissue such as ascorbic acid, lactic acid and quinone. In the soil the opposite is true with Cr (IV) being readily reduced back to Cr (III).

Fundamental to a study of chromate toxicity is an understanding of the biological function of the chromium compounds. Cr (IV) penetrates cell membranes and is toxic as an oxidising agent in plant tissue (Nriagu & Nieboer 1989). Cr (III) is very stable with a strong affinity for charged oxygen centres in plant tissue (Nriagu & Nieboer 1989). These modes of interaction with plant tissue increase the potential toxicity of chromate. According to Nriagu & Nieboer (1988) the resulting toxicity of chromate in plant tissue is caused by the following chemical reactions:

- Low-molecular-weight biomolecules such as magnesium (II) play a major role in living organisms. Mg (II) is a cofactor in the production, storage and use of the high energy compound ATP. In plant tissue chromate becomes kinetically alert, appearing to be of biologic importance to Mg (II) biochemistry. The replacement of Mg (II) by chromate at high concentrations usually results in the inhibition of critical enzymes. The chromate inhibits kinases (which involve the transfer of phosphate from ATP to a substrate) by breaking up the Mg (II)-ATPases activity. At high chromate concentrations this replacement may totally block the plant's energy supply.
- The reduced form of chromate interacts with the polynucleotides. Chromate (III) binds to the nucleic acids and shows resistance to the nucleases, thus the chromate reaches high concentrations in the plant's nucleoli. It may be expected that high concentrations of chromate in the nucleoli can alter the three-dimensional geometry of DNA and RNA through binding to the nucleic acids. An altered DNA and RNA geometry results in mutagenic consequences, rendering further protein production

impossible. At high chromate concentrations this alteration may totally inhibit the plant's protein supply.

2.6 Questions and speculations

2.6.1 Introduction

Plant populations, especially those of broadly ranging species, are often genetically adapted to local environmental conditions (Stuessy 1990). These adapted populations are better known as ecotypes. Mattioni *et al.* (1997) have shown that the populations of *Silene italica* naturally occurring on serpentine soils are more tolerant to heavy metal toxicity than those populations naturally occurring on normal soils. Adaptation is a complicated process influenced by the external, as well as internal, tolerance of the adapting taxa.

The more tolerant populations can therefore be described as physiologically adapted species, or ecotypes. In taxonomy ecotypes may be classified as varieties or subspecies due to their physiological adaptations. Unfortunately ecotypes are rarely formally recognised in South African classifications, even those of morphological distinction, and therefore the identification of physiologically adapted individuals has been dramatically impeded. This may be one possible reason why the unique flora on the ultramafics of South Africa has largely gone unnoticed.

When the status of our understanding of chromium in soil is evaluated, it seems nearly impossible to unravel the problems involving the evidence that exists. Many questions concerning chromium and vegetation anomalies still remain unanswered. In this review only a few questions in botany were addressed, but to fully understand this phenomenon, future research must involve such diverse topics as geology, geochemistry, biogeography, phytochemistry, ecology, plant physiology and phytosociology. Interdisciplinary co-operation would be essential in the study of chromium and its associated vegetation.

2.6.2 Vegetation and chromium soils

● Calcium concentration

Wild (1974b) claimed that chrome had no visible effect on the vegetation occurring upon serpentine soil. Serpentine contains hardly any calcium (Wild 1978) and such soils have a very low pH (acid). Cr (III) rapidly oxidises to Cr (IV) at low pH. Thus, the lower the calcium concentration of the soil, the higher the available concentration of chromium in the soil. Could it be that other factors, such as

surface behaviour of other chemicals, are masking the effects of chromium at low pH because of the undetectability of Cr (IV)? Are the methods used to detect chromium in plant tissues and soil, indeed capable of doing so?

It is known that certain plants accumulate high calcium concentrations in their tissues to counter the toxic effects of heavy metals (Brooks 1987). Meyer & Popp (1997) has identified the Crassulaceae and the genera *Aloe*, *Plectranthus* and *Clusia* as being calcitrophic CAM plants. Could it be possible that plants accumulate calcium in order to survive upon the chromite soils? Are certain species accumulating high concentrations of calcium on calcium-poor ultramafic soils, to create a higher external chromium toxicity for other plants, whilst maintaining safe internal environments for themselves?

● Ground water

The weathering of rocks result in the wet precipitation of metals which constitutes the most important natural source of Cr (IV) in groundwater (MacVicar *et al.* 1991). World-wide, approximately 200 000 tons per annum of chromium are released to the environment by weathering processes (Nriagu & Nieboer 1988). Water transports the stable insoluble Cr (III) to soil profiles containing high levels of manganese. A redox reaction between Cr (III) and manganese produces Cr (IV) via oxidation (Nriagu & Nieboer 1988). Cr (IV) is soluble in water and therefore it will be at its highest concentrations in the wetter areas, due to the gravitational movement of water.

Many taxa of the Cyperaceae grow in the clays alongside streams in the vicinity of chrome seams. Could it be that chromium tolerant species or accumulators are growing close to, or even alongside, waterways? What is the minimum capacity and movement necessary for waterways to hold the maximum amount of water-soluble chromium? Is it possible for the concentration of the chromium in a waterway to increase and become more toxic during dry seasons?

● Organic matter

Hughes & Noble (1991) found that certain soils at the Agnes Mine near Barberton contain resistant Cr-organic complexes and this would account for the build-up of organic matter in such shallow soils under prevailing climatic conditions (warm and humid); under stress conditions one would normally expect the rapid decay of organic matter. Chromium is also known to inhibit organic matter decomposition by reducing microbial activity (Nriagu & Nieboer 1988). Soil microbes and invertebrates are important in maintaining the soil fertility of natural ecosystems. According to Thomas & Proctor (1997), ultramafic soils of potentially toxic chemistry can still hold substantial soil invertebrate populations. It must be noted, however, that the invertebrate populations decline dramatically as toxicity increases (Thomas & Proctor 1997).

Could chromium suppress the soil fertility and thus be responsible for vegetation anomalies, such as the eroded, semi-desert like, open scrubland near chrome seams? There is a possibility that microbes are capable of breaking down chromite (S.A. de Waal pers. comm.). Could it be that certain microbe or invertebrate species are transforming chromite into its toxic form, thereby killing the 'normal' microbial activity, as well as creating Cr-organic complexes?

● Degree of crumbling

Chromite may be classified, according to its degree of crumbling, as friable or lumpy (Coetzee 1985). In the latter variety the chromite is in hard, coherent pieces which neither break nor pulverise upon handling or exposure to the atmosphere. Chromite is described as friable when it is in the form of loose grains or 'sand' (Coetzee 1985). According to Coetzee (1985), most of the BIC chromite is friable; when fresh and *in situ* such ore is very tough, but it pulverises when it is mined or is naturally exposed to the atmosphere.

It could thus be said that chromite in nature is predominantly of a chemical grade and exposed to potential breakdown. Does the friable chromium produce more available Cr (IV) than the solid, lumpy form? Is the chromium toxicity higher on soils with friable chromite? Is the potential hyperaccumulator species responsible for the breakdown of friable chromite in order to create a higher soil toxicity and thus, lower interspecific competition? Chromium is on the other hand not known to be toxic to plants in nature (Wild 1965). Are plants necessarily affected by chromium itself, or rather by the overlying gangues that accompany the chromitite rocks?

● Rooting depth

The depth at which plants are able to grow roots has important implications for an ecosystem's hydrological balance, as well as for the uptake of minerals from the soil. The results of Canadell *et al.* (1996), offer plenty of evidence that many plant species have the capacity for deep rooting in the soil and provide enough data to challenge the dogma that plants are generally shallow-rooted. Furthermore, the average root depth for savannah is $15 \pm 5,4$ metres (Canadell *et al.* 1996). Is this enough evidence to support the assertion that the vegetation of the BIC is capable of reaching deposits of heavy metals, even below the soil layer?

Plant roots have the ability to find their way down to very deep layers, through compact clay, hard pans and even very rocky substrates by means of humic acids produced by the roots (Canadell *et al.* 1996). These acids are capable of dissolving rocky substrates. Is it therefore not possible that these taxa also dissolve heavy metal minerals, such as chromium and nickel? Are those taxa with deep

rooting systems, capable of carrying heavy metals from below the soil level (via the roots) onto the soil surface (via the leaves)?

2.6.3 Physiological adaptation to chromium soils

● **Physiological need**

Wild (1974b) raises the question of whether a plant has a physiological need for chromium and nickel, although currently these elements are not known to be essential. There is evidence that chrome is beneficial, even if not essential, to some plants. It must be noted that chromium is an essential metal in the metabolic pathways of animals (Nriagu & Nieboer 1988). According to Wild (1974b), chromium has been experimentally used to increase the yield of potatoes, while extremely low chromium concentrations benefit the growth of citrus and avocado trees, and chromium trace fertilisers have been shown to benefit the yield, sugar content and ripening of grapes.

Are there unknown vegetation anomalies in nature created by the physiological need for specific concentrations of chromium in the soil? Could it be said that chromium tends to exhibit growth stimulation rather than phytotoxic effects? Could a stimulating effect (which may in turn enhance competitive ability) explain the growth of specific endemic taxa on the chromium soils of the BIC?

● **Nutrient assimilation**

Low nutrient levels of nitrogen, phosphorous, sulphur and potassium are typical of serpentine soils (Brooks & Yang 1984). It is thought that chromium may promote the assimilation of soil phosphorous and the accumulation thereof in plants (Wild 1974b). Legume species, both endemic and non-endemic to serpentine soils, are reported to have active rhizobium nodules on serpentine soils with high chromium and nickel values (Wild 1974b). Is it possible that chromium counters the infertility of otherwise toxic soils by assisting the adapted species with the uptake of the scarce nutrients (essential elements)? Might it not be that plants growing on chromite are capable of acquiring species-specific essential elements that only occur on ultramafic soils?

Might it be that certain plants accumulate calcium to counter the toxicity of accumulated heavy metals? Konstantinou & Babalonas (1996) found that certain species of the Caryophyllaceae accumulate high concentrations of Ca in their tissues when growing on metalliferous soils. These populations also show low Mg:Ca ratios. Thus, the Ca concentrations in the plant tissue are much higher than the concentration in the soil. Is it possible that increased levels of Ca in plants are related to the plants' resistance to Mg or heavy metal toxicity?

● **Suppression and buffering**

Plant species are prone to many diseases. Plants growing on a substrate with low concentrations of nickel tend to suffer heavy pest infestation (Reeves *et al.* 1983). Might it be possible for high concentrations of chromium to suppress diseases? Are chrome-accumulating plants resistant to infections from certain insects and fungi, thereby favouring the survival of accumulators upon chromium soils? Or maybe chromium enhances the infection process of certain insects and fungi, thereby eliminating all accumulator and indicator chromium species, thus favouring excluders?

Certain species of *Jatropha* accumulate small quantities of jatrophone in their tissues (Pletsch & Charlwood 1997). Pletsch & Charlwood (1997) found that the production of jatrophone is stimulated on toxic soils to buffer the toxicity of aluminium. Could it be possible that the *Jatropha* species endemic to the ultramafics have also developed a certain chemical protection against heavy metals such as chromium? Is it possible that local people and animals are able to live off certain indigenous plants growing on toxic soils, due to the chemical buffers occurring within these plant species?

CHAPTER 3

STUDY AREA

3.1 Study area history and definition

3.1.1 Sekhukhuneland history

Sekhukhuneland was named after the Pedi chief Sekhukhune (Raper 1987), who succeeded the previous chief of the Pedi, Sekwati, who died in September 1861 (Monnig 1967; Smith 1967). The Pedi may be defined as those people who have historically lived on, and around, the Leolo Mountains of Sekhukhuneland (Pollock *et al.* 1963). The area occupied by the Pedi, is located in the Northern Province, approximately 250 kilometres northeast of Pretoria. According to the map: Magisterial Districts and Provinces of the Republic of South Africa (1994), Sekhukhuneland is located in the southeastern corner of the Northern Province, bordered by Mpumalanga Province to the south, the Drakensberg to the north and east, and the Springbok Flats to the west. Sekhukhuneland formed a part of the former Lebowa, which was given to the Pedi as a homeland during the apartheid era.

According to Monnig (1967), the first Pedi settled in Sekhukhuneland in approximately 1650. Very little is known of their history between 1650 and 1800, but the first definite date established in the history of the Pedi, was the day of the solar eclipse, the day Thulare died in 1824 (Quin 1959). Chief Thulare has always been recalled as the greatest and most loved of all the Pedi rulers (Monnig 1967). He managed to build a mighty nation and thus entered upon the most prosperous period of Pedi history. After Thulare's death, the powerful Pedi empire came to a fall as a result of disruptions and arguments between his sons (Monnig 1967). At the same time the Matebele came rushing into Pedi territory to raid the kraals. The Matebele killed all Thulare's sons, except for two (Monnig 1967). One of the sons, Sekwati, gathered what he could of the Pedi and fled, leaving behind a country devastated by the Matebele, who had completely denuded the country of all stock and grain. The famine caused many of the remaining Pedi to turn to cannibalism (Otto 1934; Smith 1967).

Fortunately, Sekwati returned after an absence of four years, restoring the Pedi kingdom (Monnig 1967). Chief Sekwati was a very diplomatic leader with great military skills (Smith 1967). He managed to resist attacks from both the Swazi and the Zulu, which made him a popular leader (Monnig 1967). According to Otto (1934), Sekwati established peace with the Europeans and both parties recognised the Steelpoort River as the boundary between the Pedi country, and the Republic of the Transvaal. This peace negotiation provided the Pedi protection against the Swazi, which resulted in the development of a very powerful Pedi tribe at the beginning of 1860 (Otto 1934).

After Sekwati's death, Sekhukhune stole the chieftainship from his brother Mampuru and thus inherited a powerful nation from his father (Otto 1934; Monnig 1967; Smith 1967). Sekhukhune strengthened his nation with rifles and by accepting warriors from other nations (Otto 1934; Quin 1959). Soon Sekhukhune's warriors started harassing smaller tribes and European farmers living near the borders of Sekhukhuneland (Quin 1959; Monnig 1967). In these areas Europeans and tribesmen battled for residual heights and uplands which stand free from disease amidst the hot lowlands. Bush cover and rough terrain in the lowlands also restricted movement by horse and wagon and made such environments inaccessible (Pollock *et al.* 1963). Thus, the Europeans and smaller tribes sought their guns to protect their land from the Pedi.

The harassment of the European farmers and smaller tribes, as well as the persecution of black Christians, led to the first Sekhukhune war in 1872 (Otto 1934; Quin 1959). The European farmers drove the Pedi back into their own country and tried to upset Sekhukhune's rule, but failed. The second war was initiated by the British Empire after their annexation of the Transvaal (Quin 1959; Smith 1967). Sekhukhune indicated that he resented British authority and commenced raiding the country. British and Swazi forces defeated him in 1879 (Otto 1934; Smith 1967).

The Transvaal was retroceded to the European farmers in 1881 (Quin 1959). The Pedi, like the other tribal groups in the Transvaal, received certain rights to land during the Pretoria Convention (Pollock *et al.* 1963). It was hoped that some security from encroachment would bring the wars of the defiant Sekhukhune of the Leolo Mountains to an end. However, when the final boundary fixing came about, the Sekhukhune tribal land was not big enough to achieve anything more than 'reserve' status (Pollock *et al.* 1963). Thus, the Sekhukhuneland area, though a local borderland big enough to merit the name of the 'Basutoland of the Transvaal', did not give rise to international or provincial boundaries as happened in the British Protectorates, such as Swaziland and Lesotho (former Basutoland).

The Sekhukhuneland of today cannot stand apart from a changing Africa. In the twentieth century, Sekhukhuneland was included into the Lebowa homeland during the apartheid era in South Africa. During this time very little research took place regarding the sustainable development and conservation of the environment. Presently, population pressures are increasing and people are depleting the available natural resources as they struggle to deal with their poverty. Already there are large parts of Sekhukhuneland, which were known to be tree or thicket covered, that are now laid bare (Kritzinger 1992).

A historical overview of a region with such a stormy history, is necessary to understand why, to date, not much is known about the area's flora and vegetation. The political and social instability in the area, has focused all research on their history and hence, the flora, which form such an integral

part of the peoples lives and heritage, has been neglected. Until the beginning of 1998, no in depth research concerning the floristic uniqueness of the area has formally been documented. Sekhukhuneland, as a major part of the study area in this dissertation, should henceforth be recognised for its endemic flora and heavy metal soils.

3.1.2 'Sekhukhuneland' study area

The Sekhukhuneland Study Area [SSA] was selected partly on the basis of floristic elements, adjacent centres of endemism and the peculiar geology of the area, but especially with reference to the detailed knowledge of the supervisor of this project, Prof. A.E. van Wyk. In 1988 a project was started by the IUCN-WWF called 'Centres of Plant Diversity: A Guide and Strategy for their Conservation' (Davis *et al.* 1994). This project aimed at listing all the major endemic floras considered to be of international importance for the conservation of plant diversity.

The selection of the study area was based primarily on the fact that the area may exhibit one or more of the potential characteristics required for recognition as a Centre of Plant Diversity (Davis *et al.* 1994), namely:

- The area is evidently species-rich, even though the number of species present may not be accurately known;
- The area is known to contain a large number of endemic species;
- The area contains a significant proportion of species adapted to special edaphic conditions; and
- The area is threatened or under imminent threat of large scale devastation.

The SSA lies totally within the territory of the Republic of South Africa, and stretches across the borders of the Northern Province into Mpumalanga Province (Figure 4), covering an area of approximately 8 100 km². The SSA has a very rugged topography, meaning that the true surface area is somewhat larger. The study area is situated between 24°15' and 25°30'S latitude; 29°30' and 30°30'E longitude.

The study area lies within, and across, the borders of the Sekhukhuneland Magisterial District, because political demarcated boundaries, usually, have nothing to do with environmental and floristic tendencies. Thus, for the purpose of this study, the name 'Sekhukhuneland', is not used to describe the demarcated area on the map of the Magisterial Districts and Provinces (1994), but rather to indicate a wider study area based on geological parameters.

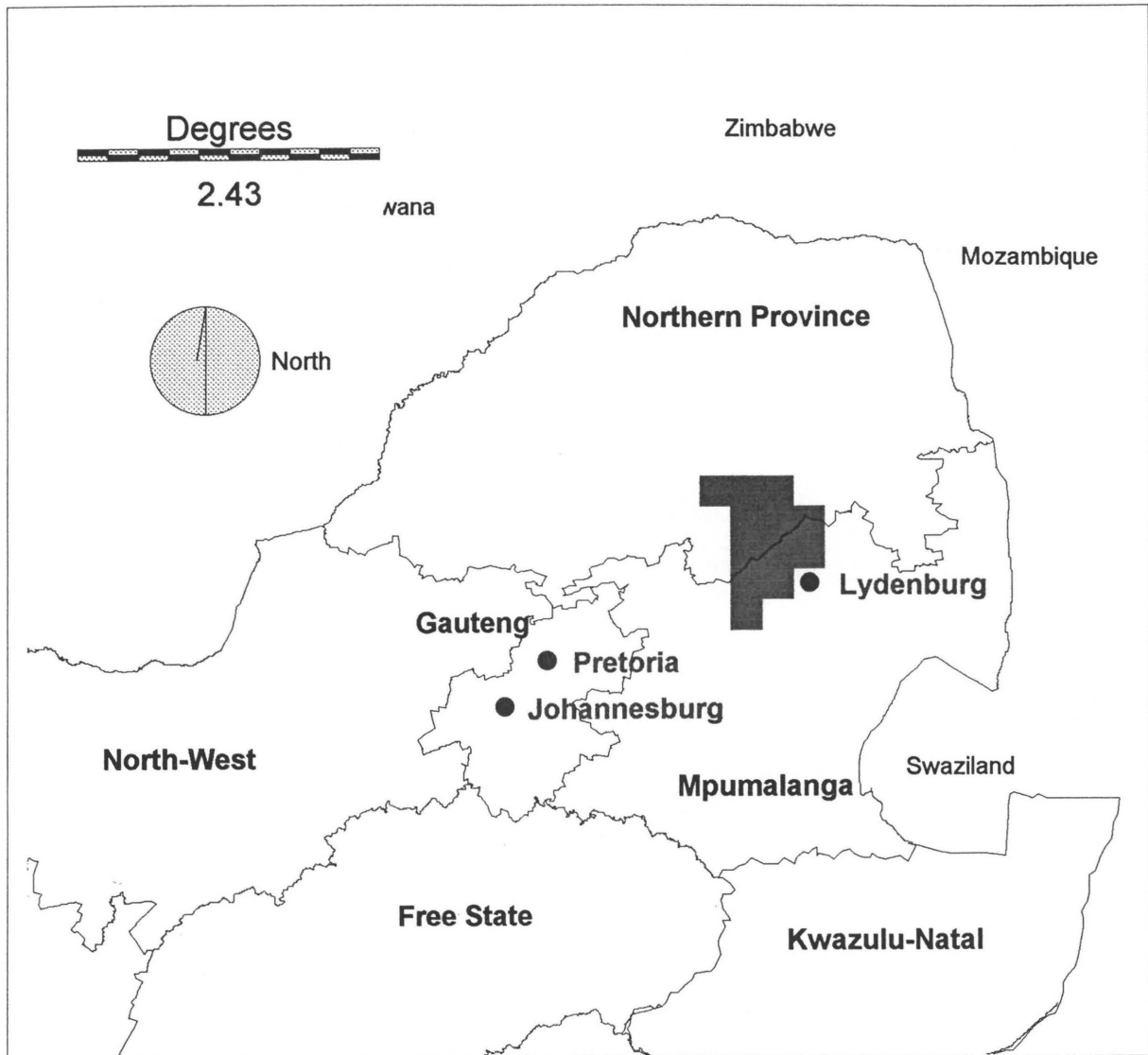


Figure 4 Location of the Sekhukhuneland Study Area [SSA] in the Northern Provinces of South Africa. The solid red polygon demarcates the position of the study area across the border between of the Northern Province and Mpumalanga.

The core area of the SSA comprises the surface outcrops of the Rustenburg Layered Suite [RLS] of the Eastern Bushveld Complex. The SSA is bordered by the Highveld Escarp to the south, Strydpoort Mountains to the north, the Steenkampsberg and Drakensberg to the east and the Springbok Flats to the west. A wider area was chosen to facilitate the identification and distribution of the floristic elements on the RLS. The area eventually proposed as the Sekhukhuneland Centre of Endemism will be defined later (see 6.2).

Towns in the SSA include Sekhukhune, Schoonoord, Stoffberg, Roosenekal, Magneetshoogte, Mecklenburg, Ga-Mankopane, Steelpoort and Burgersfort. Furthermore, the SSA incorporates 12 quarter degree grids [QDGs], with every quarter degree grid covering about 675 km² (Edwards & Leistner 1971). The following QDGs were included in the study area:

2429	2529	2430	2530
BC	BB	AC	AA
BD	BD	CA	
DB		CB	
DD		CC	
		CD	

The chosen QDGs exhibit certain characteristics which are absent from the adjacent QDGs. These characteristics are:

- The surface area is covered by a substantial percentage of ultramafic rock;
- The vegetation is predominantly mixed bushveld;
- The topography is mountainous;
- The area is situated in the rain shadow of the Drakensberg;
- The winter months are relatively frost-free.

Ultramafic rocks also occur in 2529AD, 2529BC and 2529DB, but these quarter degree grids are not included into the study. The reason for the exclusion is primarily due to the higher frost intensity in 2529BC and 2529DB (also not Bushveld) and the locality of 2529AD, which is wedged inbetween other geological substrates outside the rainfall shadow of the Drakensberg.

The included QDG 2430CD, is characterised by all, except one, of the necessary requirements. The absence of the most important requirement, ultramafic substrates, renders it inappropriate as a QDG of the SSA. However, this QDG is wedged in between the mixed bushveld of the SSA and the grassland-covered mountains of the Drakensberg and the Steenkampsberg. Thus, it is included into the SSA so that its floristic affinity with ultramafic substrates may be investigated.

3.2 Study area background

3.2.1 Topography

The topography in the SSA is very heterogeneous and complex. This is the result of tectonic forces and magma surges, upon which the climate and erosive agents are promoting geomorphological change (Marlow 1976). The area comprises a mountainous region with flat to undulating valleys. Sekhukhuneland is known for its concentric belts of rocky ridges and mountains, and its intervening, heavily eroded valleys. From the Steelpoort River valley, which lies at about 900 m asl (one of the lowest points), the Leolo Mountains rise to 1 932 m asl (the highest point).

Every quarter degree grid [QDG] of the SSA has at least one relatively high mountain and one relatively distinct valley (Table 3). These mountains and valleys are the most diagnostic topographic features of the QDGs. Note that the Leolo Mountains (three times) and the Steelpoort River Valley (five times) are the most prominent topographic features in the SSA, with either one or both of these features represented in seven of the 12 QDGs.

Table 3 The most prominent mountain and valley in each of the Sekhukhuneland Study Area quarter degree grids [QDG]

QDG	Mountain & Height asl (m)		River (= valley) & Height asl (m)	
2429BC	Mosetamong	1185	Olifants	850
2429BD	Leolo	1588	Olifants	800
2429DB	Phepane	1436	Lepellane	900
2429DD	Thaba Sekhukhune	1752	Steelpoort	850
2430AC	Madikabje	1312	Motse	700
2430CA	Leolo	1866	Motse	800
2430CB	Morole	1403	Steelpoort	750
2430CC	Leolo	1878	Steelpoort	800
2430CD	Morone	1520	Watervals	900
2529BB	Hoofstadkop	1747	Steelpoort	1050
2529BD	Tauteshoogte	1789	Steelpoort	1350
2530AA	Steenkampsberg	2070	Klip	1500

Drainage basins

The Great Escarpment was formed following continental drifting. At the same time erosion started at the seaward side of the Great Escarpment and began to divide the subcontinent into an upper and lower level (Partridge & Maud 1987). Two major upliftments of the subcontinent occurred in the Miocene and late Pliocene (Partridge & Maud 1987). These successive uplifts produced major changes in drainage patterns.

In the east, the vigorous erosion along the Great Escarpment, above the Lowveld, enabled a headwater of the Olifants River to capture a major westward-flowing river on the upper level (Partridge & Maud 1987). This resulted in the reversal of the inland drainage and the integration of the Olifants River drainage basin.

The Olifants River drainage basin is the topographic relation which exists between the mountains and the valleys (Table 3) of the SSA. The main northern valleys, Olifants, Motse and Lepellane, form the northern part of the basin and the main southern valleys, Steelpoort, Watervals and Klip, form the southern part of the drainage basin in the SSA (Leroux *et al.* 1989).

The Lepellane River valley drains the western aspects of the Phepane and northern Leolo Mountain ranges. The Motse River Valley drains the eastern aspects of the Phepane and northern Leolo Mountain ranges, as well as the northwestern aspects of the southern Leolo range. The Olifants River drains the southern aspect of the northern Northeastern Escarpment. The Lepellane and Motse Rivers are tributaries of the Olifants River. Thus, the Olifants River valley drains the northern basin of the Sekhukhuneland Study Area.

The Watervals River Valley drains the eastern aspect of the Steenkampsberg range. The Klip River Valley drains the western aspect of the Steenkampsberg range. The Steelpoort River drains the eastern aspects of both Thaba Sekhukhune and the southern Leolo range. The Watervals en Klip Rivers are tributaries of the Steelpoort River. Thus, the Steelpoort River Valley drains the southern basin of the Sekhukhuneland Study Area.

The Steelpoort River is a tributary of the Olifants River. Hence, the whole SSA is drained by the Olifants River and falls within its drainage basin. The topography of Sekhukhuneland is therefore the result of millions of years' erosion by the Olifants River, after it had broken through the Drakensberg Mountains. It created a basin directly to the west of the Drakensberg Mountains. This basin with its mountains and valleys can thus be described as a 'lowveld' within the 'highveld'.

3.2.2 Geology

The lithology of South Africa can be divided into basic and acidic rocks. The difference between the two lies in the mineral content of the rock. Ultrabasic (ultramafic) rocks contain, for example, MgO, FeO and CaO, and acidic rocks contain mineral oxides such as SiO₂, K₂O and Na₂O (Krauskopf 1967). Basic rocks are usually referred to as Basalt. The Bushveld Igneous Complex [BIC] can be described as Basaltic, because it contains relatively high concentrations of Mg, Ca, Fe, Al, and Cr compared to other rocks.

Granite and shale are acidic rocks. Granite is known for its low mineral content and shale is formed from sediments derived from weathered rocks. These rocks are therefore not rich in heavy metals and are known as 'normal' rocks. Rocks rich in heavy metals cover only a small portion of the earth's surface. Sediments derived from weathered rocks such as shale, cover about 70% of the world's surface lithology (Krauskopf 1967). The predominant inclination of soils on earth is therefore one of low heavy metal concentrations.

Ultramafic rocks are not the result of weathering and subsequent sedimentation, but are products of the earth's mantle. These rocks are relatively 'new' and have only recently been exposed to weathering. They are therefore not a normal inclination and are termed 'anomalous'. In contrast to most parts of the world, anomalous rocks (from which metalliferous or serpentiferous soils are derived) are plentiful in southern Africa (Roberts & Proctor 1992). Most of the world's economically exploitable deposits of heavy metals are located in South Africa, more specifically in the Rustenburg Layered Suite [RLS] of the Bushveld Igneous Complex [BIC] (Figure 5) (Kent 1980; Coetzee 1985).

The Sekhukhuneland Study Area [SSA] is positioned upon the Bushveld Igneous Complex, or more precisely the Rustenburg Layered Suite. The ultramafic nature of the BIC rocks and the review on the heavy metal soils (see Chapter 2) form the basis for a discussion of the geology of the RLS. The RLS comprises the dominant geological features of the SSA.

Rustenburg Layered Suite

The BIC (Figure 5), together with the Phalaborwa, Kunene and Losberg Igneous Complexes, the Vredefort Granophyre and the Uitloop Granites, were formed during the Precambrian Erathem, the greatest mineral deposit event that has ever occurred on earth (Coetzee 1985). Elements which were deposited as minerals were fluorspar, tin, tungsten, barite, radioactive minerals, nickel, **platinum**, **chromium**, apatite, vermiculite, copper, iron, **vanadium**, **titanium**, molybdenum, bismuth, thorium, jade, building stone and gold. The minerals in bold are very abundant in the SSA. According to Coetzee (1985) there were only two other main depositions of minerals by southern African intrusive igneous rocks, though these are not of such a great magnitude.

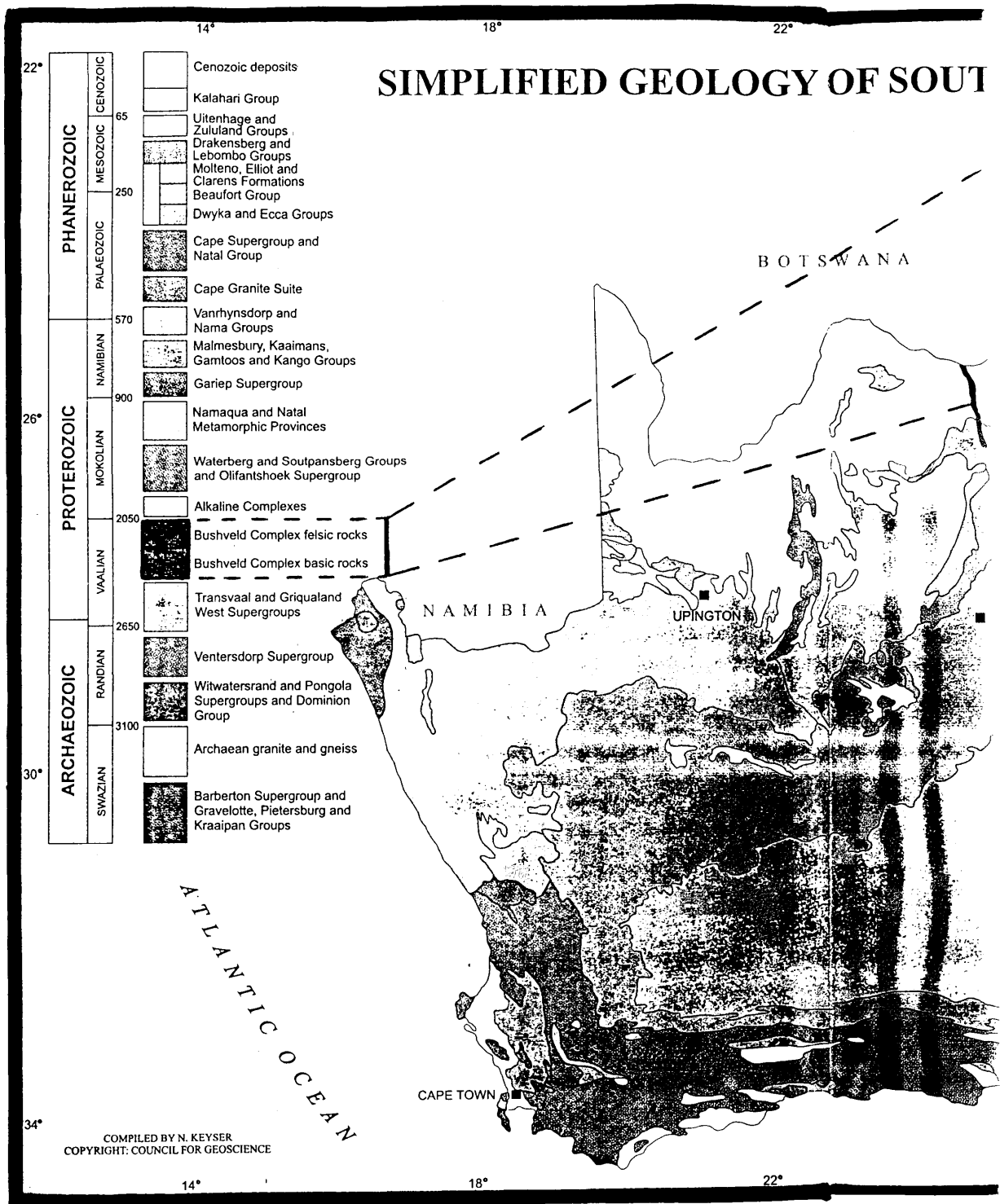
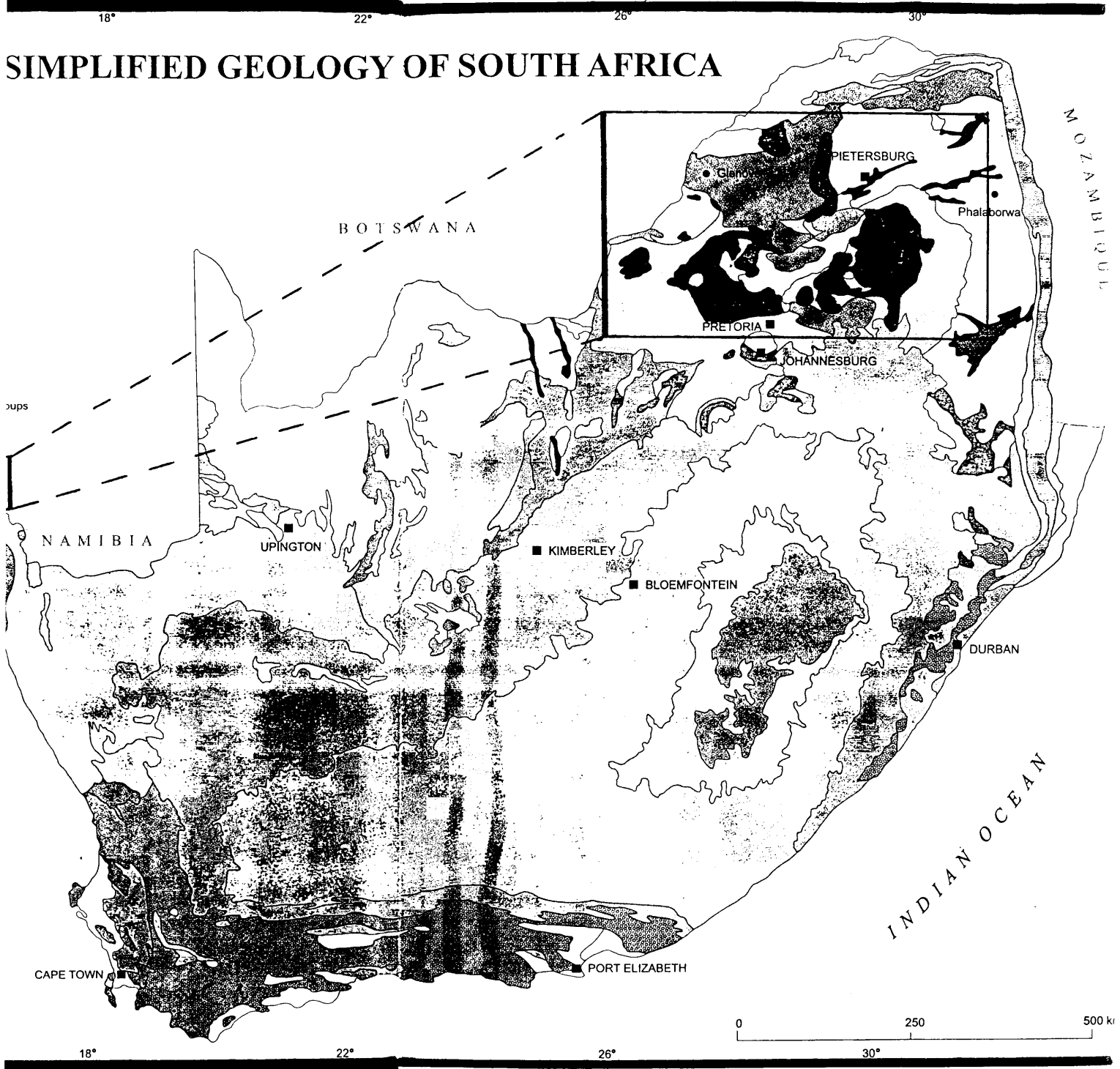


Figure 5 Location of the Bushveld Igneous Complex basic rocks in South Africa and its size and distribution in relation to the rest of the South African geology (Keyser 1998).



Complex basic rocks in South Africa and its size and South African geology (Keyser 1998).

The formation of the BIC was a rather magnificent event (Figure 6). The interior of the Northern Provinces of South Africa was covered by mainly sedimentary rocks of the Transvaal Sequence [TS] (age: 2 000 to 2 300 million years). Approximately 1 950 million years ago, lava reached the surface during volcanic intrusions. According to Visser *et al.* (1989), the emplacement of the BIC magma took place under alternating stress and pressure conditions, resulting in a series of magma surges. The great pressure forced the lava into the interior of the TS rocks, with the lava flow continuously being fed from a central volcanic pipe. When the lava crystallised it gave rise to different layers (saucers) which has been classified as the BIC (Schürmann *et al.* 1998). This immense outflow created a vast cavity lower down in the earth's crust. The tremendous weight of the lava on the surface, resulted in a collapse of the rocks of the TS. When the surface collapsed the BIC saucers were broken and all the layers were exposed to the surface at some points.

The geology of the BIC is perhaps one of the features which contributes most to the uniqueness of Sekhukhuneland. The eastern BIC consists mainly of layers of ultramafic rocks, especially so in the RLS (Marlow 1976). The layers of the RLS is emplaced as four bodies (Figure 5), namely the eastern, western, far-western and northern BIC basic rocks (Keyser 1998; Schürmann *et al.* 1998).

Sekhukhuneland is known for its concentric belts (layers) of norite, which gave rise, among others, to the Leolo Mountains. The concentric belts of the RLS in the SSA, as they are visible today, are the exposed broken 'saucers' (layers) in their weathered state. This characteristic igneous layering (saucers) of the Complex, is the product of crystallisation differentiation during successive surges of magma (Visser *et al.* 1989). The Provisional Tectonic Map of the Bushveld Complex (Hunter 1975), clearly distinguishes between three exposed layers of the RLS. The three main groups of saucers (primary layers) that were crystallised in the RLS, are the Upper Zone, the Main Zone and the Lower Zone (Kent 1980). The locality of these layers, in the SSA, is depicted in Figure 7.

Each of the layers (saucers) can be further divided into secondary layers. The secondary layers are distinguished from surrounding layers according to their main mineral component. The main mineral component consists of certain characteristic elements, e.g. olivine contains Mg and Ni and plagioclase contains Ca and Fe (S.A. de Waal, pers. comm.).

The formation of the layers was dependent on the density of the minerals concerned (Kent 1980). When the lava reached the surface, the heavier metals sunk to the bottom where they crystallised first. The first layer that crystallised, was the Lower Zone. The Lower Zone is characterised by norite, bronzitite, dunite and harzburgite as secondary layers. These secondary layers contain main mineral components made up of elements such as Mg, Ni and Cr. The second saucer which crystallised was the Main Zone. It is characterised by four predominant secondary layers namely, norite, anorthosite, pyroxenite and gabbro. These main layers are characterised by mineral components rich in Ca, Al,

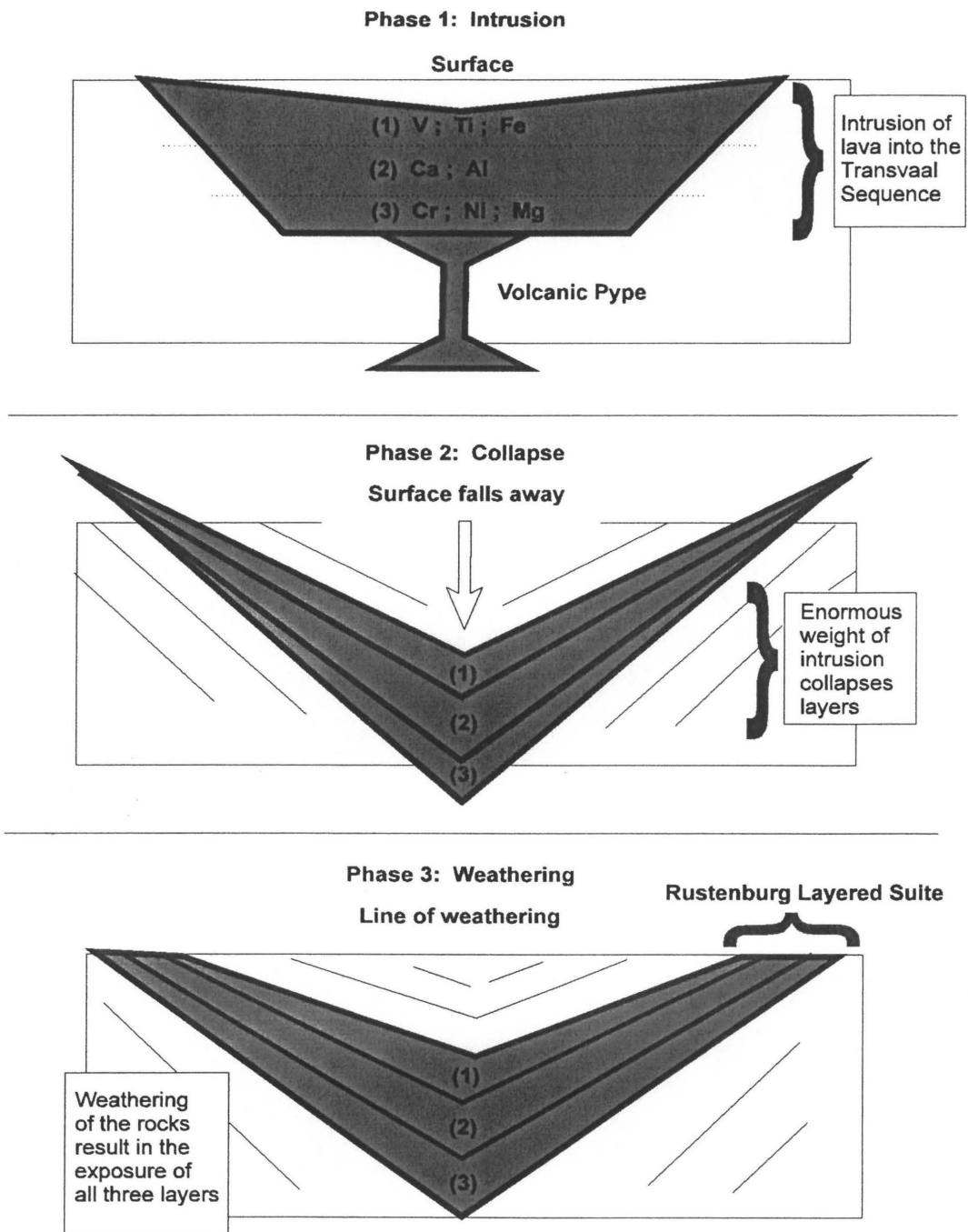
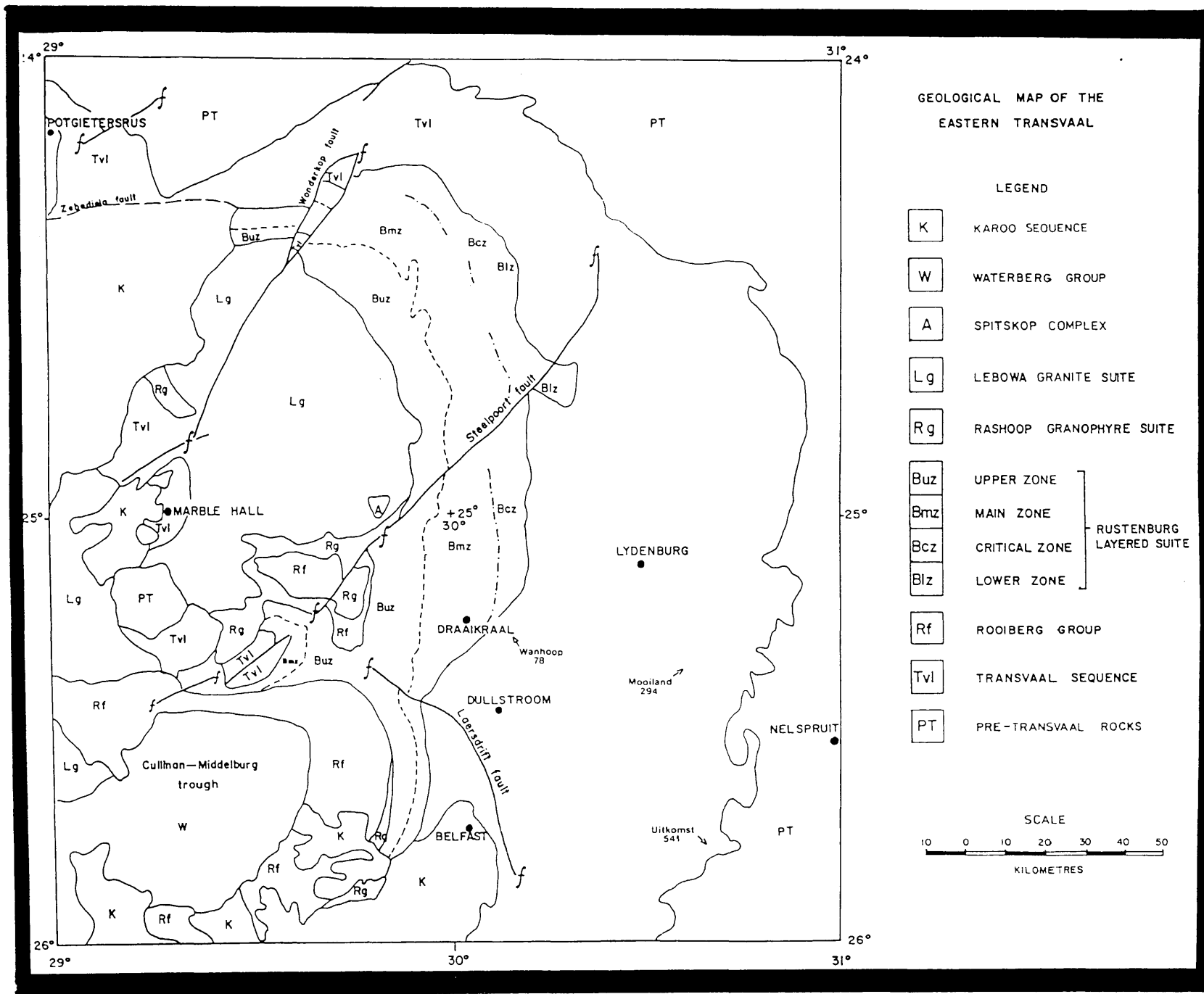


Figure 6 Origin of the Bushveld Igneous Complex, with special reference to the layers of the Rustenburg Layered Suite (Visser *et al.* (1989); A.S. De Waal pers. comm.).

Figure 7 The position of the layers of the Rustenburg Layered Suite in the Sekhukhuneveld Study Area (from Blom (1989)).



Ti and Va. The Upper Zone is characterised by two main secondary layers, namely ferrogabbro and ferrodiorite, and to a lesser degree, magnetite. The main elements within the mineral components of these secondary layers are Fe, Na, Va and Ti. The crystallisation of chromite occurred between the Lower and Upper Zones and is referred to as the Critical Zone. The Critical Zone's secondary layers are mostly pyroxenite, norite, anorthosite, dunite and harzburgite. The dominant main mineral component of the secondary layers contains rich quantities of Cr and Fe.

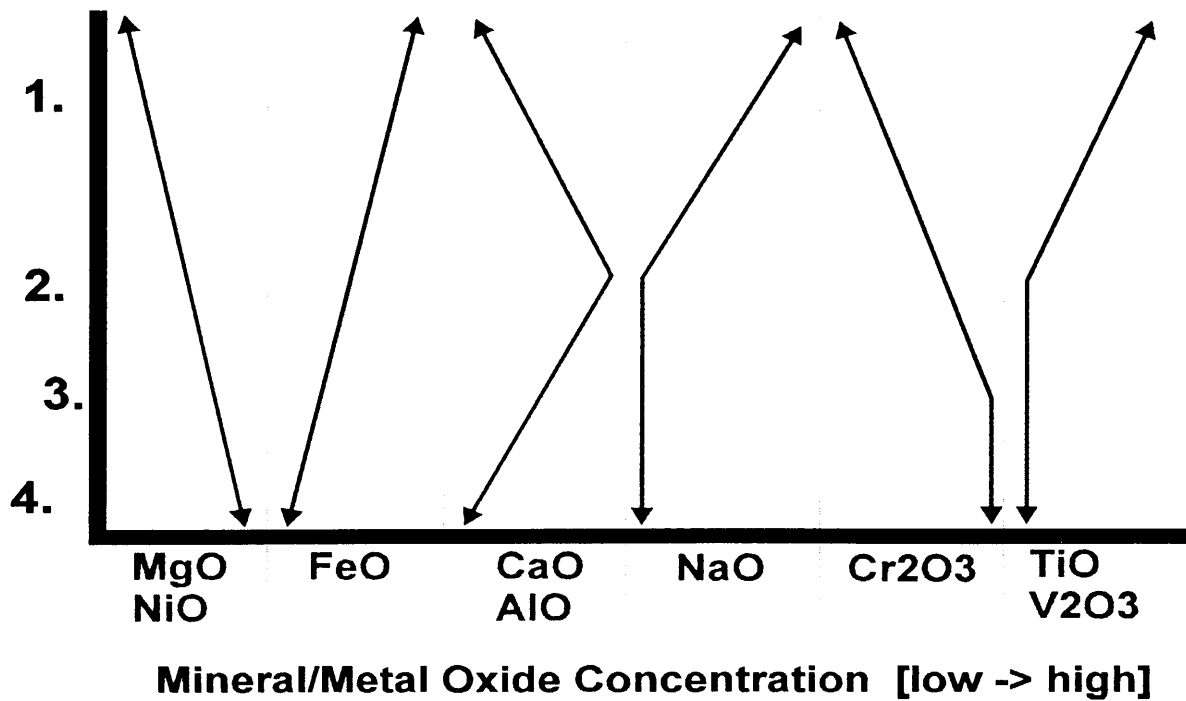
Sekhukhuneland is characterised by great variations in types, locality and abundance of minerals (Hunter 1975). Certain soils in Sekhukhuneland are rich in e.g. Cr and Al, while others are not (S.A. De Waal pers. comm.). The abundance, or dominance, of the minerals varies from one layer to another. Figure 8(b) supplements Figure 8(a), indicating the main mineral components, the abundance (low, medium or high) of their associated minerals and the layers in which they occur (A.S. De Waal pers. comm.). Thus, the type of heavy metal soil occurring in a specific region is dependent on which layers were exposed to weathering. It is important to collaborate the occurrence of heavy metal soils in specific areas with the crystallisation of the layers, the collapse of the saucers and the exposure of the layers at the surface.

Ultramafic soils

High concentrations of different heavy metals occur in ultramafic soils derived from ultramafic rocks (Kent 1980). The most naturally occurring ultramafic soils in Africa are those produced by outcrops of metal-bearing ores of copper, aluminium, nickel and iron (Wild 1978). It should be noted that in addition to the heavy metals, minerals such as arsenic, serpentine and gypsum have importance as constituents of ultramafic soils (Wild 1978).

In South Africa, the eastern rim of the BIC holds some of the highest concentrations of heavy metals, such as chromium, aluminium, vanadium and titanium, in the world (Coetzee 1985; Schürmann *et al.* 1998). These high heavy metal concentrations are contained in the soils and rocks of the Stoffberg-Roosenekal-Magneetshoogte-Steelpoort-Burgersfort region (Marlow 1976), here included in the SSA. The high concentration of metals in the soils of the SSA is therefore a consequence of its ultramafic nature.

The heavy metals of the BIC are associated with gangue minerals such as norite, anorthosite, pyroxene, gabbro, some feldspar and rarely, serpentine (Coetzee 1985). The SSA soils are derived from these ultramafic secondary layers of the RLS. These suite layers are basaltic rocks and are the intermediate form between serpentine and granite (Wild 1978). Granite gives rise to 'normal' soils and serpentine gives rise to toxic soils. Basalt contains slightly higher concentrations of heavy metals than granite and thus, together with serpentines, gives rise to heavy metal soils.



1.	Fe, V, Na and Ti dominant Magnetite (Fe - oxides) Na-rich plagioclase Cpx	Mg low Ni low Fe high Ca low Al medium Na high Cr low Ti & V high
2.	Ca and Al dominant Ca-rich plagioclase Cpx	Mg medium Ni low Fe medium Ca high Al high Na low Cr medium Ti & V low
3.	Cr dominant Chromitite	Mg high Ni high Fe low Ca low Al medium Na low Cr high Ti & V low
4.	Mg and Ni dominant Olivine Opx	Mg low Ni low Fe high Ca low Al medium Na low Cr high Ti & V low

Figure 8 The layered crystallisation of the Rustenburg Layered Suite: (a) Abundance of selected minerals in each of the layers: (1) Upper Zone, (2) Main Zone, (3) Critical Zone, (4) Lower Zone, and (b) text-assisted supplement (based on Hunter (1975); A.S. De Waal pers. comm).

Basalt (which includes norite, pyroxenite, anorthosite and gabbro) shows the highest concentration of selected minerals when it is compared with 'normal' rocks, such as granite and shale, and even the earth's crust (Krauskopf 1967) (Table 4). This geological fact illuminates the mineral abundance, and specifically the heavy metal richness, of the RLS and its associated soils.

The ultramafic soils of the RLS are either mainly red or mainly black montmorillonitic clays (Werger & Coetzee 1978). These soils are characterised by vertic to melanic A-horizons and are rich in smectite clay minerals and ions such as Ca, K and Na, and especially Mg (McVicar *et al.* 1991). The soils are generally dark-coloured and occur in both upland and bottomland positions, especially in hot, dry areas (MacVicar *et al.* 1991). Montmorillonitic clays are also characterised by swelling and shrinking. Certain areas may be described as rocky clay soils.

Table 4 Average abundance of selected elements in the earth's crust and in three common rock types (in parts per million) (Krauskopf 1967)

Element	Crust	Granite	Basalt	Shale
Al	8.2 x 10 ⁴	7.7 x 10 ⁴	8.8 x 10⁴	8.0 x 10 ⁴
Fe	5.6 x 10 ⁴	2.7 x 10 ⁴	8.6 x 10⁴	4.7 x 10 ⁴
Ca	4.1 x 10 ⁴	1.6 x 10 ⁴	6.7 x 10⁴	2.5 x 10 ⁴
Na	2.4 x 10 ⁴	2.8 x 10 ⁴	1.9 x 10⁴	0.7 x 10 ⁴
Mg	2.3 x 10 ⁴	0.2 x 10 ⁴	4.5 x 10⁴	1.3 x 10 ⁴
K	2.1 x 10 ⁴	3.3 x 10 ⁴	0.8 x 10⁴	2.3 x 10 ⁴
Ti	5700	2300	9000	4500
P	1050	700	1400	770
Mn	950	400	1500	850
V	135	20	250	130
Cr	100	4	200	100
Ni	75	1	150	95
Zn	70	40	100	80
Cu	55	10	100	57
Co	25	1	48	20

3.2.3 Climate

One outstanding feature of the SSA is that it falls within the rain shadow of the Drakensberg Escarpment, and that it is relatively arid compared to surrounding areas. The valleys have a subtropical climate with little or no frost in winter, whereas in the mountains the conditions become more temperate with increasing altitude. Climatically the SSA thus comprises an arid (karroid)

subtropical (lowveld) enclave surrounded by areas that are temperate (frost in winter) and much wetter (particularly towards the north, east and south).

There is a paucity of long-term climatic statistics for the SSA. The only rainfall statistics available for the SSA, are the rainfall averages of the Mixed Bushveld Vegetation Type (Van Rooyen & Bredenkamp 1996) and the Rainfall Deciles of Erasmus (1985). The rainfall for the Mixed Bushveld Vegetation Type varies between 350 to 650 mm, usually occurring in summer (Van Rooyen & Bredenkamp 1996). The only meaningful long-term statistics which comprise all the weather stations in the SSA, are those of Erasmus (1985). From the latter, 24 weather stations were selected within and directly adjacent to the borders of the SSA. The rainfall data obtained from Erasmus (1985) are given in Appendix 1.

Rainfall

According to the figures (Erasmus 1985), the SSA receives nearly half of its rain (48%) between December and February (summer), an average of 283 mm for these three months. The summer rains are usually preceded by spring rains which contribute 28% of the total rainfall in a single year. The average annual rainfall of 578 mm (up to 1985) varies from as little as 400 mm in some of the valleys (S10 and S13 Appendix 1), to an estimated 600 mm on the Leolo Mountains (S11 and S15; Appendix 1) and as much as 700 mm in the southern extremity (S20 and S22; Appendix 1).

It must be noted that most of the weather stations were not at the same altitude. It is known that rainfall generally increases as height above sea level increases. Therefore, it was necessary to determine the expected rainfall for a specific altitude, before the averages for the weather stations could be compared or interpreted.

The data of the 24 weather stations within and directly adjacent to the SSA (Appendix 1), and 24 other weather stations in the vicinity of the SSA (chosen stations are evenly dispersed around the SSA) were used to calculate the regression line between metres above sea level (asl) and mean average rainfall. A regression was drawn to gain a better understanding of the region's expected rainfall. The following data was obtained from Quatro Pro 5, using the calculations for regression:

a = 240.40000
Standard error = 96.62510
Correlation = 0.50383
Regression coefficient (r) = 0.31378
Standard error = 0.04749
Degrees of freedom = 45 - 2

The data were substituted into the equation for a linear graph ($y = mx + c$) and the equation for the regression line was obtained, namely: $y = rx + a$, or $y = 0.31378x + 240.40000$. The x-value is the height above sea level (m), and if substituted into the equation, the y-value gives the expected rainfall for that specific altitude in the SSA.

The SSA is divided into two zones in order to create either a west-east or a north-south transect of the rainfall in the region. Each zone is further divided into subzones, with each subzone displaying 12 weather stations. Three west-east and two north-south subzones are created (Table 5). In each subzone a weather station is plotted against (1) its mean average rainfall and (2) the expected mean average rainfall for its height asl.

Table 5 Distribution of the weather stations along the west-east and north-south transects (names of S-numbers in Appendix 1)

Zone A - Subzone A1: 29°30' - 30°30' E & 24°15' - 24°45' S													
W	S01	S02	S05	S04	S06	S03	S09	S10	S11	S12	S13	S14	E

Zone A - Subzone A2: 29°45' - 30°30' E & 24°30' - 25°00' S													
W	S05	S07	S08	S06	S15	S11	S12	S16	S17	S13	S18	S14	E

Zone A - Subzone A3: 29°45' - 30°30' E & 24°45' - 25°30' S													
W	S19	S07	S08	S20	S21	S22	S15	S23	S16	S24	S17	S18	E

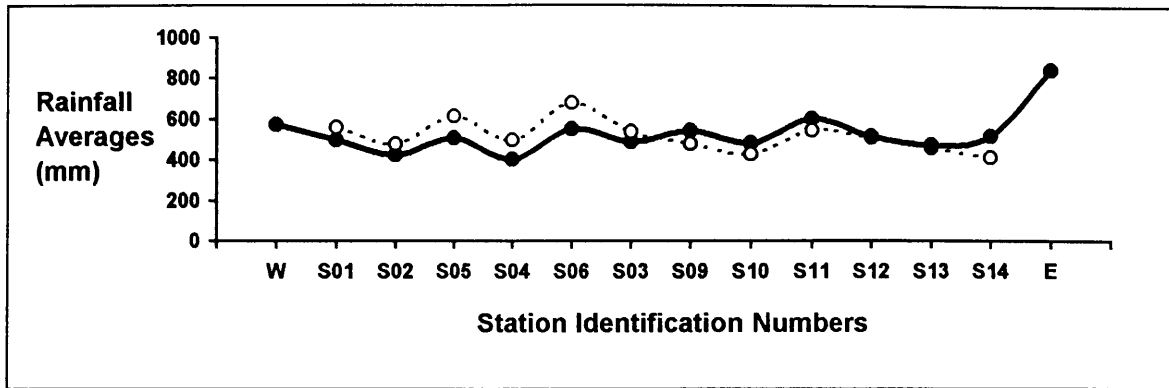
Zone B - Subzone B1: 29°30' - 30°00' E & 24°15' - 25°30' S													
N	S04	S01	S03	S02	S05	S06	S08	S07	S20	S19	S22	S21	S

Zone B - Subzone B2: 30°00' - 30°30' E & 24°15' - 25°15' S													
N	S10	S14	S09	S13	S11	S12	S15	S17	S18	S16	S24	S23	S

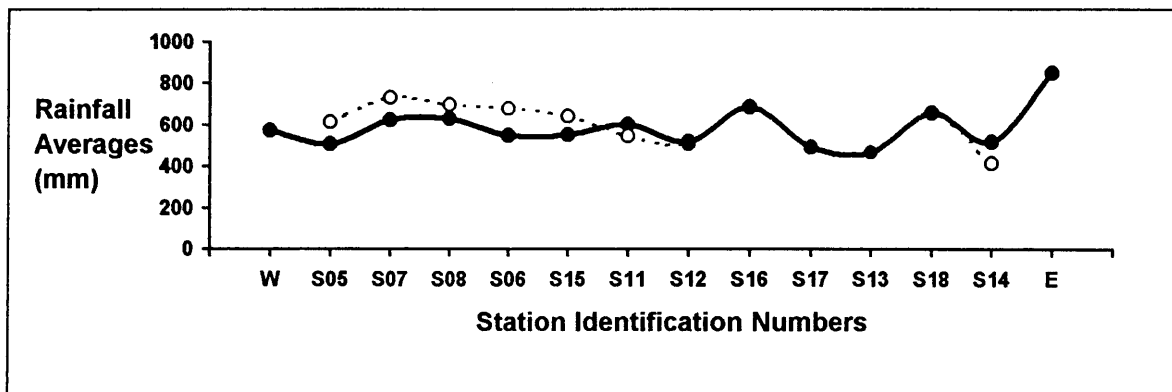
Figures 9(a) to 9(c), were compiled from Subzones A1 to A3 (Table 5) to portray the west-east rainfall gradient of the SSA. There is great fluctuation within the transect of a subzone. The fluctuations can be attributed to altitude. There is a gradual increase of rainfall from west to east, with a sharp increase in the east, on the border with the foothills of the Drakensberg. Thus, the graphs indicate that the western part of the study area receives less rain on average than the eastern parts. The graphs also show that the stations in the west receive less rain than is expected for their height asl.

The north-south rainfall gradient of the SSA also shows a tendency towards fluctuation as a result of altitude. Figures 9(d) and 9(e), were compiled from Subzones B1 and B2 (Table 5) respectively.

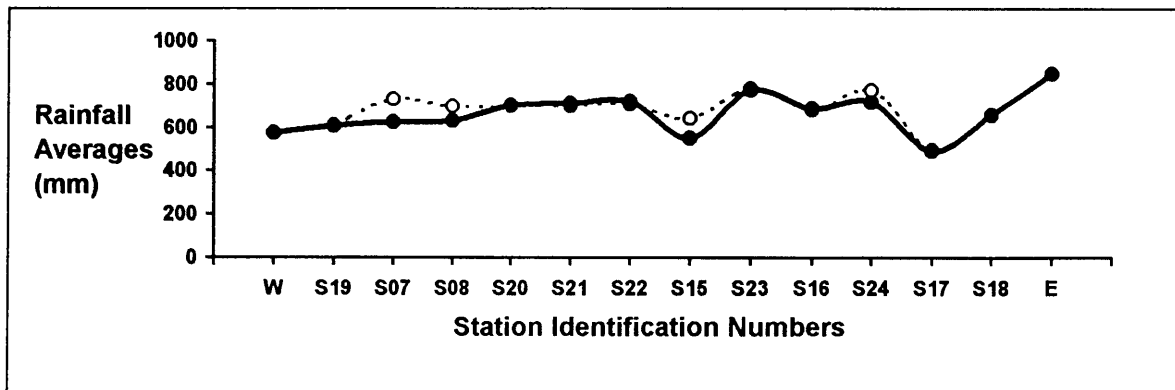
(a)



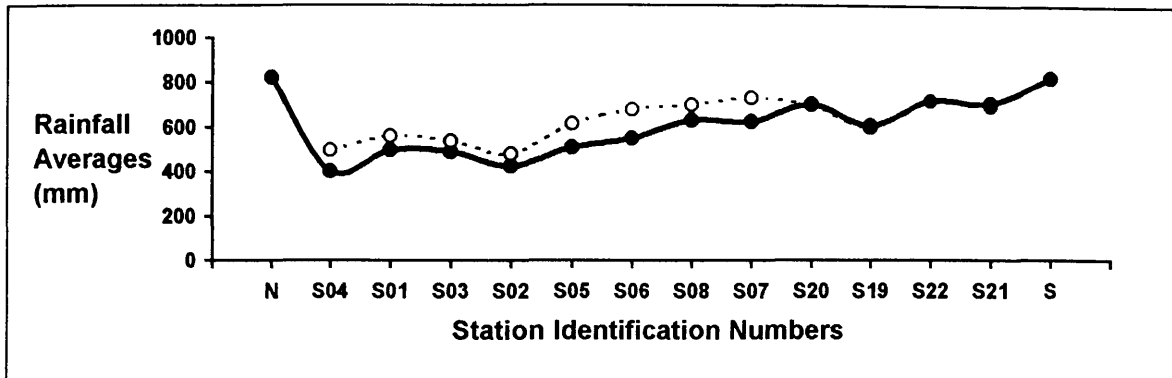
(b)



(c)



(d)



(e)

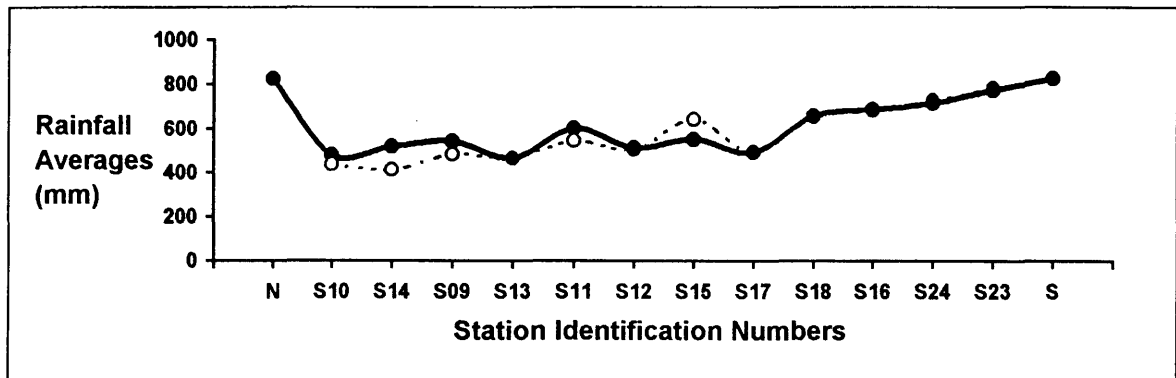


Figure 9 Factual (solid line) and expected (dotted line) rainfall averages for each of the Subzones in the Sekhukhuneland Study Area:

- (a) Subzone A1
- (b) Subzone A2
- (c) Subzone A3
- (d) Subzone B1
- (e) Subzone B2

The graphs indicate that the north-central part of the SSA area is drier than the southern part and the far-north bordering the Drakensberg. Most of the stations in the north receive less rain than would be expected for their height asl. Thus, the graphs indicate that the northern parts of the SSA are somewhat drier than the southern parts.

Temperature

Temperatures in the Mixed Bushveld range from -8°C to 40°C , with an average of 21°C (Van Rooyen & Bredenkamp 1996). Temperature averages for the study area were obtained from the Weather Bureau on 08/08/1997. According to the data, the temperatures of the study area range from -4.5°C to 38°C , with an average of 18.5°C . If the study area is divided into four regions, the average temperatures ($^{\circ}\text{C}$) can be described in a broad sense (Table 6).

Table 6 Average temperatures ($^{\circ}\text{C}$) for four theoretical regions in the Sekhukhuneland Study Area

Region	Daily averages		Year Average
	Maximum	Minimum	
Northern Region:	27.3	14.0	21.8
Eastern Region:	23.9	10.5	18.3
Southern Region:	21.2	8.2	15.8
Western Region:	29.3	13.2	22.6

The occurrence of set climatic patterns as described for the rainfall averages (Figures 9(a) to 9(e)), are also obvious in the temperature data (Table 6). The northern and western parts of the study area are on average warmer than the southern and eastern parts. The northern and western parts exhibit temperatures typical for the Mixed Bushveld (Van Rooyen & Bredenkamp 1996). The southern and eastern regions have average daily temperatures well below that expected for Mixed Bushveld.

It should, however, be noted that the temperature data have not been thoroughly analysed, as is the case with the rainfall data. The reason for the lack in data analysis can be ascribed to the fact that Sekhukhuneland has a very diverse topography, with temperatures possibly varying intensely over short distances. The purpose of the given temperature averages are merely to indicate the abrupt change in temperature within the study area as a whole. The average temperatures are calculated for wide regions and are not specific. However, the daily averages used for calculations were never above 28.3°C or below 7.2°C for the entire SSA. These maximum and minimum daily averages compare well with those expected for the Mixed Bushveld.

When the temperature data are compared with the rainfall data, it becomes clear how the lower rainfall in the western and northern parts, correlates with the warmer temperatures in the western and northern parts. Thus, the SSA can be divided into three climatic regions, namely: (1) small area, moderately dry (400-500 mm/annum), very hot; (2) small area, moderately wetter areas (800-900 mm/annum), moderately cool; and (3) large area, intermediate, typically Mixed Bushveld rainfall averages, relatively warm.

3.2.4 Vegetation

The Mixed Bushveld covers an area of 642 600 km² (Van Rooyen & Bredenkamp 1996), of which approximately 8 000 km² occurs in Sekhukhuneland. Mixed Bushveld is one of 25 broad Vegetation Types comprising the Savannah Biome (Low & Rebelo 1996). The Savannah Biome comprises mostly undulating to flat plains, at an altitude of 700 to 1 100 metres above sea level (Van Rooyen & Bredenkamp 1996). Savannah is characterised by a grassy ground layer and a distinct upper layer of woody plants. Where this upper layer is short, the ground the vegetation may be referred to as Shrubveld, where it is dense as Woodland, and the intermediate stages are locally known as Bushveld (Rutherford & Westfall 1986). Climate, fire and grazing are known to determine the structure of the Savannah Biome. Economically, Savannah is used mainly for cattle and game farming, cultivated crops and ecotourism.

Phytosociological studies

The Mixed Bushveld of the SSA has never been studied in detail. Thus far only a single phytosociological study has been undertaken in the region (Kritzinger 1992), but this is of such limited magnitude, that it can hardly be regarded as significant. According to this provisional phytosociological survey of Maandagshoek in Sekhukhuneland, the vegetation varies from open shrubland to dense bushveld.

On shallow soil, covered with chalky gravel, *Eragrostis lehmanniana* dominates the vegetation, with species such as *Diospyros lycioides* var. *guerkei* and *Heteropogon contortus* proving prominent. On the clay soils the sweet veld includes species such as *Fingerhuthia africana*, *Dichrostachys cinerea*, *Combretum hereroensis* and *Hippobromus pauciformis*. Rocky soils are characterised by *Eragrostis rigidior*, *Psiadia punctuata*, *Dichrostachys cinerea* and *Sclerocarya birrea*. On rocky dry hills *Aristida transvaalensis* becomes dominant, with species such as *Catha transvaalensis*, *Acacia caffra*, *Kirkia wilmsii* and *Elephantorrhiza praetermissa* appearing diagnostic. Other prominent species in the region include *Croton gratissimus*, *Vitex obovata* subsp. *wilmsii*, *Enteropogon macrostachys* and *Rhoicissus sekhukhuniensis* m.s.. Certain heavily eroded areas (vegetation

anomalies, though not serpentine) are very sparsely vegetated with distinctive vegetation including, *Rhus keetii*, *Euclea linearis*, *Polygala* sp. nov. and *Pterothrix spinescens*.

Vegetation Maps

At present, two small scale vegetation maps are widely used in South Africa. The vegetation map of Acocks (1953) is the older version of the two (approximately 40 years), and the map of Low & Rebelo (1996) was only published recently. The map of Acocks will be compared with that of Low & Rebelo, but the vegetation types used in the latter will be adopted for this study.

According to the vegetation map of Low & Rebelo (1996), the SSA is situated in only one biome and one vegetation type, namely the Savannah Biome and the Mixed Bushveld (18) mapping unit. The Sekhukhuneland Study Area is bordered by Moist Sandy Highveld Grassland (38) and North-Eastern Mountain Grassland (43), and to lesser degree by Clay Thorn Bushveld (14) and Afromontane Forest (2) (Low & Rebelo 1996).

According to the vegetation map of Acocks (1953), the SSA covers both the Savannah and the Grassland Biomes. The area includes three veld types, namely Mixed Bushveld (18), Sourish Mixed Bushveld (19) and North-Eastern Sandy Highveld (57). According to Acocks' map, Sekhukhuneland is bordered by North-Eastern Mountain Sourveld (8) and Bankenveld (61) and, to a lesser degree, Springbok Flats Turf Thornveld (12).

An assessment of both vegetation maps shows that the study area is mainly located in the Mixed Bushveld vegetation/veld type. Although the mapping units in the Acocks (1953) veld type map are based on agricultural potential, and the Low & Rebelo (1996) vegetation types map is based on plant communities, the core SSA was classified as Mixed Bushveld in both instances. When the vegetation types bordering or covering minor parts of Sekhukhuneland are examined, it is obvious how the classifications of Acocks (1953) and Low & Rebelo (1996) differ, due to their different approaches. The distinct impression is gained that the Mixed Bushveld in both maps served as a convenient unit with which to accommodate peculiar areas, such as Sekhukhuneland, which do not fit into the other veld/vegetation types.

Mixed Bushveld represents a great variety of plant communities, with many variations and transitions (Acocks 1953; Low & Rebelo 1996). On shallow soils *Combretum apiculatum* dominates the vegetation. Other trees and shrubs include *Acacia caffra*, *Dichrostachys cinerea*, *Lannea discolor*, *Sclerocarya birrea* and various *Grewia* species. Here the grazing is sweet, and the herbaceous layer is dominated by grasses such as *Digitaria eriantha*, *Schmidtia pappophoroides*, *Anthephora pubescens*, *Stipagrostis uniplumis* and various *Aristida* and *Eragrostis* species. On deeper and more sandy soils, *Terminalia sericea* becomes dominant, with *Ochna pulchra*, *Grewia*

flava, *Peltophorum africanum* and *Burkea africana* often prominent woody species, while *Eragrostis pallens* and *Perotis patens* are characteristically present in the scanty sour grass sward.

Floristic evaluation

On an even smaller scale, the Mixed Bushveld Vegetation Type of Rebelo & Low (1996) would be classified as part of the flora of the ‘*South Zambezan undifferentiated woodland and scrub woodland*’ in the Zambezan Domain (White 1983). In structure and floristic composition it is intermediate between ‘*North Zambezan undifferentiated woodland*’ and ‘*Tongaland-Pondoland semi-evergreen bushland and thicket*’. Half of the recorded species in the ‘*South Zambezan undifferentiated woodland and scrub woodland*’ are wide-spread in the Zambezan Domain (White 1983). The remainder are more or less confined to the southern fringes of the Zambezan Domain, which are mostly situated in South Africa, and include the SSA.

The southern fringes are recognised by certain taxa which characterise the southern element, for example (White 1983): *Acacia caffra*, *Aloe arborescens*, *Grewia flava*, *Kirkia wilmsii*, *Protea caffra*, *Ptaeroxylon obliquum*, *Rhus leptodictya*, *Schotia latifolia* and *Spirostachys africana* (White 1983). Many of these are shrubs or small bushy trees. Some are deciduous and others are evergreen. All the above mentioned diagnostic species are present in the SSA.

Although the vegetation of the SSA is mainly of Zambezan extraction, Afromontane elements are present, especially at higher altitudes. The vegetation of the Afromontane archipelago-like Regional Centre of Endemism mainly consists of dense forests, but also contains grasslands and savannahs (White 1978). The most extensive vegetation type existing today in the Afromontane is fire-maintained grassland (White 1978).

Floristically the bushveld of the SSA is quite distinctive and may deserve recognition as a separate vegetation type, provisionally referred to as **Mountain Bushveld**. Reasons for its proposed recognition as a separate vegetation type include the following:

- One of the characteristic trees in this type of bushveld is *Kirkia wilmsii*, a species which is relatively rare in other parts of the Mixed Bushveld;
- Almost pure grassland covers some of the mountain slopes in the region;
- Vegetation between the north- and south-facing aspects of the mountains are often strikingly different and floristically quite unlike other parts of the Mixed Bushveld;
- Intriguing vegetation anomalies associated with heavily eroded soils are present throughout the region;
- Species endemic to the region, for instance *Catha transvaalensis* and *Euphorbia sekhukhuniensis*, are abundant and are diagnostic species in certain plant communities;

- Fire is an important natural factor in the mountains, affecting both vegetation structure and plant biology.

3.2.5 Flora

Davis *et al.* (1994) provide statistics on the comparative floristic diversity of various parts of the world. Accordingly, the Flora of the southern Africa region (South Africa, Namibia, Botswana, Swaziland and Lesotho) plays host to the highest concentration of vascular plant species in Africa (approximately 24 000 infrageneric taxa). Furthermore, southern Africa has the richest temperate flora in the world and this enormous diversity of plants include almost 10% (that is 259 families, 2312 genera and approximately 24 000 known infrageneric taxa) of the world's known flowering plants (Arnold & De Wet 1993). Elsewhere only Brazil, Colombia, China and Borneo have more native vascular plant species than southern Africa. According to Davis *et al.* (1994), the southern Africa region carries the most endemics (> 16 000 species) in the world, resulting in a species endemism of approximately 70 %. Only a few countries (and then mainly isolated oceanic islands) have a higher percentage endemism than southern Africa.

The flora of the Northern Provinces of South Africa [NP] is represented by 204 families, 1397 genera and 5 768 known infrageneric taxa (Retief & Herman 1997). This means that 79% of the families, 60% of the genera and 24% of the known infrageneric taxa of southern Africa occur in the TR. The three largest families in the NP are the Fabaceae, Poaceae and Asteraceae (Retief & Herman 1997). Furthermore, nearly 10% of these 5768 infrageneric taxa is endemic to the NP, especially taxa in the genera *Aloe*, *Euphorbia*, *Thesium*, *Indigofera* and *Brachystelma*, with the highest occurrence of these endemics in the eastern subregion (Retief & Herman 1997).

The flora of the Sekhukhuneland Study Area [SSA] is still poorly known, with several apparently endemic species awaiting formal description. According to the Pretoria National Herbarium Computerised Information System [PRECIS] (data obtained on 11\03\1997), approximately 1 600 of the 5 768 infrageneric taxa recorded for the Northern Provinces of South Africa [NP] occur in the SSA. The endemic and near-endemic figures are provisional and rather conservative.

Floristic identity

According to the floristic map of White (1983), which indicates the main phytocoria of Africa and Madagascar, Sekhukhuneland is located within the Sudano-Zambezian Region, or more precisely, its Zambezian domain (Zambezian Regional Centre of Endemism). The Sudano-Zambezian Region comprises vast stretches of woodland, savannah and grassland vegetation with occasional dry forests and thickets, and patches of swampy vegetation (Werger & Coetzee 1978).

The Zambezian Regional Centre of Endemism covers virtually the entire high plateau of southern Africa (Werger & Coetzee 1978). The region probably has the richest and most diversified flora in Africa (White 1983). Over large parts of the enormous area covered by the Zambezian Regional Centre of Endemism, the rich flora only gradually changes, possibly as a result of the lack of strong relief and other contrasting physiographic factors (Werger & Coetzee 1978).

The SSA lies on the border between the Zambezian Regional Centre of Endemism and the Afromontane archipelago-like Regional Centre of Endemism. The latter is spread as an archipelago over southern Africa, mainly along the eastern escarpment, but also in the south, reaching the Indian Ocean coast (Werger & Coetzee 1978). This region has a diverse flora with a number of endemics and shows affinities to the Sudano-Zambezian and Guineo-Congolian Regions, and the Cape Floral Kingdom (White 1978).

The change from Afromontane to Zambezian is particularly noticeable when one descends from the high-lying, wetter, temperate Steenkampsberg to the low-lying, much drier, subtropical Roosenekal-Steelpoort area. Although the flora of the SSA is mainly of Zambezian extraction, Afromontane elements are present, especially at higher altitudes. Thus, many taxa of the SSA are shared between the Zambezian Regional Centre of Endemism and the Afromontane archipelago-like Regional Centre of Endemism.

CHAPTER 4

METHODS

4.1 Introduction

The methods applied in this dissertation include an extensive literature survey. The main functions of the literature assessment was to locate plant distribution data, to become familiar with the field of study and to put together an anthology of relevant topics.

Field work comprised three excursions to the SSA. The first two excursions, from 07/05/1997 to 10/05/1997 and 13/11/1997 to 15/11/1997, were primarily for plant identification, reconnaissance of selected areas and to study possible sampling sites. The third excursion, from 03/12/1997 to 28/04/1998, was primarily for phytosociological studies (to be reported elsewhere) and plant collection.

Extended visits to the National Herbarium (PRE), Pretoria, were conducted. The aim of these visits was to compile and update distribution maps of plant taxa from herbarium specimens, and to identify the distributions of new, unknown taxa. Extensive use was also made of the collections in the H.G.W.J. Schweikerdt Herbarium (PRU), University of Pretoria.

Computerised analysis of plant distributions was undertaken. During a first analysis, the plant distributions of SSA endemics and near-endemics were captured into a computer program, in order to create floristic maps. A second analysis was used to update the distribution data and to create final floristic maps.

4.2 Data

4.2.1 Floristic data

Plant distribution data were obtained from several sources. The data collection procedure involves the compilation of a **floristic list** of possible Sekhukhuneland endemics from applicable sources such as the Pretoria National Herbarium Computerised Information System [PRECIS], literature, herbarium specimens, checklists and field trips.

A list of the plant taxa that have been collected in the 12 quarter degree grids of the SSA, was obtained from **PRECIS** at the PRE. This list was supplemented with **checklists** which have been compiled from certain regions of the SSA. Checklists based on unpublished phytosociological data were produced by myself (2430CC, 2529BB & 2530AA), M.M. Mathee (2429BD) and J.J. Kritzinger (2430CA). Checklists concerning floristic diversity across wide sections of most of the SSA, by A.E. van Wyk and The Plant Specialist Group (M. Lotter, Mpumalanga Parks Board), were also consulted.

The provisional floristic list was checked against the national list of Arnold & De Wet (1993) to begin the elimination of non-endemic taxa. Only those taxa restricted to the Northern Provinces of South Africa [NP], or very nearly so, were considered for further evaluation. This new list was supplemented with potential NP endemic species from the existing **literature**, including the *Flora of southern Africa*, and compared with the plant distributions in the *Flora Zambesiaca*. All the taxa which were also recorded for the *Flora Zambesiaca* area, were rejected. Taxa exhibiting wide disjunct patterns between other areas and the SSA were, however, kept for further investigation.

The modified floristic list now contained the taxa which had been previously collected in the SSA and proved to be endemic or near-endemic to the Northern Provinces of South Africa. These taxa are thus either restricted only to the NP, or very nearly so, with disjunct small satellite populations in the rest of South Africa or north of the Limpopo River. The distributions of the taxa were once again checked against the plant species list of the northern provinces (Retief & Herman 1997).

Each of the taxa on the floristic list was now allocated to a quarter degree grid [QDG] distribution map of southern Africa in order to test their endemism in the SSA. The **herbarium specimens** of all the selected taxa were examined to plot their distributions on their QDG distribution maps. Specimens were examined in the National Herbarium [PRE], Pretoria and H.G.W.J. Schweickerdt Herbarium [PRU], University of Pretoria. The floristic list and QDG distribution maps were also supplemented with data on specimens collected during **field trips**, concentrating on the rare and apparently undescribed taxa.

If the QDG distribution maps proved that a taxon was widely and continuously distributed beyond the borders of the NP, it was excluded from the final floristic list. If the maps proved that a taxon was endemic or near-endemic to the SSA or very nearly so, it was included in the final list.

Distribution data of all the taxa on the 'Final List' were sorted into one of three floristic categories, namely (1) Sekhukhuneland element, (2) Wolkberg element and (3) Element of other regions. The degrees of endemism for the Sekhukhuneland Study Area were defined with the following definition:

Floristic element:	Abbreviation:	** %:
Sekhukhuneland endemic	SE	> 75
Sekhukhuneland near-endemic	SN	25 – 75

** Percentage of world distribution, recorded from herbarium specimens housed in the PRE and PRU

The Sekhukhuneland degrees of endemism are used in the drawing of plant locality maps to depict the endemic or near-endemic distributions of individual taxa. These degrees of endemism are used in the compilation of maps concerning the distribution of certain taxon groups with a uniform state of endemism. All three categories are combined in drawings of maps which indicate the linkage between these floristic categories and their degrees of endemism.

4.2.2 Geological data

A literature survey was undertaken to establish the geology of the SSA and to classify it hierarchically according to Visser *et al.* (1989). Several sources were also consulted to determine the relevant lithology of the SSA. All the literature data was summarised in a table, and sorted, to identify the most represented lithology (rock types such as norite & quartzite) of the SSA geology (formations such as Dsjate Subsuite & Silverton Formation).

Statistical data, concerning the SSA lithology, is captured within the colours of geological maps. The applicable areas on the geological maps of 2428 Nylstroom, 2430 Pelgrim's Rest, 2528 Pretoria and 2530 Barberton, of the 1:50000 Geological Series of South Africa, were scanned into a computer. The scanned images were divided into the 12 quarter degree grids [QDG].

The scanned images of the QDGs were captured with the computer program TIFF. The surface areas of the different formations were colour coded and blended to achieve optimum intensity. The geology proved too heterogeneous and the intensity of the scanned images were not very accurate. The main formations were recognisable, and could be distinguished from each other. The homogenous colours within each QDG were identified and alternately selected in order to run the TIFF program. The program determines the percentage of the surface area of a QDG that is occupied by a specific geological formation (homogeneous colour). All the surface percentages (as a direct indication of percentage rock composition) were calculated for the formations in all the QDGs.

The table data (presence/absence data), concerning the most represented rock types, and the TIFF data, concerning the formation percentages (abundance data), were evaluated to identify the main groups of geological formations. Five groups were identified as representative of the rock types within the geological formations.

The five groups of rock types were used in the drawing of histograms to depict the ultramafic-geological and ultramafic-floristic correlations in each quarter degree grid. The geological formation percentages were used in the compilation of histograms to depict the floristic affinity which might exist with specific substrates. The geological formation percentages were also related to one another in histograms, to indicate the relationship between different formations.

4.2.3 Data analysis

The floristic and geological data are analysed statistically to determine their association with one another. When the association between two variables are investigated, the correlation and regression is determined (Snedecor & Cochran 1980).

The flora of any region is dynamic and will be regarded as the dependent variable (y) for the purpose of this dissertation. The geology will be regarded as the independent variable (x). In other words, the range of y is dependent on the range of x. The x-value can be considered as the 'cause' and the y-value as the 'result'.

The y-value refers to the number of endemics in the SSA. The x-value refers to a group of rock types. In order to carry out a statistical analysis of correlation and regression, certain calculations have to be done beforehand for the number of endemics and each of the five groups of rock types. The definitions of the eight calculations are given below:

Number of QDGs = n
Sum of x = Σx (for each of the five groups)
Sum of y = Σy (only for the number of endemics)
Sum of $x^2 = \Sigma x^2$ (for each of the five groups)
Sum of $y^2 = \Sigma y^2$ (only for the number of endemics)
Sum of $xy = \Sigma xy$
Average for x = (X) (for each of the five groups)
Average for y = (Y) (only for the number of endemics)

The values of the above calculations are substituted into the equations relevant for either the calculation of correlation or regression. When the correlation (r) between the number of endemics and the percentages of a specific group of rock types is determined, the equations in the box below are applied:

Equations for each group of rock types
$SK_x = \Sigma x^2 - [(\Sigma x)^2 \div n]$
$SK_{xy} = \Sigma xy - [(\Sigma x)(\Sigma y) \div n]$

and

Equation for endemics
$SK_y = \Sigma y^2 - [(\Sigma y)^2 \div n]$

$r = SK_{xy} \div [\sqrt{(SK_x)(SK_y)}]$
--

Correlation is not a measure to determine if one variable is dependent on another, but to determine if two variables vary together. A value between -1 and 1 for the correlation coefficient 'r', indicates either a negative correlation (~ -1) or a positive correlation (~ 1). A zero value indicates that no correlation is present. A significant correlation is defined as a correlation value which is higher than the value (at P = 0.05) supplied for the degrees of freedom (n - 2) in the r-table (Snedecor & Cochran 1980). A highly significant correlation is higher than the r-table value at P = 0.01.

The formulas for the regression equation between the number of endemics and the percentages of the five groups of rock types, are given below:

Equation for each group of rock types
$SK_x = \Sigma x^2 - [(\Sigma x)^2 \div n]$
$SK_{xy} = \Sigma xy - [(\Sigma x)(\Sigma y) \div n]$

Regression equation
$y = a + bx$
$b = SK_{xy} \div SK_x$
$a = (Y) - b.(X)$

Regression is used to determine the relationship between two variables. To evaluate the regression equation, a regression line needs to be constructed. This is done by calculating two values for y at two values of x. A straight line is drawn between these two points on a graph. A linear graph with a positive gradient is indicative of a positive influence of the independent variable x on the dependent variable y. The independent variable x has no influence on the dependent variable y, if the gradient is negative.

4.3 Geographical information system

4.3.1 GIS maps

A Geographical Information System [GIS] is based on spatial data analysis and decision support. The raster-based Idrisi for Windows Version 2 was applied as the GIS 'tool'. Idrisi graphically positions map features in relation to known locations and relates these positions to other cartographic features.

The manipulation of distribution data (analysis of spatial data) is based on the implementation of relevant queries (decision support). The queries (Database Workshop) that were executed, were on-screen digitising queries. The Idrisi digitising queries that were used are not as powerful as the Idrisi database queries, because the former relies on on-screen calculations which is subject to human error. Digitising is an on-screen manipulation of data and its functions are very restricted, whereas the functionality is unlimited when database-queries are coupled to an Idrisi system.

The compilation of a high standard database, coupled with database queries, is time consuming and beyond the aims of this dissertation. A high standard database is ideal for assessments in conservation strategies and future research, but not for a small scale investigation as is the case with this dissertation.

Maps

Three types of maps were compiled for the purpose of this study. All these maps were based on the interactions between the digitising function, the symbol workshop, and map composition queries (Database Workshop) of the Idrisi program. All applicable locality values for a specific map were digitised as vector files (.vec). A symbol palette file (.sm_) was created for each specific map type. The on-screen digitising function is combined with the symbol palette to create map composition queries, which are saved as map composition files (.map). The map composition indicates a specific queries' localities on a map-layer of South Africa.

The first type of map is used as a means of orientation. The **orientation map** is used to present data concerning geology, towns, borders, mountains, priority areas and other non-botanical data. The aim with the maps is to place the necessary diagnostic features of the SSA within reach for quick reference. The diagnostic features are displayed in both symbol and text form. Each symbol is linked to a digitised point, which in turn is coupled to a text file in the Database Workshop within Idrisi. The orientation maps are solely based on on-screen digitising and manipulation of the symbol palette. The map composition query is only used in the creation of text files for diagnostic features via the Database Workshop.

The second type of map is the plant **distribution map**. Two types of distribution maps were developed. The first distribution map measures the **degree of endemism**. It is used for queries concerning the plant distributions. Each query comprises a set of plant localities, for each different species, which conform to a specific degree of endemism. The data manipulation of the distribution maps is dependent on the amount of hits occurring in each QDG. This means that if an endemic species occurs in a grid, the query receives a value of one, e.g. if ten different endemics occur in a grid, the query has a value of ten. It must be noted that only the occurrence, and not the abundance,

of an endemic species is recorded, e.g. if two endemics occur in a grid, the one species three times and the other twice, the query only receives a value of two.

The second type of distribution map displays the **plant localities** of single taxa. It only concerns the endemic and near-endemic elements of Sekhukhuneland. On-screen queries are run to display the taxa which are within the boundaries of the SSA, or nearly so. Only one taxon is displayed at a time. In other words, where the first type of distribution map focused on all the plant distributions of a specific degree of endemism, the second type focused only on the locality of a single taxon within a specific degree of endemism.

4.3.2 GIS scale

Hit Scale

The effectiveness of the distribution maps depicting the degrees of endemism, are dependent on the number of hits in a grid and the colour it portrays. The presentation of the distribution maps depicting degrees of endemism, is predetermined mathematically and forms part of on-screen digitising queries.

A specific procedure was adopted to determine a hit scale for GIS manipulation (Table 7). The occurrence of endemics in each grid of the study area was recorded. The endemism of a grid was determined as a percentage of the total number of endemics in the grids. Each of the grid percentages were multiplied with 1.2 (arbitrary figure) to gain a more even distribution across 100%. The aim of this procedure is to emphasise higher degrees of endemism. The higher the percentage endemism in a grid, for a given set of taxa at a specific degree of endemism, the higher the value added when multiplied with 1.2. The value added percentages were then categorised into intervals. Interval one contains all value added percentages from 1 to 5, interval two all value added percentages from 6 to 10, etc..

Table 7 Procedures adopted to determine the hit scale for GIS manipulation

Grid	Endemic Taxa	% of Total	Hit Scale	
			% x 1.2	Intervals
1	1	5	6 (+1)	2
2	2	10	12 (+2)	3
3	3	15	18 (+3)	4
4	5	25	30 (+5)	6
5	5	25	30 (+5)	6
6	7	35	42 (+7)	9
7	8	40	48 (+8)	10
8	9	45	54 (+9)	11
9	9	45	54 (+9)	11
10	12	60	72 (+12)	15

Colour Scale

The effectiveness of the distribution maps (Degree of Endemicity maps) is dependent on the amount of hits in a grid and the colour it portrays. The presentation of the distribution maps is based on a predetermined colour scale in the Symbol Workshop. Scaling is important to ensure that comparisons can be made, according to the colour code, between the different hit intensities of the QDGs on a single map.

In the Symbol Workshop, a 255 pixel red was chosen as one boundary and a 255 pixel yellow was chosen as the other boundary. These colours were blended at an one sixteenth convergence. The convergence created 16 colours, with each colour containing one sixteenth more, or less, red, or yellow than the previous colour.

The colour convergence implies that each plant distribution query is allowed 16 colours to draw a map. This means that the intervals of the **hit scale** must be converted to the 1/16 convergence of the colour scale. There are 16 colours, therefore 16 intervals must be created. The highest number (=16) of the colour scale is divided by the highest number of the hit scale intervals to determine a factor (HS x CS/HS). The factor is multiplied with all the intervals of the hit scale to convert them to the colour scale intervals (Table 8).

Table 8 Procedures adopted in this dissertation to determine the colour scale intervals for GIS manipulation

*Hit Scale (HS)		Colour Scale (CS)	
Intervals	16/15	Intervals	
2	x 1.07	2	
3	x 1.07	3	
4	x 1.07	4	
6	x 1.07	6	
6	x 1.07	6	
9	x 1.07	10	
10	x 1.07	11	
11	x 1.07	12	
11	x 1.07	12	
15	x 1.07	16	

Colours (1/16 convergence)	
Pixel Yellow	Pixel Red
238	17
221	34
204	51
170	85
170	85
102	153
85	170
68	187
68	187
0	255

* Taken from Table 7

Summary

The distribution maps are primarily applied to indicate concentration points of the different degrees of endemism. However, it must be noted that the scale is correlated with presence/absence data and not abundance. Therefore it is not the function of the colour scale to show the abundance correlations between the maps, but rather to enhance the endemism differences between the grids of a specific map. The enhancement of endemism is achieved by means of a more intense colour contrast which is created by limiting the colours to 16 and multiplying the hit scale intervals with a factor.

4.4 Indices and histograms

4.4.1 Indices

In the case of phytodiversity studies, it is necessary to look at indices which were developed for application in the field of biodiversity. Bykov's Formula is the relationship that exists between the percentage endemism and surface area (Major 1988). It is used for the mathematical evaluation of the degree of endemism. The formula can be used to determine the endemism index for entire regions where the surface area, total endemics and total taxa are known. Thus, the soundness of the calculated index is dependent on correct and comprehensive data applied in the equation.

The Bykov Formula (Major 1988) was selected for the purpose of this dissertation, to have a means by which to identify the 'Hot Spots' of the Sekhukhuneland Study Area [SSA]. The formula is

modified to calculate the endemism, as well as the species richness and the relative phytodiversity for every QDG.

The following equation of the Bykov Formula is used to calculate a quantitative index of endemism: $I_e = E_f / E_n$, where I_e is the Index of Endemism, E_f is the factual percentage endemism and E_n is the normal percentage endemism. E_f is calculated as the total endemics divided by the total number of taxa and E_n is read off the nomogram (percentage endemism against surface area) provided by Bykov (Major 1988). $I_e = 1$ indicates that the area has the normal expected degree of endemism; a value of > 1 indicates greater than normal and < 1 less than normal endemism (Major 1988).

The logarithm of the number of species occurring in a series of areas of increasing size increases linearly with the logarithm of the area (Myers & Giller 1988). A similar relationship holds for percentage of endemism and area. Therefore, the area of the grids, and the SSA as a whole, plays an important role during the evaluation of endemism using the Bykov Formula. The area of one quarter degree grid [QDG] is 675 km² (Edwards & Leistner 1971) and of 12 is 8 100 km². The method is explained in the box below:

There are 50 endemics in a QDG with 500 taxa. The region's area is 8100 km².
 $E_f = 50/500 (x100) = 10\%$; $E_n = 3\%$ (from nomogram at 8100 km² - endemics are endemic to whole region)
 $I_e = E_f / E_n$ therefore $I_e = 10 \% \div 3 \%$
 $I_e = 3.3$
 Thus, the QDG has a greater than normal endemism.

Evidently, a similar relationship holds for the percentage of species richness and area. The Bykov Formula is now used to determine the Index of Species Richness. The method is illustrated with an example in the box below:

There are 500 taxa in a QDG. There are 12 QDGs each covering approximately 675 km².
 $R_f = 500 \div 675 (x 10) = 7.4\%$; $R_n = 3\%$ (from nomogram at 8100 km² - taxa are indigenous to whole region)
 $I_r = R_f / R_n$ therefore $I_r = 7.4 \% \div 3 \%$
 $I_r = 2.5$
 Thus, the QDG has a greater than normal species-richness.

The **relationship** between percentage endemism and species richness can also determined using a modified Bykov Formula. This is the Index of Relative Phytodiversity. The Index of Relative Phytodiversity is a self-formulated measure to determine hot spots in poorly sampled areas, and its

values are dependent on the two other indices. The method is explained with the example in the box below:

The QDG has an Index of Endemicity of 3.3 and an Index of Species Richness of 2.5.
 $I_e = 3.3$, $I_r = 2.5$ - Thus, $P_f = 3.3 + 2.5 = 5.8$; $P_n = 2.5$ % (indices used in equation were determined with this value)
 $I_p = P_f / P_n$ therefore $I_p = 5.8 \div 2.5$ %
 $I_p = 2.3$
 Thus, the QDG has a greater than normal relative phytodiversity.

- Note that the indices are used to compare the QDGs of a closed system. In other words, tendencies outside the borders of the SSA are totally ignored. The indices are merely applied to create a means whereby the poorly sampled flora of Sekhukhuneland can be assessed meaningfully.

4.4.2 Histograms

In the case of ultramafic-phytodiversity associations, the most illustrative method used to present statistical correlations and regressions, are by means of histograms (Tyler 1996). The efficacy of the histogram is dependent on accurate statistical data and well-matched axis pairs.

The histograms in this dissertation are based on floristic and geological data. The statistical data has already been determined (see 4.2.3). Two sets of histograms are presented in this dissertation:

- The first set of histograms illustrates the relationship between the main groups of geological formations in the SSA. Five groups of geological formations have been identified. The x-axis features the quarter degree grids [QDG], in order from the highest to lowest number of endemics. The y-axis features the percentage cover of each of the five main groups of rock formations for each QDG.
- The second set of histograms illustrates the correlation and regression between the five groups of rock types and endemism. The x-axis features the QDGs in order of highest to lowest percentage endemism. The *y-axis features the percentage SSA endemics and geological rock group percentages for a specific QDG.
 * **Please note** that the y-axis has no values. The endemism and geological groups are together expressed as a percentage of a possible 200% (a meaningless value). The function of the y-axis is merely to provide a visual perception of the relationship between groups of rock types and endemism of a specific QDG, as well as the relationship between different QDGs.

CHAPTER 5

RESULTS

5.1 Floristic endemism

5.1.1 Endemic taxa

The endemic taxa of the Sekhukhuneland Study Area [SSA] number approximately 51. At least 30 of these infrageneric taxa are narrow endemics. The remaining 21 are wide endemics. The 51 endemic taxa belong to 23 families and 37 genera (Appendix 2A). Distribution maps are supplied for the endemics (Appendix 2B), and are arranged under narrow or wide endemism.

The genera *Aloe*, *Euphorbia* and *Rhus* respectively, contribute the highest number of SSA endemic taxa for their hierarchical level (Table 9). *Balanites*, *Catha*, *Premna*, *Ptaeroxylon*, and *Stylochiton* are the genera which exhibit the highest percentage endemism in the SSA, if only their members in the Northern Provinces of South Africa are considered (Table 9).

Families with the highest number of SSA endemic taxa are the families Fabaceae, Liliaceae, Euphorbiaceae and Vitaceae (Table 10). Families with the highest number of genera with endemics in the SSA are Fabaceae, Lamiaceae and Liliaceae (Table 10). The families of the dicotyledonae have the highest number of genera with endemic taxa.

Table 9 Percentage of the infrageneric angiosperm taxa in the Northern Provinces of South Africa [NP], endemic to the Sekhukhuneland Study Area [SSA]

Genus	SSA endemic taxa	NP Infrageneric taxa	Percentage endemism
<i>Acacia</i>	1	44	2
<i>Aloe</i>	4	55	11
<i>Argyrobium</i>	1	14	7
<i>Balanites</i>	1	2	50
<i>Bauhinia</i>	2	5	40
<i>Berkheya</i>	1	28	4
<i>Boscia</i>	1	6	17
<i>Catha</i>	1	2	50
<i>Ceropegia</i>	1	26	4
<i>Cyphostemma</i>	2	20	10
<i>Delosperma</i>	2	30	7
<i>Dyschoriste</i>	1	8	25
<i>Elephantorrhiza</i>	1	6	17
<i>Euphorbia</i>	4	54	7
<i>Gymnosporia</i>	1	10	10
<i>Hibiscus</i>	1	39	3
<i>Huernia</i>	1	14	7
<i>Ipomoea</i>	1	40	3
<i>Jamesbrittenia</i>	1	13	8
<i>Kleinia</i>	1	5	20
<i>Leucas</i>	1	7	14
<i>Orthosiphon</i>	1	8	13
<i>Pavetta</i>	1	17	6
<i>Plectranthus</i>	1	31	3
<i>Polygala</i>	1	23	4
<i>Premna</i>	1	2	50
<i>Protasparagus</i>	2	43	5
<i>Protea</i>	1	13	8
<i>Ptaeroxylon</i>	1	2	50
<i>Rhoicissus</i>	2	7	29
<i>Rhus</i>	3	41	7
<i>Sansevieria</i>	1	3	33
<i>Schottia</i>	1	3	33
<i>Stylochiton</i>	1	2	50
<i>Tulbaghia</i>	1	8	13
<i>Xerophyta</i>	1	7	14
<i>Zantedeschia</i>	2	7	29
37	51	645	8

Table 10 The angiosperm families with infrageneric taxa endemic to the Sekhukhuneland Study Area

Family	Genera	SSA endemic taxa
Acanthaceae	1	1
Anacardiaceae	1	3
Araceae	2	3
Asclepiadaceae	2	2
Asteraceae	2	2
Balanitaceae	1	1
Capparaceae	1	1
Celastraceae	2	2
Convolvulaceae	1	1
Euphorbiaceae	1	4
Fabaceae	4	6
Lamiaceae	3	3
Liliaceae	4	8
Malvaceae	1	1
Mesembryanthemaceae	1	2
Polygalaceae	1	1
Proteaceae	1	1
Ptaeroxylaceae	1	1
Rubiaceae	1	1
Scrophulariaceae	1	1
Velloziaceae	1	1
Verbenaceae	1	1
Vitaceae	2	4
23	37	51

5.1.2 Endemic distributions

The Sekhukhuneland Study Area [SSA] **endemic flora** is more or less centred in 2430CA, 2430CC, 2429BD and 2529BB (Figure 10). The quarter degree grids [QDG] 2430CB and 2530AA are also worth mentioning, because they contain nearly as many endemics. In other words, the 51 endemic taxa have a high occurrence (endemicity) in six of the QDGs (50%) of the SSA. Four of the other six QDGs have a slightly lower occurrence of endemic taxa (2429DB, 2430AC, 2430CD and 2529BD) and the remaining two (2429BC and 2429DD) have an occurrence of endemics comparable with that of the adjacent areas. Endemics of the SSA show a slight floristic affinity with adjacent mountain ranges. A part of the Serala Mountains (2430AA) and parts of the Blydepoort Mountains (2430DB and 2529AB), contain Sekhukhuneland endemics, which is comparable with the lowest occurrence of endemics for QDGs in the SSA (Figure 10).

Endemic distributions of taxa within the SSA represent two groups, namely narrow and wide distributions. **Narrow** endemics are those taxa with distributions which fall entirely within the

borders of the SSA. **Wide** endemics are characterised as those taxa with distributions which fall within the borders of the SSA, but also within adjacent areas of the Northeastern Escarpment (Transvaal Drakensberg).

When the narrow endemics are considered (Figure 11(a)), their core region is identified as centred within 2430CA and 2430CC. The occurrence of endemics in all the other QDGs is considerably less than in these two core grids. Of the remaining QDGs, 2429BD and 2529BB have a slightly higher occurrence of endemic taxa than the rest.

Among the SSA narrow endemics, the tree flora is not well represented. *Rhus sekhukhuniensis*, *Euphorbia sekhukhuniensis* and a form of *Acacia karroo* are examples of narrow endemic trees in the SSA. Shrub/small tree narrow endemics include *Elephantorrhiza praetermissa*, *Rhus batophylla*, *Euphorbia barnardii* and infraspecific taxa such as *Pavetta zeyheri* [form], *Premna mooiensis* [form] and *Ptaeroxylon obliquum* [forma].

Some narrow endemics are widely distributed throughout most of the SSA, for example, *Zantedeschia jucunda*, *Jamesbrittenia macrantha* and *Rhoicissus tomentosa* [form]. *Delosperma zeederbergii*, *Protasparagus sekhukhuniensis* and *Ceropegia distincta* subsp. *verruculosa* are at present only known from single localities within the SSA.

When the wide endemics are considered (Figure 11(b)), the centred distribution of these endemics falls mainly within the core region 2430CA and 2430CC. Four other QDGs (2430CB, 2430CD, 2529BB and 2530AA), also with relatively high occurrence of endemics, form the main periphery of the centred distribution. The wider ranges of the wide endemics, extend to the Wolkberg Centre of Endemism. Three principal areas are distinguished in the Wolkberg Centre for the sharing of wide endemics with the SSA: northern region (2430AA), eastern region (2430DB) and southeastern region (2530AB).

The tree flora of the wide endemics is hardly represented. *Catha transvaalensis* and *Rhus tumulicola* var. *meeuseana* forma *pumila* and forms of *Bauhinia tomentosa* and *Boscia albitrunca* are the only wide endemic trees of the SSA. Shrub/small tree wide endemics include only two taxa, namely *Aloe castanea* and *Euphorbia lydenburgensis*.

Certain wide endemics, such as *Huernia insigniflora*, *Ipomoea bathycolpos* var. *sinuatodentata* and *Orthosiphon tubiformis*, are widely distributed throughout most of the SSA. Other wide endemics are restricted to certain localities within the SSA, for example the distributions of *Delosperma rileyii*, *Dyschoriste perrottetii* and *Aloe immaculata*.

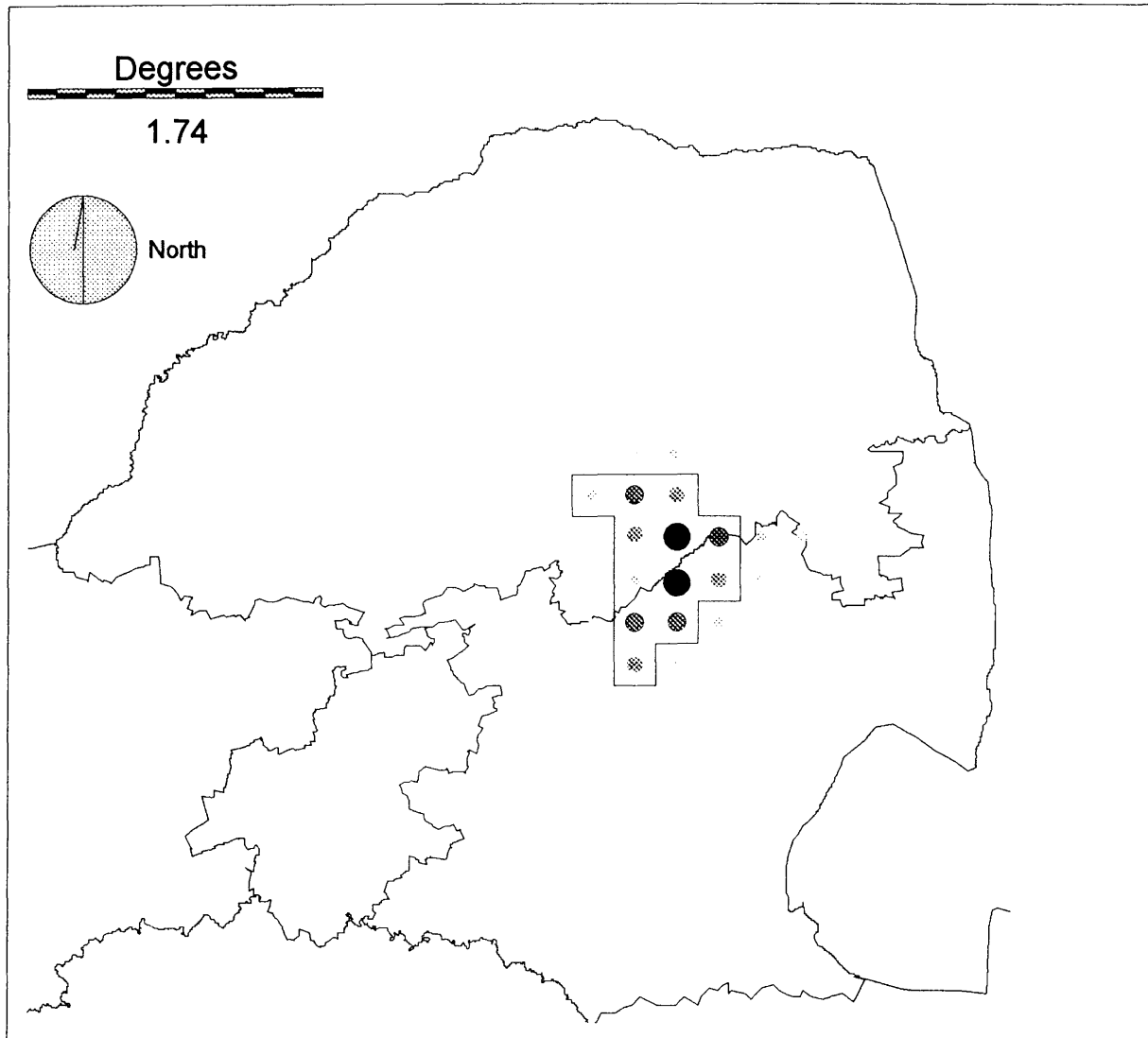


Figure 10 Combined distribution pattern of the plant taxa endemic to the Sekhukhuneland Study Area [SSA].

Key: Smallest yellow circle - 1 species
Biggest red circle - 30 species

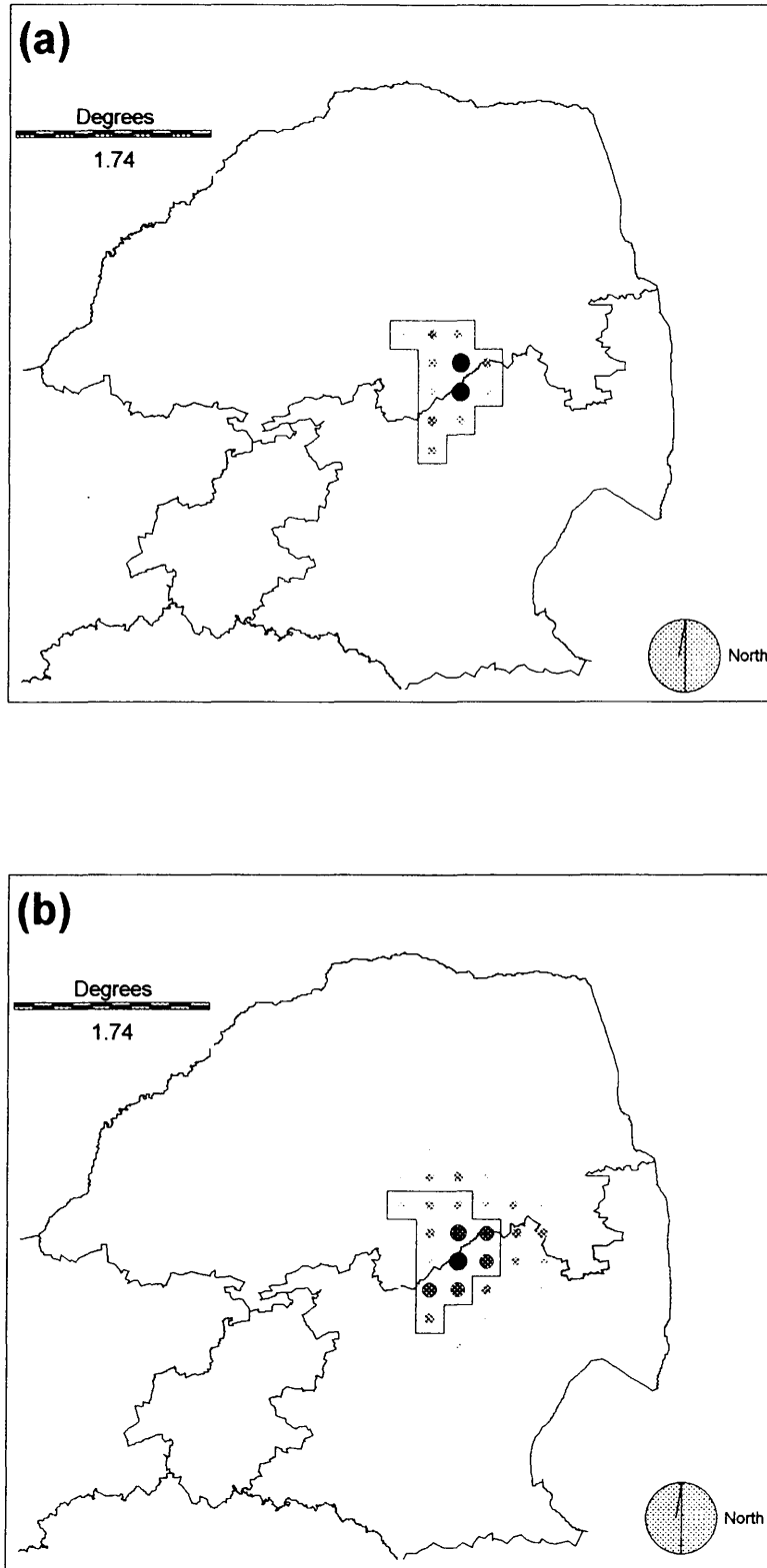


Figure 11 The two most pronounced combinations of distribution ranges for the taxa endemic to the Sekhukhuneland Study Area: **(a)** narrow endemic range and **(b)** wide endemic range.

Key: Smallest yellow circle - 1 species

Biggest red circle - 20 species

5.1.3 Near-endemic taxa

Approximately 70 taxa are near-endemic to the Sekhukhuneland Study Area [SSA]. These taxa are considered as either localised near-endemics (14 taxa) or disjunct near-endemics (56 taxa) within the Northern Provinces of South Africa. The near-endemic taxa belong to 29 families and 53 genera (Appendix 2A). A distribution map is supplied for each of the near-endemics (Appendix 2B), with the maps presented separately for localised or disjunct near-endemics.

The genera *Rhus*, *Aloe*, *Euclea*, *Euphorbia* and *Jatropha*, contribute the highest number of near-endemics at the family level (Table 11). The genera *Huerniopsis*, *Pterothrix* and *Sesamothamnus* exhibit the highest percentage near-endemism in the SSA, if only their taxa in the Northern Provinces of South Africa are considered (Table 11).

Asteraceae, Euphorbiaceae, Anacardiaceae and Fabaceae are the families which displays the highest number of near-endemic taxa at the family level (Table 12). The families with the highest number of genera with near-endemic taxa, are Asteraceae, Asclepiadaceae, Acanthaceae and Fabaceae (Table 12). The dicotyledons have the highest number of genera with near-endemic taxa.

Table 11 Percentage of the infrageneric angiosperm taxa in the Northern Provinces of South Africa [NP], which are near-endemic to the Sekhukhuneland Study Area [SSA]

Genus	SSA near-endemic taxa	NP infrageneric taxa	Percentage near-endemism
<i>Adenia</i>	1	10	10
<i>Aloe</i>	3	55	5
<i>Aneilema</i>	1	7	14
<i>Anthericum</i>	1	13	8
<i>Argyrolobium</i>	2	14	14
<i>Barleria</i>	1	32	3
<i>Berkheya</i>	1	28	4
<i>Brachycorythis</i>	1	2	50
<i>Brachylaena</i>	1	5	20
<i>Ceropegia</i>	1	26	4
<i>Cussonia</i>	1	4	25
<i>Cyphia</i>	1	10	10
<i>Cyphostemma</i>	1	20	5
<i>Dicliptera</i>	1	13	8
<i>Dyschoriste</i>	1	8	13
<i>Ehretia</i>	1	4	25
<i>Euclea</i>	3	12	25
<i>Eucomis</i>	1	6	17
<i>Euphorbia</i>	3	54	6
<i>Grewia</i>	1	20	5
<i>Helichrysum</i>	2	87	2
<i>Hermannia</i>	2	32	6
<i>Huernia</i>	1	14	7
<i>Huerniopsis</i>	1	1	100
<i>Hypoxis</i>	1	23	5
<i>Indigofera</i>	2	84	2
<i>Ipomoea</i>	1	40	3
<i>Jasminum</i>	1	8	13
<i>Jatropha</i>	3	13	23
<i>Karomia</i>	1	2	50
<i>Kirkia</i>	1	2	50
<i>Kleinia</i>	1	5	40
<i>Lotononis</i>	1	31	3
<i>Melhania</i>	1	11	9
<i>Nuxia</i>	1	6	17
<i>Orbeopsis</i>	1	5	20
<i>Orthosiphon</i>	2	8	25
<i>Ozoroa</i>	1	6	17
<i>Pachycarpus</i>	1	13	8
<i>Pegolettia</i>	1	4	25
<i>Petalidium</i>	1	3	33
<i>Phyllanthus</i>	1	14	7
<i>Plectranthus</i>	1	31	3
<i>Pterothrix</i>	1	1	100

Genus	SSA near-endemic taxa	NP infrageneric taxa	Percentage near-endemism
<i>Rhigozum</i>	1	3	33
<i>Rhus</i>	5	41	12
<i>Rhynchosia</i>	1	33	3
<i>Sesamothamnus</i>	1	1	100
<i>Tetradenia</i>	1	2	50
<i>Tetraselago</i>	1	4	25
<i>Thesium</i>	1	46	2
<i>Triaspis</i>	1	4	25
<i>Vitex</i>	1	9	11
53	70	929	8

Table 12 The angiosperm families with infrageneric taxa near-endemic to the study area

Family	Genera	SSA near-endemic taxa
Acanthaceae	4	4
Anacardiaceae	2	6
Araliaceae	1	1
Asclepiadaceae	5	5
Asteraceae	6	7
Bignoniaceae	1	1
Boraginaceae	1	1
Commelinaceae	1	1
Convolvulaceae	1	1
Ebenaceae	1	3
Euphorbiaceae	3	7
Fabaceae	4	6
Hypoxidaceae	1	1
Lamiaceae	3	4
Liliaceae	3	5
Lobeliaceae	1	1
Loganiaceae	1	1
Mapighiaceae	1	1
Oleaceae	1	1
Orchidaceae	1	1
Passifloraceae	1	1
Pedaliaceae	1	1
Santalaceae	1	1
Scrophulariaceae	1	1
Simaroubaceae	1	1
Sterculiaceae	2	3
Tiliaceae	1	1
Verbenaceae	2	2
Vitaceae	1	1
29	53	70

5.1.4 Near-endemic distributions

The **near-endemic flora** of the Sekhukhuneland Study Area [SSA], is more or less centred in 2430CA, 2430CC, 2529BB and 2429BD (Figure 12). The quarter degree grids [QDG] 2429DD, 2430CB and 2530AA of the SSA are also part of the near-endemics' centred distribution. Hence, the 70 near-endemic taxa are mainly centred in seven of the QDGs (60%) of the SSA. However, all of the QDGs in the SSA show a relatively high occurrence of SSA near-endemics, when compared to the regions in the rest of the Northern Provinces of South Africa.

The near-endemics of the SSA show a distribution linkage with the mountain ranges in the Northern Provinces of South Africa. The QDG 2429AA of the Waterberg and 2430AA (northern Drakensberg), 2430DA (eastern Drakensberg), 2531CC (Barberton), 2528CA (Magaliesberg) and 2229DD (Soutpansberg), are the principal disjunct regions for the near-endemics of the SSA (Figure 12).

The near-endemic taxa of the SSA are represented by two groups, namely those with localised and those with disjunct distributions. The **localised** near-endemics are characterised by disjunct distribution ranges beyond, but adjacent to, the borders of the SSA. The distribution of the **disjunct** near-endemics tend to radiate outwards from the SSA in all directions — the taxa exhibit a inconsistent broken distribution well beyond the borders of the SSA.

When the localised near-endemics are considered (Figure 13), their combined distribution lies entirely within the SSA (central region), Transvaal Drakensberg (eastern and southern region), Strydpoort Mountains (northern region) and Gouwsberg (southwestern region). Thus, the distribution of the localised near-endemics (14 taxa) can be described as the shortest distance of disjunction between the SSA and other regions.

There are no trees which are localised near-endemics of the SSA. Two shrubs, *Grewia vernicosa* and *Rhigosum obovatum* [form] are recognised as localised near-endemics. A localised near-endemic with a typically wide distribution within the SSA is *Adenia fruticosa* subsp. *fruticosa*. *Eucomis vandermerwei* is a localised near-endemic with a narrow distribution in the southern parts of the SSA.

The disjunct near-endemics are characterised by eight distribution patterns (disjunctions) between the SSA and other regions. Five disjunct patterns are distinguishable as Waterberg-linked distributions with the SSA (Figure 14(a) to 14(e)). The five disjunctions are with (a) Waterberg (twelve taxa), (b) Waterberg + Soutpansberg + Barberton (four taxa), (c) Waterberg + Soutpansberg (four taxa), (d) Waterberg + Magaliesberg (eight taxa) and (e) Waterberg + Magaliesberg + Soutpansberg + Barberton (seven taxa). The remaining three disjunct distribution patterns are not linked with the Waterberg (Figure 15(a) to 15(c)). These three distribution patterns display links

between the SSA and (a) Barberton (seven taxa), (b) Soutpansberg (six taxa) and (c) Magaliesberg + Barberton + Soutpansberg (eight taxa).

Certain taxa exhibit distribution ranges which are characteristic of the disjunctions in Figure 14. There are five small tree/shrub near-endemics in disjunction (a) of the Waterberg link (e.g. *Rhus keetii*), none in disjunction (b), one in disjunction (c) (*Euclea linearis*), one in disjunction (d) (*Rhus engleri*) and two in disjunction (e) (e.g. *Cussonia transvaalensis*). Certain taxa of the Waterberg-linked distributions are widely distributed within their range. Examples of such taxa are *Triaspis glaucophylla* for disjunction (a), *Rhynchosia spectabilis* for disjunction (b), *Cyphia transvaalensis* for disjunction (c), *Hermannia lancifolia* for disjunction (d) and *Kirkia wilmsii* for disjunction (e). Taxa which are narrowly distributed in their range as a SSA disjunct near-endemic in the Waterberg link is *Orthosiphon amabilis* (disjunction (a)), *Rhus wilmsii* (disjunction (b)), *Euphorbia maleolens* (disjunction (c)), *Brachycorythis conica* subsp. *transvaalensis* (disjunction (d)) and *Orbeopsis melanantha* (disjunction (e)).

Certain taxa exhibit distribution ranges which are characteristic of the disjunctions in Figure 15. Disjunction (a), of the disjunct near-endemic distributions not linked to the Waterberg, is represented by four small tree taxa (e.g. *Vitex obovata* subsp. *wilmsii*), disjunction (b) by two (e.g. *Sesamothamnus lugardii*) and disjunction (c) by one (*Rhus gracillima* var. *gracillima*). Near-endemic taxa, not linked to the Waterberg, sometimes exhibit wide distributions within their disjunct distribution pattern, such as *Karomia speciosa* forma *speciosa* (disjunction (a)), *Helichrysum edwardsii* (disjunction (b)) and *Tetraselago wilmsii* (disjunction (c)). Other near-endemics have narrow distributions within their disjunctions, for instance *Aloe reitzii* var. *reitzii* (disjunction (a)), *Euphorbia exelsa* (disjunction (b)) and *Pegolettia lanceolata* (disjunction (c)).

Four infrageneric taxa of the **Bryophyta** are near-endemic to the SSA (Appendix 2A). Distribution data on these taxa are very incomplete, with present knowledge based on less than three recorded localities for each and with no representative herbarium specimens collected in the SSA.

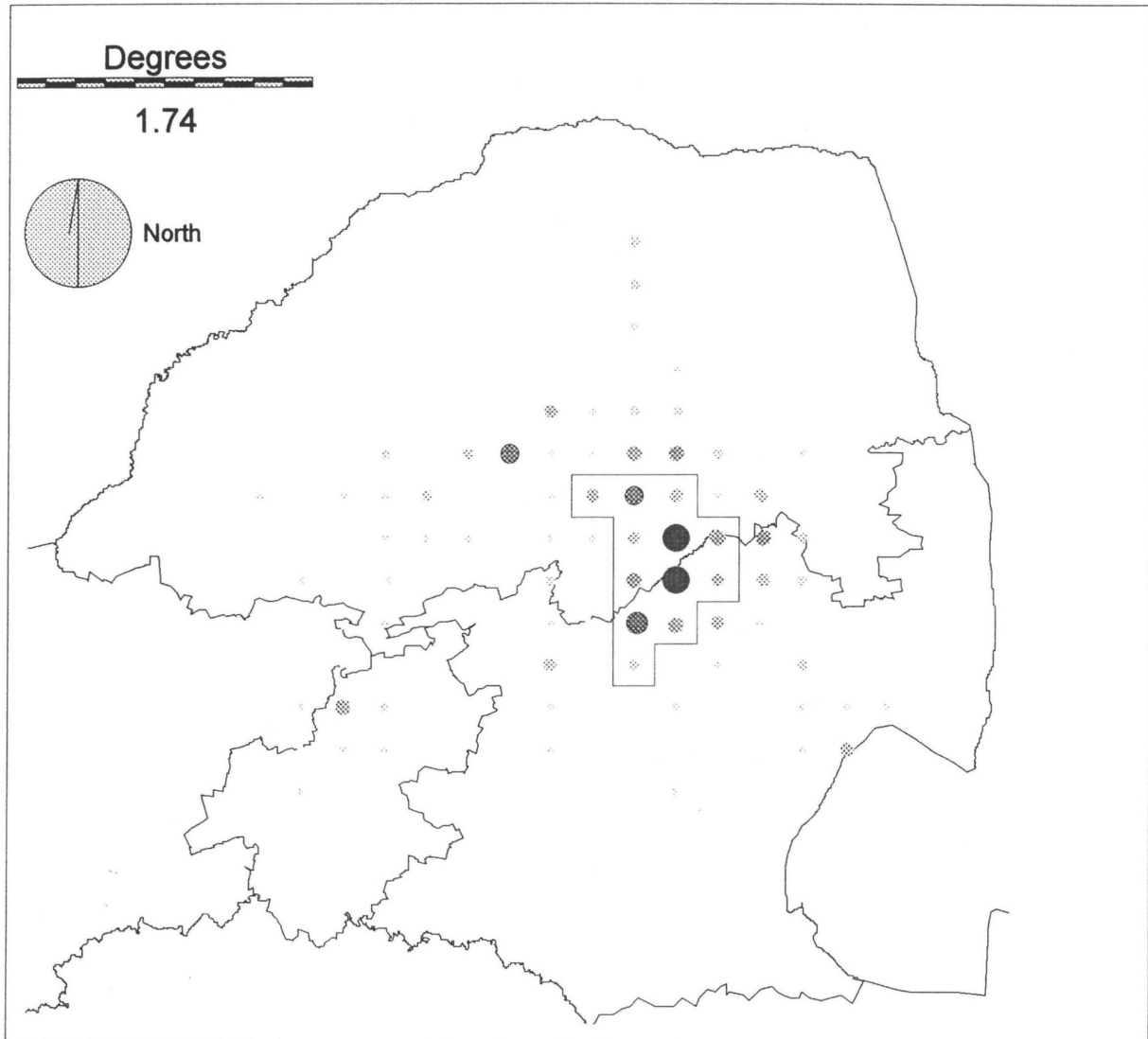


Figure 12 Combined distribution pattern of the taxa near-endemic to the Sekhukhuneland Study Area.

Key: Smallest yellow circle - 1 species

Biggest red circle - 20 species

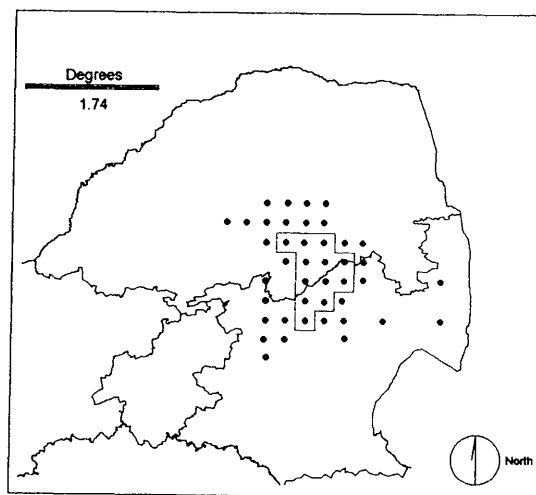


Figure 13 Range of the distribution patterns for **localised** near-endemics of the Sekhukhuneland Study Area and the Northeastern Drakensberg Escarpment.

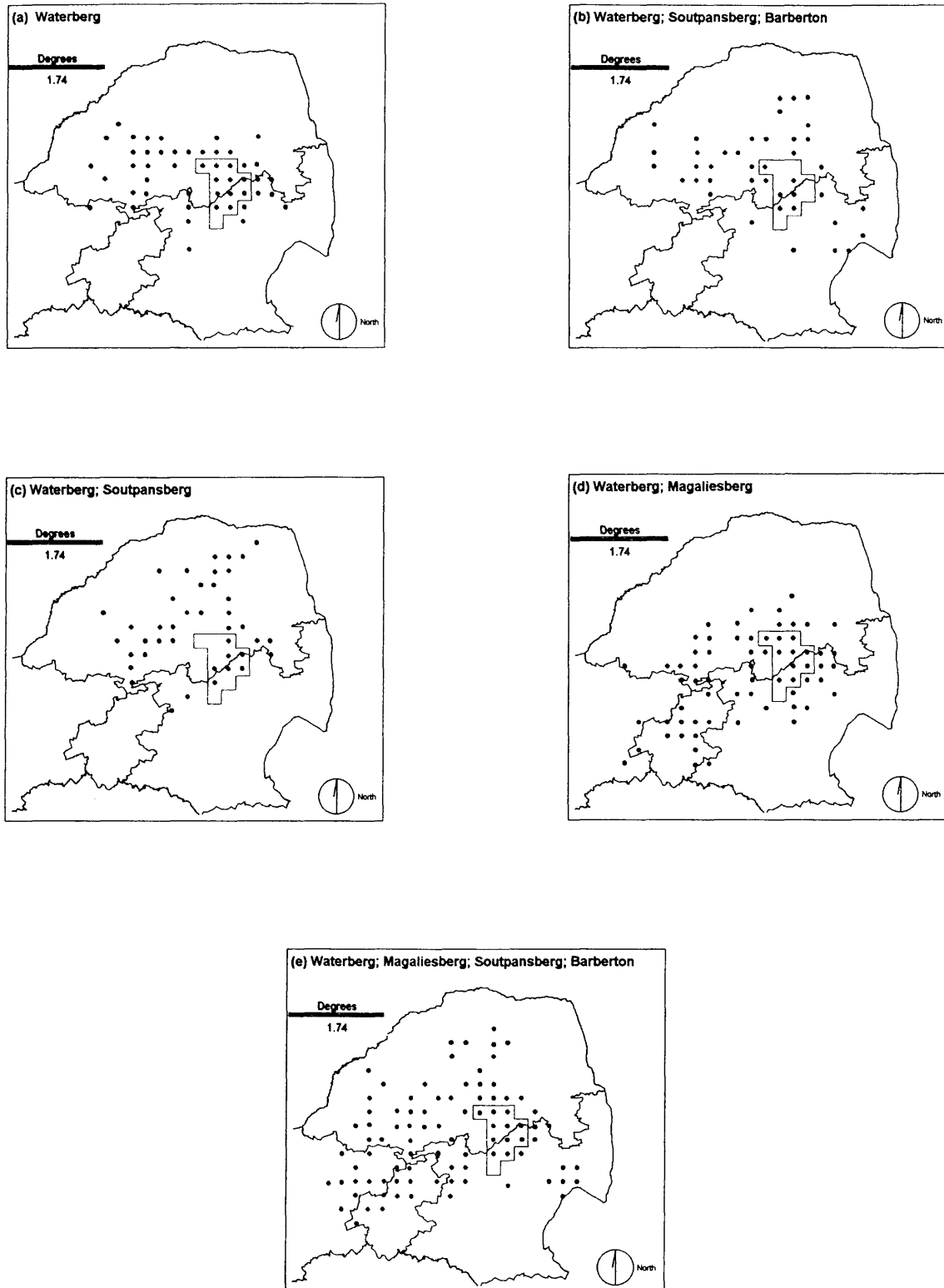


Figure 14 Range of the distribution patterns for **disjunct** near-endemics of the Sekhukhuneland Study Area, with a Waterberg-link: (a) Waterberg, (b) Waterberg + Soutpansberg + Barberton, (c) Waterberg + Soutpansberg, (d) Waterberg + Magaliesberg and (e) Waterberg + Magaliesberg + Soutpansberg + Barberton.

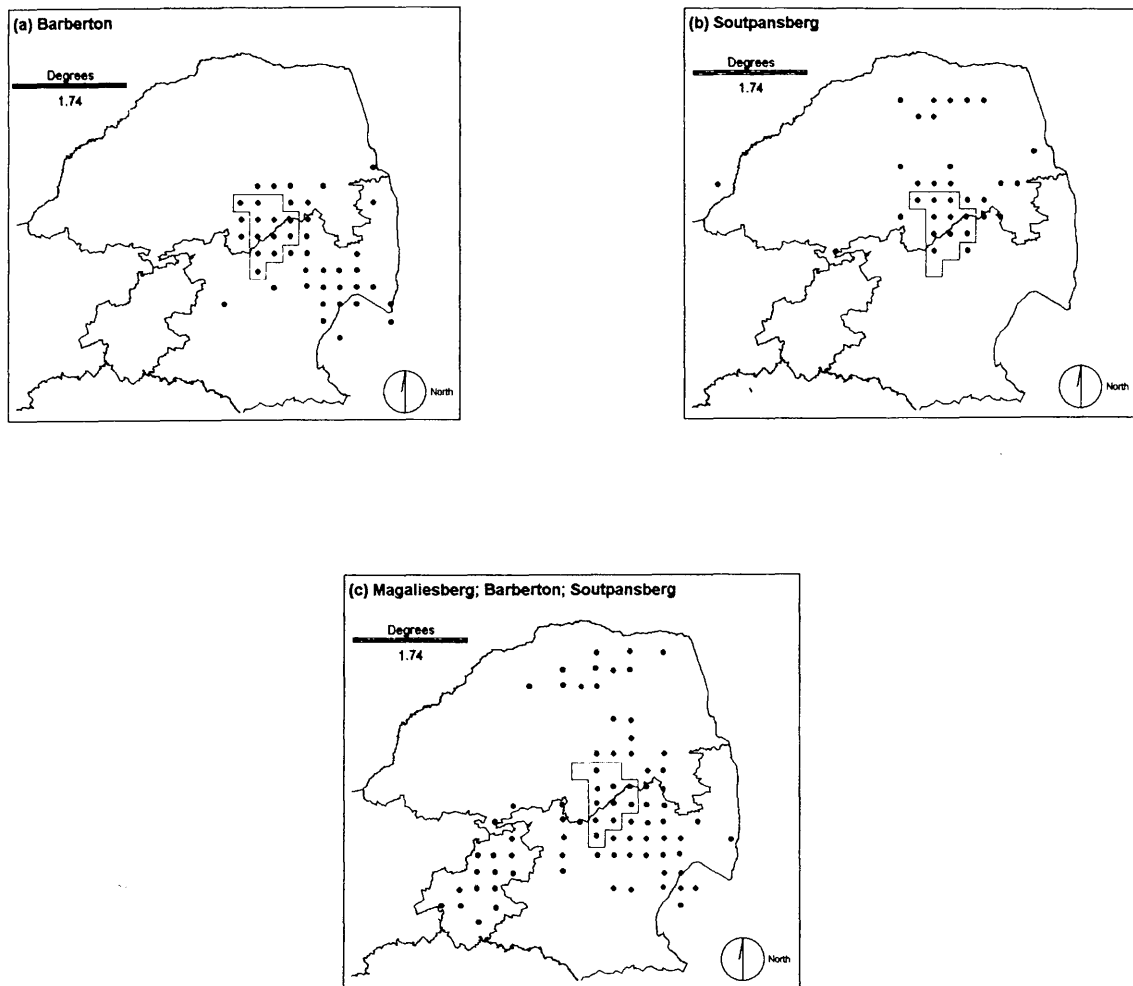


Figure 15 Range of the distribution patterns for **disjunct** near-endemics of the Sekhukhuneland Study Area, without a Waterberg-link: **(a)** Barberton, **(b)** Soutpansberg and **(c)** Magaliesberg + Barberton + Soutpansberg.

5.2 Indices of endemism

Bykov's Index of Endemicity (Major 1988), an Index of Species Richness and an Index of Relative Phytodiversity were calculated for the 12 core QDGs of the SSA (Table 13). However, caution must be taken in the interpretation of the values. The 'taxa' and 'endemic' columns indicate the numbers of species and endemics, of a possible 1500 and 51 respectively, occurring in each QDG. The Index-values are therefore not an indication of phytodiversity on a regional scale, but rather the relative phytodiversity of the individual QDGs in the Sekhukhuneland Study Area [SSA]. The values are only a measure to determine priority areas (hot spots) of high phytodiversity and endemism.

The results for each table are described according to their credibility, namely well sampled or poorly sampled. Results of well sampled QDGs comprise the index values of the six QDGs with the highest occurrence of endemic taxa. The results of poorly sampled QDGs comprise the index values of the six QDGs with the lowest occurrence of endemic taxa. For each table comparisons are only made between QDGs with the same credibility. Therefore the highest and lowest index values will be given for each group of six QDGs of a specific credibility.

All the QDGs have an above normal Index of Endemicity (Table 13(a)). The QDG 2529BD exhibits the highest (4.0) and 2429BC the lowest (1.3) index values for QDGs which have been poorly sampled. The highest index value for the QDGs which have been well sampled is 2.2 (2430CC) and the lowest is 1.6 (2530AA).

Six of the QDGs have an above normal Index of Species Richness and six QDGs are below this norm (Table 13(b)). The QDG 2430CD has the highest (0.9), and the QDG 2430AC has the lowest (0.7) species richness for the grids which have been poorly sampled. There is a high species richness in 2430CA (3.3) and the low species richness in 2430CB (1.7), for the grids which have been well sampled.

The degree of endemism, as well as the species richness of the SSA flora, is combined in an index of phytodiversity. The Index of Relative Phytodiversity compensates for high endemism within certain grids due to selective sampling of rare species and ignorance of common species (those QDGs with a high endemism, but a low species richness). Ten of the QDGs exhibit above normal phytodiversity for their surface area of approximately 675 km² (Table 13(c)). In the well sampled QDGs, 2430CA (2.2) has the highest phytodiversity index and 2530AA and 2430CB (1.5) the lowest. The QDG 2529BD (1.8) exhibits the highest relative phytodiversity for a poorly sampled grid and 2429BC and 2429DD (0.9) the lowest.

Table 13 Bykov Formula applied as self-formulated indices for: **(a)** endemism, **(b)** species richness and **(c)** relative biodiversity for the quarter degree grids [QDG] of the Sekhukhuneland Study Area [SSA] ($I = 1$ is normal; $I < 1$ poor is poor; $I > 1$ is rich)

(a)

QDG	Number of species/ intraspecific taxa	Number of endemics	E_f	I_e Endemism
2430 CA	563	29	5.2	2.1
2430 CC	519	29	5.5	2.2
2429 BD	437	17	3.9	1.6
2529 BB	380	17	4.5	1.8
2530 AA	380	15	3.9	1.6
2430 CB	284	15	5.3	2.1
2429 DB	150	12	8.0	3.2
2529 BD	100	10	10.0	4.0
2430 AC	121	10	8.3	3.3
2430 CD	157	10	6.4	2.6
2429 BC	150	5	3.3	1.3
2429 DD	136	5	3.7	1.5

I_e Endemism = E_f / E_n (with $E_n = 2.5$ at 8100km^2)

I_e Endemism = $[(\text{Endemics} \div \text{Taxa}) \times 100] / 2.5$

(b)

QDG	Number of species/ intraspecific taxa	Area (km^2)	R_f	I_r Richness
2430 CA	563	675	8.3	3.3
2430 CC	519	675	7.7	3.1
2429 BD	437	675	6.5	2.6
2529 BB	380	675	5.6	2.2
2530 AA	380	675	5.6	2.2
2430 CB	284	675	4.2	1.7
2429 DB	150	675	2.2	0.9
2529 BD	100	675	1.5	0.6
2430 AC	121	675	1.8	0.7
2430 CD	157	675	2.3	0.9
2429 BC	150	675	2.2	0.9
2429 DD	136	675	2.0	0.8

I_r Richness = R_f / R_n (with $R_n = 2.5$ at 8100km^2)

I_r Richness = $[(\text{Taxa} \div \text{Area}) \times 10] / 2.5$

(c)

QDG	I _e Endemics	I _r Richness	P _r	I _p Phytodiversity
2430 CA	2.1	3.3	5.4	2.2
2430 CC	2.2	3.1	5.3	2.1
2429 BD	1.6	2.6	4.2	1.7
2529 BB	1.8	2.2	4.0	1.6
2530 AA	1.6	2.2	3.8	1.5
2430 CB	2.1	1.7	3.8	1.5
2429 DB	3.2	0.9	4.1	1.6
2529 BD	4.0	0.6	4.6	1.8
2430 AC	3.3	0.7	3.0	1.2
2430 CD	2.6	0.9	3.5	1.4
2429 BC	1.3	0.9	2.2	0.9
2429 DD	1.5	0.8	2.3	0.9

I_p Phytodiversity = P_r / P_n (with P_n = 2.5 at 8100km²)

I_p Phytodiversity = [I_e + I_r] / 2.5

When the values of all three indices are plotted for each of the quarter degree grids [QDG] in the Sekhukhuneland Study Area (Figure 16), it demonstrates how the modified Bykov formula, namely Index of Species Richness (I_r), counteracts a high Index of Endemicity (I_e) caused by poor sampling. The other modified Bykov formula, Index of Relative Phytodiversity (I_p), is a function of the former two indices and its values are influenced most by the lowest index value of the other two. The first six QDGs have a lower Index of Endemicity and therefore its Index of Relative Phytodiversity is primarily determined by this factor and secondarily by the Index of Species Richness. The opposite is true for the last six QDGs.

The identification of the area constituting a possible Sekhukhuneland Centre of Endemism is primarily based on the Index of Relative Phytodiversity. An arbitrary index value 1.5 (average value for the 12 QDGs) was chosen as the cut-off point for hot spots in the SSA. Thus, eight QDGs of the Sekhukhuneland Study Area [SSA] were identified as the core region of the Sekhukhuneland Centre of Endemism. The eight QDGs are: 2430CA, 2430CC, 2429BD, 2529BB, 2530AA, 2430CB, 2429DB and 2529BD. However, the remaining four QDGs of the SSA should not be discarded, as they fulfil the role of ecotones between the Centre and adjacent areas.

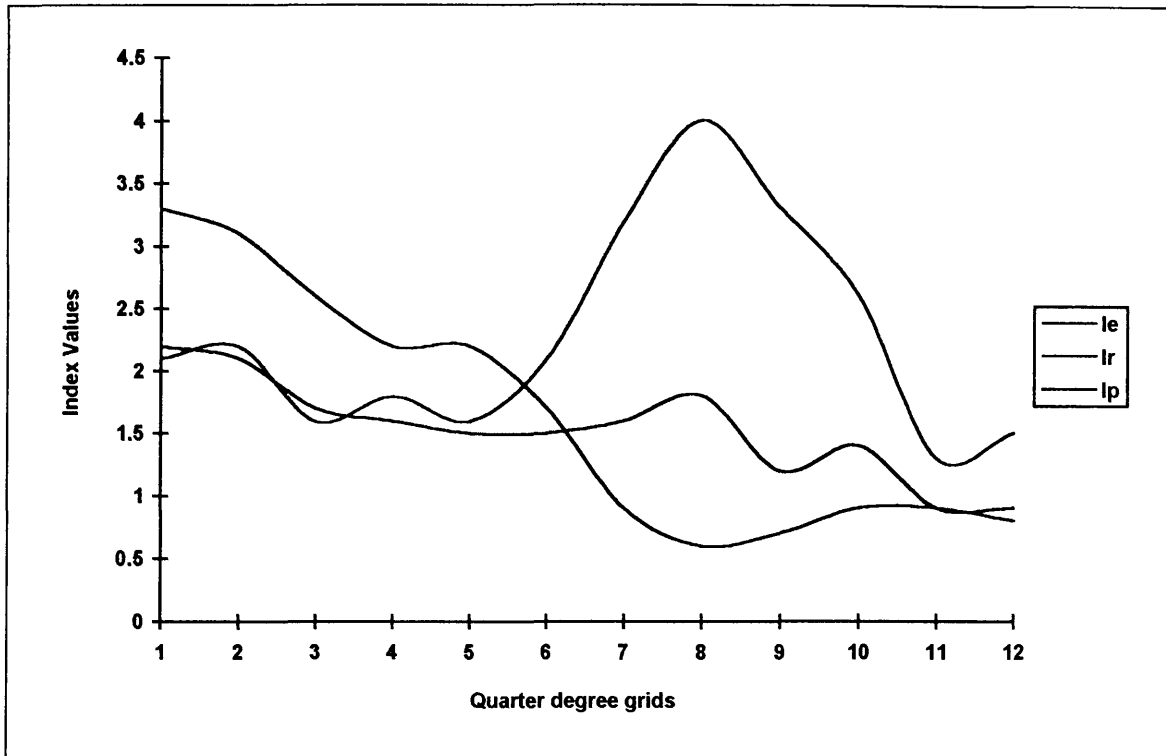


Figure 16 Index values for the 12 quarter degree grids of the study area; plotted as a line graph to indicate the relationships between the three indices as the number of endemics decreases from left to right.

Indices: I_e = Index of Endemicity

I_r = Index of Species Richness

I_p = Index of Relative Phytodiversity

Key: 1 = 2430 CA; 2 = 2430 CC; 3 = 2429 BD; 4 = 2529 BB; 5 = 2530 AA; 6 = 2430 CB;
7 = 2429 DB; 8 = 2430 CD; 9 = 2430 AC; 10 = 2529 BD; 11 = 2429 BC; 12 = 2429 DD.

5.3 Associations between flora and geology

5.3.1 Geology

The rocks of the core quarter degree grids [QDG] in the Sekhukhuneland Study Area [SSA] are derived from either one of two geological features, the Igneous and the Sedimentary Columns ('Column' refers to a group of rocks derived from the same geological feature). In the SSA the Igneous Column consists of one Complex (the BIC), with the BIC further divided into three Suites. The three Suites are made up of eight Formations. Other igneous associations contribute two Formations to the geology of the SSA. In the SSA the Sedimentary Column is represented by a single Sequence, the Transvaal Sequence. The Sequence consists of three Groups within the SSA. The three Groups comprises 17 Formations. Other sedimentary associations contribute a further three Formations.

The Formations within the QDGs of the SSA can further be broken down into different characteristic rock types (Table 14). Two main groups of characteristic rocks have been identified for the SSA. The group: **pyroxenite, norite, anorthosite and magnetite**, was identified as dominant for the Igneous Column in the SSA. The group: **quartzite, shale and hornfels**, was identified as dominant for the Sedimentary Column in the SSA.

However, the above groups are rather misleading as regards the abundance of the dominant rock types in the SSA. The identification of groups is merely based on those rocks which are **present** in most formations. The **abundance** of a characteristic rock is dependent on the surface percentages of the formations to which it belongs. Surface percentages of the formations can be measured, and therefore the abundance of the characteristic rocks can estimated as a function of the formation to which it belongs. The surface percentages of the all the formations are given for each QDG (Table 15).

Table 14 The main geological formations and lithology of the Sekhukhuneland Study Area [SSA]

GEO*	Car	Dia	Dor	Grp	Pyr	Nor	Gab	Ano	Mag	Feg	Fed	Grd	Grn	Art
C	X													
d		X	X											
Mr				X										
Vpx					X									
Vcr					X	X								
Vsn		IGNEOUS COLUMN			X	X								
Vdj					X	X	X	X	X					
Vdr					X	X	X	X	X					
Vno						X			X					
Vrs									X	X	X			
Vgd												X		
Vla													X	
Vve														X
Vvc														
Vla														
Vve														
Vvl														
Vdn														
Vms														
Vsb														
Vdp														
Vpe														
Vmb														
Vth														
Vst														
Vne														
Vdw														
Vse														
Vhe														
Vds														
I														
Q														

* GEO = Geology

IGNEOUS COLUMN			GEOLOGY
Geology	Geology	Lithology	Geology
BUSHVELD COMPLEX	(d) Croydon Subsuite (Vcr) [LOWER ZONE]	Dia - Diabase	TRANSVAAL SEQUENCE
LEBOWA GRANITE SUITE	(e) Shelter Norite (Vsn)	Dor - Dolerite	ROOIBERG GROUP
(a) Nebo Granite (Mn)	(f) Other layers: Norite (Vno) Pyroxenite (Vpx) Granodiorite (Vgd)	Car - Carbonatite	(a) Selonsrivier Formation (Vse)
RASHOOP GRANOPHYRE SUITE	OTHER ASSOCIATIONS	Grp - Granophyre	(b) Damwal Formation (Vdw)
(a) Granophyre (Mr)	(a) Diabase (d)	Pyr - Pyroxenite	PRETORIA GROUP
RUSTENBURG LAYERED SUITE	(b) Carbonatite (C)	Nor - Norite	(a) Mackekaan Formation (Vmb)
(a) Roosenekal Subsuite (Vrs) [UPPER ZONE]		Gab - Gabbro	(b) Dullstroom Formation (Vds)
(b) Dsjate Subsuite (Vdj) [MAIN ZONE]		Ano - Anorthosite	(c) Steenkampsberg Formation (Vst)
(c) Dwars River Subsuite (Vdr) [CRITICAL ZONE]		Mag - Magnetite	(d) Nederhorst Formation (Vne)
		Feg - Ferrogabbro	(e) Lakenvallei Formation (Vla)
		Fed - Ferrodiorite	(f) Vermont Formation (Vve)
		Grd - Granodiorite	(g) Magaliesberg Formation (Vma)
		Grn - Granite	

Table 15 The surface percentages of the geological *formations for the quarter degree grids [QDG] of the Sekhukhuneland Study Area [SSA]

* Abbreviations are defined in Table 14

	2429 BC	2429 BD	2429 DB	2429 DD	2529 BB	2529 BD	2430 AC	2430 CA	2430 CB	2430 CC	2430 CD	2530 AA	%
Mn	-	-	28.2	50.4	7.8	-	-	-	-	1.4	-	-	7.3
Mr	-	-	-	2.3	14.4	3.6	-	-	-	-	-	-	1.7
%	0	0	28.2	52.7	22.2	3.6	0	0	0	1.4	0	0	9.0
Vrs	51.2	15.7	41.7	25.0	36.2	41.4	-	-	-	1.2	-	-	17.7
Vdj	8.7	59.4	19.7	8.8	36.0	23.5	1.6	31.2	-	30.7	-	35.6	21.3
Vdr	-	13.1	-	-	-	-	5.2	10.7	-	10.3	-	15.5	4.6
Vcr	-	7.0	-	-	-	-	3.5	5.4	4.1	-	0.4	-	1.7
Vsn	-	-	-	-	-	-	2.7	1.4	2.8	10.1	1.2	3.6	1.8
Vno	-	-	-	-	-	-	-	-	-	1.7	-	-	0.1
Vpx	-	-	-	-	-	-	-	1.0	4.5	-	0.3	-	0.5
Vgd	-	-	-	-	-	-	1.3	-	-	-	-	-	0.1
%	59.9	95.2	61.4	33.8	72.2	64.9	14.3	49.7	11.4	54.0	1.9	54.7	47.8
d	0.8	-	-	3.8	-	-	2.2	2.5	11.7	0.5	7.5	9.4	3.2
C	-	-	-	3.1	0.2	-	-	-	-	-	-	-	0.3
%	0.8	0	0	6.9	0.2	0	2.2	2.5	11.7	0.5	7.5	9.4	3.5
%	60.7	95.2	89.6	93.4	94.6	68.5	16.5	52.2	23.1	55.9	9.4	64.1	60.3
I	-	-	-	1.3	4.4	2.9	-	-	-	-	-	-	0.7
h	-	-	-	-	-	1.1	-	-	-	-	-	-	0.1
%	0	0	0	1.3	4.4	4.0	0	0	0	0	0	0	0.8
Vse	-	-	-	-	-	2.7	-	-	-	-	-	-	0.2
Vdw	-	-	-	-	-	7.8	-	-	-	-	-	-	0.7
Vdu	3.8	-	-	-	-	-	-	-	-	-	-	-	0.3
Vpe	2.1	-	-	-	-	-	-	-	-	-	-	-	0.2
Vma	5.7	-	-	-	-	-	4.0	-	-	-	-	-	0.8
Vmc	1.8	2.9	10.4	5.3	-	-	-	-	-	-	-	-	1.7
Vds	-	-	-	-	-	14.8	-	-	-	-	-	-	1.2
Vsb	-	-	-	-	-	2.2	-	-	-	2.1	-	10.9	1.3
Vne	-	-	-	-	-	-	-	-	-	1.1	-	0.8	0.2
Vla	2.4	0.2	-	-	1.0	-	-	-	-	2.4	-	7.2	1.1
Vve	0.3	0.2	-	-	-	-	-	4.4	-	9.0	6.8	1.5	1.9
Vmb	4.3	0.5	-	-	-	-	7.2	6.1	5.1	3.0	20.7	-	3.9
Vsi	8.7	0.5	-	-	-	-	13.4	2.3	28.9	1.3	42.8	-	8.2
Vdp	-	-	-	-	-	-	4.1	-	8.4	-	-	-	1.0
Vst	2.3	0.2	-	-	-	-	-	-	-	-	-	-	0.2
Vhe	-	-	-	-	-	-	-	-	1.1	-	-	-	0.1
Vtb	5.7	0.3	-	-	-	-	10.8	-	9.9	-	-	-	2.2
%	37.4	4.8	10.4	5.3	1.0	27.5	39.5	12.8	53.4	18.9	70.3	20.4	25.1
Q	2.2	-	-	-	-	-	43.9	35.0	23.5	25.2	20.3	15.8	13.8
%	2.2	0	0	0	0	0	43.9	35.0	23.5	25.2	20.3	15.8	13.8
%	39.3	4.8	10.4	6.6	5.4	31.5	83.4	47.8	76.9	44.1	90.6	36.2	39.7

The Formations of the Igneous Column as a whole cover 60.3% of the SSA, with 2429BD covered by a maximum 95.2% and 2430CD covered by a mere 9.4% (Table 15). The formations of the Rustenburg Layered Suite [RLS] occupy 47.8% of the surface area in the SSA, with 2429BD covered by a maximum 95.2% of the RLS and 2430CD by a minimum 1.9% of the RLS. Other formations of the Igneous Column occupy 12.5% of the surface area of the SSA. The QDG 2429DD is covered by 59.6% of other formations of the Igneous Column and 2429BD by a minimum of 0% of other Igneous formations.

The Formations of the Sedimentary Column as a whole cover 39.7% of the SSA, with 2430CD covered by a maximum 90.6 % and 2429BD only covered by 4.8% (Table 15). The Formations of the Transvaal Sequence [TS] occupy 25.1 % of the surface area in the SSA, with 2430CD covered by a maximum 70.3 % of the TS and 2529BB only covered by 1.0 %. Other formations of the Sedimentary Column occupy 14.6% of the surface area of the SSA, of which 13.8% is alluvium. The QDG 2430AC is covered by 43.9% of other formations of the Sedimentary Column, and 2429BD and 2429DB by a minimum of 0% of other Sedimentary formations.

5.3.2 Associations

Each formation is comprised of many rock types. For the purpose of analysing the geology-flora association, certain formations which are indicative of specific rock types were grouped together and their percentage surface area calculated (Appendix 3A). The surface percentages of alluvium, from the sedimentary column, and of ferrogabbro, from the Rustenburg Layered Suite [RLS], is contradictory. There is a geological alternation visible when their occurrences are compared. It seems as if the one tends to be present only when the other is absent or very nearly so (Figures 17(a) & 17(b)). These rock types were placed in their own groups due to this peculiar phenomenon. This explains why the ultramafic substrates are divided into two groups. Thus, the formations of the Sekhukhuneland Study Area [SSA] are divided into five groups of rock types, following the recognition of the two main groups of characteristic rocks (see 5.3.1 - Table 14):

Group 1 = Norite, pyroxenite, anorthosite and magnetite of the RLS;

Group 2 = Quartzite, shale and hornfels of the Transvaal Sequence;

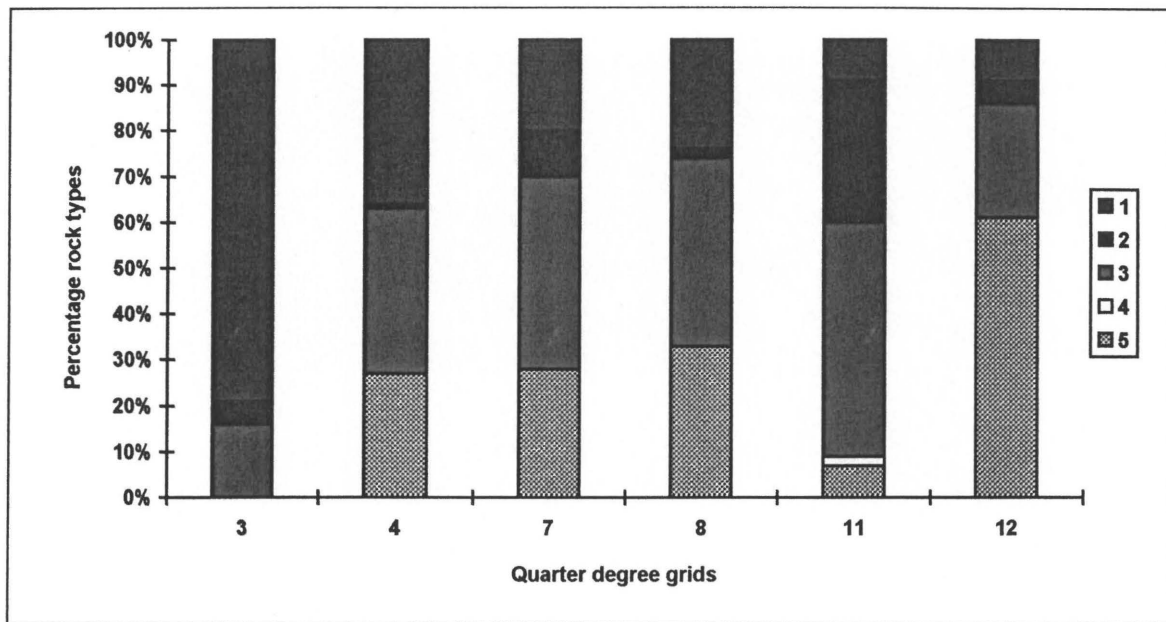
Group 3 = Ferrogabbro and ferrodiorite of the RLS;

Group 4 = Alluvium;

Group 5 = Other rocks not included into 1 to 4.

The quarter degree grids [QDG] of the SSA were plotted against the percentage cover of each of the five groups of rock types and are depicted in a histogram (Figure 18). The QDGs are arranged

(a)



(b)

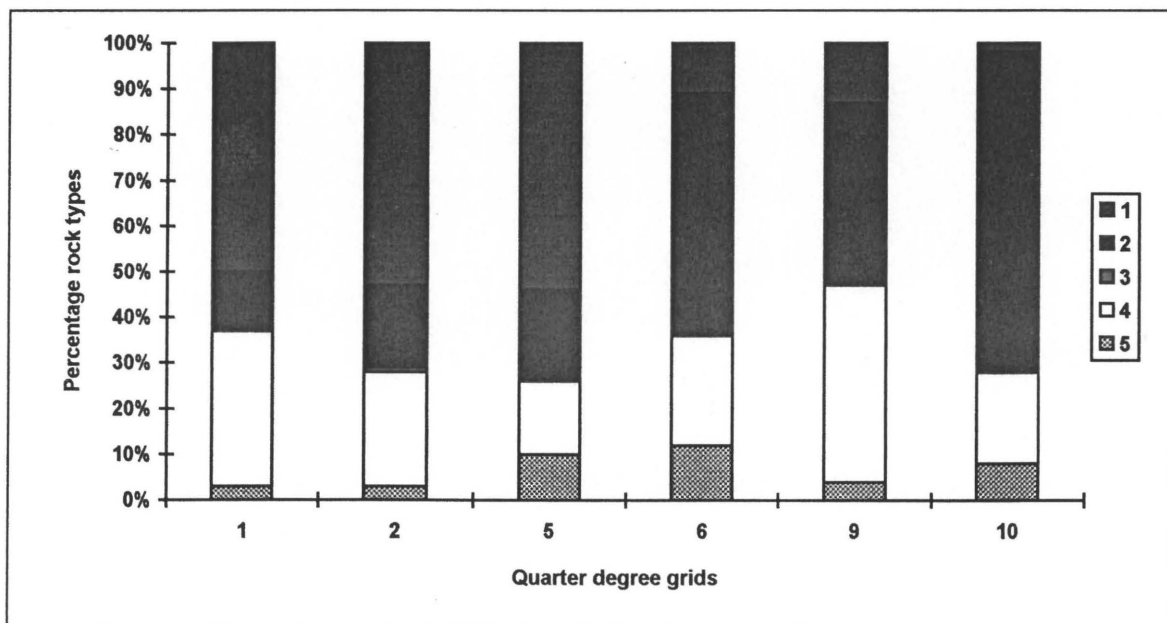


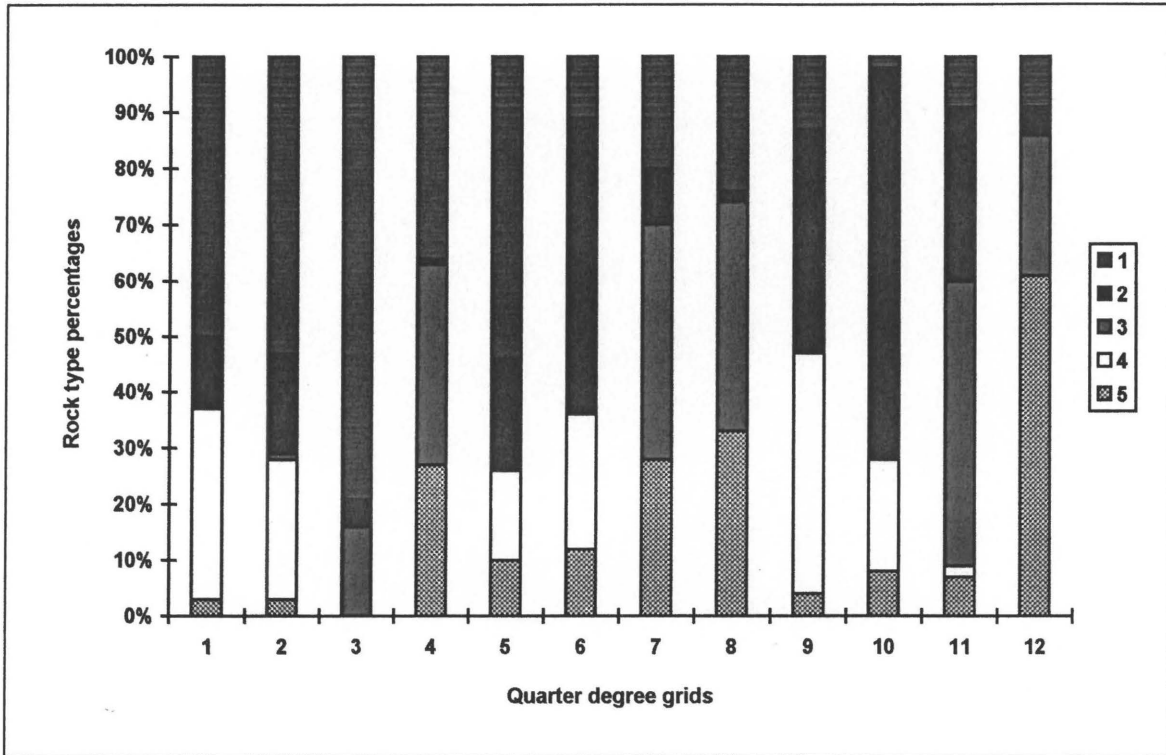
Figure 17 Percentages of the five groups of rock types for each of the quarter degree grids, displayed according to the presence of either (a) ferrogabbro (3; red) or (b) alluvium (4; yellow).

Other Groups: 1 (green) = Norite, pyroxenite, anorthosite and magnetite

2 (blue) = Quartzite, shale and hornfels

5 (grey) = Other rocks not included into 1 to 4

Key: 1 = 2430 CA; 2 = 2430 CC; 3 = 2429 BD; 4 = 2529 BB; 5 = 2530 AA; 6 = 2430 CB;
 7 = 2429 DB; 8 = 2430 CD; 9 = 2430 AC; 10 = 2529 BD; 11 = 2429 BC; 12 = 2429 DD.



Sekhukhuneland Study Area.

Groups: 1 = Norite, pyroxenite, anorthosite and magnetite of the Rustenburg Layered Suite

2 = Quartzite, shale and hornfels of the Transvaal Sequence

3 = Ferrogabbro and ferrodiorite of the Rustenburg Layered Suite

4 = Alluvium

5 = Other rocks not included into 1 to 4

Key: 1 = 2430 CA; 2 = 2430 CC; 3 = 2429 BD; 4 = 2529 BB; 5 = 2530 AA; 6 = 2430 CB;
 7 = 2429 DB; 8 = 2430 CD; 9 = 2430 AC; 10 = 2529 BD; 11 = 2429 BC; 12 = 2429 DD.

from left to right according to the decrease in the number of endemics, with grid one having the highest number of SSA endemics. The ratio between these five groups is very variable across the 12 QDGs, with a very heterogeneous pattern. The first group exhibits higher percentages in the grids on the left (high numbers of SSA endemic taxa). The second group exhibits higher percentages in the grids on the right (low numbers of SSA endemic taxa). The next two groups show no distinctive associative link with endemism, while the fifth group follows the tendency of the second group.

The percentages of Group 1 and Group 2 are contradictory. As the one steadily increases, the other steadily decreases in relation to the number of endemics in each QDG. Group 1 is positively correlated with an increase in the number of endemics per QDG (Figure 19(a)). However, it must be noted that correlations are based on the tendency along the gradient of the whole study area. Thus, between one or two grids, it may not always be true. The same can be said for Group 2. However, the number of endemics per QDG decreases, as the Group 2 percentage increases (Figure 19(b)). Thus, it seems as if the number of endemics are directly correlated to high percentages of Group 1.

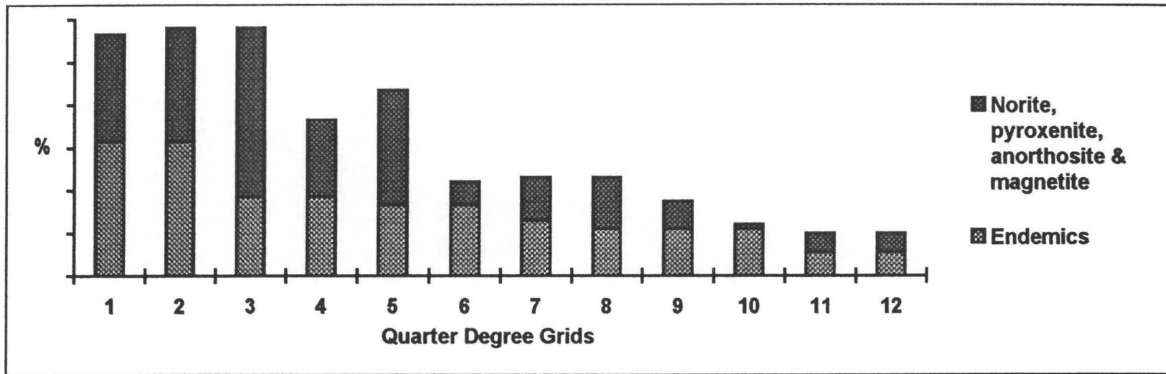
As the percentage cover of Group 5, which is derived from formations other than the Rustenburg Layered Suite [RLS] or Transvaal Sequence [TS], decreases, the number of endemics increases (Figure 19(c)). Once again it must be noted that the rule applies to the gradient along all the QDGs and it may differ between one or two grids. The tendency can be ascribed to the fact that low percentages of Group 5 make way for rock types which might be significantly correlated with endemics.

Group 3, of the Upper Zone in the RLS, was kept separate from Group 1 due to its unique iron rock type and high percentage cover in certain grids. The Group 3 percentages across the QDGs are variable and no correlation is visible as the number of endemics increases (Figure 19(d)). The same applies for Group 4 (Figure 19(e)).

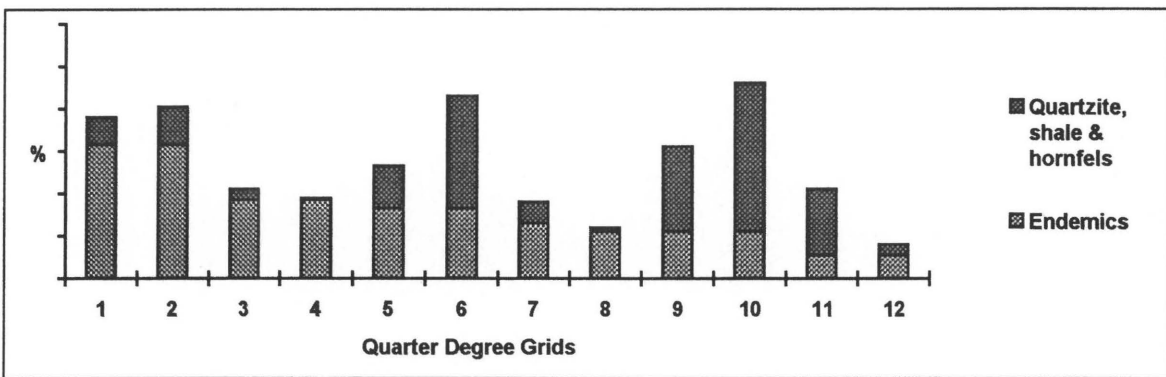
However, the influence of Group 4 (alluvium) on endemism is directly related to the percentages of Groups 1 and 2 (Figures 19(a) & 19(b)). If the surface percentage of Group 2 is higher than that of Group 1, alluvium is associated with low numbers of endemics. If the Group 1 surface percentage is higher, then alluvium is associated with high numbers of endemics. The reason for this correlation may be explained in terms of weathering. If the Group surface percentage is the highest, the alluvium soils were most probably derived from its rock types. The same applies for Group 2.

Group 3 does not display the same correlations with Groups 1 and 2 (Figures 19(a) & 19(b)). The inconsistent association with high endemism might indicate that Group 3 has an effect similar to Group 5 (Figure 19(e)). In other words, low percentages make way for rock types which can influence the flora.

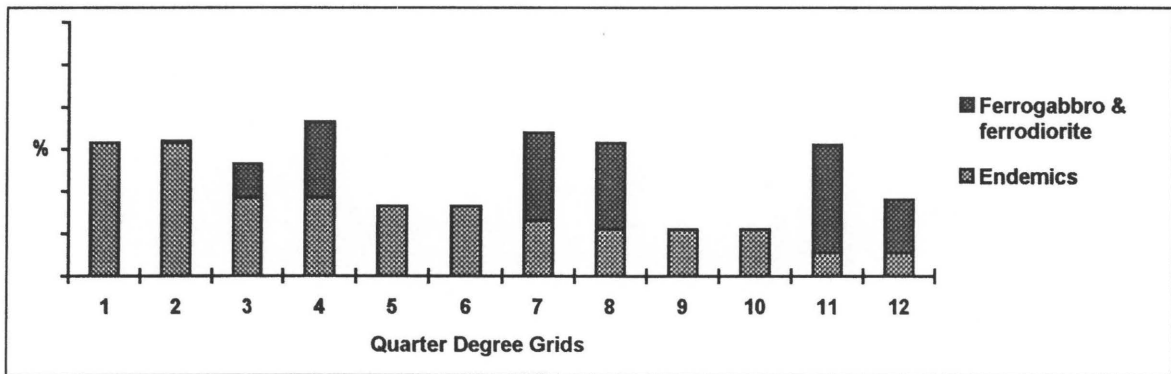
(a)



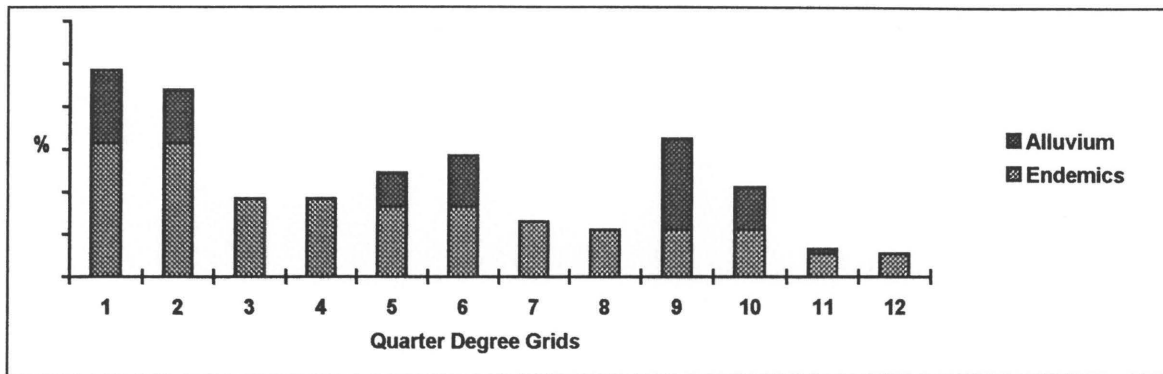
(b)



(c)



(d)



(e)

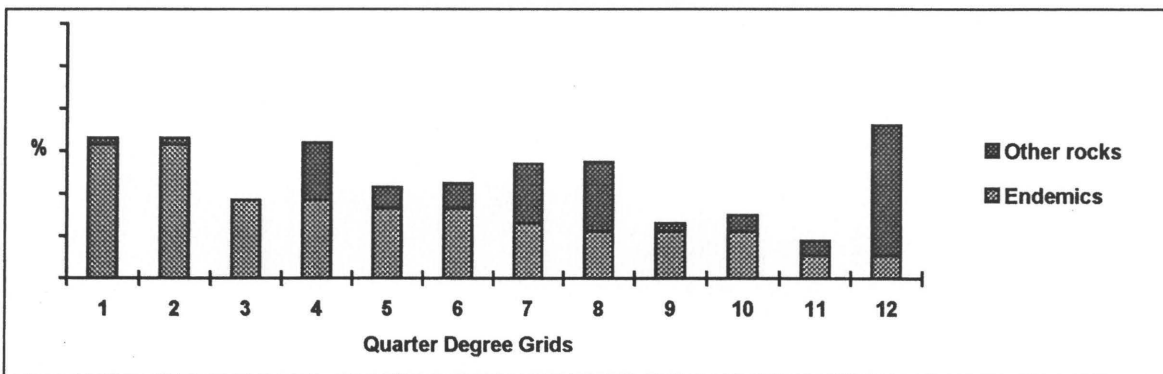


Figure 19 Relationships between the percentage of Sekhukhuneland endemics, and the surface percentage of each of the main groups of rock types, for each of the quarter degree grids of the Sekhukhuneland Study Area: (a) Norite, pyroxenite, anorthosite and magnetite; (b) Quartzite, shale and hornfels; (c) Ferrogabbro and ferrodiorite; (d) Alluvium; (e) Other rocks not included into (a) to (d).

Y-axis: Blue shaded area* = percentage of Sekhukhuneland endemics

Brown shaded area* = percentage cover of group of rock types

* Values used are displayed in Appendix 3B.

Key: 1 = 2430 CA; 2 = 2430 CC; 3 = 2429 BD; 4 = 2529 BB; 5 = 2530 AA; 6 = 2430 CB;
 7 = 2429 DB; 8 = 2430 CD; 9 = 2430 AC; 10 = 2529 BD; 11 = 2429 BC; 12 = 2429 DD.

The tendencies visible in Figures 18 and 19 are supported by correlation and regression analysis (Table 16). Group 1 shows a highly significant correlation ($r = 0.7$) with the number of endemics at $P = 0.01$. This means that the surface percentage of this group of rock types vary together with the number of endemics for each QDG. Where the surface percentage of Group 1 is high, so is the number of endemics. The correlations of Groups 2 to 4 are not significant, with Groups 2 (-0.2), 3 (-0.5) and 5 (-0.5) manifesting negative correlations and Group 4 (0.4) a positive correlation. This negative correlation indicates that the number of endemics increases as the surface percentages of Groups 2, 3 and 5 decrease. However, the correlation was not significant and therefore this will not always be the case. The positive correlation of Group 4 indicates that the number of endemics increases as the surface percentage increases. However, this correlation was also not significant and therefore it will not be a rule.

Table 16 Values used in the calculation of the correlation and regression between the number of endemics and the surface percentages of each of the five groups of rock types

Group	Σx	Σx^2	Σxy	(X)	SKx	SKxy	r	y =
1	360	17 194	6 637	30.0	6 394	1 417	0.7	$7.9 + 0.22x$
2	268	11 318	3 516	22.3	5 333	-370	-0.2	$16.1 - 0.07x$
3	212	8 224	2 207	17.7	4 479	-867	-0.5	$17.9 - 0.19x$
4	164	4 866	2 951	13.7	2 625	573	0.4	$11.5 + 0.22x$
5	196	6 714	2 089	16.3	3 513	-753	-0.5	$17.9 - 0.21x$

Endemics: $\Sigma y = 174$; $\Sigma y^2 = 3 204$; SKy = 681; (Y) = 14.5

The correlations are further investigated by drawing the regression lines for each group of rock types. The x-axis represents the surface percentage and the y-axis the number of endemic taxa (Figure 20). The lines on the graph represent each of the groups of rock types. A point on a specific line indicates the number of endemic taxa expected for that surface percentage for the specific group of rock types.

Groups 1 and 4 show a positive gradient. The positive gradient implies that the number of endemics increases as the surface percentage of these two groups of rock types increases. The expected number of endemics at a specific surface percentage is higher for Group 4 than for Group 1. Groups 2, 3 and 5 show a negative gradient. This negative gradient indicates that, as the surface percentages of the groups of rock types increases, the number of endemics decreases. Group 2 shows a higher number of endemics at high surface percentages than Groups 3 and 5. However, at surface percentages below 10%, Group 2 exhibit a lower number of endemics than Groups 3 and 5. Groups 3 and 5 display the highest number of endemics for all the Groups below a surface percentage of 15%. Group 3 has a higher number of endemics than Group 5 at any given surface percentage.

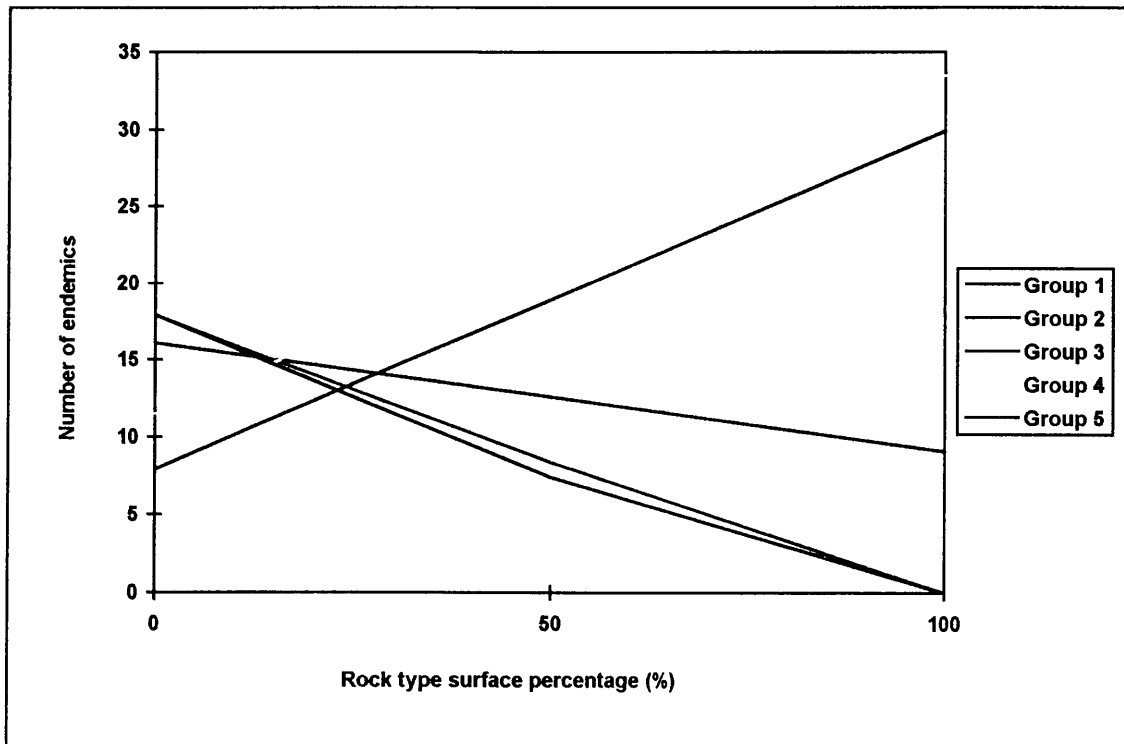


Figure 20 Regression lines for the five main groups of rock types in the Sekhukhuneland Study Area as a function of their surface percentage and their percentage floristic endemism.

- Groups:** 1 = Norite, pyroxenite, anorthosite and magnetite of the Rustenburg Layered Suite
 2 = Quartzite, shale and hornfels of the Transvaal Sequence
 3 = Ferrogabbro and ferrodiorite of the Rustenburg Layered Suite
 4 = Alluvium
 5 = Other rocks not included into 1 to 4

CHAPTER 6

DISCUSSION AND ADDITIONAL INFORMATION

The principle hypothesis of this dissertation states that the Sekhukhuneland Study Area [SSA] is a region of high endemism, with floristic patterns which can be correlated with the region's heterogeneous geology. In the light of the results obtained, the hypothesis is supported and therefore shown to be valid. The Sekhukhuneland Study Area proved to have a rich phytodiversity and characteristic floristic patterns. This met the first objective concerning the identification of endemics in Sekhukhuneland and is discussed under 6.1 (Floristic endemism). A better understanding of the region's phytodiversity, endemism and patterns of distribution in the Sekhukhuneland Study Area, addresses the second objective, namely to determine the priority areas of high phytodiversity in the region. The objective was met and is discussed under 6.2 (Sekhukhuneland Centre of Endemism). Statistical procedures identified various associations between the flora and the geology. This meets the third objective, namely to relate floristic patterns in areas of high endemism to the ultramafic substrates of the Rustenburg Layered Suite. This objective is discussed under 6.3 (Ultramafic substrates and endemism).

6.1 Floristic endemism

6.1.1 Introduction

The phenomenon of endemism has drawn attention to the often conspicuous floristic and physiognomical differences between communities occurring within floristic regions. These regions and their communities are associated with certain floristic characteristics, such as the Wolkberg Centre which consists mainly of Afromontane elements (Matthews *et al.* 1993) and the Maputaland-Pondoland Region (Van Wyk 1994) which comprises elements associated mainly with the Indian Ocean Coastal Belt and the Afromontane.

Endemic plant taxa exhibit distinct distribution patterns. In the prevailing definitions of endemic distributions, such as the one used by Stott (1981), the concepts 'rare' and 'narrow' features very prominently. According to Major (1988), a taxon is endemic if it is confined to a particular area for historical, ecological or physiological reasons. In Low & Rebelo (1996), the following definition is given for an endemic distribution in a phytosociological sense: 'the region which a vegetation type is restricted to'. The term 'endemic', as used in a biogeographical sense, refers to a taxon which is

limited in its range to a stated and defined area/substrate. There are, however, no fixed guidelines as to where the area boundaries should be set for the determination of endemism.

The degree of endemism is dependent on scale (Stott 1981). An area of endemism can be large (more than one continent) or small (a few square metres). Thus, the degree of endemism increases, as an area homogeneous in ecological conditions and floristic history is increased in size (Major 1988). Tradition has circumscribed the range of the word 'endemic' so that in normal usage it is applied mainly to taxa with comparatively or abnormally restricted distributions at the world, continental or regional scales. When the flora of the SSA, a rather small portion of South Africa, is considered, the taxa with restricted distributions (confined to the region) are referred to as endemics and the taxa with disjunct distributions (mainly confined to the region) are categorised as near-endemics. However, if South Africa is taken as a whole, both the endemics and near-endemics of the SSA would be classified as South African endemics.

In biogeography the term 'disjunction', is applied to those endemic distributions with two or more widely separated populations (Stott 1981). According to Matthews *et al.* (1993) a taxon with a range centred on a defined area, but also extending feebly beyond its boundaries (sometimes in distant satellite populations), is referred to as a 'near-endemic'. The term 'near-endemic' may somewhat obscure the importance of such taxa in Sekhukhuneland, for all the near-endemics of the SSA are endemic to the NP, or at least southern Africa. Unfortunately there is a tendency for non-scientific readers to interpret the term as a species that is nearly unique, but not quite so. Thus, near-endemics, as recognised in this dissertation, are of considerable biogeographical and conservation significance, for example:

Melhania randii Bak. f. is known from only four localities in southern Africa. The species occurs near Roossenekal in Sekhukhuneland, in the Sheba Hills near Barberton and also in Zimbabwe and Mozambique (Verdoorn 1981). This is a disjunct distribution with small localised world populations. Unfortunately, the species will qualify for the status of near-endemic in all four of its localities, as a result of politically demarcated areas. Although very localised and endemic to southern Africa, this species is unlikely to be recognised as being worthy of exceptional floristic status. It has nevertheless been included in the Red Data List of southern African plants (Hilton-Taylor 1996) where it is categorised as 'insufficiently known'. It should also be noted that the South African form of *M. randii*, and specifically the form found near Roossenekal differs from all the others (Verdoorn 1981).

Although no two distribution patterns are absolutely identical in all aspects, certain patterns tend to recur. Taxa of which the distributions show similar areal bias are defined as floristic elements for that particular area. The distribution of floristic elements is especially localised within a core region.

Hence the distribution of the floristic elements is characterised by the convergence of localities towards a centre of high endemism.

6.1.2 Endemism

The first principal objective of this dissertation was to determine the extent of endemism within the SSA. Very few botanical studies had previously been done in this region and methods had to be developed to optimally utilise the scant available data. Methods applied in this dissertation proved effective in determining the number of endemics for the Sekhukhuneland Study Area [SSA]. A total of 119 floristic elements were identified as 51 endemics and 70 near-endemics of the SSA. These numbers are provisional and further work will probably add more taxa endemic or near-endemic to the region.

There are no endemic families in the SSA. There is, however, the possibility of a near-endemic genus, if *Lydenburgia* is reinstated for *Catha transvaalensis* = *Lydenburgia cassinoides* (a SSA endemic) and *Catha abbottii* (a Pondoland Centre Endemic). Both species are closely related and quite distinct from *Catha edulis*, the type species of the generic name *Catha* (A.E. van Wyk, pers. comm.).

Approximately 3% of an estimated 1 500 plant species\infraspecific taxa are endemic to the SSA. This degree of endemism is comparable with floristic regions such as the Transvaal Drakensberg with an estimated endemism of 4% (Matthews *et al.* 1993), the KwaZulu-Natal Southern Drakensberg with an estimated endemism of 5% (Hilliard & Burt 1987), and the Great Dyke with an estimated endemism of 6% (Wild 1965). Thus, the recognition of the SSA as a Centre for endemic plant taxa is well supported.

Relatively few woody endemics were identified for the SSA. Herbaceous endemics are much more abundant. The endemic taxa display two kinds of distribution, namely narrow and wide. Analysis of these two distribution patterns revealed that the narrow endemics are strictly SSA endemics, whereas most of the wide endemics are endemic to the SSA and adjacent parts of the Drakensberg escarpment. Thus, the endemic distribution patterns reveal a close floristic affinity (relationship) between the SSA and the Afromontane Region.

Families with the largest number of endemics on the related ganges of the Rustenburg Layered Suite in the SSA, are the **Fabaceae** (s. str.), **Euphorbiaceae**, **Vitaceae**, **Liliaceae** and **Lamiaceae**. The tendency of these families to produce local endemics is also evident in adjacent regions, notably in the Wolkberg Centre of Endemism (Matthews *et al.* 1993). In the latter centre, families with the

largest number of endemics on the quartzites are the **Liliaceae**, **Iridaceae** and **Asteraceae**, and those with the largest number of endemics on the dolomites are the **Liliaceae**, **Euphorbiaceae**, **Lamiaceae** and **Acanthaceae** (Matthews *et al.* 1993). Significantly, the endemics on the quartzites are predominantly grassland species and those on the dolomites are predominantly savannah species.

The presence of savannah on the dolomites reinforces the floristic relationship which exists between the SSA and Wolkberg Centre of Endemism. The Wolkberg Centre, especially the arid dolomitic areas, share many species with the SSA, several of which are endemic to the combined region (SSA wide endemics). These floristic similarities may be explained, at least in part, by the relatively high concentrations of magnesium in both the dolomite-derived soils of the Wolkberg Centre and the ultramafic-derived soils of the SSA.

When the families of the endemic plant taxa are compared to the ranking of families which predominate in the Grassland and Savannah biomes (Gibbs Russell 1987), the similarity is rather poor, although perhaps with a slightly better association with the savannah. The reason for this poor correlation is because the SSA has **floristic elements** of the Savannah, Grassland, Forest and Nama Karoo biomes.

The plant taxa endemic and near-endemic to Sekhukhuneland are floristic elements of the SSA. Sekhukhuneland floristic elements are characterised as centred in the SSA. The first group of Sekhukhuneland elements are narrow endemics, which are entirely restricted to the 12 core quarter degree grids [QDG] of the SSA. The second group is the wide endemics which are centred within the 12 QDGs of the SSA and a further 20 adjacent QDGs. The latter taxa are centred in the Sekhukhuneland-Wolkberg ecotone and therefore they are also Sekhukhuneland-Wolkberg elements. The third group of Sekhukhuneland elements are the near-endemic taxa which are localised within the 12 QDGs of the SSA and approximately 50 other QDGs of the Northern Provinces of South Africa. These taxa may well be considered floristic elements of other floristic regions into which their disjunct distribution falls, depending on their respective centres of abundance.

The 119 SSA floristic elements display links with eleven possible floristic regions. All the floristic regions are associated with mountainous regions in the Northern Provinces of South Africa. The distribution range of the Sekhukhuneland endemic elements is restricted (>75% of each taxon's world distribution) to the mountainous regions in and around the Roossenekal-Steelpoort-Schoonoord area. Sekhukhuneland near-endemic elements are characterised by less than 75% of their world distribution (ranges) falling within the SSA. Distribution ranges of the Sekhukhuneland near-endemic elements radiate outward from the core of the SSA, to all the other main mountain ranges of the Northern Provinces of South Africa, namely the Wolkberg, Waterberg, Soutpansberg, Barberton Range and Magaliesberg. Thus, a rather unexpected distribution of floristic elements is visible in the Zambezan

flora. Most SSA near-endemics are Zambezian elements, however these elements exhibit an association with mountains, a distribution pattern rather to be expected from Afromontane taxa.

6.1.3 Intraspecific variation

Plants have moved about the earth through migration by means of dispersal, as well as by the effects of major earth events such as vicariance (e.g. climatic change and continental drift). Small scale migration, which is dependent on short distance dispersal, is the most prominent form of movement in South Africa. The development of barriers, however, interrupts this migration process and results in the isolation of certain populations (Stott 1981). In this dissertation, the barriers can be mountains on a large scale, or heavy metal soils on a small scale.

The isolation of populations of a species may result in the development of new forms of the taxon over time (Darwin 1979; Kruckeberg & Rabinowitz 1985). Such forms exhibit features which are not similar to the distinct features of the mother species. Geographical isolation of populations of the same species results in a decrease in the gene-flow, which limits natural selection to 'select' only from a deprived genetic stock. Forms which have been isolated from their typical gene pool for some time eventually develop into new species. It may, for example, be argued that *Rhus sekhukhuniensis* and *Elephantorrhiza praetermissa* developed as separate species in the SSA, after being isolated from their putative wide ranging parental species, namely *Rhus leptodictya* and *Elephantorrhiza burkei*, respectively.

However, what might be considered a distinct taxon to one taxonomist, might be denied by another. Research at the genetic level has highlighted the uncertainty of the species concept (Stace 1989). Not only do species differ genetically from one another, but every individual in a species differs to a greater or lesser degree (Stott 1981). Most classification systems clearly do not reflect the full spectrum of intraspecific genetic variation.

To identify genetically distinct forms, it is necessary to focus on the geographical distribution of species. Through the recognition and formal labelling of these forms, the biological diversity of a region is more clearly reflected. Unfortunately, most existing classification systems are based on high predictivity (natural classification systems) (Stace 1989). Natural classification systems do not reflect all biodiversity, e.g. ecotypes, unless they are formally named. Thus, in the Sekhukhuneland floristic region there is a need for special purpose classifications which provide better resolution of genetic diversity at the intraspecific levels. These forms can be very important, for example certain grass species are known for their special forms which are adapted to heavy metal soils (Wild 1965). Such

physiological forms should be recognised, for these taxa might, for example, contribute to agriculture or the rehabilitation of mine dumps.

It is often claimed by succulent enthusiasts that Burgersfort and the surrounding areas of the Sekhukhuneland Study Area, have the richest *Aloe* diversity in the world (B-E. van Wyk, pers. comm.). These areas also contain several *Aloe* endemics, as has been identified in this dissertation. With so much species diversity in the region, special forms will certainly be present. Field work for this dissertation has shown that the morphology of many of the widespread plant taxa in the SSA differs slightly from the 'typical' forms in other regions.

Perhaps the majority of the Sekhukhuneland Elements may well be differentiated as distinct local forms of common species. In fact, many potential infrageneric taxa in the SSA have not been formally described. Some of the undescribed taxa might even be species, but until properly investigated, all aberrant forms will be treated as forms of existing species. Some of the undescribed forms are listed below, together with a brief mentioning of the substrate, vegetation-association and diagnostic features of each taxon:

1. *Acacia karroo* [form]: Clay soils (turf) in valleys; dry or wet mountain bushveld; hairy pod.
2. *Aloe cryptopoda* [form]: Clay soils on mountain slopes; dry or wet mountain bushveld; variation in flower colour.
3. *Balanites maughamii* [form]: Clay soils in valleys; dry shrubland; scanty shrub.
4. *Bauhinia tomentosa* [form A]: Eroded, clay soils in valleys; dry shrubland; stunted shrub.
5. *Bauhinia tomentosa* [form B]: Clay soils on mountain slopes; dry or wet mountain bushveld; hairy pod.
6. *Berkheya insignis* [form]: Clay soils in valleys; wet grassland in bushveld; form with needle-like leaves.
7. *Boscia albitrunca* [form]: Clay soils of mountain slopes; dry mountain bushveld; flowers with two petals like *B. oleoides*.
8. *Brachylaena ilicifolia* [form]: Clay soils of ultramafic origin; dry and wet mountain bushveld; form has a prominently dentate leaf margin.

9. *Cyphostemma oleraceum* [form]: Ultramafic clays on hills; wet mountain bushveld; more robust than typical form.
10. *Cyphostemma paucidentatum* [form]: Clays on mountain slopes; wet, dense mountain bushveld; forms a climber with thick, longitudinally-grooved stems.
11. *Ehretia obtusifolia* [form]: Ultramafic clay soils in valleys; dry shrubland; glabrous-leaved form and suffrutex.
12. *Euclea crispa* [form]: Ultramafic clay soils; dry or wet shrubland; broad-leaved, greyish leaves.
13. *Euclea linearis* [form]: Ultramafic clay soils in valleys; dry shrubland; broad-leaved and suffrutex.
14. *Euphorbia schinzii* [form]: Ultramafic clay soils on rocky terrain; dry open mountain bushveld; aberrant-looking growth form.
15. *Gymnosporia senegalensis* [form]: Ultramafic clay soils on hills; wet mountain bushveld; suffrutex.
16. *Kleinia longiflora* [form]: Clay soils; dry mountain bushveld; base of flowerheads swollen.
17. *Leucas capensis* [form]: Ultramafic clay soils; dry mountain bushveld; stems erect and slender.
18. *Nuxia gracilis* [form]: Clay soils; between rocks alongside streams; shrub.
19. *Pavetta zeyheri* [form]: Ultramafic clay soils on rocky terrain; dry or wet mountain bushveld; robust with larger leaves and inflorescence.
20. *Polygala hottentotta* [form]: Eroded, clay soils in valleys; dry shrubland; flowers display marked structural differences.
21. *Premna mooiensis* [form]: Ultramafic clay soils on rocky terrain; dry or wet mountain bushveld; small-leafed.
22. *Protasparagus intricatus* [form]: Clay soils; dry shrubland on rocky hills; stouter branchlets and disjunct distribution.

23. *Protea caffra* [forma]: Clay soils; wet grassland in bushveld; flower heads smaller than normal.
24. *Ptaeroxylon obliquum* [form]: Clay soils; dry shrubland in valleys; stunted shrub.
25. *Rhoicissus tomentosa* [form]: Clay soils on rocky terrain; dry mountain bushveld; leaves are trifoliolate.
26. *Rhoicissus tridentata* [form]: Clay soils in valleys; wet grassland in bushveld; yellow, densely pubescent lamina.
27. *Sansevieria hyacinthoides* [forma]: Clay soils; dry mountain bushveld; leaves flat on the ground.
28. *Schotia latifolia* [form]: Ultramafic clay soils; dry mountain bushveld; disjunct with pink flowers.
29. *Stylochiton natalense* [form]: Ultramafic clay soils in rock crevices; dry mountain bushveld; small-leaved.
30. *Xerophyta retinervis* [form]: Clay soils on rocky terrain; dry mountain bushveld; branched tree.

6.1.4 Disjunct distribution patterns

The primary cause of localised distribution patterns of endemics is their adaptation to a combination of localised and specialised environmental factors (Krukkeberg & Rabinowitz 1985). The same can be said for disjunct distribution patterns of near-endemics. Primary causative factors such as average annual rainfall, average annual temperature, soil texture and soil chemistry are the most common, but by no means the only ones (Codd 1949; White 1983).

Most, if not all species move over time, advancing in some areas and retreating in others. Occasionally, species will coincide in their distributions and sometimes they separate. What are currently regarded as plant associations and communities within the SSA, may in fact be unique to the present time, differing from past associations and not to be repeated in the future. Vegetation is dynamic and what we see is a single snapshot in time (Huntley 1991). Thus, distributions are not fixed, but are rather a continuous process of a higher or lower status. The status changes with time, becoming higher in some areas and lower in other areas. The present Afromontane Region's distribution, for example, is of a lower status than that of the Zambezi Region and the result of more than 25 000 years of change (White 1981).

The distribution of the SSA floristic elements as a whole, shows a radial pattern at the present time. Floristic elements are centred within the SSA, with their distribution patterns radiating outwards. One may well describe this dispersal pattern as indicative of an expanding range. However, if each species' distribution is considered individually, the distribution patterns appear relictual or localised. Most endemics display a curious phenomenon: despite the abundant presence of what appears to be suitable habitats, they are, for no obvious reason, absent from most (Kruckeberg & Rabinowitz 1985). The same can be said for near-endemics. According to Poynton (1983), such patterns are typical of ranges which are contracting due to fragmentation.

It seems as if the near-endemic flora of the study area is trying to 'escape', but each species is experiencing some kind of difficulty in its migration which is keeping it largely confined to (centred in) the SSA. The whole floristic scenario within the SSA can be ascribed to the present post-glacial epoch in southern Africa (Poynton 1983). The post-glacial epoch consists of faunas and floras which can be grouped as either radiating and 'tropical' or contracting and 'nontropical'. Radiating patterns of plant and animal diversity seem centred on the warm eastern lowlands and interdigitate with patterns showing fragmentation and sometimes taxonomic differentiation on isolated cool uplands.

There is no single explanation for the disjunct distribution patterns displayed by the SSA floristic elements. The interpretation of the disjunct distributions is often very speculative because of a lack of knowledge concerning the history of the South African flora. However, in seeking a theoretical basis for the interpretation of the disjunct distribution patterns, a series of frequently recurring cases (explanations) are discussed by Stott (1981). Only those explanations likely to be applicable to Sekhukhuneland disjuncts will be mentioned. Each of the applicable cases will be discussed separately, although in reality disjunctions are often only explicable in terms of a **combination of the cases outlined**.

Stott (1981) defines disjunction in terms of only two widely separated populations, but in a heterogeneous environment, as is the case in South Africa, it is necessary to evaluate disjunct distribution patterns as if consisting of two **or more** separated populations, for separation may involve many populations of the same taxon.

There are two types of disjunction, namely real and unreal. Real disjunctions can be divided further into populations which are genetically identical and those which are not. The different cases are discussed below:

- The first case of importance in real disjunct patterns, with genetically related populations, is **refugia**. In this case there is acceptable historical evidence that in the geological past the taxon

was much more widely distributed than at present, and the now separated populations were once linked by a more continuous distribution. The present disjunction is therefore a relict one, with the relict taxon surviving in its two or more separate localities even though the surrounding areas have been vacated. The sites at which it has persisted are termed refuges or refugia, and they probably possess some distinctive ecological, geomorphological or geological characteristics which account for the survival of the relict taxon. *Pterothrix spinescens* and *Rhigozum obovatum* are examples of taxa which formerly may have been widespread during arid climatic periods, but are now restricted to refugia in the SSA, far away from their main occurrence in the Karoo.

- The second real disjunction, with genetically related populations, is of an **ecological** origin. The populations developed in a few separated localities from the same mother species. Habitat conditions had to be suitable for the germination, establishment and growth of the taxon. Obviously habitat disjunction is a significant explanatory factor in many short-range disjunctions and especially for taxa with highly specialised habitat requirements, e.g. aquatics and, with special reference to this dissertation, species adapted to heavy metal soils and arid environments. This disjunction is closely related to, and is a primary mechanism of, refugia. Examples of such potential disjunctions are *Euclea linearis* on ultramafic soils in the SSA and Zimbabwe, *Sesamothamnus lugardii* in arid Mountain Bushveld of the SSA and the arid Mopane Bushveld of the Limpopo River (north of the Soutpansberg), and *Nuxia gracilis* on the ultramafics of the SSA and the dolomites of the Wolkberg Centre and the Ghaap Plateau further west.
- The third real disjunction, with genetically more or less identical populations, concerns the case of short distance dispersal. This disjunction is explained in terms of the taxon dispersing itself from its original population, across intervening barriers to establish other populations, and thus creating a disjunct distribution. Barriers, such as mountain or valley vegetation, are crossed by means of wind, water and animal mediated dispersal. An example of a species capable of short distance dispersals from beyond a mountain barrier, is *Balanites maughami*, which may have migrated from the Lowveld into Sekhukhuneland via the Olifants River Valley. An example of a species capable of migrating across unfavourable valley vegetation by means of short distance dispersal, is *Ozoroa albicans*. It probably migrated from its principal high altitude habitat in the Wolkberg, across arid bushveld, onto high altitude habitats in Sekhukhuneland.
- Populations which are disjunct, but not genetically identical, form part of a very distinctive and important case of real disjunctions. The species are said to be **vicarious**, meaning that the taxa are closely related allopatric species which have descended from a common ancestral population and which have attained spatial isolation, hence their disjunct distribution. Whenever plant populations become separated from each other, they are subject to different selection pressures, and such a state is the first step towards differentiation and possible eventual speciation. For example,

the dwarfed forms of *Ptaeroxylon obliquum* and *Bauhinia tomentosa* show morphological differences which may well be as a result of isolation caused by mountain barriers and the interaction of climate and ultramafic substrates.

- In some instances the disjunction may not in fact be real, for between the two known populations of the taxon, there are probably further, **linking populations** as yet undiscovered and unrecorded. It is important to keep this possibility in mind when poorly studied areas are analysed.

6.2 Sekhukhuneland Centre of Endemism

6.2.1 Introduction

The second main objective of this dissertation was to determine the local focal areas of endemism ('hot spots'). Priority areas, or 'hot spots', are those areas with a high biodiversity (Davis *et al.* 1994). However, in practice this is not always the case, for the Great Dyke in Zimbabwe is not species rich, but is regarded as a 'hot spot' in Davis *et al.* (1994) solely on the grounds of its high proportion of endemics (20 species!).

It is generally accepted that a rich biodiversity is primarily dependent on a high proportion of endemic species, as well as a high species richness. Thus, for the purpose of this dissertation, a 'hot spot' is defined as an area containing a high number of species, usually coupled with a high proportion of endemic species. Both these factors are combined in this dissertation as relative phytodiversity. Although a quarter degree grid [QDG] might be poorly sampled, a high Index of Relative Phytodiversity will indicate whether the grid is a potential 'hot spot' or not.

In the Sekhukhuneland Study Area [SSA], and in any other region for that matter, certain QDGs will contribute more to the area's biodiversity than others. These QDGs form the core area for the Sekhukhuneland Centre of Endemism. The 'hot spot' grids are labelled as high priority areas for further research and conservation. It can be speculated that many endemics are still hidden in these areas. Plant taxonomists, including E. Retief, M. Jordaan and R. Archer from PRE, as well as Prof. A.E. van Wyk and S.J. Siebert from PRU, have identified potential new species in the SSA, such as forms of *Cyphostemma*, *Gymnosporia*, *Euphorbia*, *Euclea* and *Stylochiton* (see 6.1.3). Recently, a very distinct new species, *Plectranthus venteri*, was described from the region (Van Jaarsveld & Hankey 1997). Other variations have also been recognised, such as a form of *Acacia karroo* (Ross 1971).

6.2.2 Problems with 'hot spot' identification

The discussion of 'hot spots' in the Sekhukhuneland Study Area is presented with the caution that many areas remain unexplored, and that the number of endemics is likely to increase with a better knowledge of the region's flora. Matthews *et al.* (1993) indicated the considerable disparity in collection intensity between grids in the adjacent Wolkberg Centre. This is largely a reflection of the accessibility of the different areas to botanists. Areas without roads, or even main routes, as is the case in large parts of the Sekhukhuneland Study Area, are very poorly sampled.

Particular uncertainties influence the accuracy of the indices. For instance, the total number of taxa and endemics for each of the QDGs of the SSA is not known precisely, but are based on informed estimates. Calculations of the indices are therefore not accurate and must be viewed as provisional. Furthermore, it should be noted that the surface area of the SSA is only an approximation – most of the terrain has an undulating topography, which means that the actual surface area must be in excess of the approximated 675 km² allocated to each QDG.

Many QDGs, as field work has shown, are definitely poorly sampled. It can certainly be expected that an area of 675 km² will be comprised of more than 100 different taxa (referring to 2529BD) in the eastern parts of South Africa. This sampling disparity, when compared to the collections made in 2430CA, is attributed to former sampling of unusual species and not common ones. It could be expected that each of the 12 QDGs should at least have a species richness of more than 100 species, if approximately 1500 species have been recorded for the whole of the SSA.

The same can be said for the percentage endemism. If the endemism is high in a grid, the number of endemics and the number of species must be considered, before the results can be accepted as meaningful. A QDG with a high number of species and endemics, for instance 2430AC, is far more likely to be a meaningful centre of high biodiversity, due to more intense sampling, relative to the other QDGs of the SSA. The low-intensity sampled QDGs exhibit a rather high endemism due to selective sampling of rare and unusual taxa.

Problems were also experienced with the concepts applied in the identification of priority areas. There is disagreement about the delimitation of species. Definitions concerning distribution patterns are contradictory and render the identification of endemics difficult (Poynton 1983). Endemism appears to be a function of a multitude of factors (Major 1988) and the factors determining endemism are themselves strongly hypothetical (Kruckeberg & Rabinowitz 1985). While so many discrepancies exist, it seems premature to rely on one's own methods to put forward new ideas in this field.

The immobility of rooted plants makes them theoretically mappable and countable, with only the seed stage being more or less mobile. However, during the collection, processing and evaluation of the plant distribution data in the SSA, certain problems were encountered. In view of these difficulties, the floristic analysis of the SSA should be viewed as **provisional**. The reason for this caution stems from the following limitations:

- The mapping of taxa in the SSA does not display accurate distributions:
 - ◆ Endemicity is based on the distribution data obtained from the PRE and PRU **only**;
 - ◆ Large parts of the region are densely populated and occupied by subsistence farmers;
 - ◆ Floristic sampling in Sekhukhuneland is still incomplete;
 - ◆ Floristic sampling took place mainly along main routes and in the vicinity of towns;
 - ◆ No data are available on the relative abundance of the endemics per QDG;
 - ◆ Locality references of most herbarium specimens are only accurate to the level of the nearest QDG.

- The PRECIS database contains certain errors:
 - ◆ Certain species definitely present within the specified QDGs are not collected or listed;
 - ◆ Not all the herbarium specimens' localities are registered;
 - ◆ Not all the specimens filed in the cupboards of PRE are listed;
 - ◆ No collections of other herbaria are listed;
 - ◆ Certain specimens were allocated to the wrong QDG;
 - ◆ Localities in Botanical Gardens (cultivated plants) are listed as natural distributions.

- Problems with the determination of localities according to information on the specimen labels:
 - ◆ Some of the handwriting on the labels are illegible;
 - ◆ Most of the locality descriptions are very vague;
 - ◆ Wrong QDGs were allocated to specimens lacking localities by encoders at a later stage;
 - ◆ Some of the specimens were without grid references.

- Problems with the identification of herbarium specimens:
 - ◆ Too few specimens of certain variations of specific taxa are housed in the herbarium;
 - ◆ Rare and unusual forms are sometimes only represented by sterile herbarium specimens;
 - ◆ Human error resulted in the wrong identification of certain herbarium specimens.

- Base images of the SSA geology, topography and climate for use in the GIS mapping are expensive and not readily available.

- The present list of SSA endemic/near-endemic taxa represents a first approximation and statistics based on it may change with better knowledge of the region's flora.

6.2.3 Sekhukhuneland focal points of endemism

According to Werger & Coetzee (1978), it is probably more sensible to distinguish local centres of endemism with gradual boundaries within the Zambebian Regional Centre of Endemism, than to subdivide the region into sharply bounded sectors where floristic changes are mainly gradual and a large proportion of the species have a very wide distribution area. Importantly, the location and species richness of the Zambebian Regional Centre of Endemism has emphasised the importance of gathering data on diversity and endemism by means of natural phytogeographical centres and not by political subdivisions.

The occurrence of several endemics in the Sekhukhuneland Study Area [SSA], more than twice the number recorded for the Great Dyke, clearly justifies its recognition as a 'small' local Centre of Endemism. 'Small' refers to both its size (approximately 4 000 km²) and the low number of endemics (51 species and infraspecific taxa) when compared with other centres in the Northern Provinces of South Africa such as the Wolkberg Centre, with its more than 113 endemics in an area of nearly 6 000 km². The Sekhukhuneland Centre of Endemism is defined as the flora of the Rustenburg Layered Suite in the eastern Bushveld Igneous Complex, without the southwestern and northwestern parts of the Suite, which stretches into the Highveld and Springbok Flats respectively. The Sekhukhuneland Centre of Endemism cannot be defined in terms of quarter degree grids, because the grids lie across different geological substrates. However, the core region of the Centre corresponds with 2429BD, 2430CA, 2430CC and 2529BB.

Provisionally it is proposed that three floristic subcentres be recognised in the Sekhukhuneland Centre of Endemism. These subcentres are: Roossenekal Subcentre, Steelpoort Subcentre and Leolo Subcentre. Whereas the main Centre is based on ultramafic substrates, the existence of the three subcentres is based on the climate and topography. The Roossenekal Subcentre is geographically separated from the other two subcentres. However, the Steelpoort and Leolo Subcentres are in close geographical proximity, but are separated by altitude.

The Roossenekal Subcentre is characterised by its climate (see 3.2.3) which differs from that of the other subcentres. The Roossenekal Subcentre receives approximately 700 mm annually and is on average the coolest region. The Steelpoort and Leolo Subcentres receive approximately 450 mm annually and are on average the warmest regions. The Roossenekal Subcentre is defined as the region

situated in the cool, moist extreme south of the Sekhukhuneland Centre of Endemism, and is centred in 2529BB, 2529BD and 2530AA.

The Leolo Subcentre is characterised by its topography (see 3.2.1), which differs from that of the Steelpoort Subcentre. The Leolo Subcentre comprises all the mountainous regions of the arid northern part of the main centre. The Steelpoort Subcentre comprises all the low lying (valleys) regions of the arid northern part of the main centre. The Leolo and Steelpoort Subcentres are defined as the regions centred in the warm, dry central and north of the Sekhukhuneland Centre of Endemism and comprise either (1) all the mountains, and centred in 2429BD, 2429DB, 2430CA, 2430CB and 2430CC (Leolo Subcentre) and (2) all the valleys, and centred in 2429BD, 2429DB, 2430CA, 2430CB and 2430CC (Steelpoort Subcentre).

6.3 Ultramafic substrates and endemism

6.3.1 Introduction

Whereas some work has been conducted on the plant ecology of the serpentiniferous ultramafic complexes in South Africa (Morrey *et al.* 1989), studies on the role of non-serpentiniferous ultramafics on phyto geography are lacking. In this dissertation the non-serpentiniferous ultramafic rocks of the Sekhukhuneland Centre are correlated with its floristic endemism, in accordance with the stated third main objective of the study. In view of this, a review on heavy metal soils was presented (Chapter 2) to evaluate, in particular, the potential phytotoxicity of the most abundant heavy metal, chromium, in the rocks of the Sekhukhuneland Study Area.

Since plants are not able to move in order to acquire resources, they respond and are forced to adapt to their environment, or face extinction. This adaptation to the climate and soil is visible as differing patterns of vegetative and reproductive growth (Silverton & Rabinowitz 1985). Soil formation is but one geological setting for the evolution of plant life, especially unique soil types. The unique soils derived from ultramafic rocks are characterised by high magnesium (Mg)/calcium (Ca) ratios and are associated with high concentrations of phytotoxic elements such as chromium (Cr) and nickel (Ni) (Brooks 1987). Metalliferous soils derived from ultramafic outcrops are likely to be important refugia for endemic and near-endemic plant taxa.

Plant-environment linkages may develop into such close dependence, that the individuals occupying the locality will become adapted and might differ significantly from their population of origin (Stott 1981; Stuessy 1990). Studies of such linkages are therefore very important for the assessment of affinities between ultramafic soils and floristic patterns. Floristic regions in South

Africa display a tendency to develop plant taxa which are adapted, and hence endemic, to their substrates. It is known that closely related species-pairs of the Fynbos Biome grow on selected substrates, namely either limestone soils or colluvial sands (Mustart *et al.* 1994). The Wolkberg Centre is known for its lithological endemics which prefer soils derived from either quartzite or dolomite (Matthews *et al.* 1993).

6.3.2 Irreversible self-organisation

The Sekhukhuneland Study Area is characterised by a heterogeneous geology. By dividing the geology of the Sekhukhuneland Study Area into five main groups, it was shown that there is a correlation between the number of endemics in a quarter degree grid and the percentage cover of its ultramafic substrates. It is therefore speculated that the high phytodiversity and endemism in the Sekhukhuneland Centre of Endemism is the result of ultramafic soils. When these observations are considered, a question arises: what is the driving force behind this endemism and its association with ultramafic substrates?

Ultramafic soils (diverse chemistry) of the Sekhukhuneland Centre of Endemism, together with the diversity in climate and topography, contribute to speciation as a direct consequence of irreversible self-organisation. The purpose of the theory of Irreversible Self Organisation is to explain speciation in heterogeneous environments (Prigogine & Stengers 1985). The basis for the theory is the two Laws of Thermodynamics:

The first law states that the energy of the whole must stay constant (despite conversion of one form of energy into another):

$$E(\text{system}) + E(\text{environment}) = \text{constant}; \text{ or}$$
$$\Delta E(\text{system}) + \Delta E(\text{environment}) = 0$$

The second law states that the entropy of the whole must increase (towards a maximum):

$$S(\text{system}) + S(\text{environment}) = \text{increase}; \text{ or}$$
$$\Delta S(\text{system}) + \Delta S(\text{environment}) > 0$$

Any system, including living systems, functions with its energy (First Law of Thermodynamics). An increase in the entropy of the system is driven by the exchange of the energy between the system and its environment (Second Law of Thermodynamics). When entropy is produced in a heterogeneous natural environment (living system), the environment will enter a state of either chaos or order.

Chaos and order

One viewpoint is that chaos and order are contradictive, that is opposites working against each other. But from another point of view, they are also complementary (A. De Lange pers. comm.). It means that the one cannot exist without the other, and that the whole is dependent on this interaction. For example, a 'noun' and a 'verb' are complementary duals – both are needed to construct a sentence (the whole).

Order is the pattern of the harmony between the diversity of structures in living systems. At low rates of entropy production in a system, the harmony between its structures become more apparent. Chaos is the diversity of processes in living systems. The higher the entropy production of the system, the greater the diversity of processes. Any differences as a result of heterogeneity (in soil, climate and topography), like differences in temperature or chemical potential, are known creators of chaos (entropic forces) in living systems. A heterogeneous environment has a high rate of entropy production due to a continual flow of energy. High entropy production in certain areas creates diversity of processes. Low entropy production in other areas allow for harmony between a diversity of structures.

The Cape of Storms is known for the two great weather systems which meet there. These two systems work against each other, producing a high entropy. The region is also characterised by a diverse topography and geology. Is the rich biodiversity of the region coincidental? Another example, more applicable for this dissertation, is the areas where two variable geological systems meet. It is only necessary to think of soils derived from dolerite, low in pH and rich in iron, to realise what high entropy is produced where they meet with soils derived from Dolomite, high in pH and rich in calcium. It is perhaps no coincidence that most of the Centres of Endemism in South Africa (Van Wyk & Van Wyk 1997) are located in areas with a heterogeneous geology.

Entropy

It should be noted that entropy is determined by two factors. These factors may be intensive (such as temperature), or extensive (such as geology). Intensive factors remain the same in both halves of a system which is divided, but extensive factors are halved together with the system. The deficit which is experienced by the extensive factors during disturbance in a system is responsible for the creation of entropy by a **force-flood pair** (A. de Lange pers. comm.).

Macro changes in geology, climate and topography which influence a force-flood pair, trigger the initiation of entropy production. To these triggers can be added the micro changes in groundcover, humus and shade. Speciation usually occurs where the entropic forces are the greatest, under

conditions of continual variation in temperature, air pressure, humidity and chemical potential. When the latter sentence is 'translated' into the language of a taxonomist, it would read: 'Endemism usually occurs where the existing environmental heterogeneity is the greatest, under conditions of continual variation in climate, topography and geology.'

As the heterogeneity of an area increases, it is manifested by a diversity of processes (chaos). These processes can be seen as selection pressures. The diversity of processes create an environment which is only favourable for the best-adapted individuals. However, all processes experience resistance. When entropy is produced in a heterogeneous environment, energy is dispersed into the existing structure. This results in the accumulation of entropy in the heterogeneous system.

When the entropy accumulates, the structures (species) become very unstable. This leads to a point of bifurcation. After bifurcation the energy is concentrated in a new structure. When bifurcation has occurred either constructive or destructive structures result. If the possibility is destructive, the main structure (species) develops into many forms which are not fully adapted to conditions and is referred to as a higher state of chaos. When it is constructive, two complex, independent structures (species) evolve from the mother species and is referred as a state of order.

Back in the living system, the destructive possibility will once again be under great selection pressure and will once again be split into even more forms and finally into discreet new species. As a result of changing environments, neither order, nor chaos will be in control for very long. In other words, new species will age and once again undergo speciation into new species.

Synopsis

An area with a heterogeneous geology is more prone to speciation than a homogeneous one. The energy flow in an area with a heterogeneous geology is higher than that of an area with a homogeneous geology, therefore a higher entropy is expected in the former. A high entropy is the core driving force behind adaptation and thus, speciation. When the question: 'Why does life + geology = endemism?', or in a mathematical sense, 'why does $1 + 1 = 3$?', is reviewed in the light of Irreversible Self Organisation, the following logical adaptation could be made to make it more meaningful:

Life + Geology + **Entropy** = Endemics ; or $1 + 1 + 1 = 3$.

This discussion was aimed at explaining the association between the endemic taxa and the ultramafic soils in the Sekhukhuneland Centre of Endemism. It also illustrates the significance of considering energy flow, to determine the gradients in a specific region that are responsible for the

transformation from a 'normal' to a 'high' biodiversity. These gradients mediate certain ecological processes, such as competition and plasticity, which are directly responsible for endemism and diversification.

6.4 Questions to contemplate

● Geological time vs. speciation

There is often a close relationship between the number of endemics and the geological age of the habitats they occupy (Moore *et al.* 1996). Moreover, younger terrains tend to be characterised by neoendemics, and older terrains by palaeoendemic taxa. According to Coetzee (1985), the formation of the Great Dyke in Zimbabwe occurred 3 000 million years ago. At present the area boasts approximately 20 endemics (Wild 1965).

The Transvaal Sequence [TS] and the Bushveld Igneous Complex [BIC] are younger (2 000 million years) and are occupied by approximately 200 endemics. These formations are more than twice the age of the formations on which the Richtersveld Centre or the Cape Floristic Region occurs. However, the latter centres of endemism have a much higher biodiversity and more endemics than the Wolkberg and Sekhukhuneland Centres.

What is important to note is the time of surface exposure, and not the time of formation. Most of the BIC and the TS were covered by the Karoo Sediments for considerable periods (Marlow 1976). The correlation between lithology and endemism for the Rustenburg Layered Suite (BIC) was shown. Could it be that endemism in the Wolkberg and the Sekhukhuneland Centres is dependent on the chemical content of the geological formations of the BIC and TS? If so, is its lower phytodiversity and percentage endemism ascribable to non-sufficient surface exposure time? Is the present exposure of the BIC and TS, and the resultant production of edaphic factors, the driving force behind the present speciation in these areas?

● Reduction in phytodiversity

Wild (1965) and Roberts & Proctor (1992) have pointed out the floristic poverty of the ultramafic soils on the Great Dyke compared with that on other soils in Zimbabwe. On the Great Dyke only 322 species have been recorded for an area of about 3 280 km². Notwithstanding the low phytodiversity, the Great Dyke contributes exceedingly towards the phytodiversity of Zimbabwe as a whole.

Relatives of the taxa on the Great Dyke are located mostly beyond the borders of Zimbabwe and therefore its flora can be defined as old. Endemics on the Great Dyke are therefore palaeoendemics. According to Stott (1981), palaeoendemics may experience a new burst of evolution and diversification.

It was indicated that although the SSA has a relatively low phytodiversity, it contributes significantly towards the biodiversity of the Northeastern Escarpment. Is the flora of the Sekhukhuneland Centre of Endemism [SCE] caught up in early speciation (neoendemism) as a result of the recent exposure of its ultramafics? Or is the SCE in the early process of adaptive radiation, which is the diversification of form in old taxa (palaeoendemism), in response to the pressures of different ecological habitats, such as soils rich in heavy metals?

● **Diversification**

Trees are not likely to be the most rapid in their response to environmental changes, because of their relatively slow maturation rates (Ritchie 1986). The spread of trees is not only limited by maturation rates, but also the dispersal capacity of their fruits (Moore *et al.* 1996). Herbaceous species share with trees all the problems of dispersal, but they often have shorter generation times (production of seed within two years of establishment) which make up for the dispersal problem (Ritchie 1986).

Herbaceous species (pioneers) are the first species to spread into areas after an environmental change, such as regions which experienced sudden warming in post-glacial times (Moore *et al.* 1996) and substrates which became heavy metal soils due to weathering of nickel containing rocks (Wild 1970). This is a result of shorter generation times, suggesting that herbaceous species can diversify into wider habitats, whereas woody species, due to a slower generation time, are more specialised.

Herbaceous dicotyledoneae have proved most prolific in their diversification in the SSA. What are the environmental factors stimulating their diversification in the SSA? Could it be the exposure of ultramafic rocks? What are the dispersal mechanisms of the endemics? Are shorter generation times or tolerance to heavy metals soils, the driving force behind the herbaceous taxa's diversification in the Sekhukhuneland Centre of Endemism?

● **Genetic diversity**

The geographic range of a species is significantly correlated with the levels and amounts of genetic variation it maintains (Chung & Kang 1996). Endemic or narrowly distributed plants tend to maintain less genetic variation than widespread species. Species consisting of small, isolated populations with limited geographic distributions may not only be susceptible to extinction through

disasters (Kruckeberg & Rabinowitz 1985), but also through the loss of genetic diversity due to limited numbers of reproductive individuals (Chung & Kang 1996).

A loss of genetic diversity due to a narrowly distributed, localised world distribution, may result in the extinction of a species. Thus, specialist endemic plant taxa are more susceptible to survival pressures as a result of slight environmental changes than are generalists.

The occurrence of the SCE endemic species has been identified as localised on the ultramafic substrates of the relatively dry habitats of the Drakensberg rain shadow. Is the genetic diversity of the localised endemics depauperated? If so, could it be said that the SCE is on the verge of extinction due to a loss of genetic diversity by its localised species? Or, is the SCE, as a result of its geographic position, on the verge of immense speciation as a result of the rich genetic diversity flowing into it from the rich genetic diversity within the adjacent Afromontane and bushveld vegetation?

● Speciation

The adaptation of phenotypes to their changing environments leads to evolution. Evolution is the process behind speciation (Darwin 1979). Speciation does not influence the whole species, but rather isolated populations of a species (Stott 1981).

Gradual speciation is the slow change of a genotype over time. Gradualism is the result of natural selection, which influences the phenotype during environmental isolation. Gradualism is dependent on phenotypic plasticity, that is, the gradual selection for the best adapted phenotype in a population. Abrupt speciation is the sudden change of a genotype in time. Abrupt speciation includes mechanisms such as chromosome doubling (polyploidy). This speciation is dependent on genotypic isolation due to a genetic event, that is, the sudden change of genetically stable characteristics.

In this dissertation the endemism, distribution patterns and phytodiversity of the region was analysed. Is speciation the force behind endemism, distribution patterns and phytodiversity in the SCE? Are the endemics of the SCE the result of gradualism? Or, could it be said that the endemics are the products of abrupt speciation? For instance, did the endemics develop through gradual adaptation to the climate, followed by individual abrupt speciations, resulting in certain species being adapted to the ultramafic soils? What was the role of vicariant events in the establishment of the Sekhukhuneland Centre endemics?

● Evolution and endemism

Two main types of endemics are distinguished, namely neoendemics and palaeoendemics (Stott 1981; Stuessy 1990). Neoendemics represent new taxa which have arisen by differential evolution in a

particular area from which they have not yet spread or are unable to spread. Palaeoendemics are taxa which once possessed much wider distributions but are now confined to a very limited portion of their former range.

According to Kruckeberg & Rabinowitz (1985), endemics with more than one disjunct population are most likely relictual (palaeoendemics), while endemics confined to a single population can be either palaeoendemics or neoendemics. Moreover, the nature of a plant distribution will alter through time and all species must start as neoendemics and end as palaeoendemics (Stott 1981).

Endemics and near-endemics were identified for the SSA. Can one assume that the near-endemics with their relict distributions are mainly palaeoendemics? And what about the status of the endemic taxa? Are the infraspecific forms neoendemics? Are the endemic taxa of genera with high percentages of endemism in the SSA palaeoendemics (e.g. *Catha*), while endemic taxa of genera with low percentages of endemism are neoendemics (e.g. *Acacia*)? Could it be speculated that genera with many endemic infrageneric taxa are producing neoendemics (e.g. *Euphorbia*), whereas genera with few endemic taxa represent palaeoendemics (e.g. *Hibiscus*)?

● Biotic Factors

Plants are fixed in one place (stationary), because they are attached to their substrate. Plants are only 'mobile' by means of vectors, e.g. pollinators and dispersal agents (Endress 1994). Vectors are a part of the reproductive biology in most plants. Thus, the biotic factors of the environment are important in determining plant distributions.

Rooted plants need their vectors to come to them and then to move on to new habitats after the visit; pollen and seed would otherwise be shed only in the vicinity of the mother plant (Endress 1994). When the vectors are absent, plants are genetically isolated due to their immobility. This isolation may have serious consequences for the long term viability of the species.

Evidence was provided for the occurrence of many infraspecific forms in the Sekhukhuneland Centre. Are the forms the result of a hostile environment? Have the harsh effects of a dry climate, rugged topography and ultramafic soils altered the structure of the vectors, thus resulting in adaptations affecting the structure of flowers, fruit and seed? Could the diminishing numbers or even extinction of specific pollinators and dispersal agents have resulted in the adaptation of the species' reproductive structures, so as to correlate with those of new vectors?

● Interspecific competition

Interspecific competition is sometimes responsible for inducing plant refugia (Kruckeberg & Rabinowitz 1985). A plant refuge is a habitat, such as heavy metal soils, which is not the most favourable habitat for the prevailing 'normal' vegetation. In the light of geology-flora associations, a plant refuge can therefore be considered as a safe haven for otherwise weak competitors on 'normal' soils.

In the **absence** of interspecific competition, the weak competitor will rather grow on the adjacent 'normal' soils (Cook *et al.* 1971). However, in the **presence** of intense interspecific competition, the generally sparsely vegetated heavy metal soils become more favourable. It has been speculated that on serpentines certain plants were forced to adapt to heavy metal soils, because of heavy interspecific competition on the adjacent 'normal' soils (Wild 1965; Wild 1978).

Could the same assumption be made for the ultramafic soils of the SSA? Certain endemic taxa are found to be isolated on the ultramafic substrates. Are these species physiological ecotypes of ancient floras, presently only capable of survival on heavy metal soils (refugia) with low interspecific competition? Are the effects of interspecific competition, in combination with the harsh environmental conditions of the Sekhukhuneland Centre, responsible for vegetation anomalies? Why should the apparently relictual Nama-Karoo element, *Pterothrix spinescens*, be confined to sparsely vegetated anomalies?

● Climate change

The disjunct distribution of Afromontane species in highland areas can be explained by the drier conditions prevailing in southern Africa today (Jacobsen 1989). Disjunct species survive in moist temperate refugia within the mountain ranges, which simulate the Afromontane climate of the past. The vegetation of areas within the Zambezian domain fluctuated between tropical bushveld and temperate grassland, with a proliferation of bushveld in more recent times as a result of climate change (White 1983).

When plants respond to climate change, each species acts independently of the others. Ultimately each species has its own climatic optimum and tolerance limits (Salisbury & Ross 1992), which may be modified by other species growing with it and competing for limited resources (Cook *et al.* 1971). As the climate of a region changes, species spread into new areas where they can survive and compete with other plants already in residence. As a result, plant communities may undergo drastic floristic changes. The resident plants may find themselves under climatic stress due to the climatic change, and may become out-competed in some parts of their range.

It was found that the flora of the SCE displays elements of both Zambezian (bushveld) and Afromontane (grasslands and forests) affinity. Are the endemics of the SCE the relicts of a flora intermediate between the Afromontane- and the Zambezian Regional Centres of Endemism (Phytochoria)? Could it be that floristic fluctuations, as a result of climatic changes, enabled both bushveld and grassland to adapt to ultramafic soils in the SCE?

● **Climate and vegetation**

Climatic factors are important as ecological data in the interpretation of floristic distributions (Stott 1981). These factors include rainfall, humidity, soil moisture, seasonal and diurnal temperatures, available light, altitude and fire. Consequently, the climate of South Africa can be correlated with its vegetation types.

The SSA is classified as part of the Mixed Bushveld Vegetation Type (Low & Rebelo 1996). A major part of the SSA is also described as a semi-desert (Codd 1949). It was shown that the rainfall and temperature averages for the drier areas of the SCE are within the range demarcated for Mixed Bushveld and Karroo. The wetter and cooler areas of the SCE have a climate intermediate between that of the Mixed Bushveld and the Northeastern Mountain Grassland.

The SCE does not exhibit a vegetation type which is definitely related to a specific climate. Is the climate of the SCE best described as bushveld, grassland or karoo? Why is the vegetation of the SCE regarded as Mixed Bushveld? Does the climate not primarily contribute to a much wider concept of vegetation type? If this is so, could it consequently indicate that the flora of the SCE is the result of special climatic factors acting upon a separate vegetation type perhaps best described as **Mountain Bushveld**?

● **Patchworks**

There is a short term cycling of vegetation, as 'patches' become opened by minor catastrophe, such as fire (Cowling 1987) or even by shifting agriculture. Patchwork can also be imposed by varying topography and soils, which can lead to a mosaic development of vegetation. The different patches of the mosaic are at different stages of development and possibly even are following different developmental courses. It is upon such a successional patchwork that climatic changes exert their selective pressures (Ritchie 1986).

When anomalous substrates, such as ultramafic heavy metal soils, are exposed, patches scarce in vegetation develop. Most plants are adapted to 'normal' soils. In other words, most plants are not

adapted for growth on anomalous substrates, hence the occurrence of vegetation anomalies (patchworks) on such soils. The change in vegetation results in a change in micro-climate and thus also in adaptation by the plants growing in these patches.

Whilst examining herbarium specimens, it became obvious that many taxa are restricted to eroded, arid, ultramafic or heavily grazed areas. Are certain endemics of the SCE the products of a flora adapted to specific patches? How can micro-climatic changes be related to speciation in patchworks? Where does different kinds of patchwork vegetation fit into succession? Is the SCE, when the flora of southern Africa is viewed, a patchwork on a large scale due to its ultramafic nature?

● Topography

The burst of speciation in South Africa probably resulted from topographic deformation and accompanying fluctuation of climate (Werger & Coetzee 1978). As escarpments formed and mountains were elevated around the rim of South Africa, broad basins developed and the low areas became drier and the mountains, moister. Climate was alternating between wet and dry phases so that populations were shifting continuously.

Mountains, like islands, served as isolated centres of endemism (Kruckeberg & Rabinowitz 1985; Endress 1994). Mountainous regions exhibit highlands and lowlands, each with their own characteristic vegetation and flora. Under these conditions, together with ecological factors, speciation is accelerated, with relicts differentiating through adaptive radiation (Stott 1981).

It was shown that taxa of diverse floristic affinity exist within the SCE, several of which are endemic to the region. The SCE is a basin with a mountainous topography. Are the floristic elements of the SCE a direct result of its mountainous topography? Are the endemics in the SCE relicts of a former more widespread arid flora which became trapped in the hot, arid intermountain basin of Sekhukhuneland, when climatic patterns changed?

● Edaphic factors

Abiotic factors need to be considered in the interpretation of floristic patterns (Stott 1981). One of the most important abiotic factors is soil. Sandy soils, limestone-derived soils, and numerous other variations, can often be factors in producing different distribution patterns (Stuessy 1990).

Soils are so important that it is clear that they have played an important role as a stimulus for speciation (Kruckeberg & Rabinowitz 1985). Many endemic species of the Western Cape are a direct result of adaptation to its nutrient poor soils (Campbell 1986). Thus, vegetation patterns are a direct

consequence of edaphic factors. Vegetation types will therefore be correlated with their substrates, such as the Mixed Bushveld with its coarse, sandy and shallow soils on granite, quartzite, sandstone or shale (Van Rooyen & Bredenkamp 1996).

Whilst assessing the geology of the study area it was found that most areas in the SCE have a distinct clayey soil, presumably rich in heavy metals, overlying norite, anorthosite and pyroxenite. Is the vegetation of the SCE correlated with its edaphic factors, as is the case with its endemics? Are there certain vegetation patterns which can be linked with the distribution of endemics on the soils of the SCE?

● Heavy metal soils

White (1983) describes the Zambebian flora on heavy metal soils. The uniformity of the prevailing woodland in the Zambebian Regional Centre of Endemism is broken by areas with very sparse vegetation, as a result of toxic amounts of heavy metals in the soil. Certain taxa have also been identified as hyperaccumulators of some of these heavy metals, for example, species of *Dicoma*, *Blepharis* and *Indigofera* (Wild 1970).

These plants have apparently evolved tolerance to high levels of inorganic ions in the soils and maintained this high level of ionic concentrations in their tissues even when secondarily adapted to slightly different soil regimes (Stuessy 1990). According to Nriagu & Nieboer (1988), heavy metal soils can only exhibit heavy metal toxicity at a very low pH. The heavy metal soils of the Rustenburg Layered Suite have a moderate to high pH (6–8) (Loock *et al.* 1982).

The endemics of the SCE have been correlated with the ultramafics of the Rustenburg Layered Suite [RLS]. Are the heavy metal soils of the RLS toxic to its natural vegetation? Is the relatively high pH suppressing the toxic effects of heavy metals in the soils of the RLS? If not, are there any vegetation anomalies characteristic of heavy metal soils in the SCE? Are there any ecological factors contributing to the occurrence of anomalies in SCE, which are not linked to soil toxicity?

● Small scale distribution

The effect of heavy metals on plants is not always manifested in a dwarfing, or destructive manner, but may influence the distribution of certain species. The distribution of *Protea caffra* was correlated with high heavy metal concentrations on the Rooiberg felsitic lavas in the Loskop Dam Nature Reserve, Mpumalanga (Theron 1975).

However, the chemically most toxic soils in heavy metal anomalies are the ones with the most depauperated and treeless vegetation types (Wild 1974a; Werger *et al.* 1978). Thus, the distribution of most tree species on ultramafic soils is correlated with areas of non-toxic concentrations of heavy metal soils. These correlations are confirmed by the studies of Kritzing (1992), who found that the vegetation at an old platinum mine reveals a complex mosaic of similar communities recurring in different places, with many transitional forms.

The endemic taxa of most growth forms are correlated with high ultramafic surface percentages. Are different degrees of heavy metal concentrations on ultramafic substrates grouping plants of similar tolerance towards toxicity, into plant communities? Is the occurrence of certain taxa on specific soils an indication of the substrate's heavy metal concentration? What is the influence of other environmental factors on the ultramafic correlated distribution patterns of endemic taxa?

● Short distance dispersal

Although Afromontane species do not feature prominently in Zambezian vegetation, there is some degree of floristic linkage (mixing) when the Afromontane region is represented upon mountain ranges within the Zambezian region (White 1983). Such linkages are the result of seed dispersal and an intermediate climate on the ecotone between the two phytochoria.

Although endemic species are usually confined to their preference regions, their seeds frequently disperse across floristic boundaries (Stott 1981). Due to the intermediate climate in the ecotone, conditions are favourable for the establishment of certain species from both regions. The preponderance of Euphorbiaceae in the Valley Bushveld of mountains (Acocks 1953), is an example of Zambezian vegetation penetrating the hot, arid valleys which are often present in the Afromontane Region.

It was shown that the endemics of the proposed Sekhukhuneland Centre of Endemism and the endemics of the Wolkberg Centre of Endemism tend to converge where the Bushveld Igneous Complex and the Transvaal Sequence meet. Is the area of convergence an ecotone with an intermediate climate? Can this convergence be ascribed to short distance seed dispersal? Are there any taxa specifically endemic to this area of convergence?

6.5 Further research

Endemism is a very important aspect of biodiversity. It is not yet clear whether the patterns of endemism are simply a collection of special, unrelated cases or whether there are a number of underlying unifying processes. Autoecological studies of plant endemics are obviously needed. They should combine field, botanical garden and laboratory work, probably in that order. Synecological studies are however also needed since endemic plants exist within communities.

Further studies of the proposed Sekhukhuneland Centre of Endemism should include extensive exploration of its physical environment. According to Major (1988), endemics should be studied in relation to their climates (heat and moisture availability), soil parent materials (substrate peculiarities), relief (microclimates), successional time (duration of recovery), fire (intensity and frequency) and, probably of most importance, the associated fauna and flora. This will enable the researcher to make more informed decisions as to the classification of the Sekhukhuneland Centre into a floristic hierarchy and an ecological vegetation type.

Research concerning infraspecific diversity in the Sekhukhuneland Centre is necessary to determine the variety of taxa within the region. According to Endress (1994), research concerning systematic hierarchy is necessary on all levels, even down to population and individual variance. Variants within species' populations have certain unique traits or attributes, which can be of immense value in programmes for improving the genetic stocks of the plants to be utilised by humanity in the future. Future research must address the identification of as many of these variants as possible for the maintenance and sustainable use of biodiversity. Furthermore, the interactions between the organisms in ecosystems are still too poorly understood to allow the diversity, particularly of plants, to decline (Botkin 1984).

The Sekhukhuneland Centre of Endemism is situated on the world's richest heavy metal substrates (Kent 1980; Coetzee 1985). There is a great need for more information on the abundance of heavy metals in the top soil. Experiments should be done to determine whether plants take up heavy metals and to what degree these metals are accumulated in various parts of the plant. Procedures such as X-ray Fluorescence (Morrey *et al.* 1989), Ultrasonic Slurry Sampling Electrothermal Atomic Absorption Spectrometry (Takuwa *et al.* 1997) and Proton-Induced X-ray Emission with proton Back-Scattering (Mesjasz-Przybylowicz *et al.* 1991) can be used to identify heavy metals in soil and plant tissue.

The Convention on Biological Diversity states in its preamble that the contracting parties must recognise the dependence of local communities on biological resources (Geneva Executive Centre 1994). For future research to be holistic, the people inhabiting Sekhukhuneland and especially their traditional dependence on the vegetation of the region, should be taken into consideration. The

traditional ways of plant utilisation should be taken into account. The recognition of the human component is relevant to the conservation and sustainable use of biodiversity.

Successful research and conservation is usually accompanied by some kind of Geographical Information System (Pfab & Witkowski 1997). The computer work used in further studies must be such that the Geographical Information System [GIS] is linked to a detailed database. The use of a database separate from the GIS, gives a powerful query tool not usually available in GIS programs. The work of Felton & Matthews (1997) has shown how this type of small regional database can help to further our knowledge on plant distributions in southern Africa.

There is considerable scope for further botanical research in the Sekhukhuneland Centre of Endemism. Many questions concerning its phytodiversity still remain unanswered. Specific ideas for further research are listed as questions below:

Edaphic

- Are the soils in the Sekhukhuneland Centre toxic to its vegetation?
- Is the flora of the Sekhukhuneland Centre tolerant to heavy metals in the ultramafic substrates?
- Are there any hyperaccumulators of heavy metals in the Sekhukhuneland Centre?
- Are certain endemic species or communities restricted to specific soils of the ultramafic substrates?
- Which elements are mainly associated with the substrates on which the endemics or communities grow?
- Why do the alluvium clays of the Sekhukhuneland Centre carry more endemics than the ferrogabbro clays?
- What are the shared elements between (1) the soils of bushveld vegetation on the Pretoria Group and (2) the soils of bushveld vegetation on the Rustenburg Layered Suite?

Flora

- Are there threatened species in need of inclusion in the South African Red Data Book of Plants?
- Which taxa in the Sekhukhuneland Centre are phylogenetically 'old'?
- Why are there no records of grasses, or at least ecotypes, endemic to the Sekhukhuneland Centre?
- Why are certain quarter degree grids (regions) in the Sekhukhuneland Centre more prolific in the production of endemics?
- Why is there a floristic connection between the Sekhukhuneland Centre and other mountainous regions of the Northern Provinces of South Africa?
- What is the Sekhukhuneland Centre's floristic relationship with other Centres of Endemism?
- How does climate and topography influence the endemism and species richness of the Sekhukhuneland Study Area?
- Is the Sekhukhuneland Centre a refuge for former more widespread floras?

Other

- What is the faunal richness and degree of endemism in the Sekhukhuneland Centre?
- Are there endemics with flowers and fruits that serve as food for specific pollinators and dispersers?
- How can GIS techniques be used to establish endemic-environmental correlations and to implement its conservation?
- Is effective nature conservation possible in this socioeconomically impoverished region of rural South Africa?
- What effect do mining activities have on the fauna and flora of the Sekhukhuneland Centre?

6.6 Conservation priorities

Potential areas for conservation may be based on their degree of endemism (Davis *et al.* 1994). As the number of endemics increases in a specific region, the biodiversity increases and so does its priority for conservation. The concept of centres of high diversity (and endemism) is increasingly being employed by conservationists, both as a tool to determine which areas should receive priority attention, as well to decide which conservation actions are necessary.

Article 8 (*in situ* Conservation) of the Convention on Biological Diversity [CBD] (Geneva Executive Centre 1994) states that each Contracting Party shall conserve its biological diversity, develop strategies for the implementation thereof, establish bodies to manage conservation and sustainable use, and promote the conservation process. The implementation of Article 8 of the CBD in southern Africa can only meet the scope of the convention if the region's 'hot spots' of phytodiversity have been identified as priority areas for conservation (Wilson 1992).

Based on sheer surface area, the Savannah Biome is the best conserved biome in South Africa. However, not all the vegetation types of this biome are equally well conserved. Only 3% the Mixed Bushveld vegetation type is conserved, while approximately 60% is transformed (destroyed) (Van Rooyen & Bredenkamp 1996). The Sekhukhuneland Centre is presently classified as a distinct variation of Mixed Bushveld (Acocks 1953). Currently 0% the centre is formally conserved. The Mopane Bushveld, Sweet- and Mixed Lowveld Bushveld, are amongst the better conserved vegetation types in the biome (25–100%). Conservation of the latter vegetation types in the Savannah Biome is focused on tourism which is mainly based on large mammals (e.g. Kruger National Park).

'Hot spot' conservation

The establishment of conservation areas in the savannah regions of southern Africa has hitherto been based mainly on the presence of large game, rather than on phytodiversity. The phytodiversity of the Sekhukhuneland Centre of Endemism [SCE] is an essential underpinning of its terrestrial ecosystems. Important roles of these ecosystems are their functions — the protection of watersheds, stabilisation of slopes, improvement of soils, moderation of climate and provision of a habitat for humans. It is impossible to attach a precise monetary value to these services, except by counting the costs of failing to maintain them or repairing the consequent damage, such as soil erosion.

Endemism is not only a species property. Plant communities may also be endemic to a region. Endemism at the species level can be reflected in endemism at the community level (Major 1988). The preservation of rare and endangered species is therefore only possible through the preservation of their habitat — that is the communities in which they are found (Botkin 1984). However, small populations are in greater danger of becoming locally extinct than are large ones (Kruckeberg & Rabinowitz 1985), because a limited range means that a single disturbance can destroy an endemic. Coherent arrays of communities which share common species and endemics (and abundance of species), possess a similar vegetation structure (vertical profile), and which share the same set of ecological processes, must therefore be identified. These endemic communities would thus have similar uses, management programmes and conservation requirements.

Efforts to conserve high priority areas in the SCE must acquire an increased urgency in the light of their unusual natural features, such as the rich phytodiversity on the ultramafic soils. High numbers of plant endemics on the ultramafics are an indication of communities of exceptional interest. Furthermore, the conservation of genetic diversity calls for the identification of special forms (variants) of common species (e.g. the dwarf form of *Ptaeroxylon obliquum*). Certain quarter degree grids in SCE have been identified as 'hot spots' for conservation (see 6.2.3). These 'hot spots' should receive priority attention in future conservation projects. Conservation efforts in the SCE are influenced by potential problems and possible solutions:

Conservation problems:

- Plant endemics are endangered as a result of disturbance by mining and inappropriate agricultural practices;
- Plant endemics have limited distributions and small populations which make them vulnerable;
- The area has hitherto been seen as of low conservation status because its high levels of plant endemism were not appreciated by conservationists;
- Most of the people living in the SCE are poor and there are major socio-economic problems;

- Low levels of education contribute to the people's lack of awareness of their unique botanical heritage;
- Mining companies are unaware of the need to get involved in the conservation and upliftment of local communities.

Possible conservation solutions:

- Conservation-orientated legislation and the implementation thereof in mining and farming practices;
- Identification and protection of vulnerable plant endemics and their communities;
- Promoting the SCE among the public and conservation authorities;
- Assisting the local people with the development of conservation initiatives which could provide job opportunities;
- Presentation workshops and courses concerning plants, their uses, importance and conservation;
- Encouragement of mining companies to allocate a percentage of their profits to the environment and its people.

If the conservation of the SCE, as a selection of natural ecosystems and natural resources, is to succeed, effective management will have to be applied. Upliftment and education of the local people seem a logical approach towards achieving these goals in the SCE.

Endemic herpetofauna

From a conservation point of view, it may be worth noting that the SCE also harbours a diverse herpetofauna. Herpetofauna are not as mobile as birds or mammals and, therefore, they are more sensitive to their immediate environments and more dependent on conservation. This sensitivity is accentuated by the distributions of the herpetofauna in the Transvaal Region (Jacobsen 1989), which closely match the disjunct distribution patterns of plant taxa in the Northern Provinces of South Africa.

Lizards undergo adaptive radiation when exposed to a new or unique environment (Morell 1997). The occurrence of three endemic reptile species in the SCE is thus indicative of its unique environmental conditions. It is important to take note of these taxa and to include their habitats as priority areas for conservation. Habitat data for the three endemic lizards are given below (from Jacobsen (1989)):

Afroedura langi 'Leolo' is a localised, narrow endemic, restricted to the basalt formations alongside the central part of the Sekhukhuneland Centre of Endemism. It lives in crevices provided by

exfoliating rock on the underside of large boulders. This lizard occurs in Mixed Bushveld and North Eastern Mountain Grassland at an altitude of 1 200–1 800 m. It has not yet been formally described.

Platysaurus orientalis fitzsimonsi is a localised, narrow endemic, restricted to the low-lying rocky ridges in the eastern part of the Sekhukhuneland Centre of Endemism. It inhabits crevices between rocks or exfoliating slabs of basalt. This subspecies occurs in Mixed Bushveld at an altitude of 900–1 500 m.

Platysaurus orientalis orientalis is endemic to the western rim of the Drakensberg which fringes the bushveld basin and is a near-endemic of the Sekhukhuneland Centre of Endemism. It lives on rocky outcrops in the crevices between the rocks. This subspecies occurs in Mixed Bushveld and North Eastern Mountain Grassland at altitudes of 700–1 700 m.

CONCLUSIONS

Review of heavy metals soils

- An extensive literature list regarding heavy metal soils was compiled, with special attention paid to chromium.
- Chromium, as Cr (IV), is bioavailable to plants and is mobile in the soil.
- There are no reliable records of floras specifically adapted to chromium-rich soils anywhere on earth.
- Chromium is accumulated by certain species, but the concentrations in the plants are low and references to such accumulations are few.
- There is no conclusive experimental evidence that chromium in ultramafic soils contributes towards the toxicity of such substrates.
- Should chromium indeed be responsible for vegetation anomalies on ultramafic soils, it would be so in combination with many other environmental factors.

Aspects of phytodiversity

- As a result of its high number of endemics and rich phytodiversity, the Sekhukhuneland Study Area [SSA] is defined as a Centre of Endemism.
- The Sekhukhuneland Centre of Endemism [SCE] is predominantly centred in the quarter degree grids 2429BD, 2430CA, 2430CC and 2529BB.
- At least 51 plant species and infraspecific taxa are endemic to the SCE, and this endemism comprises 3% of the SCE's flora.
- The degrees of endemism for the SCE is comparable with that of other Centres of Endemism in the summer rainfall regions of southern Africa.
- *Euphorbia*, *Aloe* and *Rhus* are the genera with the highest number of endemics in the SCE.
- Fabaceae, Euphorbiaceae, Vitaceae and Liliaceae are the families with the highest number of endemics in the SCE.
- The Vitaceae has proven especially rich in new forms in the SCE.
- Disjunct floristic links exist between the SCE and other regions, with the combined area sharing 70 endemic plant species/infraspecific taxa.
- The flora of the SCE shows floristic affinity with all the main mountain ranges of the Transvaal Region, especially the Wolkberg, Waterberg, Soutpansberg, Barberton Range and Magaliesberg.
- Approximately endemics are shared between the Sekhukhuneland and Wolkberg Centres.
- Nearly all the near-endemics of the SCE have floristic links with the Wolkberg Centre.
- Floristic identity of the SCE is primarily Zambezian, with Afromontane influence.

- The SCE is rich in infraspecific variants (ecotypes) of common species.
- This dissertation is the first thorough investigation of the SCE flora and the first to provide a list of its endemics.

Aspects of ultramafic substrates

- Norite, pyroxenite, anorthosite and magnetite are the dominant rock types of the SSA and belong to the Rustenburg Layered Suite of the Bushveld Igneous Complex.
- The main rocks of the Transvaal Sequence are quartzite, shale and hornfels, which are also the second most dominant rock types in the SSA.
- The rocks of the Rustenburg Layered Suite are more abundant than those of the Transvaal Sequence.
- The Transvaal Sequence exhibits a greater diversity of rock types than the Rustenburg Layered Suite.
- A positive correlation exists between the ultramafic substrates (and alluvium derived from it) and the number of plant endemics in each quarter degree grid.
- The surface area of outcrops of the ultramafic Rustenburg Layered Suite is defined as the core region of the SCE.
- Heterogeneous environments, such as the ultramafics of the SCE and their rugged topography, produce entropy and can therefore be related to the degree of endemism and speciation.
- This dissertation is the first formal research to show the association between the ultramafic substrates and the endemic flora of the SCE.

General

- Not only the geology, but also the climate and topography of the SCE are heterogeneous.
- Rainfall increases and temperatures decreases in the SCE along a north-south and west-east gradient.
- The topography of the SCE is the result of erosion by the Olifants River and its tributaries.
- A literature list on the relevant topics concerning the SCE was compiled to serve as basis for further research and conservation.
- There is a great need for further research on the unique flora of the SCE and several questions in need of elucidation are presented.
- High priority areas for conservation in the SCE have been identified.

SUMMARY

Ultramafic substrates and floristic patterns in Sekhukhuneland, South Africa

by

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Supervisor: Prof. Dr. A.E. van Wyk

Co-supervisor: Prof. Dr. G.J. Bredenkamp

Submitted in partial fulfilment of the requirements for the degree

MAGISTER SCIENTIAE

Efficient land use and conservation objectives can only be attained with a thorough knowledge of the biodiversity and ecology of an area. Little information has been collated to date on the biodiversity of the Sekhukhuneland Study Area, a region rich in ultramafic substrates. The aims of this study were to review the literature on heavy metal soils, to establish which plant taxa are endemic/near-endemic to the Sekhukhuneland Study Area, to determine the areas of high phytodiversity in the region and to relate floristic patterns in the region with its ultramafic substrates. The objectives were formulated so as to conform to the hypothesis of this dissertation: that the Sekhukhuneland Study Area is an area of high floristic endemism with plant distribution patterns which can be correlated with the area's heterogeneous geology.

A review of existing publications on heavy metal soils introduces the known concepts concerning heavy metal accumulation in plants and evaluates the potential toxicity of chromium on vegetation. Although no conclusive evidence for the toxicity of chromium was found, there remains a need for more research on its effects on plants.

Literature and herbarium specimens were investigated to identify plant taxa endemic/near-endemic to the Sekhukhuneland Study Area. This was backed by extensive field work in the region. Distribution data of the relevant taxa were captured into a Geographical Information System computer programme (Idrisi) to map the plant distribution patterns. These maps were used to evaluate the status of Sekhukhuneland as a Centre of Endemism.

Literature and geological maps were used to identify the various rock types in the study area. The surface percentage of each rock type was calculated for each quarter degree grid with a Micro-analysis

computer program (TIFF) to identify the dominant and other abundant rock types. Surface percentages of the various rock types were used to relate the ultramafic substrates statistically to the patterns of floristic endemism.

A high proportion of endemic and near-endemic plant taxa was identified for the study area. Ultramafic substrates of the Rustenburg Layered Suite proved to be the primary cause of endemism in the Sekhukhuneland Study Area. Distribution patterns of the Sekhukhuneland floristic elements show a strong affinity with mountainous regions, especially with the northeastern Drakensberg Escarpment (Wolkberg) and the Waterberg.

A total of 119 floristic elements were identified for the Sekhukhuneland Study Area of which 51 are endemic and 70 near-endemic. Distribution maps are supplied of each of these taxa. This high number of endemics, together with a rich phytodiversity of 1 500 taxa, merits the recognition of the study area as a Centre of Endemism. As a result of the positive correlation between the ultramafic substrates and endemism, the surface outcrops of the Rustenburg Layered Suite in the eastern Bushveld Igneous Complex are used as the primary criteria to demarcate the Sekhukhuneland Centre. Four quarter-degree grids were identified as local foci of endemism ('hot spots') in the Centre, namely 2429BD, 2430CA, 2430CC and 2529BB.

A holistic approach towards the interpretation of floristic endemism in the Sekhukhuneland Centre gives a better insight into those factors which determine it. However, several questions concerning the floristic endemism of the study area remain unanswered. Some of these are listed in the dissertation, together with comments on conservation priorities in the region.

OPSOMMING

Ultramafiese substrate en floristiese patrone in Sekhukhuneland, Suid-Afrika

deur

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Voorgelê ter gedeeltelike vervulling van die vereistes vir die graad

MAGISTER SCIENTIAE

Effektiewe landgebruik en bewaringsdoelwitte kan slegs toegepas word as deeglike kennis oor die biodiversiteit en ekologie van 'n gebied beskikbaar is. Daar is tans min inligting oor die fitodiversiteit van die ultramafiese substrate in die Sekhukhuneland-Studiegebied beskikbaar. Die doel van hierdie ondersoek was om 'n literatuuroorsig saam te stel oor swaarmetaal gronde, om te bepaal watter planttaksa is endemies/na-endemies aan die Sekhukhuneland-Studiegebied, om daardie dele van die gebied met hoë fitodiversiteit te identifiseer en om die floristiese patrone met die ultramafiese substrate in die gebied te korreleer. Die doelstelling is geformuleer om by die hipotese van die verhandeling aan te sluit, naamlik: die Sekhukhuneland-Studiegebied is 'n gebied met 'n hoë floristiese endemisme en met plant verspreidingspatrone wat met die gebied se heterogene geologie gekorreleer kan word.

'n Literatuuroorsig van bestaande publikasies oor swaarmetaal gronde verskaf 'n samevatting van reeds-bekende beginsels van toepassing op swaarmetaal akkumulering deur plante en evalueer die potensiale vergiftiging van plantegroei deur chroom. Alhoewel geen deurslaggewende bewyse vir die toksisiteit van chroom bestaan nie, is daar nog steeds 'n behoefte om die invloed daarvan op plante verder te ondersoek.

Literatuur en herbariumeksemplare is bestudeer om te bepaal watter planttaksa endemies/na-endemies aan die Sekhukhuneland Studiegebied is. Uitgebreide veldwerk in die gebied het die resultate aangevul. Verspreidingsdata van die relevante taksa is met behulp van 'n Geografiese Inligtingstelsel rekenaarprogram (Idrisi) verwerk om die plante se verspreidings te karteer. Hierdie kaarte is gebruik om die status van die Sekhukhuneland Sentrum van Endemisme te bepaal.

Literatuur en geologiese kaarte is gebruik om die onderskeie rotssoorte in die studiegebied te identifiseer. Die oppervlakpersentasie van elke rotssoort is bereken vir elke kwart vierkante graad met behulp van 'n mikro-analise rekenaarprogram (TIFF) om sodoende die dominante en ander volop rotssoorte te identifiseer. Oppervlakpersentasies van die verskillende rotssoorte is gebruik om die ultramafiese substrate statisties met die patrone van floristiese endemisme in verband te bring.

'n Hoë verhouding endemiese en na-endemiese planttaksa is geïdentifiseer in die studiegebied. Ultramafiese gesteentes van die Gelaagde Suite Rustenburg is aangedui as die primêre oorsaak van endemisme in die Sekhukhuneland-Studiegebied. Verspreidingspatrone van die Sekhukhuneland floristiese elemente toon 'n sterk affiniteit met bergagtige gebiede, veral die noordoostelike Drakensberg Eskarpement (Wolkberg) en die Waterberg.

'n Totaal van 119 floristiese elemente is vir die Sekhukhuneland-Studiegebied geïdentifiseer, waarvan 51 endemies en 70 na-endemies is. Verspreidingskaarte word vir elkeen van hierdie taksa voorsien. Die hoë getal endemiese taksa en die ryk fitodiversiteit van 1 500 taksa, ondersteun die erkenning van die studiegebied as 'n Sentrum van Endemisme. As gevolg van die positiewe korrelasie tussen die ultramafiese substrate en endemisme, word die oppervlakgesteentes van die Gelaagde Suite Rustenburg in die oostelike Bosveld Stollingskompleks gebruik as die primêre kriterium om die Sekhukhuneland Sentrum af te baken. Vier kwart vierkante grade is geïdentifiseer as lokale fokuspunte van endemisme ('hot spots') in die Sentrum, naamlik 2429BD, 2430CA, 2430CC en 2529BB.

'n Holistiese benadering tot die interpretasie van floristiese endemisme in die Sekhukhuneland Sentrum, gee 'n beter insig van die faktore wat dit bepaal. Nogtans, is daar talle vrae betreffende floristiese endemisme in die studiegebied wat onbeantwoord bly. Sommige hiervan is in die verhandeling gelys, tesame met die voorkeurgebiede vir bewaring in die Sekhukhuneland Sentrum.

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CURRICULUM VITAE

Stefan John Siebert was born on 27 September 1974 in Empangeni, KwaZulu-Natal. He attended King Edward High School in Matatiele, KwaZulu-Natal, where he matriculated in 1992.

In 1993 he joined the South African Defence Force, where he became an officer and obtained the rank of second lieutenant at 4 Artillery Regiment in Potchefstroom.

In 1994 he enrolled at the University of Pretoria, and was awarded his B.Sc. degree in 1996, with Botany and Zoology as majors.

He registered for an Honours degree in Botany at the University of Pretoria in 1997, where he specialised in taxonomy and ecology. During the same year he received the H.G.W.J. Schweickerdt Medal for Botany at the Honours level.

In 1998 he registered for a Masters degree in Botany at the same university, specialising in the phytodiversity of ultramafics.

APPENDICES

Appendix 1 Rainfall averages for the Sekhukhuneland Study Area (adapted from Erasmus (1985))

The first four columns show, from left to right, station name ('Rustplaas'), locality of the station in a grid ('2416 2932 [2429BC]'), identification code ('S01') and altitude (alt.) in metres ('1 023 m'). The next five columns indicate the mean average rainfall (mm). This mean average rainfall is given from left to right as: spring, summer, autumn, winter and annual (factual). Seasonal averages were based on the following months:

- Spring: September, October & November;
- Summer: December, January & February;
- Autumn: March, April & May; and
- Winter: June, July & August.

The last column show the expected (exp.) mean average rainfall (mm) for the specific altitude, as determined with regression analysis.

Weather Station	Locality in Grid	ID	Alt.	Mean Average Rainfall					Exp.
Rustplaas	2416 2932 [2429BC]	S01	1023	146	241	89	8	499	561
Wonderboom	2428 2937 [2429BC]	S02	0762	135	214	72	12	427	480
Paschaskraal	2423 2959 [2429BD]	S03	0911	130	268	101	15	489	526
Malipsdrif	2414 2949 [2429BD]	S04	0823	129	193	70	9	404	499
Lobethal	2443 2944 [2429DB]	S05	1196	152	246	95	15	509	616
Jane Furze	2446 2952 [2429DB]	S06	1402	155	265	121	18	551	680
Nebo	2455 2946 [2429DD]	S07	1570	179	307	125	18	625	733
Glen Cowrie	2450 2948 [2429DD]	S08	1466	175	312	135	20	631	700
Forest Hill	2429 3004 [2430AC]	S09	0853	134	263	120	16	544	508
Stellenbosch	2415 3005 [2430AC]	S10	0692	135	240	95	11	484	458
Maandagshoek	2436 3005 [2430CA]	S11	0975	165	310	122	17	603	546
Derdegelid	2437 3012 [2430CA]	S12	0820	138	256	102	16	515	498
Pretoria Farm	2432 3024 [2430CB]	S13	0686	133	233	95	13	469	456
Dublin	2422 3039 [2430CB]	S14	0560	133	262	107	20	520	416
Sekhukhune	2445 3001 [2430CC]	S15	1280	151	270	111	13	553	642
Martenshoop	2459 3014 [2430CC]	S16	1408	201	327	143	20	685	682

De Grootboom	2447 3021 [2430CD]	S17	0820	143	241	103	13	493	498
Weather Station	Locality in Grid	ID	Alt.	Mean Average Rainfall				Exp.	
Klipfontein	2458 3026 [2430CD]	S18	1320	196	311	138	19	658	655
Buffelsvallei	2513 2940 [2529BB]	S19	1230	169	281	139	16	607	626
Roosnekal	2512 2956 [2529BB]	S20	1448	203	346	130	18	702	695
Blinkwater	2523 2950 [2529BD]	S21	1463	196	349	148	17	710	699
Laersdrift	2522 2950 [2529BD]	S22	1450	202	350	146	18	721	695
Tonteldoos	2525 3006 [2530AA]	S23	1771	221	371	160	23	774	796
Beetgeskraal	2506 3017 [2530AA]	S24	1615	203	329	158	24	716	747
AVERAGES		-	1148	163	283	117	17	578	601

Appendix 2A Endemic and near-endemic plant taxa of the Sekhukhuneland Centre of Endemism

- Column one: Scientific names of the taxa of interest. ([form] refers to distinct variants of a species, some of which may deserve formal taxonomic recognition);
- Column two: Representative herbarium specimen of the taxon collected in the SSA. Information is presented in the following order: collectors name, collection number & herbarium;
- Column three: Degree of endemism for each taxon:
 - SEN - Sekhukhuneland narrow endemic
 - SEW - Sekhukhuneland wide endemic
 - SNE - Sekhukhuneland near-endemic

ANGIOSPERMAE

MONOCOTYLEDONAE

ARACEAE

<i>Stylochiton natalense</i> Schott [form]	S.J. Siebert 390 (PRU)	SEN
<i>Zantedeschia jucunda</i> Letty	Barnard & Mogg 991 (PRE)	SEN
<i>Zantedeschia pentlandii</i> (Watson) Wittm.	L.E.W. Codd 8227 (PRE)	SEW

COMMELINACEAE

<i>Aneilema longirrhizum</i> Faden	A.E. van Wyk 1388 (PRE)	SNE
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HYPOXIDACEAE

<i>Hypoxis interjecta</i> Nel	R.G.N. Young A230 (PRE)	SNE
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LILIACEAE

(Alliaceae)

<i>Tulbaghia coddii</i> Vosa & R.B. Burb.	A.A. Balsinhas 2766 (PRE)	SEW
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(Anthericaceae)

<i>Anthericum cyperaceum</i> Kies ex Oberm.	F. van der Merwe 1306 (PRE)	SNE
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(Asparagaceae)

Protasparagus intricatus (Oberm.) Fellingham & N.L. Mey. [form] A.O.D. Mogg 16890 (PRE) SEN

Protasparagus sekhukhuniensis (Oberm.) Fellingham & N.L. Mey. Mogg & Barnard 602B (PRE) SEN

(Asphodelaceae)

Aloe burgersfortensis Reynolds G.W. Reynolds 1958 (PRE) SNE

Aloe castanea Schönland L.E. Taylor 2346 (PRE) SEW

Aloe cryptopoda Baker [form] W.G. Barnard 361 (PRE) SNE

Aloe fosterii Pillans W.G. Barnard 309 (PRE) SEW

Aloe immaculata Pillans I.B. Pole-Evans 38083 (PRE) SEW

Aloe laxissima Reynolds G.W. Reynolds 767 (PRE) SEW

Aloe reitzii Reynolds var. *reitzii* G.W. Reynolds 2308 (PRE) SNE

(Dracaenaceae)

Sansevieria hyacinthoides (L.) Druce [forma] Van Wyk, Siebert & Retief (PRU) SEW

(Hyacinthaceae)

Eucomis vandermerwei I. Verd L.E.W. Codd 8224 (PRE) SNE

ORCHIDACEAE

Brachycorythis conica (Summerh.) Summerh. ssp. *transvaalensis* Summerh. C.L. Leipoldt 17074 (PRE) SNE

DICOTYLEDONAE

ACANTHACEAE

Barleria rotundifolia Oberm. Schlieben & Strey 8389 (PRE) SNE

Dicliptera fruticosa K. Balkwill K. Balkwill 1570 (PRE) SNE

Dyschoriste erecta C.B. Clarke S. Krynauw 1140 (PRE) SNE

Dyschoriste perrottetii (Nees) Kuntze F. Wilms 1194 (PRE) SEW

Petalidium oblongifolium C.B. Clarke W.G. Barnard 373 (PRE) SNE

ANACARDIACEAE

Ozoroa albicans R. & A. Fern. S.J. Siebert 442 (PRU) SNE

Rhus batophylla Codd R.O. Moffett 1991 (PRE) SEN

<i>Rhus engleri</i> Britten	J.P. Nel 224 (PRE)	SNE
<i>Rhus gracillima</i> Engl. var. <i>gracillima</i>	Barnard & Mogg 51 (PRE)	SNE
<i>Rhus keetii</i> Schönland	R.O. Moffett 1998 (PRE)	SNE
<i>Rhus sekhukhuniensis</i> Moffett	B. Lombaard 423 (PRE)	SEN
<i>Rhus tumulicola</i> S. Moore var. <i>meeuseana</i> forma <i>pumila</i>	R.G.N. Young A514 (PRE)	SEW
<i>Rhus wilmsii</i> Diels	D.S. Hardy 4038 (PRE)	SNE
<i>Rhus zeyheri</i> Sond.	D.S. Hardy 4058 (PRE)	SNE

ARALIACEAE

<i>Cussonia transvaalensis</i> Reyneke	A.O.D. Mogg 16913 (PRE)	SNE
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ASCLEPIADACEAE

<i>Ceropegia distincta</i> N.E. Br. ssp. <i>verruculosa</i> R.A. Dyer	A.E. van Wyk 5242 (PRE)	SEN
<i>Ceropegia stapeliiformis</i> Haw. ssp. <i>serpentina</i> (E.A. Bruce) R.A. Dyer	D.S. Hardy 6130 (PRE)	SNE
<i>Huernia insigniflora</i> C.A. Maass	D.S. Hardy 4071 (PRE)	SEW
<i>Huernia kirkii</i> N.E. Br.	D.S. Hardy 6856 (PRE)	SNE
<i>Huerniopsis atrosanguinea</i> (N. E. Br.) A. C. White & B. Sloane	D.S. Hardy 5455 (PRE)	SNE
<i>Orbeopsis melanantha</i> (Schltr.) L.C. Leach	W.G. Barnard 278 (PRE)	SNE
<i>Pachycarpus transvaalensis</i> (Schltr.) N.E. Br.	F. Venter 11225 (PRE)	SNE

ASTERACEAE

<i>Berkheya densifolia</i> Bohnen ex Roessler	A.E. van Wyk 12364 (PRE)	SNE
<i>Berkheya insignis</i> (Harv.) Thell. [form]	J.S. Siebert 257 (PRU)	SEN
<i>Brachylaena ilicifolia</i> (Lam.) E. Phillips & Schweick. [form]	N.J. van Warmelo 37995 (PRE)	SNE
<i>Helichrysum uninervium</i> Burt Davy	M. Stalmans 123 (PRE)	SNE
<i>Helichrysum edwardsii</i> Wild	P. Vorster 2820 (PRE)	SNE
<i>Kleinia longiflora</i> DC. [form]	Van Wyk, Siebert & Retief 13239 (PRU)	SEW
<i>Kleinia stapeliiformis</i> (E. Phillips) Stapf	W.G. Barnard 139 (PRE)	SNE
<i>Pegolettia lanceolata</i> Harv.	R.G. Strey 3423 (PRE)	SNE

<i>Pterothrix spinescens</i> DC.	Van Wyk & Siebert 12983 (PRU)	SNE
BALANITACEAE		
<i>Balanites maughamii</i> Sprague [form]	Van Wyk, Siebert & Reftief 13233 (PRU)	SEN
BIGNONIACEAE		
<i>Rhigozum brevispinosum</i> Kuntze	J.S. Siebert 353 (PRU)	
BORAGINACEAE		
<i>Ehretia obtusifolia</i> Hochst. ex DC. [form]	W.G. Barnard 200 (PRE)	SNE
CAPPARACEAE		
<i>Boscia albitrunca</i> (Burch.) Gilg & Gilg-Ben. [form]	Van Wyk, Siebert & Retief 13182 (PRU)	SEW
CELASTRACEAE		
<i>Catha transvaalensis</i> Codd	A.O.D. Mogg 13808 (PRE)	SEW
<i>Gymnosporia senegalensis</i> (Lam.) Loes. [form]	S.J. Siebert 458 (PRU)	SEN
CONVOLVULACEAE		
<i>Ipomoea bathycolpos</i> Hallier f. var. <i>sinuatodentata</i> Hallier f.	R.G. Strey 4148 (PRE)	SEW
<i>Turbina robertsiana</i> (Rendle) A. Meeuse	W.G. Barnard 327 (PRE)	SNE
EBENACEAE		
<i>Euclea crispa</i> (Thunb.) Guerke subsp. <i>crispa</i> [form]	N. Jacobsen 1183 (PRE)	SNE
<i>Euclea linearis</i> Zeyh. ex Hiern	L.E.W. Codd 6697 (PRE)	SNE
<i>Euclea linearis</i> Zeyh. ex Hiern [form]	L.E.W. Codd 8796 (PRE)	SNE

EUPHORBIACEAE

<i>Euphorbia barnardii</i> C. White, R.H. Dyer & B. Sloane	W.G. Barnard 449 (PRE)	SEN
<i>Euphorbia enormis</i> N.E. Br.	Obermeyer & Verdoorn 37 (PRE)	SNE
<i>Euphorbia exelsa</i> A.C. White, R.H. Dyer & B. Sloane	F. van der Merwe 1028 (PRE)	SNE
<i>Euphorbia lydenburgensis</i> Schweick. & Letty	F. van der Merwe 2167 (PRE)	SEW
<i>Euphorbia maleolens</i> E. Phillips	F. van der Merwe 1009 (PRE)	SNE
<i>Euphorbia schinzii</i> Pax [form]	Van Wyk, Siebert & Retief 13194 (PRU)	SEN
<i>Euphorbia sekhukhuniensis</i> R.A. Dyer	Ross-Frames 4 (PRE)	SEN
<i>Jatropha latifolia</i> Pax var. <i>angustata</i> Prain	M. Jordaan 780 (PRE)	SNE
<i>Jatropha latifolia</i> Pax var. <i>latifolia</i>	E. Fourie 395 (PRE)	SNE
<i>Jatropha zeyheri</i> Sond. var. <i>subsimplex</i> Prain	R.G.N. Young 32741 (PRE)	SNE
<i>Phyllanthus parvulus</i> Sond. var. <i>garipensis</i> (E. Mey. ex Drège) Radcl.-Sm.	A.E. van Wyk 13025 (PRU)	SNE

FABACEAE

<i>Acacia karroo</i> Hayne [form]	L.E.W. Codd 10487 (PRE)	SEN
<i>Argyrolobium lancifolium</i> Burt Davy	R.G.N. Young A662 (PRE)	SNE
<i>Argyrolobium transvaalense</i> Schinz	A.O.D. Mogg 16881 (PRE)	SNE
<i>Argyrolobium wilmsii</i> Harms	S.J. Siebert 159 (PRU)	SEW
<i>Bauhinia tomentosa</i> L. [forma A]	S.J. Siebert 444 (PRU)	SEN
<i>Bauhinia tomentosa</i> L. [forma B]	Barnard & Mogg 736 (PRE)	SEW
<i>Elephantorrhiza praetermissa</i> J. H. Ross	P. Vorster 2129 (PRE)	SEN
<i>Indigofera nebrowniana</i> J.B. Gillett	G.Germishuizen 3751 (PRE)	SNE
<i>Indigofera reducta</i> N.E. Br.	Strey & Schlieben 8491 (PRE)	SNE
<i>Lotononis wilmsii</i> Dummer	L.E.W. Codd 9831 (PRE)	SNE
<i>Rhynchosia spectabilis</i> Schinz	N.J. van Warmelo 79 (PRE)	SNE
<i>Schotia laifolia</i> Jacq. [form]	L.E.W. Codd 9828 (PRE)	SEN

LAMIACEAE

<i>Leucas capensis</i> (Benth.) Engl. [form]	Van Wyk & Siebert 13007 (PRU)	SEN
<i>Orthosiphon amabilis</i> (Bremek.) Codd	W.G. Barnard 421 (PRE)	SNE
<i>Orthosiphon fruticosus</i> Codd	J.P. Kluge 2372 (PRE)	SNE

<i>Orthosiphon tubiformis</i> R.D. Good	Codd & Dyer 7696 (PRE)	SEW
<i>Plectranthus venteri</i> Van Jaarsv. & Hankey	F. Venter 13626 (PRE)	SEN
<i>Plectranthus xerophilus</i> Codd	L.E.W. Codd 7712 (PRE)	SNE
<i>Tetradenia brevispicata</i> (N. E. Br.) Codd	N.J. van Warmelo 37 (PRE)	SNE

LOBELIACEAE

<i>Cyphia transvaalensis</i> E. Phillips	S. Venter 11241 (PRE)	SNE
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LOGANIACEAE

<i>Nuxia gracilis</i> Engl. [form]	A.O.D. Mogg 16967 (PRE)	SNE
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MALPIGHIACEAE

<i>Triaspis glaucophylla</i> Engl.	A.E. van Wyk 5234 (PRE)	SNE
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MALVACEAE

<i>Hibiscus barnardii</i> Exell	F. Brusse 5773 (PRE)	SEN
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MESEMBRYANTHEMACEAE

<i>Delosperma rileyii</i> L. Bolus	H. Hall 4554 (PRE)	SEW
<i>Delosperma zeederbergii</i> L. Bolus	From literature only	SEN

OLEACEAE

<i>Jasminum quinatum</i> Schinz	C.E. Gray 4186 (PRE)	SNE
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PASSIFLORACEAE

<i>Adenia fruticosa</i> Burt Davy ssp. <i>fruticosa</i>	W.G. Barnard 454 (PRE)	SNE
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PEDALIACEAE

<i>Sesamothamnus lugardii</i> N.E. Br. ex Stapf	Van Wyk, Siebert & Retief 13192 (PRU)	
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POLYGALACEAE

Polygala hottentotta Presl [form] Van Wyk & Siebert 12982 (PRU) SEN

PROTEACEAE

Protea caffra Meisn. subsp. *caffra* [form] Van Wyk & Siebert 12982 (PRU) SEN

PTAEROXYLACEAE

Ptaeroxylon obliquum (Thunb.) Radlk. [form] A.E. van Wyk 5236 (PRE) SEN

RUBIACEAE

Pavetta zeyheri Sond. [form] S.J. Siebert 22 (PRU) SEN

SANTALACEAE

Thesium multiramulosum Pilg. S. Krynauw 687 (PRE) SNE

SCROPHULARIACEAE

Jamesbrittenia macrantha (Codd) Hilliard I.B. Pole-Evans 4693A (PRE) SEN

Tetraselago wilmsii (Rolfe) Hilliard & B.L. Burt F. Wilms 5818 (PRE) SNE

SIMAROUBACEAE

Kirkia wilmsii Engl. B.J. Coetzee 1249 (PRE) SNE

STERCULIACEAE

Hermannia antonii I. Verd. G. Germishuizen 194 (PRE) SNE

Hermannia lancifolia Szyszyl. G. Germishuizen 193 (PRE) SNE

Melhania randii Baker f. I.C. Verdoorn 2485 (PRE) SNE

TILIACEAE

Grewia vernicosa Schinz C.E. Gray 60256 (PRE) SNE

VELLOZIACEAE

Xerophyta retinervis Baker [form] Van Wyk, Siebert & Retief 13208
(PRU)

VERBENACEAE

Karomia speciosa (Hutch. & Corbishley) R. Fern. A.D.J. Meeuse 10643 (PRE) SNE
 forma *speciosa*
Premna mooiensis (H. Pearson) W. Piep. [form] J.P.H. Acocks 20939 (PRE) SEN
Vitex obovata E. Mey. ssp. *wilmsii* (Gürke) C.L. J.P.H. Acocks 20938 (PRE) SNE
 Breidenkamp & D.J. Botha

VITACEAE

Cyphostemma oleraceum (Bolus) J.J.M. van der W.G. Barnard 459 (PRE) SNE
 Merwe
Cyphostemma oleraceum (Bolus) J.J.M. van der S.J. Siebert 88 (PRU) SEN
 Merwe [form]
Cyphostemma paucidentatum (Klatt) Desc. ex Wild S.J. Siebert 172 (PRU) SEN
 & R.B. Drumm. [form]
Rhoicissus tomentosa (Lam.) Wild & R.B. Drumm. S.J. Siebert 456 (PRU) SEN
 [form]
Rhoicissus tridentata (L.f.) Wild & Drumm. ssp. S.J. Siebert 48 (PRU) SEN
canefolia (Eckl. & Zeyh.) Urton [form]

BRYOPHYTES

AMBLYSTEGIACEAE

Platyhypnidium macowanianum (Paris) M. Fleisch. no voucher SNE

BRYACEAE

Brachymenium systylium (C. Müll.) A. Jaeger no voucher SNE

Appendix 2B Distribution maps of the plant taxa endemic or near-endemic to the
 Sekhukhuneland Centre of Endemism

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Distribution maps of the endemic/near-endemic taxa

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Sekhukhuneland narrow endemics: 1–30

Sekhukhuneland wide endemics: 30–51

Sekhukhuneland near-endemics: 52–121

Sekhukhuneland localised near-endemics: 52–65

Sekhukhuneland disjunct near-endemics: 66–121

Sekhukhuneland-Waterberg: 66–77

Sekhukhuneland-Waterberg-Soutpansberg-Barberton: 78–81

Sekhukhuneland-Waterberg-Soutpansberg: 82–85

Sekhukhuneland-Waterberg-Magaliesberg: 86–93

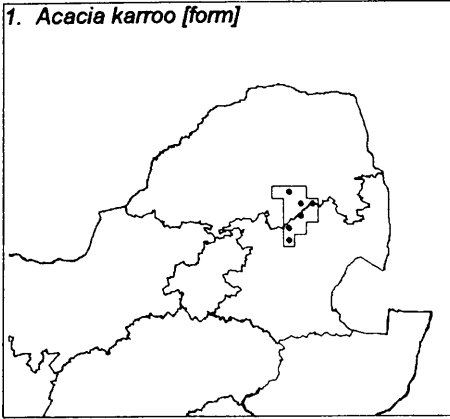
Sekhukhuneland-Waterberg-Soutpansberg-Barberton-Magaliesberg: 94–100

Sekhukhuneland-Barberton: 101–107

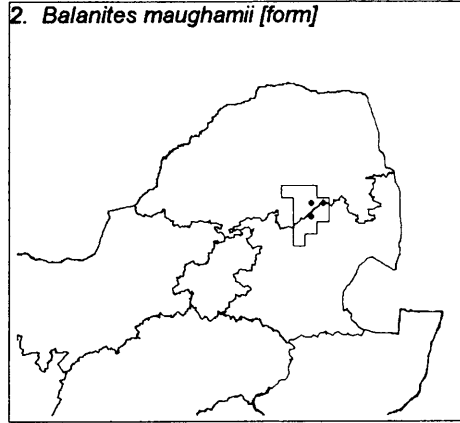
Sekhukhuneland-Soutpansberg: 108–113

Sekhukhuneland-Magaliesberg-Barberton-Soutpansberg: 114–121

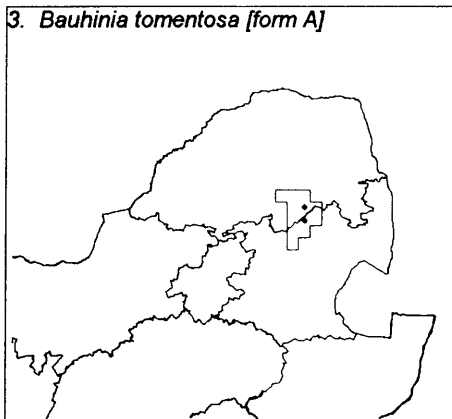
1. *Acacia karroo* [form]



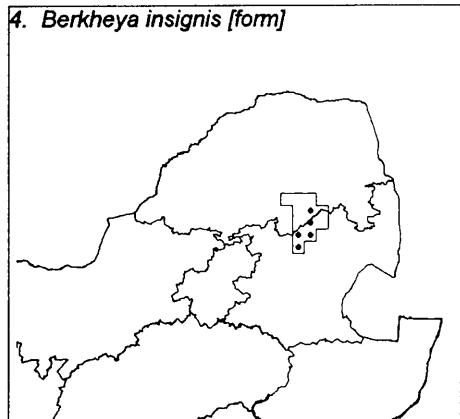
2. *Balanites maughamii* [form]



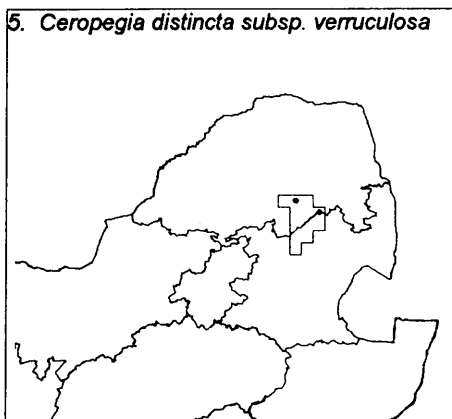
3. *Bauhinia tomentosa* [form A]



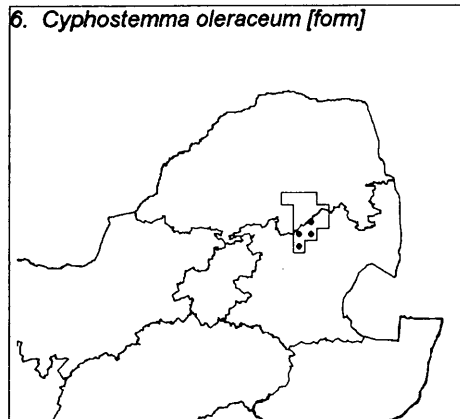
4. *Berkheya insignis* [form]



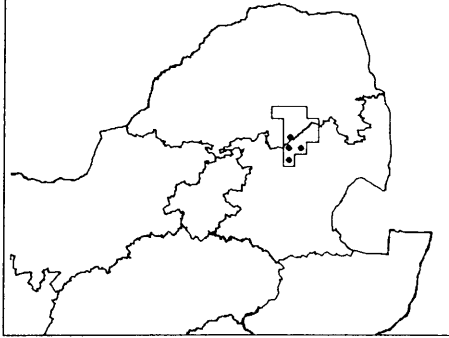
5. *Ceropegia distincta* subsp. *verruculosa*



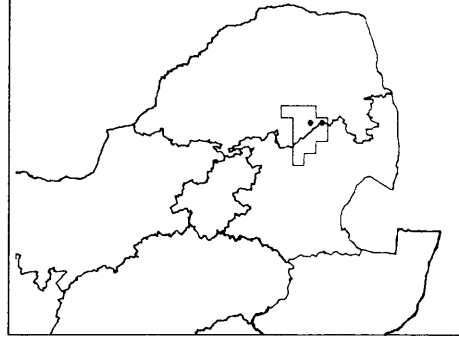
6. *Cyphostemma oleraceum* [form]



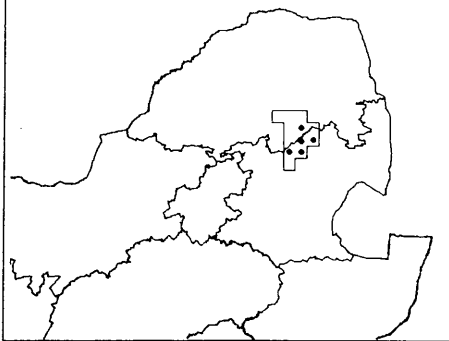
7. *Cyphostemma paucidentatum* [form]



8. *Delosperma zeederbergii*



9. *Elephantorrhiza praeternissa*



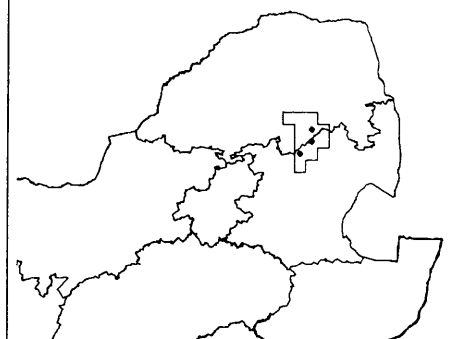
10. *Euphorbia barnardii*



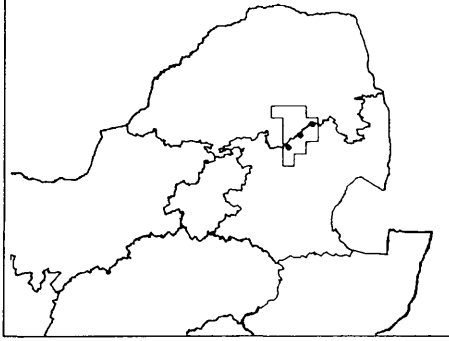
11. *Euphorbia schinzii* [form]



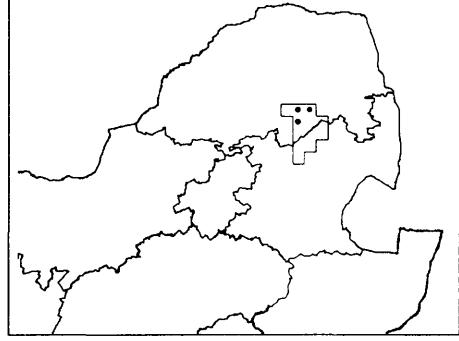
12. *Euphorbia sekhukhuniensis*



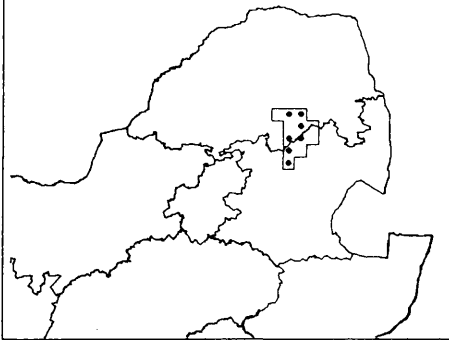
13. *Gymnosporia senegalensis* [form]



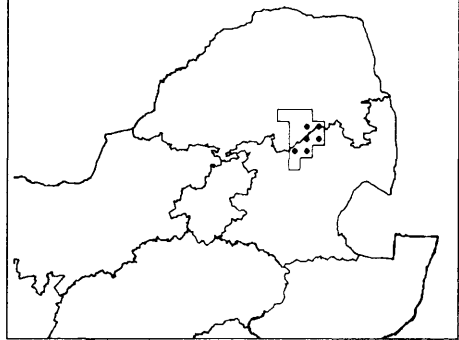
14. *Hibiscus bamardii*



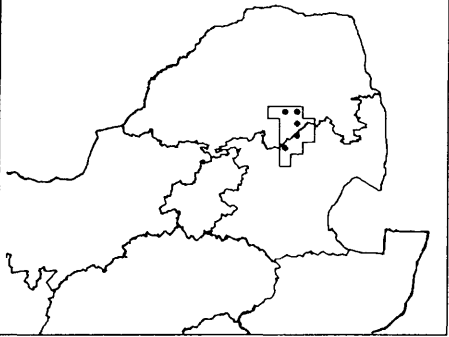
15. *Jamesbrittenia macrantha*



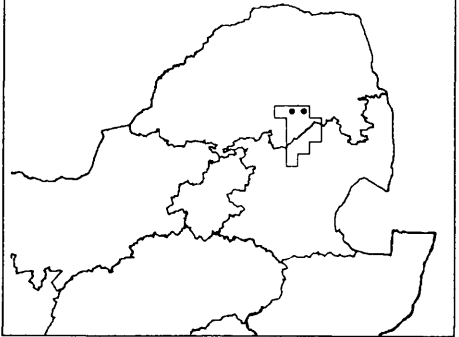
16. *Leucas capensis* [form]



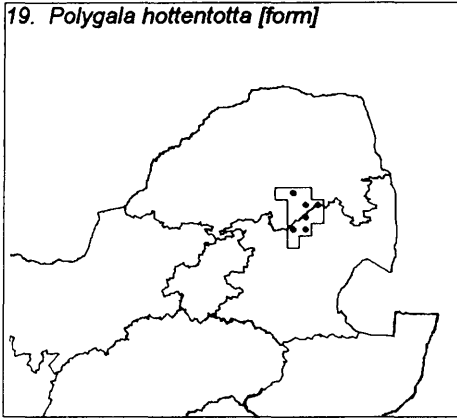
17. *Pavetta zeyheri* [form]



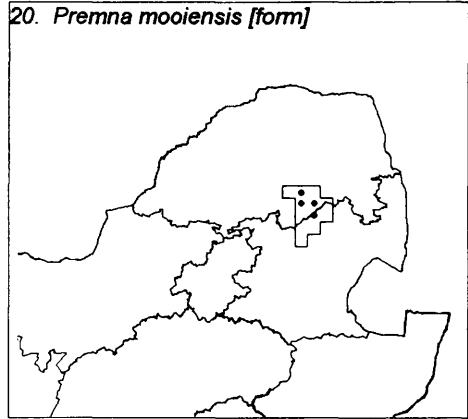
18. *Plectranthus venterii*



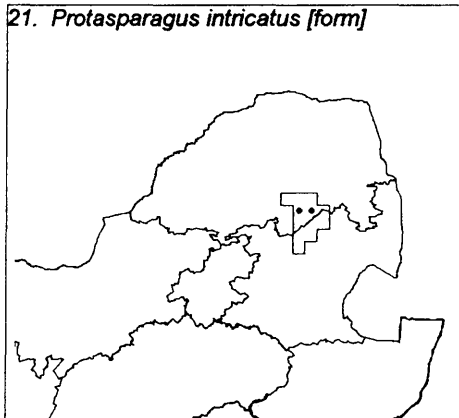
19. *Polygala hottentotta* [form]



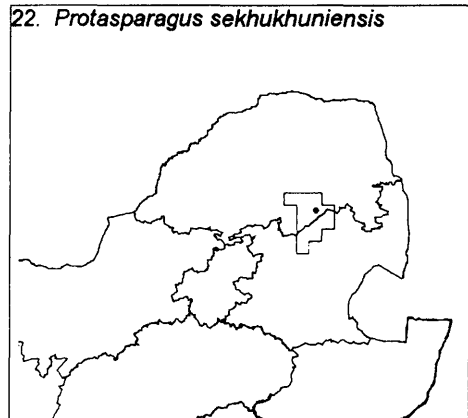
20. *Premna mooiensis* [form]



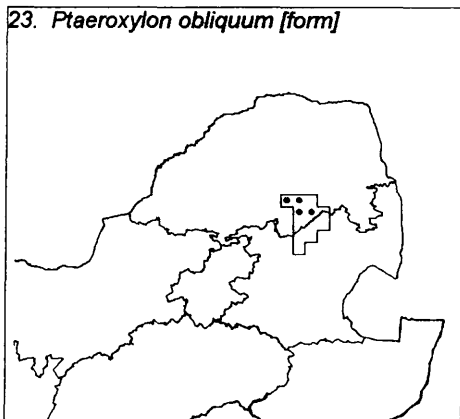
21. *Protasparagus intricatus* [form]



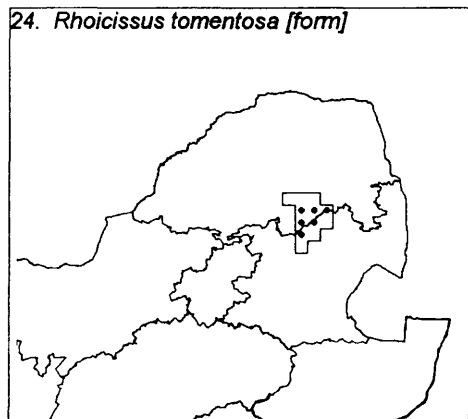
22. *Protasparagus sekhukhuniensis*



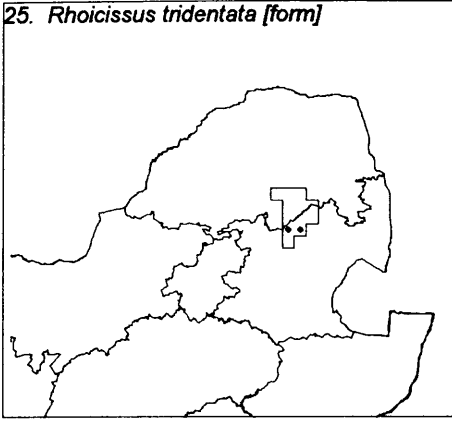
23. *Ptaeroxylon obliquum* [form]



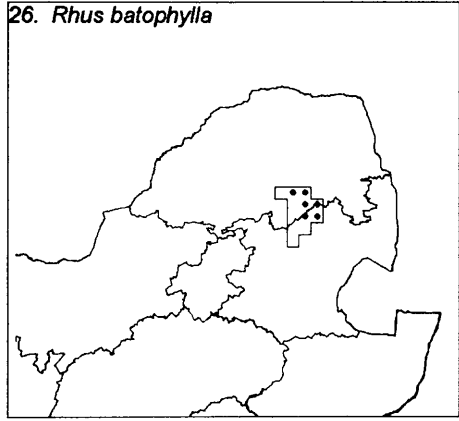
24. *Rhoicissus tomentosa* [form]



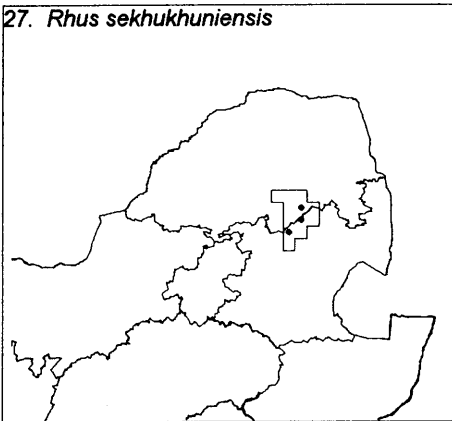
25. *Rhoicissus tridentata* [form]



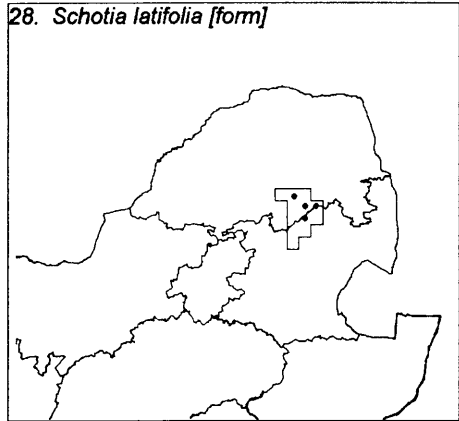
26. *Rhus batophylla*



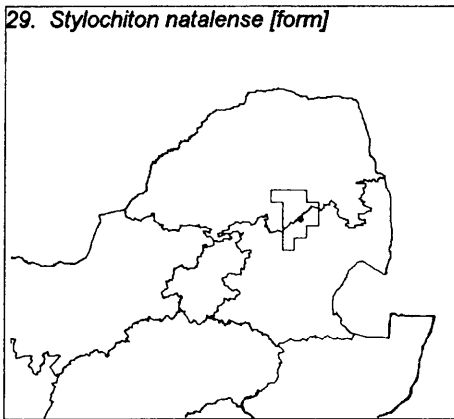
27. *Rhus sekhukhuniensis*



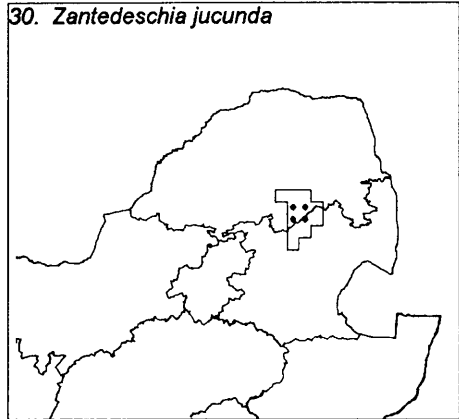
28. *Schotia latifolia* [form]



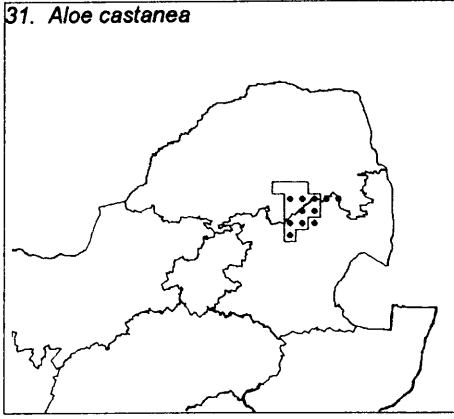
29. *Stylochiton natalense* [form]



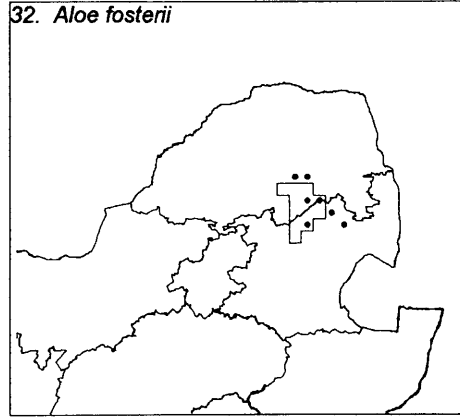
30. *Zantedeschia jucunda*



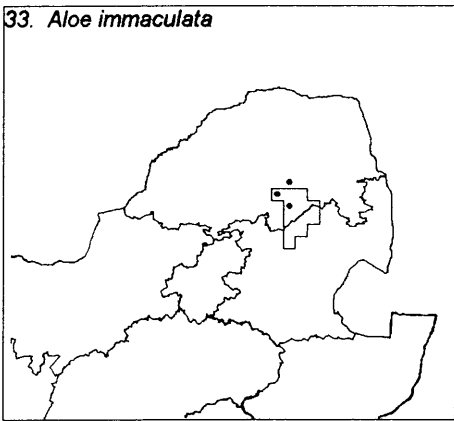
31. *Aloe castanea*



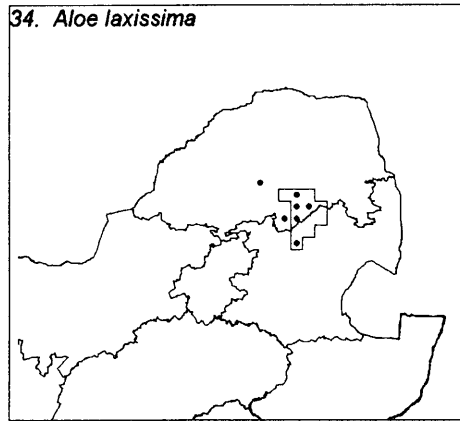
32. *Aloe fosterii*



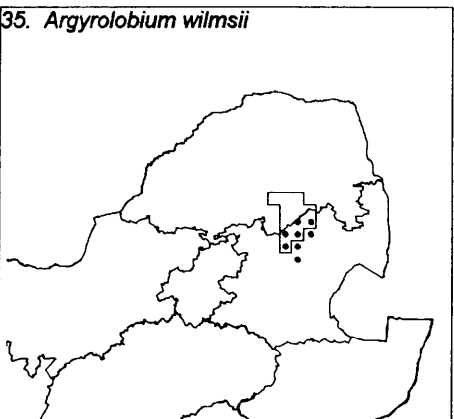
33. *Aloe immaculata*



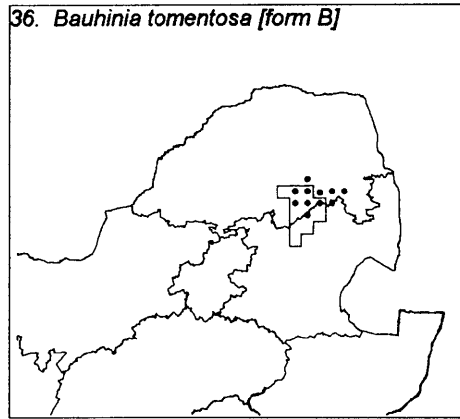
34. *Aloe laxissima*



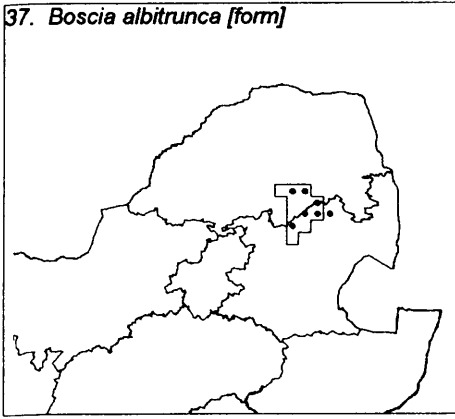
35. *Argyrobium wilmsii*



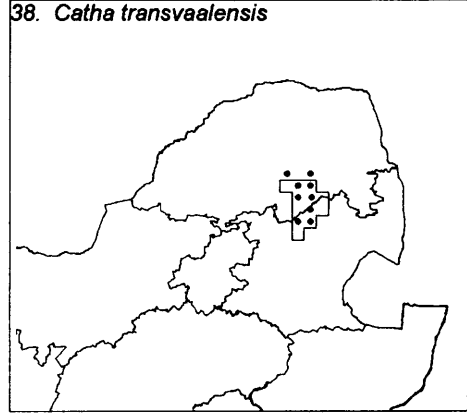
36. *Bauhinia tomentosa* [form B]



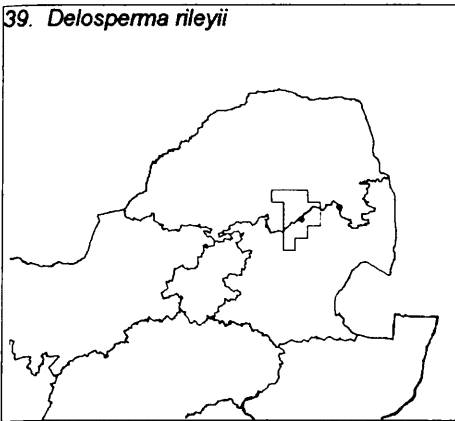
37. *Boscia albitrunca* [form]



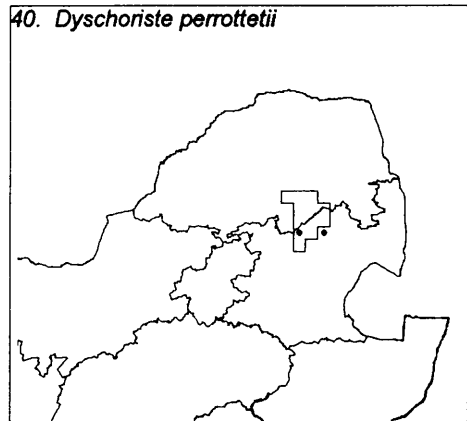
38. *Catha transvaalensis*



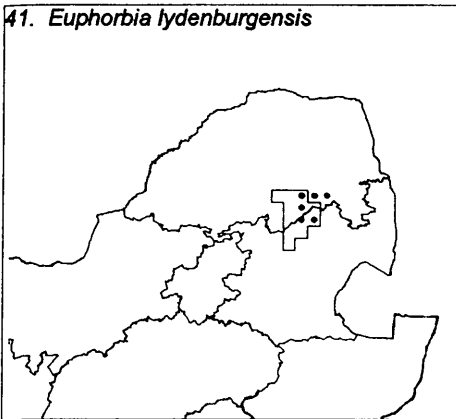
39. *Delosperma rileyi*



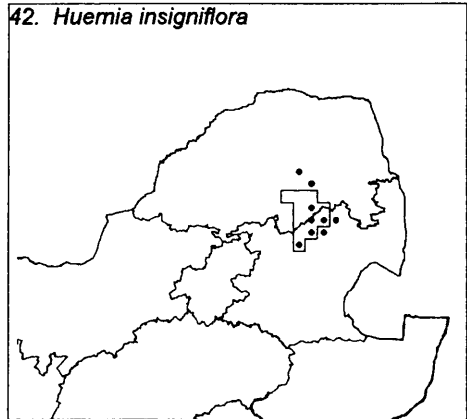
40. *Dyschoriste perrottetii*



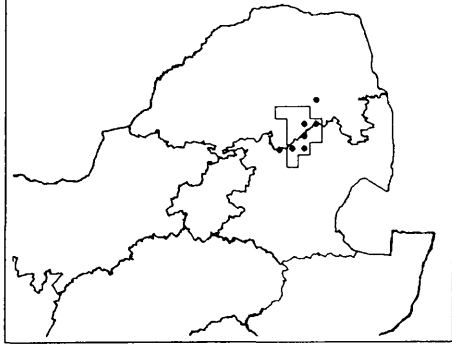
41. *Euphorbia lydenburgensis*



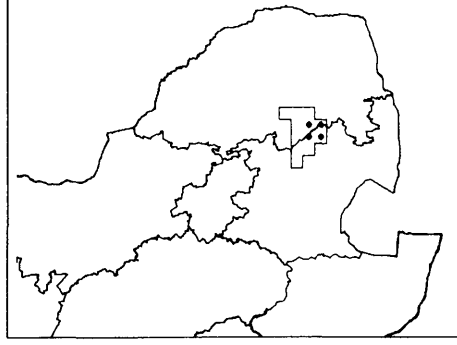
42. *Huemia insigniflora*



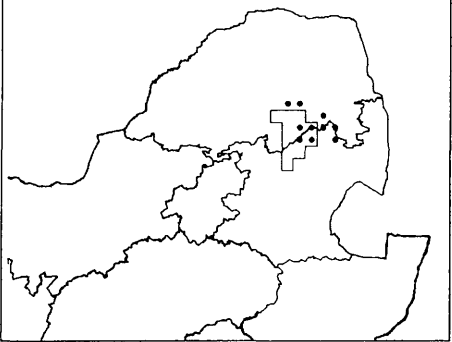
43. *Ipomoea bathycolpos* var. *sinuatodentat*



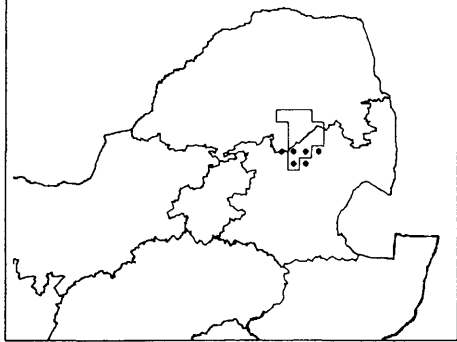
44. *Kleinia longiflora* [form]



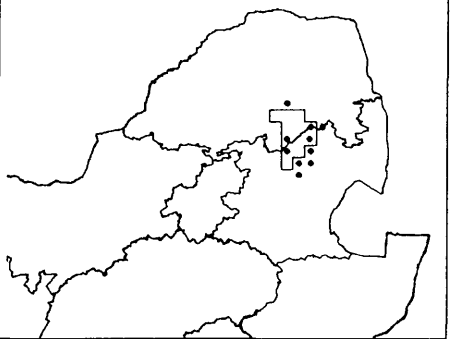
45. *Orthosiphon tubiformis*



46. *Protea caffra* [form]



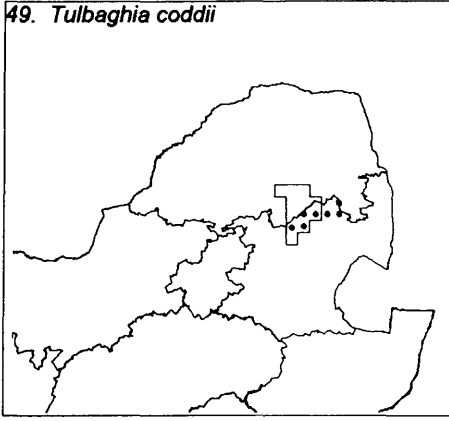
47. *Rhus tumulicola* var. *meeus. forma pumi*



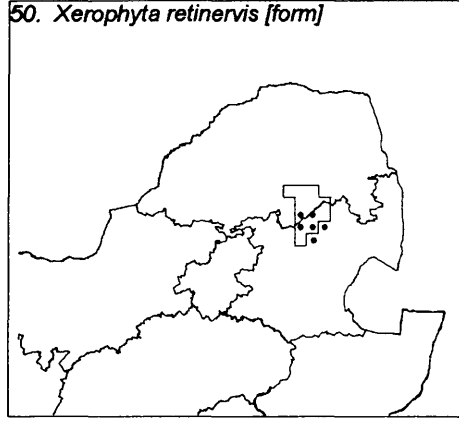
48. *Sansevieria hyacinthoides* [form]



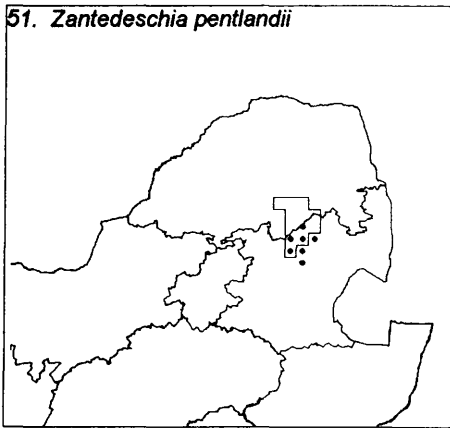
49. *Tulbaghia coddii*



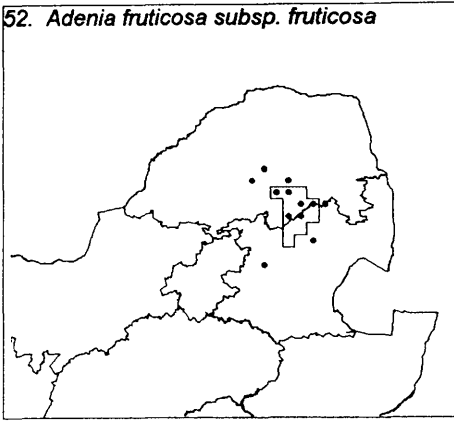
50. *Xerophyta retinervis* [form]



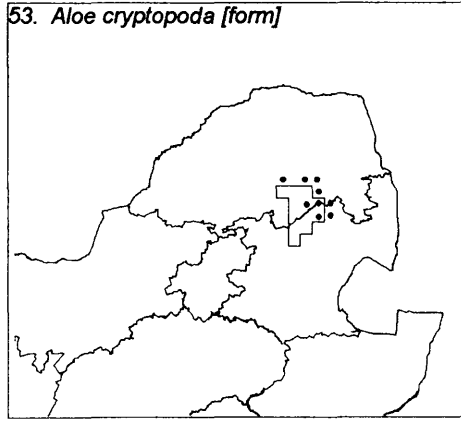
51. *Zantedeschia pentlandii*



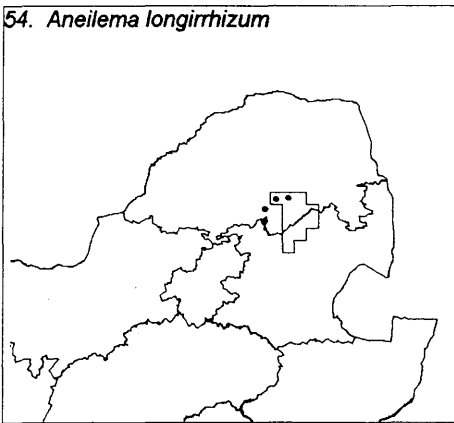
52. *Adenia fruticosa* subsp. *fruticosa*



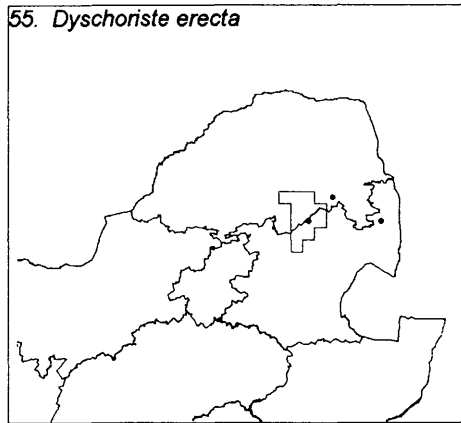
53. *Aloe cryptopoda* [form]



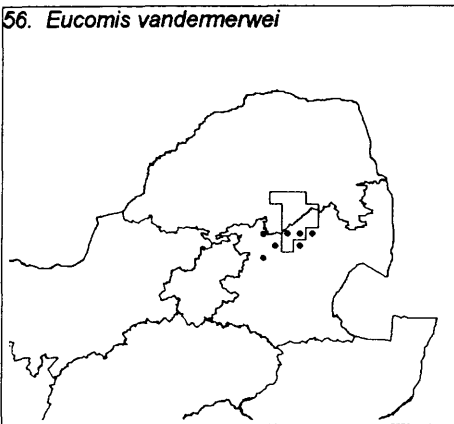
54. *Aneilema longirhizum*



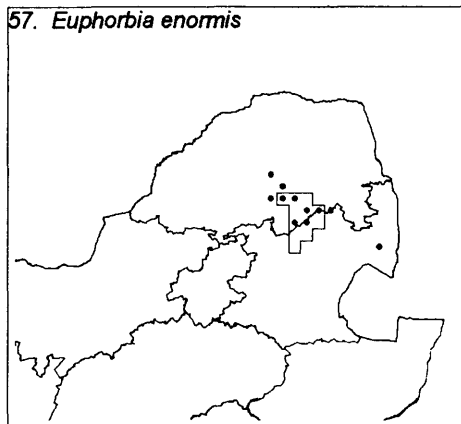
55. *Dyschoriste erecta*



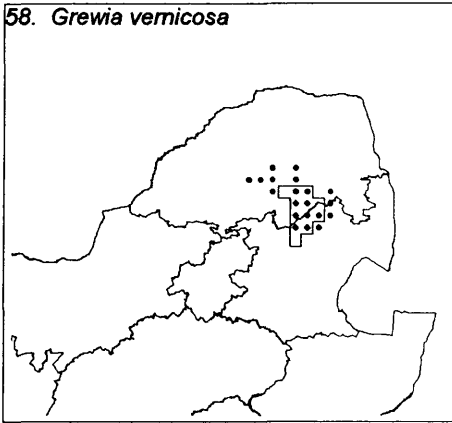
56. *Eucomis vandermerwei*



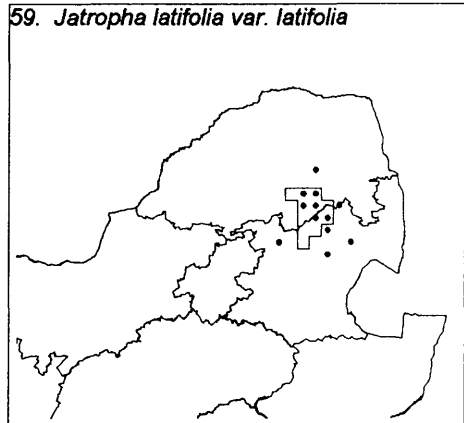
57. *Euphorbia enormis*



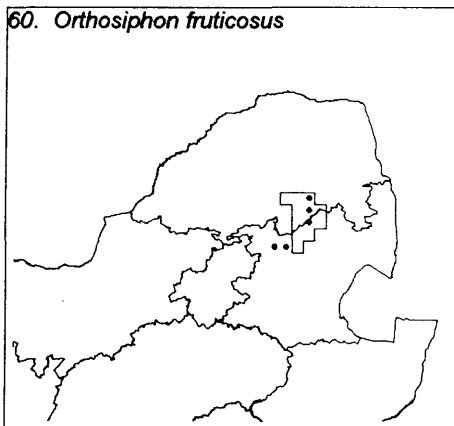
58. *Grewia vermicosa*



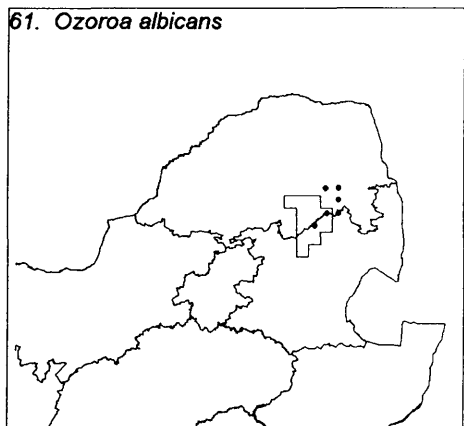
59. *Jatropha latifolia* var. *latifolia*



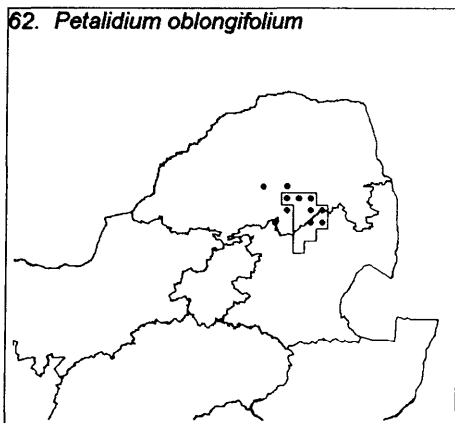
60. *Orthosiphon fruticosus*



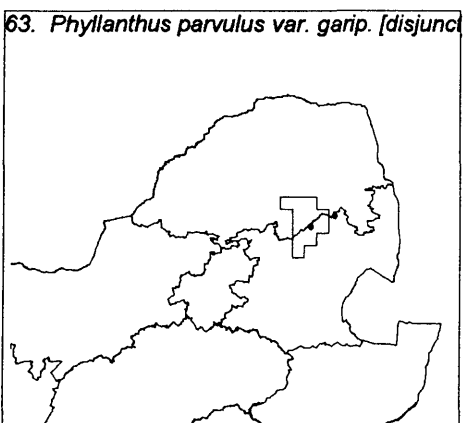
61. *Ozoroa albicans*

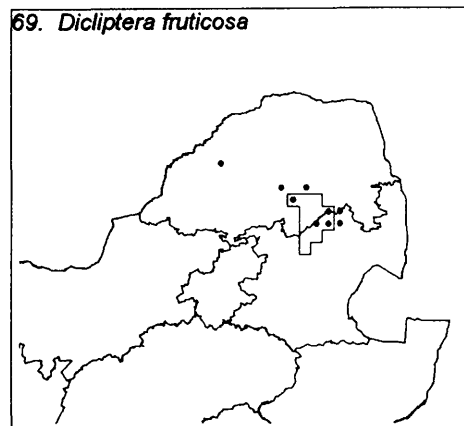
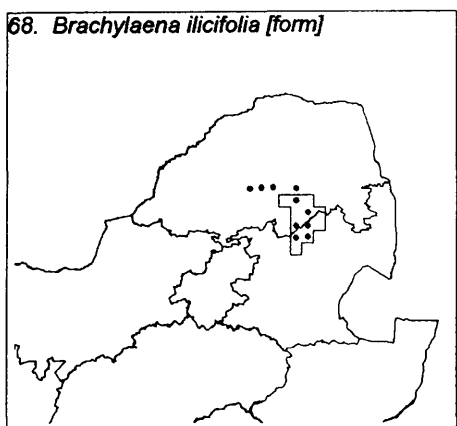
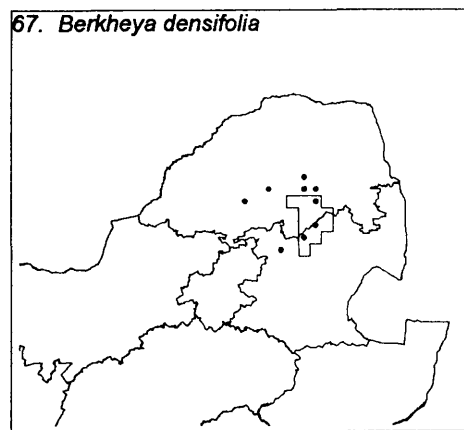
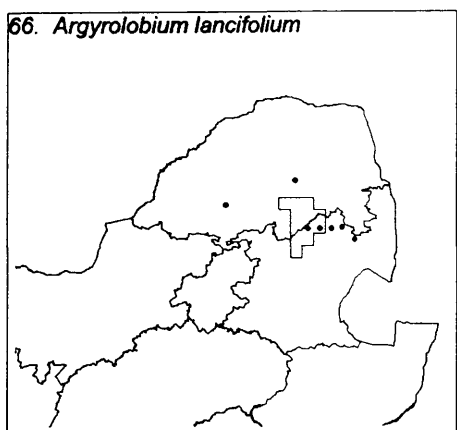
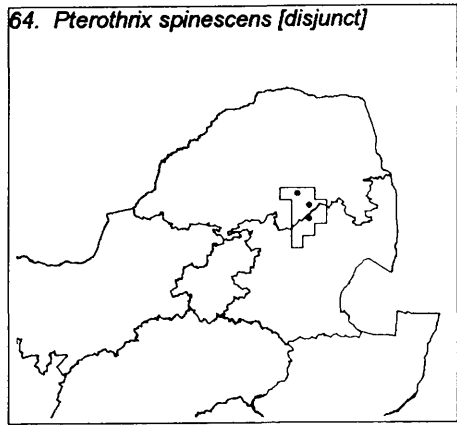


62. *Petalidium oblongifolium*

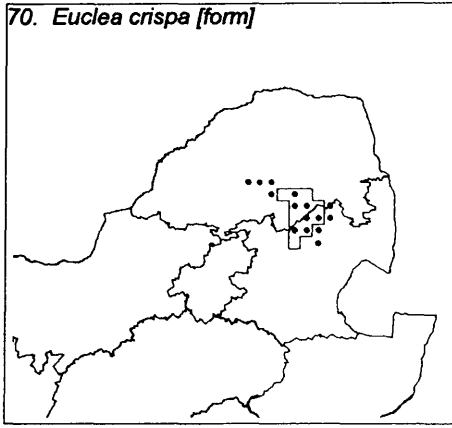


63. *Phyllanthus parvulus* var. *garip.* [disjunct]

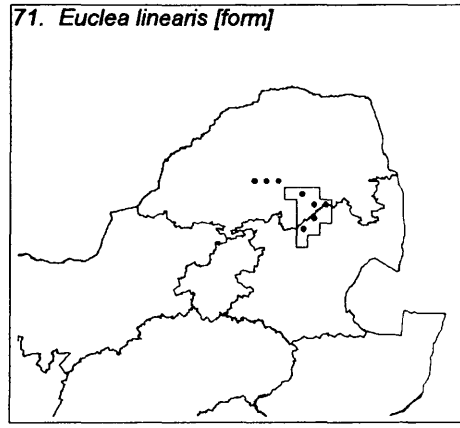




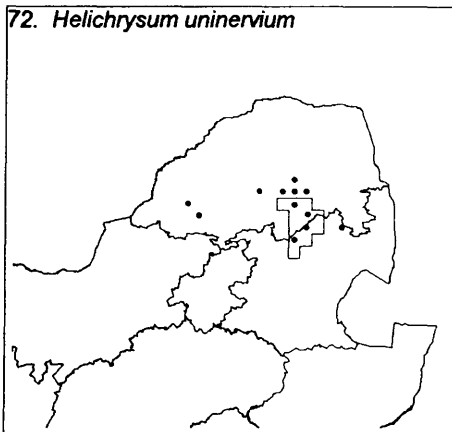
70. *Euclea crisper* [form]



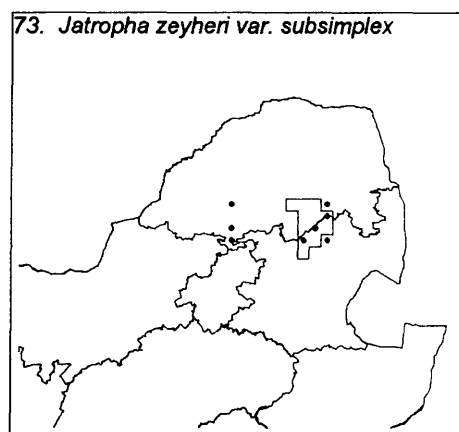
71. *Euclea linearis* [form]



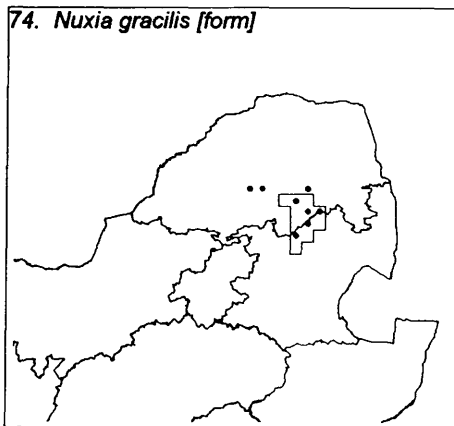
72. *Helichrysum uninervium*



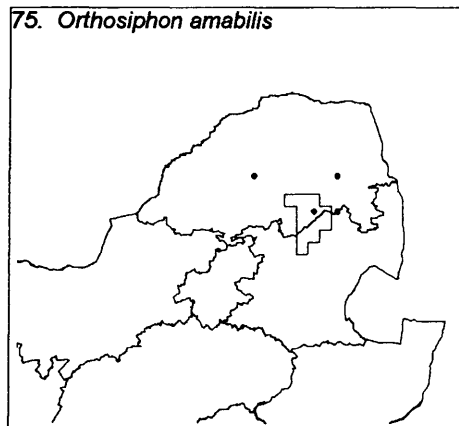
73. *Jatropha zeyheri* var. *subsimplex*



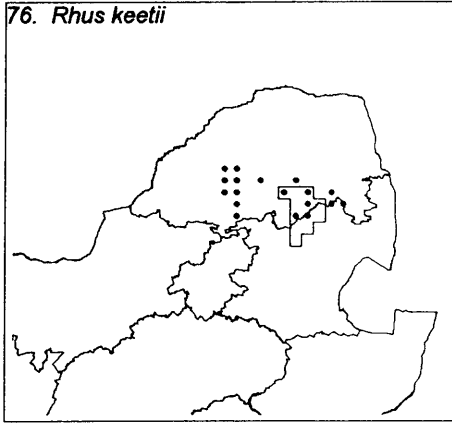
74. *Nuxia gracilis* [form]



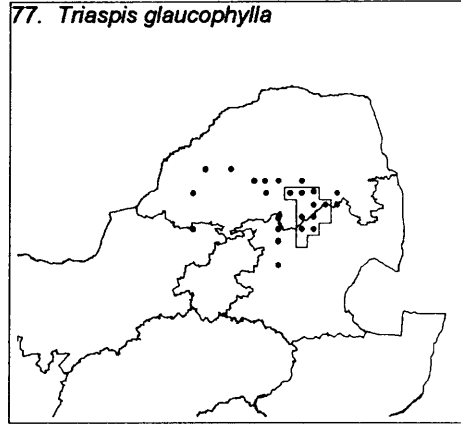
75. *Orthosiphon amabilis*



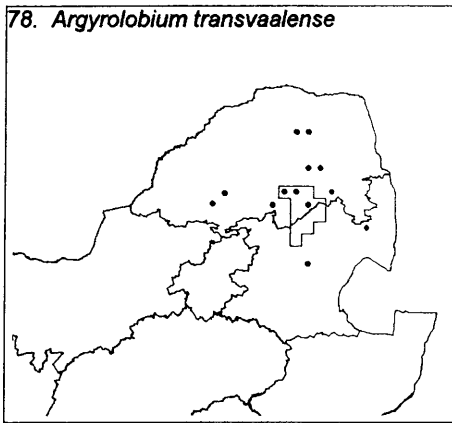
76. *Rhus keetii*



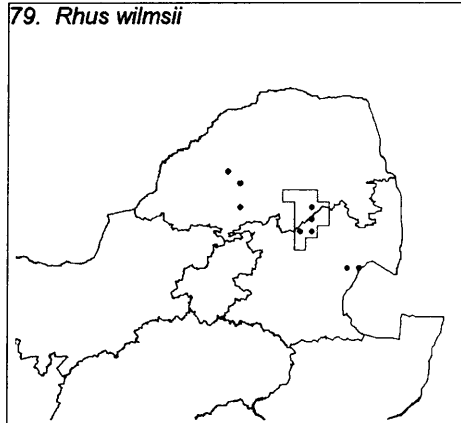
77. *Triaspis glaucophylla*



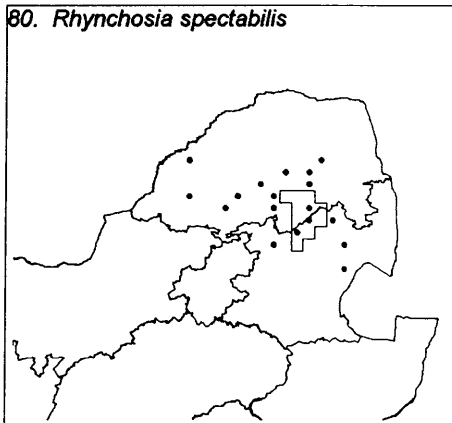
78. *Argyrobium transvaalense*



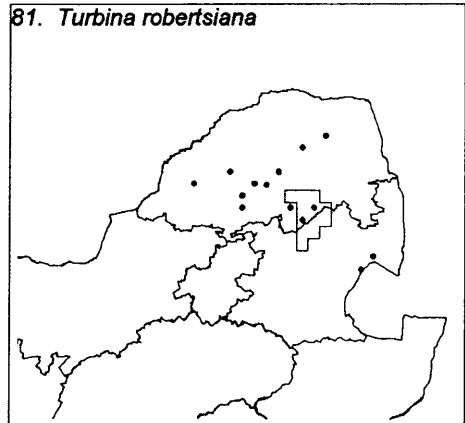
79. *Rhus wilmsii*



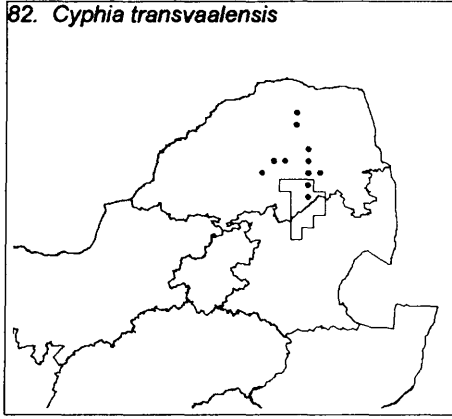
80. *Rhynchosia spectabilis*



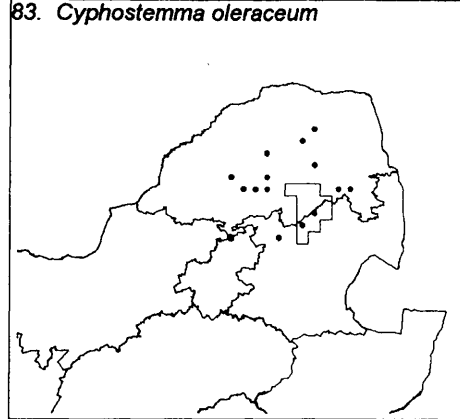
81. *Turbina robertsiana*



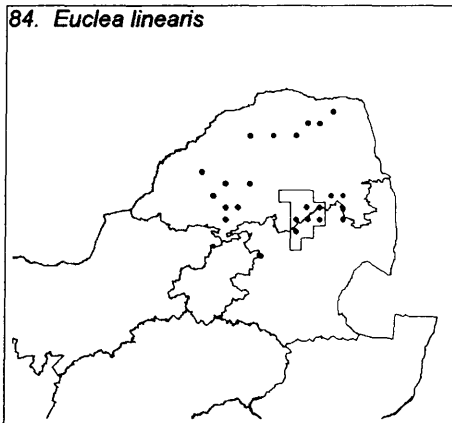
82. *Cyphia transvaalensis*



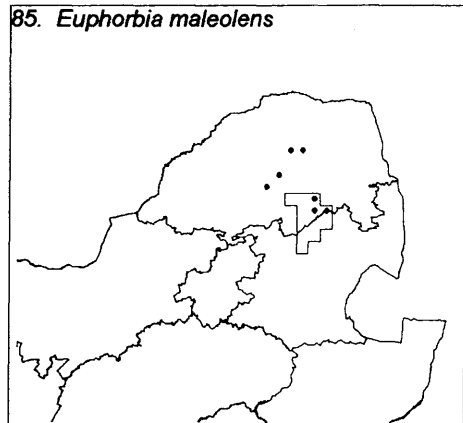
83. *Cyphostemma oleraceum*



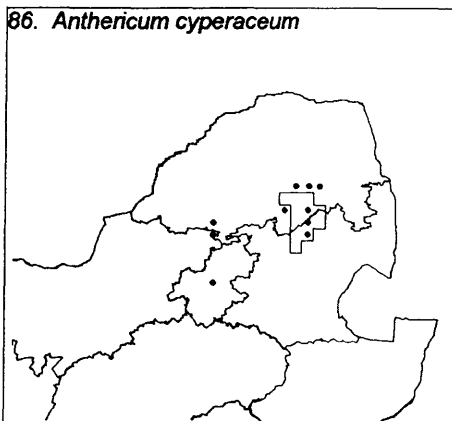
84. *Euclea linearis*



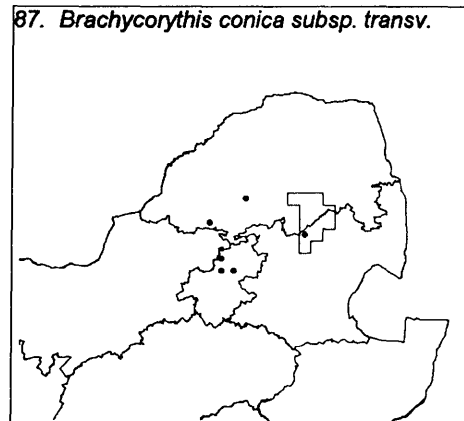
85. *Euphorbia maleolens*



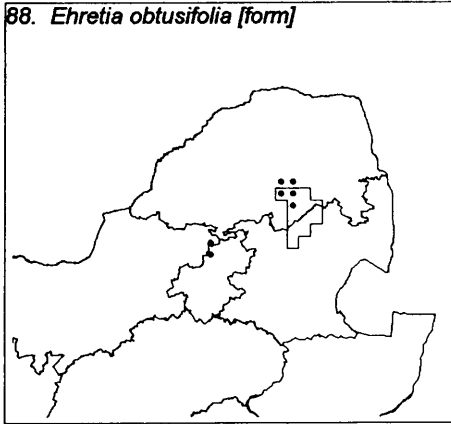
86. *Anthericum cyperaceum*



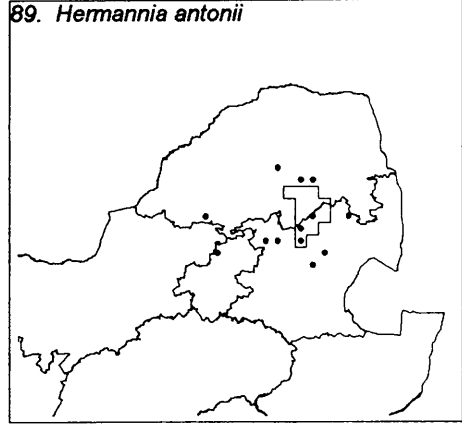
87. *Brachycorythis conica* subsp. *transv.*



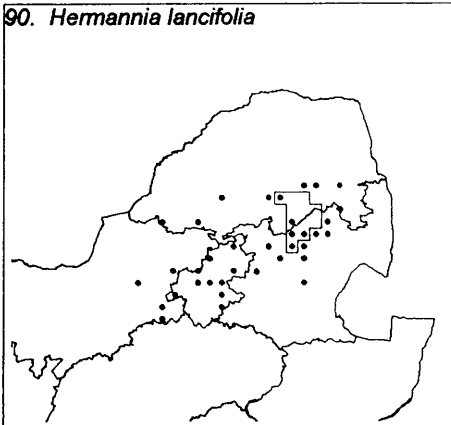
88. *Ehretia obtusifolia* [form]



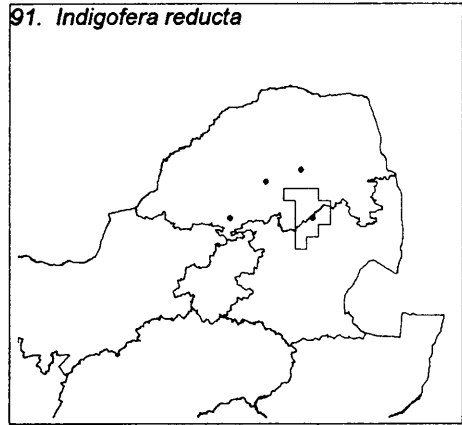
89. *Hermannia antonii*



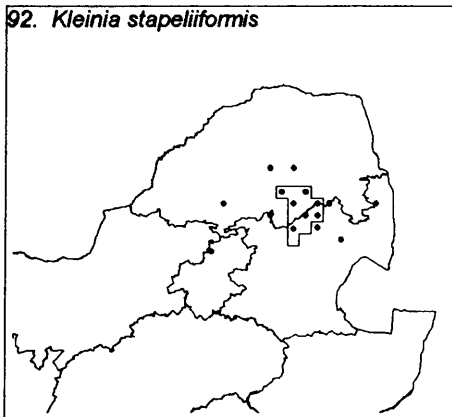
90. *Hermannia lancifolia*



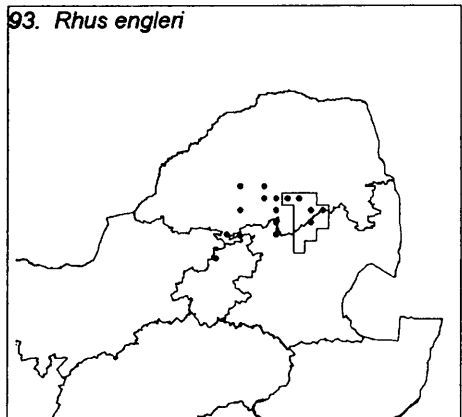
91. *Indigofera reducta*

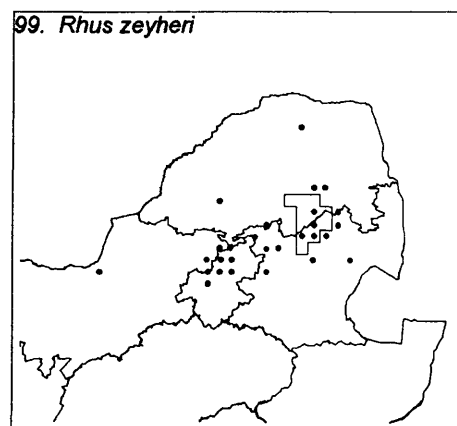
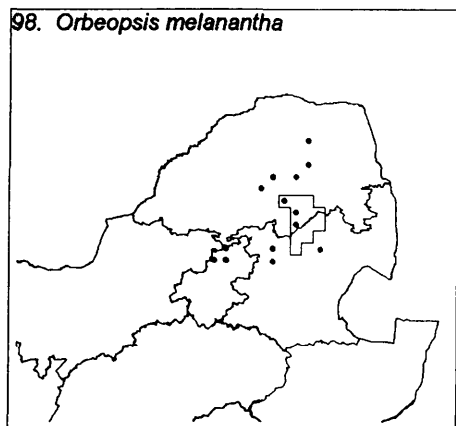
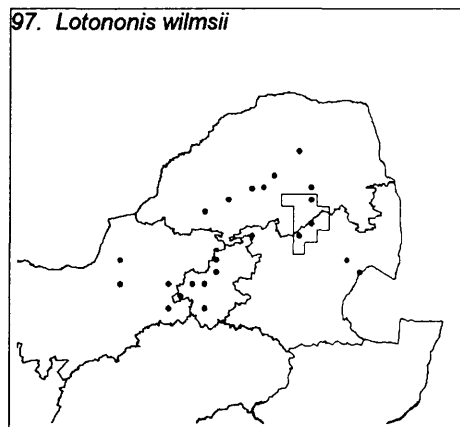
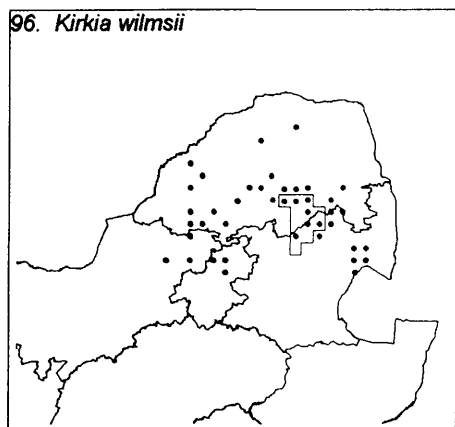
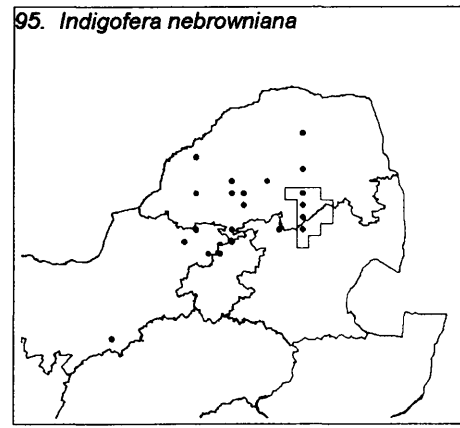
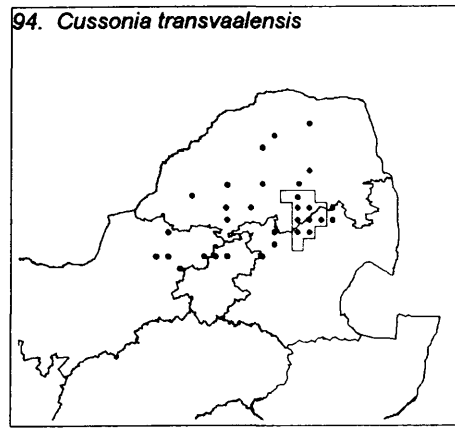


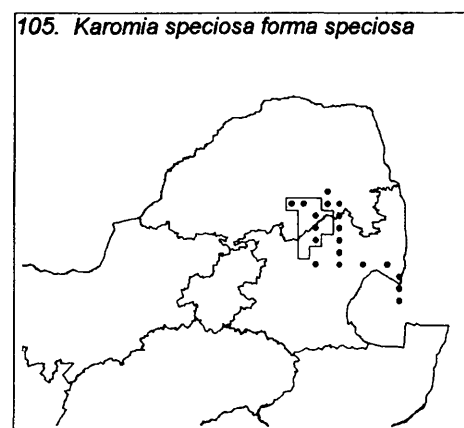
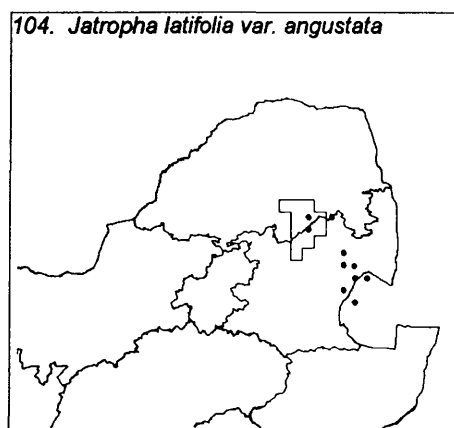
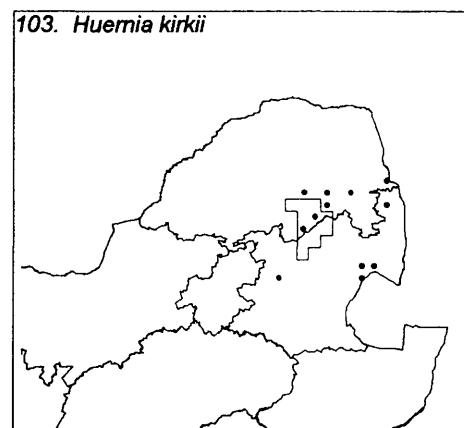
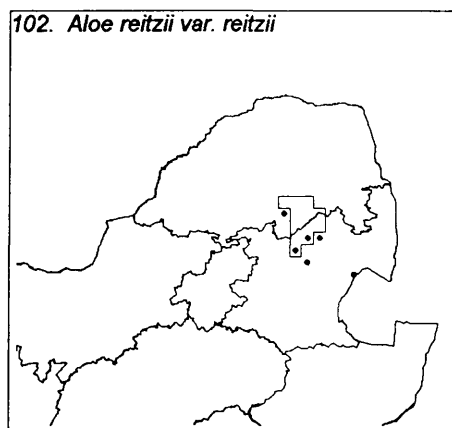
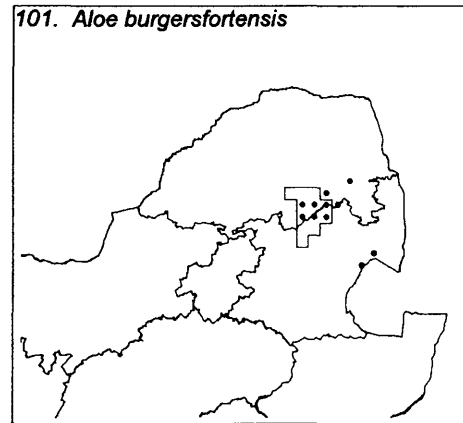
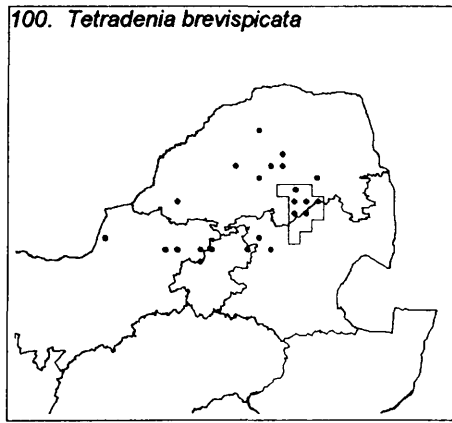
92. *Kleinia stapeliiformis*

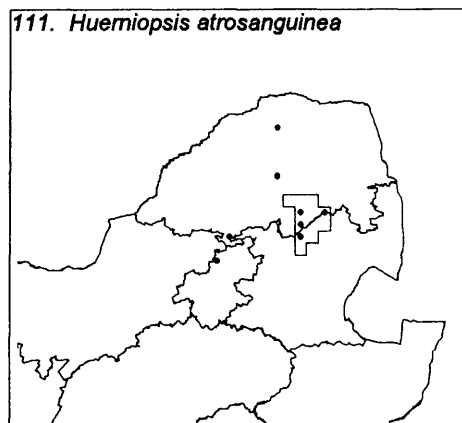
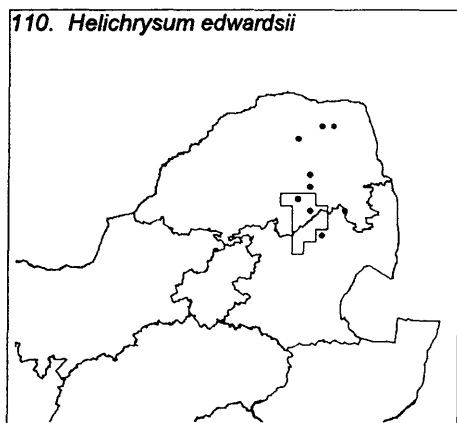
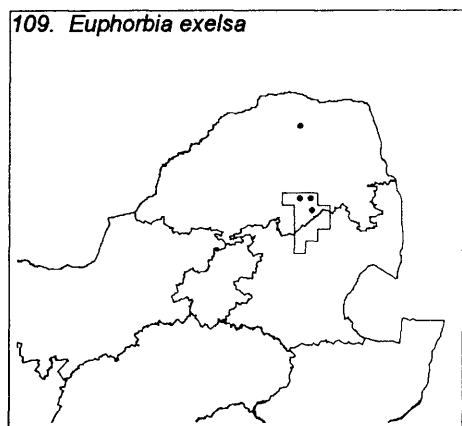
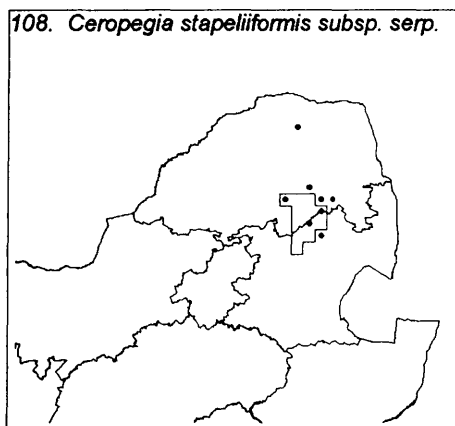
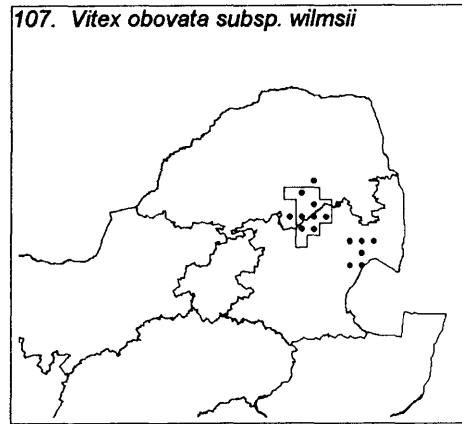
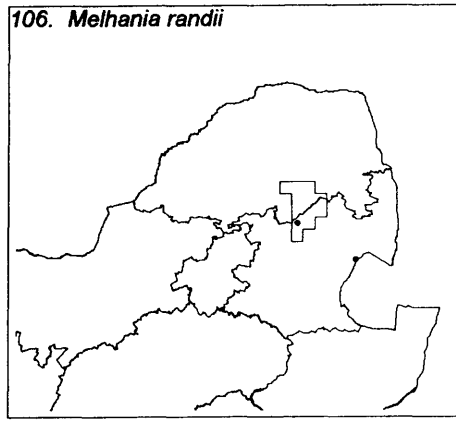


93. *Rhus engleri*

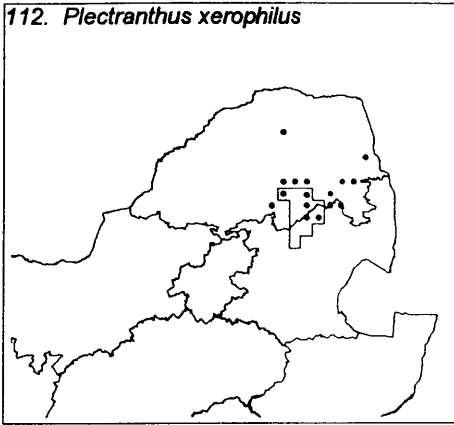




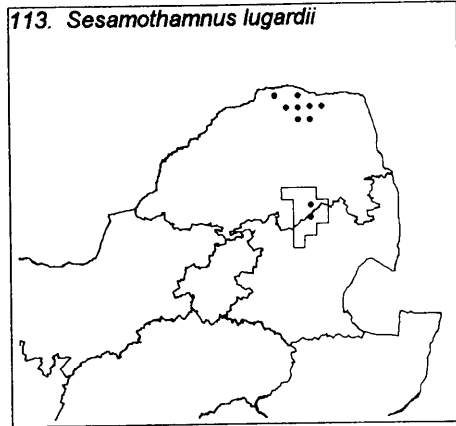




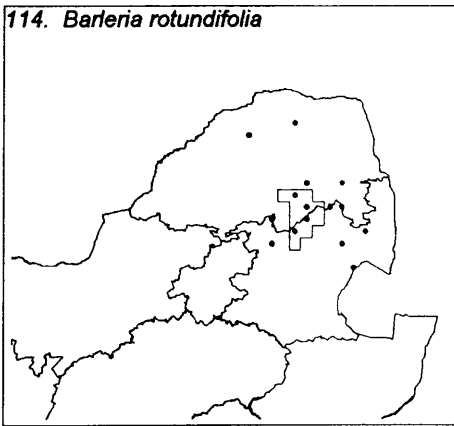
112. *Plectranthus xerophilus*



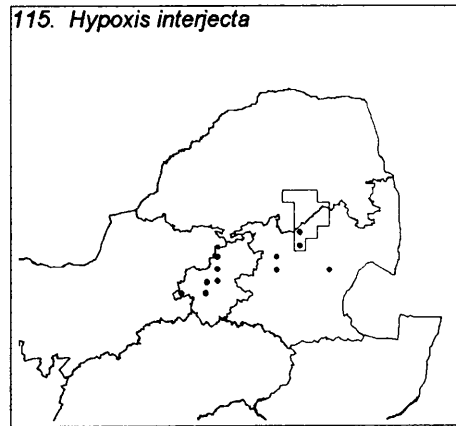
113. *Sesamothamnus lugardii*



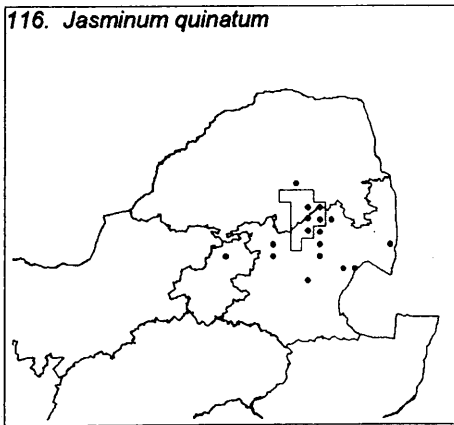
114. *Barleria rotundifolia*



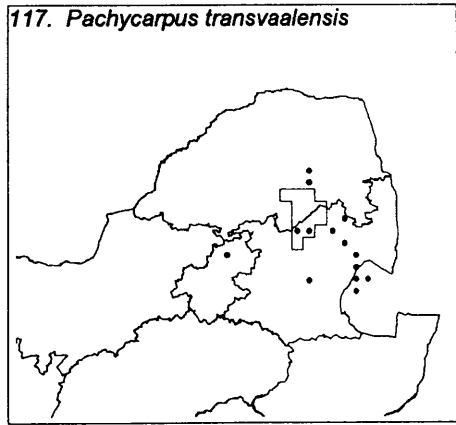
115. *Hypoxis interjecta*



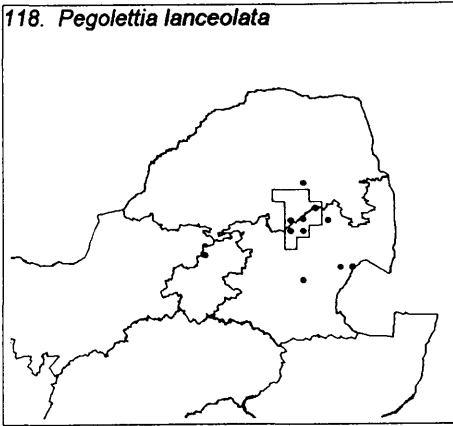
116. *Jasminum quinatum*



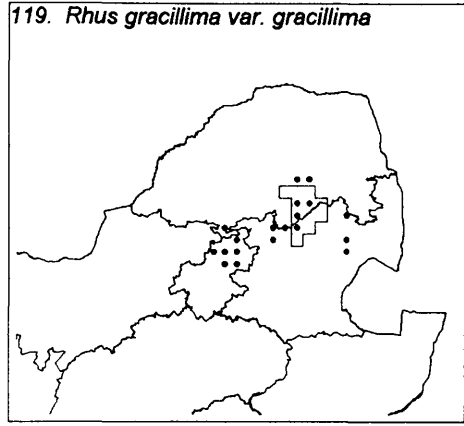
117. *Pachycarpus transvaalensis*



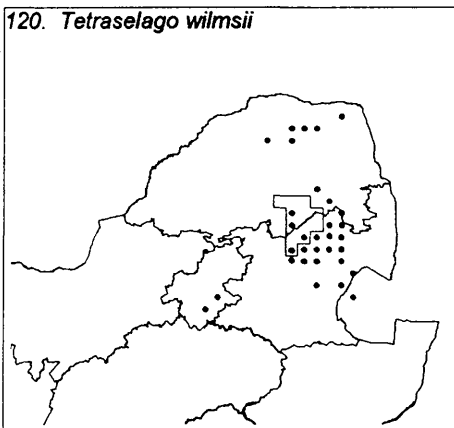
118. *Pegolettia lanceolata*



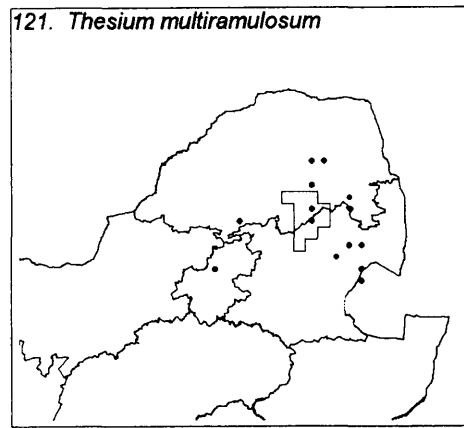
119. *Rhus gracillima* var. *gracillima*



120. *Tetraselago wilmsii*



121. *Thesium multiramulosum*



Appendix 3A Formation percentages in each quarter degree grid grouped according to the five main rock types of the Sekhukhuneland Study Area

The percentage composition of each rock formation in each quarter degree grid is given. The order of the quarter degree grids and the rock formations are kept the same as in Table 14. The five main groups of rock types (formations) are listed below:

1. = Norite, pyroxenite, anorthosite and magnetite of the RLS;
2. = Quartzite, shale and hornfels of the TS;
3. = Ferrogabbro and ferrodiorite of the RLS;
4. = Alluvium;
5. = Other rocks not included in 1 to 4.

The percentage surface area for each rock type, and each group of rock types, are given on the next page.

**	2429 BC	2429 BD	2429 DB	2429 DD	2529 BB	2529 BD	2430 AC	2430 CA	2430 CB	2430 CC	2430 CD	2530 AA	%
d	0.8	-	-	3.8	-	-	2.2	2.5	11.7	0.5	7.5	9.4	3.2
C	-	-	-	3.1	0.2	-	-	-	-	-	-	-	0.3
Mr	-	-	-	2.3	14.4	3.6	-	-	-	-	-	-	1.7
%*1	0.8	0	0	9.2	14.6	3.6	2.2	2.5	11.7	0.5	7.5	9.4	5.2
Vpx	-	-	-	-	-	-	-	1.0	4.5	-	0.3	-	0.5
Vcr	-	7.0	-	-	-	-	3.5	5.4	4.1	-	0.4	-	1.7
Vsn	-	-	-	-	-	-	2.7	1.4	2.8	10.1	1.2	3.6	1.8
Vdj	8.7	59.4	19.7	8.8	36.0	23.5	1.6	31.2	-	30.7	-	35.6	21.3
Vdr	-	13.1	-	-	-	-	5.2	10.7	-	10.3	-	15.5	4.6
Vno	-	-	-	-	-	-	-	-	-	1.7	-	-	0.1
%*1	8.7	79.5	19.7	8.8	36.0	23.5	13.0	49.7	11.4	52.8	1.9	54.7	30.0
Vrs	51.2	15.7	41.7	25.0	36.2	41.4	-	-	-	1.2	-	-	17.7
%*3	51.2	15.7	41.7	25.0	36.2	41.4	0	0	0	1.2	0	0	17.7
Vgd	-	-	-	-	-	-	1.3	-	-	-	-	-	0.1
Mn	-	-	28.2	50.4	7.8	-	-	-	-	1.4	-	-	7.3
h	-	-	-	-	-	1.1	-	-	-	-	-	-	0.1
%*1	0	0	28.2	50.4	7.8	1.1	1.3	0	0	1.4	0	0	7.5
Vmc	1.8	2.9	10.4	5.3	-	-	-	-	-	-	-	-	1.7
Vla	2.4	0.2	-	-	1.0	-	-	-	-	2.4	-	7.2	1.1
Vve	0.3	0.2	-	-	-	-	-	4.4	-	9.0	6.8	1.5	1.9
Vsi	8.7	0.5	-	-	-	-	13.4	2.3	28.9	1.3	42.8	-	8.2
Vdu	3.8	-	-	-	-	-	-	-	-	-	-	-	0.3
Vma	5.7	-	-	-	-	-	4.1	-	-	-	-	-	0.8
Vsb	-	-	-	-	-	2.2	-	-	-	2.1	-	10.9	1.3
Vdp	-	-	-	-	-	-	4.1	-	8.4	-	-	-	1.0
Vpe	2.1	-	-	-	-	-	-	-	-	-	-	-	0.2
Vmb	4.3	0.5	-	-	-	-	7.2	6.1	5.1	3.0	20.7	-	3.9
Vtb	5.7	0.3	-	-	-	-	10.8	-	9.9	-	-	-	2.2
Vst	2.3	0.2	-	-	-	-	-	-	-	-	-	-	0.2
Vne	-	-	-	-	-	-	-	-	-	1.1	-	0.8	0.2
%*2	37.1	4.8	10.4	5.3	1.0	2.2	39.6	12.8	52.3	18.9	70.3	20.4	23.0
Vdw	-	-	-	-	-	7.8	-	-	-	-	-	-	0.7
Vse	-	-	-	-	-	2.7	-	-	-	-	-	-	0.2
Vhe	-	-	-	-	-	-	-	-	1.1	-	-	-	0.1
Vds	-	-	-	-	-	14.8	-	-	-	-	-	-	1.2
I	-	-	-	1.3	4.4	2.9	-	-	-	-	-	-	0.7
%*1	0	0	0	1.3	4.4	28.2	0	0	1.1	0	0	0	2.9
Q	2.2	-	-	-	-	-	43.9	35.0	23.5	25.2	20.3	15.8	13.8
%*4	2.2	0	0	0	0	0	43.9	35.0	23.5	25.2	20.3	15.8	13.8
1.	8.7	79.5	19.7	8.8	36.0	23.5	13.0	49.7	11.4	52.8	1.9	54.7	30.0
2.	37.1	4.8	10.4	5.3	1.0	2.2	39.6	12.8	52.3	18.9	70.3	20.4	23.0
3.	51.2	15.7	41.7	25.0	36.2	41.4	0	0	0	1.2	0	0	17.7
4.	2.2	0	0	0	0	0	43.9	35.0	23.5	25.2	20.3	15.8	13.8
5.	0.8	0	28.2	60.9	26.8	32.9	3.5	2.5	12.8	1.9	7.5	9.4	15.6

** Rock formation

Appendix 3B Percentage values used in Figure 19 (5.3.2) to display the relationship between percentage endemism* and rock type surface percentage for the quarter degree grids of the Sekhukhuneland Study Area

* Based on the number of SSA endemics in each QDG

Number	QDG	Endemics	1	2	3	4	5
1	2430 CA	60	50	13	0	3.4	0.3
2	2430 CC	60	53	18	1	2.5	0.3
3	2429 BD	36	79	05	16	0	0
4	2529 BB	36	36	01	36	0	2.7
5	2530 AA	32	54	20	0	1.6	1.0
6	2430 CB	32	11	53	0	2.4	1.2
7	2429 DB	26	20	10	42	0	2.8
8	2430 CD	22	02	70	0	2.0	0.8
9	2430 AC	22	13	40	0	4.3	0.4
10	2529 BD	22	24	02	41	0	3.3
11	2429 BC	12	09	31	51	0.2	0.7
12	2429 DD	12	09	05	25	0	6.1

Additional Notes: Endemism & near-endemism (also compare 4.2.1)

A taxon with 75% of its world distribution centred in the Sekhukhuneland Study Area [SSA], was viewed as endemic to this region, whereas a taxon with 25-75% of its world distribution centred in the SSA, was viewed as a near-endemic. Arguments for the choice of these percentages are based on the following:

Endemism

The percentage cut off point for an endemic distribution was chosen below 100 percent and above 75 percent of a taxon's world distribution due to one or more of the following reasons:

1. Why should taxon A with 100% of its world distribution in the SSA be regarded as an endemic and taxon B with 99% of its world distribution as near-endemic? The SSA and its surroundings are poorly sampled. Future studies might indicate that taxon A which is now thought to have a 100% world distribution in the SSA, will then exhibit 98%. If the rule of 100% world distribution for endemism was followed, taxon A would have been recognised, for many years, as an endemic. However, the opposite would have been true, with taxon B exhibiting a higher endemism than taxon A.
2. The distribution of ultramafic rocks in the SSA is narrow, elongated and wedged inbetween other geological formations. Plant migration patterns radiate outwards equally well in all directions, however in the narrow east-west part of the study area, plant distributions on the ultramafic rocks are limited. Many endemic taxa are therefore found on the ecotone adjacent to the study area. The ecotones were not included in the SSA for the purpose of this dissertation and therefore these endemics received a percentage world distribution in the SSA of 75-99%. If the ecotones were taken into account as part of the SSA, these endemic taxa would exhibit a world distribution in the SSA of 100%.
3. If single localities of a taxon occur outside the borders of the SSA, its presence within the SSA was compared to its presence outside the SSA. If its presence (please note: not abundance) were more frequent and intense within the SSA than outside, it was viewed as endemic. The presence of each taxon was inferred from the frequency of herbarium collections at the National Botanical Institute, as well as observations made during field work.

Near-endemism

The percentage cut off point for a near-endemic distribution was arbitrarily chosen below 75 percent and above 25 percent of a taxon's world distribution due to one or more of the following reasons:

1. A cut off point of <75% was chosen as the upper margin, for 75% was chosen as the lower margin for endemism. An alternative lower margin for near-endemism would have been 50%, but due to the same reasons supplied under Endemism (1 and 2) for the lower endemism cut off point of 75%, a lower near-endemism cut off point of 25% was chosen to allow some margin for plant distribution, influenced by poor sampling in the region.
2. All taxa presented in this dissertation are endemic to a higher order region within the Northern Provinces of South Africa. This inclusive region of endemism can further be divided into smaller centres of endemism. These centres share certain species and characteristic distribution patterns. If the distribution pattern of an endemic taxon of the higher ranking region of endemism is viewed, it occurs only in certain areas. It is seen as endemic to the main region, but near-endemic to the subordinate constituent centres of endemism. For example, *Cussonia transvaalensis* is near-endemic to Sekhukhuneland as well as several other areas in the main region of endemism.
3. If a taxon is known from other localities outside the borders of the SSA, its presence within the SSA was compared to its presence outside the SSA. Unfortunately, for a number of species, no reliable information on presence outside the SSA was available. Hence, certain taxa were provisionally labelled as near-endemics pending further research. Examples of such taxa include *Rhus zeyheri*, *Indigofera nebrowiana*, *Barleria rotundifolia* and *Hermannia lancifolia*. If its presence (please note: not abundance) was more frequent within the study area than outside its borders, but it was endemic to the main region of endemism in the Northern Provinces of South Africa, it was provisionally included amongst the near-endemics. The presence of each taxon are based on field experience and was also checked at the National Botanical Institute.