Montane Wetlands of the South African Great Escarpment: Plant Communities and Environmental Drivers

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Abstract

Wetlands provide a number of valuable functions to both the surrounding environment and society. The anaerobic conditions created by flooding in wetlands provide a habitat that supports unique assemblages of plant life. High altitude wetlands are amongst the most species-rich in South Africa. They house a number of rare species and play a vital role in the supply of water to lower lying areas. These are some of the reasons that mountain wetlands are of high conservation value.

A phytosociological study was undertaken on the high altitude wetlands of the Great Escarpment with the aim of classifying the plant communities and identifying the environmental drivers of plant community patterns within these ecosystems. Data collection was focused in the Eastern Cape and was supplemented with data from existing studies to gain a more complete understanding of the wetlands of the Great Escarpment of South Africa.

Using the Braun-Blanquet approach, Hierarchical Cluster Analysis and Indicator Species Analysis; five broad wetland groups were identified, comprised of 33 individual plant communities and 81 indicator species. Multivariate analysis, including Canonical Correspondence Analysis revealed that the effects of altitude, such as temperature and rainfall, are the most significant large-scale drivers of vegetation patterns. Smaller scale drivers include wetness and soil nutrients including nitrogen, phosphorus, electrical conductivity, sodium, and organic content.

The identification of indicator species served to reveal potentially important wetland species across different areas of the Great Escarpment. The effects of altitude on plant community patterns highlights the susceptibility of the high altitude specific communities to upward temperature zone shifts resulting from global warming. Other threats include livestock trampling, water extraction, and land use change for agricultural purposes. The relative absence of alien species in these wetlands gives an indication of their pristine condition and therefore their importance as a reference from which they may be monitored. A large proportion of the wetlands studied here occur outside protected areas, and given the rate of wetland loss in South Africa, it is important that continued effective land management is practiced to ensure that these ecosystems are conserved in the future .

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AZf 1	Cape Lowland Freshwater Wetlands
AZf 2	Cape Vernal Pools
AZf 3	Eastern Temperate Freshwater Wetlands
AZf 4	Drakensberg Wetlands
AZf 5	Lesotho Mires
AZf 6	Subtropical Freshwater Wetlands
Biodiversity Act	National Environment Management: Biodiversity Act
CCA	Canonical Correspondence Analysis
Cluster five	Montane Grassy Wetland Vegetation
DAC	Drakensberg Alpine Centre
Depress	Depression
EC	Eastern Cape
Flood	Floodplain
Ftslope	Footslope
Gd	Drakensberg Grassland bioregion
Gd 1	Amathole Mountain Grassland
Gd 2	Amathole Mistbelt Grassland
Gd 3	Stormberg Plateau Grassland
Gd 4	Southern Drakensberg Highland Grassland
Gd 6	Drakensberg-Amathole Afromontane Fynbos
Gh	Dry Highveld Grassland bioregion
Gh 1	Karoo Escarpment Grassland
GWA	Great Winterberg-Amathole
HC	Hierarchical Clustering
HGM	Hydrogeomporphic Unit
Inundat	Inundation
ISA	Indicator Species Analysis
IV	Indicator Value
KZN	KwaZulu-Natal
MEA	Millenium Ecosystem Assessment
NEMA	National Environmental Management Act
Na	Sodium

NFEPA	National Freshwater Ecosystem Priority Areas
NKu	Upper Karoo bioregion
Nku 4	Eastern Upper Karoo
NMDS	Nonmetric Multidimensional Scaling
NWA	National Water Act
NWVD	National Wetland Vegetation Database
Org Con	Organic Content
P	Phosphorus
SANBI	South African National Biodiversity Institute
SIMPER	Similarity Percentage
Soil dep	Soil Depth
TVE	Total Variation Explained
Valbot	Valley bottom without a channel
Valbotc	Valley bottom with a channel
Vallhead	Valleyhead seepage
VD	Vegetation data only
VED	Vegetation and environmental data
VESD	Vegetation, environmental, and soil nutrient data
WRC	Water Research Commission

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Declaration

This thesis is the result of the author's original work except where acknowledged or specifically stated in the text. It has not been submitted for any other degree of examination at any other university or academic institution.

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M.R. Janks

CHAPTER 1

GENERAL INTRODUCTION

Wetlands: An Overview

An inclusive definition of a wetland is difficult to find, and there is disagreement among scientists as to what constitutes a wetland. This is due to their highly dynamic character and challenges regarding defining the wetland boundary (Turner et al., 2003). Dugan (1990) acknowledges that there are over 50 wetland definitions currently in use. Similarly a global classification of wetland types is also lacking (Turner et al., 2003).

Wetlands are generally considered to be areas that are inundated for at least a few weeks of each year containing plants, animals, and soils that are different to those found in aquatic and terrestrial systems (Woodward and Wui, 2001). The National Water Act, Act 36 of 1998 defines a wetland as "land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil.

Wetlands make up an estimated 6% of the Earth's surface. They are recognised as a major ecosystem type that has attracted the attention of botanists, ecologists, soil scientists, geographers, and economists (Keddy, 2010). Unlike other major landscapes, wetlands have only received attention as recently as the 1960's. The World Conservation Strategy (Talbot, 1980) recognised wetlands as the third-most import life support system on the planet. They also differ from other landscapes as they do not occupy continuous stretches of land and exist in a variety of different climates (Mucina and Rutherford, 2006). They are found in almost every climatic zone ranging from the tundra of the poles to the tropical mangroves of the equator and are found on every continent except for Antarctica (Reddy and DeLaune, 2008; Williams, 1993).

The recent recognition of the value of ecosystem services to other life and the disturbing rate of wetland loss has resulted in wetlands receiving greater attention (Cook, 2004; Mucina and Rutherford, 2006; Williams, 1993).

Acknowledgement of the sensitivity and adaptive ability of wetlands has resulted in the formulation of management plans aimed at preserving and/or restoring wetland systems (Turner et al., 2003). Biologists and conservationists are faced with a number of challenges, including: identifying priority areas for conservation, and the production of management plans. The difficulty lies in identifying criteria that may be used to address the above challenges (Cook, 2004).

Wetland Services

Cronk and Fennessy (2001) classify three categories of wetland services: (1) physical/hydrological, (2) biochemical, and (3) plant and animal habitat functioning, that are related to the existence, quantity, quality, and movement of water (Carter et al. 1979). Each function provides a service/s that is of value to people and/or the surrounding environment (Cronk and Fennessy, 2001; Horwitz and Finlayson, 2011).

Hydrological Functions

Groundwater supplied by wetlands provides an important source of water (Cronk and Fennessy, 2001; Horwitz and Finlayson, 2011) particularly in arid areas where the effect of drought is buffered by the ability of a wetland to hold water (Williams, 1993). The water storage ability also plays an important role in protection against flooding (Cronk and Fennessy, 2001; Horwitz and Finlayson, 2011; U.S. EPA, 2002; Williams, 1993).

Biogeochemical Functions

Wetlands by nature have shallow water (allowing for maximum interaction between sediments and the water), are highly productive, contain both aerobic and anaerobic sediments, and gather litter (Mitsch and Gosselink, 2000). Such conditions enable natural cleaning of water to take place (Cronk and Fennessy, 2001; Horwitz and Finlayson, 2011) whereby suspended sediments are removed from the water (Fennessy et al, 1994). Water purification is arguably the most important service that wetlands provide; a function that has been exploited by humans through the use of both natural and artificial wetlands across the world to treat industrial, agricultural, and domestic wastewater (Cronk and Fennessy, 2001).

Plant and Wildlife Habitat

Wetland plant communities are some of the most productive ecosystems in the world (Mitsch and Gosselink, 2000). They contribute to the surrounding food web by exporting large

amounts of organic carbon. High productivity provides support for many animal and fish species in the form of habitat or water supply (Cronk and Fennessy, 2001; Horwitz and Finlayson, 2011; U.S. EPA, 2002).

Wetland Soils

Anaerobic conditions caused by inundation creates distinctive hydric soils. These are formed by chemical and microbial processes that take place in the absence of oxygen (Cowardin et al., 1979; Janisch and Molstad, 2004; Keddy, 2010; Tiner, 1999; Yin and Lu, 2006). The oxygen-deprived environment requires specific plant adaptations to ensure survival (Keddy, 2010; Tiner, 1999).

Anaerobic soils are characterised by dull colours formed by a lack of iron oxides as result of the reduced state of inundated soils, the presence of mottling, and high organic content (Marnewecke and Kotze, 1999; Tiner, 1999). Wetland soils generally lack red and yellow colours resulting in grey to greenish colours and a gleyed soil matrix (neutrally grey, greenish, or bluish in colour) (Schoeneberger et al., 1998; Vepraskas and Caldwell, 2008). Mottling of a yellow, orange, brown, or reddish colour indicate periods of wetting and drying. The colour, vertical position in the upper soil layer, and frequency of mottling reveals the length of period that a wetland area experiences anaerobic conditions. These characteristics provide a means of delineating the wetland environment (Tiner, 1999; Vepraskas and Caldwell, 2008).

Wetland Plants

Most descriptions of a wetland plant refer to the wetness period that a species is able to survive under. A widely accepted definition considers wetland plants as “growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content” (Cowardin et al., 1979). Given the adaptations required for survival under anaerobic conditions one would expect wetland vegetation to be easily distinguishable from dry land vegetation (Tiner, 1999). In reality there is a continuum that ranges from tolerance to dry land conditions only to tolerance of permanent underwater conditions. There are no distinct categories along this continuum in terms of wetness adaptation, and one is not able to define where terrestrial plants end and wetland species begin (Cronk and Fennessy, 2001; Marnewecke and Kotze, 1999; Tiner, 1999).

Despite the continuum of dry land to wetland tolerant plant species, five categories have been defined along the continuum according to their affinity for wetland conditions (Cronk and Fennessy, 2001; Tiner, 1999):

1. Obligate Wetland species (almost always occurs in wetlands);
2. Facultative Wetland species (usually occurs in wetlands);
3. Facultative species (equally likely to occur in wetland and upland conditions);
4. Facultative Upland species (usually occur outside wetlands);
5. Obligate Upland species (almost always occurs outside wetlands).

Traditional plant ecology has strived to understand the driving force behind the establishment of different plant communities. A recent interest in wetland protection and the development laws governing the use of wetlands initially in the United States of America and more recently in South Africa, requires the delineation of wetland boundaries to ensure that wetland destruction does not occur (Yin and Lu, 2006). The use of wetland indicator species in addition to soil wetness indicators plays a vital role in the identification and delineation of wetland ecosystems (Tiner, 1999; U.S. EPA, 2002).

Threats to Wetlands

Global freshwater ecosystem degradation has been widespread due to anthropogenic activities (Junk, 2002; Moilanen et al., 2008) despite the legislation designed to protect them (Turner et al., 2000). Freshwater ecosystems include lakes, rivers, and wetlands, of which wetlands may be the most endangered (MEA, 2005). Wetland degradation has resulted in a loss of ecosystem services, a decline of wetland plant diversity (Gibbs, 2000), and an unnaturally high number of threatened plant species (Lentz and Dunson, 1999; Murdock, 1994). Wetland loss is primarily a result of altered hydrological regime through alien invasive plants, water extraction, impoundments, inter-basin transfer, afforestation, and other developments requiring water resources (Burger, 2008). Direct and indirect threats to wetlands are related to land use changes including recreational and urban developments, afforestation, agriculture, and mining developments (Burger, 2008).

As a large extent of South Africa is classified as semi-arid with a mean annual rainfall of 400 mm (Schulze, 1997), effective management of the country's water resources is vitally important. Protection of wetlands has been identified as one of the aspects that may enhance water resource conservation in the country (Sieben, 2010; Taylor et al., 1995). Unfortunately

many of these ecosystems in South Africa have been lost or degraded, most often as a consequence of conversion from wetland to another land use (Mucina and Rutherford, 2006). Farming, both commercial and subsistence, is one of the more threatening land use changes to wetlands in South Africa (Kotze et al., 1995; Lannas and Turpie, 2009). Thieme et al. (2005) consider freshwater ecosystems to be under 'exceptional' threat, and it is estimated that over 50% of South Africa's wetlands have been lost. Of the remaining wetland habitat 48% is classified as critically endangered (Nel and Driver, 2011).

Wetland Conservation

The global decline in wetland habitat has caused a recent surge in concern by scientists, engineers and the general public (McCarthy et al., 2009). The response to wetland degradation is evident through global initiatives such as the Ramsar Convention on Wetlands (Ramsar Convention Secretariat, 2010) and the Millennium Ecosystem Assessment (MEA, 2005).

In South Africa initiatives such as the Water Research Commission (WRC), the National Freshwater Ecosystem Priority Areas (NFEPA) project, and legislation have been formulated to address the freshwater ecosystem and wetland habitat loss. WRC projects include the Wetland Management Series that provides background to wetland management, tools that may be used guide wetland management and rehabilitation, and the evaluation of wetland rehabilitation (Dada et al., 2007).

The aims of the NFEPA project are to identify freshwater ecosystem priority areas (FEPAs) to meet national biodiversity goals for freshwater ecosystems, and to protect FEPAs by enabling effective implementation measures (Nel et al., 2011). The legislation established in South Africa in the National Water Act 36 of 1998 (NWA), National Environmental Management Act of 1998 (NEMA), and the National Environment Management: Biodiversity Act 10 of 2004 (Biodiversity Act) are aimed at protecting water resources and the natural biodiversity within these water resource ecosystems (Armstrong, 2009).

Wetlands of South Africa

Much of the wetland research in South Africa is focused on small areas or has been given side line status in studies devoted to other environments such grasslands and savannas (Mucina and Rutherford, 2006). A number of wetland classification systems exist in South

Africa (Ewart-Smith et al., 2006) that account for wetland variation on a regional scale, but are not appropriate on a national scale (Ollis et al., 2009).

A large scale wetland classification by Cowan (1995) divided South Africa up into four wetland groups: plateau wetlands, mountain wetlands, coastal slopes wetlands, and rimland and coastal plain wetlands. These regions were defined by similar topography, hydrology, and nutrient regimes. Further divisions of each wetland region were based on geomorphology, climate, and geology which determined 26 wetland regions of South Africa (Cowan, 1995).

The more recent large scale wetland classification of Mucina and Rutherford (2006) aimed to map the azonal vegetation of southern Africa. Azonal vegetation is determined by local environmental drivers (soil type, waterlogging, flooding) that override large scale drivers such as climate. The azonal vegetation of southern Africa includes Freshwater Wetlands, Alluvial Vegetation, and Inland Saline Vegetation (Mucina and Rutherford, 2006).

Mucina and Rutherford (2006) define six categories of freshwater wetlands in South Africa; Cape Lowland Freshwater Wetlands (AZf 1), Cape Vernal Pools (AZf 2), Eastern Temperate Freshwater Wetlands (AZf 3), Drakensberg Wetlands (AZf 4), Lesotho Mires (AZf 5), and Subtropical Freshwater Wetlands (AZf 6). These freshwater wetland systems are small and highly fragmented within the mainland biomes of South Africa and most commonly occur in areas with a mean annual rainfall of 500 – 600 mm or more (Mucina and Rutherford, 2006). The high altitude AZf 4 and AZf 5 wetlands are particularly interesting as they have a long evolutionary history, are home to a number of relict species of the past afromontane flora migrations, such as species of the *Aloe* and *Kniphofia* genera and house a high number of endemic species (Mucina and Rutherford, 2006). This classification is the most recent and comprehensive large-scale mapping classification of wetland types in South Africa, it does however suffer from two limitations. Firstly, a significant proportion of wetlands, such as seeps and longitudinally thin wetlands are too small to be detected by remote sensing and have therefore ignored (Nel et al., 2011). Secondly, wetlands are high in vegetation diversity which is often overlooked by topographical mapping (Sieben, 2010).

A call for a national classification system based on abiotic factors that drive wetland functionality from wetland managers and scientists (Ollis et al., 2009) resulted in the hydrogeomporphic unit (HGM) classification system developed by Ewart-Smith et al. (2006).

HGM classification has also been applied internationally (e.g. Brinson, 1993). This system acknowledges the importance of hydrology and geomorphology as vital processes to the ecological functioning of wetlands (Ollis et al., 2009; Sieben et al., 2014).

The HGM unit classification system was refined by Ollis et al. (2009) and recognises eight primary HGM types:

1. Channel: an open conduit with clearly defined margins that continuously or periodically contains flowing water.
2. Channelled valley-bottom wetland: a predominantly flat valley-bottom wetland dissected by and generally elevated above a channel.
3. Unchannelled valley-bottom wetland: a predominantly flat valley-bottom wetland without a channel running through it.
4. Floodplain wetland: a predominantly flat or sloping wetland adjacent to and formed by a lowland or upland floodplain river that is subject to periodic inundation by overtopping of the channel bank.
5. Depression wetland: a landform with closed elevation contours that increases in depth from the perimeter to a central area of greatest depth, and within which water typically accumulates.
6. Flat: a near-level wetland area with little or no gradient, situated on a plain or a bench in terms of landscape setting.
7. Hillslope seep: a wetland area located on sloping land which is dominated by the gravity driven, unidirectional movement of material down-slope.
8. Valleyhead seep: a gentle-sloping concave wetland area located on a valley floor at the head of a drainage line.

This classification system is useful for wetland management at the landscape scale (Sieben et al., 2014). It does however have limitations for practices such as conservation planning because biodiversity depends on local conditions, such as the extent of temporary, seasonal and permanent wetness areas within a wetland. Local drivers such as wetness have a greater influence on biodiversity at a local scale than a top-down driver such as HGM type. Large scale conservation planning requires a comprehensive taxa based classification system that may be easily detected and monitored (Sieben et al., 2014).

Mountain Wetlands of South Africa

Cowan (1995) indicates that there are two mountain wetland regions in South Africa; the Cape Fold mountains, and the Drakensberg/Maluti mountains. Both areas contain cool and moist south facing slopes as well as alpine elements. The common wetland types found in these areas are fens, sedge and restio marshes, and seeps (sponges).

The majority of in depth mountain wetland research in southern Africa has been conducted in the Drakensberg and Lesotho (e.g. Backéus, 1989; Jacot-Guillarmond, 1963, 1962; Sieben et al., 2010, 2009; van Zinderen Bakker and Werger, 1974). These high altitude wetlands have been described as bogs and fens (Jacot-Guillarmond, 1963, 1962; van Zinderen Bakker and Werger, 1974). Bogs are defined by Schwabe (1995) as having high soil organic content and a high water table. They are not linked to a stream system and are generally found on the cooler south facing slopes. Fens are characterised by a lack of organic content and have a stream channel either entering or leaving them (Schwabe, 1995). It is important to note that a fen and a bog wetland as described by Schwabe (1995) differs from widely accepted definitions that state that a fen is a peat-forming wetland that differs from a bog which is fed by precipitation alone in comparison to fens that are also fed by upstream and/or upslope flows (Mitsch and Gosselink, 1986).

Du Preez and Brown (2011) suggest that according to the widely accepted definition of a bog the classification of these high altitude wetlands as bogs is incorrect. Du Preez and Brown (2011) prefer the term peatland, rather than fen and bog as it also includes intermediate wetlands that do not fall into the fen or bog class (Du Preez and Brown, 2011).

High altitude wetlands are some of the most species rich in South Africa (Sieben et al., 2014). They are typically dominated by short grass and sedge species (Schwabe, 1995; Sieben et al., 2010) and have a higher composition of bulbous monocot and dicot species in comparison to lowland wetlands (Sieben et al., 2014, 2010). Colder temperatures and other environmental variables associated with high altitudes create an environment occupied by a unique suite of plant communities (Körner, 2007; Sieben et al., 2014). These wetlands are a conservation priority not only because of their housing of rare species and unique biodiversity (Cooper, 1996), but also because of the vital role that they play in water supply to lower lying areas (Körner, 2004; Lei, 2005; Messerli et al., 2004).

Rationale

The most recent and comprehensive mapping of wetland vegetation by Mucina and Rutherford (2006) has provided an important and useful tool for conservation planning (Sieben, 2010). It does however have its limitations (as mentioned above). Sieben (2010) has identified the need for an infield study that will enable the classification and representation of wetland plant communities in an environmental ordination. This will account for wetland biodiversity and build on the understanding of the environmental conditions that drive plant communities which may be greater use for conservation.

The National Wetland Vegetation Database (NWVD) (Sieben, 2010) has been initiated to provide more detailed information on the wetland vegetation of South Africa. The study has aimed to collect plant abundance and environmental wetland data from across South Africa, including both historical data sets and data collected throughout the course of the project. The results of the study will help inform the setting of restoration targets and targets for strategic conservation planning (Sieben, 2010).

The importance of a phytosociological approach to be able to meet the aims of the NWVD is highlighted by Mucina (2010) and Brown et al. (2013). This approach enables the description of plant communities and their environmental drivers, which is an important tool for documenting vegetation variability (Brown et al., 2013; Mucina, 2010). Grouping similar wetlands into classes effectively reduces natural variability, enabling a more meaningful comparisons between wetlands to be made (Chytrý et al., 2011; U.S. EPA, 2002) which is fundamental to informing wildlife management and nature conservation decisions (Brown et al., 2013; Kennedy et al., 2006).

The purpose of this thesis is to use a phytosociological approach to provide insight into the vegetation communities and associated environmental variables of the mountain wetlands of the Eastern Cape, otherwise known as the southern Great Escarpment or Cape Midlands Centre of Endemism (Clark et al., 2014). Much of the mountain research in South Africa is concentrated in the Drakensberg, neglecting other important areas such as the southern Great Escarpment. The data collected throughout the duration of this study has been included in the NWVD to help fill the data gap that previously existed in the southern Great Escarpment.

At the outset of this thesis the scope and duration of the study meant that the analysis was going to be focussed on the southern Great Escarpment wetlands. However, in order to gain a

more complete and contextualised understanding of the wetlands of this area it is important to consider the summer rainfall section of the Great Escarpment as a whole. It was therefore essential to analyse the NWVD mountain data set in its entirety, including external data provided by the NWVD, rather than isolating the southern Great Escarpment. The NWVD mountain data, namely, the Montane Grassy Wetland vegetation cluster, as identified by Sieben et al. (2014) is the focus of this thesis. The Montane Grassy Wetland vegetation cluster extends from the southern Great Escarpment to the Mpumalanga Escarpment, also including the Drakensberg and KwaZulu-Natal (KZN) Midlands. In this way the understudied wetlands are placed in a national context.

Aims

This thesis aims to achieve the following:

1) Classify and describe the mountain wetland plant communities across the Great Escarpment using the Braun-Blanquet approach (Chapter 3).
2) Compare the wetland indicator species identified in this study to the important taxa of the Freshwater Wetlands described by Mucina and Rutherford (2006; Chapter 3)
3) Determine the environmental drivers of the wetland plant communities (Chapter 4).
4) Assess if certain wetland plant communities are of greater biodiversity and/or conservation value than others based on the rarity, threats to and the state of the communities, and suggest management and conservation plans (Chapter 5).
5) Provide data appropriate for inclusion in the in the NWVD.

Thesis Structure

This thesis is comprised of a single data set, but for the purpose of flow and easy reading the data has been separated into two chapters that are structured as stand-alone papers. The first data chapter (Chapter 3) deals with vegetation characteristics, vegetation community classification, and community description. Chapter 4 deals with environmental drivers of the vegetation communities identified in Chapter 3. Chapter 2 details general material and methods that apply to both data analysis chapters.

CHAPTER 2

GENERAL MATERIALS AND METHODS

Description of the Study Area

The Great Escarpment of southern Africa is a horseshoe-shaped series of mountain ranges and scarps extending for 5 000 km separating the low-lying coastal area from the inland plateau that rises 1 000 m above sea level (Bond, 1971; Clark, 2011a, 2010, Figure 1). It is comprised of three sections (Clark et al., 2011a): (1) the western section from the Kamiesberg in South Africa through Namibia and into Angola, (2) the southern section from the Hamtamberge in the west to the Great Winterberg-Amathole (GWA) and Stormberg in the east of South Africa, and (3) the eastern section from the Drakensberg and Lesotho highlands to the Chimanimani Highlands of Zimbabwe.

The focus of data collection in this study is on the southern Great Escarpment. This includes the Nuweveldberge in the Western Cape, and the Sneeuberg, GWA, Stormberg, Witteberg, and Eastern Cape (EC) Drakensberg in the Eastern Cape (Figure 2).

The highest lying areas in the Eastern Cape are found in the Drakensberg with peaks rising above 2 600 m in both the EC Drakensberg (Ben MacDhui 3001 m, Breslin's Kop 2863, Tina Head 2824 m, Table Hill 2730 m and Scobell's Kop 2731 m) and the Witteberg (Avoca Peak 2769 m, Balloon Peak 2648 m) (Figure 3).

The Stormberg is considered by some to be part of the Drakensberg Escarpment (Clark, 2010), whereas others do not (Carbutt and Edwards, 2006). It lies south west of the Drakensberg Escarpment and includes the Bamboesberg. It is largely a plateau area at an altitude of between 1 400m and 1 800m (Hoare and Bredenkamp, 2001; Mucina and Rutherford, 2006) with a number of peaks rising above 2 000m (Rooiberg 2 130m, Torinberg 2 111m, Middleberg 2 107m, Bobbejaanberg 2 079m) (Figure 3).

The GWA Escarpment section lies south of the Stormberg, it separates the low-altitude coastal areas from the inland Eastern Cape plateau (Meadows and Meadows, 1988). It is divided into the western Winterberg section and the eastern Amathole section (Clark et al., 2014). The GWA mountains are moderately undulating below the major peaks (Mucina and

Rutherford, 2006). The highest point reaches 2 369m and a number of peaks rise over 2 000m (Great Winterberg -2 369m, Klein-Winterberg 2 117m, Elandsberg 2 017m, Bakenkop 2 011m) and it is one of the most prominent mountain ranges on the Great Escarpment (Holmes et al., 2003) (Figure 4).

The Sneeuberg lies adjacent to the GWA separated by the Great Fish River Interval (Clark et al., 2009). The Sneeuberg contains the highest peaks on the South African escarpment outside of the Drakensberg (Compassberg 2 504m, Nardousberg 2 429m) and other peaks above 2 200m (Renosterberg 2 298m, Toorberg 2 278m) (Figure 4). The Nuwevelberge lies adjacent to the Sneeuberg, separated by the Nelspoort Interval (Clark et al., 2009). It may be divided into the Western, Central, and Eastern Nuweveldberge, each region contains peaks over 1 900m (Bontberg 1 922m, Tafelberg 1 913m, Tafelberg 1 956m, Puttersvlei Peak 1 909m, Teepunt 1 946m) (Figure 4).

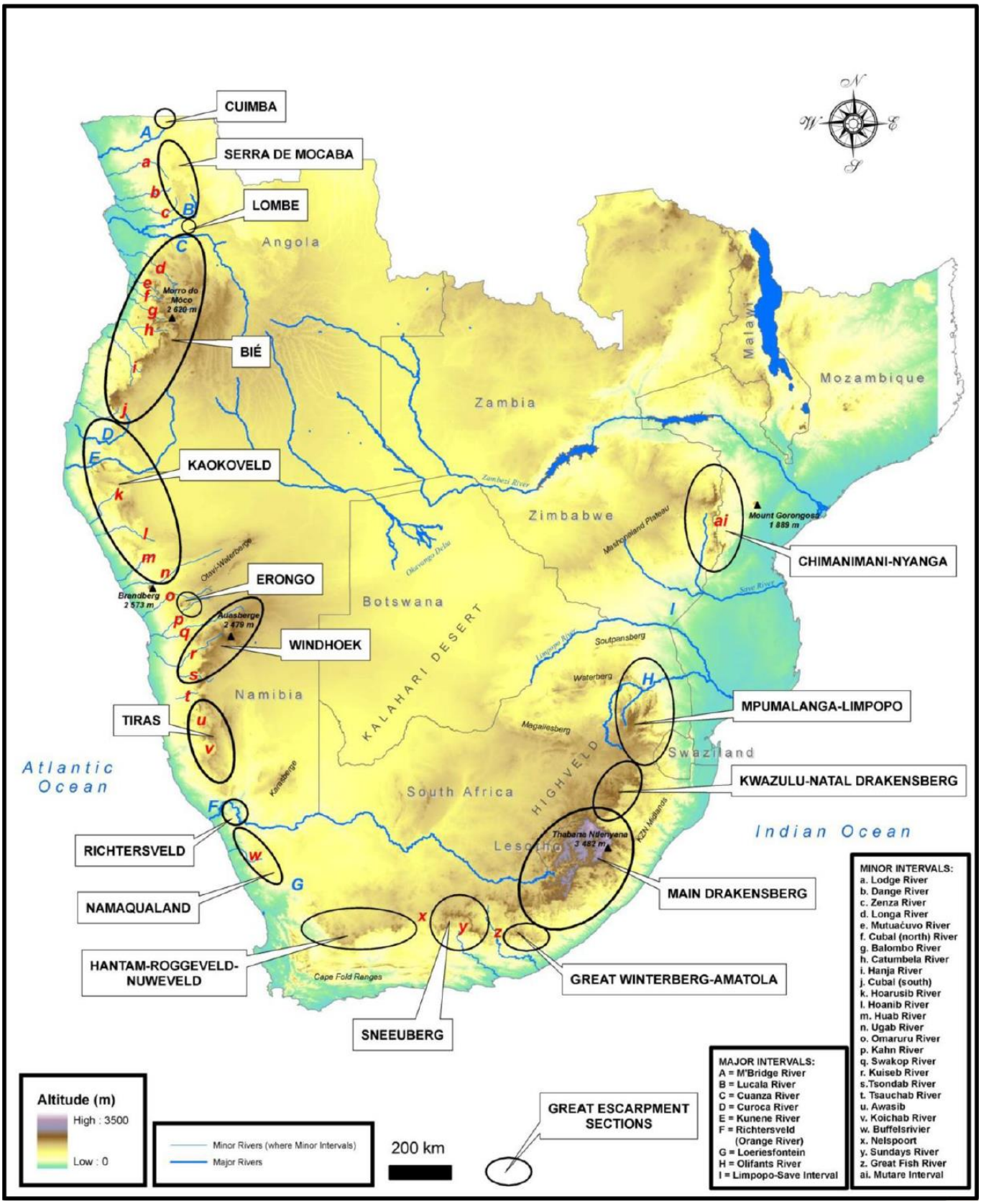

Figure 1. The Great Escarpment in southern Africa, indicating Great Escarpment sections, relief, principal drainage, and both major and minor intervals (Clarke, 2010).

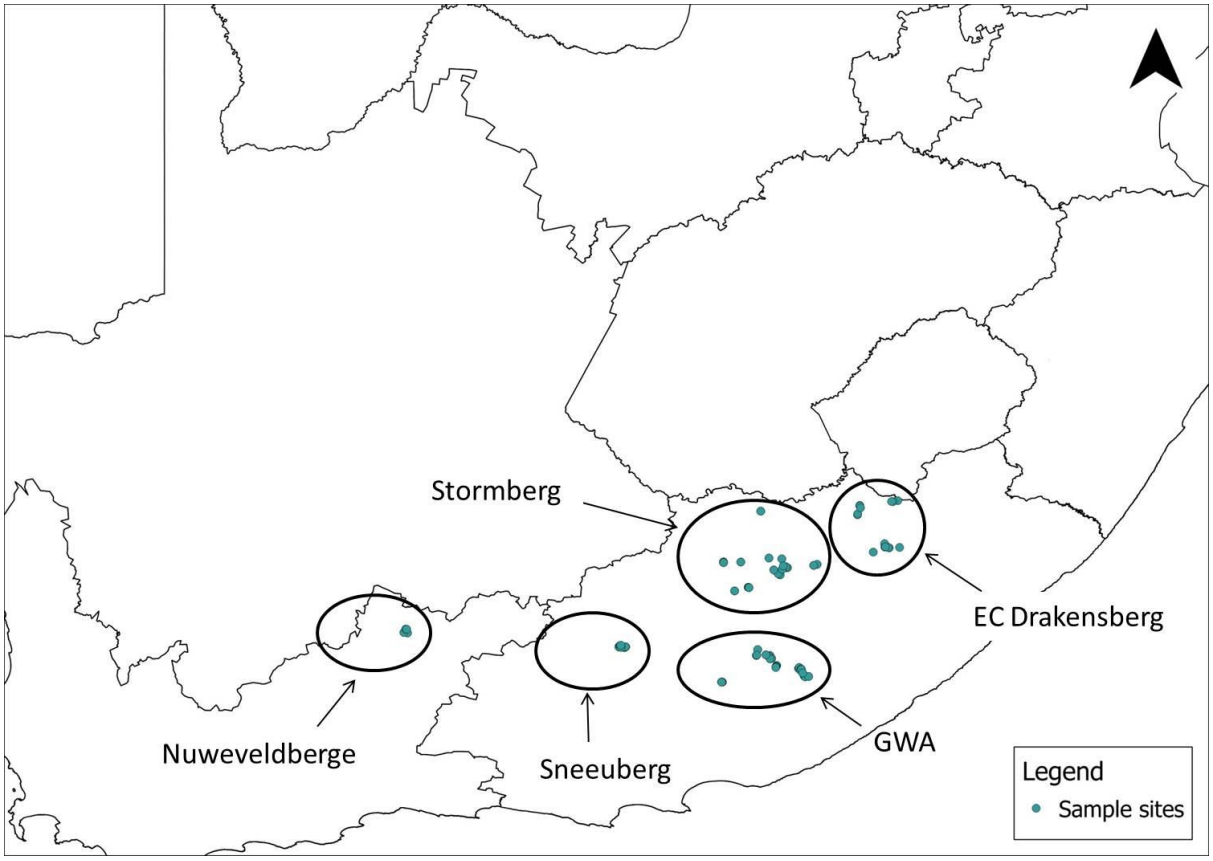

Figure 2. Map showing sample sites across the different mountain regions of the central Great Escarpment.

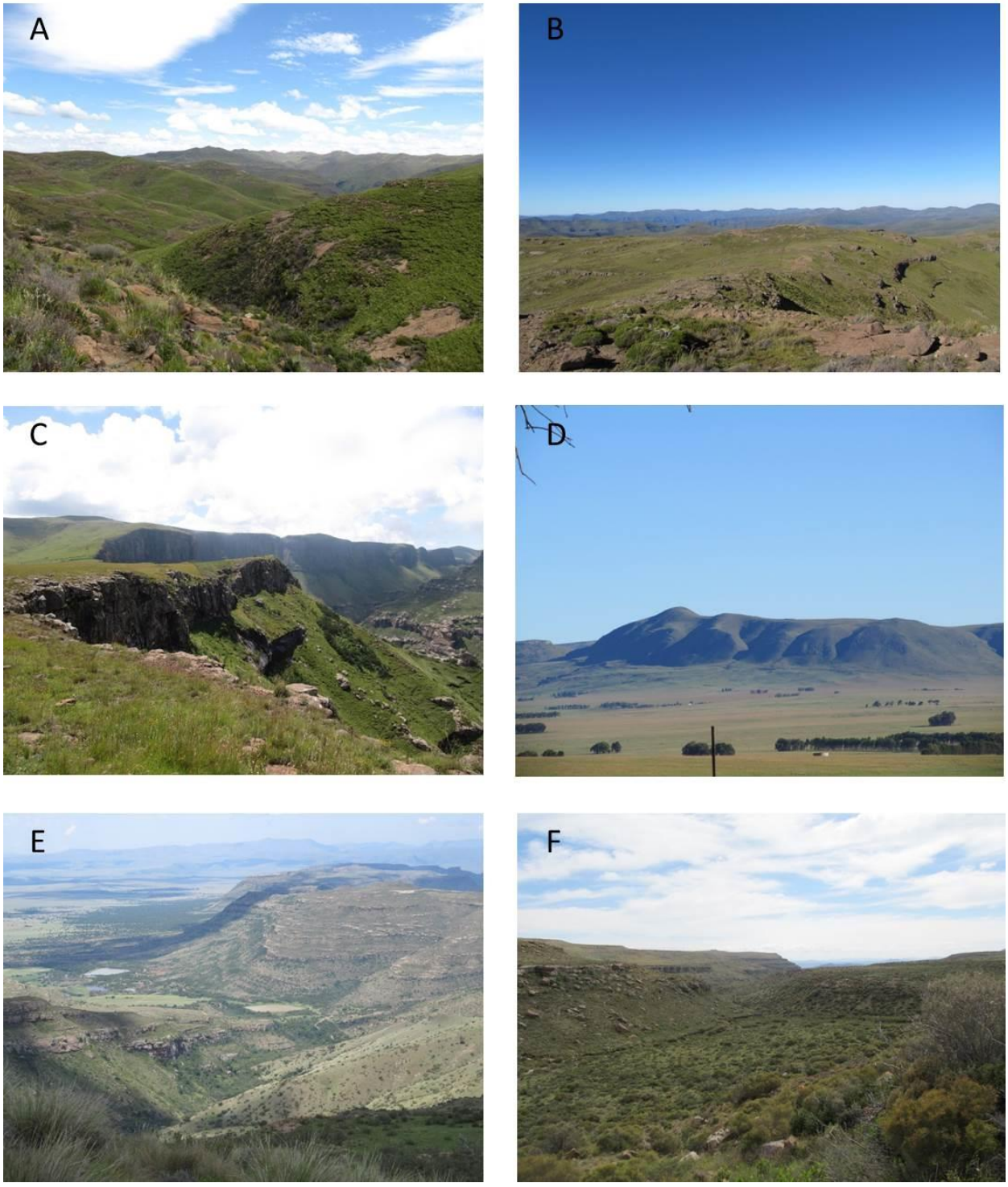

Figure 3. A selection of photos from the Great Escarpment: (A) the Witteberg, (B) the EC Drakensberg from Ben MacDhui peak, (C) the Barkly Pass cliff line of the EC Drakensberg, (D) The Penhoek Pass area of the Stormberg, (E) the eastern most section of the Bamboesberg, (F) the north west section of the Bamboesberg. Photos taken by MR Janks.

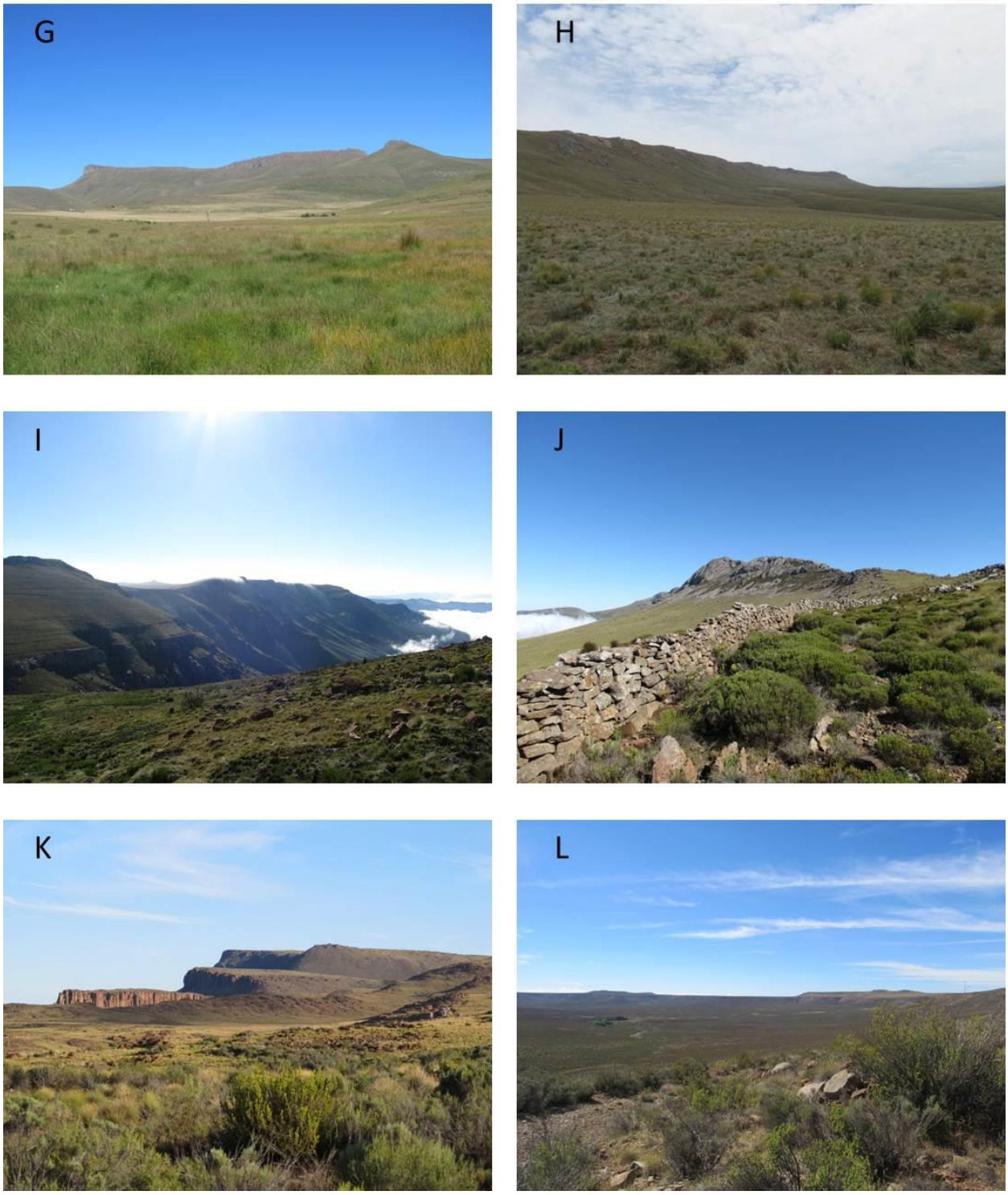

Figure 4. A selection of photos from the Great Escarpment: (G) the main Winterberg peak in the GWA, (H) the main Elandsberg peak in the GWA, (I) cliff line of the Nardousberg area of the Sneeuberg (J) the Nardousberg peak in the Sneeuberg, (K) the eastern Nuweveldberge cliff line, (L) the eastern Nuweveldberge plateau. Photos taken by MR Janks.

Vegetation: General Patterns

The eastern parts of the southern Great Escarpment forms part of the Grassland Biome, and more specifically the Drakensberg Grassland (Gd) bioregion (Mucina and Rutherford, 2006). This includes the EC Drakensberg, GWA, and the central and eastern sections of the Stormberg. The GWA occurs within the Amathole Mountain Grassland (Gd 1) and Amathole Mistbelt Grassland (Gd 2) vegetation units. The Gd 1 vegetation type is distributed in the lower mountain ranges (650 to 1 500m) and is defined by short grasses with high diversity of Asteraceae (Mucina and Rutherford, 2006). The Gd 2 vegetation type occurs on the highest ridges of the GWA (1 380 to 2 080m) and is also characterised by short grassy species and a high diversity of Asteraceae species. Both the Gd 1 and Gd 2 grasslands are categorised as least threatened. Five percent of the Gd 1 grasslands and four percent of the Gd 2 grasslands are conserved in statutory conservation areas (Mucina and Rutherford, 2006).

The Stormberg mountains support the Stormberg Plateau Grassland (Gd 3) vegetation unit. It is characterised by a mixture of grass and dwarf shrub species at an altitude between 1 520 and 1 960m. It is categorised as least threatened, but there is no statutory conservation of this grassland and nine percent of it has been transformed by cultivation (Mucina and Rutherford, 2006). The higher eastern regions of the Stormberg and the mid-altitude EC Drakensberg area forms the Southern Drakensberg Highland Grassland unit (Gd 4). This vegetation type is characterised by dense tussock grassland and dwarf shrub vegetation at an altitude between 1 420 and 2 080m. The Gd 4 vegetation type is least threatened and nine percent is statutorily conserved (Mucina and Rutherford, 2006). The higher altitude areas of the EC Drakensberg occur in the Drakensberg-Amathole Afromontane Fynbos (Gd 6) vegetation type (1 520 to 2 600m). The southernmost outlier of this unit is found in GWA. It is characterised by evergreen shrubs and is least threatened due to more than 50 % being conserved (Mucina and Rutherford, 2006).

The western region of the Grassland Biome comprises Dry Highveld Grassland (Gh) bioregion. The Sneeuberg falls within the Karoo Escarpment Grassland (Gh 1) vegetation unit. It is characterised by wiry tussock grass species with an obvious low shrub element that occurs between an altitude of 1 000 and 2 502m. It is least threatened and three percent is statutorily conserved (Mucina and Rutherford, 2006).

The eastern section of the Nuweveldberge mountains are situated in the Nama-Karoo Biome and more specifically the Upper Karoo (NKu) bioregion. The Nuweveldberge is nested in the Eastern Upper Karoo (NKu 4) vegetation unit which also encompasses western sections of the Sneeuberg and Stormberg. The NKu 4 vegetation is dominated by dwarf shrubs and 'white' grasses of the genera *Aristida* and *Eragrostis*, predominantly between an altitude of 1 100 and 1 700m. It is least threatened and conserved in a number of conservation areas (Mucina and Rutherford, 2006).

Geology and Soils

The Southern Great Escarpment contains relatively uniform geology composed of Beaufort Series shales and sandstones of the Karoo Supergroup heavily intruded by dolerites. This geology occurs in the Nuweveldberge, Sneeuberg and GWA (Johnson et al., 2006). The Stormberg is composed of Molteno and Clarens Formation Sandstones, and Drakensberg Basalts (Johnson et al., 2006). The DAC is composed of Clarens Sandstones capped by Drakensberg Basalts (Moore and Blenkinsop, 2006).

The soils of the EC Drakensberg and Stormberg vary with topography. The soils of the mountain areas are shallow, weakly developed lithosols (Hoare and Bredenkamp, 2001). The soils of the lower lying plains are generally deeper sandy loams containing many boulders and gravel (Werger, 1980).

Soils on the steeper slopes of the Sneeuberg are nutrient poor, shallow soils on sedimentary strata. The more gentle slopes contain richer and moderately deep soils. The deepest soils are found on the summit plateau (Clark et al., 2009). The soils of the GWA region are deep, freely drained and highly weathered soils (Hartmann, 1988). The soils of the Nuweveldberge are poorly developed and easily eroded. An arid climate prevents chemical weathering of the rock and thus the soil is deprived of minerals. Vegetation is sparse and any exposed soil is easily eroded (Clark et al., 2011b).

Climate

The general climate trend across the southern Great Escarpment is dry in the west to wet in the east. For example, 200 to 300 mm per annum is received in the western area of the Nuweveldberge (Clark et al., 2011b) in comparison to 1 600 mm in the KZN Drakensberg (Sene et al., 1998). The climate is driven predominantly by the cold Benguela Current in the west and the warm Mozambique/Agulhas Current in the East. The Nuweveldberge is situated

in the “all-year rainfall” zone described by Chase and Meadows (2007), between the winter and summer rainfall regimes (Clark et al., 2011b), resulting in unreliable rainfall and regular periods of drought (Esler et al., 2006). The eastern Nuweveldberge receives just over 400mm (Clark et al., 2011b).

The Sneeuberg is also located between the winter and summer rainfall regime areas (Clark et al., 2009). The mean annual rainfall is evenly distributed between spring, summer, and autumn (Cannon, 1924). The area is affected marginally by all major weather systems in southern Africa (Desmet and Cowling, 1999). The majority of the west and central mountain areas receive between 400 mm and 500 mm a year, and the eastern Sneeuberg mountains receive between 500 mm and 600 mm (Holmes, 1998).

The GWA is located in an area of climatic transition. Maximum rainfall is received in autumn. Rainfall over the Winterberg mountain region is greater than 500 mm a year (Hoare and Bredencamp, 1999), and increases to over 2000 mm a year in the Amathole mountain region (Kopke, 1988). Clark et al. (2011a) indicate that the GWA area as a whole receives between 800 mm and 1 000 mm per annum.

The Stormberg, and EC Drakensberg both fall within the summer rainfall area of South Africa (Clark et al., 2011a, Dollar and Rowntree, 1995; Hoare and Bredenkamp, 2001). The Stormberg receives between 400 mm and 700 mm across a west to east gradient (Hoare and Bredenkamp, 2001). The high altitude areas of the Witteberg receive in excess of 1 000 mm per annum. The EC Drakensberg receives between 700 mm and 1 300 mm of rainfall a year (Dollar and Rowntree, 1995). Up to 1 600 mm falls east of the EC Drakensberg over the Lesotho highlands and KZN Drakensberg (Sene et al., 1998).

Methods

Site Selection

Wetlands to be sampled were identified using Google Earth, 1: 50 000 topographic maps, and through communication with local farmers. No lower cut-off altitude level was used, but areas above 1 400 m.a.s.l were targeted. A total of 76 wetlands across the southern Great Escarpment were visited (Table 1). Larger wetlands were targeted to enable as much variation in habitat as possible to be captured. A major sampling focus was in the GWA, EC

Drakensberg, and Stormberg. Less focus was directed towards the Sneeuberg and Nuweveldberge due to time constraints and relative uniformity of the wetlands in these areas.

Table 1. Sampling effort featuring coverage of mountain areas, farms visited, wetlands sampled, and relevés collected.

Mountain area	**Farms Visited**	**Wetlands Sampled**	**No. of Relevés**
EC Drakensberg	10	15	71
Stormberg	13	21	69
GWA	9	27	100
Sneeuberg	2	9	29
Nuweveldberge	1	4	11
Total	**35**	**76**	**280**

Vegetation Survey

Vegetation sampling was carried out during the growing seasons between January and March 2012, and November and March 2013. Vegetation was sampled according to the protocol outlined by Sieben (2010), to match the requirements of the NWVD. A total of 280 relevés (sample plots) were collected during the course of the study. A minimum quadrat size of 2 x 2 meters was used, a 3 x 3 meter quadrat was used in areas of greater diversity to account for a greater number of species. These quadrat sizes are suggested for grassland and tall herb communities by Mueller-Dombois and Ellenberg (1974) and similar quadrat sizes have been used in other mountain wetland vegetation studies (e.g. Kamrani et al., 2011; Sieben et al., 2009; Sieben et al., 2010; Walters et al. 2006).

The traditional Braun-Blanquet method (Braun-Blanquet, 1964) was used to score the percentage cover of each species per relevé. This is a widely used phytosociological study method that has been recently recommended for phytosociological studies in South Africa (Brown et al., 2013). The placement of each relevé was within a floristically uniform unit (homogeneous vegetation habitat) in order to represent a single plant community (Brown et al., 2013). The number of relevés recorded in each wetland was dependent on the number of homogeneous vegetation units in each wetland. All species present in each relevé were

identified in the field if possible. Unknown specimens were identified and housed in the Selmar Schonland Herbarium in Grahamstown.

Description of Environmental Variables

The environmental data collected for each sample plot includes hydrogeomorphic (HGM) unit, altitude, wetness, soil inundation, altitude, slope, topography, soil texture, soil depth, and landscape (Table 2). The HGM type was determined using the Ollis et al. (2009) level four classification system. Wetness was determined using hydromorphic soil characters according to the guidelines for delineating the boundaries of a wetland and the zones within the wetland in terms of the South African Water Act (Kotze et al., 1996).

Table 2. Environmental variables measured and/or assessed per vegetation relevé.

Variable	**Scale**	**Measurement/state**
HGM Type	Nominal	Floodplain, flat, channelled valley-bottom, unchannelled valley-bottom, hillslope seepage, valleyhead seepage
Wetness	Nominal	Not wetland, temporary wetness, temporary-seasonal wetness, seasonal wetness, semi-permanent wetness, permanent wetness
Inundation	Ratio	Assessed in centimetres
Altitude	Ratio	GPS (in meters)
Location		GPS
Slope	Ratio	Assessed in degrees
Topography	Nominal	Floor, slope, bench, foot
Soil texture	Nominal	Sand, loam, clay, peat, silt, gravel
Soil depth	Ratio	Assessed in centimetres
Landscape	Nominal	Natural, rural, urban

One soil sample was collected per wetland in a particular relevé. The purpose of the soil data collection was to get an indication of the soil environment inhabited by the plants, thus the top 20cm of soil was used. Soil samples analysed by the Agricultural Research Council, Institute for Soil, Water and Climate. Each sample was tested for pH, electrical conductivity, nitrogen, phosphorus, sodium, potassium, magnesium, calcium, soil particle size, and organic matter (Table 3).

Table 3. Soil variables measured and the methods used to obtain each measurement. Table adapted from Sieben et al. (2014).

Variable	Method	Scale
pH	Water extraction	
Electrical conductivity	Water extraction	mS/m
Nitrogen	Summed up concentration of nitrate, nitrite and ammonium	mg/kg
Sodium, potassium, magnesium, calcium	1:10 water extraction	mg/kg
Extractable Phosphorus	P-Bray 1 method	mg/kg
Organic matter	Walkley-Black method	% carbon

Incorporation of Data into the National Wetlands Vegetation Database

Each relevé was stored with associated environmental data in the NWVD using the software programme TURBOVEG (Hennekens and Schaminée, 2001). The NWVD was managed by Dr. Erwin Sieben at the University of the Free State. The NWVD includes appropriate historical vegetation data converted to the standardised NWVD format and data collected throughout the duration of the NWVD data collection phase. The NWVD is comprised of 5 583 vegetation relevés of which 3 633 are from historical datasets. This study contributed 280 relevés to the database.

The software JUICE (Tichý et al., 2002) was used by Dr. Erwin Sieben to sort the relevés into eight major groups based on the similarity of plant composition. These are referred to as the main clusters (Sieben et al., 2014):

1. Sclerophyllous Wetland Vegetation;
2. Swamp Forest;
3. Subtropical Wetland Vegetation;
4. Estuarine, Brackish, and Saline Wetland Vegetation;
5. Montane Grassy Wetland Vegetation;
6. Temperate Grassy Wetland Vegetation;
7. Short Lawn Grassy Wetland Vegetation; and
8. Hydrophytic Vegetation.

The Montane Grassy Wetland Vegetation (cluster five) is analysed as a whole in this thesis. The data sets included in this study are shown in Table 4. A map of the sampling areas from which the cluster five dataset is comprised is shown in (Figure 5). The contribution of this thesis to the cluster five data set is 138 relevés. The other 142 relevés collected during the course of this thesis have been included in the Temperate Grassy Wetland Vegetation, Short Lawn Grassy Wetland Vegetation, and Hydrophytic Vegetation clusters. A description of these data is available in Sieben et al. (2014).

Table 4. Data sets included in the Montane Grassy Wetland Vegetation cluster indicating the authors and date, study area, published status, and the number of relevés contributed.

Source	Area	Published	No. Relevés
Sieben et al. (2010)	Wetlands in the Maloti-Drakensberg Transfontier Park	Bothalia 40: 117-134	104
Goge (2002)	Wetlands of Eastern Shores St Lucia	Thesis UKZN	2
Eckhardt et al. (1996)	Wetlands of Northwestern KwaZulu-Natal	South African Journal of Botany 62: 306-315	5
Perkins et al. (2000)	Wetlands Southern KwaZulu-Natal	Bothalia 30: 175-185	16
Cowden et al. (2014)	KwaZulu-Natal	African Journal of Aquatic Science 39: 237-247	1
Sieben (2008)	Didima KwaZulu-Natal	Unpublished	11
Fuls (1992)	Grassland of the Northern Free State	Thesis NMMU	1
Eckhardt et al. (1993)	Wetlands of Northeastern Freestate	Navors. Nas. Mus. Bloemfontein 9:245-262	1
Sieben et al. (2009)	Eastern Free State data collection	Unpublished	3
Collins (2012)	Free State	Unpublished	18
Sieben (2006)	Eastern Free State	Unpublished	2
Bloem et al. (1992)	Vegetation of Verlorenvallei, Mpumalanga	South African Journal of Botany 59: 281-286	34
Burgoyne et al. (2000)	Northeastern Sandy Highveld, Mpumalanga	Bothalia 30: 187-2000	2
Van Zinderen Bakker and Werger (1974)	Bogs in Lesotho	Vegetatio 29: 37-49	20
Janks (2014)	**Eastern Cape Mountain Wetlands**	**Unpublished**	**138**

Source	Area	Published	No. Relevés
Sieben (2006)	Western Cape various	Unpublished	7
Sieben (2014)	Various	K5/1980 WRC Report	47
Total			**412**

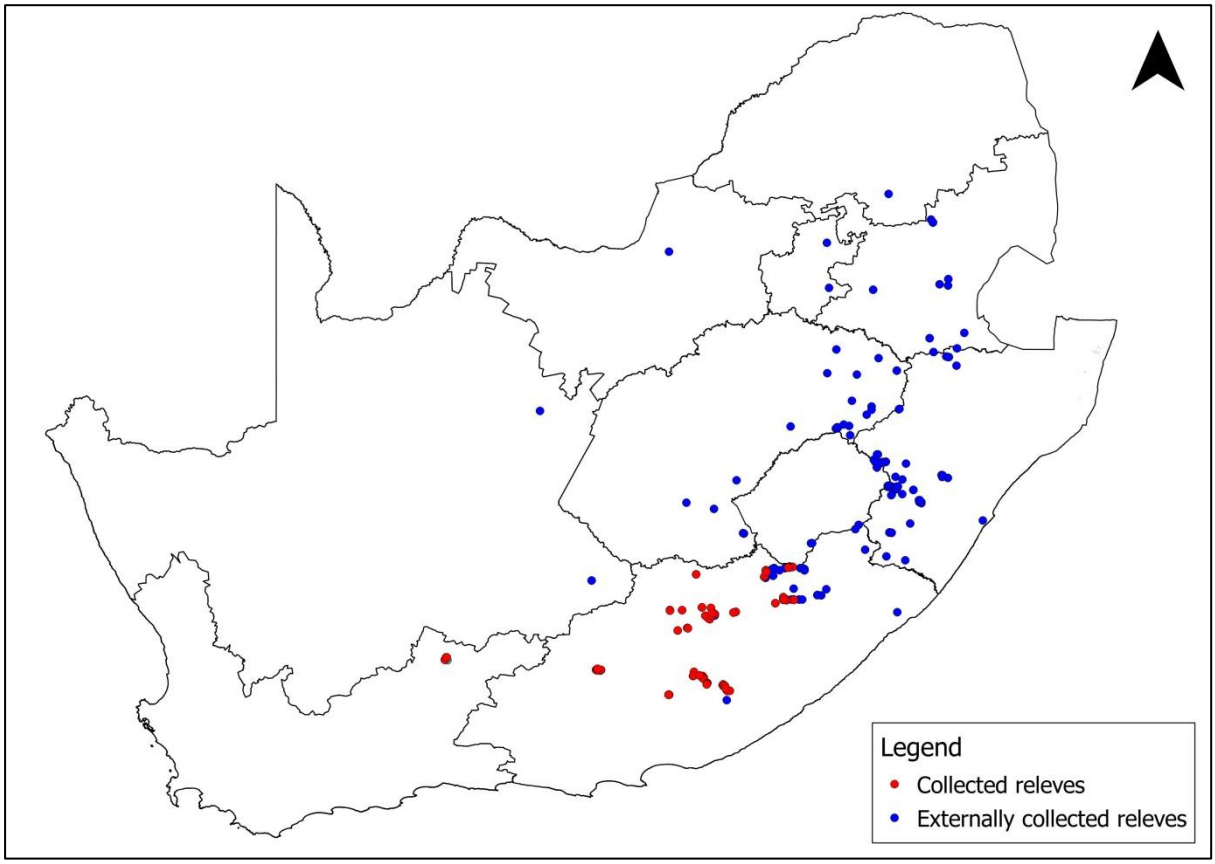

Figure 5. The sample sites included in the cluster five dataset. The samples collected during the course of this study are distinguished from the samples collected from the external studies.

The cluster five data set is divided into three levels according to the level of detail of environmental data associated with each relevé:

1. Vegetation data only (412 relevés; hereafter VD, analysed in Chapter 3).
2. Vegetation and environmental data (333 relevés; hereafter VED, analysed in Chapter 4).
3. Vegetation, environmental, and soil nutrient data (79 relevés; hereafter VESD, analysed in Chapter 4).

Analysis

Depending on the nature of data available for each level of data, different analyses were undertaken to classify plant communities and determine the environmental drivers of each community (Table 5). The analysis of the vegetation only database is undertaken in Chapter 3, and the analysis of the vegetation and environmental database and the vegetation, environmental and soil nutrient database is undertaken in Chapter 4.

Table 5. Data available, number of relevés and analyses undertaken for each level of data.

Database	**No. of relevés**	**Available Data**	**Analysis**
Vegetation only	412	Species abundance	Clustering, Indicator Species Analysis
Vegetation and environmental data	333	Species abundance, HGM type, wetness, inundation, altitude, slope, topography, soil texture, soil depth, landscape	Ordination
Vegetation, environmental and soil nutrient data	79	Species abundance, HGM type, wetness, inundation, altitude, slope, topography, soil texture, soil depth, landscape, pH, electrical conductivity, nitrogen, sodium, potassium, magnesium, calcium, phosphorus, organic matter	Ordination

CHAPTER 3

VEGETATION CHARACTERISTICS, COMMUNITY CLASSIFICATION, AND COMMUNITY DESCRIPTION OF THE GREAT ESCARPMENT WETLANDS

Introduction

Phytosociology is the science of recognising and identifying patterns in vegetation within an overwhelming amount of vegetation variation (Bredenkamp, 1982). The first observable spatial or temporal change in habitats is through vegetation (Brown et al., 2013). In order to interpret and simplify the spatial and temporal complexity of natural ecosystems, vegetation classification and mapping is a widely used tool to help vegetation scientists classify and map complex ecosystems (Mucina and Rutherford, 2006).

A plant community refers to a 'collection of plant species growing together in a particular location that show a definite association or affinity with one another' (Kent, 2012). According to Brown et al. (2013), phytosociological studies should be fundamental to informing decisions on wildlife management and nature conservation and provides scientifically defendable data upon which decision can be made. In addition, it provides a method to plan and monitor plant communities and rare and endangered species (Chytrý et al., 2011). With climate change, phytosociological studies will become more important, and can provide a baseline to which future datasets may be compared (Brown et al., 2013).

In South Africa, research on wetland vegetation has been conducted for many years. The data generated from these studies has only recently been combined in a comprehensive phytosociological based classification system with the publication of "The Vegetation of South Africa, Lesotho and Swaziland" by Mucina and Rutherford (2006) in which six freshwater wetland vegetation units are described (Brand et al., 2013). Mucina and Rutherford (2006) also list important taxa of each wetland vegetation unit. As mentioned in Chapter 1, the classification of wetland vegetation by Mucina and Rutherford (2006) is large scale, and therefore it ignores wetlands that are small in size, and it overlooks the high diversity that is often present in wetland habitats.

By studying the wetlands of the Great Escarpment using a phytosociological approach, a more detailed classification of these wetlands may be made, and important species not listed by Mucina and Rutherford (2006) may be identified.

Aims

The aims of this chapter are to:

1) Classify and describe the mountain wetland plant communities across the Great Escarpment using the Braun-Blanquet approach.
2) Compare the wetland indicator species identified in this study to the important taxa of the Freshwater Wetlands described by Mucina and Rutherford (2006).

Materials and Methods

The vegetation only dataset was used to classify plant communities. The plant species abundance data was transformed by assigning a numerical value to each Braun-Blanquet class as follows: R = 1, + = 2, 1 = 3, 2m = 4, 2a = 5, 2b = 6, 3 = 7, 4 = 8, and 5 = 9.

Plant Community Classification

Vegetation data were classified using hierarchical clustering (HC) and indicator species analysis (ISA) carried out in the software package PC-Ord version 6 (McCune and Mefford, 2011) using the vegetation data (VD) only dataset.

HC was used to identify similar relevés based on similar species composition which was visually represented by a dendrogram. The relative Euclidean distance measure and the Ward's group linkage method was used as recommended by McCune and Grace (2002).

ISA is a method used for determining statistically significant indicator species within a given group/cluster of relevés based on the frequency of species occurrence and confinement to that cluster (Peck, 2010). A Monte Carlo test of significance determines the most significant indicator species of a given cluster based on a derived indicator value (IV) and p-value for each species. ISA may also be used as a quantitative, objective criterion to determine the most appropriate point to group similar relevés.

In order to test for the most ecologically significant point to define clusters of similar relevés, the ISA method was applied using the lowest possible number of groups (two), this process was repeated increasing the number of groups by one on each occasion until the most

appropriate number of groups was found. The number of groups at which the lowest average p-value was obtained indicated the most appropriate grouping of relevés (Peck, 2010). Each group is considered a separate plant community comprised of one or more indicator species.

The indicator species of each group was also determined using ISA by considering the IV and p-value of each species. Species that obtained a p-value less than 0.05 and an IV greater than 20 have been classified as indicator species. A low IV suggests that a species is common to a group but is also found in other groups, a large IV suggest that a species is more confined to a specific group.

Major groups of communities were defined by observing the primary branches of the dendrogram (i.e. the lowest level of similarity). Similarity Percentage (SIMPER) analysis was carried out in the software package PRIMER version 6 to determine the species most common to each major group of communities. Subgroups of similar communities were defined based on lower level branching of the dendrogram.

Plant communities were given the names of the most dominant species in each community. The subgroups were named according to the type of species within the communities (i.e. grass, sedge, forb or mixed), if the subgroup contained only two communities the group was named after the communities in the subgroup (i.e. *Carex acutiformis – Gunnera perpensa* wetlands). The major groups of wetland communities were named based on location and/or habitat of the communities in each group.

Results

Wetland Flora and Diversity

A total of 653 different species from 287 genera were identified in the montane grassy wetland vegetation (cluster 5) dataset. This flora is composed of 9 Pteridophytes (1%), 2 Bryophytes (0.2%), 315 Monocots (44%), 395 Dicots (55%). I suggest that the number of Bryophyte species is a gross underestimate, given the lack of knowledge and expertise in the field of South African mosses. The 653 species belong to some 85 different families. The most represented families include the Asteraceae, Poaceae, and Cyperaceae. One hundred and forty species (19%) belong to the Asteraceae, 133 (18%) to the Poaceae, 82 (11%) to the Cyperaceae, and 20 (3%) to the Scrophulariaceae families.

The SANBI (2014) Red Data list was used to identify the conservation status of each species. One species is classified as endangered, one species is classified as near threatened, two species are classified as rare, three species are classified as vulnerable, four species are classified as declining (Table 6), 58 species (9%) are classified as not evaluated, and 571 species (89%) are classified as least concern.

The SANBI Red Data list was also used to identify exotic and endemic species within the montane grassy wetland dataset. 58 species (9%) are classified as exotics, and 59 species (9%) are classified as endemic to South Africa.

Table 6. IUCN Red Listed species of the grassy montane wetlands (SANBI, 2014).

Species	**Family**	**Status**
Felicia wrightii	Asteraceae	Critically Rare
Erica anomala	Ericaceae	Rare
Isolepis pellocolea	Cyperaceae	Rare
Satyrium hallackii subsp. hallackii	Orchidaceae	Endangered
Alepidea amatymbica	Apiaceae	Vulnerable
Carex subinflata	Cyperaceae	Vulnerable
Colpodium drakensbergense	Poaceae	Vulnerable
Crinum bulbispermum	Amaryllidaceae	Declining
Eucomis autumnalis subsp. autumnalis	Hyacinthaceae	Declining
Gunnera perpensa	Gunneraceae	Declining

The more frequently occurring wetland species belong to the Poaceae family (Table 7). Other frequently occurring families include Juncaceae, Asteraceae, Cyperaceae, Ranunculaceae, Gunneraceae, Lobeliaceae, Asphodelaceae, and Onagraceae. 10 species were found in 10% (42) or more of the vegetation relevés. *Andropogon appendiculatus* is the most commonly found species, occurring in 25% of all relevés. Other Poaceae species found in more than 10% of all samples (42 occurrences) include *Agrostis lachnantha* (17%), *Festuca caprina* (14%), *Pennisetum sphacelatum* (14%), *Merxmuellera macowanii* (12%), and *Koeleria capensis* (11%). *Ranunculus meyeri* (16%) and *Ranunculus multifidus* (11%) were also commonly found species belonging to the Ranunculaceae family. Juncaceae species that were found in more than 10% of samples include *Juncus dregeanus* (10%) and *Juncus inflexus*

(10%). *Haplocarpha nervosa* and *Helichrysum aureonitens* are the two *Asteraceae* species that were found in more than 10% of relevés. *Gunnera perpensa* (Gunneraceae) was also found in 10% of relevés. Other commonly found species are listed in Table 7 below.

Table 7. Most common montane wetland species (found in 20 relevés or more out of 412 relevés), indicated by the number of times each species was observed in a relevé.

Species		**Family**	**Species**		**Family**
Andropogon appendiculatus	(105)	Poaceae	*Pseudognaphalium luteo-album*	(32)	Asteraceae
Agrostis lachnantha	(71)	Poaceae	*Fingerhuthia sesleriiformis*	(31)	Poaceae
Ranunculus meyeri	(66)	Ranunculaceae	*Kniphofia caulescens*	(30)	Asphodelaceae
Festuca caprina	(57)	Poaceae	*Isolepis angelica*	(30)	Cyperaceae
Pennisetum sphacelatum	(56)	Poaceae	*Isolepis costata*	(30)	Cyperaceae
Merxmuellera macowanii	(48)	Poaceae	*Eriocaulon dregei*	(29)	Eriocaulaceae
eleria capensis	(47)	Poaceae	*Helictotrichon turgidulum*	(29)	Poaceae
Ranunculus multifidus	(47)	Ranunculaceae	*Themeda triandra*	(29)	Poaceae
Haplocarpha nervosa	(43)	Asteraceae	*Carex cognata*	(29)	Cyperaceae
Juncus dregeanus	(43)	Juncaceae	*Senecio erubescens*	(28)	Asteraceae
Juncus inflexus	(42)	Juncaceae	*Oxalis depressa*	(27)	Oxalidaceae
Gunnera perpensa	(42)	Gunneraceae	*Carex glomerabilis*	(25)	Cyperaceae
Helichrysum aureonitens	(41)	Asteraceae	*Bulbostylis schoenoides*	(25)	Cyperaceae
Miscanthus capensis	(41)	Poaceae	*Pennisetum thunbergii*	(24)	Poaceae
Juncus oxycarpus	(40)	Juncaceae	*Arundinella nepalensis*	(24)	Poaceae
Monopsis decipiens	(39)	Lobeliaceae	*Cyperus denudatus*	(24)	Cyperaceae
Isolepis fluitans	(36)	Cyperaceae	*Cotula hispida*	(23)	Asteraceae
Poa binata	(36)	Poaceae	*Athrixia fontana*	(22)	Asteraceae

Species		**Family**	**Species**		**Family**
Aristida junciformis	(36)	Poaceae	*Fuirena pubescens*	(21)	Cyperaceae
Eragrostis planiculmis	(36)	Poaceae	*Commelina africana*	(21)	Commelinaceae
Stiburus alopecuroides	(34)	Poaceae	*Mentha longifolia*	(21)	Lamiaceae
Epilobium capense	(33)	Onagraceae	*Mentha aquatica*	(20)	Lamiaceae
Eleocharis dregeana	(32)	Cyperaceae			

Floristic Affinities

According to Sieben (2010), Mucina and Rutherford (2006) provide the most comprehensive overview of wetland vegetation in South Africa. The wetlands surveyed in this study predominantly fall within the Freshwater Wetland vegetation unit (Figure 6). A number of the important taxa of the above mentioned wetland unit listed by Mucina and Rutherford (2006) are common to the vegetation identified in this study; namely the Eastern Temperate Freshwater Wetlands (AZf 3 - 60 species), Drakensberg Wetlands (AZf 4 - 42 species), and Lesotho Mires (AZf 5 - 32 species). The Cape Lowland Freshwater Wetlands (AZf 1 - 12 species), and Cape Vernal Pools (AZf 2- six species) wetland distributions do not fall with the study site. However there are a small number of important taxa of these wetlands also identified in the cluster five wetlands.

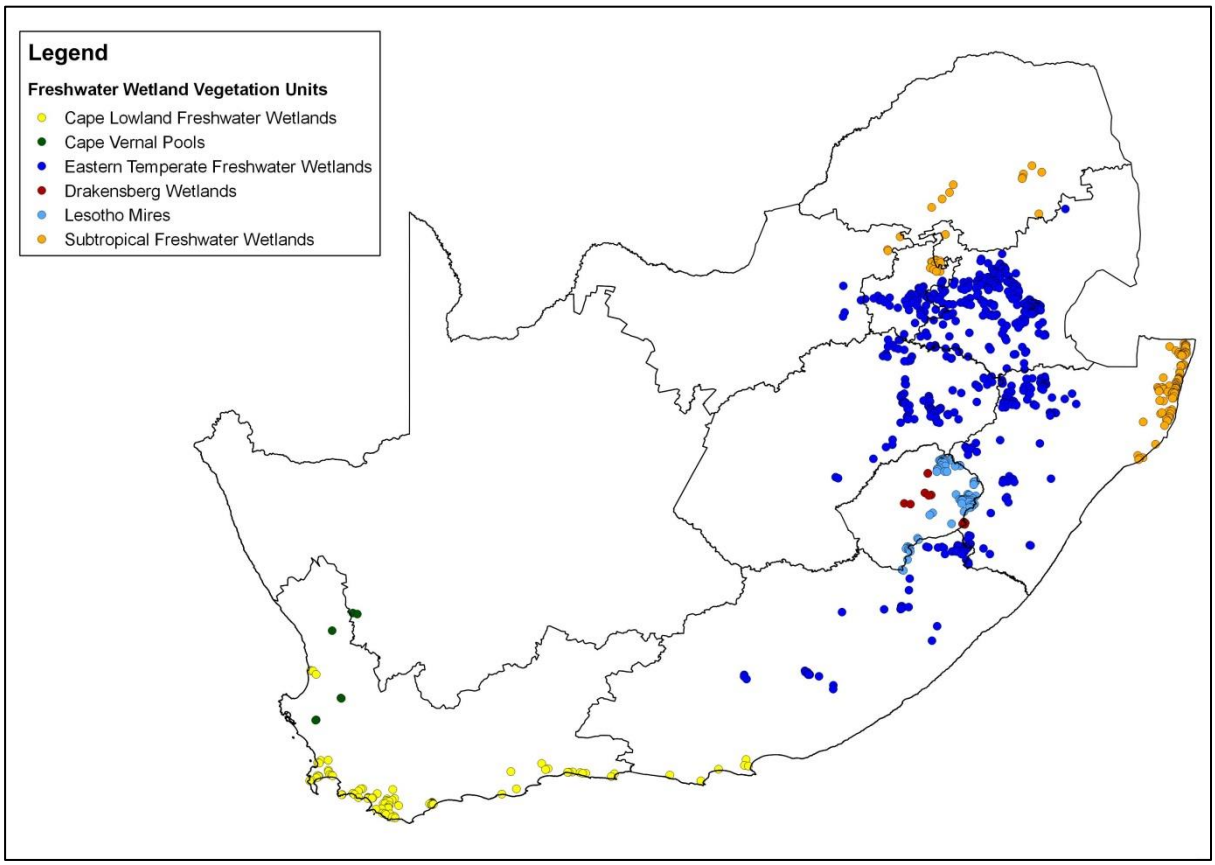

Figure 6. The distribution of the distribution of the Mucina and Rutherford (2006) Freshwater Wetlands vegetation units.

Classification

A total of 81 indicator species were identified that are indicative of 33 wetland communities (Table 8). The communities were named according to the most strongly supported indicator

species in each community. Five groups of closely related communities were revealed by HC analysis based on the primary branches of the dendrogram (Figure 7):

1. *Merxmuellera macowanii* Wetlands;
2. High Altitude Fen and Seepage Wetlands;
3. Common Escarpment Sedge and Grassy Wetlands;
4. *Miscanthus capensis* Wetlands; and
5. Eastern Escarpment Wetlands

A detailed classification of the major wetland groups, subgroups and communities is shown in Table 9.

The dendrogram (Figure 7) gives an indication of the similarity between the different wetland groups and communities based on plant composition. SIMPER analysis identified the species contributing to 70% of the similarity within each group of communities (Appendix 1)

The Eastern Escarpment Wetlands are the most distinct of the wetland groups. This is indicated by the first level of branching in the hierarchical clustering that is split into seven communities. *Andropogon appendiculatus* is particularly common to these wetlands. *Monopsis decipiens* is not identified as an indicator species, but it is also common to this group of communities (Appendix 1). This group has been split into four subgroups: (5.1) *Fimbristylis complanata* wetlands, (5.2) Midlands Mistbelt wetlands, (5.3) *Andropogon appendiculatus* wetlands, and (5.4) *Juncus oxycarpus* and *Stiburus alopecuroides* wetlands.

The *Miscanthus capensis* Wetlands are the most separated of the *Merxmuellera macowanii*, High Altitude Fen and Seepage, and Common Escarpment Sedge and Grassy Wetlands. This group is comprised of only one community and is characterised by the presence of *M. capensis* (Appendix 1).

The *Merxmuellera macowanii* Wetlands are also well separated, although show a slightly closer relationship with the High Altitude Fen and Seepage Wetlands and Common Escarpment Sedge and Grassy Wetlands than the *Miscanthus capensis* Wetlands. This group is also comprised of only one community and is characterised by the presence of *M. macowanii* (Appendix 1).

The High Altitude Fen and Seepage and Common Escarpment Sedge and Grassy Wetlands show the closest floristic relationship of the wetland groups. The Common Escarpment Sedge

and Grassy Wetlands are comprised of six subgroups (3.1 to 3.6) and 15 separate communities (3.1.1 to 3.6.3). The subgroups include: (3.1) *Gunnera perpensa* and *Carex acutiformis* wetlands, (3.2) mixed sedge wetlands, (3.3) *Agrostis lachnantha* wetlands, (3.4) *Carex austro-africana* wetlands, (3.5) *Pennisetum sphacelatum* wetlands, (3.6) and *Juncus inflexus* wetlands. The particularly common species to this group are listed in Appendix 1, of which *Ranunculus multifidus*, *Eleocharis dregeana*, *Ranunculus meyeri*, *Isolepis costata*, *Andropogon appendiculatus*, and *Carex glomerabilis* are not classified as indicator species. This suggests that they are common across the communities.

The High Altitude Fen and Seepage Wetlands consist of four subgroups (2.1 to 2.4) and nine communities (2.1.1 to 2.4.1). The subgroups include: (2.1) high altitude mixed sedge and grassy wetlands, (2.2) high altitude forb wetlands, (2.3) *Senecio cryptolanatus* wetlands, and (2.4) *Carex cognata* wetlands. The particularly common species to this community are listed in Appendix 1 of which *Ranunculus meyeri* is the species common to this group that was not identified as a community indicator species suggesting that it is present within a number of communities.

Table 8. Monte Carlo test of significance showing species supported as indicator species in each community.

Indicator species	**Community**	**Indicator value**	**P-value**
Merxmuellera macowanii	1.1.	64.0	0.0002
Carpha filifolia	2.1.1.	36.4	0.0010
Dierama pauciflorum	2.1.1.	34.4	0.0010
Wurmbea elatior	2.1.1.	27.5	0.0020
Restio sejunctus	2.1.1.	23.9	0.0030
Agrostis bergiana	2.1.1.	20.7	0.0020
Alepidea natalensis	2.1.1.	20.0	0.0070
Tetraria sp.	2.1.2	38.5	0.0010
Tenaxia disticha	2.1.2	26.0	0.0010
Schoenoxiphium sp.	2.1.2	22.5	0.0010
Poa binata	2.1.2	20.6	0.0030
Festuca caprina	2.1.3.	28.0	0.0010
Rhodohypoxis rubella	2.1.4.	87.5	0.0010
Alepidea pusilla	2.1.4.	87.5	0.0010
Schoenoxiphium filiforme	2.1.4.	75.3	0.0010
Athrixia fontana	2.1.4.	55.1	0.0010
Felicia sp.	2.1.4.	50.0	0.0010

Indicator species	Community	Indicator value	P-value
Rhodohypoxis baurii	2.1.4.	30.2	0.0010
Eriocaulon dregei	2.1.4.	25.9	0.0020
Senecio natalicola	2.1.4.	28.3	0.0030
Sebaea repens	2.1.4.	22.3	0.0050
Senecio macrocephalus	2.1.4.	20.2	0.0050
Merxmuellera drakensbergensis	2.1.5.	83.0	0.0010
Haplocarpha nervosa	2.2.1.	31.2	0.0010
Kniphofia caulescens	2.2.2	63.6	0.0010
Senecio cryptolanatus	2.3.1.	87.5	0.0010
Limosella longiflora	2.3.1.	74.1	0.0010
Agrostis subulifolia	2.3.1.	72.9	0.0010
Helichrysum bellum	2.3.1.	68.8	0.0010
Thesium nigrum	2.3.1.	50.0	0.0010
Bryum argenteum	2.3.1.	49.5	0.0010
Cotula hispida	2.3.1.	41.7	0.0010
Koeleria capensis	2.3.1.	24.6	0.0010
Carex cognata	2.4.1.	55.1	0.0010
Gunnera perpensa	3.1.1.	36.1	0.0010
Epilobium salignum	3.1.1.	25.0	0.0020
Nidorella agria	3.1.1.	20.5	0.0100
Carex acutiformis	3.1.2.	24.2	0.0010
Isolepis fluitans	3.2.1.	30.4	0.0010
Fingerhuthia sesleriiformis	3.2.2.	48.6	0.0010
Poa pratensis	3.2.2.	24.0	0.0030
Fuirena coerulescens	3.2.3.	70.4	0.0010
Lobelia flaccida subsp. flaccida	3.2.3.	25.7	0.0020
Limosella major	3.2.4.	67.7	0.0010
Kyllinga pulchella	3.3.1.	75.9	0.0010
Limosella inflata	3.3.1.	21.3	0.0060
Limosella africana	3.3.2.	53.6	0.0010
Scirpus ficinioides	3.3.2.	29.9	0.0010
Crassula gemmifera	3.3.2.	21.8	0.0080
Isolepis angelica	3.3.3.	44.9	0.0010
Juncus lomatophyllus	3.3.3.	21.9	0.0040
Juncus bufonius	3.3.3.	20.8	0.0040
Trifolium africanum	3.3.4.	26.3	0.0010
Agrostis lachnantha	3.3.4.	21.5	0.0010
Carex austro-africana	3.4.1.	81.3	0.0010

Indicator species	Community	Indicator value	P-value
Phragmites australis	3.4.1.	28.3	0.0020
Pennisetum sphacelatum	3.5.1.	31.1	0.0010
Juncus inflexus	3.6.1.	31.2	0.0010
Crassula vaillantii	3.6.2.	68.1	0.0010
Pentaschistis densifolia	3.6.2.	46.6	0.0010
Veronica anagallis-aquatica	3.6.2.	35.4	0.0010
Juncus dregeanus	3.6.2.	20.5	0.0010
Sebaea macrophylla	3.6.2.	22.4	0.0020
Mentha longifolia	3.6.3.	47.6	0.0010
Miscanthus capensis	4.1.1.	71.6	0.0010
Fimbristylis complanata	5.1.1.	72.3	0.0010
Tristachya leucothrix	5.2.1.	42.2	0.0010
Aristida junciformis subsp. junciformis	5.2.1.	26.1	0.0010
Harpochloa falx	5.2.1.	21.6	0.0050
Ledebouria sp.	5.2.2.	57.8	0.0010
Pycreus cooperi	5.2.2.	43.7	0.0010
Pycreus macranthus	5.2.2.	34.0	0.0010
Xyris gerrardii	5.2.2.	33.9	0.0010
Gladiolus papilio	5.2.2.	45.0	0.0020
Bulbostylis schoenoides	5.2.2.	21.0	0.0030
Scleria welwitschii	5.2.3.	55.4	0.0010
Monocymbium ceresiiforme	5.2.3.	53.1	0.0010
Helichrysum aureum	5.2.3.	21.2	0.0010
Andropogon appendiculatus	5.3.1.	67.3	0.0010
Juncus oxycarpus	5.4.1	37.5	0.0010
Stiburus alopecuroides	5.4.2.	60.7	0.0010

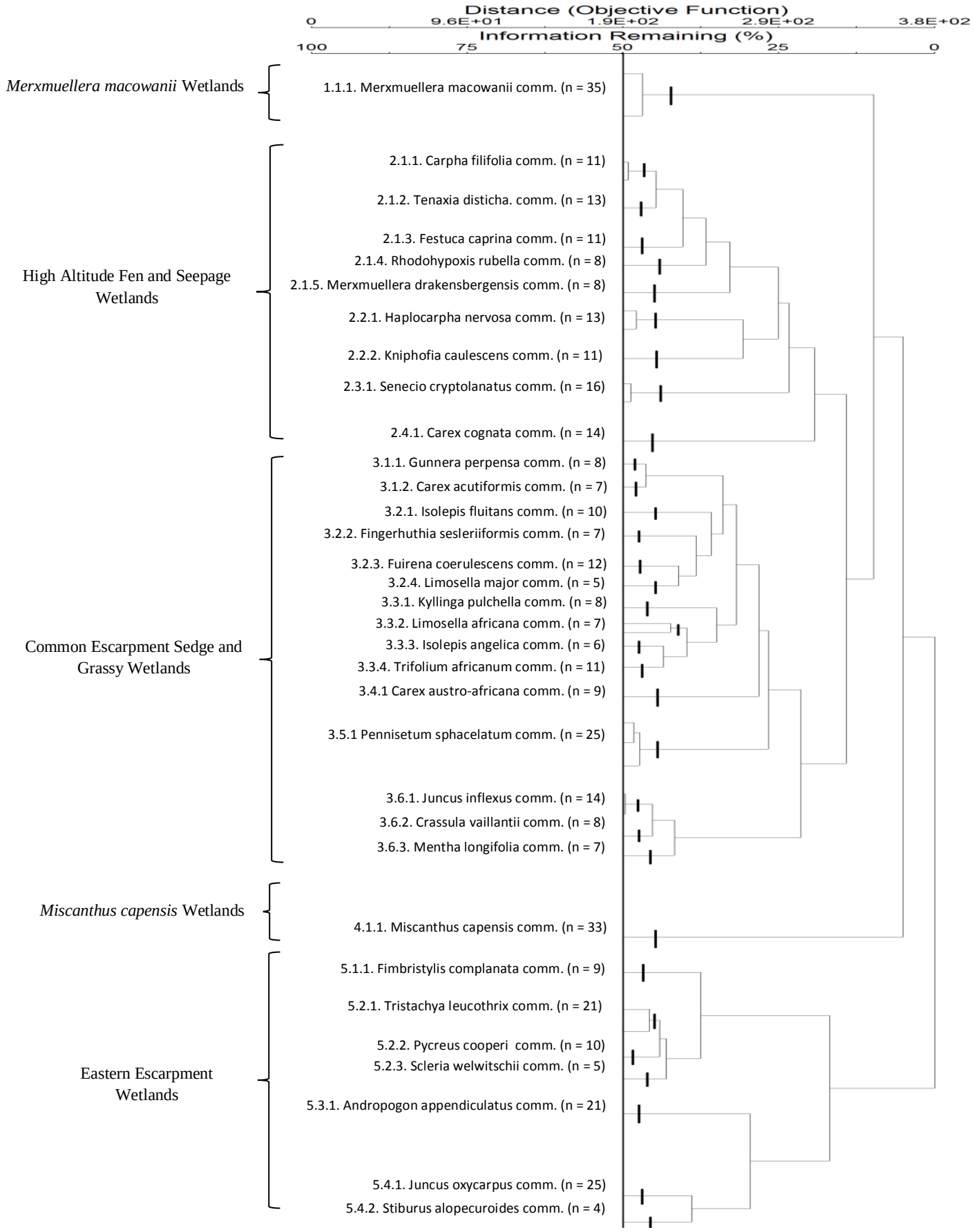

Figure 2. Dendrogram showing the relationship between the five wetland groups and individual communities based on species composition. The point at which each community was defined using ISA is indicated by the black markers on the branches.

Table 9. Hierarchical classification of wetland communities based on dendrogram above. Species names are described including genus names above.

Broad Wetland Groups	**Subgroups**	**Communities**
1. *Merxmuellera macowanii* Wetlands		1.1.1. *M. macowanii* comm.
2. High Altitude Fen and seep Wetlands	2.1. Mixed sedge and grassy wetlands	2.1.1. *C. filifolia* comm.
		2.1.2. *Tenaxia disticha* comm.
		2.1.3. *F. caprina* comm.
		2.1.4. *R. rubella* comm.
		2.1.5. *M. drakensbergensis* comm.
	2.2. Forb wetlands	2.2.1. *H. nervosa* comm.
		2.2.2. *K. caulescens* comm.
	2.3. *Senecio cryptolanatus* wetlands	2.3.1. *S. cryptolanatus* comm.
	2.4. *Carex cognata* wetlands	*2.4.1. C. cognata* comm.
3. Common Escarpment Sedge and Grassy Wetlands	3.1. *G. perpensa - C. acutiformis* wetlands	3.1.1. *G. perpensa* comm.
		3.1.2. *C. acutiformis* comm.
	3.2. Mixed sedge wetlands	*3.2.1. I. fluitans* comm.
		3.2.2. F. sesleriiformis comm.
		3.2.3. F. coerulescens comm.
		3.2.4. L. major comm.
	3.3. *Agrostis lachnantha* wetlands	*3.3.1. K. pulchella* comm.
		3.3.2. L. africana comm.
		3.3.3. I. angelica comm.
		3.3.4. T. africanum comm.
	3.4. *Carex austro-africana* wetlands	*3.4.1. C. austro-africana* comm.
	3.5. *Pennisetum sphacelatum* Wetlands	*3.5.1. P. sphacelatum* comm.
	3.6. *Juncus inflexus* wetlands	*3.6.1. J. inflexus* comm.
		3.6.2. C. vaillantii comm.
		3.6.3. M. longifolia comm.
4. Miscanthus capensis Wetlands		*4.1.1. M. capensis* comm.
5. Eastern Escarpment Wetlands	5.1. *Fimbristylis complanata* wetlands	*5.1.1. F. complanata* comm.
	5.2. Midlands Mistbelt wetlands	*5.2.1. T. leucothrix* comm.
		5.2.2. Pycreus cooperi comm.
		5.2.3. S. welwitschii comm.
	5.3. *Andropogon appendiculatus* wetlands	*5.3.1. A. appendiculatus* comm.
	5.4. *Juncus oxycarpus - Stiburus alopecuroides* wetlands	*5.4.1. J. oxycarpus* comm.
		5.4.2. S. alopecuroides comm.

Descriptions of the Montane Wetland Plant Communities of the Great Escarpment

The following section describes each of the major wetland groups in terms of distribution, wetland communities, and indicator species. This information is compared to findings of past studies. For detailed distribution maps of each plant community please refer to Appendix 2.

Merxmuellera macowanii Wetlands

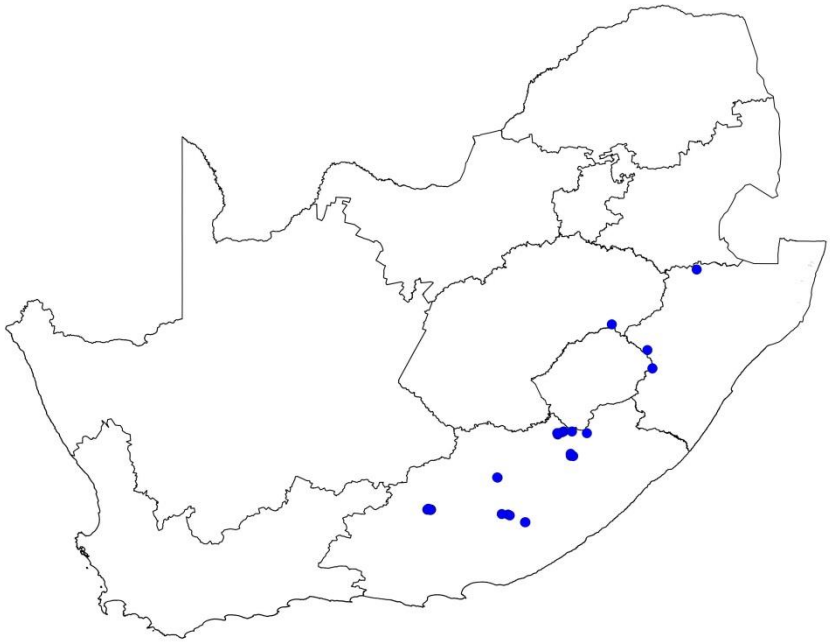

Figure 8. Distribution of *Merxmuellera macowanii* Wetlands.

The *Merxmuellera macowanii* community is a commonly found, widespread single species-dominated tussock grassland community that makes up 8% of the total sample. *M. macowanii* is classified as an important Drakensberg Wetland species by Mucina and Rutherford (2006), and is well-recognised as a DAC and Lesotho wetland community (Backéus, 1989; Bussman, 2006). It has also been found as a wetland community in the Boschberg (Clark et al., 2011c) and Sneeuberg (Clark et al., 2012, 2009), which is in agreement with the distribution found in this study. The community shown here is particularly common in the Eastern Cape Escarpment area and extends towards the Mpumalanga escarpment (Figure 8). It is suggested that *M. macowanii* be included as an important taxon of the Eastern Temperate Freshwater Wetland group. A photographic representation of the *Merxmuellera macowanii* wetlands is shown in Figure 9.

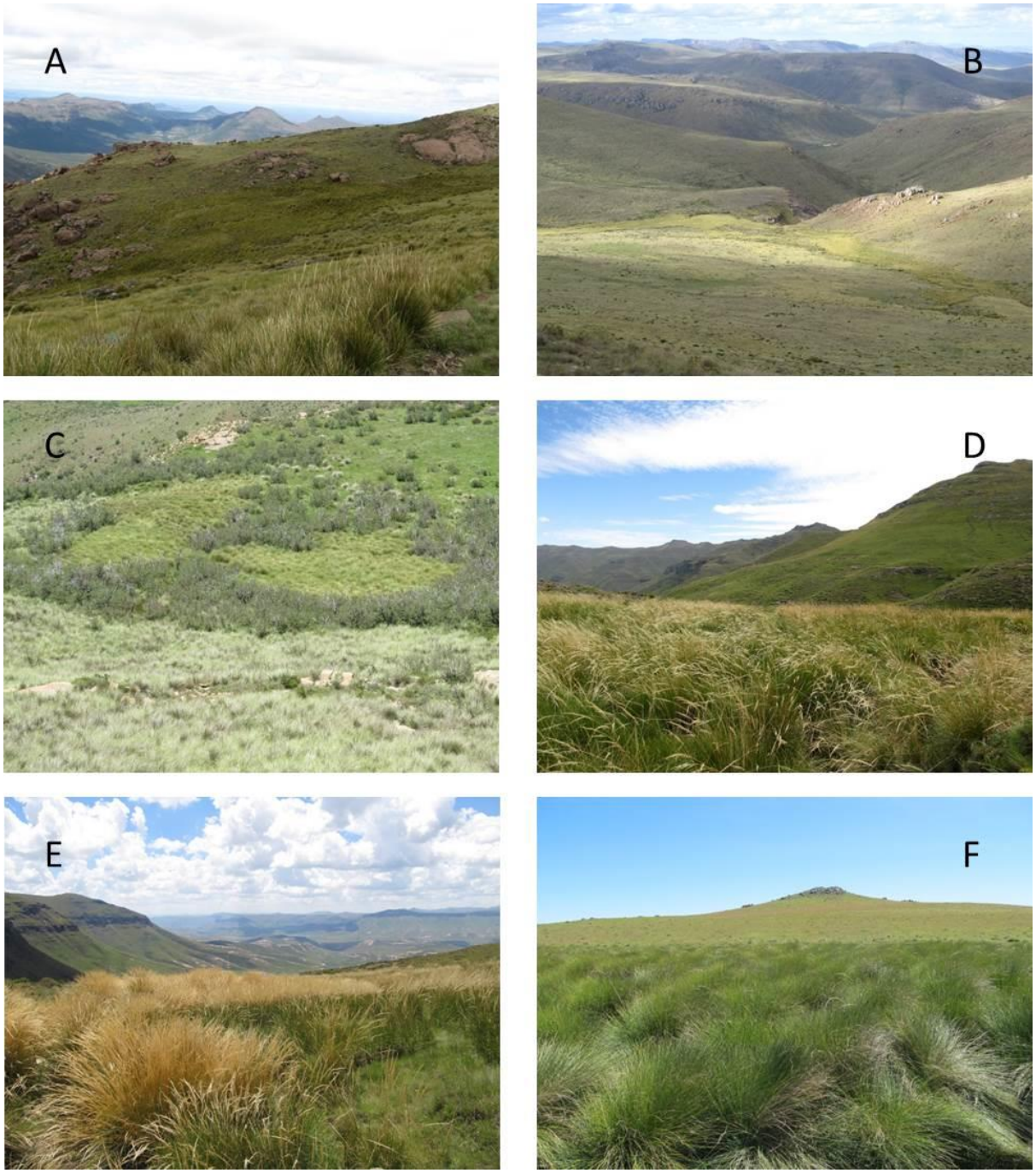

Figure 9. A selection of photographs of the *Merxmuellera macowanii* wetlands: (A) High peak slope seepage community in the Sneeuberg, (B) high peak valleyhead seepage community in the Sneeuberg, (C) slope seepage community in the Stormberg, (D and E) high peak slope seepage communities in the EC Drakensberg, (F) valley bottom community in the GWA. Photos taken by M.R. Janks.

The High Altitude Fen and Seepage Wetlands

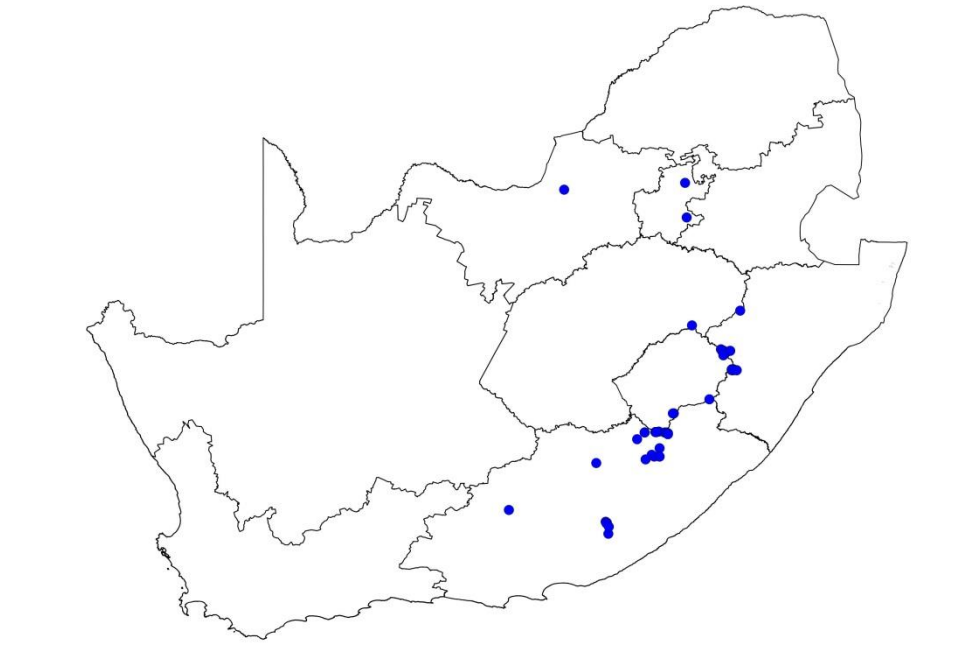

Figure 10. Distribution of the High Altitude Fen and Seepage Wetlands.

The High Altitude Fen and Seepage Wetlands are concentrated in the Drakensberg (Figure 10). A few of the communities are found outside the Drakensberg which include the *Haplocarpha nervosa* (Sneeuberg and GWA), *Festuca caprina* (GWA) and *Carex cognata* (Stormberg and Highveld) communities. A photographic representation of some of the high altitude fen and seepage wetlands is shown in Figure 11.

Mixed sedge and grassy wetlands

The *Carpha filifolia* community is a mixed sedge and forb community comprised of six co-dominant species, also including *Dierama pauciflorum*, *Wurmbea elatior*, *Restio sejunctus*, *Agrostis bergiana*, and *Alepidea natalensis*. This community has floristic affinities with the Drakensberg Wetlands and Lesotho Mires units of Mucina and Rutherford (2006). *C. filifolia* and *D. pauciflorum* are listed as important Drakensberg Wetland species, and *W. elatior* and *A. bergiana* are listed as important Lesotho Mires species (Mucina and Rutherford, 2006). Sieben et al. (2010) and Brand et al. (2013) both identify of *C. filifolia* as a wetland community in the DAC.

The *Tenaxia* (previously *Merxmuellera*) *disticha* community is a mixed sedge and grassy community also comprised of *Tetraria sp.*, *Schoenoxiphium sp.* and *Poa binata*. Mucina and

Rutherford (2006) list *Tetraria cuspidata* as the only wetland plant from the *Tetraria* genus, which is listed in the Fynbos Riparian Vegetation group. Assuming this is a different species to the Drakensberg species, the *Tetraria sp*. mentioned here is not listed by Mucina and Rutherford. Neither do Sieben et al. (2010) or Brand et al. (2013) list any of these as wetland indicator species. van Zinderen Bakker and Werger (1974) identify both *Tenaxia disticha* and *Poa binata* as slope and plateau wetland species of high altitude Lesotho bog wetlands. It is suggested that the indicator species of this community may be added to the Mucina and Rutherford (2006) Drakensberg Wetland unit.

The *Festuca caprina* community is a single grass species-dominated community. It is distributed in the GWA and Drakensberg regions. *F. caprina* is not mentioned by Mucina and Rutherford (2006). It has however been previously identified as a dominant wetland species in Lesotho (Bussman, 2006; van Zinderen Bakker and Werger, 1974) and the DAC as a hygrophilous grassland community (Brand et al., 2013; Sieben et al., 2010). It has also been listed as a non-wetland grassland dominant in Lesotho (Kopij, 2005) and the Sneeuberg (Clark et al., 2009). It is suggested that *F. caprina* be included in the Mucina and Rutherford (2006) Drakensberg Wetland unit.

The *Rhodohypoxis rubella* community is a mixed-forb community also comprised of *Alepidea pusilla*, *Schoenoxiphium filiforme*, *Athrixia fontana*, *Felicia sp*., *Rhodohypoxis baurii*, *Eriocaulon dregei*, *Senecio natalicola*, *Senecio repens*, and *Senecio macrocephalus*. The species recognised as important Lesotho Mire taxa by Mucina and Rutherford (2006) include *A. pusilla S. filiforme*, *A. fontana*, and *S. macrocephalus*. The remaining species are not listed by Mucina and Rutherford (2006). This is however a well-recognised combination of wetland plants in Lesotho and the DAC area (Brand et al., 2013; Du Preez and Brown, 2011; Grab and Deschamps, 2004; van Zinderen Bakker and Werger, 1974) suggesting that these are important wetland taxa of the Lesotho Mire and Drakensberg Wetlands.

The *Merxmuellera drakensbergensis* community resembles the *M. macowanii* community as a single-tussock grass species community. It is less common and restricted mainly to the DAC. It has been recognised as a wetland species in the DAC and Lesotho (Bussman, 2006; Grab and Deschamps, 2004) which suggests that it should be added to the important wetland taxa of the Drakensberg Wetlands and Lesotho Mires.

Forb wetlands

The *Haplocarpha nervosa* community is a mat-forming forb-dominated community. It was found as a dominant in the Drakensberg, GWA and Sneeuberg, indicating that it is widespread in the central to western areas of the Escarpment. *H. nervosa* is listed under important taxa of the Lesotho Mires wetland unit (Mucina and Rutherford, 2006) and is well-recognised as a common wetland community in the DAC (Backéus, 1989; Du Preez and Brown, 2011; Sieben et al., 2010; van Zinderen Bakker and Werger, 1974). It has also been identified as a wetland species in the Sneeuberg (Clark et al., 2009) emphasising the distribution identified in this study. This suggests that *H. nervosa* should also be included as an important taxon of the Drakensberg Wetland and Eastern Temperate Freshwater Wetland units.

The *Kniphofia caulescens* community is a single-herb species-dominated community. The distribution identified here is restricted to the DAC. It is listed under endemic taxa of the Lesotho Mires unit (Mucina and Rutherford, 2006) and has been classified as a DAC wetland species by others (Bussman 2006; Sieben et al., 2010). It has been documented in the GWA (Clark et al., 2014) and Sneeuberg (Clark et al., 2012, 2009) but not as a dominant species. It is suggested that *K. caulescens* be classified as an important taxon of the Lesotho Mire wetlands rather than an endemic species and is also included as an important taxon of the Drakensberg Wetlands.

Senecio cryptolanatus wetlands

The *Senecio cryptolanatus* community is a mixed community also dominated by *Limosella longiflora, Agrostis subulifolia, Helichrysum bellum, Thesium nigrum, Bryum argenteum, Cotula hispida,* and *Koeleria capensis*. It was found restricted to the north east area of the Drakensberg at one site on the Lesotho boarder. *S. cryptolanatus, A. subulifolia* and *H. bellum* are listed as a biogeographically important species of the Lesotho Mires wetland unit (Mucina and Rutherford, 2006). *T. nigrum, C. hispida, and K. capensis* are listed as an important species of the Lesotho Mires wetland unit (Mucina and Rutherford, 2006).

Carex cognata wetlands

The *Carex cognata* community is single-species dominated sedge community concentrated in the Drakensberg and Stormberg areas, and extends onto the Highveld. It is listed as an important taxon under both the Drakensberg and Lesotho Mires wetland units (Mucina and

Rutherford, 2006) and recognised by others in the same areas (Sieben et al., 2010). Existing studies suggest that this is a wide-spread community found also in the Sneeuberg (Clark et al., 2009), KwaZulu-Natal Midlands (Grenfell et al., 2005) as well as outside South Africa (Ssegawa and Kalema, 2008). It is suggested that *C. cognata* also be included as an important taxon of the Eastern Temperate Freshwater Wetlands.

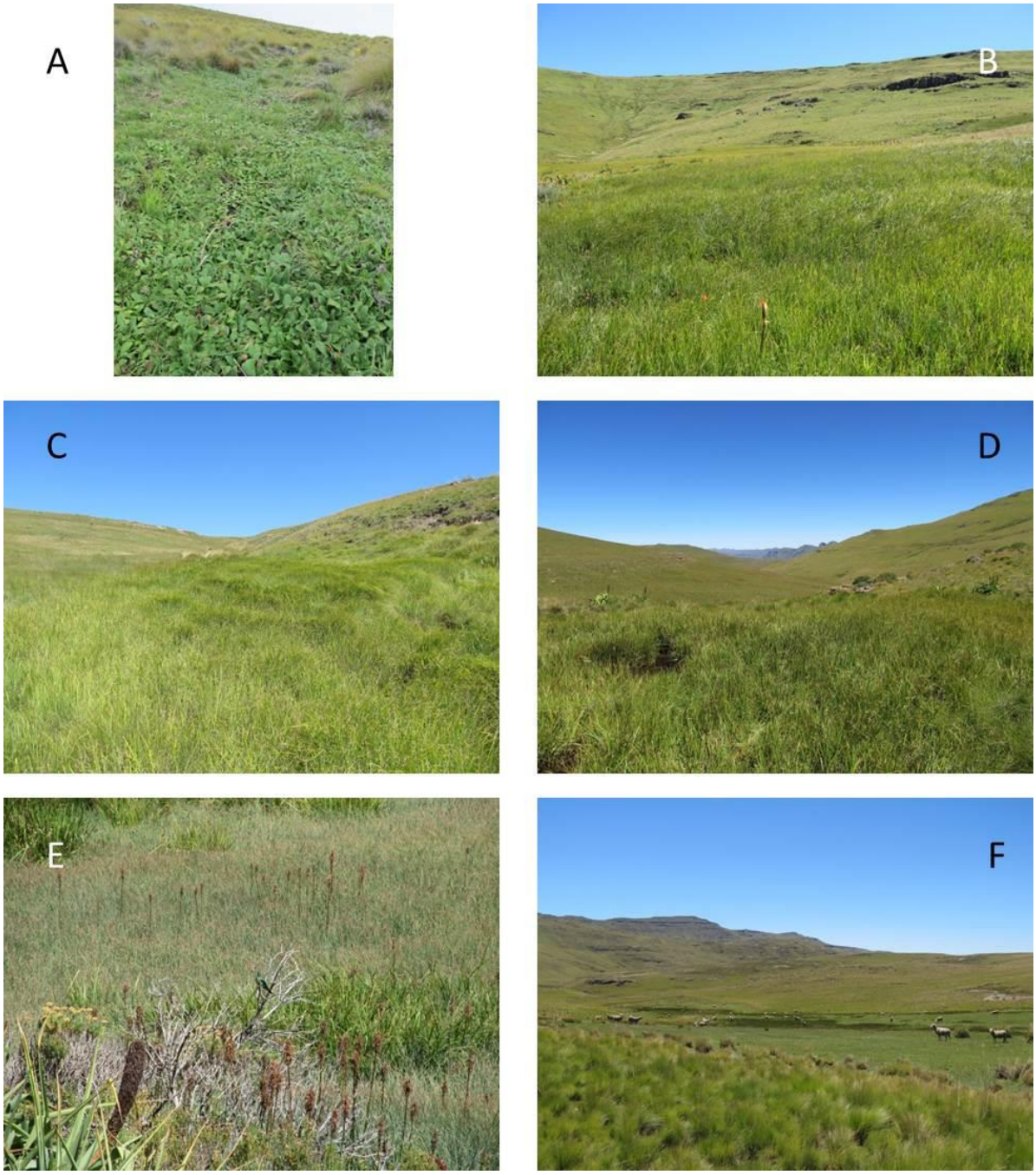

Figure 11. A selection of photographs of the high altitude fen and seepage wetlands: (A) *Haplocarpha nervosa* community on the Sneeuberg high peaks, (B, C, D) *Carex cognata* community in the EC Drakensberg, (E) *Kniphofia caulescens* community in the EC Drakensberg, (F) *Merxmuellera drakensbergensis* community in the foreground and *Kniphofia caulescens* community in the background in the EC Drakensberg. Photos taken by M.R. Janks.

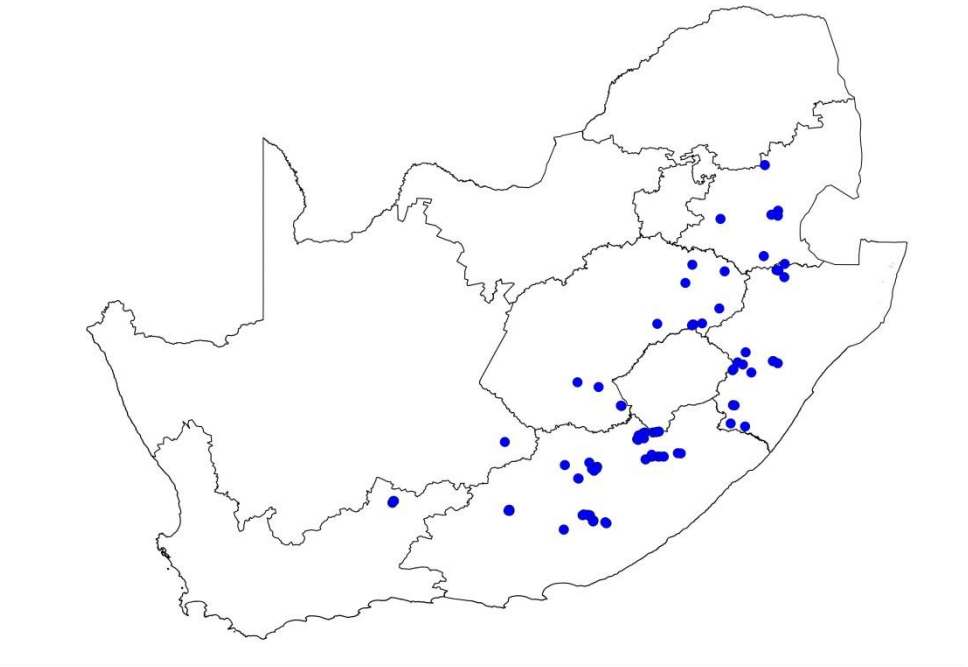

Figure 12. Distribution of the Common Escarpment Sedge and Grassy Wetlands.

The Common Escarpment Sedge and Grassy Wetlands are distributed across the Great Escarpment (Figure 12). A photographic representation of some of the Common Escarpment Sedge and Grassy Wetlands is shown in Figure 13**.**

Gunnera perpensa - Carex acutiformis wetlands

The *Gunnera perpensa* community is a single herbaceous-species dominated community occurring in the Drakensberg and KwaZulu-Natal Midlands areas. It is listed as an important taxon of the Drakensberg wetlands (Mucina and Rutherford, 2006). Other literature suggests that *G. perpensa* is a widespread wetland species that has been documented in the Western Cape (Mergili and Privett, 2008), Nuweveldberge (Clark et al., 2011b), Sneeuberg (Clark et al., 2009), and in high altitude areas across Africa (Ruto et al., 2012). It is suggested that it is included in the important taxa of the Eastern Temperate Freshwater Wetland unit, especially considering its status as a Red Data List 'Declining': species (SANBI, 2014). This is as a result of overharvesting for use as a traditional medicine (Mahlalela, 2014).

The *Carex acutiformis* community is a tall-standing single species sedge-dominated community distributed from the Drakensberg to the Mpumalanga Escarpment. Mucina and Rutherford (2006) list this species as an important Drakensberg and Eastern Temperate

Freshwater Wetland taxon. Other studies show this to be a common community outside of South Africa (Bissels et al., 2004; Falinska, 1995; Güsewell, 2003).

Mid-altitude mixed sedge wetlands

The *Isolepis fluitans* community is a short-standing single species sedge-dominated community distributed from the GWA to the Mpumalanga Escarpment. It is well documented as a common wetlands species in the Drakensberg (Backéus, 1989; Bussman, 2006) and is widespread outside South Africa (Benzie and De Silva, 1988; Daley and Kirkpatrick, 2004; Leck and Brock, 2000; Nicol et al., 2003). It is listed as an important taxon of the Drakensberg Wetland unit (Mucina and Rutherford, 2006) but should also be considered as an important Eastern Temperate Freshwater Wetland taxon.

The *Fingerhuthia sesleriiformis* community is a mixed-grassy community also dominated by *Poa pratensis*. The study identified its distribution to be concentrated in the GWA and Stormberg areas. Neither species is recognised by Mucina and Rutherford (2006) although *F. sesleriiformis* is recognised as a wetland species by other studies in the Nuweveldberge (Clark et al., 2011b), Drakensberg (Brand et al., 2013; Kotze and O'Connor, 2000), and Mpumalanga Escarpment areas (Myburgh and Bredenkamp, 2004). *P. pratensis* is a naturalised exotic (SANBI, 2014) also previously recognised as a wetland species (Goslee et al., 1997). It is suggested that *F. sesleriiformis* be added to the important taxa of the Eastern Temperate Freshwater Wetland unit.

The *Fuirena coerulescens* community is a mixed-sedge community co-dominated by *Lobelia flaccida subsp. flaccida* concentrated in the Stormberg and GWA. Mucina and Rutherford (2006) recognise *F. coerulescens* as an important taxon of the Inland Saline Vegetation wetland unit, and not the Freshwater Wetlands unit. It has been previously been documented as common throughout the Eastern Cape Escarpment (Clark et al., 2011a). *Lobelia flaccida subsp. flaccida* is listed as an important taxon of the Drakensberg Wetland unit (Mucina and Rutherford, 2006) and is recognised by others as a wetland species in the DAC area (Brand et al., 2013). The distribution of both species suggests that they should both be included as important taxa of the Freshwater Eastern Temperate Wetlands.

The *Limosella major* community is a mat-forming herbaceous community distributed from the Drakensberg to the Mpumalanga Escarpment. Grab and Deschamps (2004) refer to *L. major* as a notable wetland species in Lesotho. It is not recognised by Mucina and Rutherford

(2006) but is worth adding to the important taxa of the Drakensberg and Eastern Temperate Freshwater Wetland units.

Agrostis lachnantha wetlands

The *Kyllinga pulchella* community is a short-standing community co-dominated by *Limosella inflata*. It is widely distributed from the Stormberg to the Mpumalanga Escarpment but concentrated in the Drakensberg. *K. pulchella* is not listed by Mucina and Rutherford (2006). Sieben et al. (2010) recognise *K. pulchella* as a rare wetland species in the DAC. Mucina and Rutherford (2006) do list *L. inflata* as a biogeographically important Lesotho Mire taxon, endemic to the Drakensberg and it has been recognised in Lesotho (Backéus, 1989) and the DAC (Brand et al., 2013) by others. It is worth considering both *K. pulchella* and *L. inflata* as important taxa of the Drakensberg Wetland unit.

The *Limosella africana* community is lawn-like mixed community co-dominated by *Scirpus ficinioides* and *Crassula gemmifera*. It is concentrated in the Drakensberg and extends into the Mpumalanga Escarpment. Mucina and Rutherford (2006) list both *L. africana* and *S. ficinioides* as important taxa in both the Drakensberg and Lesotho Mire wetland units, and *C. gemmifera* as a biogeographically important taxa of the Lesotho Mire wetland unit. *S. ficinioides* is well-recognised as a dominant wetland species in the Drakensberg and Lesotho by others (Bussman, 2006; Schwabe, 1995; Sieben et al., 2010). *L. africana* is recognised outside the Drakensberg as a wetland species in the Northern Cape area (Helme, 2010; Roux et al., 2009).

The *Isolepis angelica* community is a lawn-like sedge and rush community also dominated by *Juncus lomatophyllus* and *Juncus bufonius*. It is concentrated in the Eastern Cape, distributed from the GWA to the EC Drakensberg. *Isolepis angelica* is well-documented in the Drakensberg (Grab, 2012; Schwabe, 1995) and is listed as an endemic species of the Drakensberg Wetland unit (Mucina and Rutherford, 2006). It has been recognised in the Sneeuberg (Clark et al., 2009), Nuweveldberge (Clark et al., 2011b) and Roggeveld (Clark et al., 2011d), thus classification as an important taxon of the Drakensberg Wetlands rather than an endemic species may be more accurate. *J. bufonius* is a widespread wetland species occurring outside South Africa (Boutin and Keddy, 1993; Casanova and Brock, 2000; Leck and Brock, 2000). Inclusion of all three indicator species in as important taxa of the Eastern Temperate Freshwater Wetland unit is also suggested.

The *Trifolium africanum* community is a mixed community co-dominated by *Agrostis lachnantha* concentrated in the Eastern Cape mountain areas and extending towards the Mpumalanga Escarpment. *A. lachnantha* is a widespread wetland species across the Eastern Cape Escarpment (Clark et al., 2009; Clark et al., 2011b; Pond et al., 2002) and Drakensberg Escarpment areas (Brand et al., 2013). Mucina and Rutherford (2006) list it as an important species of the Eastern Temperate Freshwater Wetland and Lesotho Mire units. *T. africanum* is not well-documented as a wetland species. Given the distribution identified in this study it is suggested that *T. africanum* be included as an important taxon of the Eastern Temperate Freshwater Wetlands.

Carex austro-africana wetlands

The *Carex austro-africana* community is a tall-standing mixed community co-dominated by *Phragmites australis* distributed from the KwaZulu-Natal Midlands to the Mpumalanga Escarpment. Both species are listed as important taxa of the Eastern Temperate Freshwater Wetlands (Mucina and Rutherford, 2006). *P. australis* is a particularly widespread species in South Africa and also included as an important taxon of the Cape Lowland Freshwater and Subtropical Freshwater Wetlands (Mucina and Rutherford, 2006). *C. austro-africana* is listed as an important taxon of the Drakensberg Wetlands (Mucina and Rutherford, 2006).

Pennisetum sphacelatum wetlands

The *Pennisetum sphacelatum* community is a single species grass-dominated community distributed from the Eastern Cape Escarpment to the Mpumalanga Escarpment. It is well-recognised as a wetland species in the Drakensberg area (Brand et al., 2013; Du Preez and Brown, 2011; Sieben et al., 2010) and in the GWA (Clark et al., 2014). Mucina and Rutherford (2006) include *P. sphacelatum* as an important taxon of the Eastern Temperate Freshwater Wetlands.

Juncus inflexus wetlands

The *Juncus inflexus* community is single species-dominated rush community that is concentrated in the Eastern Cape Escarpment and extends to the Mpumalanga Escarpment. It is well- recognised outside South Africa as a wetland species (Bernaldez et al., 1989; Hájek et al., 2002; Naqinezhad et al., 2009; Ranwell, 1961) but surprisingly it is ignored by Mucina and Rutherford (2006), given that it is one of the more common wetland species identified by

this study. It is suggested that this species is added to the important taxa of the Drakensberg and Eastern Temperate Freshwater Wetland units.

The *Crassula vaillantii* community is a low-growing community also dominated by *Pentaschistis densifolia*, *Veronica anagallis-aquatica*, *Juncus dregeanus* and *Sebaea macrophylla* concentrated only in the Nuweveldberge and Sneeuberg. Both *V. anagallis-aquatica* and *J. dregeanus* have been previously recognised as Drakensberg wetland species (Brand et al., 2013), but only *J. dregeanus* is recognised by Mucina and Rutherford (2006) as an important taxon of the Drakensberg Wetlands. Given the distribution of this community it is suggested that these indicator species be included in the important taxa of the Eastern Temperate Freshwater Wetland unit.

The *Mentha longifolia* community isdominated by a single herbaceous species. It is concentrated in the EC Drakensberg area. It has been previously recognised as a wetland species in the Drakensberg (Sieben et al., 2010), Sneeuberg (Clark et al., 2009) , Nuweveldberge (Clark et al., 2011b), and outside of South Africa (Muller et al., 2012; Naqinezhad et al., 2009) suggesting a wider distribution than that found in this study. It is not recognised by Mucina and Rutherford (2006) but it is suggested that it is included as an important taxon of the Eastern Temperate Freshwater Wetlands.

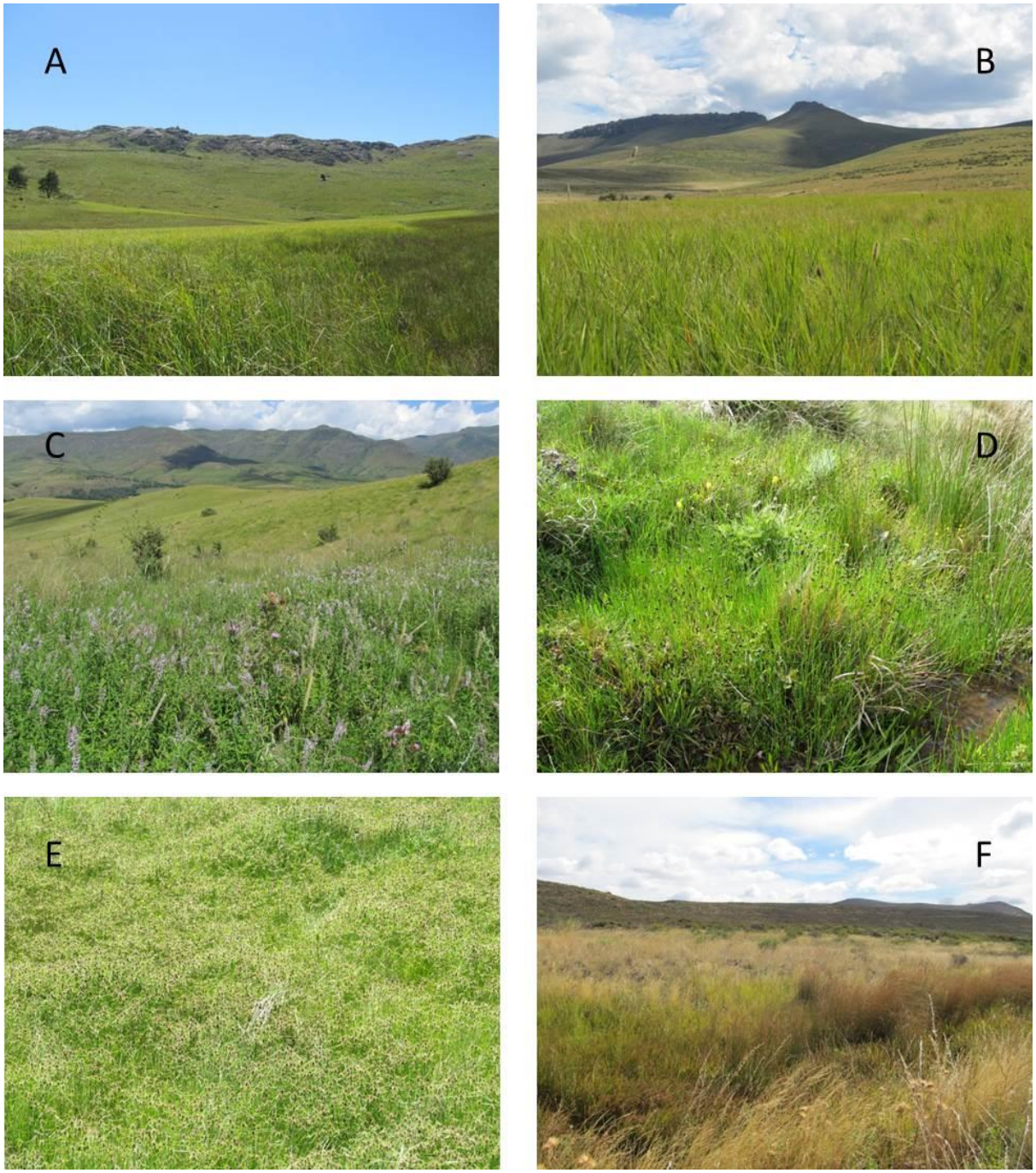

Figure 13. A selection of photographs of the mid-altitude mixed sedge and grassy wetlands: (A) Valley bottom *Carex acutiformis* community in the GWA, (B) valley bottom *Fingerhuthia sesleriiformis* community in the GWA, (C) slope seepage *Mentha longifolia* community in the EC Drakensberg, (D) slope seepage *Isolepis angelica* community in the GWA, (E) Depression *Kyllinga pulchella* community in the Stormberg, (F) typical mixed sedge and grassy wetland comprised of the *Juncus inflexus* and *Agrostis lachnantha* communities in the Nuweveldberge.

The Miscanthus capensis Wetlands

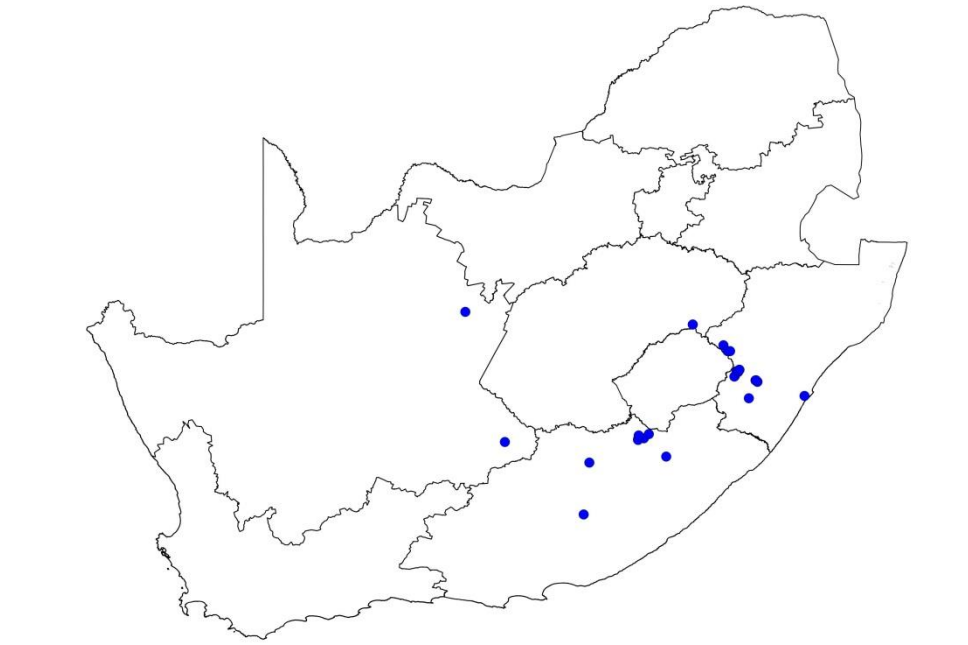

Figure 14. Distribution of the *Miscanthus capensis* Wetlands.

The *Miscanthus capensis* community is a single grass-species dominated community concentrated in the Drakensberg and extending into the EC Escarpment (Figure 14). It has been previously documented as a wetland species in the Drakensberg (Walters et al., 2006) and Sneeuberg (Clark et al., 2009). It is ignored by Mucina and Rutherford (2006) as a freshwater wetland species, thus it is suggested that *M. capensis* should be included as an important taxon of the Drakensberg Wetlands.

The Eastern Escarpment Wetlands

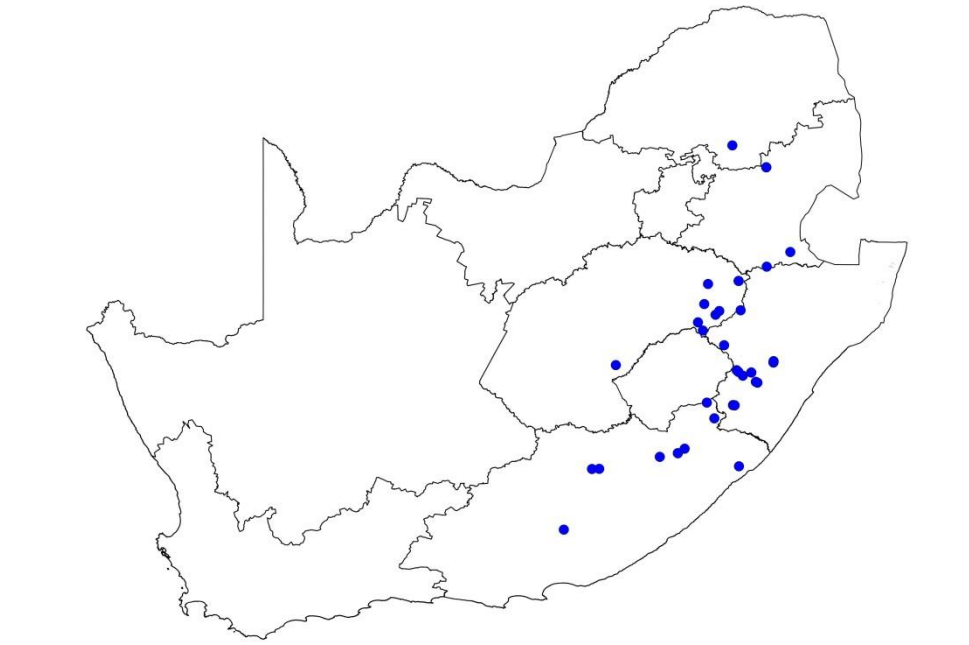

Figure 15. Distribution of Eastern Escarpment Wetlands.

Fimbristylis complanata wetlands

The *Fimbristylis complanata* community is a single sedge-species dominated community distributed along the eastern areas of the Escarpment. It is listed as an important taxon of the Eastern Temperate Freshwater Wetlands (Mucina and Rutherford, 2006), and is a well-recognised widespread wetland species outside of South Africa (Ssegawa and Kalema, 2008; Woldu, 1986; Yang et al., 2012; Zerihun and Backéus, 1991).

Midlands Mistbelt wetlands

The *Tristachya leucothrix* community is a mixed grassland community that is concentrated in the KwaZulu-Natal Midlands. It is also dominated by *Aristida junciformis subsp. junciformis* and *Harpochloa falx*. These species have previously been recognised as non-wetland species (Brand et al., 2011, 2008) apart from *A. junciformis subsp. junciformis* which has been documented as a wetland plant in the Drakensberg (Brand et al., 2013; Sieben et al., 2010) but is not mentioned by Mucina and Rutherford (2006). It is suggested that all three indicator species are included as important taxa of the Eastern Temperate Freshwater Wetlands.

The *Pycreus cooperi* community is a mixed community also dominated by *Ledebouria sp.*, *Pycreus macranthus*, *Xyris gerardii*, *Gladiolus papilio*, and *Bulbostylis schoenoides*

concentrated in the KwaZulu-Natal Midlands. *P. macranthus*, *X. gerardii*, and *G. papilio* are well-recognised wetlands species included in the Eastern Temperate Freshwater Wetlands important taxa list (Mucina and Rutherford, 2006). *B. schoenoides* is documented in the Drakensberg area as a wetlands species (Brand et al., 2013) and thus I suggest its inclusion in the important taxa of the Drakensberg and Eastern Temperate Freshwater Wetlands. Identifying *Ledebouria* taxa is problematic, and similar difficulties were had by Carbutt and Edwards (2004) and Clark et al. (2009). Thus classification of this species as an important wetland species is not possible.

The *Scleria welwitschii* community is a mixed community also dominated by *Monocymbium ceresiiforme* and *Helichrysum aureum* concentrated in the KwaZulu-Natal Midlands. None of these species are recognised by Mucina and Rutherford (2006) despite their recognition as wetland species by others. *S. welwitschii* is well-documented as a wetland species in the Drakensberg (Brand et al., 2011; Walters et al., 2006), KwaZulu-Natal Midlands (Kotze and O'Connor, 2000), and outside South Africa (Kerfoot, 1963-1964). Both *M. ceresiiforme* and *H. aureum* are less commonly recorded as wetland species, *H. aureum* in the Drakensberg (Brand et al., 2013) and *M. ceresiiforme* outside South Africa (Rattray and Wild, 1961-1962). It is suggested that all three indicator species should be included in the Eastern Temperate Freshwater Wetlands.

Andropogon appendiculatus wetlands

The *Andropogon appendiculatus* community is a single grass-species dominated community concentrated in the KwaZulu-Natal Midlands and Drakensberg but is distributed across the Escarpment. It is a well-documented wetland species from the EC Escarpment (Clark et al., 2009) to the Drakensberg (Brand et al., 2013; Sieben et al., 2010) and is included in the important taxa of the Eastern Temperate Freshwater Wetlands unit (Mucina and Rutherford, 2006)

Juncus oxycarpus-Stiburus alopecuroides wetlands

The *Juncus oxycarpus* community is a tall-standing single rush dominated community concentrated on the Mpumalanga Escarpment. It is one of the most common species identified in this study suggesting it is present in a number of other communities but only becomes dominant on the Mpumalanga Escarpment. It is well-documented as a wetland species in the Drakensberg (Brand et al., 2013) and EC Escarpment (Clark et al., 2009; Clark

et al., 2011b). It is listed as an important species of the Drakensberg Wetlands (Mucina and Rutherford, 2006), and the distribution identified by this study and others suggests that it should be included in the Eastern Temperate Freshwater Wetlands as well.

The *Stiburus alopecuroides* community is a single grass-species dominated community distributed from the northern Drakensberg to the Mpumalanga Escarpment. *Stiburus alopecuroides* has been previously identified as a wetland species in the Drakensberg (Sieben et al., 2010) and Mpumalanga Escarpment (Smuts, 1933). It is absent from the Freshwater Wetland unit (Mucina and Rutherford, 2006) and it is suggested that it is included in the Eastern Temperate Freshwater Wetland unit.

Conclusion

The 33 plant communities classified in this study help identify wetland species that have not previously received recognition as important wetland taxa across the southern Great Escarpment region. Few exotic and/or invasive species were found, and seldom as dominant species, indicating that the wetlands studied here are in a close to natural state and are therefore of high conservation value. The following chapter attempts to identify the relationship between these plant communities and certain environmental variables to better understand the environmental drivers of the different plant communities.

CHAPTER 4

Environmental Drivers of Wetland Plant Community Patterns

Introduction

The collection and analysis of vegetation data allows researchers to describe and classify different ecosystems. To further our understanding of vegetation patterns, research should try to understand why differences in vegetation occur and why certain plant species are found in some locations and not in others (Kent, 2012). The reasons why certain plants are able to grow together in a particular environment is often because they have similar environmental requirements (e.g. temperature), or they have the ability to tolerate biotic activities (e.g. competition) (Kent, 2012). To understand the underlying drivers of vegetation patters, the relationship between species distributions and environmental or spatial variables is analysed (Lötter, 2014).

Plant community data are multivariate, and in order to make sense of this data methods have been developed to summarise patterns of variation within the data and determine drivers of vegetation patterns. A number of methods are widely used, and although comparative evaluations of these methods have been undertaken, none have been able to clearly demonstrate one 'best' method (Kent, 2012).

A number of studies have been undertaken in South Africa to identify the drivers of mountain wetland plant communities (e.g. Sieben et al., 2009; Sieben et al., 2010). These studies have been carried out over a small geographic area, and there has been a general focus on the Drakensberg region of the Great Escarpment. This thesis provides insights into the drivers of wetland vegetation patterns across the Great Escarpment of South Africa, which will improve our understanding of the drivers of mountain wetland vegetation over a large geographic area.

Aims

The aim of this chapter is to identify and understand the drivers of the wetland plant communities classified in Chapter 3 by using the canonical correspondence (CCA) multivariate ordination method.

Materials and Methods

The vegetation and environmental data (VED) and the vegetation, soil and environmental data (VESD) datasets were used to analysed to determine the environmental drivers of the vegetation patters identified in Chapter 3.

Influence of Vegetation Pattern Drivers

To investigate the drivers of vegetation patterns, both Canonical Correspondence Analysis (CCA) and Correspondence Analysis (CA) were used to determine the relationships between the plant communities and environmental variables. These analytical methods were applied on different scales to assess effect of different drivers at different scales. Large scale drivers were assessed by analysing the VED database as a whole. Small scale drivers were assessed by analysing each of the major wetland groups as separate ordinations. The VESD database was analysed as a whole.

A Monte Carlo test of significance was used to assess the usefulness of each ordination under the null hypothesis that there is no significant relationship between the species data and environmental data (Peck, 2010). The difference between the CCA and CA eigenvalues was used to measure the extent to which environmental variables accounted for species composition variation. The outputs of the analysis were interpreted according to the rules given in Ter Braak (1987). The sample plots are represented as dots and the environmental variables are represented by arrows that point in the direction of maximum variation. The longer the length of the arrow, the more important the environmental variable. Nominal environmental variables are plotted as dots.

Results

Species-Environment Ordination Analysis Using the VED Data Set

The major wetland group ordination analysis

The results of the broad classification CCA ordination are shown in Figure 16. The summary outputs of the ordination are presented in Table 10. The CCA ordination accounted for a low cumulative percentage variation of species (Table 10). The eigenvalue of the first axis was, however, greater than 0.5 (Table 10). The difference between the CCA and CA eigenvalues, which indicates the extent to which measured environmental variables account for species composition variation (Ter Braak, 1987) was less for axis 1 and 2 than for the remaining

axes. This indicates that although some of the most important variables were accounted for, there were still outstanding environmental variables. The Monte-Carlo test of significance indicated that the measured environmental variables accounted for a significant amount of variation, both for the first canonical axis (p-value = 0.0020) and for all canonical axes (p-value = 0.0020).

The most important environmental factor explaining species variability was altitude. The samples were arranged primarily along an altitude gradient (988 to 3189 m.a.s.l.) that varies in directional manner across the ordination plane defined by axis 1 and 2. The High Altitude Fen and Seepage Wetlands were concentrated at the high end of the altitude gradient. *Merxmuellera macowanii* Wetlands were concentrated in the middle of the altitude gradient and extended towards the higher end of the gradient. The Common Escarpment Sedge and Grassy Wetlands were distributed across the altitude gradient, but were concentrated in the middle of the gradient. The *Miscanthus capensis* and Eastern Escarpment Wetlands were concentrated around the mid to low end of the gradient.

Soil depth was most strongly correlated with axis 1, but less so than altitude. The Eastern Escarpment Wetlands were present on the higher end of the soil depth gradient, which was associated with sand and loam soils, and the valley bottom and depression HGM units. *Merxmuellera macowanii* Wetlands, High Altitude Fen and Seepage Wetlands, and Common Escarpment Sedge and Grassy Wetlands were concentrated towards the lower end of the soil depth gradient. The low end of the soil depth gradient was positively correlated with the seepage wetland types and clay soils.

Wetness was most strongly correlated with the second axis, but less so than altitude. *Merxmuellera macowanii*, Common Escarpment Sedge and Grassy Wetlands and Eastern Escarpment Wetlands were concentrated in the middle to the lower end of the wetness gradient. These three wetland groups were, however, also present less frequently at the high end of the wetness gradient. The High Altitude Fen and Seepage Wetlands were concentrated from the middle to higher end of the wetness gradient and the *Miscanthus capensis* Wetlands were concentrated at the low end of the wetness gradient.

The High Altitude Fen and Seepage Wetlands were strongly associated with the valleyhead seepage HGM unit, the Common Escarpment Sedge and Grassy Wetlands were correlated across the HGM unit types, but were most strongly correlated with the slope seepage HGM unit. *Merxmuellera macowanii* Wetlands were strongly correlated with slope and valleyhead

seepage HGM units. The Eastern Escarpment Wetlands were strongly associated with the valley bottom and depression HGM units. A photographic illustration of the typical mountain wetlands is shown in Figure 17.

Within each wetland group the major drivers of wetland vegetation patterns will differ because of scale differences. Thus to assess the community-environment relationships on a small scale, the major wetland groups analysed above have been separated. The analyses of the five wetland groups are described below.

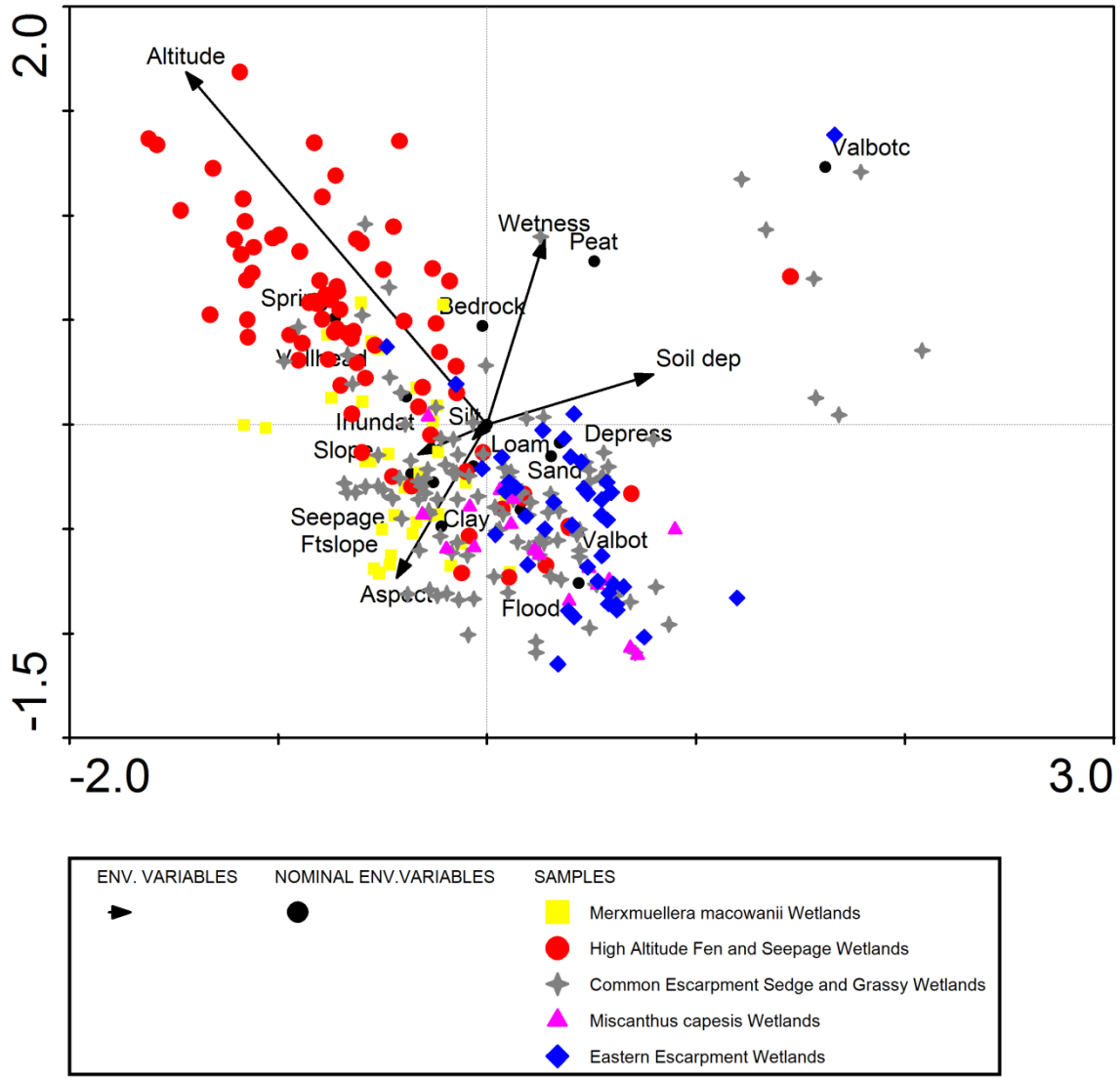

Figure 16. CCA Ordination diagram of the major wetland groups showing axis 1 and axis 2.

Table 10. Summary of outputs for the canonical correspondence analysis (CCA) with CA eigenvalues also included for the major wetland community group ordination

Axis	**Eigenvalues**		**Species-environmental correlation**	**Cumulative % variance of species data**	**Cumulative % variance of species-environment relation**
	CCA	CA			
1	0.552	0.756	0.896	2.0	16.6
2	0.494	0.657	0.898	3.8	31.5
3	0.343	0.584	0.799	5.0	41.9
4	0.264	0.544	0.763	6.0	49.8

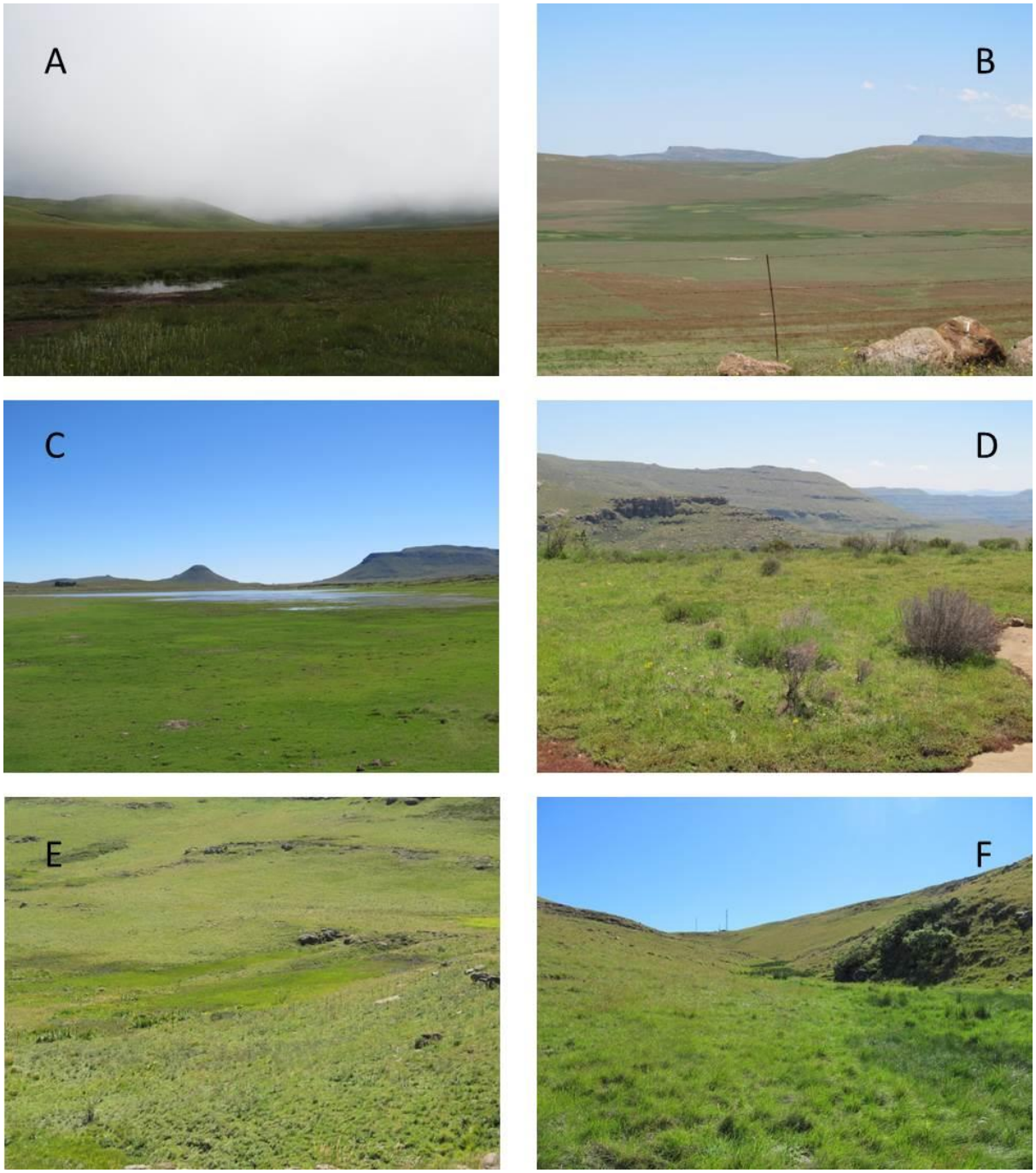

Figure 17. A selection of photographs illustrating the variety of wetland settings in the EC Escarpment: (A) Valley bottom wetland in the EC Drakensberg, (B) extensive valley bottom system in the GWA, (C) large depression wetland in the Stormberg, (D) small depression wetland in the Stormberg, (E) high peak slope seepage wetland in the EC Drakensberg, (F) valleyhead seepage wetland in the Stormberg.

The *Merxmuellera macowanii* Wetlands ordination analysis

The results of the *Merxmuellera macowanii* Wetlands CCA ordination are shown in Figure 18. The summary outputs of the ordination are presented in Table 11. The CCA ordination accounted for a low cumulative percentage variation of species (Table 11). The eigenvalue of the first axis was, however, greater than 0.5 (Table 11). The difference between the CCA and CA eigenvalues was less for axis 1 and 2 than for the remaining axes. This indicates that although some of the most important variables were accounted for, there were still outstanding environmental variables. The Monte-Carlo test of significance indicated that the measured environmental variables did not account for a significant amount of variation, both for the first canonical axis (p-value = 0.2480) and for all canonical axes (p-value = 0.0600).

Altitude (1565 to 2540 m.a.s.l.) and slope appear to be the strongest drivers of vegetation pattern along the first axis, and wetness and inundation appear to be the strongest drivers of vegetation pattern along the second axis. A few relevés were present at the higher end of the altitude gradient that represent the high Drakensberg and Sneeuberg peaks. These relevés were associated with seasonally wet sandy soils in valley head seepage wetlands. The majority of the relevés were present at the mid to low end of the altitude and wetness gradient (temporary to seasonal wetness), associated with slope seepage wetlands with clay soils. These wetlands were, however, occasionally found in valley bottom wetlands in the temporary wetness zone, or in the permanent wetness zone of slope seepage wetlands.

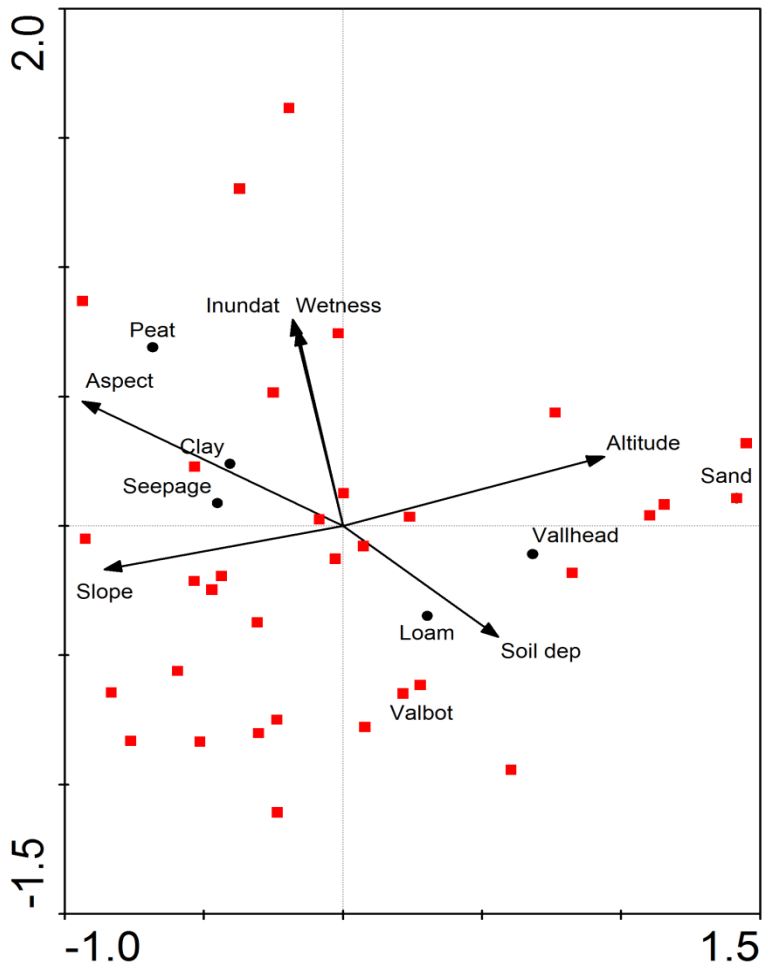

Figure 18. CCA ordination diagram of the *Merxmuellera macowanii* Wetlands showing axis 1 and axis 2. The arrows indicate environmental variables, black dots indicate nominal environmental variables and the red squares represent the vegetation samples

Table 11. Summary of outputs for the canonical correspondence analysis (CCA) with CA eigenvalues also included for the *Merxmueller macowanii* Wetlands ordination

Axis	**Eigenvalues**		**Species-environmental correlation**	**Cumulative % variance of species data**	**Cumulative % variance of species-environment relation**
	CCA	CA			
1	0.531	0.650	0.964	6.7	17.1
2	0.432	0.568	0.950	12.2	31.0
3	0.350	0.599	0.909	16.6	42.2
4	0.316	0.520	0.941	20.6	52.4

The High Altitude Fen and Seepage Wetlands ordination analysis

The results of the High Altitude Fen and Seepage Wetlands CCA ordination are shown in Figure 19. The summary outputs of the ordination are presented in Table 12. The CCA ordination accounted for a low cumulative percentage variation of species (Table 12). The eigenvalue of the first axis was, however, greater than 0.5 (Table 12). The difference between the CCA and CA eigenvalues was less for axis 1 than for the remaining axes. This indicates that although some of the most important variables were accounted for, there were still outstanding environmental variables. The Monte-Carlo test of significance indicated that the measured environmental variables accounted for a significant amount of variation, both for the first canonical axis (p-value = 0.0020) and for all canonical axes (p-value = 0.0020).

The first axis was best explained by altitude (1329 to 3189 m.a.s.l.) and the second axis was best explained by wetness. The communities at the high end of the altitude gradient were the *Rhodohypoxis rubella*, *Tenaxia disticha*, and *Carpha filifolia*, communities of which the *R. rubella* community occurred in permanent wetness areas, the *C. filifolia* community occurred in seasonal wetness areas, and the *M. disticha* community was found in the temporary wetness areas. The *Carex cognata*, *Merxmuellera drakensbergensis*, and *Festuca caprina* communities were concentrated at the lower end of the altitude gradient but extended to higher altitudes. The *C. cognata* and *M. drakensbergensis* communities were found at the middle to high end of the wetness gradient and the *F. caprina* community was found at the low end to middle of the wetness gradient. The *Haplocarpha nervosa* and *Kniphofia*

caulescens communities were present at the middle to high end of the altitude gradient. *H. nervosa* occurred in temporary to seasonal wetness areas and the *K. caulescens* community occurred in seasonal to permanent wetness areas.

The valley bottom with a channel HGM unit was associated with lower altitudes and the *C. cognata* and *F. caprina* communities were strongly associated with this HGM unit. The seepage HGM unit was associated with the middle of the altitude gradient and the lower end of the wetness gradient. The *M. disticha*, *H. nervosa*, *F. caprina*, and *C. filifolia* communities were correlated with the slope seepage HGM unit. The valleyhead seepage HGM unit was correlated with the high end of the altitude gradient. The communities correlated with the valleyhead seepage HGM unit were the *K. caulescens*, *C. filifolia*, *H. nervosa*, and *M. disticha* communities. The *R. rubella* community was strongly correlated with the depression HGM unit.

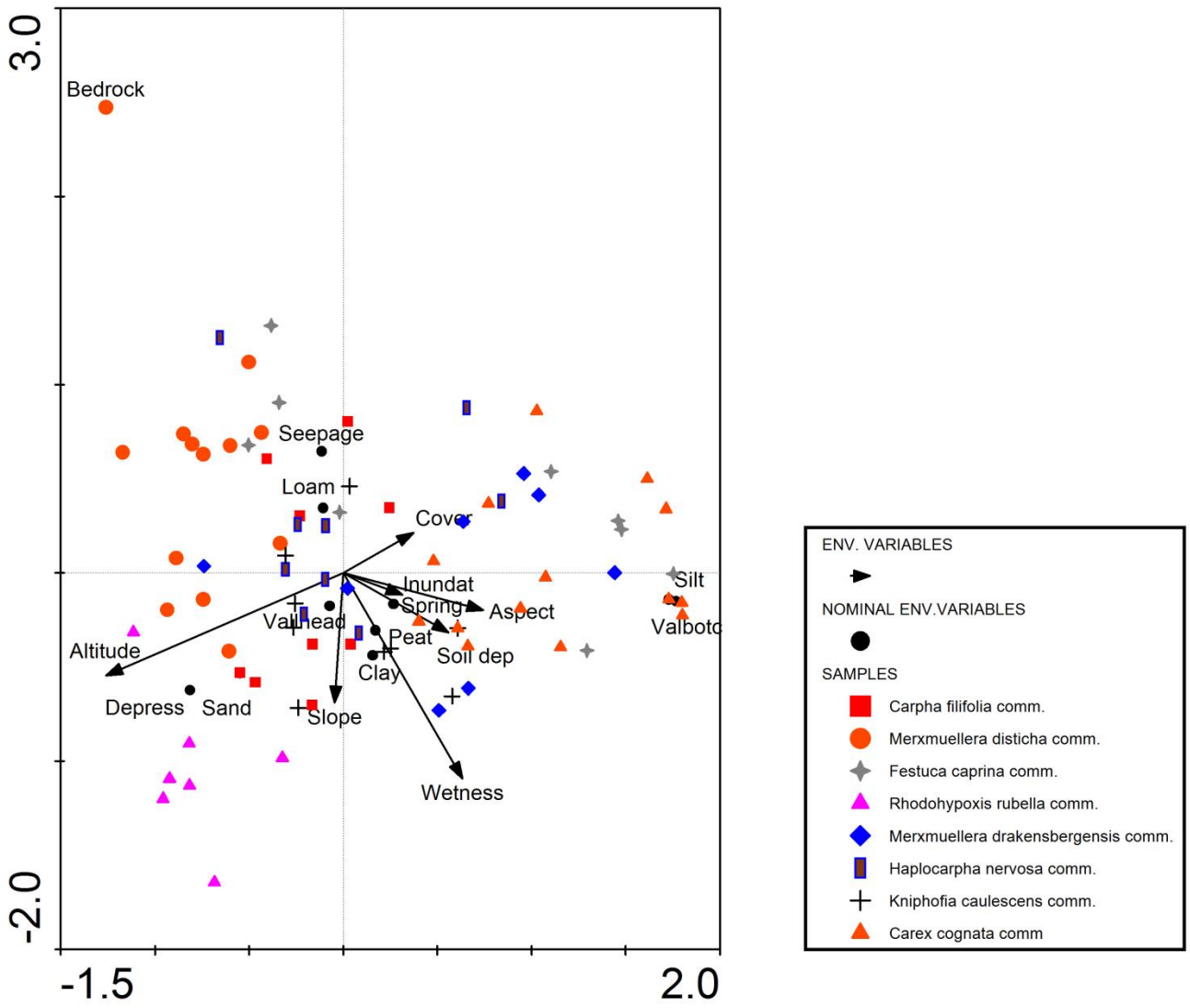

Figure 19. CCA ordination diagram of the High Altitude Fen and Seepage Wetland communities showing axis 1 and axis 2.

Table 12. Summary of outputs for the canonical correspondence analysis (CCA) with CA eigenvalues also included for the High Altitude Fen and Seepage Wetlands ordination

Axis	**Eigenvalues**		**Species-environmental correlation**	**Cumulative % variance of species data**	**Cumulative % variance of species-environment relation**
	CCA	CA			
1	0.630	0.761	0.962	4.1	14.1
2	0.476	0.658	0.926	7.1	24.7
3	0.386	0.639	0.883	9.6	33.4
4	0.351	0.574	0.907	11.9	41.2

The Common Escarpment Sedge and Grassy Wetlands ordination analysis

The results of the Common Escarpment Sedge and Grassy Wetlands CCA have been separated into three subset ordination diagrams, which are shown in Figure 20, Figure 21 and Figure 22. The summary outputs of the ordination are presented in Table 13. The CCA ordination accounted for a low cumulative percentage variation of species (Table 13). The difference between the CCA and CA eigenvalues was greater for axis 1 than for the remaining axes. The Monte-Carlo test of significance indicated that the measured environmental variables accounted for a significant amount of variation, both for the first canonical axis (p-value = 0.0240) and for all canonical axes (p-value = 0.0020).

The first axis was best explained by altitude (1237 to 2625 m.a.s.l.), slope, and cover. The second axis was best explained by wetness and soil depth. The communities correlated with the higher end of the altitude gradient include the *Crassula vaillantii*, *Juncus inflexus*, and *Mentha longifolia* communities. The *C. vaillantii* and *J. inflexus* communities were correlated with the higher end of the wetness gradient and the *M. longifolia* community was correlated with the lower end of the wetness gradient. The *Fuirena coerulescens*, *Isolepis fluitans*, *Trifolium africanum*, *Fingerhuthia sesleriiformis*, and *Limosella major* communities were placed predominantly in the middle of the altitude gradient but did extend towards the higher and lower end of the gradient. These communities were distributed across the wetness gradient apart from the *I. fluitans* community which was associated with the higher end of the wetness gradient.

The communities correlated with the lower end of the altitude gradient but extended to the higher end of the altitude gradient include the *Pennisetum sphacelatum, Limosella africana, Carex acutiformis, Gunnera perpensa, Kyllinga pulchella,* and *Isolepis angelica* communities. The *P. sphacelatum, L. africana, K. pulchella* communities were associated with temporary to seasonal wetness. The *C. acutiformis* and *I. angelica* communities were associated with the higher end of the wetness gradient, and the *G. perpensa* community was distributed across the wetness gradient. The *Carex austro-africana* community was correlated with the low end of the altitude gradient in permanent wetness areas.

The slope seepage and valleyhead seepage HGM units were correlated with the higher end of the altitude gradient on steeper gradients and clay soils. These communities are correlated with the higher end of the cover gradient in comparison to the valley bottom and valley bottom with a channel HGM units. The communities associated with the slope seepage HGM unit include the *F. coerulescens, I. angelica, C. vaillantii, F. sesleriiformis,* and *T. africanum* communities. *M. longifolia* and *F. coerulescens* communities were correlated with the valley head seepage HGM unit.

The valley bottom with a channel and valley bottom HGM units were correlated with the lower end of the altitude gradient. The *P. sphacelatum* community was strongly associated with the valley bottom with a channel HGM unit which occurred on deeper soils. The communities common in valley bottom wetlands include the *C. acutiformis, C. austro-africana, I. angelica, P. sphacelatum, L. major, K. pulchella,* and *F. coerulescens* communities.

The depression and floodplain HGM units were not well sampled in the Common Escarpment Sedge and Grassy Wetlands. The *K. pulchella, L. africana,* and *T. africanum* communities were sampled in these settings on sandy soils.

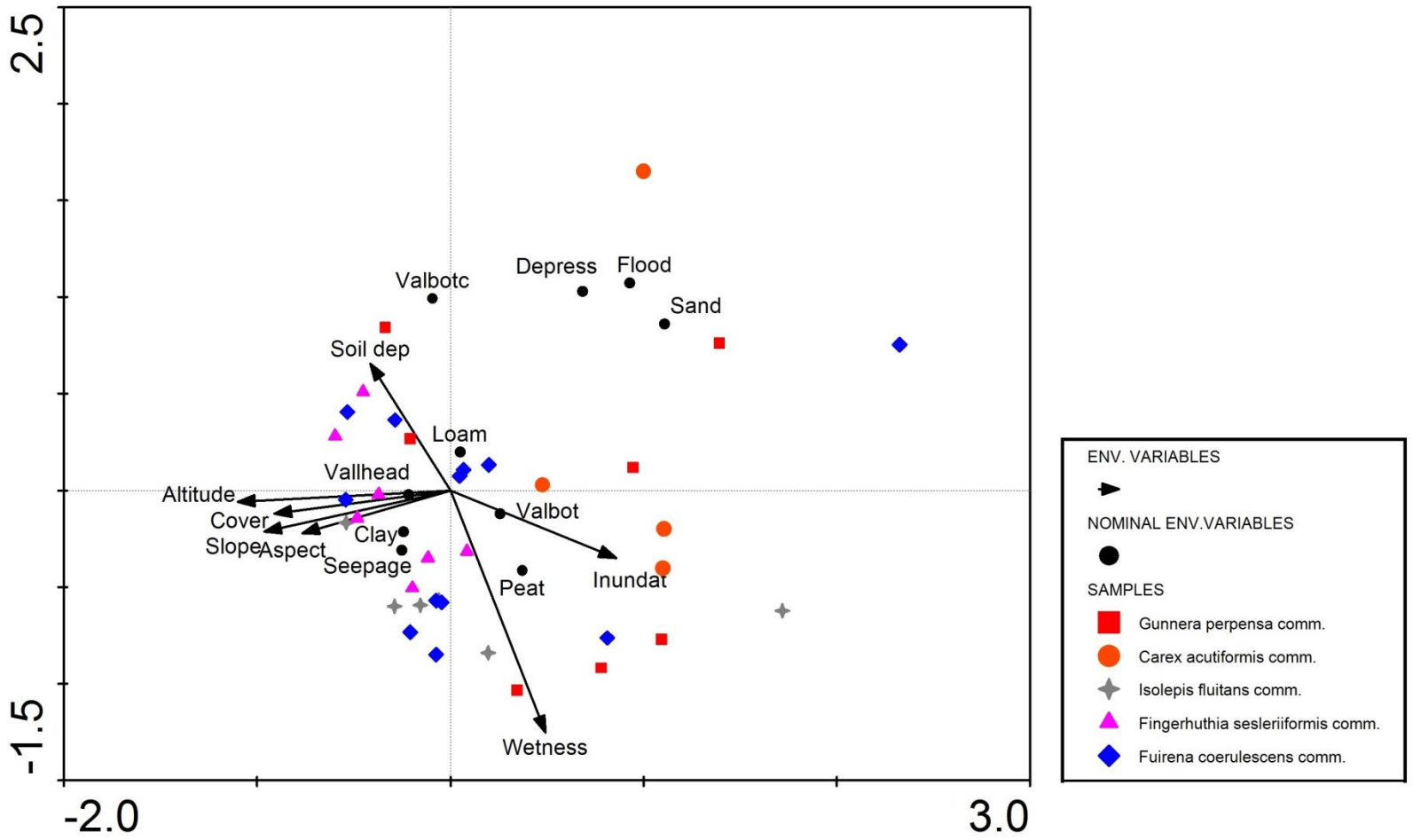

Figure 20. Subset CCA ordination diagram of five of the Common Escarpment Sedge and Grassy Wetland communities showing axis 1 and 2.

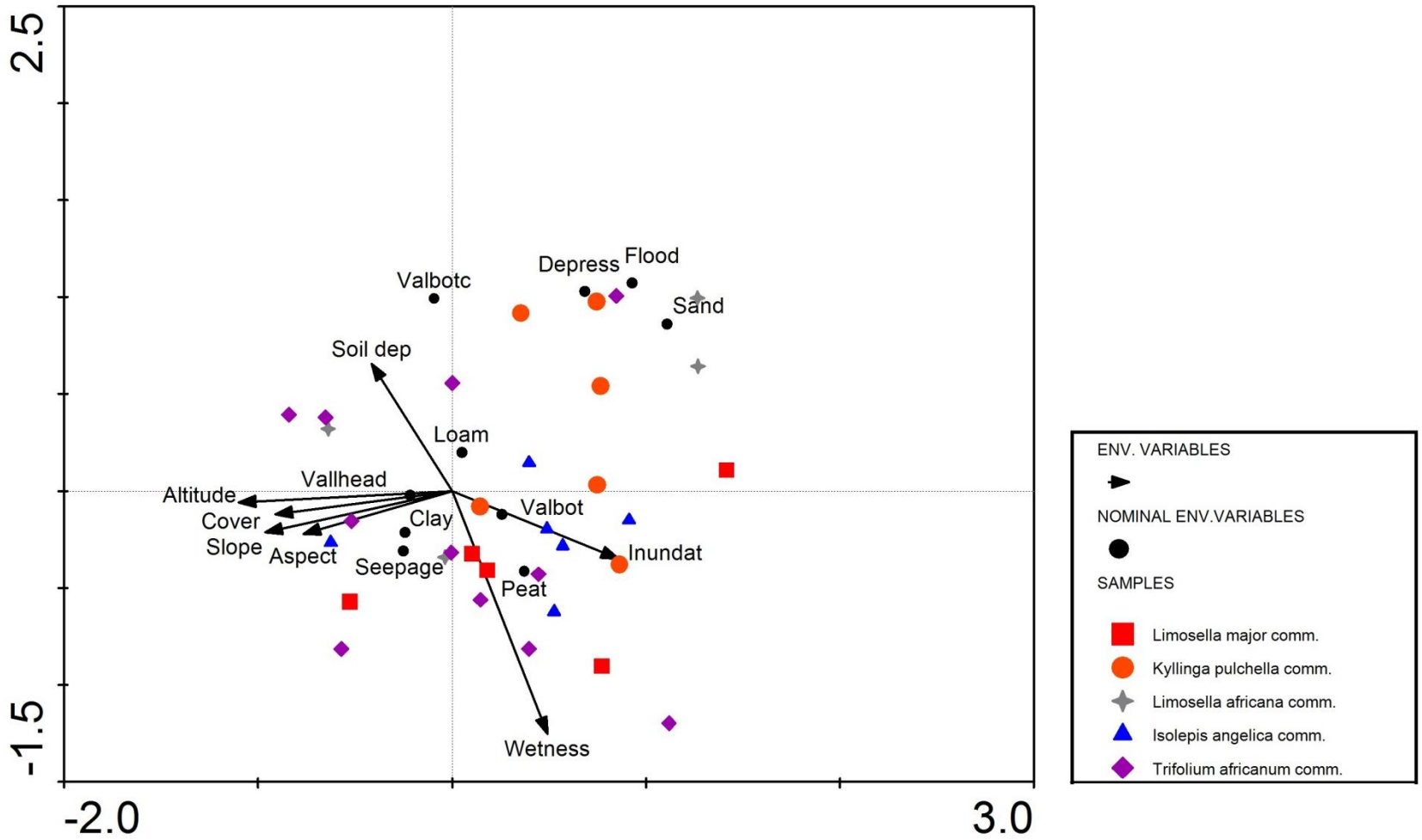

Figure 21. Subset CCA ordination diagram of five of the Common Escarpment Sedge and Grassy Wetland communities showing axis 1 and 2.

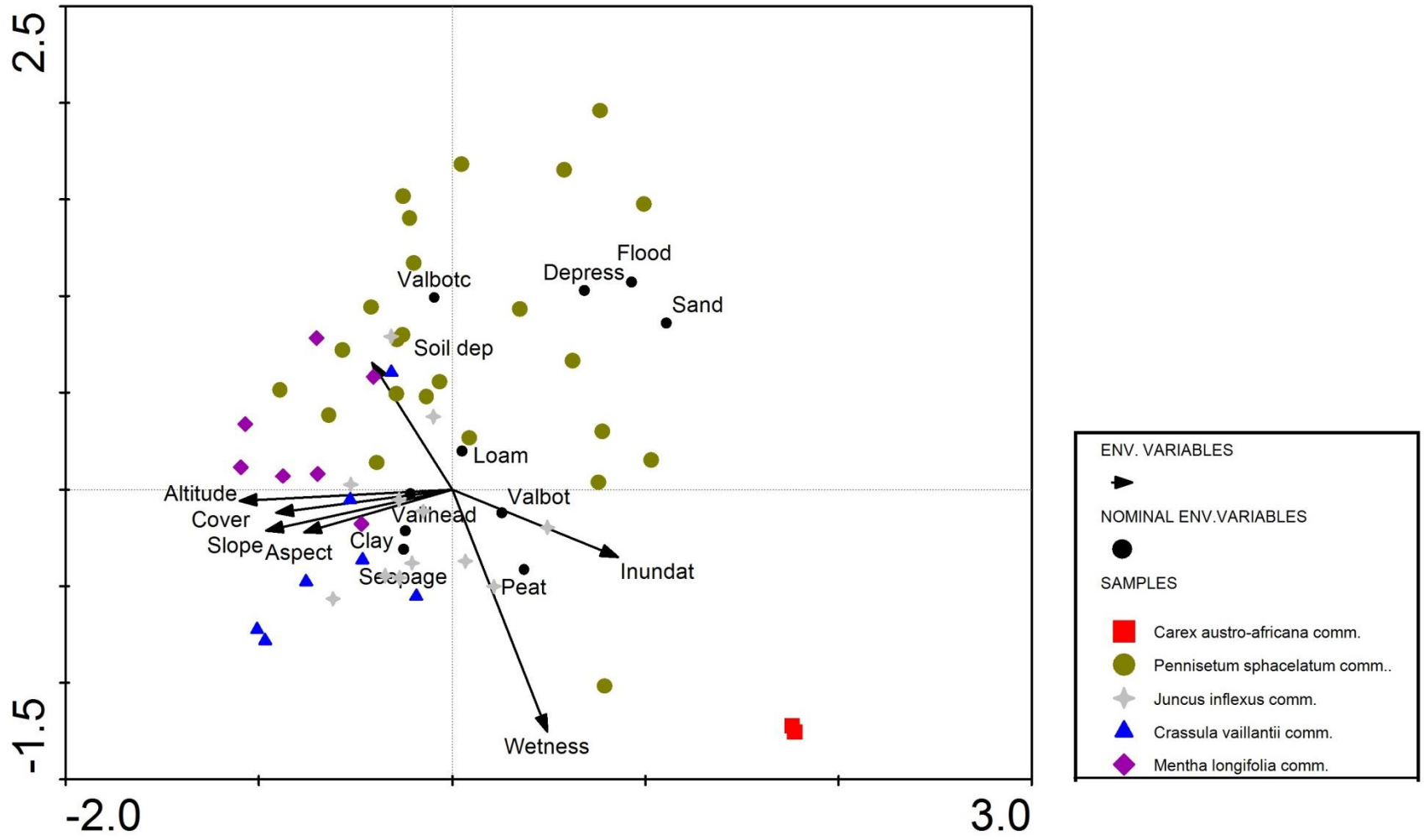

Figure 22. Subset CCA ordination diagram of five of the Common Escarpment Sedge and Grassy Wetland communities showing axis 1 and 2.

Table 13. Summary of outputs for the canonical correspondence analysis (CCA) with CA eigenvalues also included for the Common Escarpment Sedge and Grassy Wetland ordination

Axis	**Eigenvalues**		**Species-environmental correlation**	**Cumulative % variance of species data**	**Cumulative % variance of species-environment relation**
	CCA	CA			
1	0.403	1.000	0.868	2.1	12.8
2	0.384	0.652	0.840	4.1	25.1
3	0.291	0.624	0.781	5.6	34.3
4	0.286	0.570	0.830	7.1	43.5

The *Miscanthus capensis* Wetlands ordination analysis

The results of the *Miscanthus capensis* Wetlands CCA ordination are shown in Figure 23. The summary outputs of the ordination are presented in Table 14. The CCA ordination accounted for 34.2 cumulative percentage variation of species (Table 14). The eigenvalue of the first, second and third axes were greater than 0.5 (Table 14). There was a small difference between the CCA and CA eigenvalues for all four axes. This indicates that the most important variables were accounted for. The Monte-Carlo test of significance indicated that the measured environmental variables accounted for a significant amount of variation, both for the first canonical axis (p-value = 0.0120) and for all canonical axes (p-value = 0.0020).

The ordination showed very little variation within the *Miscanthus capensis* Wetlands. This community was generally found at low to mid-altitudes at the lower end of the wetness gradient as indicated by the major wetland group ordination above. It was found in depression, valleyhead seepage, and flood plain HGM units. Two outliers were present in the ordination, one at the high end of the altitude gradient, and the other at the high end of the slope gradient.

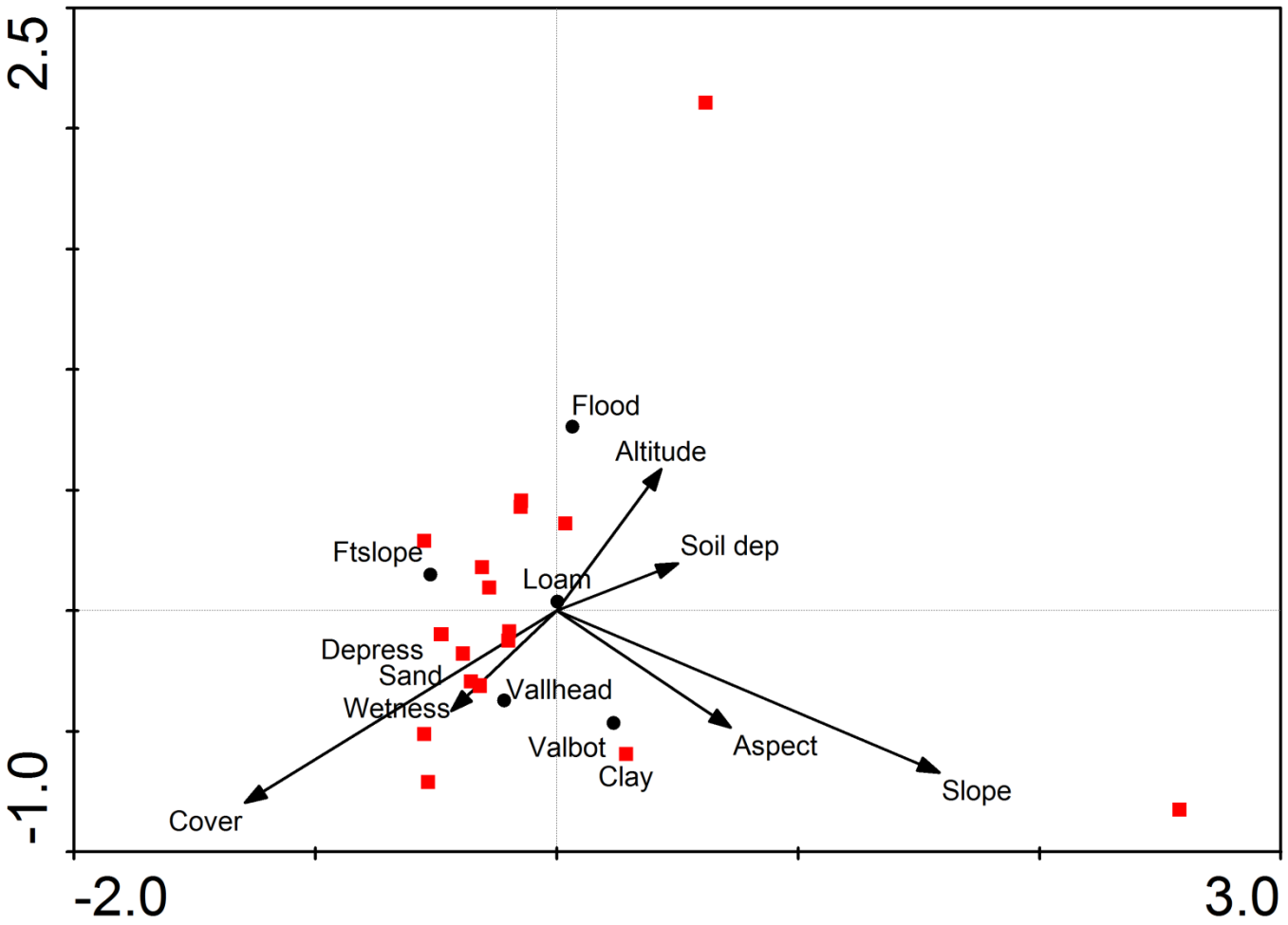

Figure 23. CCA ordination diagram of the *Miscanthus capensis* Wetlands showing axis 1 and 2. The arrows indicate environmental variables, black dots indicate nominal environmental variables and the red squares represent the vegetation samples.

Table 14. Summary of outputs for the canonical correspondence analysis (CCA) with CA eigenvalues also included for the *Miscanthus capensis* Wetlands ordination

Axis	**Eigenvalues**		**Species-environmental correlation**	**Cumulative % variance of species data**	**Cumulative % variance of species-environment relation**
	CCA	CA			
1	0.706	0.723	0.995	10.4	17.0
2	0.604	0.643	0.981	19.3	31.5
3	0.524	0.591	0.964	27.1	44.1
4	0.483	0.565	0.997	34.2	55.7

Eastern Escarpment Wetlands ordination analysis

The results of the Eastern Escarpment Wetlands CCA ordination are shown in Figure 24. The summary outputs of the ordination are presented in Table 15. The CCA ordination accounted for a low cumulative percentage variation of species (Table 15). The eigenvalue of the first axis was, however, greater than 0.5 (Table 15). The difference between the CCA and CA eigenvalues was less for axis 1 than for the remaining axes. This indicates that although some of the most important variables were accounted for, there were still outstanding environmental variables. The Monte-Carlo test of significance indicated that the measured environmental variables accounted for a significant amount of variation, both for the first canonical axis (p-value = 0.0020) and for all canonical axes (p-value = 0.0020).

The first axis was best explained by the altitude (568 to 2268 m.a.s.l.) and wetness gradients, which were both negatively correlated to cover. The *Juncus oxycarpus* community was concentrated at the high end of the wetness and altitude gradient and was strongly associated with the channelled valley bottom HGM unit. The other communities were present at the low end of the altitude and wetness gradient and were characterised by a high vegetative cover. The interpretation of other environmental variables was made difficult by the relevé arrangement along the second axis which was poorly described. The *Pycreus cooperi* community was strongly associated with the valley bottom HGM unit. The *Tristachya leucothrix*, *Andropogon appendiculatus*, *Scleria welwitschii*, *Stiburus alopecuroides*, and

Fimbristylis complanata communities were correlated with the depression, valley bottom, and valleyhead seepage HGM unites.

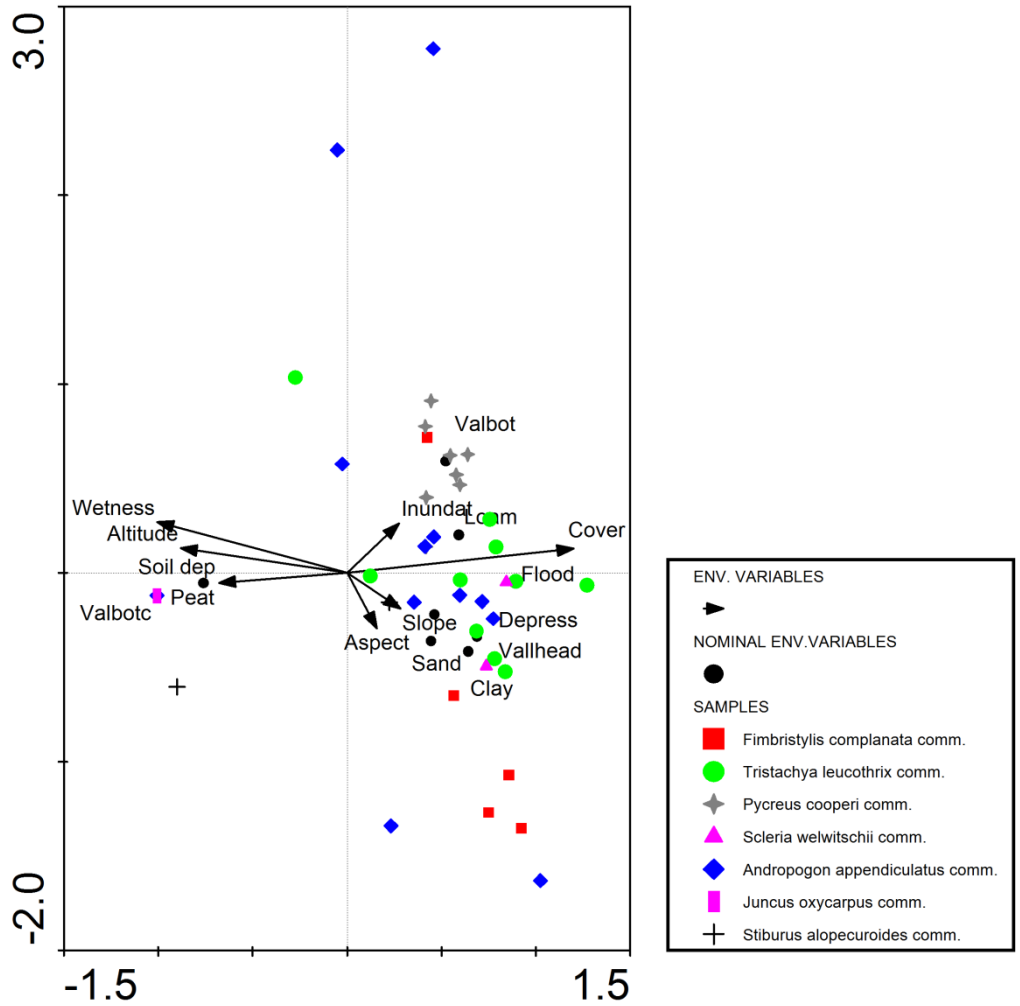

Figure 24. CCA ordination diagram of the Eastern Escarpment Wetland communities showing axis 1 and 2.

Table 15. Summary of outputs for the canonical correspondence analysis (CCA) with CA eigenvalues also included for the Eastern Escarpment Wetlands ordination

Axis	Eigenvalues		Species-environmental correlation	Cumulative % variance of species data	Cumulative % variance of species-environment relation
	CCA	CA			
1	0.643	0.681	0.983	6.4	16.2
2	0.473	0.670	0.937	11.1	28.2
3	0.405	0.580	0.949	15.1	38.4
4	0.338	0.519	0.915	18.4	46.9

Species-Environment Ordination Analysis Using the VESD Data Set

This dataset contains species abundance and associated soil nutrient, altitude and wetness data. The smaller size of this dataset requires only one ordination analysis, rather than separating the data according to the major wetland groups as shown above. The ordination has been divided into three separate figures to allow for easier reading and interpretation.

Soil nutrient ordination analysis

The results of the soil nutrient, altitude and wetness CCA ordination are shown in Figure 25, Figure 26 and Figure 27. The summary outputs of the ordination are presented in Table 16. The CCA ordination accounted for a low cumulative percentage variation of species (Table 16). The eigenvalue of the first axis was, however, greater than 0.5 (Table 16). The difference between the CCA and CA eigenvalues for axis 1 is larger than for the remaining axes. This indicates that there were outstanding environmental variables that have not been accounted for. The Monte-Carlo test of significance indicated that the measured environmental variables did not account for a significant amount of variation for the first axis (p-value = 0.0660), but did account for a significant amount of variation for all canonical axes (p-value = 0.0160).

The most important environmental factors explaining species variability were electrical conductivity, nitrogen, phosphorus, sodium, wetness and altitude. The communities that were correlated with the higher end of the altitude gradient include the *Merxmuellera macowanii*, *Kniphofia caulescens* and *Carex cognata* communities.

The communities that were correlated with the high end of the nitrogen, phosphorus and electrical conductivity gradients which were negatively correlated with wetness and sodium were the *Merxmuellera macowanii*, *Gunnera perpensa*, *Pennisetum sphacelatum*, *Carex. austro-africana*, *Tristachya leucothrix*, *Pycreus cooperi*, *Andropogon appendiculatus* and *Stiburus alopecuroides* communities. These communities were also correlated with the high end of the calcium, magnesium, potassium and silt gradients.

The communities that were correlated with the high end of the sodium and wetness gradients include the *Festuca caprina*, *Merxmuellera drakensbergensis*, *Carex acutiformis*, *Isolepis fluitans* and *Fimbristylis complanata* communities.

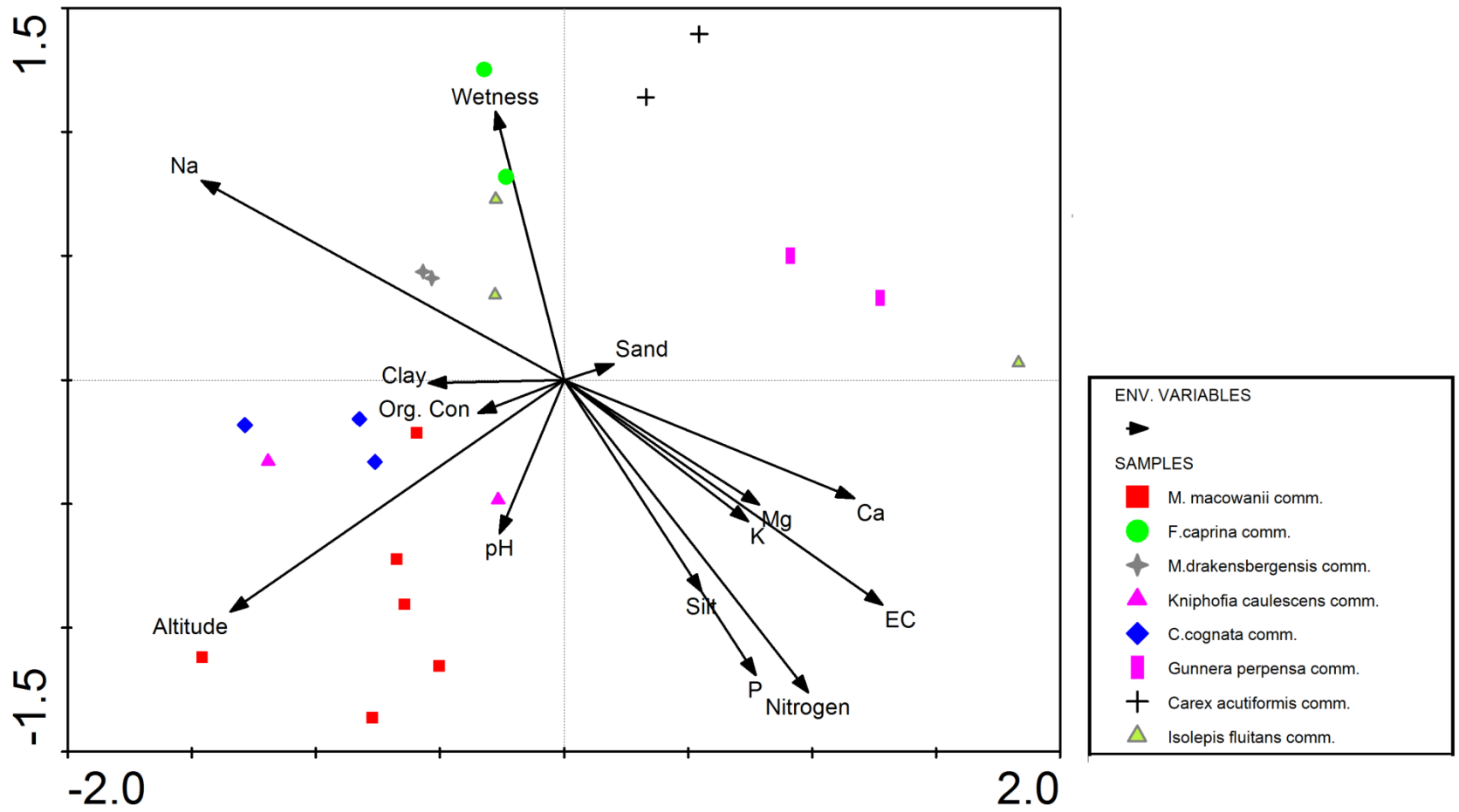

Figure 25. Subset CCA ordination diagram of eight communities showing axis 1 and 2.

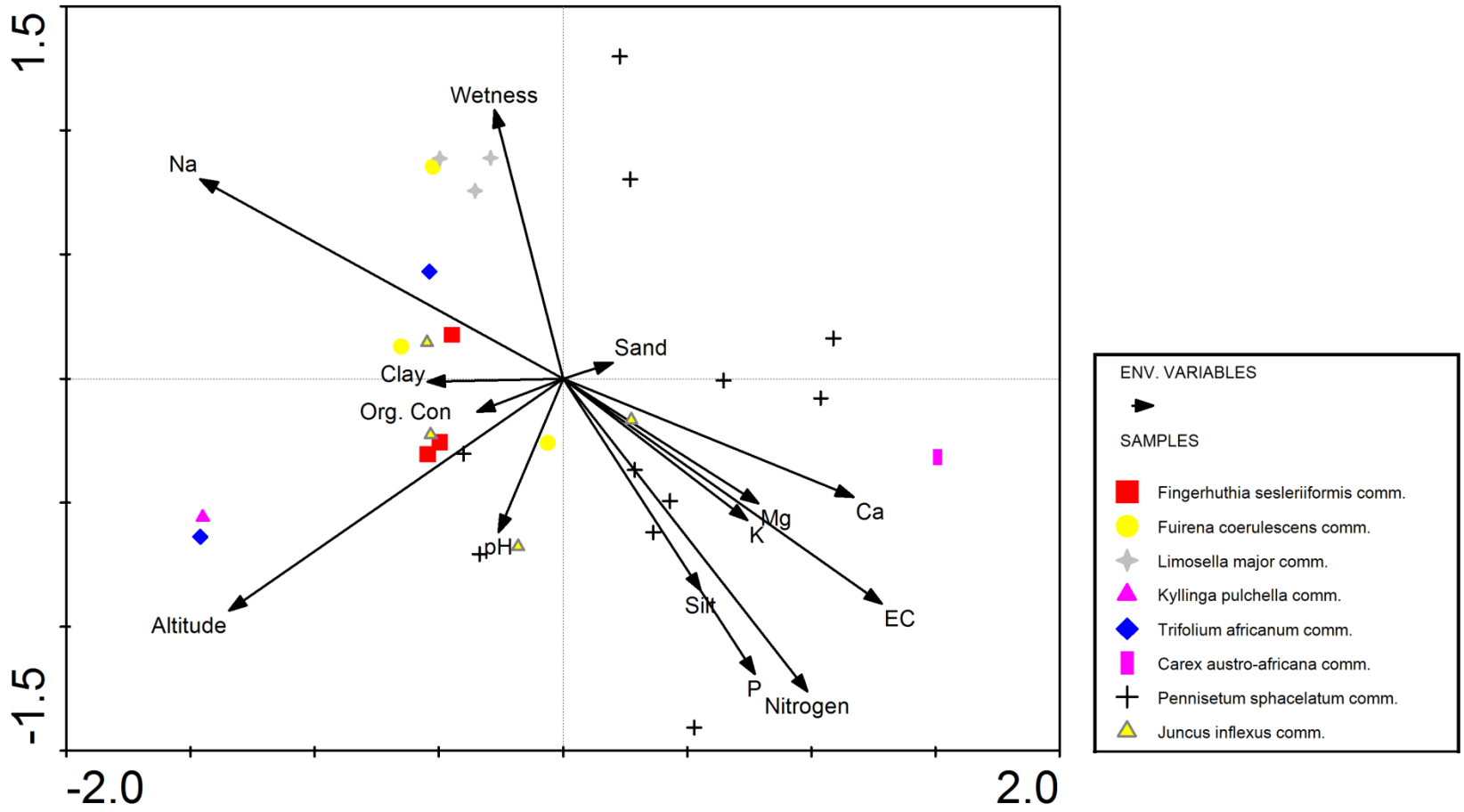

Figure 26. Subset CCA ordination diagram of eight communities showing axis 1 and 2.

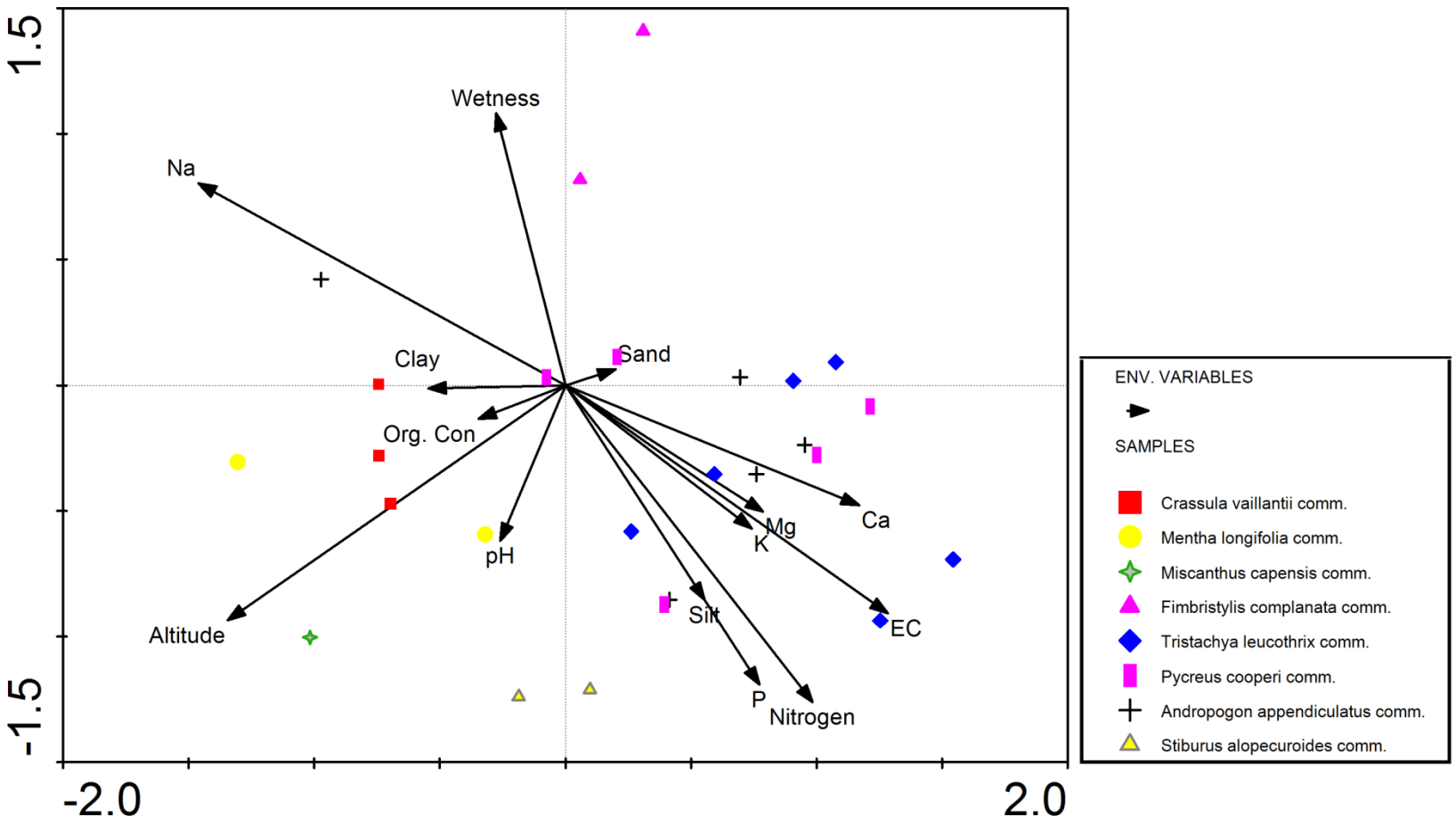

Figure 27. Subset CCA ordination diagram of eight communities showing axis 1 and 2.

Table 16. Summary of outputs for the canonical correspondence analysis (CCA) with CA eigenvalues also included for the soil nutrient, altitude and wetness ordination.

Axis	Eigenvalues		Species-environmental correlation	Cumulative % variance of species data	Cumulative % variance of species-environment relation
	CCA	CA			
1	0.524	1.000	0.887	2.9	13.4
2	0.463	0.751	0.917	5.5	25.2
3	0.371	0.685	0.873	7.5	34.7
4	0.367	0.626	0.866	9.5	44.0

Discussion

The most significant environmental drivers identified in the VED analysis include altitude and wetness and the most significant environmental drivers identified in the VESD analysis include nitrogen content, phosphorus content, electrical conductivity, organic content, sodium content, altitude and wetness.

Altitude

Altitude accounts for most of the large-scale and a significant amount of the smaller scale variation in the vegetation of the wetlands studied here. Altitude has been recognised by other studies as an important influence of vegetation pattern (e.g. Hájková et al., 2006; Kamrani et al., 2011; Kotze and O'Connor, 2000; Naqinezhad et al., 2009; Rolon and Maltchik, 2006; Sieben et al., 2010). It is a surrogate measure of two climatic variables, temperature and rainfall (Hájek et al., 2008; Körner, 2007). Across a wide geographical area plant distribution is determined by climate, but at the site-specific scale, it is determined by local environmental variables (Billings, 1952). The significance of climate as a determinate of species turnover is well-documented (Hájek et al., 2008) which is again evident in this study, although it is complicated by the wide geographic region over which this study has focused on.

The lower altitude to mid-altitude communities are dominated mainly by grasses and sedges, whereas a number of the high altitude communities (High Altitude Fen and Seepage and Common Escarpment Sedge and Grassy Wetland communities at the high end of the altitude

gradient) are composed of a larger proportion of bulbous monocot and dicot species including the *Carpha filifolia*, *Rhodohypoxis rubella*, *Haplocarpha nervosa*, *Kniphofia caulescens*, *Senecio cryptolanatus*, *Crassula vaillantii, Limosella major*, *Limosella africana*, and *Mentha longifolia* communities. Plant height has been shown to reflect competitive ability (Kennedy et al., 2006) suggesting that a lack of tall grass and sedge species at high altitudes as a result of colder temperatures opens a niche for other species to occupy (Sieben et al., 2010, 2009). A good example explained by Sieben et al. (2009), which is evident in the wetlands of this study, is seen in dicot species such as *Ranunculus meyeri* and *Haplocarpha nervosa* that are present across the altitude gradient but become more abundant at higher altitudes (Appendix 4).

Evident in this study is the restricted distribution of the high altitude communities in contrast to the wider distribution of the mid to low altitude communities. A number of the high altitude fen and seepage wetland communities, including the *Carpha filifolia*, *Tenaxia disticha*, *Rhodohypoxis rubella*, *Kniphofia caulescens*, and *Senecio cryptolanatus* communities were found only in the high altitude areas of the study area. The widely distributed communities were found within the *Merxmuellera macowanii*, *Miscanthus capensis*, Common Escarpment Sedge and Grassy, and Eastern Escarpment Wetlands. Similar trends are commonly observed (Beniston, 2003; Hájek et al., 2008; Kamrani et al., 2011; Naqinezhad et al., 2009; Noroozi et al., 2008), although the interpretation of the ecological processes controlling species distribution are problematic, because altitude constitutes a complex environmental gradient (Naqinezhad et al., 2009).

Körner (2007) cautioned against using altitude as a surrogate for rainfall at a large scale because there is no general relationship between these two variables. In South Africa the increasing rainfall gradient from West to East causes difficulties in associating rainfall with altitude. For example, the mean annual rainfall in the western Sneeuberg area is between 400 and 500 mm (Holmes, 1998), compared to 1600 mm received in the Drakensberg (Sene et al., 1998), even though both areas well exceed altitudes of 2000 m.a.s.l.

Many of the widely distributed communities are found within different biomes across the Escarpment that are generally defined by climate (Mucina and Rutherford, 2006). A direct impact of low rainfall is less harsh on wetland habitats compared to the surrounding dryland habitats, because of the drought buffering function of wetlands (Naqinezhad et al., 2009). This may explain the wide distribution of communities such as the *Merxmuellera macowanii*,

Juncus inflexus, *Trifolium africanum*, *Limosella africana*, *Kyllinga pulchella*, *Pennisetum sphacelatum*, and *Andropogon appendiculatus* communities across the escarpment, from areas of high rainfall to areas of low rainfall. These communities are common in the temporary and seasonal zones of wetness, therefore they do not require permanent inundation. They may be able to exist across a rainfall gradient because wetlands accumulate surface run-off and subsurface water flows. They retain this water because of surface roughness created by vegetation cover that slows the flow of water through the wetland. There is therefore more water retained for a longer period of time in wetlands compared adjacent terrestrial areas (Kotze et al., 2007).

Analysis of the effect of altitude on biodiversity (Margalef's diversity) and species richness (N) showed no relationship and was thus not included in the results (the results showing the relationship between species diversity and species richness are presented in appendix 2). A greater altitude gradient may be required to understand this relationship as undertaken by Sieben et al. (2014) where a positive correlation was found in wetlands across South Africa. A review by Rahbek (1995) attempted to demonstrate the negative relationship between altitude and species richness. This relationship is widely accepted (Kwon, 2014) and has been attributed to adaptation limitation; limited area, limited functional space due to steep slopes, seasonal time constraints, and geological time constraints (Körner, 2004). Closer analysis of the species richness-altitude relationship by studies such as McCain (2005, 2004) have shown that the decreasing trend is complex, often exhibiting the mid-domain effect. The mid-domain effect describes a mid-elevational peak in species richness and has been demonstrated on a global scale (McCain, 2005, 2003). Factors such as rainfall, temperature, longer periods of cloud cover at the highest altitudes (McCain, 2004), and the mass effect (Grytnes et al., 2008) are among some of the variables suggested to cause the mid-domain effect. The mass effect describes the large sink population at mid-altitudes that receive sources from both above and below in contrast to low and high altitude areas that receive sources from only one direction (Grytnes et al., 2008). The reasons for the mid-domain effect however, appear to remain largely unresolved. Testing the effect of altitude on species richness in wetlands is complicated by factors such as wetness that may override the influence of altitude. This may be one of the contributing factors to the poor trend observed in this study.

Wetness

The identification of the degree of wetness as an influential driver of wetland plant communities is in agreement with the consensus amongst wetland ecologists (Keddy, 2010; Kotze and O'Connor, 2000; Nygaard and Ejrnæs, 2009; Sieben et al., 2010, 2009; Zweig and Kitchens, 2008) due to the specialised adaptation required to surviving anaerobic conditions (Keddy, 2010). Here it is not a strong driver between the major wetland groups, but rather a driver that acts on a local scale that drives the change in plant communities within a wetland.

The general trend is that communities found at the temporary to seasonal end of the wetness gradient are the grassy communities that are dominated by *Merxmuellera macowanii*, *Pennisetum sphacelatum*, *Fingerhuthia sesleriiformis*, *Festuca caprina*, *Miscanthus capensis*, *Tristachya leucothrix* and *Andropogon appendiculatus*. The communities at the seasonal to permanent end of the wetness gradient are the sedge communities dominated by *Carex cognata*, *Fuirena coerulescens*, *Isolepis fluitans*, *Isolepis angelica*, *Carex austro-africana*, and *Juncus oxycarpus*. Sedges are generally better adapted to wet conditions than grasses and this trend is well-documented (Kotze and O'Connor, 2000; Sieben et al., 2010, 2009).

An exception to this trend is found at high altitude, where the permanent wetness area is dominated by the forb and bulbous *Rhodohypoxis rubella* and *Kniphofia caulescens*. Other studies have found similar forb-rich communities in the high altitude permanent wetness areas (Backéus, 1988; Backéus and Grab, 1995; Jacot-Guillarmond, 1963, 1962). This may be explained the lack of competition by taller grass and sedge species at higher altitudes as described above (Sieben et al., 2009).

An attempt has been made here to correlate plant communities with a specific hydrological regime (i.e. temporary, seasonal, permanent wetness). There are general trends that have emerged as described above, but also a number of communities that occur across the wetness gradient. Bridgham et al. (1996) and Goslee et al. (1997) both cautioned against inferring hydrology from vegetation on a large scale, as regional environmental variation makes this difficult. This is likely the cause of varied correlations between hydrology and plant communities made in this study.

Soil Nutrients

Nitrogen is regarded as one of the most limiting nutrients of plant productivity (Reddy and DeLaune, 2008; Saunders and Kalff, 2001; Tilman, 1987). Understanding the biogeochemistry of nitrogen is complicated by vegetation and hydrological variation, as well as the complexity of the nitrogen cycle itself (Bowden, 1987; Vymazal, 2007). A number of processes add and remove nitrogen within a wetland system, of which mineralisation is a major input process, and denitrification is a major output process (Bowden, 1987; Saunders and Kalff, 2001). The negative relationship between organic matter and nitrogen content observed in this study is probably as a result of the process of mineralisation causing decomposition of organic matter and accumulation of inorganic nitrogen (Verhoeven et al., 1990).

If one examines both the VED and VESD ordinations, it is clear that the grassland communities common in temporary wetness areas occur at the high end of the nitrogen gradient (*Pennisetum sphacelatum*, *Andropogon appendiculatus, Tristachya leucothrix*, and *Stiburus alopecuroides* communities), in contrast to the more seasonal and permanent wetness forb and sedge communities that are associated with the low end of the nitrogen gradient and high end of the wetness gradient (*Carex cognata, Carex acutiformis*, *Kniphofia caulescens*, *Limosella major*, *Crassula vaillantii*, *Fuirena coerulescens* and *Juncus inflexus* communities).

The rate of mineralisation is higher under aerobic conditions and the rate of denitrification is higher under anaerobic conditions (Ambus and Christensen, 1993; Hefting et al., 2004; Kennedy et al., 2006; Olde Venterink et al., 2002; Verhoeven et al., 1990; Zak and Grigal, 1991). Thus soil drainage increases nitrogen availability by breaking down organic matter (Hefting et al., 2004; Olde Venterink et al., 2002), and denitrification under anaerobic conditions removes nitrogen from the soil by converting it nitrogen gas (Vymazal, 2007). Higher levels of nitrogen are indicative of drained soils or soils that undergo a cycle of drying and rewetting .

Correlated with high levels of nitrogen are high levels of phosphorus and electro-conductivity. Similar correlations were found by Rolon et al. (2008). Although this study found a correlation between increased levels of nitrogen and phosphorus, the processes that accumulate these nutrients in soils are independent of each other (Koerselman and Meuleman, 1996).

Nutrient limitation of nitrogen and phosphorus select for different assemblages of plant species. High levels of phosphorus in the absence of nitrogen promotes the growth of leguminous plants (Koerselman and Meuleman, 1996). Whereas high levels of nitrogen in the absence of phosphorus promotes the growth of grass species (DiTommaso and Aarsen, 1989).

The general effect of nitrogen and phosphorus concentrations on wetland plant communities and richness is unresolved (Rolon et al., 2008). Teasing out the impact of soil and water chemistry on plant communities is made difficult due to other influential factors such as hydroperiod, altitude, and habitat area (Rolon et al., 2008). Attempting to correlate soil nutrients to plant communities suffers the same large scale limitations as hydrology (Goslee et al., 1997). In order to gain a better understanding of these relationships a more in depth small-scale geographic study is required, that focus on the nutrient gradient within a single or few wetlands in the study area.

Conclusion

The multiple ordination analyses undertaken to reveal the environmental drivers of the classified plant communities identified a number of trends. The forb dominated communities were found towards the higher end of the altitude gradient, grass and sedge dominated communities were found across the altitude gradient, however, the species within these communities differed from the low end to the high end of the gradient.

Wetness defined plant communities within each sampled wetland (on a local scale). In general, the grass dominated communities within each major wetland group were correlated with the low end of the wetness gradient and the sedge dominated communities were correlated with the higher end of the wetness gradient. The forb dominated communities occurred across the wetness gradient. The VESD ordination revealed that nitrogen and phosphorus content and electrical conductivity were negatively correlated to wetness and sodium content. This may be attributed to the process of mineralisation, and these conditions were correlated with the grass dominated communities.

The identified environmental drivers of the plant communities (altitude, wetness and soil nutrients) provide potentially important insights into the communities under threat from climate change, and important environmental variables that require monitoring into the future. This is discussed in greater detail in the following chapter.

CHAPTER 5

IMPLICATIONS AND CONCLUSIONS

The high altitude wetland communities are relatively unique when compared to lowland wetlands in South Africa in terms of growth form and a higher species diversity (Sieben et al., 2014). The low proportion of exotic species (9%) in these wetlands, also found by Mucina and Rutherford (2006), points to a low level of anthropogenic disturbance (Brand et al., 2013). It is therefore important to identify the threats to these relatively pristine wetland systems to help inform conservation.

The findings of this study have several implications for the conservation of wetlands across the Great Escarpment. These are:

1. A number of potentially important wetland species were identified that are not included in The Vegetation of Southern Africa, Lesotho, and Swaziland (Mucina and Rutherford, 2006).
2. A number of potentially important wetland species were not identified in this study which also require attention.
3. Strong altitudinal influence indicates that certain plant communities such as the high altitude fen and seepage wetland communities may be susceptible to global warming.
4. Correlating communities to a hydrogeomorphic unit may enable predictions of likely land use impacts.
5. Relatively pristine sites examined in this study provide reference data that may be useful to restoration and monitoring signs of wetland degradation.
6. The studied wetlands are common in unprotected areas and therefore require careful management.
7. This study provides a comprehensive overview of wetland plant communities across the Great Escarpment but there are certain regions that remain under sampled and opportunities for further research.

Each of these points is expanded upon below.

Revisions of the Important Taxa of the Freshwater Wetlands of South Africa

The Vegetation of South Africa, Lesotho and Swaziland (Mucina and Rutherford, 2006) is used as a conservation planning tool (Sieben, 2010). It is recognised by the authors that the wetlands have not been sufficiently dealt with to inform conservation planning (Mucina and Rutherford, 2006). It is therefore of value to compare the 'important' or indicator species and their distributions identified in this study to those of Mucina and Rutherford (2006) and make suggestions about species that are not included in Mucina and Rutherford (2006). This has been dealt with in Chapter 3 and a summary of the species requiring attention is listed below (Table 17).

Table 17. Potential species to be included in the important taxa of the Freshwater Wetlands of Mucina and Rutherford (2006).

Taxa	**Wetland Unit**
Tenaxia disticha	Drakensberg Wetlands
Poa binata	Drakensberg Wetlands
Festuca caprina	Drakensberg Wetlands
Rhodohypoxis baurii	Drakensberg Wetlands
Rhodohypoxis rubella	Drakensberg Wetlands
Eriocaulon dregei	Drakensberg Wetlands
Senecio natalicola	Drakensberg Wetlands
Senecio repens	Drakensberg Wetlands
Merxmuellera drakensbergensis	Drakensberg Wetlands
Kyllinga pulchella	Drakensberg Wetlands
Limosella inflata	Drakensberg Wetlands
Miscanthus capensis	Drakensberg Wetlands
Haplocarpha nervosa	Drakensberg Wetlands and Eastern Temperate Freshwater Wetlands
Limosella major	Drakensberg Wetlands and Eastern Temperate Freshwater Wetlands
Juncus inflexus	Drakensberg Wetlands and Eastern

Taxa	Wetland Unit
	Temperate Freshwater Wetlands
Bulbostylis schoenoides	Drakensberg Wetlands and Eastern Temperate Freshwater Wetlands
Merxmuellera macowanii	Eastern Temperate Freshwater Wetlands
Carex cognata	Eastern Temperate Freshwater Wetlands
Gunnera perpensa	Eastern Temperate Freshwater Wetlands
Isolepis fluitans	Eastern Temperate Freshwater Wetlands
Fingerhuthia sesleriiformis	Eastern Temperate Freshwater Wetlands
Fuirena coerulescens	Eastern Temperate Freshwater Wetlands
Lobelia flaccida subsp. flaccida	Eastern Temperate Freshwater Wetlands
Isolepis angelica	Eastern Temperate Freshwater Wetlands
Juncus lomatophyllus	Eastern Temperate Freshwater Wetlands
Juncus bufonius	Eastern Temperate Freshwater Wetlands
Trifolium africanum	Eastern Temperate Freshwater Wetlands
Crassula vaillantii	Eastern Temperate Freshwater Wetlands
Pentaschistis densifolia	Eastern Temperate Freshwater Wetlands
Veronica anagallis-aquatica	Eastern Temperate Freshwater Wetlands
Juncus dregeanus	Eastern Temperate Freshwater Wetlands
Sebaea macrophylla	Eastern Temperate Freshwater Wetlands
Pentaschistis densifolia	Eastern Temperate Freshwater Wetlands
Mentha longifolia	Eastern Temperate Freshwater Wetlands
Tristachya leucothrix	Eastern Temperate Freshwater Wetlands
Aristida junciformis subsp. junciformis	Eastern Temperate Freshwater Wetlands
Harpochloa falx	Eastern Temperate Freshwater Wetlands
Scleria welwitschii	Eastern Temperate Freshwater Wetlands
Monocymbium ceresiiforme	Eastern Temperate Freshwater Wetlands

Taxa	Wetland Unit
Helichrysum aureum	Eastern Temperate Freshwater Wetlands
Juncus oxycarpus	Eastern Temperate Freshwater Wetlands
Stiburus alopecuroides	Eastern Temperate Freshwater Wetlands

Unidentified Wetland Communities of the Great Escarpment

This study focuses on mountain specific wetland plant communities, and for that reason, a number of communities that are found across the Great Escarpment as well as at lower altitudes have been excluded from the dataset analysed in this study. These communities are included in other groups of the NWVD, namely the Temperate Grassy Wetland and Subtropical Wetland vegetation groups (Table 18). These communities are described by Sieben et al (2014) and should not be ignored as important wetland plant communities across the Great Escarpment region. By comparing the communities included in the Montane Grassy Wetland vegetation group to those found by Sieben et al. (2010) (which does not differentiate between mountain specific and non-specific communities), the under sampled mountain communities may be determined (Table 18). The communities listed by Sieben et al. (2010) that are not present in any of the NWVD groups appear to be under sampled, and although they are not documented in this study, they are potentially important wetland indicator species in the mountain regions of South Africa.

Table 18. Communities found in the Great Escarpment but classified in other NWVD groups and under sampled communities in the Great Escarpment

NWVD communities (Sieben et al., 2014)	**Under sampled communities**
Temperate Grassy Wetland communities	*Alepidea amatymbica*
Arundinella nepalensis	*Aristida monticola*
Cyperus fastigiatus	*Artemisia afra*
Cyperus marginatus	*Catalepis gracillis*
Eleocharis dregeana	*Crassula dependens,*
Eragrostis plana	*Helichrysum splendidum*
Eragrostis planiculmis	*Kniphofia linearifolia*
Hyparrhenia dregeana	*Kniphofia northiae*
Imperata cylindrica	*Ludwigia palustris*
Leersia hexandra	*Mentha aquatica*
Leucosidea sericea	*Microchloa caffra*
Persicaria decipiens	*Persicaria lapathifolia*
Schoenoplectus decipiens	
Typha capensis	
Subtropical Wetland communities	
Eleocharis limosa	

Global Warming and Plant Community Vulnerability

Global climate change has stimulated an ecological response from plants that has altered the altitudinal distribution of plants species (Beniston, 2003; Lenoir et al., 2008; Root et al., 2003). The upward altitudinal shift in plant species distribution is a response to increasing temperatures as species respond to a change in their optimal elevation (Pauli et al., 1996; Peñuelas and Boada, 2003). It has been shown that mountain areas are particularly sensitive to this change by a larger shift in mountain species distributions (Beniston, 2003; Keller et al., 2000; Lenoir et al., 2008; Peñuelas and Boada, 2003).

Körner (1995) proposed that a 1 to 2 °C temperature increase could be within the tolerance limits of most alpine species, but that alpine species would not be able to withstand a 2 to 4 °C temperature increase. This is not only because alpine species would not be able to shift their distribution upwards, but also because disturbances caused by a rise in temperature such as increased rainfall, degradation of the permafrost and early snow create opportunity for disturbance tolerant species to colonise alpine areas. Nogués-Bravo et al. (2007) predicted an average temperature increase of between 2.1 and 3.2 °C by 2055 and 2.8 and 5.3 °C by 2085 in mountain areas on a global scale. Erasmus et al. (2002) predict 2.5 to 3 °C temperature increase in southern Africa between the pre-industrial era and 2050. Such increases will cause a 500 m upward shift in altitudinal zones (Peters, 1992) that may cause a significant change to mountain vegetation structure and composition (Taylor, 1996). The communities in this study most susceptible to a temperature zone shift are those endemic to the high peaks (Sanz-Elorza et al., 2003) which include the communities of the High Altitude Fen and Seepage Wetlands. In particular the *Carpha filifolia*, *Tenaxia disticha*, *Rhodohypoxis rubella*, *Kniphofia caulescens*, and *Haplocarpha nervosa* communities are the most stringently confined to the highest altitudes and therefore there is no room for them to follow the shift of their 'natural' temperature zone. The *Merxmuellera macowanii* and Common Escarpment Sedge and Grassy Wetlands should not be ignored as communities such as the *Crassula vaillantii*, *Juncus inflexus*, *Mentha longifolia*, and *Merxmuellera macowanii* communities are also restricted to higher altitudes.

Given the relatively close relationship between the Common Escarpment Sedge and Grassy Wetlands and the High Altitude Fen and Seepage Wetlands, one would expect this relationship to become closer under rising temperatures as the mid-altitude communities move to higher altitudes. As a consequence the diversity of wetland communities across the Escarpment may be reduced.

Land Use Impacts: a Study by Walters et al. (2006) on Different HGM Units

A study by (Walters et al., 2006) correlated different land uses to HGM units in the southern Drakensberg mountains. Assuming that similar land use practices are followed across the Escarpment, we can predict the land use practices that are likely to affect certain communities identified in this study. Walters et al. (2006) found that the most heavily impacted HGM unit were the flatter valley bottom wetlands, particularly the areas of a more temporary hydoperiod due to their suitability to cultivation. The communities commonly found in valley

bottom wetlands include the *Carex cognata*, *Festuca caprina*, *Merxmuellera drakensbergensis*, *Pennisetum sphacelatum*, *Carex acutiformis*, *Carex austro-africana*, *Isolepis angelica*, *Kyllinga pulchella*, *Pycreus cooperi*. *Andropogon appendiculatus*, and *Juncus oxycarpus* communities. Of these the *Pennisetum sphacelatum*, *Pycreus cooperi*, and *Andropogon appendiculatus* communities are found in the temporary wetland zone. These are some of the more commonly found wetland communities, but should nevertheless be of conservation concern as they could become rarer under changing land use (Sieben et al., 2014).

The hillslope seeps are less suitable to cultivation given their steeper slopes and often seasonal inundation periods. They are therefore of greater use for grazing which increases their susceptibility to trampling (Walters et al., 2006). The majority of the communities identified in this study are either hillslope seepage or valleyhead seepage communities due to the steeper sloping mountain landscape (Sieben et al., 2014).

Grazing and trampling are likely to be the most frequent impacts on these ecosystems (pers. obs.), which has been indicated as the main land use in areas such as the Sneeuberg (Boardman et al., 2003). These impacts have been shown to strongly affect richness, structure, and the composition of wetland vegetation communities (Jones et al., 2011; Moran et al., 2008; Noroozi et al., 2008; Ruto et al., 2012; Walters et al., 2006). A consequence of overgrazing is the threat of alien invasive species which was observed in hillslope seeps by Walters et al. (2006). The wetlands studied here are not heavily impacted by exotic species, indicating that effective grazing management has been implemented in these areas.

Percentage cover has been used in other studies as an indication of grazing intensity (Du Preez and Brown, 2011; Moran et al., 2008), although the large study area used in this study is subjected to a wide range of climatic and edaphic variation, percentage cover may be used as a crude indication of grazing intensity. A strong cover gradient was identified here in the Common Escarpment Sedge and Grassy Wetlands and Eastern Escarpment Wetlands. The majority of the relevés in these wetland groups are associated with the high end of the cover gradient and the seepage HGM units. The seepage HGM units (as mentioned above) are susceptible to over grazing and poor land use management. The high percentage cover found in seepage HGM units in this study provides further evidence of effective grazing management. It is important that the current practices continue into the future to preserve the integrity of these wetlands. It must be noted that most of the sampling effort was focused on

private and conserved land, the effects of grazing are more severe in communal areas (Walters et al., 2006).

Many of the High Altitude Fen and Seepage communities extend into Lesotho, where wetland degradation as consequence of overgrazing is well-recognised (Backéus, 1989; Du Preez and Brown, 2011; Jacot-Guillarmond, 1962; van Zinderen Bakker and Werger, 1974; Zunckel, 2003). It is therefore vitally important to effectively manage these communities in South Africa to avoid further losses.

Utilising the 'Pristine' State of the Great Escarpment Wetlands

We may never know the state of our ecosystems prior to European settlement; in South Africa there is a lack of reference wetland descriptions (Sieben et al., 2011). The absence of exotic species in the wetlands studied here does give an indication of their relatively pristine condition as we understand it. Of the indicator species identified here, none are amongst the most common wetland invaders in South Africa (Sieben et al., 2014), nor are any listed as 'current' emerging alien invaders of the DAC (Carbutt, 2012). Three of the 23 'current' emerging alien invaders of the DAC (*Cirsium* vulgare, *Oenothera rosea*, and *O. tetraptera*) were found in this study, but not as dominant species. A potential threat to the montane wetlands of the Great Escarpment is *Glyceria maxima*, although it was not found in any of the wetlands studied here, it has been previously found invading wetlands in the Maloti-Drakensberg (Kotze, 2006). This species is a major threat to biodiversity and it is vitally important to ensure that it does not become a common invader across the Great Escarpment.

The identified indicator species that are exotic include *Juncus bufonius, Poa annua*, and *Poa pratensis*, of which none are classified as invasive (SANBI, 2014). It is also unknown whether certain species that are distributed outside Africa are indigenous or not (Sieben et al., 2014), such as *Carex acutiformis, Crassula vaillantii*, *Fimbristylis complanata*, *Isolepis fluitans, Juncus inflexus*, and *Mentha longifolia*. The relatively pristine wetlands studied here provide a reference database that may be useful for setting conservation targets (Sieben et al., 2014), wetland rehabilitation (Rheinhardt et al., 1997), and the early identification of wetland degradation (Grenfell et al., 2005; Kutcher, 2011; Sieben et al., 2014).

A key concept to conservation planning involves selecting areas that complement each other to conserve areas that will provide a biodiversity gain, rather than repeatedly conserving the same species (Cowling et al., 2003; Linke et al., 2007). This needs to take into account

differences, similarities, and connectivity between the candidate areas (Moilanen et al., 2008), and protecting the processes that maintain biodiversity (Pressey, 2004). Some argue that setting conservation targets should be based on the mapping of species data (Brooks et al., 2004) although this does have its limitations such as bias towards easily accessible areas and false negatives (Pressey, 2004). The data collected here are certainly not sufficient for addressing the requirements of conservation planning. However, the distribution of indicator species and their major drivers (altitude and wetness) found here does provide useful information that may be used as a starting point for conservation planning. Such information includes the identification of rare wetland vegetation types, rare combinations of environmental variables, which vegetation types are expected in certain environmental conditions and areas housing a diverse range or unique of suite of vegetation types.

The use of reference sites to guide ecological restoration has gained increasing acceptance as a method of comparing the structure and processes of an intact ecosystem to that of a similar degraded ecosystem (Brinson and Rheinhardt, 1996; Fulé et al., 1997; Kentula et al., 1993; Palik et al., 2000). A common goal of restoration is to re-establish native taxa to which it is important to understand the processes that drive and maintain reference conditions (Bedford 1996; Kirkman et al., 2000, 1999; Palik et al., 2000). The data generated by this thesis provides insights into the native taxa and processes that drive the communities across the Great Escarpment.

The dependence of wetlands on water makes these systems particularly susceptible to degradation (Kotze and Breen, 1994; Whitlow, 1992). Vegetation gives an indication of environmental changes within a wetland because of the quick response to vegetation drivers (Sieben, 2010; U.S. EPA, 2002), and the changes in plant composition as a result of altered water inputs has been shown by studies such as Goslee et al. (1997) and Grenfell et al. (2005). This response has been used in many wetland health evaluation methods (Fennessy et al., 2007). The data generated in this study and the correlation of communities to certain wetness regimes provides a base for further monitoring of wetland condition and human induced stresses in the study area. Monitoring these systems will help gain a greater understanding of plant and environment relationships, which needs to be acquired through small-scale studies.

Great Escarpment Wetland Conservation

The majority of the Great Escarpment wetlands studied here are located outside formally protected areas. This is not to say that the protected areas that were not visited do not house some of these wetland communities, but rather emphasises the importance of good land use management to ensure that these communities are not lost. The nature reserves that do protect some of these wetlands include the uKhahlamba Drakensberg Park, Qwaqwa National Park, and Golden Gate Highlands National Park which are located in the KwaZulu-Natal and Free State sections of the Drakensberg.

The following communities are found in protected areas: *Andropogon appendiculatus, Carex austro-africana, Carex cognata, Carpha filifolia, Festuca caprina, Gunnera perpensa, Haplocarpha nervosa, Kniphofia caulescens, Kyllinga pulchella, Limosella africana, Tenaxia disticha, Merxmuellera macowanii, Miscanthus capensis, Pennisetum sphacelatum, Pycreus cooperi, Rhodohypoxis rubella, Scleria welwitschii* and *Tristachya leucothrix* communities. This represents half the communities of the southern Great Escarpment.

The communities that are not conserved are concentrated predominantly in the Eastern Cape's Great Escarpment section. These include the *Crassula vaillantii, Fingerhuthia sesleriiformis, Fuirena coerulescens, Isolepis angelica* and *Juncus inflexus* communities. Implying that the Eastern Cape communities are poorly conserved would be a result of a false negative finding because the protected areas in the Eastern Cape were not sampled. It is however, important to note that the proportion of formally protected areas in the Eastern Cape Great Escarpment region is considerably lower than in KwaZulu-Natal and Free State regions. Therefore the opportunity to formally conserve the wetland communities of the Eastern Cape Great Escarpment region is lower. This issue emphasises the importance of careful and effective monitoring and management of these wetlands without which these wetlands are at risk of degradation and subsequent loss. Monitoring methods that may be considered include the periodic re-sampling of the relevés included in this study to assess whether a change from natural dominated vegetation to alien dominant vegetation is occurring, or whether a change from wetland dominated vegetation to dryland dominated vegetation is occurring. Collecting this data across a wide geographic area would require the involvement of citizen science whereby members of the community, such as landowners, are involved in the data collection process (Sieben et al., 2014). Tools such an illustrated guide to the most common wetland plants in South Africa, which is an outcome of the NWVD, will

help citizen scientists to identify a change in wetland condition based on the identification of wetland vegetation (Sieben et al., 2014).

Limitations and Opportunities for Further Research

This study has attempted to build on the existing montane wetland vegetation database by filling the gap in the southern Great Escarpment region of South Africa. Combining the data collected throughout the duration of this research with data collected by other researchers has provided a comprehensive overview of the montane wetlands of the Great Escarpment of South Africa. There are, however, areas that remain under sampled.

Due to time constraints, the data collected in this study was limited in areas such as the Sneeuberg and Nuweveldberge, and as such a data gap in these areas still remains. Given that these areas are considerably drier than the more eastern sections of the Great Escarpment, they potentially support a unique suite of wetland plant communities. A second data gap that still exists is within the conserved areas of the Eastern Cape. Although the area of formally conserved land in the Eastern Cape is considerably lower than in KwaZulu-Natal, it is important to determine which of the Eastern Cape confined wetland communities are housed in conservation areas.

To build on the base provided by this study and in order to gain a more in depth understanding of the montane wetland plant communities of the Great Escarpment, future research should focus on the representation of the different plant functional groups within these wetlands. By building on the study of Sieben et al. (2009), a more in depth understanding of the influence of environmental drivers on plant communities will be gained. Such research may enhance predictions and interpretations of the plant communities in relation to management and climate change effects and ultimately the conservation of our wetlands.

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Appendix 1 – SIMPER Analysis Results

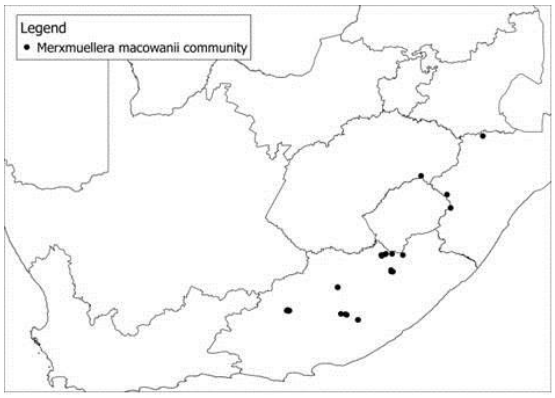
Table 19. SIMPER analysis results showing the species contributing to 70% of the similarity between relevés within each wetland group.

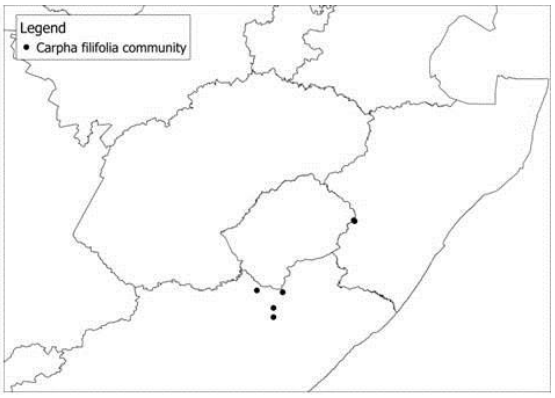
Species	Contribution (%)	Cumulative (%)
Merxmuellera macowanii wetlands		
Merxmuellera macowanii	90.32	90.32
High altitude fen and seepage wetlands		
Carex cognata	21.01	21.01
Festuca caprina	15.16	36.16
Ranunculus meyeri	11.8	47.96
Kniphofia caulescens	10.09	58.05
Haplocarpha nervosa	7.03	65.08
Merxmuellera drakensbergensis	2.99	68.06
Koeleria capensis	2.92	70.98
Mid-altitude mixed sedge and grassy wetlands		
Agrostis lachnantha	14.31	14.31
Pennisetum sphacelatum	13.15	27.46
Juncus inflexus	10.69	38.15
Fingerhuthia sesleriiformis	4.74	42.89
Gunnera perpensa	4.64	47.52
Ranunculus multifidus	3.67	51.19
Eleocharis dregeana	3.62	54.81
Juncus dregeanus	3.34	58.15
Ranunculus meyeri	3.01	61.16
Isolepis costata	2.99	64.15
Andropogon appendiculatus	2.21	66.35
Isolepis angelica	2.13	68.49
Carex glomerabilis	2.13	70.62
Miscanthus capensis wetlands		
Miscanthus capensis	93.35	93.35
Eastern Escarpment wetlands		

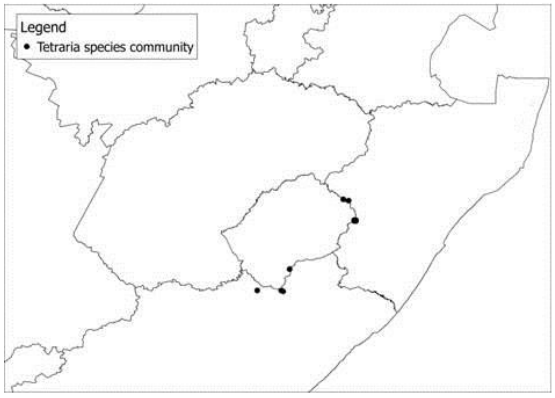
Andropogon appendiculatus	54.6	54.6
Juncus oxycarpus	8.42	63.03
Species	**Contribution (%)**	**Cumulative (%)**
Monopsis decipiens	8.12	71.14
Stiburus alopecuroides	7.04	78.19

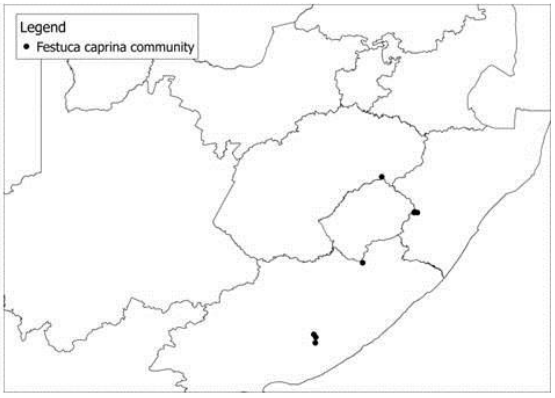
Appendix 2 – Plant Community Distribution Maps

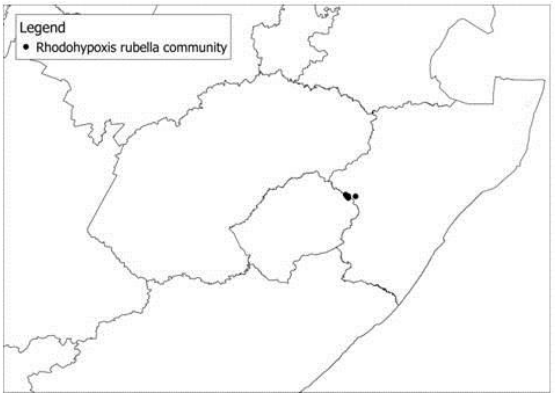
Distribution maps of each wetland plant community

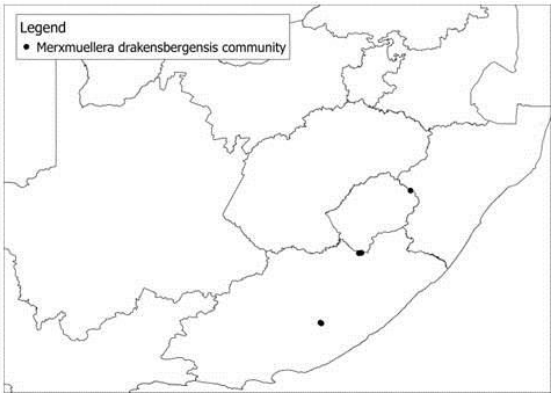


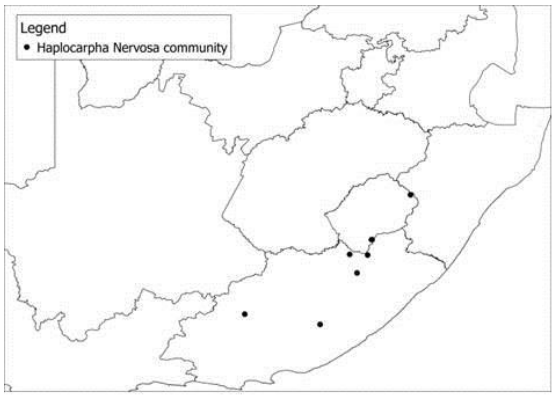


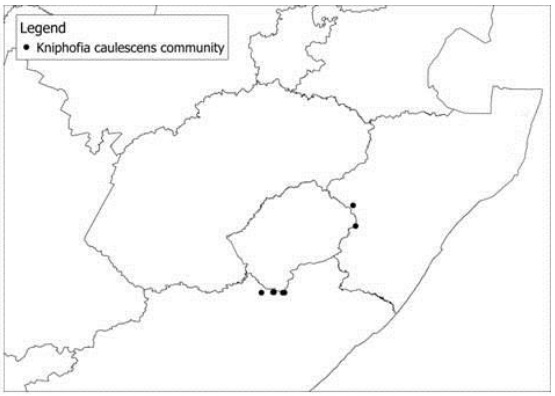









Legend
Haplocarpha Nervosa community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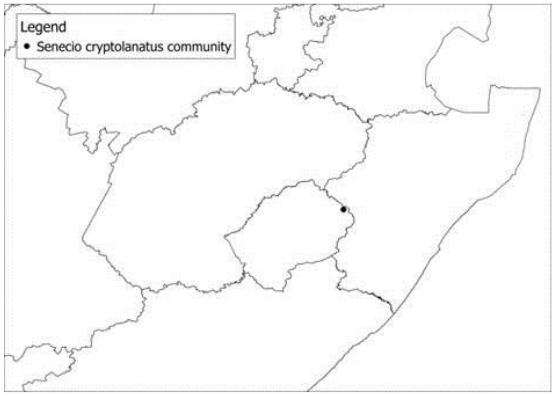
Kniphofia caulescens community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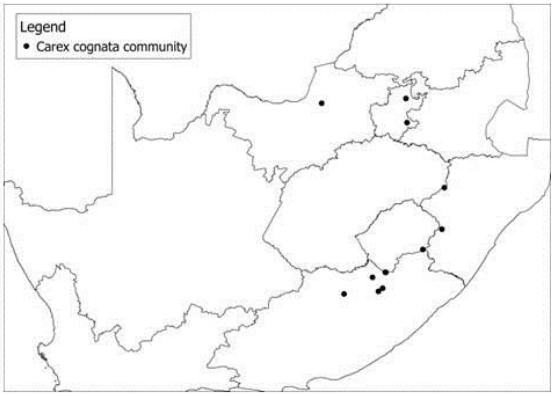
Senecio cryptolanatus community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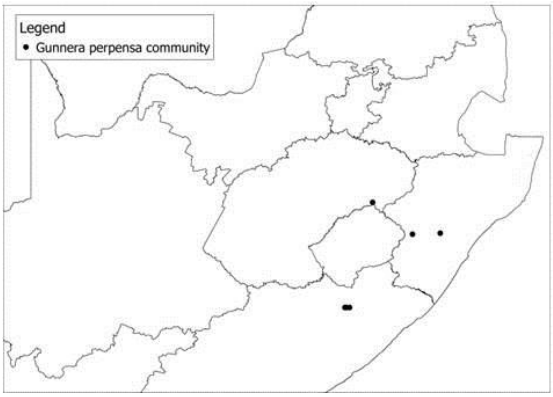
Carex cognata community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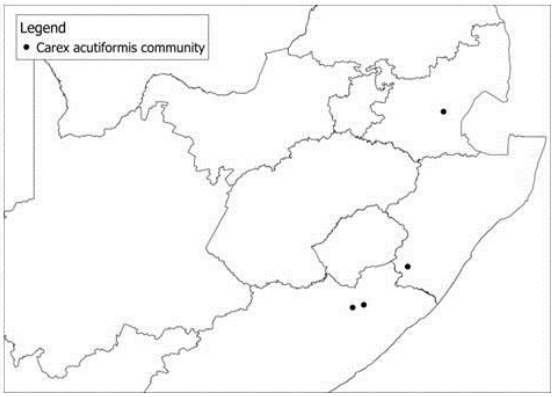
Gunnera perpensa community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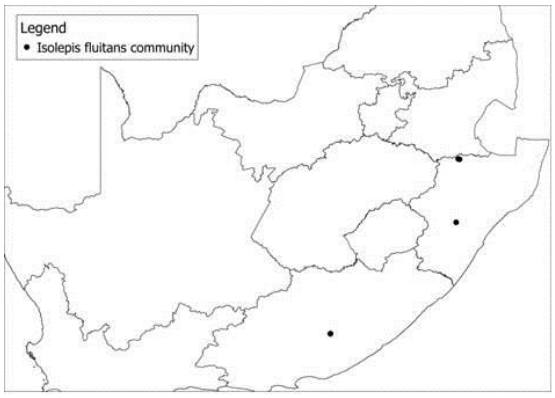
Carex acutiformis community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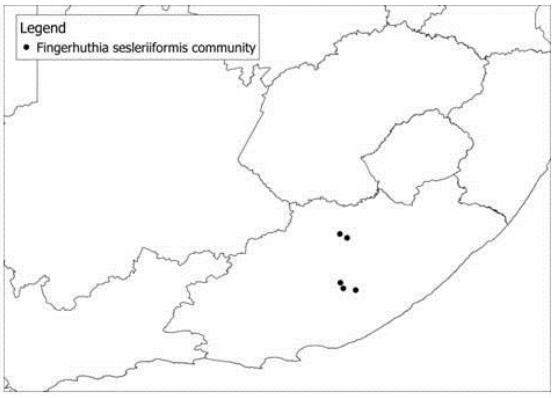
Isolepis fluitans community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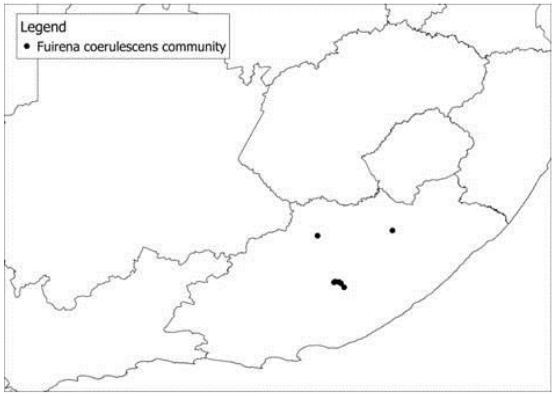
Fingerhuthia sesleriiformis community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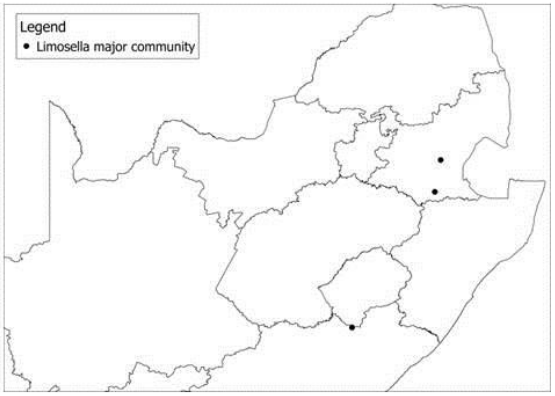
Fuirena coerulescens community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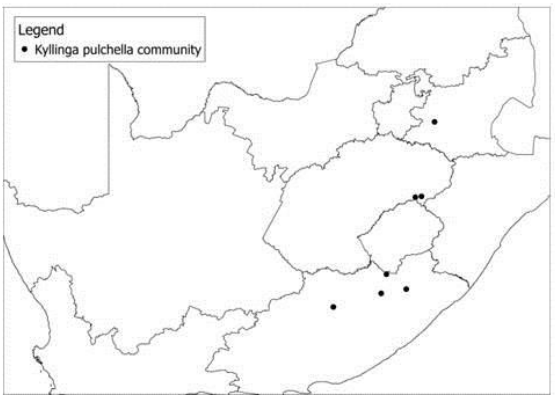
Limosella major community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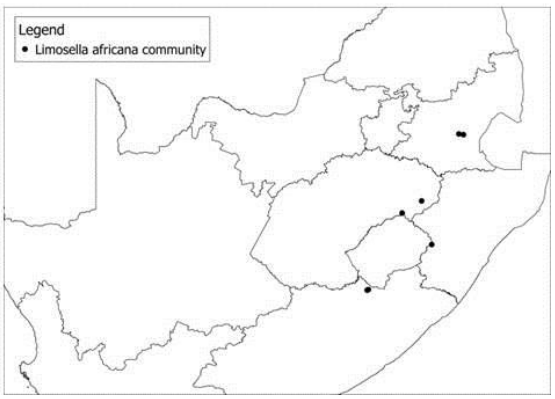
Kyllinga pulchella community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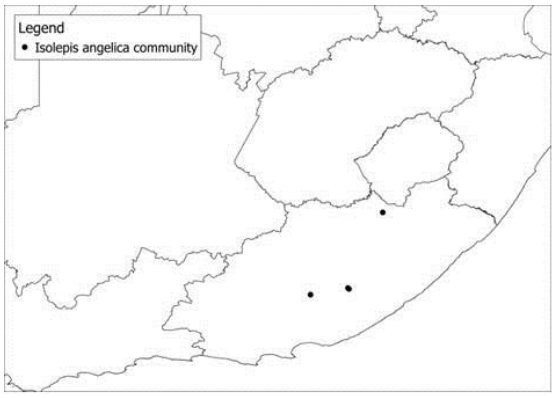
Limosella africana community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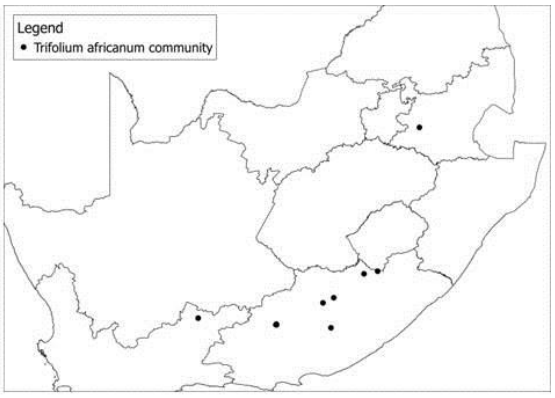
Isolepis angelica community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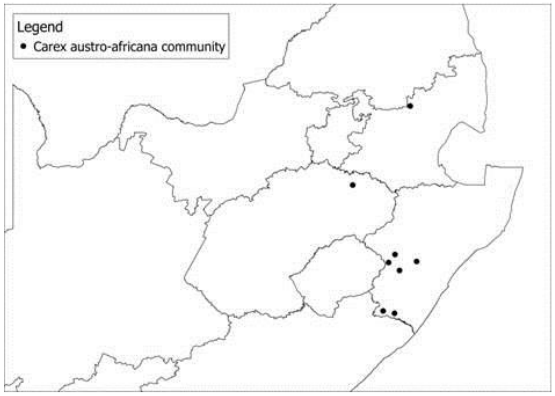
Trifolium africanum community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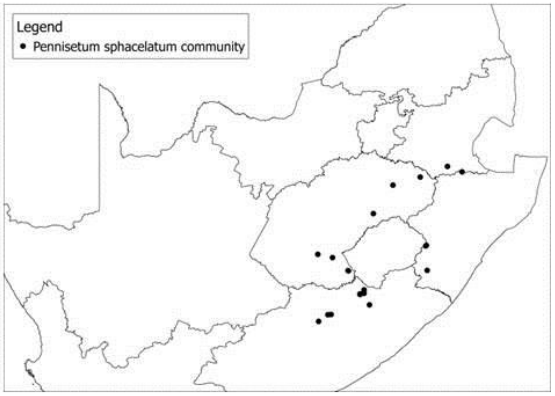
Carex austro-africana community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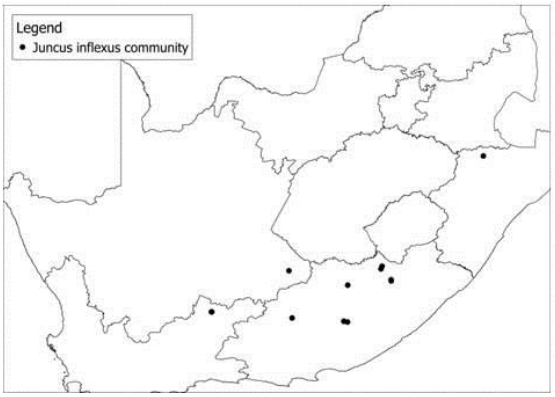
Pennisetum sphacelatum community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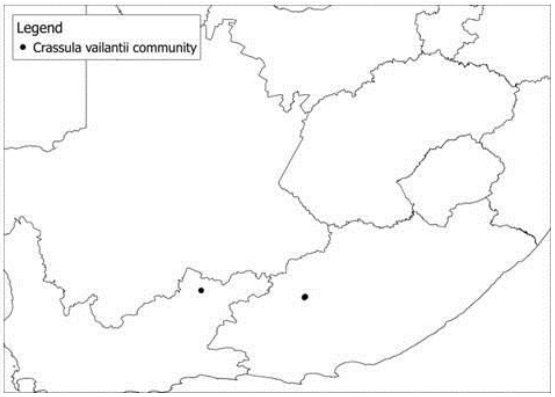
Juncus inflexus community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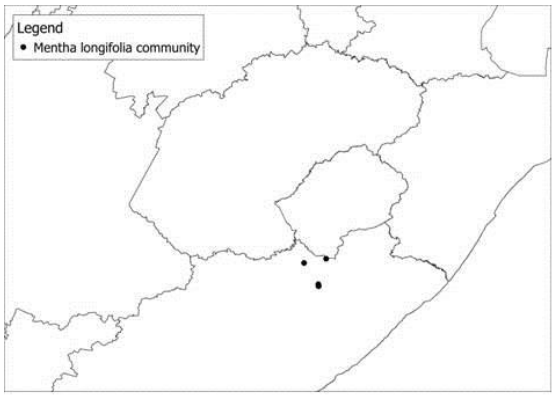
Crassula vailantii community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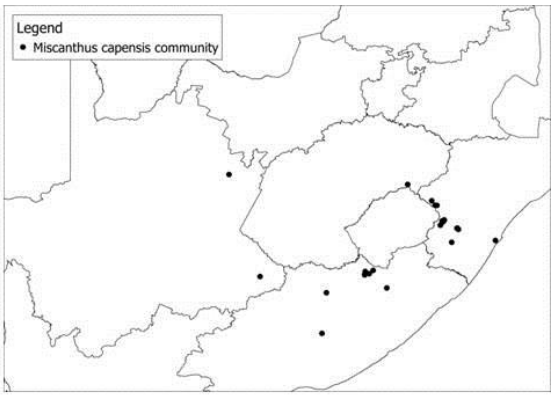
Mentha longifolia community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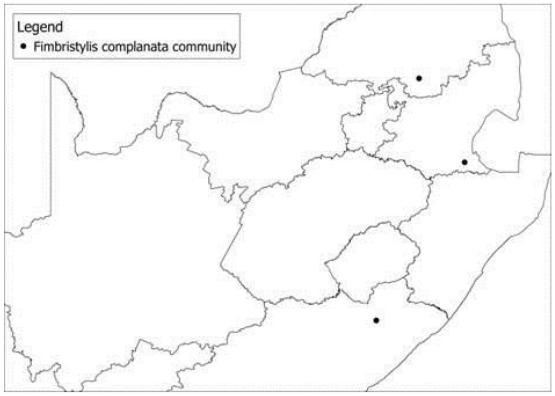
Miscanthus capensis community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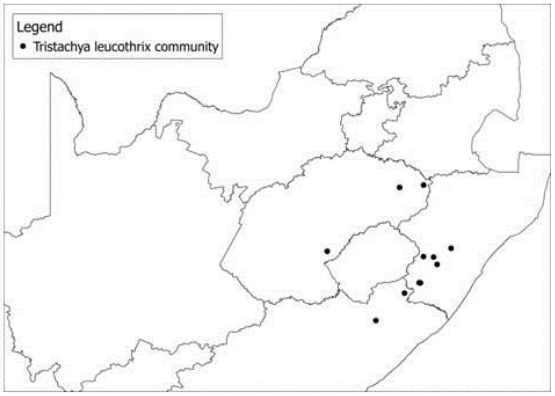
Fimbristylis complanata community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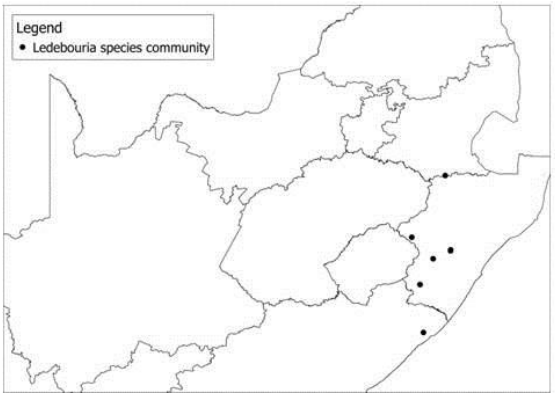
Tristachya leucothrix community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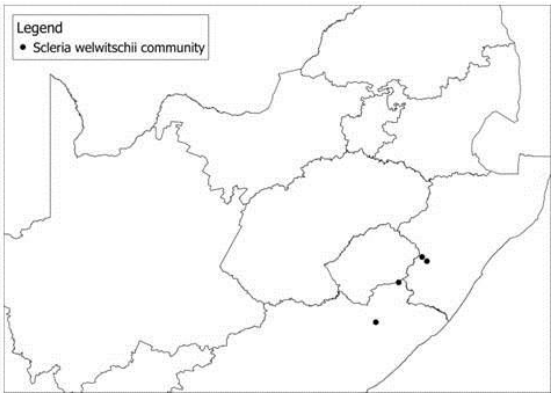
Ledebouria species community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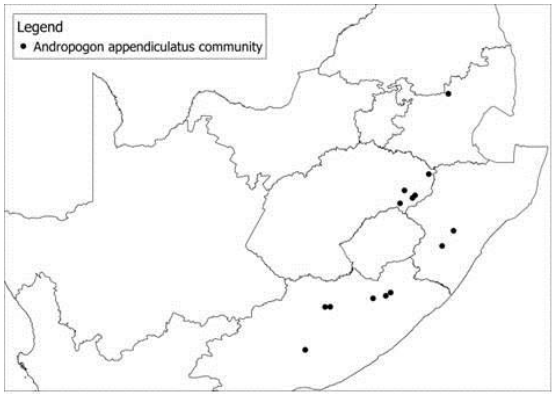
Scleria welwitschii community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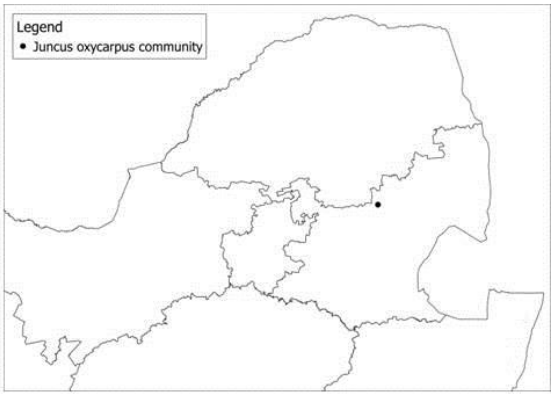
Andropogon appendiculatus community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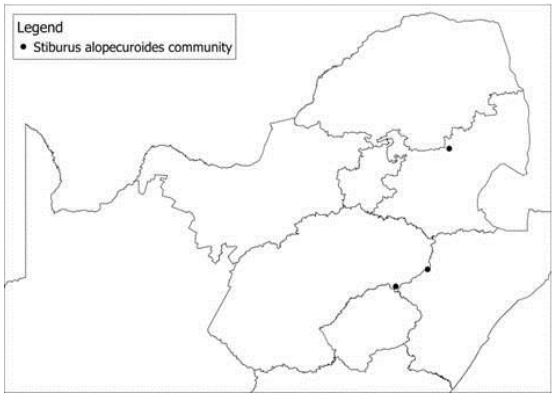
Juncus oxycarpus community


Legend
Stiburus alopecuroides community

Appendix 3 – The Effect of Altitude on Species Biodiversity

Analysis of the relationship between biodiversity and altitude, and species richness and altitude

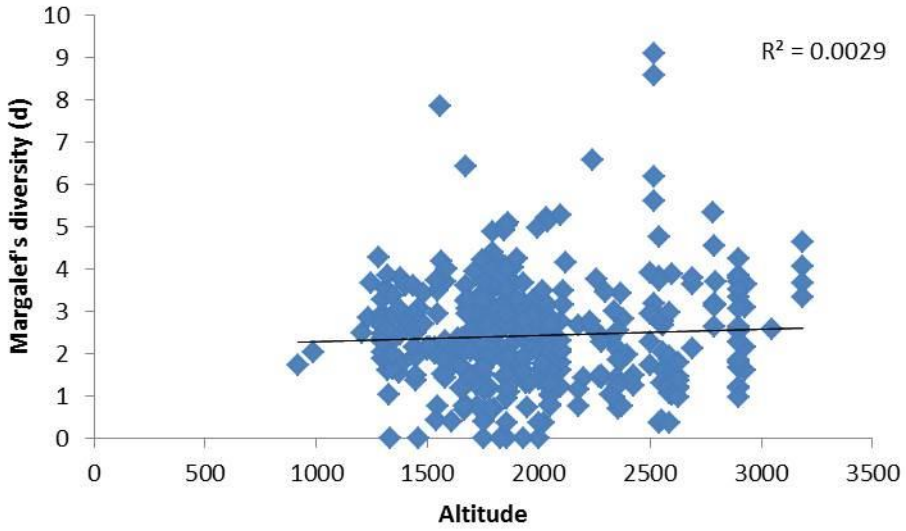


Figure 28. The relationship between altitude and species biodiversity of the montane wetlands of the Great Escarpment using the Margalef diversity index (d).

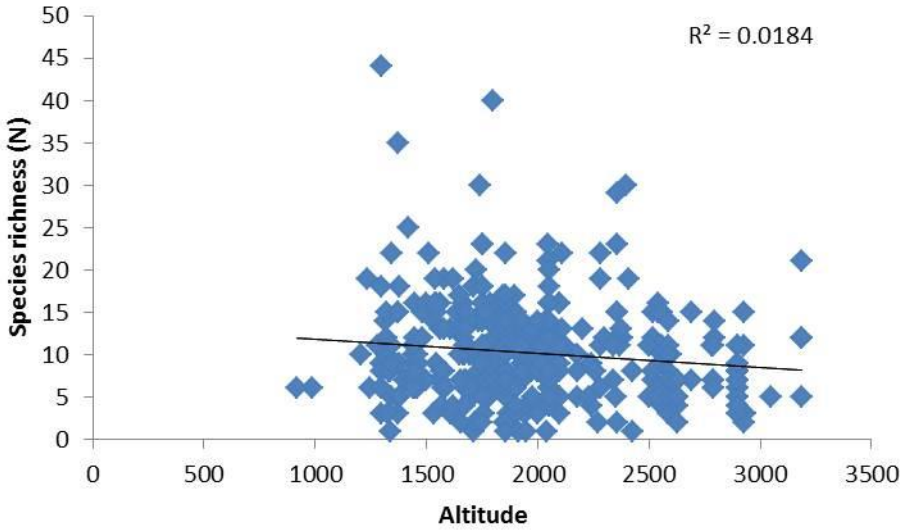


Figure 29. The relationship between altitude and species richness (N) of the montane wetlands of the Great Escarpment.

Appendix 4 – The Effect of Altitude on Selected Plant Species

Analysis of the modelled relationship between percentage cover and altitude for the species *Ranunculus meyeri* and *Haplocarpha nervosa* using the software package HyperNiche version 2.0.

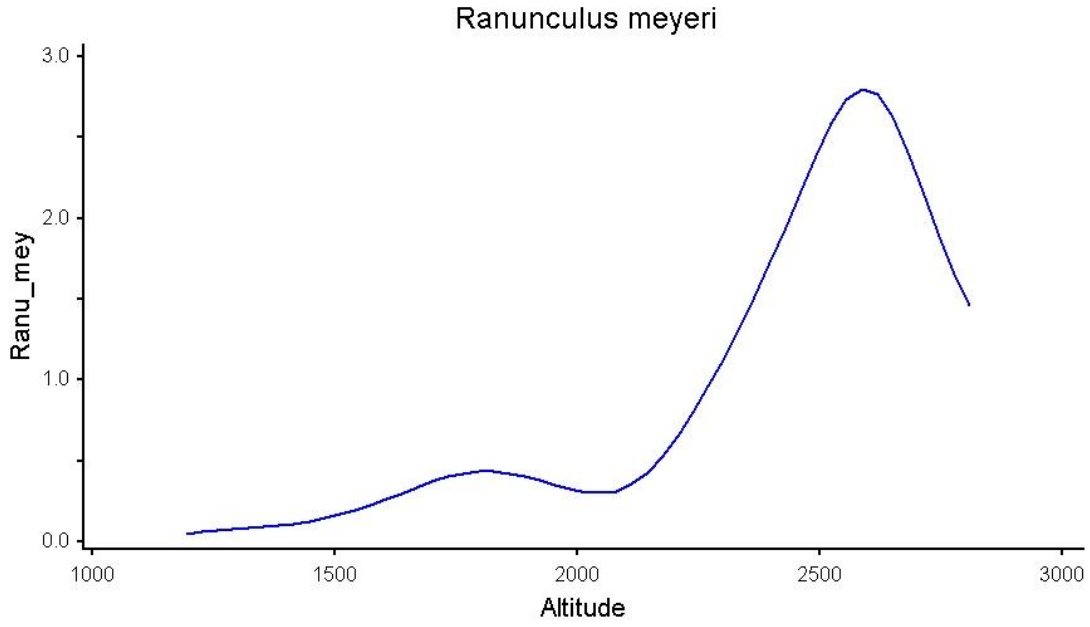


Figure 30. The change in percentage cover of *Ranunculus meyeri* with increasing altitude

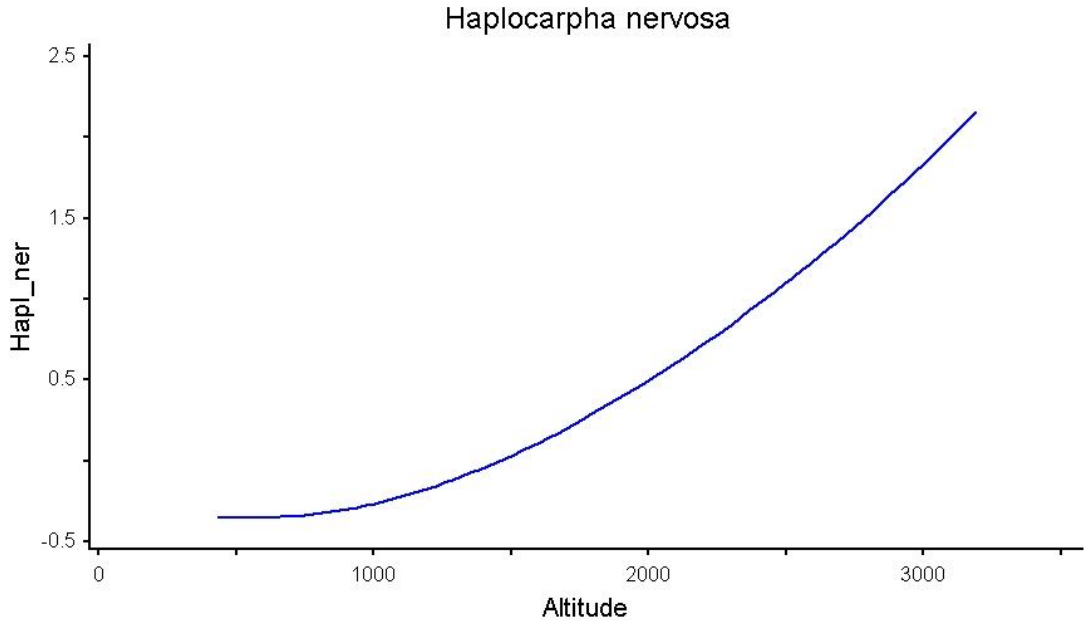


Figure 31. The change in percentage cover of *Haplocarpha nervosa* with increasing altitude