NATIONAL WETLAND VEGETATION DATABASE: CLASSIFICATION AND ANALYSIS OF WETLAND VEGETATION TYPES FOR CONSERVATION PLANNING AND MONITORING

Report to the
WATER RESEARCH COMMISSION

by

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WRC Report No. 1980/1/14
ISBN 978-1-4312-0569-1

July 2014

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EXECUTIVE SUMMARY

BACKGROUND

Wetlands are important ecosystems in the South African context as the country is likely to face a water crisis and only by means of careful planning for water resource management can the government guarantee safe drinking water for all of its citizens. Wetlands provide many different ecosystem services, particularly as they are linked to the hydrological cycle, but they also play an important role as habitats for biodiversity. Plant species occurring in wetlands are useful in terms of their indicator value, as they can help an ecologist to interpret the environmental conditions and changes therein in the wetlands.

RATIONALE

Since many different types of changes are expected to take place in wetland environments, it is useful to understand the link between plant community composition and the physical environment of the wetlands. Since 2005, attempts have been made to develop an index for wetland health for wetlands in South Africa, but due to the large amounts of data needed for such a task, the developed indices were applicable only to a relatively small area. It was deemed necessary to develop a database with wetland vegetation data, mostly in a natural or reference condition together with a basic set of environmental variables before the wide range of possible human impacts should be taken into consideration.

OBJECTIVES AND AIMS

AIM 1

The development of a database with detailed species composition data for vascular plants as well as basic environmental information that can be queried and by which wetland communities across the country can be compared in a standardized way.

AIM 2

A classification of wetland vegetation types that can help in setting restoration targets and targets for strategic conservation planning. This classification should be supplemented by a list of indicator species that help in the identification of these communities.

AIM 3

Obtaining an understanding of the link between environmental gradients which express variation in some physical parameters and the responses of plant community composition to these environmental gradients.

AIM 4

The determination of specific responses of selected species that are considered important to environmental gradients so that shifts in community composition involving these species can be directly translated towards changes in the physical environment.

METHODOLOGY

A database was built by first collating vegetation data from existing literature sources, designing a sampling protocol and supplementing this data with fieldvisits from all over the country. Vegetation data was subdivided into eight main groups, which were each subjected to subsequent data analysis. Some of these data had detailed soil data available as well and therefore different subsets of the data could be used for different types of data analysis.The resulting dataset was then analysed with the help of hierarchical cluster analysis, indicator species analysis and canonical correspondence analysis. Species response curves for selected indicator and dominant species were carried out with Non-Parametric Multiplicative Regression. These analyses were carried out using the programs PC-Ord, Hyperniche and CANOCO.

RESULTS AND DISCUSSION

The final database that has emerged has a total of 5583 vegetation plots with a proportionate spread over the entire country (at least those areas with wetlands), but with a slight bias towards KwaZulu-Natal due to the many historical studies that were carried out in the area.

A total of 244 plant communities can be recognized and classified from this dataset although there are also many plots that have been discarded and not utilized for the classification. Some of these communities are rare and under-sampled and some areas still require more attention. Most plant communities can be recognized by the presence of indicator species which are listed, but other communities can only be recognized by the dominance of a specific widespread species.

Ordination diagrams have been produced for all of the Main Clusters and the most important environmental factors that drive wetland community composition are different for different areas of the country and different per type of wetland. The most important factors are wetness, altitude, organic matter content, substrate (clay, sand) and the major cations causing salinity. An important factor that has not yet been included is climate.

Species response curves have been drafted for many species, even though some of them are only very poorly represented in the data. Species response curves have been plotted for combinations of species that tend to occur together, so that the responses of different species relative to one another can be seen, as these are the community shifts that will be observed in the field when biological monitoring takes place.

GENERAL

The landscape level drivers of community composition in wetlands can be understood and these can assist in predicting what will happen when environmental changes take place. This should play an important role in conservation planning for freshwater biodiversity and in monitoring the effects of South Africa’s freshwater resource management. There are some very species-rich wetlands in the country, and they are mostly located in the high mountains, the mistbelt region of KwaZulu-Natal, and the renosterveld of the Western Cape. The most common wetland plants are mostly grasses, but sedges tend to be dominant in the wettest parts of the wetlands. Wetlands can also be characterized in terms of structure and functional composition as the main functional types are also driven by specific ecological factors.

RECOMMENDATIONS FOR FUTURE RESEARCH

The database should be maintained and expanded as a centralized database with public access. Expansion of the database is still necessary as many rare types are still underrepresented. A number of follow-up studies can be made, and some specific questions can be addressed in case study wetlands, building on the information available from the database:

- The specific responses of wetland vegetation to climatic and hydrological factors should be studied in more detail. Climatic data can be obtained and linked to the geographical coordinates. A more detailed and exact measurement of 'wetness' is difficult to obtain for a large number of wetlands as it requires long-term measurements of watertables or redox potentials.
- Specific traits that help plants survive in specific environments should be investigated and linked to their indicator values. Plant traits can be connected to ecosystem properties, both as response and effect traits, and therefore will provide opportunities to build predictive models for changes in community composition and wetland dynamics.
- The degree to which the vegetation in wetlands is 'zonal' or 'azonal' can be investigated. In previous conservation planning, the conservation value of wetland was often determined by looking at the terrestrial vegetation in which they were embedded. It can now be established whether the assumption that the terrestrial vegetation more or less determines what vegetation is found in the wetland is actually true.
- Studies should investigate the feasibility of the use of satellite imagery for wetland monitoring, as this would be an effective way to cover many wetlands at once. There have been a number of studies that confirm that it is possible to recognize individual species from their spectral signature but it is often complicated by the fact that part of the signature is determined by the physical environment, mixtures of species or the health of plant populations.

ACKNOWLEDGEMENTS

This work is dedicated to the memory of our friend and colleague Thilivhali Nyambeni, who unfortunately passed away prematurely when this report entered its final stages. His energy and enthusiasm and his readiness to take on new things should be an inspiration to wetland ecologists in the country.

Many people have been of assistance during the gathering of data to fill the database. Nomadlozi Nhlapo, Modise Kganye and Khetiwe Mtshali all have been very helpful in capturing historical data. Many collaborators have been contributing with fieldwork generating vegetation data and carrying out species identifications. They are Thilivhali Nyambeni, who collected data in Limpopo province, Donovan Kotze, Nancy Job, Douglas Euston-Brown and Muthama Muasya, who were collecting data out in the Cape, Anton Linstrom and Duncan MacKenzie in the north of Mpumalanga, Ina Venter in Gauteng and North-West Province, and lastly Thabo Matela, Duduzile Mazibuko, Solomon Zondo and Seadi Mofutsanyana in various parts of Mpumalanga and KwaZulu-Natal.

There have been many people who have been helping out in the field, outside of those people who have been mentioned as collaborators, among them Moeti Taioe, Serero Modise, Wayne Matthews, Sammy Motitsoe, Kubashni Govender, Samantha Adey, Bikila Dullo, Damian Walters, Rick van Wyk, Andre Grobler, Ralph Clarke, Cara-Jane Thorne, Chantal Taylor and Goetz Neef.

Fred Ellery and Greg Mullins have been so kind to share the unpublished data from a series of students working in the Mkhuze Swamps in the late 1990s with the project which forms an important part of the database. Retief Grobler, Lulu Pretorius, Althea Grundling, Phumelele Gama and Johann Dupreez have been collaborating with this project, aligning their own data collection to serve the needs of the national database and ultimately also sharing their data.

The authors would like to thank the Reference Group of the WRC Project for the assistance and the constructive discussions during the duration of the project: Mrs. R.P. Glen, Dr. C.E. Van Ginkel, Ms. N. Mbona, Dr. W. Vlok, Dr. H. Malan, Dr. B. Escott, Mr. H. Marais, Mr. M.J. Wentzel, Mr. S. Buthelezi and the late Dr. A. Batchelor. Our colleague from the University of the Free State, Qwaqwa Campus, Dr. Lisa Buwa has been helping out with the editing of the text.

Lastly, we would like to thank the Water Research Commission for their generous funding and support during the course of this project. Apart from the direct support that we received for this particular project, they have also been playing a crucial role in bringing a community of wetland scientists together in the form of the National Wetland Indaba, without which a project of this scope would never have been possible.

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LIST OF ABBREVIATIONS

ARC- ISCW	Agricultural Research Council – Institute for Soil, Climate and Water
AWL	Advanced Wetland Layer
CCA	Canonical Correspondence Analysis
EC	Electrical Conductivity
EPWP	Expanded Public Works Programme
GAM	Generalized Additive Modelling
GLM	Generalized Linear Modelling
HGM type	Hydro-geomorphic type
ISA	Indicator Species Analysis
IV	Indicator Value
LAI	Leaf Area Index
NEMA	National Environmental Management Act
NFEPA	National Freshwater Ecosystem Priority Areas
NMDS	Non-Metric Multidimensional Scaling
NPMR	Non-Parametric Multiplicative Regression
PCA	Principal Components Analysis
SAEON	South African Environmental Observatory Network
SANBI	South African National Biodiversity Institute
SAWCS	South African Wetlands Classification System
TI	Total Inertia
TVE	Total Variance Explained
VB	Valley bottom wetland
VB wc	Valley bottom wetland with channel
WfWet	Working for Wetlands
WRC	Water Research Commission

1 INTRODUCTION AND OBJECTIVES

1.1 Wetlands and their ecosystem services

South Africa is regarded as largely an arid country as it has an overall average rainfall of only 452 mm per year with only very few areas where annual rainfall exceeds evaporation. It is therefore also regarded as a country that is susceptible to a water crisis and the management of water resources is regarded as a high priority for government planning (Davies & Day 1998). Future projections of water usage in the country predict that even the lowest estimates of water demand would exceed the total of water resources available at the surface in just a few decades. Of course, it is possible to start building more infrastructures to exploit groundwater resources further, which is already happening in the Western part of the country, but also this water is limited and it just represents water in a different part of the same water cycle (Davies & Day 1998). What is really needed is an overview of all water resources, and a careful management plan regarding these resources and a system that monitors changes in aquatic ecosystems. The current study will focus on the study of wetlands, as their linkages with the overall water cycle are not always well understood, but they are regarded as providing important ecosystem services and playing an important role in the overall water cycle.

Already in the late 1970s and early 1980s it was understood that wetlands had been neglected in terms of conservation and management (Noble & Hemens 1978). In the last fifty years, there has been a considerable loss and degradation of many important wetland areas in South Africa, but at the same time, water managers have started to consider the important role that wetlands play within the hydrological cycle. This resulted in more attention being paid to the status of South African wetlands, evidenced by the designation of 22 Ramsar sites, the designation of specific wetlands as having World Heritage Status, and by mentioning them as requiring special attention in the National Environmental Management Act of 1998. The Water Law of 1998 states that ecosystems that provide water such as wetlands should be recognized as requiring a basic amount of water as an “ecological reserve”. Additionally, the Expanded Public Work Programmes of Working for Water and Working for Wetlands have raised an awareness of wetlands in South Africa in the public mind.

Wetlands are recognized as belonging to the world’s most productive environments. As such, they provide important ecosystem services, maintain the hydrological cycle and form an important habitat that contributes to biodiversity across the landscape. Humans directly benefit from wetlands because they use the water for irrigation, they are protected from floods due to water retention by wetlands and they obtain resources that are exploited directly, such as grazing grounds and plant species that are harvested as building materials.

Wetlands maintain biodiversity and hydrological cycles by protecting and regulating water resources, holding water during floods and releasing it during dry periods, reducing flood damage, soil erosion control, and removing pollutants from the water. Destruction or degradation of headwater wetlands generally has extensive effects on ecosystem processes further downstream, so people living downstream have an interest in maintaining ecosystem health upstream (Kotze et al. 2005).

Despite the recognition of the importance of these ecosystem services, wetlands remain among the most threatened habitats in the world (Ramsar Convention 1971). More than half of the wetlands in South Africa have been degraded and the remaining wetlands are under pressure of human population growth and utilization (Kotze et al. 1995). An integrated approach to the management of water resources is needed and wetlands play an important role in that (Driver et al. 2011; Nel et al. 2011).

1.2 Classification of wetlands

The definition given by the Water Act 36 of 1998 states that wetlands are characterized by wet soils resulting from prolonged saturation, the presence of water loving plants and a high watertable that results in saturation at or near the surface of the land (DWAF 2008). The most important aspect that determines the habitat conditions in a wetland is the hydrology, the flow of water in and out of the wetland (Mitsch & Gosselink 2000). Hydrological conditions determine whether a place is temporary or permanently flooded, whether the water is flowing or standing still, whether the flow is channelized or diffuse, whether the soils are saturated or inundated, and where in the wetland the various types of sediments are deposited (Bullock & Acreman 2003; Ellery et al. 2008).
Hydrology and geomorphology are such important aspects in understanding the ecological functioning of wetlands that they are also used as the main characteristics that subdivide wetlands into different types, which are then referred to as Hydrogeomorphic types (HGM types). These types of wetlands basically describe wetlands in terms of the shape of the basin where water is stored, and the main inputs and outputs of water in that basin. Recently the South African Wetland Classification System (SAWCS) (Ollis et al. 2009, 2013) has been developed, based on the principles of the hydrogeomorphic classifications which have been successful around the world. This classification system is also hierarchical, meaning that wetland classification can be carried out to various level of detail, with level 4 representing the Hydrogeomorphic (HGM) Unit, the main 'unit' by which a single wetland can be recognized and which will shortly be discussed below. The finer levels of the classification, from levels 5 up to 8 represent the description of the wetland habitat units occurring within a single wetland, and this is where most of the environmental changes in a wetland can be detected.
One of the most important parameters that play a role at these levels is the hydroperiod, which refers to the fraction of time in which a certain part of the wetland is inundated on average and in the long term. Generally, hydroperiod is assessed by looking at soil hydromorphic features. This is necessary as detailed data on watertable fluctuations in the long term is very scarce. The hydromorphic features in a soil develop in response to water fluctuations in the soil which in turn affect the redox potential and the soil chemistry. These changes in soil chemistry result in patterns in soil form and colour that can be directly observed (Kotze et al. 1996).

The seven hydrogeomorphic (HGM) types as defined by level 4 of the SAWCS are used to classify wetland ecosystem types on the basis of hydrology and geomorphology, which is an important first step in characterizing the habitat unit as it characterizes the wetland as a whole (Ollis et al. 2013).

1. **Slope seepage**: This is wetland area located on gentle to steep slopes, driven by discharge of groundwater or by water percolating through the upper layers of the soil layer. Slope seepages generally feed into drainage basins or rivers
2. **Valleyhead seepage**: This is a typical concave wetland area located on gentle sloping land on a valley floor at the head of a drainage line. Water input is mainly from subsurface flow.

3. **Unchannelled valley bottom wetland**: This is a wetland area on a valley floor that is connected to a drainage network, but without a major channel running through it. It is characterized by the prevalence of diffuse flow, which is at or near the surface especially after rainfall events. Water mainly enters the wetland through an upstream channel, but sometimes also from adjacent slopes.
4. **Channelled valley bottom wetland**: This is a wetland area on the valley floor that is divided by and typically elevated above a stream channel, which makes that this wetland generally drains faster than an unchannelled valley bottom wetland. Water inputs to these areas are from adjacent valley side slopes and from the overtopping of the channel during floods.
5. **Floodplain**: This is a flat wetland area adjacent to a river channel in its lower reaches that is subject to periodic inundation due to flood events in the wet season. These flood events can be quite turbulent and leave many marks in the landscape, such as levees, oxbow lakes and depressions where fine sediment is deposited.
6. **Flat**: These represent areas where the groundwater is near the surface, mostly on coastal plains. Their main input of water is from rainfall. The flow is imperceptible and these wetlands are basically a transition between a depression and a valley bottom wetland.
7. **Depression**: This is a closed basin where water accumulates, usually with a concave shape, but sometimes very flat, in which case it it is called a pan and can be confused with a flat wetland. When the shape of the basin is concave it is usually referred to as a pool or a lake.

The SAWCS system plays a central role in the National Wetland Inventory and lies at the heart of many strategic initiatives for conservation planning that involve wetlands, the most important of which is the delineation of the National Freshwater Ecosystem Priority Areas (Nel et al. 2011), often supplemented by provincial conservation plans. Even though the classification of HGM units is a very useful tool for managers and planners at the landscape scale, it is limited in its scope for management goals within the wetland, where all kinds of environmental variables may be impacted by small- or large-scale disturbances that affect ecosystem health (Macfarlane et al. 2008).

Particularly for the sake of conservation planning, an HGM Classification has its shortcomings, as the biodiversity of a locality is not exclusively determined by large-scale top-down processes, but depends a lot on specific local conditions as well. Habitat classifications on the basis of actual biodiversity are more suitable for this purpose (Driver et al. 2011). For this reason, nature conservation agencies such as Ezemvelo KZN Wildlife have taken steps to build a wetland classification system based on aspects of biodiversity for freshwater ecosystems in the Province of KwaZulu-Natal (Rivers-Moore & Goodman 2010; Rivers-Moore et al. 2007, 2011). This classification targets both wetlands and riverine systems and includes the use of several biota such as fish, amphibians and vascular plants. KwaZulu-Natal is one of the more mesic provinces in South Africa and therefore a classification based on such broad range of taxa would not necessarily be applicable to other provinces where there are less perennial river systems and many wetlands are dry and saline for a large part of the year. Several taxa such as amphibians or fish may not even be present in such wetlands. The feature that is most suitable to look at over a broad range of habitats would be the vascular plants as they are present in all wetlands.

This was one of the most important reasons for starting to build a database on wetland vegetation for the entire country (Sieben 2010).

1.3 Plants as indicators

The most visible aspect of the wetland environment is the vegetation, which also plays an important role in the functioning of wetlands (Cronk & Fennesey 2001). Wetland plants are those plants that are adjusted to growing in a substrate that is, at least for part of the year, deficient in oxygen and affected by the altered soil chemistry in reduced environments. Most wetland plants are herbaceous plants but in some situations also woody species are prominent. Some wetland plants are floating or submerged (e.g. water lilies, pondweeds and algae), but the largest numbers are emergent, which means that the largest part of their shoots emerge above the water surface (e.g. sedges, grasses, etc.) (Cronk & Fennessy 2001; Cook 2004).

The importance of plants lies primarily in the fact that they form the base of the food chain and therefore a major conduit for energy flow in the system (Cronk & Fennessy 2001). Wetland vegetation slows down the flow of water and enhances water quality by trapping nutrients, pollutants, and sediments in downstream aquatic ecosystems. Some plant species remove toxic substances in their tissues by sequestering them in their tissues and generally they trap sediments in an anoxic environment where anaerobic bacteria reduce many nutrients to a gaseous form. Both of these processes have a positive impact on water quality (Cronk & Fennessy 2001).

Plants are regarded as good indicators of wetland condition because they have a high level of species richness, rapid growth rates, and they respond quickly to environmental changes (DWAF 2008). In the wetland environment, the two most important environmental factors affecting the plant community are water quantity and quality. The composition of the plant community in any habitat is determined by the climate, the soil, the position in landscape, and competition between plant species (Van der Maarel 2005). Changes in the environment, whether they are due to natural causes or human actions, result in shifts in plant community composition. Individual species of plants may then be used as indicators because they show a differential tolerance to environmental conditions. In this way, the reference types that are described for certain wetland environments and that may aid in strategic conservation planning, may start to change over time due to anthropogenic alterations. Those plants that are regarded as characteristic of those wetland environments should be monitored in the long term to see whether significant changes in the wetland environment are taking place. For this reason, it is important to supplement the HGM classification discussed in section 1.2 with a bottom-up classification based on plant community data (Sieben 2010).

In order to answer the questions about which plant species should be used as indicator species for wetland condition in South Africa, it is necessary to collate data from a large number of wetlands across the country and store and analyze this data in a standardized way, making comparisons between studies feasible.

The classification that will result from such a database will play a major role in conservation planning for wetlands, as it can be determined which wetland vegetation types are rare and in which kinds of environments they can be expected. The database will also serve to understand the ecology of the most important species occurring within it by relating their occurrence to the environmental conditions that prevail within wetlands and therefore provide answers to questions about trends in populations that can be expected when certain environmental changes happen. Lastly, the database will provide data on reference conditions that can be used to set restoration targets during wetland rehabilitation, as it is becoming more evident that restoration needs to be guided by ecological knowledge and understanding of the reference conditions. With the South African government spending more resources on effective water management and the associated Public Works Programme, it is becoming more evident that the effects of these projects need to be monitored more effectively in terms of the desired outcomes for biodiversity (Driver et al. 2011a).

1.4 Aims of the study

Since many of South Africa's wetlands are still under threat from several forms of degradation, it has become increasingly important to know which plants are useful as biological indicators, so that an early warning system can be used when things start to go wrong in a particular wetland. This is why the classification of all existing data plots into community types, and tools to identify these communities is of high importance for wetland conservation in South Africa.

It is important to understand how wetlands function if one wants to effectively conserve and manage them. A wetlands database helps to create a clear picture on vegetation composition and the environmental factors controlling the distribution of plant species in a wetland. Since the last overview of South African wetland vegetation by Mucina & Rutherford (2006), large amounts of data have become available that can help in understanding in greater detail how South African wetlands function. Several particular aims in the analysis of the existing database are:

- The development of a database of wetland vegetation where plant community composition is linked to a standardized set of environmental variables.
- To obtain a classification of wetland vegetation types that can be used as reference types for wetland restoration and that can help in setting conservation targets for strategic conservation planning. This would be greatly helped by an inventory of the historic extent of those vegetation types, although it is not clear whether such an inventory may be obtained.
- To understand the correlations between community types and environmental variables so that it is understood what the ecological drivers of diversity in wetlands are.
- To obtain information on the exact species responses to particular environmental variables so that eventual shifts in community composition can be interpreted in terms of the environmental drivers of the ecosystem.

2 METHODOLOGY

2.1 National Wetland Vegetation Database

The first step that was taken in building a national wetland vegetation database was bringing together all existing vegetation data from previous studies on wetland vegetation. This started as a pilot project from the Water Research Commission (Project K8/789) which has been reported by Sieben (2010). This project started out with a workshop convening several wetland and vegetation experts to decide what should be considered minimum data requirements in the database. The fourteen variables that are considered basic information in the wetland environment are listed in Table 2.1. Four additional variables are listed that are not always known but that are desirable to be included as well. Data that was found in historical records and that fell short of these minimum data requirements was included in the database but an extra field in the database was added to inform the user about the suggested 'completeness' of the data. This field has the value '1' if the data fits in with the minimum data requirements, the value '2' if one or two fields are missing that can easily be recorded on a site visit, and the value '3' if the data is considered incomplete (Sieben 2010). The data of the last type will not be useful for many purposes of data analysis.

The initial database was built by re-entering data from historical studies into a central database using the programme Turboveg (Hennekens 1998).

A sampling protocol has been devised so that additional studies will have a more systematic approach and so that soil and hydrological data are collected in a way that makes comparison across the country possible. To this end, a standardized dataform has been created defining all the relevant data that needs to be collected at a particular site by field ecologists. This dataform is shown in Appendix A and should be used to encourage future researchers in wetlands to be thorough in their data gathering. Firstly, this protocol makes use of the HGM classifications that have been devised in recent years (Ewart-Smith et al. 2006; Ollis et al. 2013) and assesses hydroperiod by means of soil hydromorphic features (Kotze et al. 1996).

Preferably, large wetlands will be visited and an overview of all habitat units and vegetation units is required to proceed in sampling vegetation. In each recognized vegetation unit a vegetation sample should be made in a plot of a suitable size (3 x 3 meters in grassland and 10 x 10 meters in forest). This can eventually be supplemented by a soil sample to make more detailed analysis possible. Vegetation surveys for wetlands should best focus on such large wetlands since they display a wide variety of wetland habitat types and sampling those wetlands will therefore be more cost- and time effective than travelling around to find a large number of small wetlands. Small wetlands should only come in focus when they are easily accessible, when they contain unique vegetation types, or when large wetlands of a similar hydrogeomorphic type do not occur in the region.

Based on the database that is a compilation of existing studies and using the sampling protocol that is illustrated in Appendix A, new vegetation samples were made in all parts of the country in order to obtain a complete overview of the wetland vegetation types of South Africa.

The current database contains 5583 vegetation plots including 3633 plots from 43 historical studies, of which the most recent ones take the minimum data requirements as indicated in the protocol provided in Appendix A (and additional data such as soil variables) into account. The rest of the data in the database originates from previously unpublished vegetation plots by the main author and additional field studies carried out in the past few years with the specific purpose of populating the wetlands vegetation database with data from all over South Africa and covering all possible types of wetland vegetation. This last effort resulted in an addition of 1855 vegetation plots, many of which have additional soil data, which can be utilized for various types of analysis. The sources of the historical data that has been included in the database is shown in Appendix B.

Two large-scale and detailed studies that focused entirely on wetlands in the last decade have been included in the database and formed a basic model for how to conduct wetland vegetation studies in South Africa. These are the studies by Collins (2011) on the pans and valley bottom wetlands in the Free State and Corry (2011) on wetland vegetation in the Western Cape coastal forelands, one of the most diverse areas in the country. For both of these datasets, many different soil variables were measured and these are very useful in terms of the overall comparison of wetland environments in the country.

2.2 Structure of the database

Every plot in the database contains both vegetation data (which consists of species composition including cover-abundance scales according to the Braun-Blanquet method) and environmental data according to the minimum data requirements listed in Table 2.1. Reference specimens were collected for identification in the herbarium and voucher specimens were prepared for the National herbaria.

For a limited number of plots, sample bags have been filled with soil for a more detailed measurement of potential explanatory variables. Due to logistic limitations, this sampling has been restricted to at most one soil sample per wetland, even when many vegetation samples have been collected in a single wetland. Data included in the studies by Collins (2011) and Corry (2011) also contained soil data and comparison with that data is feasible, but required some conversions as some variables had been measured in different laboratories and in different units. In the end, a standard list of variables has been compiled for soil analysis (see Table 2.2). All soil samples that were collected within the scope of this project were analyzed by the ARC-ISWC in Pretoria. Due to an apparent incompatibility issue with the dataset from Collins (2011) which has not been resolved yet by the time of publication of this report, the data for the main cations (Sodium, Magnesium, Calcium and Potassium) has been standardized (which means that, after log-transformation, they have had the mean of the whole dataset subtracted, and been divided by their standard deviation). This has been carried out for the two incompatible datasets separately: Collins (2011) and the data from Corry (2011) combined with the newly collected data that was analysed by ARC-ISWC.

Additional data from the original data form that is available for the whole database is indicated in Table 2.3, together with the abbreviations that are used for those variables in subsequent chapters.

Table 2.1 Minimum data requirements as decided on a workshop on Wetland Vegetation in August 2008 (Sieben 2010).

1	**Vegetation description**	Complete Braun-Blanquet cover data with cover-abundance classes in 9 categories
2	**Vegetation structure**	Assessment of height and cover of different vegetation strata
3	**Locality description**	GPS coordinates in Decimal Degrees, WGS 84 datum, including altitude
4	**Date of recording**	Important for assessing seasonal aspects
5	**Slope and aspect**	Slope in categories Flat (0-0.5%), Slight (0.5-1%), Very Gentle (1-2 %), Gentle (2-3%), Moderate (3-10%), Steep (> 10%), Aspect in categories N, NE, E, SE, S, SW, W, NW
6	**Hydrogeomorphic unit (wetland type)**	Level 4 of SAWCS classification system (Ewart-Smith et al. 2006; Ollis et al. 2009)
7	**Topography**	Position in the landscape (floor, foot, slope, top, plain, see Ollis et al. 2009)
8	**Hydroperiod**	Three classes assessed on Hydromorphic features in soil, see Kotze et al. (1996)
9	**Inundation depth**	Assessed at time of recording
10	**Soil type**	Texture of topsoil, assessed in seven categories: Bedrock, Sand, Clay, Loam, Peat, Silt/Mud, Saltcrust. Includes soil depth, up to 50 cm, the presence of impermeable layers below like a clay lens and the amount of organic material in three categories: Mineral, Humic/Dark and Peaty
11	**Water velocity**	Three classes (stagnant, slow-flowing, fast-flowing), recorded at time of survey
12	**Salinity**	Saline Yes/No
13	**Disturbance**	If applicable, write notes about disturbance, grazing, fire etc.
14	**Reference**	Field number and reference to original study
	Additional data	
15	**Soil Form**	Soil Form according to the Soil Classification Working Group (MacVicar et al. 1992)
16	**Nutrient status**	If chemical analysis of soils has been carried out, supply a reference to that study
17	**Hydrology**	Source of water and assessments of the contribution to water in the wetland
18	**Landscape**	Natural landscape, Agricultural landscape or Urban landscape

Table 2.2 Soil variables as measured by the Agricultural Research Council - Institute for Soil, Water and Climate. The abbreviations in the third column refer to the abbreviations used in ordination diagram and species response curves in the results section of Chapter 3. All of these variables have been transformed during analysis using the transformation log(X+1).

Variable	Measurement	Abbreviation
pH	Water extraction	PH
Electrical Conductivity	Measured in mS/m	EC
Nitrogen	Summed up concentration of Nitrate, Nitrite and Ammonium, each of which measured in mg/kg	Nitrogen
Phosphorus	P-Bray I method, in mg/kg	Phosphorus
Sodium, Potassium, Magnesium, Calcium	1:10 water extraction measured in mg/kg	Na, K, Mg, Ca
Soil particle distribution	In mass percentages for three fractions Clay (<0.002mm), Silt (0.05 – 0.002mm), Sand (2 – 0.05mm)	%Clay, %Sand, %Silt
Organic matter	Using the Walkley-Black method, expressed in mass %	%Carbon

The presence of soil data for some plots but not for others means that subsets of the entire dataset will have to be taken for specific types of analysis. This can be referred to as different levels of data resolution. In order to strategically plan the use of data for different types of analysis, the database has been divided into different groups that ultimately result in the creation of different data matrices. Each of these data matrices has been embedded in one another as the minimal the subset where the most detailed data is available can also be used for analyses that do not require that data. The database has been subdivided into three groups, namely 1) Vegetation plots with only vegetation data, environmental data not complete, 2) Vegetation plots with complete environmental data available, and 3) Vegetation plots with environmental data as well as soil data available. These three categories are shown in Figure 2.1 together with the number of plots that fall into that category in the database.

Table 2.3 Environmental variables from the original dataform that have been included in the analyses with the abbreviations used in subsequent chapters. Variables such as Soil_texture and Organic matter have been left out when exact measurements are available.

Variable	**Measurement / Assessment**	**Abbreviation**
HGM_Type	Categorized as the following (Following Ollis et al. 2009): Depression (includes Flat) Valley bottom with channel Valley bottom without channel Seepage(includes Slope and Valleyhead) Floodplain Channel (includes riverbank)	 Depression VB_wc VB Seepage Fldplain Channel
Wetness	Index from 1 to 6 (see Sieben 2010)	Wetness
Inundation	Assessed in cm	Inundation
Altitude	From GPS or Google Earth (in m)	Altitude
Slope	Assessed in degrees	Slope
Topography	Categorized following Ollis et al. (2009) as: Floor Slope Bench Foot	 Floor Hillslope Bench Foot
Soil_texture	Assessed from field by touch Categorized as: Sand Clay Loam Peat Silt Gravel	 Sand Clay Loam Peat Silt Gravel
Soil_depth	Soil augering, categorized into two categories: Soils deep (> 50 cm) Soils shallow (< 50 cm)	 Soil_dp Soil_sh
Organic	Index for assessment of organic matter in top soil (upper 10 cm) (see Sieben 2010), 1 for greyish or reddish mineral soils, 2 for black or brown mineral soils, 3 for peaty soils.	Organic
Landscape	Context of larger landscape, categorized in categories: Natural Rural Urban	 Natural Rural Urban

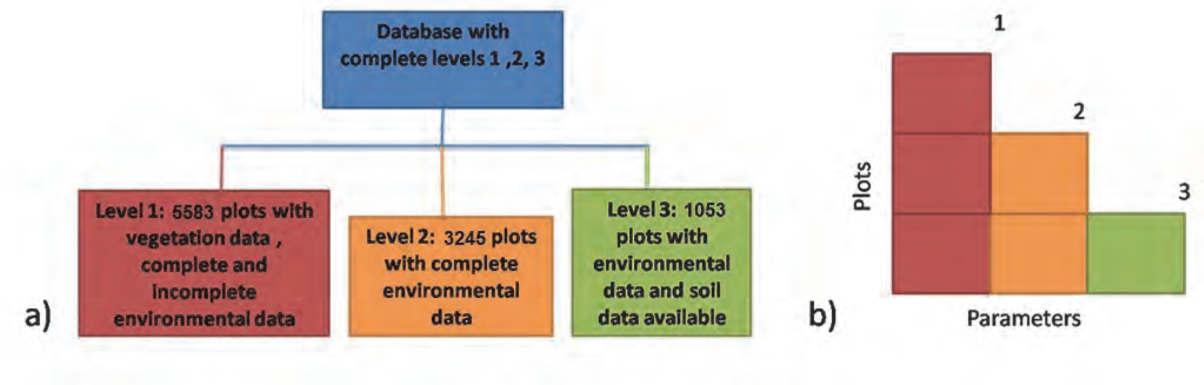


Figure 2.1 Availability of vegetation data in three different categories of data resolution in the National Wetlands vegetation database a) The three different data matrices that can be subtracted from the central database b) Diagram showing how the three matrices are embedded within one another, in terms of the number of variables (parameters) per plot.

In order to make the large amounts of data workable a further subdivision in the dataset has been carried out with the help of the Programme JUICE (Tichý et al. 2002). This classification is tentative but the Programme JUICE provides a good overview of all vegetation plots so that a good idea can be developed which plots are comparable and therefore can be combined in subsequent analysis. This category has been referred to as 'Main Clusters' and the following eight Main Clusters have been recognized. The names of these Main Clusters form the names of the subsections of the results chapter.

The Main Clusters are:
Main Cluster 1: Sclerophyllous Wetland Vegetation
Main Cluster 2: Swamp Forest
Main Cluster 3: Subtropical Wetland Vegetation
Main Cluster 4: Estuarine, Brackish, and Saline Wetland Vegetation
Main Cluster 5: Montane Grassy Wetland Vegetation
Main Cluster 6: Temperate Grassy Wetland Vegetation
Main Cluster 7: Short Lawn Grassy Wetland Vegetation
Main Cluster 8: Hydrophytic Vegetation

2.3 Statistical packages and tools

The extraction of useful information from a large database such as the National Wetlands Vegetation Database is facilitated by the use of multivariate statistical techniques. Multivariate analysis consists of a range of techniques based on matrix algebra and that have become more easily accessible by the increase in computing power of modern computers. The use of multivariate analysis in ecology provides effective ways to summarize and communicate the general patterns in the data and it can lead to a proper interpretation of the trends which facilitates the understanding of the factors that influence ecological systems. Additionally, after an initial exploration of the data, multivariate techniques may direct future research by generating new hypotheses and by focusing the attention of a researcher on particular environmental factors that may affect ecosystems in complex ways (Legendre & Legendre 2012). The various statistical techniques that were used to analyze the wetlands vegetation database are presented in the sections below and are available through the package PC-Ord (McCune & Grace 2002) and HyperNiche (McCune & Mefford 2009). The algorithms of these packages are presented in Appendix C.

The initial storage facility of the National Wetland Vegetation Database used for analysis is the programme TURBOVEG (Hennekens & Schaminée 2001). TURBOVEG is a database management system that can be used for storage, selection, import and export of vegetation data (relevés) facilitated by the presence of an overall species list for the region (Hennekens & Schaminée, 2001). In order to partition the data in sizeable datasets, a first partitioning took place in the programme Juice (Tichý 2003). Further analyses for each of the Main Clusters were carried out in PC-Ord version 6 (McCune & Mefford, 2011) and HyperNiche version 2 (McCune & Mefford, 2009). The three methods from PC-Ord that were used for data analysis are classification using hierarchical clustering methods, ordination by means of Canonical Correspondence Analysis (**CCA**), and indicator species analysis (**ISA**). The last method, that was used to obtain species response curves in the programme HyperNiche was Nonparametric Multiplicative Regression (**NPMR**).

All of the above-mentioned methods make use of similarity indices or distance measures that express the similarity or dissimilarity among sample units. There are various types of distance measures, each with their own characteristics. Some of these distance measures are not compatible with negative numbers, and other measures assume that the data are fractions ranging between zero and one (McCune & Grace 2002). In the analyses throughout this study the Sorensen (Bray-Curtis) similarity index is the main index measure that was used to compare groups of communities. The Sorensen (Bray-Curtis) similarity index is recommended because it works well with binary (0/1) data as well as quantitative data (McCune & Grace 2002). The similarity indices are calculated for all pairs of variables, creating a similarity matrix that can then be used for all subsequent analyses.

2.3.1 Classification: Cluster analysis

The aim of classification methods is to identify and group plots/samples that share common properties into clusters, for example clusters of plots with similar species composition in the case of vegetation plots. There are various types of clustering methods: some use divisive methods and work from the total number of objects down by dividing the datasets in groups at every step, whereas others use agglomerative methods by working from the individual objects up by grouping similar objects together at every step so that these groups grow in the process. In this research project, the method of classification that was employed was a hierarchical agglomerative method (Peck 2010). This is a bottom-up classification where the algorithm treats each sample unit as a single cluster and then joins similar individuals together in one branch of a dendrogram and then continue through the procedure as a combined plot/cluster until all clusters are combined in the end (Kent & Coker 1992; McCune & Grace 2002). This means that similar units end up close to each other (on the same main branch of the dendrogram) and dissimilar units end up far apart. The similarity index used in the current study was Sorensen’s similarity index and the linkage method that was used was Ward’s method.

2.3.2 Ordination: General

Ordination refers to a procedure used to summarize the variation in a dataset by organizing vegetation plots in multivariate space and projecting that ordering in a limited number of dimensions so that it can be visualized. In this projection the most similar plots, according to the distance measure that was utilized, end up in close proximity to each other while dissimilar plots end up on other sides of the ordination diagram. There are various methods for ordination in existence but they can generally be split into the two groups: ordinary methods and canonical methods. In ordinary ordination the interpretation of environmental gradients is done indirectly as the ordering of plots only considers plot data (vegetation composition data or response data) while arranging plots along a gradient, so the interpretation of how species composition correlates with environmental variables or environmental gradients has to be done afterwards, indirectly, by the vegetation scientist. In canonical ordination, the environmental variables are taken into consideration by combining the concepts of ordination with regression, in a manner in which ordinations of the response variable (species composition) is constrained to be a linear combination of vectors from the matrix of explanatory variables (the environmental variables). With the data analysis of wetland vegetation in South Africa, two methods were considered, namely Non-Metric Multidimensional scaling (NMDS), an ordinary ordination method and Canonical Correspondence Analysis, a canonical method. In the end, the Canonical Correspondence Analysis was the only method applied, since NMDS did not result in stable solutions for all datasets and the impact of explanatory variables was also considered particularly important in the project, considering the research questions at hand.

Canonical Correspondence Analysis (CCA)

Canonical Correspondence Analysis was first developed by Ter Braak (1987) and first implemented in the programme CANOCO (Ter Braak & šmilauer 2002), which was also used in this project. It is based on the canonical version of an ordination method that is called Correspondence Analysis, in which each axis of ordination is constructed as a linear combination of the environmental variables that are supplied.

Hereby, the matrix of response variables is stated as Y (vegetation composition) and the matrix of explanatory variables as X.

Although the calculation of Canonical Correspondence Analysis is a complex procedure that requires specialist software, the ordination diagrams are often straightforward to interpret and help in understanding the difference between plots that have been allocated to different plant communities.

2.3.3 Indicator Species Analysis

Statistical methods have been developed to determine statistical indicators that express species' indicator value for a particular cluster and the most important method in that regard is Indicator Species Analysis (ISA, Dufrêne & Legendre 1997).

The statistical indicators in this method are based on information on the frequency of species occurrence in a given cluster and the faithfulness of that species to that particular cluster (McCune & Grace 2002). When an indicator species in a particular group is perfect, it should always be present in that group and never be present in any other group. Dufrêne and Legendre's (1997) Iindicator Species Analysis produces indicator values for each species in each group, relative to what would be a perfect indicator. The significance of this indicator value is tested by means of a Monte Carlo permutation procedure. Indicator species can be used to contrast the performance of an individual species among different clusters of sample units (McCune & Grace 2002). Additionally, it is also used as a criterion to decide on the number of groups that should be chosen in agglomerative hierarchical cluster analysis.

2.3.4 Species response curves

When both species abundance and environmental variables have been recorded in the field, the response curve of such species to that environmental variable provides important information for environmental monitoring, as it can help predict what will happen to the abundance of that species if certain environmental changes take place, and if certain changes in community composition take place, it can be reasoned backwards which environmental factors may have been the cause of such changes. In such ecological models, where the response variable (abundance of a species) is explained as a function of an explanatory variable (environmental variable), it needs to be taken into account that the absence of a species (response variable = 0) does not necessarily mean that the environment is not suited for that species, as presence of a species is also restricted by dispersal.

Species response curves do not always resemble normal bell-shaped curves, even though much of ecological modelling is based on that assumption (Austin 1987). In most cases where a variable is modelled as a function of another variable in a flexible and dynamic way, Generalized Linear Models (GLM) and Generalized Additive Models (GAM) are used to find the best model that explains the correlation function between the two variables. The programme HyperNiche uses another type of habitat model that is built on the basis of the environmental variables that are provided. The regression method that is used in Hyperniche to build these habitat models is Non-parametric Multiplicative Regression models (NPMR, McCune 2009). NPMR can be regarded as a form of Generalized Additive Modelling where a single term using multiplicative weights for all predictors is used. It is therefore particularly well adjusted to explore interactions between environmental factors.

2.4 Research procedure

In this section, the following will be discussed: which of the techniques discussed above have been employed, in which order and which criteria have been used to make decisions about where to go next with data analysis. It will also be shortly discussed how the results section in chapter 3 will be reported and some common conventions will be discussed.

Not all analyses have been carried out on all data, as not all data plots have the same amount of data available, given that the vegetation plots come from a variety of sources. The subdivision of the overall database into three main components on the basis of differences in data resolution (Figure 2.1) is an important first consideration as the researcher will have to use a subset of the overall dataset in order to answer specific questions. It also means that not all questions can be answered for all recognized vegetation types. The outcomes of one type of analysis may inform decisions on the next analysis as well.

For each of the eight Main Clusters as they have been defined in paragraph 2.2, a complete data matrix for both environmental data and species data was made. Subsequently, this dataset has been altered to represent the three levels of data resolution by removing plots that do not have certain environmental data available and by adding that environmental data for those plots that do have it available. In most cases this means also that species will have to be removed from the species data matrix.

Classification by means of hierarchical cluster analysis is the first step and it is best carried out including as large a dataset as possible, so all plots, including those that have incomplete environmental data are included. However, in some cases, particularly when data is not strictly comparable (for example, because of a very different plot size - or in case a

different cover-abundance scale was used) large sections of data have been removed from the dataset.
The final dataset that is decided upon after cleaning out outliers or moving them to another Main Cluster is subjected to hierarchical cluster analysis. The optimal number of clusters is decided by Indicator Species Analysis, which informs that by minimizing the average p-value for all indicator species. For this reason, several cluster analyses have been carried out, with various numbers of clusters. Usually, one cluster, or in some cases more than one cluster, contains a mixture of plots that are clearly different from each other and that can be regarded as outliers. These clusters have then been subjected to a separate cluster analysis, in which they have often been clustered together in much smaller groups. These groups are the under-sampled clusters and have been indicated with dummy variables in the overall cluster analysis for the whole Main Cluster in order to emphasize them.
Indicator Species Analysis, which was already carried out to determine the optimal number of clusters, was used to make a table with all the indicator species that can be used to recognize a certain cluster. The significance level of each indicator species is determined by a Monte Carlo permutation test with a 1000 runs. All species with Indicator values of higher than 20% (or between 10 and 20% if IV values higher than 20% are not there) and with significance levels of higher than 95% ($p < 0.05$) have been listed as characterizing communities, following Dufrêne & Legendre (1997). In some cases, there are no indicator species for a specific community and in this case, the dominant species, which is often shared with other communities, is listed in the table as well, however without any statistical indicators. These communities can be regarded as 'rump' communities, which are mostly characterized by the absence of certain indicator species. The dominant species in combination with the most conspicuous indicator species were used to name the plant communities. Most of these species, if they have sufficient occurrences in vegetation plots with the full range of environmental variables available, have been used to determine species response curves.

Ordination by means of NMDS has been abandoned since it could not provide stable solutions for all datasets and therefore it could not be compared across all the clusters. Instead, the focus has rather been on CCA using the programme CANOCO (Ter Braak & šmilauer 2002) since this form of ordination also provides direct information about how environmental factors impact on species composition in the communities. In most cases, ordination has been carried out twice. The first CCA ordination is carried out on the dataset that does contain soil variables, which is a limited section of the dataset, and does not necessarily have all clusters present. The second CCA ordination is carried out on the overall dataset and this ordination is sometimes so big that the dataset needs to be split into several subsets: this has then been done following the ordination diagram so that similar clusters end up in the same ordination diagram. Many of the environmental variables have been log-transformed before being used, but species abundances have been left untransformed. The scaling that is used focuses on inter-species distances and uses a biplot scaling. Nominal variables (variables where each plot is allocated to a certain 'type', or category, such as HGM types or soil types) have been indicated as triangles in the ordination diagram whereas the other variables have been indicated as arrows. After the ordination, the clustering that has resulted from hierarchical cluster analysis is overlaid over the ordination diagram so that plots belonging to the same cluster are indicated by the same symbol in the ordination diagram. The total Inertia and Total Variance Explained have been indicated with each ordination, and an assessment is made as to how complete the environmental information is in the ordination.

Species response curves have been determined for groups of species that often occur together, so that contrasting responses could be easily picked up and changes in community composition can be easily interpreted. The environmental variables that were used in the species response curves are mostly log-transformed (except for altitude, slope, inundation, wetness and pH) and have not been scaled back to their original values as the most important issue in species response curves is to see how species respond relative to one another. The groups of species that were selected were entered into a matrix with their occurrences in those plots where sufficient soil data is available. The Free Search method in Hyperniche was used to create a large number of models, and afterwards the best models with the highest xR^2 value were selected for each species and each number of variables. The most important explanatory variables were selected on the basis of these selected models and then the responses of all species were shown together in the same graph. No interactive effects of several environmental factors combined have been reported here although these effects are certainly known to be common. More detailed analysis and an understanding of biogeochemical processes can elucidate the interactions that environmental factors have and their combined effects on the performance of wetland plants.

In Figure 2.2 a flowchart is shown of all decisions that need to be taken on the basis of these analyses is indicated. This figure serves as a guideline to the analysis for any group of plots coming from the analysis of Main Clusters.

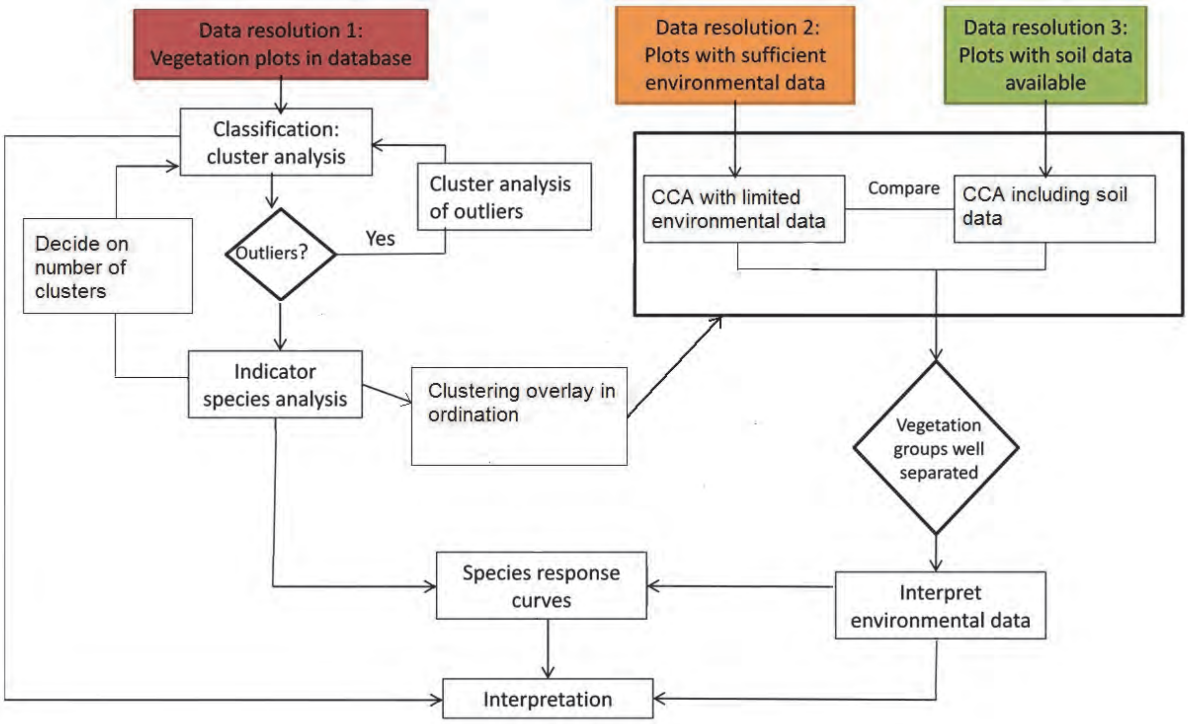


Figure 2.2. Flowchart and decision criteria guiding through the methods of analysis that can be used for all analyses carried out on all groups.

3 RESULTS AND DISCUSSION

3.1 Summary of Wetland vegetation classification

The wetland vegetation types have been tentatively subdivided into eight Main Clusters (which align very clearly with the recognized vegetation types of the South African Vegetation Map of Mucina & Rutherford (2006)) which will be used as a guiding principle to present the wetland vegetation types in the coming sections. Each of these Main Clusters has been used as a starting point for subsequent analysis. They have been formed in such a way that a user can easily allocate a new plot to any of these eight clusters and allocation of such a plot to one of the clusters should be unambiguous. However, in nature, sharp borders are very rare and everything grades into one another. What follows are the eight Main Clusters accompanied by a short description and the number of communities within them. The points of contact between the Main Clusters as mentioned below will be highlighted while they are being described.

Main Cluster 1: Sclerophyllous Wetland Vegetation
These are actually the most clearly defined wetland vegetation types as they grow exclusively on sandstone and other extremely nutrient-poor substrates. They are for the main part dominated by species endemic to the Western Cape and are of various growth forms: shrubs, restios, grasses, sedges. Some of these communities extend outside of the Western Cape towards the **Subtropical Wetland Vegetation**, where a certain subsection is also specialized in very nutrient-poor substrates and these communities can be mixed with species from Main Cluster 1.
This Main Cluster has 27 communities described and additionally 3 under-sampled.

Main Cluster 2: Swamp Forest
This is another well-defined vegetation type in South Africa as it is dominated by trees with the herb layer either dominated by ferns, by sedges or largely absent (only in the South of its range is it dominated by grasses). They are mainly restricted to peat habitats on the coastal plains in KwaZulu-Natal, but one type stands out as it occurs in floodplains further inland and is referred to as Riverine Forest. Swamp Forest develops through succession from **Subtropical Wetland Vegetation**, but the Riverine Forest has links both with Subtropical Wetland Vegetation and **Short Lawn Grassy Wetland Vegetation**, which also have types with a sparse cover of trees.
This Main Cluster has 7 communities described.

Main Cluster 3: Subtropical Wetland Vegetation
These are all sedge and grass dominated wetlands in the warm regions of South Africa, largely dominated by C_4 sedges of the genera *Cyperus, Pycreus, Kyllinga, Scleria* and *Rhynchospora*. Many of them occur in peaty substrates and in very wet conditions. There are transitions between Subtropical Wetland Vegetation and **Swamp Forest**, as it can develop in that, and between Subtropical Wetland Vegetation and **Sclerophyllous Wetland Vegetation** as some of the elements from Sclerophyllous Wetland Vegetation are also found in the subtropical wetlands of nutrient-poor substrates. There are also transitions towards **Temperate Grassy Wetland Vegetation** as some of the temperate species do very well in the warmer regions as well, such as *Phragmites*, *Leersia* and *Typha*. At last, there are some

transitions possible towards the **Short Lawn Grassy Wetland Vegetation**, as some of the drier habitats of this type occur on floodplains in subtropical areas.
This Main Cluster has 49 communities described with an additional four under-sampled communities.

Main Cluster 4: Estuarine, Brackish, and Saline Wetland Vegetation
These are all the plant communities from hypersaline, saline and brackish habitats, whether by inundation with sea water, or by evaporation in dry inland climates, and that are dominated by succulent shrubs and grasses, especially of the genus *Sporobolus*. There is only one Main Cluster where there are important transitions with this type, namely the **Short Lawn Grassy Wetland Vegetation**, that also have many species occurring in dry climates and saline conditions, but here the communities are clearly dominated by grasses.
This Main Cluster has 35 communities described, but three of these are actually under-sampled.

Main Cluster 5: Montane Grassy Wetland Vegetation
These are all the plant communities from the higher altitudes, in seepages and at the headwaters of most streams, or found in the foothills of most montane areas, which consist of the Drakensberg, the Eastern Cape mountains, the Mpumalanga escarpment and the KwaZulu-Natal midlands. There are strong transitions between this Main Cluster and the **Temperate Grassy Wetland Vegetation** especially in the foothills of the large mountain chains (where wetlands are usually very common). There are also transitions possible in the Western part of the Drakensberg with **Short Lawn Grassy Wetland Vegetation**.
This Main Cluster has 32 communities described.

Main Cluster 6: Temperate Grassy Wetland Vegetation
These represent the communities from the mesic part of the Highveld and constitute mainly of wetlands with very common species that occur all over the country, the strongest transitions are between these types of vegetation and **Montane Grassy Wetland Vegetation**, as these are also adapted to moist climates, between these types of vegetation and **Subtropical Wetland Vegetation**, as some species are very widespread and enter the subtropical areas as well, and between this community and the **Short Lawn Grassy Wetland Vegetation** as these wetlands grade into the wetlands from the drier areas towards the West and some species such as *Cyperus marginatus* are comfortable in both regions.
This Main Cluster has 25 communities described and additionally there are nine under-sampled communities.

Main Cluster 7: Short Lawn Grassy Wetland Vegetation
These represent grassland communities that experience some form of disturbance during part of the year, mostly in the form of drought, but also intensive grazing, flooding on a floodplain or high fluctuations of the watertable. The vegetation is generally much shorter than that of the communities of the previous Main Cluster and if there is taller vegetation it is generally sparse in cover. They are found mostly in the semi-arid areas on the edge of the Karoo, in the Western Cape, and in floodplains in subtropical regions. There are many connections with other Main Clusters, particularly with the **Temperate Grassy Wetland Vegetation**, that occur in the more moist regions where there is less disturbance, the **Subtropical Wetland Vegetation**, that have some species in common on floodplains in the warmer regions, the **Estuarine, Brackish and Saline Wetland Vegetation** that often grade

in with these wetlands in saline conditions, and even with **Swamp Forests**, as some wooded grasslands in subtropical floodplains grade into Riverine Forests. At last, in the drier mountains of the Eastern Cape, Short Lawn Grassy Wetland Vegetation can grade into **Montane Grassy Wetland Vegetation**.

This Main Cluster has 54 communities described and an additional four under-sampled ones.

Main Cluster 8: Hydrophytic Vegetation

This Main Cluster represents the hydrophytic (submerged or floating) vegetation in deeper pools, which are generally too deep for emergent sedges and grasses. Here species require special adaptations to the aquatic environment, such as diffusion of nutrients from the water, a lack of a cuticle, a lack of support structures, pollination and dispersal through water. This Main Cluster is on the one hand the most distinct, whereas on the other hand it can share species with nearly any of the previous clusters, especially the wetter communities, such as those from Main Clusters 1, 3 and 6, because it would border them in those places where pools are found in a wetland. Most emergent species that end up standing in open water are however clearly occasional occurrences and not a significant part of the deep water zone of a wetland.

This Main Cluster has 20 communities described, but four of these are actually under-sampled.

When the term 'under-sampled' is used in the text below, it can mean one of two things: either a community has less than four plots because of its overall rarity, or otherwise, the clustering algorithm did not recognize the community as standing on its own and combined it with several other under-sampled communities. This happened mainly in Main Cluster 6 and these communities are described in detail there.

The rest of this chapter deals with the detailed description of the different Main Clusters. Each section first deals with the classification, then ordination, species response curves, followed by general descriptions of communities and an overall conclusion.

Each chapter contains four types of figures and tables, for which the general explanation will be given here. Firstly, there are dendrograms, which show the similarities between the different communities based on species cover/abundance values. The dendrograms are scaled by Wishart's (1969) objective function, expressed as the percentage of information remaining at each level of grouping (McCune & Grace 2002). The numbering in the dendrogram can be used as a subscript under the number of the Main Cluster and this is how communities are referred to in the text. Each community is indicated with that number as well as the number of plots in each cluster between brackets.

Secondly, there are tables listing the communities with their indicator species that can be used for identifying plant communities on the basis of dominant species and indicator species. For each species, the observed maximum indicator value (IV) is given together with the p-value for Monte Carlo randomization tests with 1000 permutations. In general, only those species that are statistically significant ($p<0.05$) and with an IV of higher than 20% are listed, except where there are no species with IV values of higher than 20%.

Thirdly, there are CCA ordination diagrams, which use symbols for each individual community, which consist of the number of the Main Cluster combined with the number in the dendrograms. In some cases, the names of communities are abbreviated. In general, only the first two axes are indicated except in some diagrams for Main Cluster 1 where the third and forth axis were useful in the ecological interpretation. In many cases, ordination diagrams will be displayed both for the datasets including soil data as well as for the entire dataset containing only the most basic environmental data. In the first case, several communities may not be present in the diagram as soil data is not available for them.

Lastly, there are species response curves, which indicate response curves from NPMR for the most important environmental variables for a selected group of species. Absolute values for environmental variables are not given here (and are often on a logarithmic scale) as only the relative abundance compared to species with a similar niche plays a role when using indicator species in environmental monitoring.

For a full explanation of the abbreviations of environmental variables utilised in the ordinations and Species response curves, the reader is referred to Tables 2.2 and 2.3.

3.2 Main Cluster 1: Sclerophyllous Wetland Vegetation

This first Main Cluster represents the wetlands on extremely nutrient-poor substrates of the Table Mountain Group Sandstones and it is mostly dominated by shrubs, restios and tough sclerophyllous grasses or sedges. A few communities from this Main Cluster are also found far outside of the actual Fynbos Biome on similar nutrient-poor substrates in the Eastern Cape (Msikaba Sandstone Formation) and Limpopo (various rock formations in the Waterberg, Wolkberg and Soutpansberg) which shows that many wetland plant species may be much more flexible in their dispersal than the plants from the surrounding uplands. To a large extent, the montane wetlands in the Western Cape have been ignored and it is expected that much more diversity is to be found here and it may require a separate study to supplement the database here. Many of these wetlands occur in seepage zones in the mountains, which are common in the sandstone substrate and substrates are generally sandy or occasionally peaty. In the lowlands, the database seems to be more complete although more samples are certainly desired, since these are quite unique wetland vegetation types.

Mucina & Rutherford (2006) describe two types of azonal vegetation that largely fit in with this Main Cluster, namely Cape Lowland Freshwater Wetlands (AZf1) and Fynbos riparian vegetation (Aza1). Many wetlands in this cluster are however associated with rivers and riparian vegetation and wetlands often share many species (for example *Prionium serratum* (Palmiet) and *Cliffortia strobilifera*), so a more detailed look at the actual plant communities may reveal that there would be actually quite some overlap between the two types described by Mucina & Rutherford (2006).

Further work is required in this cluster, especially in the Western Cape Mountains, and many vegetation types in this cluster have a narrow distribution and contain rare and endemic species. Taxonomical problems that may be encountered during research in these wetlands can be expected particularly among the Restionaceae and the Ericaceae which are particularly species-rich in these wetlands, although Ericaceae is not often dominant. On a plot-basis however, these wetlands are not particularly species-rich, especially when compared to the upland fynbos.

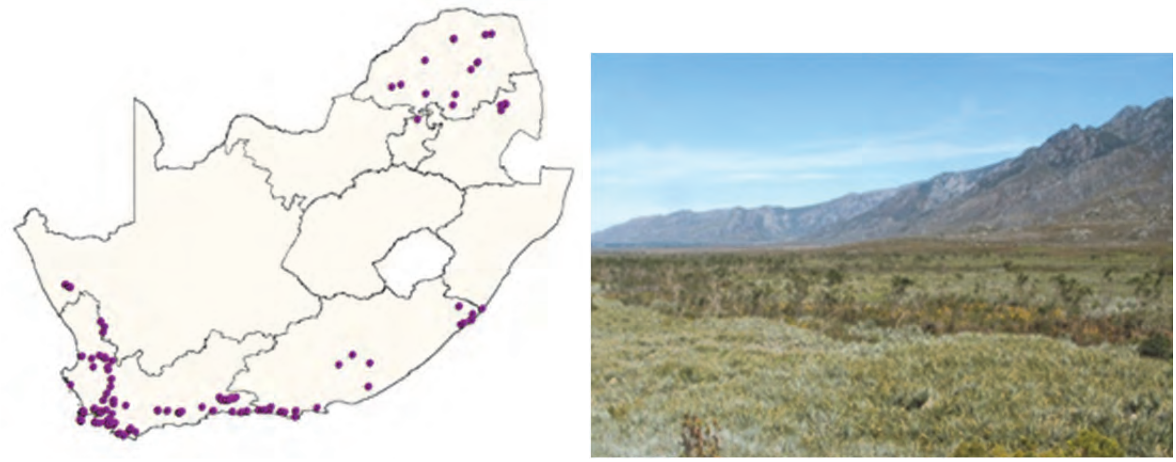


Figure 3.1 Distribution of Sclerophyllous Wetland Vegetation and a picture illustrating an example of a wetland with such vegetation near Theewaterskloof Dam.

3.2.1 Classification and Indicator Species Analysis

The data analysis from the Sclerophyllous Wetland Vegetation is based on 321 vegetation plots and 700 plant species. A hierarchical cluster analysis using indicator species to determine the optimal number of clusters produced 30 clusters, three of which represented by only two plots each and so should be regarded as under-sampled (Figure 3.2). These under-sampled communities and four other communities can be regarded as communities belonging specifically to mountain Sclerophyllous Wetland Vegetation and the wetlands in the Western Cape Mountains still require more sampling. Indicator species analysis shows clear indicator species for most communities, except for two (Communities 1.16 and 1.23). Community 1.16 is probably heterogeneous as it represents Mountain Fynbos which is largely under-sampled and the community is mostly centred on a study of springs in the Kamanassie Mountains (Cleaver et al. 2004). Community 1.23 is dominated by a species which is mostly shared with community 1.24 and also quite common in other Western Cape wetlands, so the species *Pennisetum macrourum* did not come out as an indicator species, but Community 1.23 can be recognized by it being dominant.

Most plant communities in this cluster can be recognized by a single indicator species, which happens to be the dominant as well, which reveals that these wetlands are generally relatively species-poor on a plot-basis, as compared with the upland vegetation which is covered by extremely species-rich fynbos vegetation.

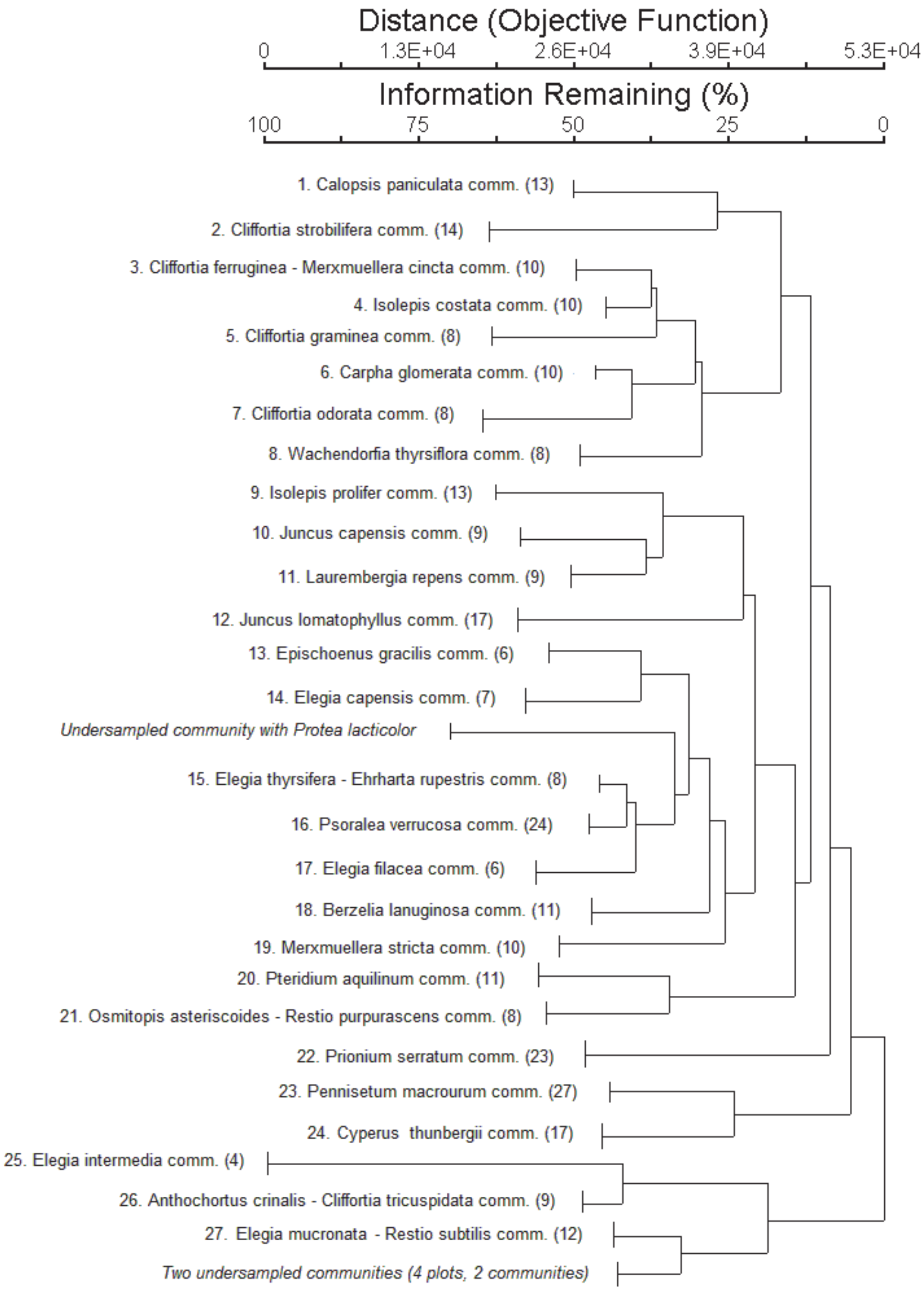


Figure 3.2 Cluster dendrogram for vegetation types of Sclerophyllous Wetland Vegetation.

Table 3.1 Communities of Sclerophyllous Wetland Vegetation (Main Cluster 1) with their indicator species.

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
1	13	*Calopsis paniculata*	Western Cape, Eastern Cape	*Calopsis paniculata*	36.7	0.001
2	14	*Cliffortia strobilifera*	Western Cape, Limpopo	*Cliffortia strobilifera*	42.1	0.001
3	10	*Merxmuellera cincta, Cliffortia ferruginea*	Southern Cape	*Cliffortia ferruginea*	41.7	0.007
				Merxmuellera cincta	25.7	0.006
4	10	*Isolepis costata*	Southern Cape	*Isolepis costata*	28.6	0.015
				Thelypteris confluens	24.9	0.008
5	8	*Cliffortia graminea*	Southern Cape	*Cliffortia graminea*	59.8	0.001
6	10	*Carpha glomerata*	Southern Cape	*Carpha glomerata*	29.5	0.002
7	8	*Cliffortia odorata*	Southern Cape	*Cliffortia odorata*	79.1	0.001
8	8	*Wachendorfia thyrsiflora*	Southern Cape	*Wachendorfia thyrsiflora*	39.6	0.005
				Senecio rigidus	36	0.008
				Ursinia species	25	0.042
				Panicum subalbidum	25	0.047
9	13	*Isolepis prolifer*	Western Cape	*Isolepis prolifer*	70	0.001
10	9	*Juncus capensis*	Western Cape, Eastern Cape	*Juncus capensis*	39.3	0.001
11	9	*Laurembergia repens*	W Cape, E Cape, Limpopo	*Isolepis inyangensis*	44.4	0.001
				Laurembergia repens	35	0.002
				Fuirena species	22.2	0.037
				Hypericum lalandii	22.2	0.043
				Plecostachys serpyllifolia	27.1	0.049
12	17	*Juncus lomatophyllus*	W Cape, E Cape, Limpopo	*Juncus lomatophyllus*	52.2	0.001
13	6	*Epischoenus gracilis*	Western Cape	*Epichoenus gracilis*	56.9	0.001
				Oxalis eckloniana	44.4	0.004
14	7	*Elegia capensis*	Western Cape	*Elegia capensis*	61.2	0.003
15	8	*Elegia thyrsifera, Elegia neesii*	Western Cape	*Ehrharta rupestis* ssp. *tricostata*	25	0.045
				Tetraria fimbriolata	25	0.05
16	24	No dominants, *Psoralea verrucosa*	Kamanassie, WC Mountains	-		
17	6	*Elegia filacea*	Western Cape, Southern Cape	*Elegia filacea*	75.7	0.001
				Elegia cuspidata	66.7	0.001
				Cliffortia subsetacea	50	0.001
				Restio distichus	50	0.001
				Diastella divaricata	33.3	0.041
				Bobartia indica	33.3	0.042
				Tetraria fasciata	33.3	0.042
				Erica laeta	30.8	0.033
				Erica bruniades	28.2	0.05
				Oxalis depressa	26.4	0.019

Table 3.1 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
18	11	*Berzelia lanuginosa*	Western Cape coast	*Berzelia lanigunosa*	51.5	0.002
				Erica colorans	27.3	0.044
				Ficinia capitella	27.3	0.046
				Tetraria cuspidata	23.7	0.015
19	10	*Merxmuellera stricta*	Western Cape	*Merxmuellera stricta*	96.8	0.001
20	11	*Pteridium aquilinum*	W Cape, Limpopo	*Pteridum aquilinum*	39.4	0.001
21	8	*Osmitopsis asteriscoides, Restio purpurascens*	Western Cape	*Osmitopsis asteriscoides*	85.9	0.001
				Erica fontana	37.5	0.033
				Elegia fenestrata	25	0.048
				Berzelia abrotanoides	22.1	0.011
				Cassytha ciliolata	20.9	0.046
22	23	*Prionium serratum*	Western Cape, Pondoland	*Prionium serratum*	75.5	0.001
23	27	*Pennisetum macrourum*	W Cape, E Cape, Limpopo	-		
24	17	*Cyperus thunbergii*	Western and Eastern Cape	*Cyperus thunbergii*	80.8	0.001
25	4	*Elegia intermedia*	Hottentots Holland	*Elegia intermedia*	82.9	0.001
				Campylopus stenopelma	32.8	0.02
26	9	*Anthochortus crinalis*	Hottentots Holland	*Cliffortia tricuspidata*	53	0.002
				Ficinia argyropa	50.7	0.003
				Anthochortus crinalis	30.2	0.014
				Ehrharta setacea ssp. *setacea*	26.3	0.015
				Epischoenus villosus	24.6	0.019
27	12	*Elegia mucronata*	Hottentots Holland	*Restio subtilis*	59.4	0.002
				Elegia mucronata	46.2	0.01
				Chrysitrix junciformis	36.9	0.002
				Erica intervallaris	35.8	0.013
				Tetraria capillacea	26.4	0.012
Add. 1	2	*Protea lacticolor*	Mountains ?	*Protea lacticolor*	100	0.001
				Restio perplexus	100	0.001
Add. 2	2	*Cliffortia ovalis, Erica autumnalis*	Mountains ?	*Aristea bakeri*	100	0.001
				Aster species	100	0.001
				Cliffortia ovalis	92.3	0.001
				Erica autumnalis	80	0.001
Add. 3	2	*Berzelia alopecuroides, Berzelia squarrosa*	Mountains ?	*Adenandra acuta*	100	0.001
				Erica sitiens	100	0.001
				Gnidia galpinii	100	0.001
				Brunia alopecuroides	88.2	0.002
				Berzelia squarrosa	85	0.001
				Stoebe cinerea	84.2	0.001
				Clutia polygonoides	82.2	0.001
				Erica fastigiata	81.4	0.001
				Erica coccinea	80	0.001

3.2.2 Canonical ordination

Canonical Correspondence Analysis was carried out twice, once on the portion of the dataset that included soil variables and subsequently on the entire dataset, with a much more limited set of possible explanatory variables. This is a small Main Cluster but due to its uniqueness it was regarded as relevant to collect many soil samples, so the dataset including the soil variables was carried out on a data matrix containing 81 vegetation plots and 315 species. Surprisingly, these 81 plots represent nearly all the plant communities (24 of them, all except the montane communities 1.25, 1.26 and 1.27) although a large number (nine) of them were only represented by a single plot (1.5 *Cliffortia graminea-Merxmuellera cincta* Community, 1.6 *Carpha glomerata* Community, 1.7 *Cliffortia odorata* Community, 1.8 *Wachendorfia thyrsiflora* Community, 1.13 *Epischoenus gracilis* Community, 1.15 *Elegia thyrsifera-Ehrharta rupestris* community, 1.16 *Psoralea verrucosa* Community, 1.17 *Elegia filacea* Community and 1.24 *Cyperus thunbergii* Community)

The CCA analysis including soil data produces an ordination with a Total Inertia of 30.34 whereas the sum of all canonical eigenvalues is 11.07, so about one third of the variation is explained by the explanatory variables that are provided.

The first axis is mostly correlated with the major cations which are negatively associated with the axis, with nutrient-rich communities on the left. The only nutrient that is not included here is Nitrogen which is barely correlated to any axis. Interestingly, the nutrient concentration seems negatively associated with the clay and silt percentage along this axis, which suggests that it is possible that most plants obtain their nutrients from the groundwater and not so much from the soils, which seem to be very poor even when the clay percentage is high. Another variable that is strongly correlated with the first axis is the number of species, but this is strictly speaking not an explanatory variable. The community that has the highest species numbers are the Palmiet wetlands of community 1.22, but this is mostly due to the plots from the Eastern Cape, particularly Pondoland where this community is particularly rich in species.

The second axis is mostly correlated with altitude and here the picture is distorted by the fact that a small number of communities are found on the Highveld in Limpopo, which represents an entirely different climate. This is mainly Community 1.12, the *Juncus lomatophyllus* Community. Another important variable along this axis is Inundation and this community is also indeed occurring in some of the wettest patches in the wetlands. In this ordination diagram also Wetness and inundation are pointing in opposite direction which is also quite unusual.

The most interesting story however in this ordination can be derived from the third and the fourth axes. The third axis is mostly correlated with Electrical Conductivity and along this axis, percentage clay and the major cations are pointing in more or less the same direction, which is what would be expected. Now a real differentiation between nutrient-poor and 'less nutrient-poor' environments can be made (all wetlands on sandstone substrates are poor in nutrients, but especially along drainage lines it is possible that some nutrients accumulate in nutrient-sinks downstream, so there is still some differentiation possible). It appears that the Communities 1.13, 1.14, 1.15, 1.16, and 1.17 are the most nutrient-poor with the lowest values for Electrical Conductivity, and indeed these are the communities that are most likely to be found in the foothills of sandstone mountains upstream of most other wetlands. Most likely, Communities 1.25, 1.26, 1.27, which are not represented in this ordination diagram, would also be found on the most nutrient-poor part of this ordination diagram. It is interesting to see that also a community such as 1.10, *Juncus capensis* Community is found on the

nutrient-poor extreme of this ordination diagram, even though it is quite common in the lower reaches of Western Cape rivers. The Communities 1.1, 1.2, 1.3, 1.5, 1.7 and 1.8 are typical communities found in the lower reaches of the catchments and they are associated with higher electrical conductivities, as are the pioneer communities of 1.9, 1.11 and 1.12, which are often found in shallow channels that are frequently inundated and where there is an unstable substrate. Communities 1.6, 1.17 and 1.18 are found on intermediate positions of this gradient, but of course more data on more plots would be desirable.
The fourth axis is negatively associated with Nitrogen and positively with pH, two variables that were only very weakly associated with any of the previously axes. The lowest in Nitrogen are Communities 1.15, 1.16 and 1.17 of which the first two are real montane communities but Community 1.17 is still located at relatively low altitudes mostly on sandy soils.

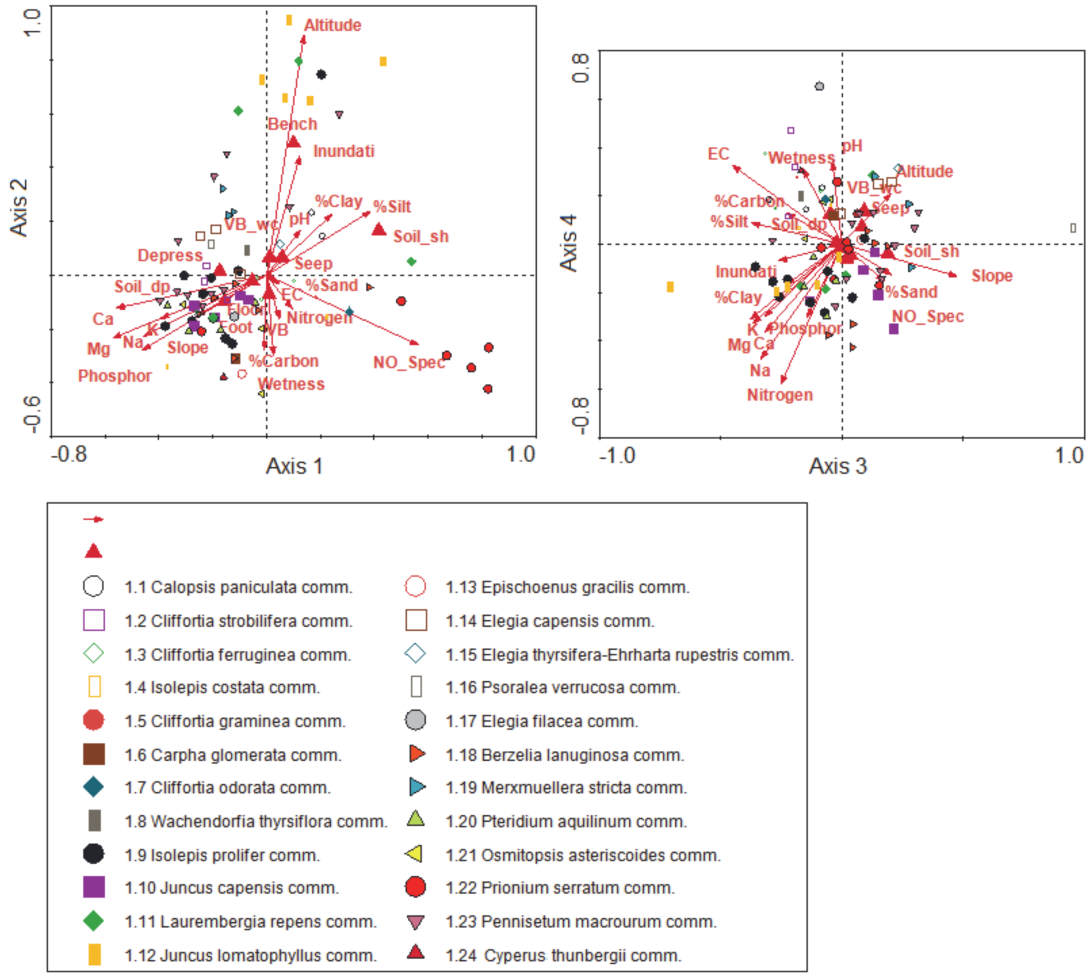


Figure 3.3 Ordination biplots of four axes of the CCA ordination of the Sclerophyllous Wetland Vegetation.

The independent effect of Nitrogen separate from Phosphorus and the major cations is interesting in the nutrient-poor environment of the Western Cape. Nitrogen is quite mobile as Nitrates dissolve readily in water whereas Phosphorus is more immobilized and tied to the rock. It is no surprise that Phosphorus is a major limiting nutrient in the Western Cape wetlands as the sandstone substrate is very poor in Phosphorus, but it is quite possible that there is a differentiation between Nitrate-limited wetlands and Phosphorus-limited wetlands in the Western Cape wetlands, dependent on the place of the wetland in the catchment and the climatic regime (small amounts of Nitrates are also dissolved in rain water). This is certainly an area that requires further investigation.

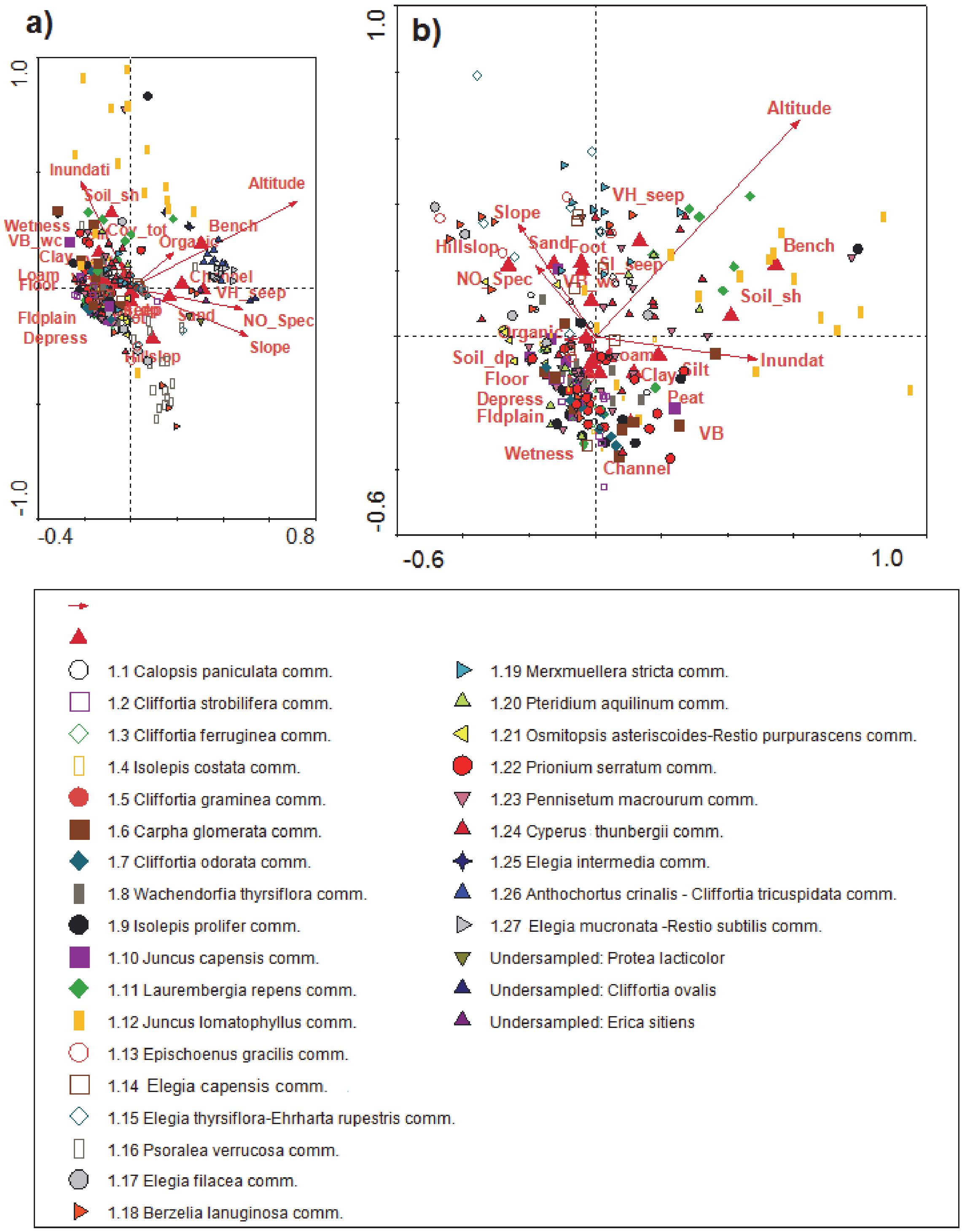


Figure 3.4 Ordination biplot for the first two axes of a CCA ordination. Ordination diagram b) is the result of leaving out Communities 1.16, 1.25, 1.26, 1.27 and the under-sampled communities as they account for most of the outliers in the first ordination diagram.

The second CCA ordination that includes a larger number of plots, namely those that do not have detailed soil data available, does not add much more information except for that the high-altitude Communities 1.25, 1.26 and 1.27 are now included. They also separate out quite well from the other communities as they are found at higher altitudes. All other communities are very densely packed together in the left-hand side of the ordination diagram and therefore it is useful to leave out these high-altitude communities as well as Community 1.16, which are representative of the Western Cape montane wetlands which are worthy of a study in their own right. When they are left out, as shown in Figure 3.4b, not a very clear picture emerges as we could see in Figure 3.3 that most Sclerophyllous Wetland Vegetation separate well only on the basis of variables like Electrical Conductivity, Nitrogen, Phosphorus and the major cations. It is worth conducting a more detailed study on these wetlands as they are among the most unique wetlands in South Africa.

3.2.3 Species response curves

Species response curves indicate how an individual species is distributed along a gradient and they therefore help in interpreting species composition changes. The power of the predictive model for a single species depends on how many times this species was recorded within a plot where soil variables were measured. This is in some cases quite low, but the species was still included even if there is less than 10 datapoints available and the species is regarded as an important indicator species. One important species that is however still quite important, where insufficient data is available, is *Cliffortia strobilifera*, but more data for *Wachendorfia thyrsiflora*, *Cliffortia graminea* and *Cliffortia ferruginea* would also be desirable.

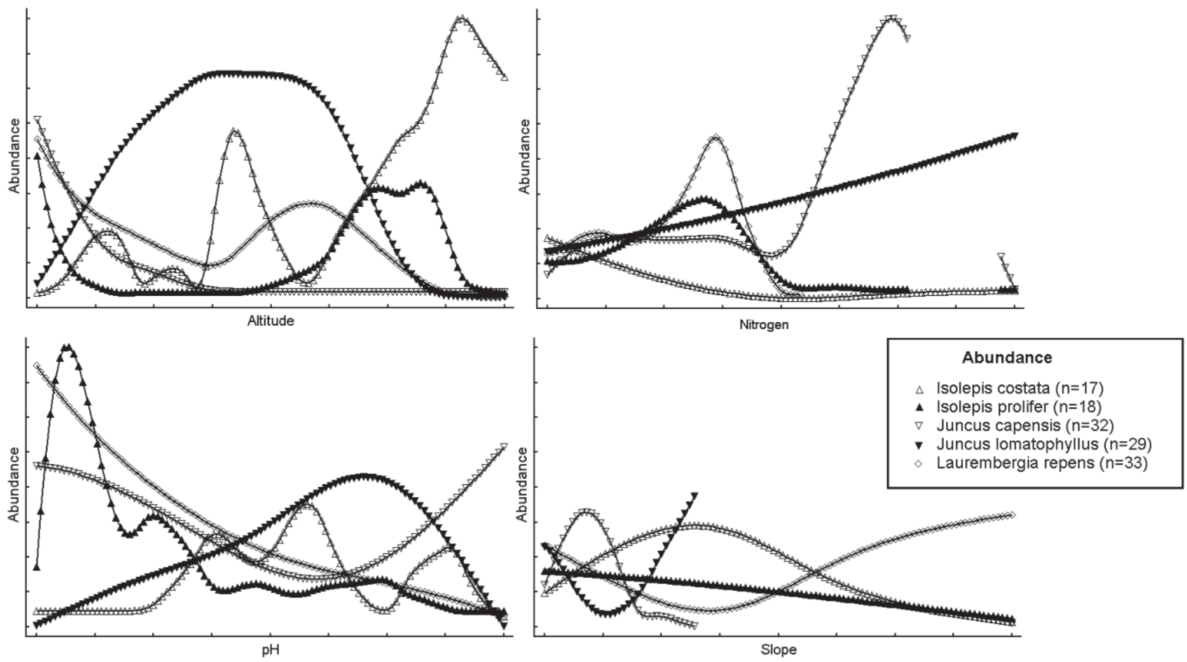


Figure 3.5 Species response for five species occurring under pioneer conditions in Western Cape wetlands, but that are also found in other nutrient-poor substrates elsewhere in the country.

The first species for which species response curves are displayed are the five species that occur in the pioneer Communities 1.4, 1.9, 1.10, 1.11 and 1.12 where each of these species can become dominant. In terms of altitude the response curves are quite complex, but it is only *Isolepis costata* that is still doing well on higher altitudes. Both *Juncus capensis* and *Juncus lomatophyllus* respond positively to an increase in Nitrogen, whereas the other species decrease with Nitrogen. In terms of pH, *Juncus capensis* forms a bit a mirror-image of *Juncus lomatophyllus*, as it has a bimodal response, preferring both low pH values and high pH values, whereas *Juncus lomatophyllus* prefers the intermediate values for pH. In terms of slope, responses are quite weak, but *Laurembergia repens* stands out as a species that still like steep slopes, indicating its preference for seepage zones.

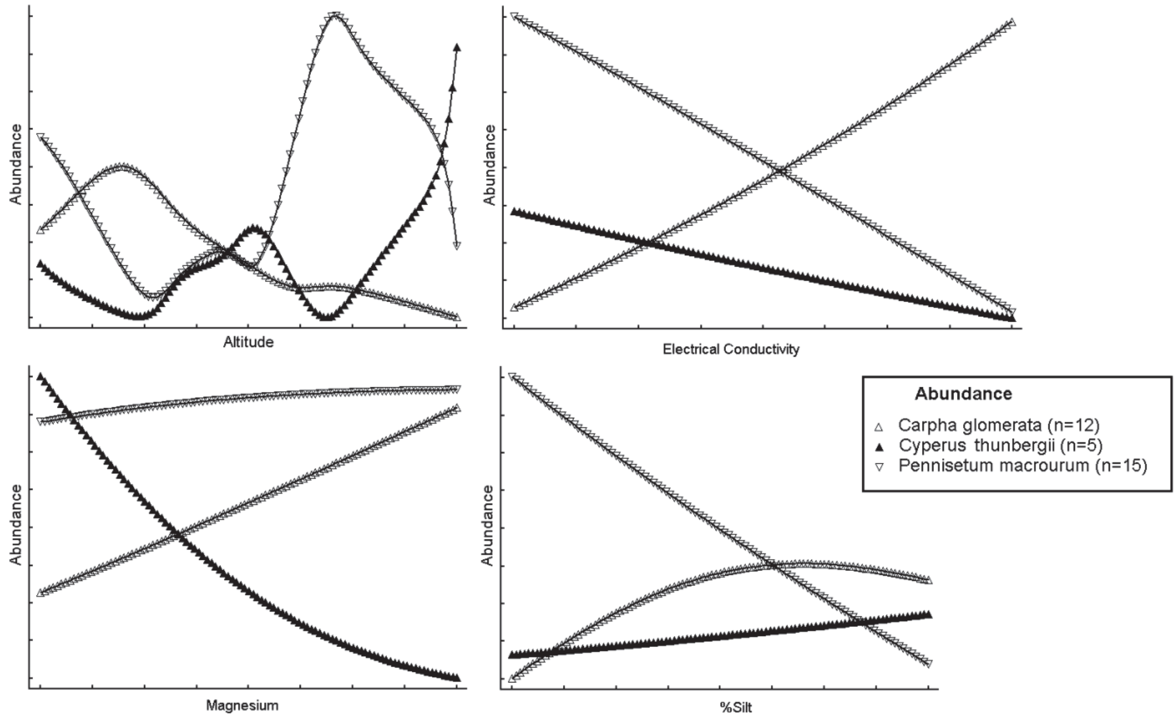


Figure 3.6 Species response curves for three tall grasses and sedges that are common in Sclerophyllous Wetland Vegetation and that sometimes achieve dominance.

The response curves indicated in Figure 3.6 are of two tall sedges and one tall grass, which become dominant in Communities 1.6, 1.23 and 1.24. Of these species, *Cyperus thunbergii* is a bit poorly represented as only five records are included. It is clear that *Carpha glomerata* disappears at the higher altitudes and that *Cyperus thunbergii* becomes the most competitive at high altitudes. *Carpha glomerata* has a positive response to Electrical Conductivity so it is more adapted to the nutrient-rich substrates in the cape lowlands, while the other two species are more adapted to nutrient-poor substrates. *Carpha glomerata* also responds positively to Magnesium concentration, whereas *Pennisetum macrourum* seems quite indifferent to this mineral and *Cyperus thunbergii* responds negatively. *Pennisetum macrourum* is best adapted to an absence of fine-grained particles in the soil which also means it is best adapted to the sandstone-derived soils in the mountains.

The species displayed in Figure 3.7 are important species in Sclerophyllous Wetland Vegetation, although all of them are still slightly under-sampled. They represent the species that become dominant in Communities 1.1, 1.18, and 1.22. All three species become less dominant at higher altitudes, but *Calopsis paniculata* still does quite well at mid-altitudes. The species that does best in situations with a low Magnesium concentration is *Prionium serratum*. In terms of Nitrogen, all three species have very distinct responses, as *Calopsis paniculata* disappears when Nitrogen increases, *Prionium serratum* prefers intermediate Nitrogen levels and *Berzelia lanuginosa* increases with Nitrogen. Please note that this all takes place within a context of the low nutrient substrates of the Table Sandstone Group, so 'high Nitrogen' is only relative. *Calopsis paniculata* prefers the finer substrates with a high silt fraction as compared to the other two species.

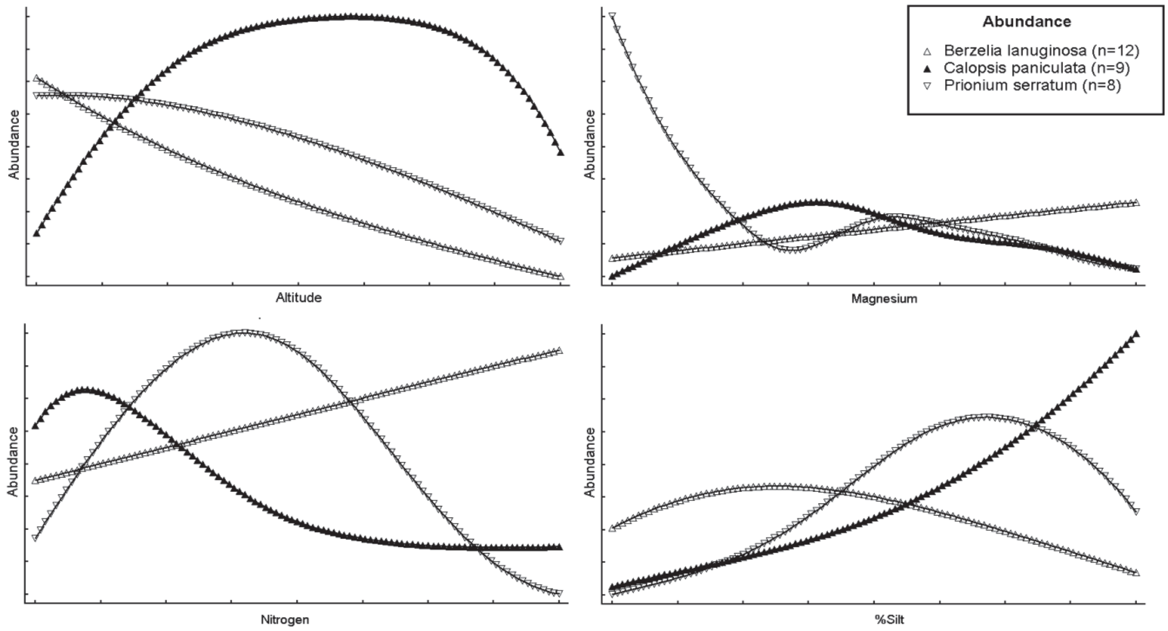


Figure 3.7 Species response curves for three typical fynbos wetland species (one shrub, one restio and a woody sedge).

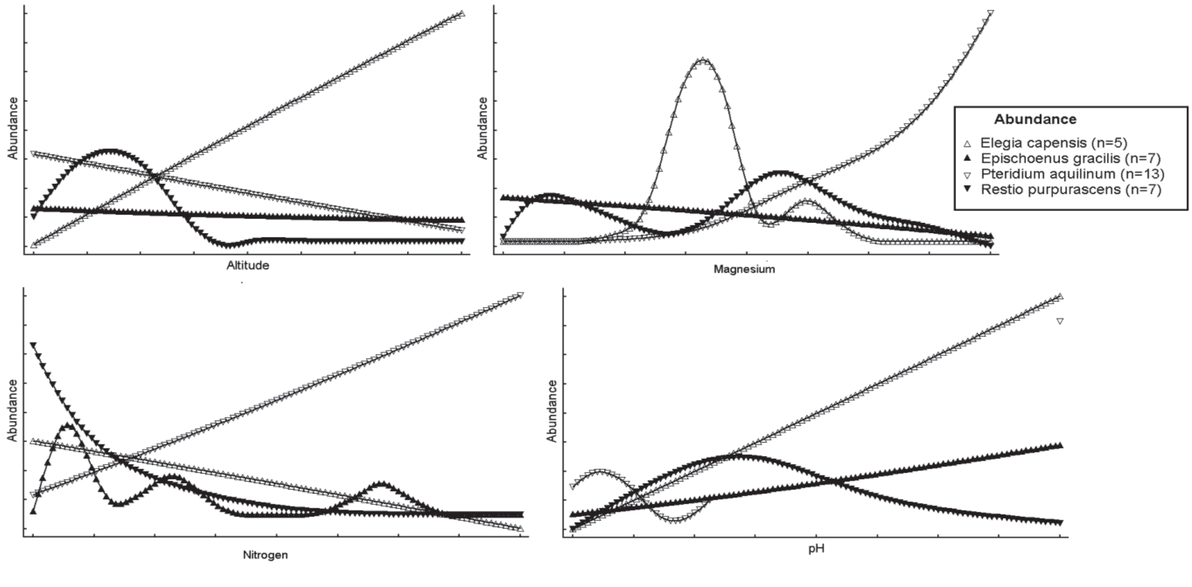


Figure 3.8 Species response curves for four species of Sclerophyllous Wetland Vegetation, among them two restios and bracken fern, which is common outside the Fynbos Biome.

The species displayed in Figure 3.8 represent two restios, a sedge and the bracken fern. This last species is not a typical fynbos species, but curiously, it sometimes becomes dominant in the fynbos in wetlands, whereas in other biomes it is much more terrestrial (less competitive in wetlands). These species become dominant in Communities 1.13, 1.14, 1.20 and 1.21 but in terms of species response curves, they are all (except for the bracken fern) a bit under-sampled, particularly *Elegia capensis*. This species is the only one of the four that prefers the higher altitudes. *Epischoenus gracilis* is a small tuft-forming sedge and it seems quite indifferent to most of these variables, so it is not quite clear what causes its dominance in some communities. Bracken (*Pteridium aquilinum*) is best adapted to nutrient concentrations, both for Nitrogen and Magnesium, whereas the other three, typically for fynbos, are best suited for a nutrient-poor environment (An exception is *Elegia capensis*, which has a small peak at intermediate Magnesium levels). In terms of pH, it is only *Elegia capensis* and *Pteridium aquilinum* which are adapted to slightly alkaline conditions.

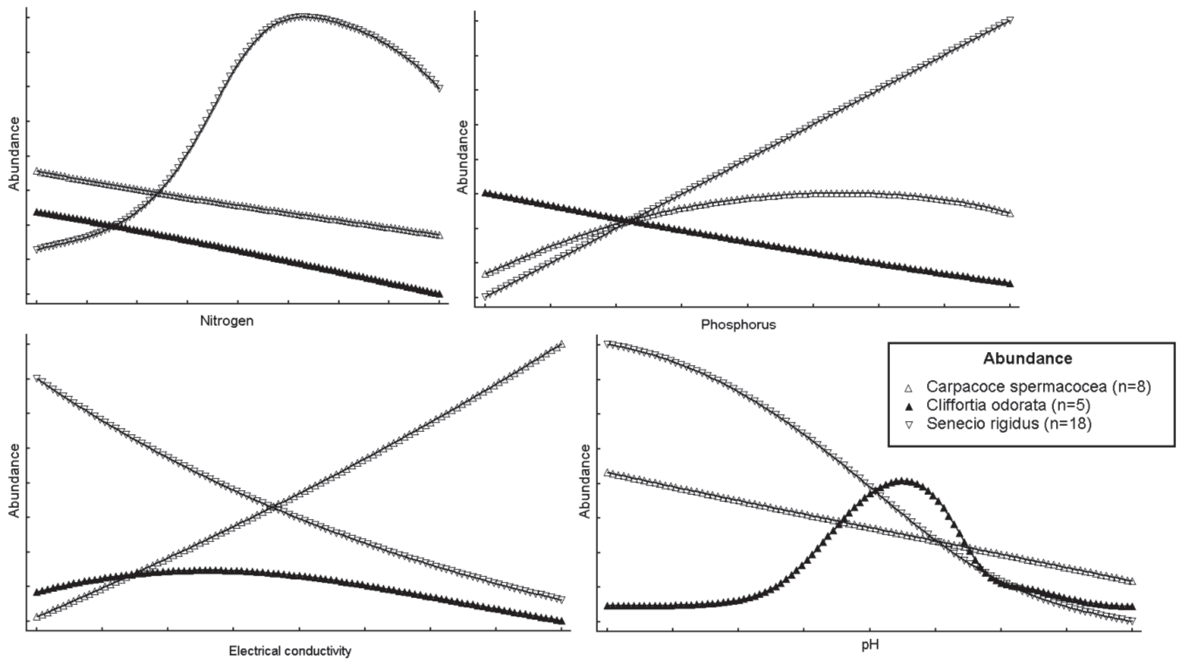


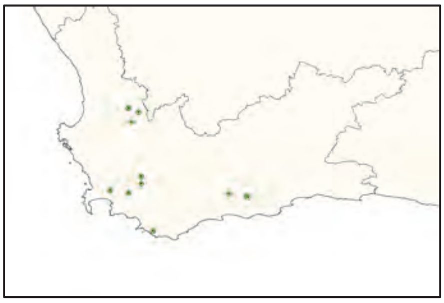
Figure 3.9 Species response curves of three shrubby wetland species in Sclerophyllous Wetland Vegetation, of which only *Cliffortia odorata* forms its own community.

The species in Figure 3.9 are less common in the wetlands of Main Cluster 1 and only *Cliffortia odorata* is an important indicator species (of Community 1.7). However, this species is also quite underrepresented in this dataset. It is clear that *Senecio rigidus*, which is not often dominant in fynbos wetland communities, responds positively to Nitrogen and Phosphorus. This is probably what happened in the Krom River system, where farmers commented that they had never seen this yellow shrub before and it suddenly became dominant, towering over the palmiet (*Prionium serratum*). In terms of Electrical Conductivity, *Senecio rigidus* decreases with more nutrients whereas *Carpacoce spermacocea*, which often co-occurs with several *Cliffortia*-dominated communities in the Southern Cape, increases with higher Electrical Conductivity. Both species decrease with higher pH, whereas *Cliffortia odorata* seems to have a little peak at intermediate pH levels. This may explain its dominance in those cases where it forms its own community.

3.2.4 Description of communities

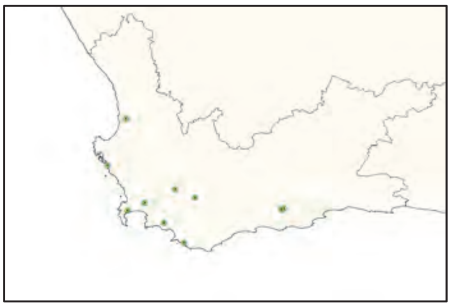
1. *Calopsis paniculata* Community

This is a community commonly associated with riverine wetlands at the foothills of the Western Cape. It can occur both in monocultures as well as mixed with other species. It occurs on relatively fine-grained substrates. It mostly occurs in the Western Cape but it has been recorded in the Southern Cape as well, where it is often also replaced by another restio, *Platycaulos callistachyos* in communities such as Community 1.5 *Cliffortia graminea* Community.



2. *Cliffortia strobilifera* Community

This is another species that is associated with riverine wetlands of the Western Cape. This is a woody shrub that can become quite tall and can in that case also achieve mono-dominance. It is often co-occurring with Palmiet and *Calopsis paniculata*.



3. *Cliffortia ferruginea – Merxmuellera cincta* Community

This community is restricted mainly to the Southern Cape, although the species *Cliffortia ferruginea* in some cases has also been found in the Agulhas plain and even on the Cape flats. This species can become quite weedy and starts dominating quite quickly and it even occurs together with some pioneer species in mown places next to roads in the Eastern Cape. This community might represent actually various communities and it is worth sampling in more detail.

4. *Isolepis costata* Community

The species *Isolepis costata* is one of the most widespread species of this cluster and is also known from the grassland biome.

5. *Cliffortia graminea* Community

This community is very restricted in its distribution but is very common in the wetlands of the Tsitsikamma region, where most wetlands are under pressure from plantation forestry that is often growing right at the edges of the wetlands. The community is rich in species but dominated by the shrubby *Cliffortia graminea* which superficially resembles a grass.

6. *Carpha glomerata* Community

This community is dominated by the tall sedge *Carpha glomerata*, which sometimes nearly occurs as a monodominant species. It is particularly common in the Southern Cape. It grows in seasonally or permanently wet valley bottom wetlands.

7. *Cliffortia odorata* Community

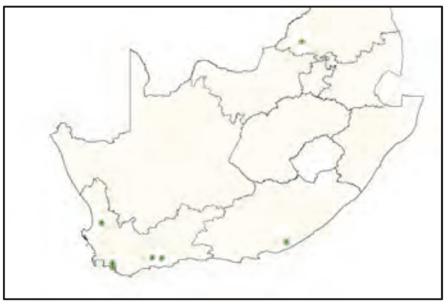
Cliffortia odorata is a conspicuous round-leaved shrub that tends to occur in monocultures as it easily overgrows all other plant species in the community. It is typically associated with rivers, but it does also occur in valley bottom wetlands connected to a drainage network.

8. *Wachendorfia thyrsiflora* Community

This is one of the most attractive of all Sclerophyllous Wetland Vegetation communities as it is dominated by the large yellow flowers of *Wachendorfia thyrsiflora*. It occurs in permanently wet valley bottom wetlands and is particularly common on the Humansdorp plains.

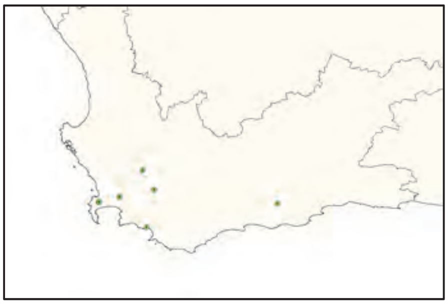
9. *Isolepis prolifer* Community

This is the first of the typical fynbos pioneer communities, that occur on open patches in between the fynbos or areas where streamflow prevents the establishment of larger plants. This community is dominated by *Isolepis prolifer*, a proliferous annual sedge that tends to grow in water of up to 20 cm deep.



10. *Juncus capensis* Community

This is a second pioneer community in the Sclerophyllous Wetland Vegetation but it tends to occur more on drier ground, in places that are only seasonally wet. It is dominated by *Juncus capensis*, a very variable species that tends to occur in quite species-rich communities.

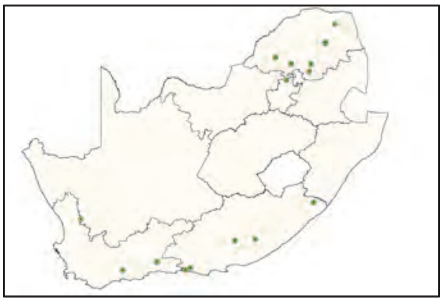


11. *Laurembergia repens* Community

This is a community dominated by the species *Laurembergia repens*, which however has two different subspecies, with subspecies brachypoda occurring in the winter rainfall region as a creeping forb and subspecies repens in the summer rainfall region, which is more erect as a bush. So, even though the two subspecies have been lumped in this case, for the sake of oversight, they are structurally quite distinct from each other. This community represents a pioneer community on wet and unstable substrates.

12. *Juncus lomatophyllus* Community

This is one of the Sclerophyllous Wetland Vegetation communities that are also more widespread outside of the Fynbos Biome. This is due to the fact that *Juncus lomatophyllus*, is more widespread and can be found on nutrient-poor substrates anywhere in the country. It is generally found as a pioneer community on unstable substrates and in the Fynbos it grows in open patches in between the taller fynbos vegetation. It is particularly common in Limpopo Province.



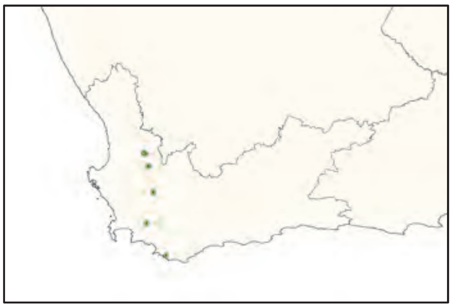
13. *Epischoenus gracilis* Community

This community is dominated by the slender tuft-forming sedge *Epischoenus gracilis*, which is regularly found in Sclerophyllous Wetland Vegetation, but only rarely becomes dominant. In between the tufts this community is still quite rich in species with many fynbos shrubs found in the community.

14. *Elegia capensis* Community

This community is a typical fynbos community, in that it is dominated by

Restios and is typically found along riverine wetlands in the lower mountain reaches in the Cape Fold Mountains. In most cases, the community is very species-poor and it can reach monodominance, which is in stark contrast with the surrounding more drier parts of the landscape. The Restio *Elegia capensis* is a tall species and forms a very distinct growth form with the surrounding vegetation with its typical 'horsetail' shape.



15. *Elegia thyrsifera – Ehrharta rupestris* Community

This community represents a diverse group of fynbos plots that have few characteristics in common, most notably that they occur on sandy soils, are structurally very similar to the surrounding dryland vegetation and have a high species richness, with several species of Restios and Ericas. If more sampling takes place, it may well appear that this actually represents several communities.

16. *Psoralea verrucosa* Community

This community is very diverse and probably heterogeneous, as it mainly consists of very variable plots that were part of a survey of springs in the Kamanassie Mountains, but includes various other montane vegetation plots that have been done during the last few years. It is best to first sample more intensively in the Western Cape Mountains before any conclusions are drawn about these communities.

17. *Elegia filacea* Community

This community is another wetland community that is structurally not distinguishable from the surrounding upland vegetation and represents 'typical fynbos', with a high proportion of dwarf shrubs, various species of Restios and several smaller forbs in between. It is best represented in the Cape of Good Hope Nature Reserve, but it can be found on various other places with deep sands and temporary to seasonal inundation as well, even in the lower parts of the Cape Fold Mountains. It is best recognizable by the abundance of the tussock-forming *Elegia filacea*.

18. *Berzelia lanuginosa* Community

This is a very characteristic fynbos wetland community and it is dominated by tall shrubs (up to 2 meters) of the family Bruniaceae which is one of the endemic families of the Western Cape. It is restricted to the southwestern coastline of the Western Cape which is the part of the province receiving the highest rainfall. The community occurs on sandy soils in temporarily to seasonally wet areas.

19. *Merxmuellera stricta* Community

This community is dominated by the grass *Merxmuellera stricta* and does not look very much like typical fynbos, although there are many species of Ericaceae and Restionaceae that can occur within the matrix of grass. It is typically a northern element within the Sclerophyllous Wetland Vegetation and is commonly found in the Cedarberg all the way up to Namaqualand.

20. *Pteridium aquilinum* Community

This community, even though it is dominated by a cosmopolitan species that is widespread within South Africa, is nonetheless typically a fynbos wetland, as elsewhere in the country, bracken fern (*Pteridium aquilinum*) does not venture into wetlands, but forms large carpets that are invading montane grassland, for example in the Drakensberg. The species has a wide tolerance, especially for nutrient-poor conditions, and it produces allelopaths, which are chemicals released in the soil that are toxic to other plants. It seems that only in specific circumstances this problematic plant can grow in wetlands, and it only invades the temporary zones on the edges. It is quite possible that it has been stimulated by the forestry industry in the Tsitsikamma region as this species is quite common under plantation forestry worldwide.

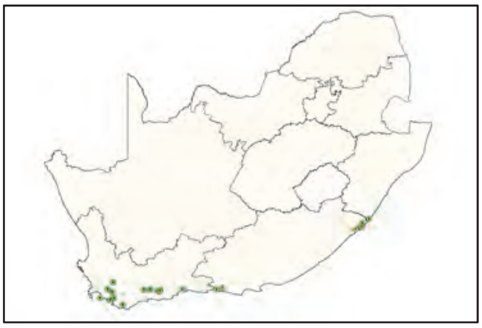
21. *Osmitopsis asteriscoides – Restio purpurascens* Community

This is one of the most attractive fynbos wetland plant communities but it has a very limited distribution in the wettest and most pronounced winter rainfall sections of the Western Cape. The community is rich in species, particularly Erica's, Restio's and Brunia's, but the most conspicuous element is the large woody daisy *Osmitopsis asteriscoides* which has white flowers. It is typically found in seepage zones with a peaty substrate on the lower slopes of the sandstone mountains.

22. *Prionium serratum* Community

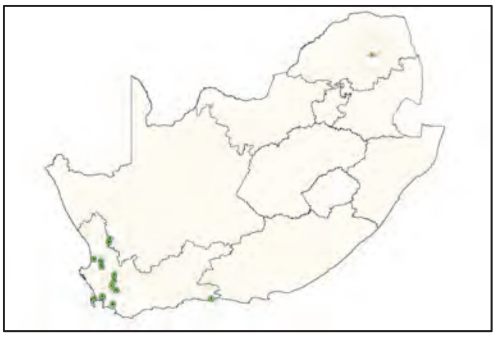
This is another one of the typical sclerophyllous wetland types, dominated by the unique species palmiet (*Prionium serratum*). This species occupies the banks of mountain streams in the Western Cape but in certain circumstances in the foothills it chokes the river which starts to deposit its sediment which makes Palmiet thrive over a larger surface area. In this sense, Palmiet can be regarded as an ecosystem engineer (Sieben 2012) which is at the source of the creation of the wetland environment. It is together with Papyrus probably the only South African example of such a species. Palmiet is very common in rivers entering the foothills in the Southern Cape mountains and has created many wetlands there, which are however very fragile for erosion, and many have disappeared, most importantly the massive Duivenhoks River system. Palmiet represents a unique growth form and it is very good in withstanding huge floods and plays an important role in flood attenuation and associated ecosystem services. This is mainly because of its extensive root system, very unusual for wetland plants, which can go up to three meters deep into a permanently inundated peatland.

Palmiet is also found on the Msikaba group sandstones in Pondoland where it is often mixed with a larger group of species (in the Western Cape it can easily achieve monodominance) and often co-occurs with *Scleria angusta* - *Abildgaardia hygrophila* wetlands (3.33).



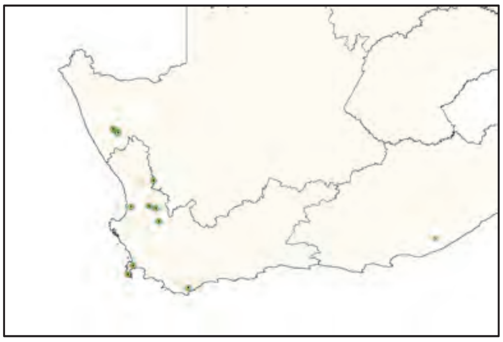
23. *Pennisetum macrourum* Community

This is one of the most common Fynbos wetland types, particularly in the western part of the Western Cape. *Pennisetum macrourum*, even though it is a grass and not a restio, represents a typical fynbos element in that it is stiff and sclerophyllous, and is one of the few species of Sclerophyllous Wetland Vegetation that is also found on sandstone substrates in the north of the country, often together with *Cliffortia strobilifera*. *Pennisetum macrourum* wetlands are poor in species and can often achieve monodominance.



24. *Cyperus thunbergii* Community

This community is a common variant to the previous community. *Cyperus thunbergii* regularly occurs mixed in with *Pennisetum macrourum* in wetlands but there are many occasions where it actually becomes dominant. The community is most common in valley bottom wetlands on sandy soils with a temporary to seasonal inundation.



25. *Elegia intermedia* Community

This community stands out in the very rich fynbos as it forms a monoculture of a single species of restio, *Elegia intermedia*, which is a reasonably tall species. It has been sampled in a single area in the Hottentots-Holland Mountains and is probably not very widespread as the dominant species is not known to have a wide distribution range. The community grows on a very coarse peat layer.

26. *Anthochortus crinalis – Cliffortia tricuspidata* Community

This community stands out by the abundance of the restio *Anthochortus crinalis*, which forms characteristic hummocks that give it the name 'orgy grass'. In the hollows between these hummocks different species can grow, but in general, this community is quite poor in species. The existence of several other species of *Anthochortus* growing in the same type of habitats, suggests that there are also similar communities like this occurring elsewhere in the extreme Southwestern tip of South Africa. This habitat has been sampled only in a limited way because of the access to these areas and is presently known only from a single study.

27. *Elegia mucronata – Restio subtilis* Community

This community is typical for high altitude seepages in the Cape Fold Mountains but is so far restricted in its distribution range because of the limited sampling that was done in the high mountains of the Western Cape. However, the species *Elegia mucronata*, *Erica intervallaris* and *Grubbia rosmarinifolia* seem to be more widespread across the Western Cape, so it is very well possible that this community is more widespread. The community is structurally very diverse as the restio *Elegia mucronata* forms a high stratum over an often short layer of small restios and dwarf shrubs.

3.2.5 Discussion of Sclerophyllous Wetland Vegetation

An interesting aspect of fynbos wetland communities is that they are often more poor in species than the surrounding upland vegetation (but not always, especially not in the mountains). This low diversity corresponds with a general pattern found in wetlands and is most likely a consequence of numerous factors including physiological constraints associated with periodic inundation, strong competition arising from relatively high productivity. However, when it comes to diversity on a regional scale, it appears that the identified wetland communities are mostly dominated by species endemic to Cape Floristic Region and most of the communities are also restricted to the areas. Another interesting aspect of these wetlands is that they are structurally very diverse: some communities look very much like typical fynbos with a species-rich mixture of Ericaceae, Restionaceae and Proteaceae. Others are dominated by woody shrubs that are not the most typical fynbos shrubs, such as Bruniaceae or Rosaceae (*Cliffortia*). Yet others again are dominated by grasses and sedges, comparable to the wetland plant communities in other parts of the country, for example 1.6 *Carpha glomerata* Community or 1.19 *Merxmuellera stricta* Community. This raises some interesting questions about the phylogeny of wetland plants. Many wetland plants are from clades that gave rise to many species of wetland plants but in the Fynbos (or even the winter rainfall area in general) there are many more clades of normally terrestrial species that have given rise to wetland species as well, such as Ericaceae, Rosaceae, Fabaceae, Asteraceae.

At present, the overview of communities belonging to Sclerophyllous Wetland Vegetation is not yet complete as the wetlands of the high mountains of the Western Cape have not been visited extensively. This was an intentional choice, as this overview of national wetland vegetation types mainly serves to provide a reference framework for plant communities that face threats from agriculture, urbanization and other human causes. The wetlands in the high mountains of the Western Cape were thought to be ‘safe’ and there is less human interaction with these kinds of communities, whereas it is also very time-consuming to visit these wetlands as they are located in quite inaccessible areas. It may however be time to change the perspective on this because the effects of groundwater pumping will very likely already have an impact on these communities as well. It is also quite certain that there will be many special and rare communities in the mountains and that there is still a lot of diversity that has not yet been covered within the scope of this project.

3.3 Main Cluster 2: Swamp Forests

Swamp Forests represent unique plant communities in South Africa in that they are the only wetland plant communities in the country that are dominated by woody plants that can grow to the size of proper trees. Occasionally, woody plants enter into other communities but never play a really dominant role and are usually associated with rivers / floodplains or arid conditions. In the Sclerophyllous Wetland Vegetation, there are many woody species, but none of them grow up to the size of a real tree. Swamp Forests in South Africa are restricted to the subtropical climates of the eastern seaboard and extend along the east coast of Africa of the Zanzibar-Inhambane bioregion. Elsewhere in the world, woody species occur in wetlands also in temperate regions, such as Bald cypress forests in the Southern U.S. or Alden forests in Europe, but in Southern Africa no tree species that prefer the colder climates combined with permanently inundated conditions exist.

Figure 3.10 Distribution map of Swamp Forest vegetation in South Africa and a picture representing a typical stand of Swamp Forest.

There are a total of 223 vegetation plots that have been allocated to the group of Swamp Forests, but some of these have come from studies that have not collected data from the herbaceous layer, notably the study by Wessels (1997). This has posed some complications for the classification. Another complication is created by the fact that early successional communities have also been included here and in some of these cases, the tree layer is very sparse or even missing.

3.3.1 Classification and Indicator Species Analysis

Cluster analysis was initially carried out twice, once only based on the tree stratum, including the 59 vegetation plots of Wessels (1997) and once based on all vegetation strata, where the vegetation plots by Wessels (1997) were excluded. What became evident in this way is that one forest type, *Barringtonia racemosa* – forest, was barely represented outside of the Wessels (1997) study and did not stand out as a distinct unit when these plots were excluded. The final solution was to give species in the different strata different weights, so that trees are more strongly represented in the data matrix. In this way, the herb layer is considered less important and therefore does not really have an impact even when it is not recorded. Every species in the tree layer (except the epiphytes and vines that were recorded in that stratum) was duplicated six times and every species in the shrub layer (again without epiphytes and vines) was duplicated two times. The cluster algorithm in combination with indicator species analysis led to seven clusters, which were evaluated visually for heterogeneity. Two clusters were judged to be heterogeneous which were then subjected to cluster analysis separately. This clustering led to four clusters, two of which remained distinct and two of which were then merged with already existing clusters. In this way, the seven Main Clusters represent the main variation in Swamp Forest types, whereas in the majority of clusters, the herb layer is well described, except for the *Barringtonia racemosa* - Forest. The dendrogram belonging to this classification is indicated in Figure 3.11 and the table with indicator species is indicated in Table 3.2.

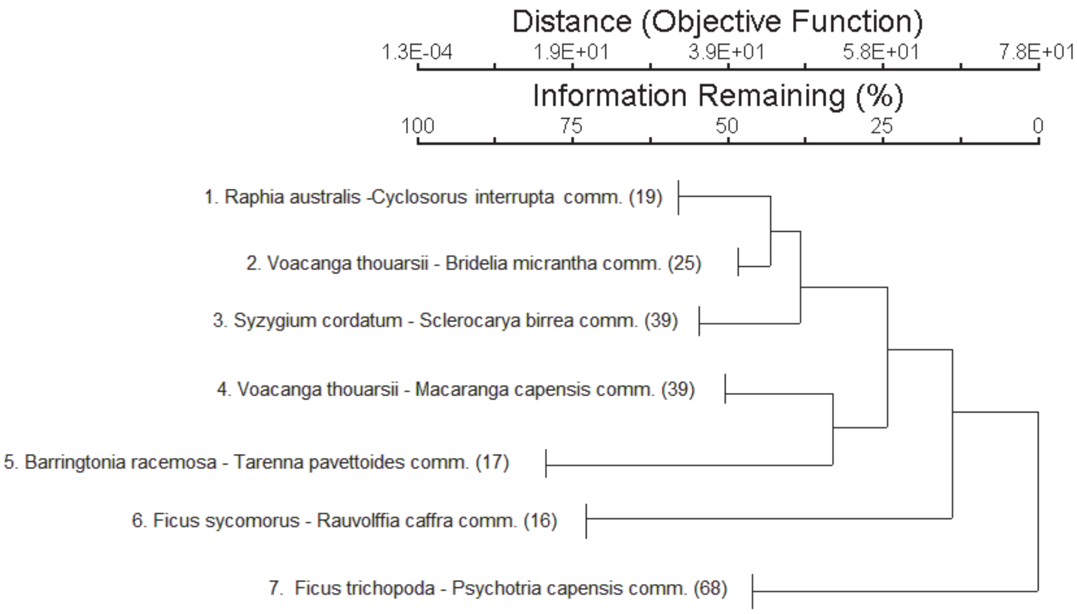


Figure 3.11 Cluster dendrogram for Swamp Forest.

Table 3.2 Communities in Swamp Forest including the indicator species.

Vegtype	Stratum	Indicator species	Indicator Value (IV)	p-value
1 (19 plots)	Dominant species: *Cyclosorus interruptus* (herb layer)			
	Tree	*Raphia australis*	13.7	0.004
	Herb	*Cyclosorus interruptus*	19.5	0.003
		Ficus trichopoda	14.6	0.006
		Cyperus prolifer	13.5	0.026
		Panicum parvifolium	11.2	0.016
		Trema orientalis	11.1	0.011
		Commelina benghalenis	11.1	0.021
		Hydrocotyle bonariensis	10.4	0.018
2 (25 plots)	Dominant species: *Voacanga thouarsii - Bridelia micrantha*			
	Tree	*Diospyros mespiliformis*	12	0.004
	Shrub	*Rubus rigidus*	43	0.001
		Bridelia micrantha	22.7	0.001
		Jasminum multipartitum	22.5	0.001
		Myrsine africana	15.4	0.003
		Searsia nebulosa	12.5	0.006
		Phoenix reclinata	11.5	0.021
		Clausena anisata	10.2	0.007
	Herb	*Thelypteris* species	30.2	0.001
		Phragmites australis	23.3	0.001
		Cyperus involucratus	16.6	0.002
		Typha capensis	15.7	0.004
		Phragmites mauritianus	13.7	0.005
		Tephrosia species	12	0.004
		Imperata cylindrica	11.8	0.015
		Dissotis canescens	11.3	0.022
		Commelina africana	10.9	0.024
		Senecio madagascariensis	10.4	0.003
		Eriosema psoraleoides	10.3	0.009
		Ipomoea aquatica	10.2	0.013
3 (39 plots)	Dominant species: *Syzygium cordatum*			
	Tree	*Sclerocarya birrea*	17.9	0.003
	Shrub	*Vangueria infausta*	13.3	0.006
		Acacia species	12.8	0.008
	Herb	*Digitaria eriantha*	15.4	0.001
		Helichrysum kraussii	15	0.004
		Acalypha villicaulis	12.8	0.005
		Panicum maximum	10.8	0.023
		Flueggia virosa	10.3	0.006
		Lobelia flaccida	10.3	0.006
		Desmodium dregeanum	10.3	0.014
4 (39 plots)	Dominant species: *Voacanga thouarsii - Macaranga capensis*			
	Tree	*Macaranga capensis*	37.6	0.001
		Morella serrata	11.7	0.023
	Shrub	*Tarenna pavettoides*	51.2	0.001
		Smilax anceps	34	0.001
		Keetia gueinzii	31.7	0.001
		Stenochlaena tenuifolia	31.4	0.001
		Halleria lucida	26.2	0.001
		Lygodium microphyllum	21.7	0.001
		Peddiea africana	21.4	0.001
		Macaranga capensis	20.4	0.002
		Rhoicissus rhomboidea	19.5	0.001
		Schefflera umbellifera	13.6	0.002
		Morella serrata	13.1	0.007
		Syzygium cordatum	12	0.019
		Voacanga thouarsii	11.1	0.041
	Herb	*Keetia gueinzii*	43.9	0.001
		Tarenna pavettoides	39.3	0.001
		Nephrolepis biserrata	38.9	0.001
		Morella serrata	29.5	0.001
		Desmodium adscendens	28.1	0.001
		Peddiea africana	22.7	0.001
		Rhoicissus rhomboidea	22.7	0.001
		Voacanga thouarsii	21.6	0.001
		Smilax anceps	21.1	0.002
		Syzygium cordatum	21.1	0.002
		Lygodium microphyllum	19.8	0.002
		Cissampelos torulosa	18.6	0.001
		Mikania natalensis	16.8	0.005
		Macaranga capensis	14.3	0.007
		Rubus rigidus	14.2	0.006
		Anthericum species	13.6	0.006
		Phaulopsis imbricata	13.5	0.002
		Hewittia malabarica	13.1	0.004
		Halleria lucida	12.7	0.006
		Ilex mitis	10.3	0.015
5 (17 plots)	Dominant species: *Barringtonia racemosa*			
	Tree	*Tarenna pavettoides*	79.9	0.001
	* Data from other strata not available	*Cussonia sphaerocephala*	58.1	0.001
		Cassipourea gummiflua	36.1	0.001
		Barringtonia racemosa	35.7	0.001
		Ficus sur	23	0.001
		Phoenix reclinata	22.2	0.001
		Sapium ellipticum	20.2	0.001
		Rapanea melanophloeos	18.1	0.009
		Ilex mitis	14.8	0.002

Table 3.2 (Continued)

Vegtype	Stratum	Indicator species	Indicator Value (IV)	p-value	Vegtype	Stratum	Indicator species	Indicator Value (IV)	p-value
6 (16 plots)	Dominant species: *Ficus sycomorus - Trichillia emetica*				**7** (68 plots)	Dominant species: *Ficus trichopoda*			
	Tree	*Ficus sycomorus*	87.1	0.001		Tree	*Baphia racemosa*	18.8	0.002
		Trichilia emetica	68.5	0.001			*Burchellia bubalina*	11.9	0.022
		Rauvolffia caffra	68	0.001		Shrub	*Psychotria capensis*	21.1	0.001
		Syzygium guineense	37.5	0.001			*Mikania natalensis*	19.7	0.001
	Shrub	*Adenopodia spicata*	68.8	0.001			*Ficus trichopoda*	16.7	0.004
		Ficus capreifolia	50	0.001			*Ipomoea mauritiana*	10.8	0.023
		Grewia caffra	44.2	0.001		Herb	*Microsorium* species	15.2	0.003
		Breonadia salicina	43.8	0.001					
		Allophyllus decipiens	37.5	0.001					
		Kraussia floribunda	20.2	0.001					
		Monanthotaxis caffra	13.8	0.003					
	Herb	*Dicliptera heterostegia*	75	0.001					
		Ageratum conyzoides	25	0.001					
		Phyla nodiflora	25	0.001					
		Ipomoea mauritiana	18.5	0.003					
		Setaria megaphylla	18.3	0.003					
		Cissampelos mucronata	15.1	0.004					
		Oplismenus hirtellus	14.2	0.007					
		Cotula australis	12.5	0.01					

It must be noted that Community 2.6 is not strictly Swamp Forest in the sense of Mucina & Rutherford (2006), but rather a form of Lowland Riverine Forest as it was indeed found in a further inland area than the other Swamp Forests. It is a type of forest found in floodplain areas and the substrate is generally not permanently inundated.

3.3.2 Canonical ordination

There have not been many soil samples taken from Swamp Forest plots so the possibilities for ordination and group testing are quite limited. In this case, soil variables have not been included and only one Canonical Correspondence Analysis was carried out.

The results of CCA for the Swamp Forest data (excluding those plants that only have tree data available is shown in Figure 3.12. The sum of all canonical eigenvalues for this ordination is 25.45 whereas the sum of all canonical eigenvalues is 4.94 which means that about 19% of the variation can be explained by the environmental variables supplied. This is certainly not much and more detailed knowledge about the explanatory factors in Swamp Forests would be desired. The ordination was carried out with 164 plots and a total of 444 species, but this includes the same species in different strata.

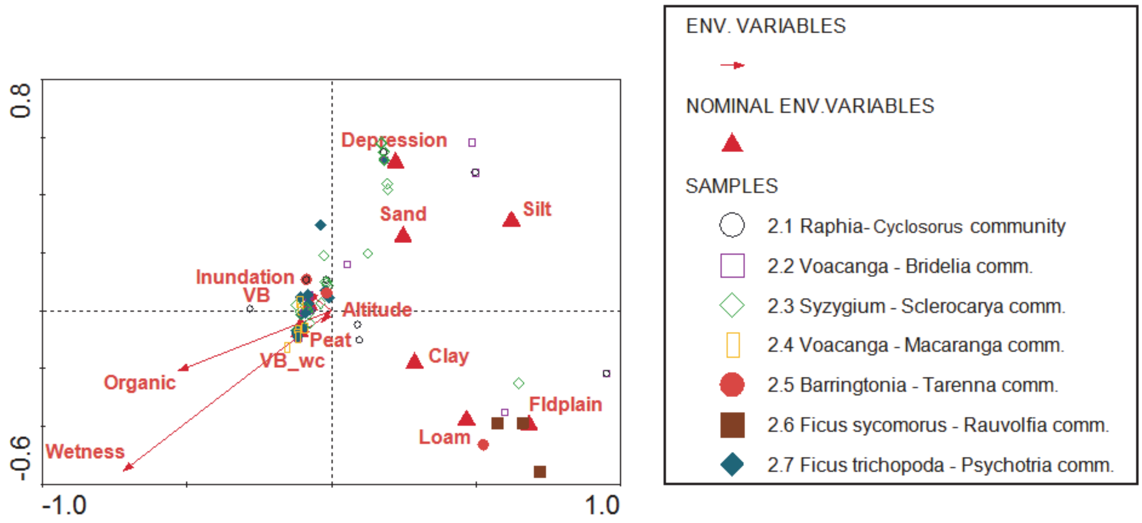


Figure 3.12 CCA ordination diagram of Swamp Forest data.

It is clearly visible in this ordination diagram that the riverine forests of Community 2.6 (*Ficus sycomorus – Rauvolfia caffra* Community) are occurring in very different habitats than the other Swamp Forest types, as they occur on loam soils and in floodplains. Of the 'typical' Swamp Forests, it is only Communities 2.7 *Ficus trichopoda-Psychotria capensis* Community and 2.4 *Voacanga thouarsii-Macaranga capensis* Community that occur strictly in the typical Swamp Forest habitat: valley bottom wetlands around a channel with a peaty substrate that is permanently inundated. The other communities are also regularly found in depressions and in sandy habitats which could suggest that these are more like early successional stages of Swamp Forest. Community 2.5. *Barringtonia racemosa – Tarenna pavettoides* Community is under-sampled and requires more data.

3.3.3 Species response curves

The possibilities to look into species response curves for Swamp Forests are quite limited but it may be possible to look into including variables that were included in Grobler's (2009) study of Swamp Forests and to see how they are compatible with the variables utilized in the database.
Only four species had sufficient species present to present species response curves, and even for these species the data is quite limited. What is immediately striking is that these four species in most cases have very similar responses to environmental variables and therefore occur in very similar habitats. The process of facilitation may even take place in which one species makes the environment more suitable for the establishment of another species. The different communities of Swamp Forest may therefore merely represent different successional stages, rather than different environments. Of course this can merely be hypothesized for the four species represented here and the other important indicator species may still tell a very different story. Particularly the *Barringtonia racemosa* Swamp Forest represents probably different environmental conditions as this species seems to be more salt-tolerant and in many cases is found fringing Mangrove swamps. But it would certainly also be interesting to obtain more data on *Ficus trichopoda* Swamp Forests.

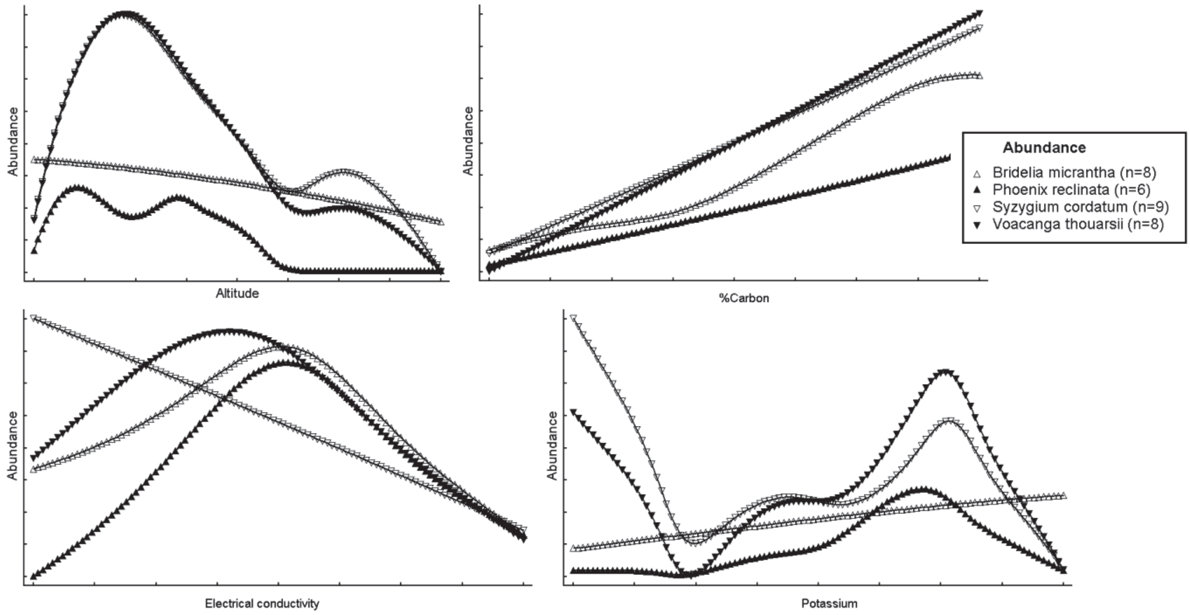


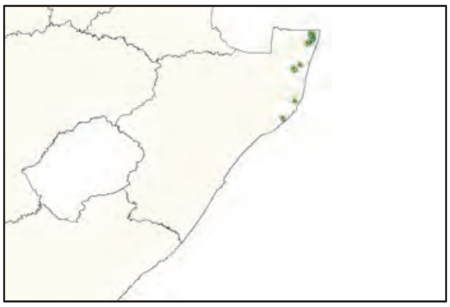
Figure 3.13 Species response curves for four species of trees occurring in Swamp Forest, mostly as pioneer species.

It is obvious that the species presented here prefer lower altitudes, higher carbon, intermediate levels of Electrical Conductivity and two species have a bimodal distribution for Potassium (with *Phoenix reclinata* sharing one of the two peaks). More data is certainly welcome and would elucidate the picture of the Swamp Forest environment better.

3.3.4 Description of communities

1. *Raphia australis - Cyclosorus interruptus* Community

This community can be regarded as an early-successional stage on its way towards proper Swamp Forest. The most conspicuous diagnostic species, *Raphia australis*, is found only in the north of its distribution near Kosi Bay and this species seems to fit quite well with the pioneer communities where most Swamp Forest species are only present in the form of small shrubs or seedlings. It is not clear whether this species would form its own distinct community if plots from further north would be taken into consideration. Important species in the herb layer are the ferns *Cyclosorus interruptus* and *Stenochlaena tenuifolia.*



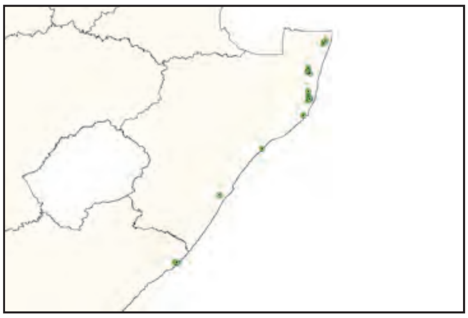
2. *Voacanga thouarsii – Bridelia micrantha* Swamp Forest

This is another early-successional community with many species in the herb layer. The two trees *Voacanga thouarsii* and *Bridelia micrantha* are quite dominant in the early successional stages, although most woody species only occur in the shrub layer. The herb layer is dominated by tall reeds (*Phragmites)*, Bullrushes

(*Typha*) and some tall sedges (*Cyperus involucratus*). This community is mainly found in the far north of Maputaland.

3. *Syzygium cordatum – Sclerocarya birrea* Swamp Forest

This is the most common and most widespread Swamp Forest community and *Syzygium cordatum* is often the most common tree in Swamp Forest in early successional stages. It is also the most common species in the South of its distribution range. The forests in the south of its distribution range are dominated by grasses (particularly *Panicum glandulopaniculatum*) in the herb layer, whereas in the north the herb layer is more dominated by ferns, although this distinction does not lead to a differentiation in clustering. However, if more data becomes available, this difference can be investigated further.



4. *Voacanga thouarsii – Macaranga capensis* Swamp Forest

This Swamp Forest community seems to be the richest in terms of the indicator species in it, but is still dominated mainly by the species *Macaranga capensis*, which is often found in early successional stages, although it can grow to become a very tall forest tree.

5. *Barringtonia racemosa – Tarenna pavettoides* Swamp Forest

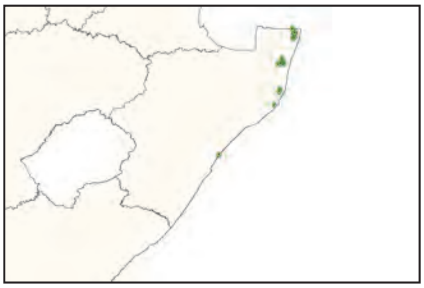
This community stands out because of the high density of the beautiful tree *Barringtonia racemosa*, which is often found bordering on estuaries and lagoons. There is only few data available that includes herb strata, but these communities are expected to be poorly vegetated in the herb layer as the canopy is very dense. This community also seems the most rare Swamp Forest community, with plots only from St. Lucia, Amatikulu and the South Coast. The community seems to be absent from the far north which was however very intensively sampled by Grobler (2009).

6. *Ficus sycomorus – Rauvolffia caffra* Riverine Forest

This is a type of riverine forest that enters into Floodplains and can form floodplain forests on the banks of the Pongola River between Ndumo nature reserve and the town of Jozini. There are certain affinities between Swamp Forest and Riverine forest as shown by the fact that this is not the most dissimilar forest community. The ecological drivers between Swamp and Riverine forests are however very different with riverine forests driven by flood events and quite dry conditions outside of the rainy season. The data that forms the basis of this community is quite old (Furness 1981) and it can be asked how much this community has changed since then, since there have been quite some hydrological alterations in this area since the construction of the Jozini Dam.

7. *Ficus trichopoda – Psychotria capensis* Swamp Forest

This is the climax stage of Swamp Forest with a dominance of the forest giant *Ficus trichopoda*. This represents a very common forest type, especially in the northern parts of the KwaZulu-Natal coast. It is also the most mature stage of forest succession with a sparse shrub layer and a dense canopy.



3.3.5 Discussion of Swamp Forest

Even though the Swamp Forests, a relatively small group of communities with a narrow distribution, have been very well represented with 223 vegetation plots, the Main Cluster still requires more attention as these plots mainly came from historical studies that in some cases did not consider all the factors that we are currently interested in. Particularly there are very few complete plots (that is, plots including the herb layer) for the *Barringtonia racemosa* forests. Another problem is the lack of detailed soil data, and although Grobler (2009) provides detailed environmental data in his study, the compatibility with the variables that were collected within this study still needs to be investigated.
A complicating factor in studying forest is the time aspect. These communities have been there on a much longer time-scale than the communities in the other Main Clusters and it is therefore difficult to compare wetland plant communities between these different Main Clusters. They will also respond much slower to environmental changes as the main constituents, trees, have become much more robust within their environment.
To understand the time aspect of Swamp Forest, the primary research goal should be to understand the successional pathways. Seedlings of Swamp Forest trees can often be found in *Cyclosorus interruptus* - *Cyperus latifolius* communities (3.19) but the factors that make these seedlings survive for a long time until such stage that they start to change the microclimate and have an impact on the survival of other species in the community, are as yet unknown. In order to understand successional pathways in Swamp Forest, the autecology of the various Swamp Forest trees needs to be understood better as well as the ecological factors that select the survivors in a community in the long term, also termed

community assembly rules (Weiher & Keddy 1999). At this stage, most people assume that what differentiates Swamp Forest from surrounding wetlands is just exclusion of fire, but this answer is somehow not satisfactory, as the border between forest and sedgeland is often very sharp and the two communities are growing on similar substrates with a similar hydrology.

3.4 Main Cluster 3: Subtropical Wetland Vegetation

The plant communities in this group are among the most common in the country, but they are generally lacking on the interior plateau because of the regular occurrence of frost. These wetlands are mostly found on the coastal forelands of the Cape, the lowlying regions of KwaZulu-Natal and Mpumalanga, and the whole of Limpopo, with some odd plots in the Kalahari and elsewhere further inland. The species in these wetlands are dominated by C_4 sedges of the genera *Cyperus*, *Pycreus*, *Kyllinga*, *Rhynchospora* and *Scleria*, with several grass species being very common as well, particularly *Leersia hexandra*, *Ischaemum fasciculatum* and *Phragmites australis*.
A high level of diversity of plant communities is found in Maputaland and many plant communities are restricted to this region. It is quite possible that if one would look at a broader geographic scale that the wetlands of the Zanzibar-Inhambane bioregion (which would also include Maputaland) are distinct from those of the Zambezian bioregion, but within South Africa, it was not regarded as necessary to split this cluster up into the Subtropical Wetland Vegetation of Maputaland and those of elsewhere in the country.

Figure 3.14 Distribution of Subtropical Wetland Vegetation and a picture representing a typical subtropical wetland.

A typical growth form of sedges in this cluster is represented by the giant sedges such as *Cyperus papyrus*, *Cyperus dives* and *Cladium mariscus*. Sedges of this size are generally lacking in inland regions and they appear as a distinct growth form of subtropical wetland vegetation.

3.4.1 Classification and Indicator Species Analysis

The dataset of subtropical wetlands consisted of 1112 vegetation plots with a total of 1054 species. This dataset was subject to cluster analysis and in the first round of clustering, the

Indicator species analysis was used to identify the most optimal number of clusters to be identified. This appeared to be 47 clusters, however, 3 of these clusters appeared to be heterogeneous and were subjected to further cluster analysis. With the help of dummy variables, the initial three clusters ended up being six clusters, one of which was still heterogeneous and consisted of three under-sampled communities. The final classification therefore consisted of 49 well-defined clusters and one heterogeneous cluster of rare and under-sampled communities.

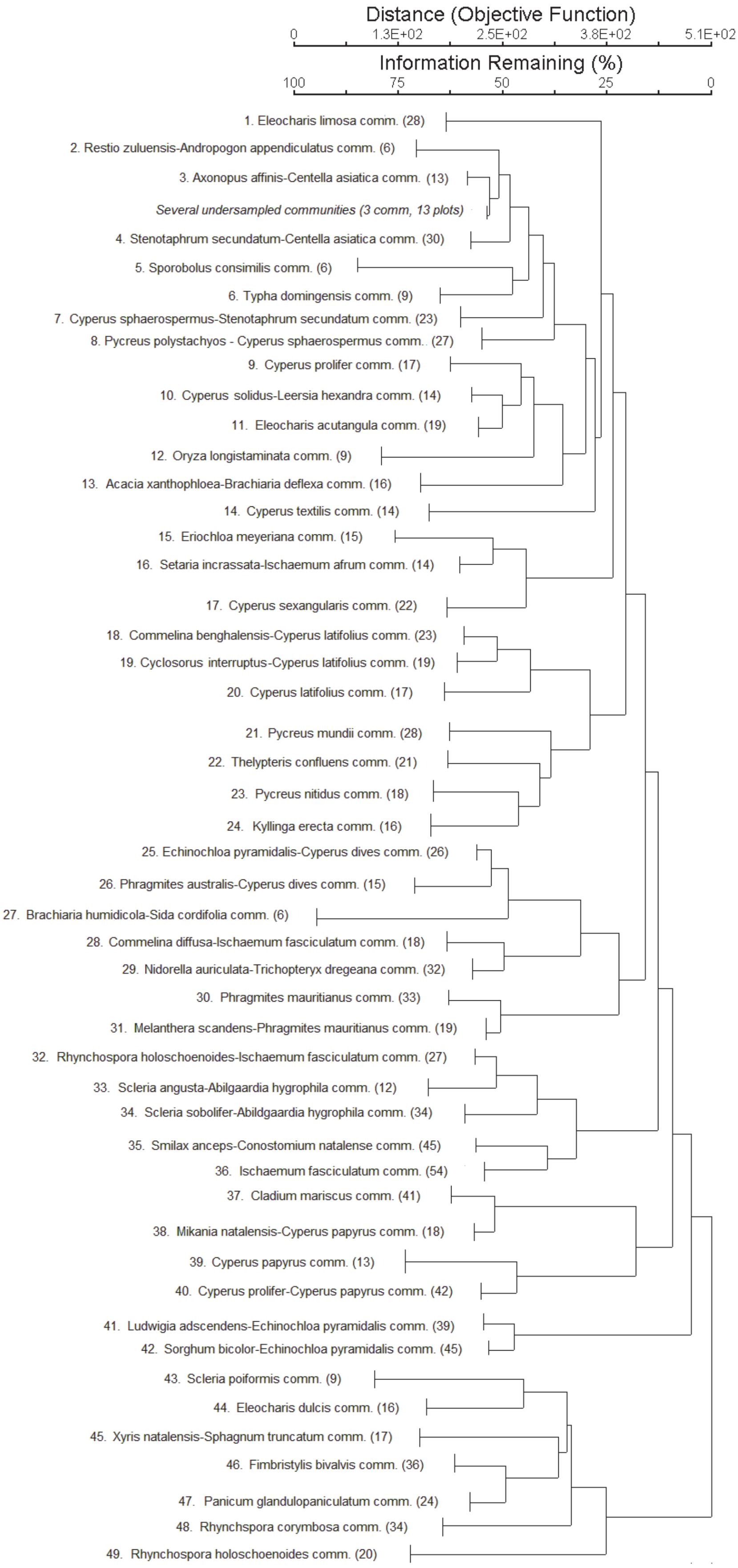


Figure 3.15 Cluster dendrogram for subtropical wetlands vegetation.

The first subdivision in the dendrogram splits a group of seven communities from Mfabeni Swamp off from all the other wetlands (Communities 3.43 up to 3.49). This emphasizes the uniqueness of that system and the many distinct communities from the Maputaland region, but it may also be an artifact of the fact that one of the studies in Mfabeni Swamp used 1 square meter plots instead of the usual 9 square meter plots.

Other related communities in the dendrogram are based on some dominants that are in common between several clusters, such as the large sedges of *Cyperus latifolius* and *Cyperus dives* and the reeds *Echinochloa pyramidalis* and *Phragmites mauritianus*, which all occur across a range of related communities.

Table 3.3 Communities and the associated indicator species for Subtropical Wetland Vegetation (Main Cluster 3).

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
1	28	*Eleocharis limosa*	Coastal pans	*Eleocharis limosa*	57	0.001
2	6	*Andropogon appendiculatus, Restio zuluensis*	Dry pans St Lucia	*Andropogon appendiculatus*	72.2	0.001
				Restio zuluensis	33.5	0.001
				Neurotheca congolana	33.3	0.001
				Vernonia oligocephala	30.1	0.001
3	13	*Centella asiatica, Eragrostis plana*	Drier edges of wetlands	*Eragrostis plana*	32.9	0.002
				Hypochaeris radicata	31.5	0.001
				Axonopus affinis	23.1	0.001
				Kyllinga pulchella	23.1	0.002
4	30	*Centella asiatica, Stenotaphrum secundatum*	Edges of wetlands Cape, KZN	-		
5	6	*Sporobolus consimilis*	Floodplains Limpopo and major rivers	*Sporobolus consimilis*	97.1	0.001
6	9	*Typha domingensis*	Various places highveld	*Typha domingensis*	86.5	0.001
				Cyperus eragrostis	22.2	0.001
				Melilotus alba	22.2	0.001
				Epilobium tetragonum	22.2	0.003
7	23	*Cyperus sphaerospermus, Stenotaphrum secundatum*	Drier edges of wetlands coastal Cape	*Stenotaphrum secundatum*	36.3	0.001
				Cyperus sphaerospermus	30.9	0.001
				Isolepis hystrix	23.6	0.001
8	27	*Juncus kraussii*	Freshwater seepage in Lake St. Lucia	*Lactuca inermis*	51.9	0.001
				Eleocharis caduca	48.1	0.001
				Xyris anceps	46.5	0.001
				Pycreus polystachyos	38.4	0.001
				Andropogon eucomus	36.3	0.001
				Eragrostis sarmentosa	29.9	0.001
				Bacopa monnieri	25.9	0.001
				Sporobolus virginicus	23.6	0.001
				Blumea species	20.4	0.002
9	17	*Cyperus prolifer*	Shrubby wetlands KZN coast	*Cyperus prolifer*	26.8	0.001
				Senecio deltoideus	25.8	0.001
10	14	*Leersia hexandra*	Shrubby wetlands KZN coast	*Cyperus solidus*	36.4	0.001
11	19	*Eleocharis acutangula, Eleocharis limosa*	Tropical, Limpopo, wet parts	*Eleocharis acutangula*	50.5	0.001
				Xysmalobium gerrardii	10.5	0.033
12	9	*Oryza longistaminata*	Nylsvlei	*Oryza longistaminata*	98.5	0.001
				Persicaria species	55.6	0.001
				Eleocharis species	22.2	0.001
				Cyperus species	20.9	0.001
13	16	*Acacia xanthophloea, Brachiaria deflexa*	Floodplains KZN	*Acacia xanthophloea*	85.1	0.001
				Brachiaria deflexa	49.6	0.001
				Justicia betonica	37.5	0.001
				Euclea divinorum	25	0.003
				Abutilon angulatum	21.2	0.002
14	14	*Cyperus textilis*	Dense stands on clay flats	*Cyperus textilis*	63.1	0.001
15	15	*Eriochloa meyeriana*	Tropical savanna pans	*Eriochloa meyeriana*	68.1	0.001
				Parthenium hysterophorus	20	0.002

Table 3.3 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
16	14	*Eriochloa meyeriana*	Pans Kruger Park and Savanna	*Ischaemum afrum*	71.4	0.001
				Setaria incrassata	70.5	0.001
				Malvastrum coromandelianum	23.1	0.001
				Chloris gayana	20.2	0.002
17	22	*Cyperus sexangularis*	Tropical wetlands, drier edges, Limpopo	*Cyperus sexangularis*	50.8	0.001
18	23	*Ischaemum fasciculatum*, *Cyperus latifolius*	Coastal wetlands KZN	*Commelina benghalensis*	50.8	0.001
19	19	*Cyclosorus interruptus*	various subtropical	*Cyclosorus interruptus*	44.1	0.001
20	17	*Cyperus latifolius*	various subtropical	*Cyperus latifolius*	42.4	0.001
21	28	*Pycreus mundii*	various subtropical	*Pycreus mundii*	49.5	0.001
22	21	*Thelypteris confluens*, *Carex acutiformis*	Towards higher areas	*Thelypteris confluens*	48.5	0.001
				Persicaria meisneriana	22.5	0.002
23	18	*Pycreus nitidus*	Various	*Pycreus nitidus*	25.2	0.001
				Ledebouria cooperi	22.2	0.001
24	16	*Kyllinga erecta*	Towards higher areas	*Kyllinga erecta*	37.1	0.001
				Fuirena coerulescens	23.2	0.003
25	26	*Cyperus dives*	Drier parts of floodplains	*Alternanthera* species	14.2	0.005
				Ambrosia artemisiifolia	13.7	0.002
26	15	*Cyperus dives*	Wetter parts of various wetlands	*Cyperus dives*	26	0.001
27	6	*Brachiaria humidicola*, *Sida cordifolia*	Dry parts floodplains	*Brachiaria humidicola*	85.6	0.001
				Sida cordifolia	69	0.001
				Senna didymobotra	47.9	0.001
28	18	*Ischaemum fasciculatum*, *Kyllinga erecta*	Various	*Cyperus esculentus*	32.7	0.001
				Commelina diffusa	21.2	0.001
29	32	*Trichopteryx dregeana*, *Ischaemum fasciculatum*	Mpumalanga	*Nidorella auriculata*	29.1	0.001
30	33	*Phragmites mauritianus*	Reedlands Limpopo	*Phragmites mauritianus*	27	0.001
31	19	*Phragmites mauritianus*	Reedlands Limpopo	*Ipomoea mauritiana*	52.1	0.001
				Melanthera scandens	34.8	0.001
				Rubus rigidus	26.7	0.001
				Ricinus communis	24.2	0.001
32	27	*Ischaemum fasciculatum*, *Rhynchospora holoschoenoides*	Coastal KZN	-		
33	12	*Abildgaardia hygrophila*	Pondoland	*Xyris* species	88.2	0.001
				Scleria angusta	66.7	0.001
				Berkheya speciosa	53.3	0.001
				Nerine species	41.4	0.001
				Eriospermum cooperi	35	0.001
				Phyllanthus species	34.4	0.001
				Carpacoce spermacocea	33.3	0.001
				Trachypogon spicatus	26.9	0.001
				Rhynchospora brownii	25	0.001
				Fuirena ecklonii	20.7	0.001

Table 3.3 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
34	34	*Scleria sobolifer, Abildgaardia hygrophila*	Coastal KZN, sandy/peaty	*Scleria sobolifer*	74.5	0.001
				Abildgaardia hygrophila	23.9	0.001
35	45	*Ischaemum fasciculatum, Centella asiatica*	Coastal KZN, sandy habitats	*Smilax anceps*	42.6	0.001
				Conostomium natalense	30.3	0.001
				Desmodium dregeanum	27	0.001
				Digitaria eriantha	26.5	0.001
				Cymbopogon pospischilii	24.5	0.001
				Helichrysum kraussii	22.1	0.001
				Maytenus procumbens	20	0.001
36	54	*Ischaemum fasciculatum*	Coastal KZN, sandy	-		
37	41	*Cladium mariscus*	Coastal valley bottoms + Kalahari	*Cladium mariscus* ssp. *jamaicense*	49.5	0.001
38	18	*Cladium mariscus*	Shrubby edges large wetlands	*Dactyloctenium geminatum*	20.3	0.004
39	13	*Cyperus papyrus*	Papyrus swamps Northern KZN	*Cyperus papyrus*	52.1	0.001
40	42	*Cyperus prolifer, Typha capensis*	Rich swamps peat Northern KZN	*Thelypteris* species	30.1	0.001
41	39	*Echinochloa pyramidalis*	wetter parts floodplains	*Ludwigia adscendens* ssp. *diffusa*	15.2	0.002
42	45	*Echinochloa pyramidalis*	Drier parts floodplains Maputaland	*Echinochloa pyramidalis*	42.4	0.001
				Sorghum bicolor	34.1	0.001
				Ipomoea cairica	24.5	0.001
43	9	*Scleria poiformis*	Dry interdune depressions	*Scleria poiformis*	98.1	0.001
				Dactyloctenium species	22.2	0.001
44	16	*Schoenoplectus brachyceras, Eleocharis dulcis*	Wettest parts St Lucia peatlands	*Eleocharis dulcis*	58.4	0.001
				Schoenoplectus brachyceras	22.3	0.001
45	17	*Sphagnum truncatum, Xyris natalensis*	Peatlands Limpopo, KZN	*Sphagnum truncatum*	92	0.001
				Xyris natalensis	62.4	0.001
				Andropogon huillensis	22.8	0.001
46	36	*Fimbristylis bivalvis*	Mfabeni Swamp	*Fimbristylis bivalvis*	56.1	0.001
47	24	*Panicum glandulopaniculatum*	Mfabeni Swamp	*Panicum glandulopaniculatum*	23.1	0.001
48	34	*Rhynchospora corymbosa*	Wetter parts St. Lucia peatlands	*Rhynchospora corymbosa*	45.6	0.001
49	20	*Rhynchospora holoschoenoides, Fimbristylis bivalvis, Panicum glandulopaniculatum*	Mfabeni Swamp	*Rhynchospora holoschoenoides*	54.9	0.001
Add.	13	3 communities: *Schoenoplectus muricinux, Fuirena pachyrrhiza* or *Echincochloa colona*		*Schoenoplectus muricinux*	28.6	0.001
				Fuirena pachyrrhiza	26	0.001
				Echinochloa colona	23.1	0.001

3.4.2 Canonical ordination

The plots of this cluster that include soil data are quite limited, mainly because there are many clusters that are only available in historical studies in Maputaland, for which there are no detailed soil variables available. The results of the CCA ordination are shown in **Figure 3.16.** There are a total of 160 plots that include 24 different communities, five of which are only represented by a single plot (*Sporobolus consimilis* Community (3.5), *Eleocharis caduca-Lactuca inermis* Community (3.8), *Setaria incrassata – Ischaemum afrum* Community (3.16), *Cyclosorus interruptus-Cyperus latifolius* Community (3.19) and *Fuirena pachyrrhiza* under-sampled community), which means that there are at least 25 communities that are not represented at all. The majority of these plots are from Maputaland, which is an area which has a large amount of historical data available (especially from various students at the University of KwaZulu-Natal under Prof. Fred Ellery), but unfortunately not in a format that makes it comparable to the bulk of data in the National database. Particularly Papyrus swamps and various *Rhynchospora* and *Scleria* dominated wetlands from peat in Maputaland are missing from the CCA ordination diagram of **Figure 3.16.** An ongoing study on the wetlands on the coastal sands of Maputaland by Althea Grundling, Lulu Pretorius and Cornie van Huyssteen will make more detailed soil data from this area available in the near future.

The Total Inertia of this ordination is 40.8 and the sum of the canonical eigenvalues is 8.8 so about 21.5% of the variation could be explained by the environmental variables supplied. The cumulative variance of species-environment correlation that is explained on the first two axes is about 16.6%. Only the first two axes seem to be easily interpretable and will be discussed below.

Among the communities that could be compared however, it is clear that the first axis is mainly correlated with clay contents and Electrical Conductivity, which are clearly associated with each other as clay provides many adhesive surfaces for cations to bind into the soil. The most clearly contrasting communities are those that are very low in clay contents and Electrical Conductivity and these are mainly from coastal sands, such as the *Cyperus sphaerospermus-Stenotaphrum secundatum* Community (3.7), the *Cyperus textilis* Community (3.14), *Centella asiatica-Stenotaphrum secundatum* Community (3.4) and the *Cladium mariscus* Community (3.37). Within this group, the first one seems to be the poorest in Calcium content, whereas the *Cyperus textilis* Community seems to have a slightly higher clay contents than the rest. An intermediate community on this axis towards a higher clay contents is the *Eleocharis limosa* Community (3.1). All other communities seem to be much more located towards clayey and loamy soils, although there are a number of very peaty soils as well.

The second axis is mainly correlated with Wetness, Nitrogen and with various nominal variables, such as soil depth and HGM unit, with the high energy environments with channels (such as floodplains and Valley bottoms with channels, 'VB-wc') more towards the top of the diagram while the low-energy environments such as seeps and Valley bottoms, 'VB' more towards the bottom of the diagram. In this part of the diagram we also find the very peaty habitats which are mainly occupied by the *Rhynchospora holoschoenoides – Ischaemum fasciculatum* Community (3.32) and the *Scleria angusta – Abildgaardia hygrophila* Community (3.33). These two communities are also very poor in nutrients as they seem to be mostly associated with extremely poor substrates on the Natal Group sandstones, where peat formation is common, as it is also very wet. Similar communities from the coastal sands of northern Maputaland are not well represented with detailed soil data.

A number of variables are associated simultaneously with axis 1 and axis 2, such as altitude which is associated negatively with axis 1 and positively with axis 2, Carbon contents, which is associated negatively with axis 1 and axis, Calcium (as well as most other cations except Potassium) positively with axis 1 as well as axis 2, and at last Phosphorus, which is associated positively with axis 1 and negatively with axis 2.

At an intermediate level on the second axis we find the communities with *Cyperus latifolius*, with the *Commelina benghalensis-Cyperus latifolius* Community (3.18) further along the Carbon gradient than the *Cyperus latifolius* Community (3.20). The first community is also more confined to the KwaZulu-Natal coast whereas the second community is more widespread. Another community that is found in this part of the ordination diagram, but that is generally found at higher altitudes, is the *Thelypteris confluens* Community (3.22).
In the first quadrant of the ordination diagram we also find the subtropical communities that are mostly confined to the higher altitudes, that is, in Limpopo. This is particularly the *Oryza longistaminata* Community (3.12), confined to Nylsvley, and the *Pycreus nitidus* Community (3.23), which is found also elsewhere in Limpopo.

In order to obtain a basic understanding of the 25 communities which are not represented in this ordination diagram, **Figure 3.17** (a-c) shows the ordination diagrams for the entire dataset where basic environmental data is available, but not complete soil data. The dataset is split into three, with the first diagram representing Communities 3.1 to 3.14, which represent the communities from floodplains and coastal sands, containing *Centella asiatica*, *Eleocharis limosa* and *Cyperus sphaerospermus*, the second diagram representing Communities 3.15 to 3.31, which are mostly the communities tall sedgelands in tropical areas, dominated by *Cyperus latifolius*, *Cyperus dives*, *Cyperus sexangularis* or *Phragmites mauritianus*, and lastly, the third diagram representing the Communities 3.32 to 3.49, which tend to be the communities occurring on peat, whether they are short sedgelands or tall Papyrus swamps.
From this first ordination diagram (**Figure 3.17a**) it becomes evident that the *Typha domingensis* Community (3.6) is another Subtropical Wetland Vegetation community confined to high altitudes, whereas within the coastal sands, there is a distinction between communities from low and high carbon contents, with the *Cyperus prolifer* Community (3.9), *Cyperus solidus-Leersia hexandra* Community (3.10), *Eleocharis acutangula* Community (3.11) occurring in places with higher organic matter than the *Cyperus sphaerospermus-Stenotaphrum secundatum* Community (3.7) and the *Centella asiatica-Stenotaphrum secundatum* Community (3.4).
From the second diagram (**Figure 3.17b**) it becomes clear that the *Kyllinga erecta* (3.24) and *Pycreus nitidus* Communities (3.23) are also more restricted to higher altitudes (that still have subtropical climates, for example the Mpumalanga escarpment or the KZN Midlands). The *Melanthera scandens-Phragmites mauritianus* Community (3.31) and the *Echinochloa pyramidalis-Cyperus dives* Community (3.25) are the most important communities for lowland river floodplains in tropical areas, although the last one also occurs in more hydrogeomorphic settings.
The third ordination diagram (**Figure 3.17c)** reveals that there is a whole suite of communities (Communities 3.44 to 3.49) which are confined to the wettest and most peaty parts of the landscape, which is why they are mostly restricted to Mfabeni Swamp on the Eastern shores of Lake St. Lucia. Communities with Papyrus (Communities 38 to 40) are found in slightly less peaty environments, and communities with *Echinochloa pyramidalis* (Communities 3.41 and 3.42) are restricted to floodplain settings.

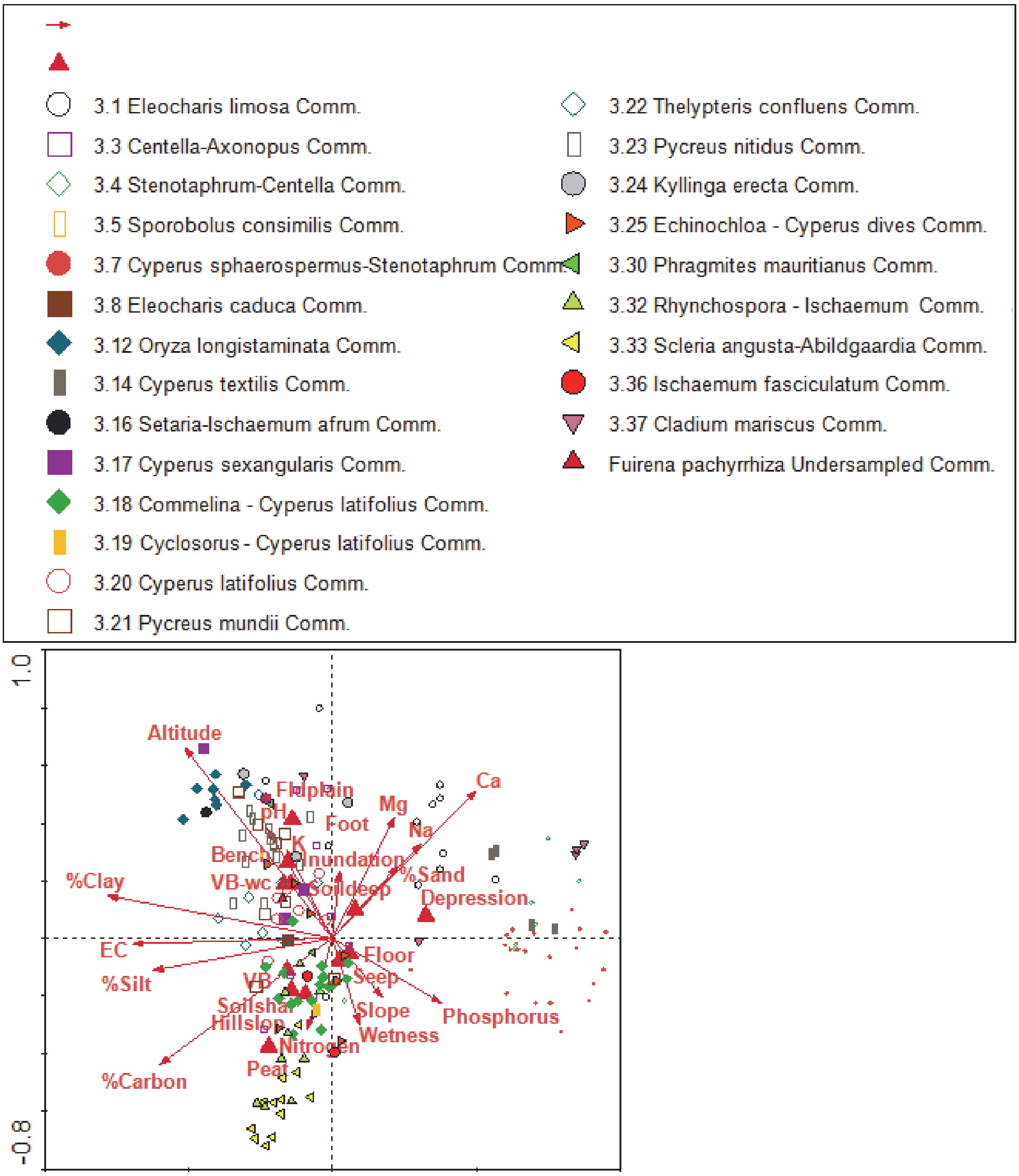


Figure 3.16 CCA Ordination diagram for Subtropical Wetland Vegetation containing all environmental variables including soil variables. Not all community types are fully represented here because some vegetation types do not include plots with soil variables available.

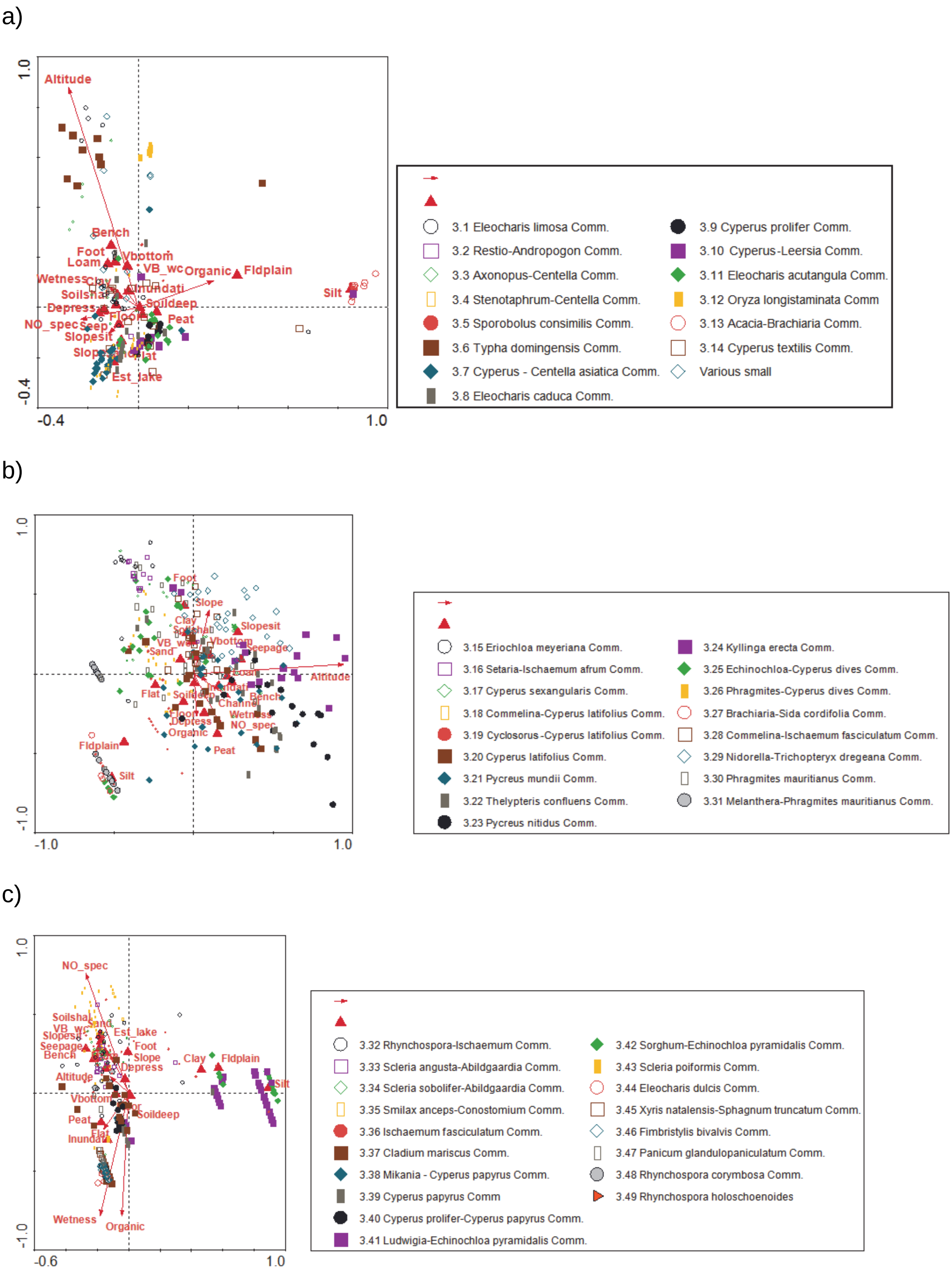


Figure 3.17 Ordination diagrams for the entire dataset of subtropical wetlands split into three groups according the dendrogram of figure 3.15.

3.4.3 Species response curves

The community responses to environmental gradients lead to questions about the responses for individual species, which is why species response curves to various environmental variables should be considered as well, especially for those species that are recognized as important indicator species. However, the restriction of having only 160 plots in these communities having detailed soil data available is also a limitation in plotting species response curves, especially (again) for the Maputaland special communities.

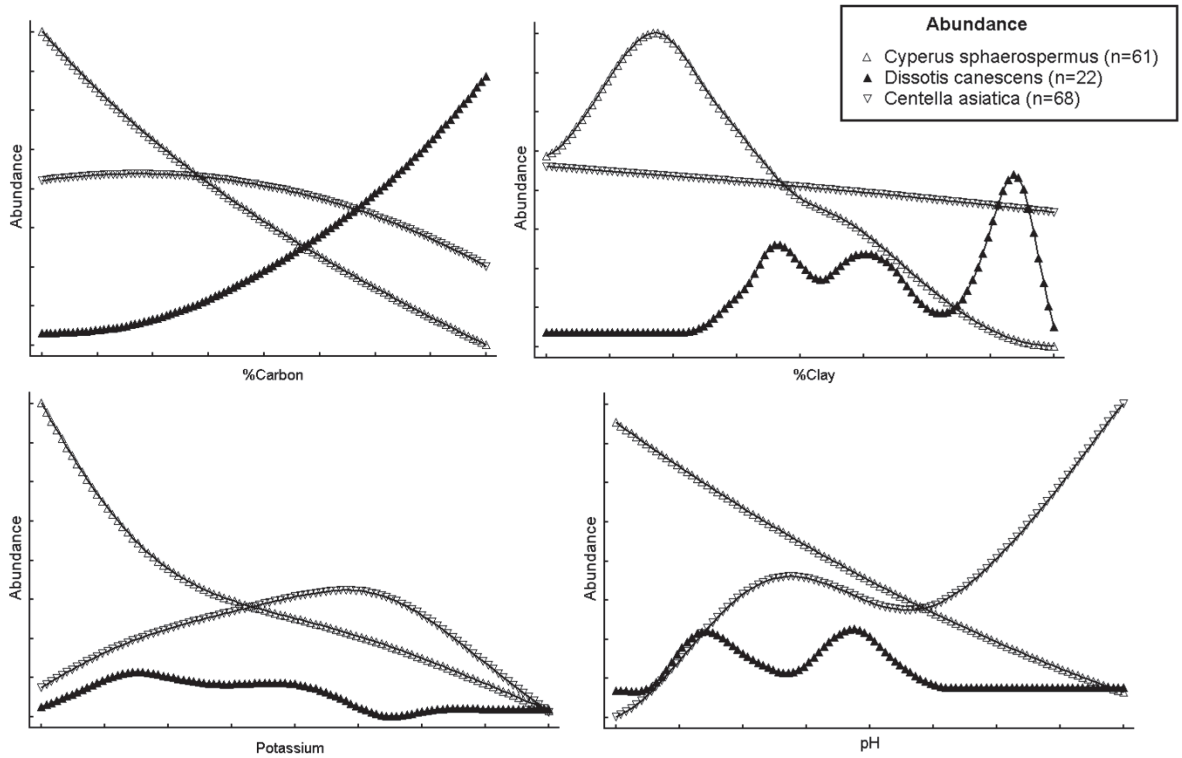


Figure 3.18 Species response curves for three species common in subtropical wetlands occurring on coastal sands.

The three species shown in Figure 3.18 often occur together in wetlands on coastal sands that are temporarily inundated and they become dominant in Communities 3.3, 3.4 and 3.7. They show however very contrasting responses to various environmental factors. The attractive purple flowers of *Dissotis canescens* become prominent only if there is a high carbon content in the soil, but it also shows a small peak at high clay contents. *Cyperus sphaerospermus* is the most competitive under situations where there is low clay content (so high sand content), low Potassium and a low pH, whereas *Centella asiatica* has a weaker negative response to clay contents, prefers an intermediate Potassium contents and more alkaline conditions.

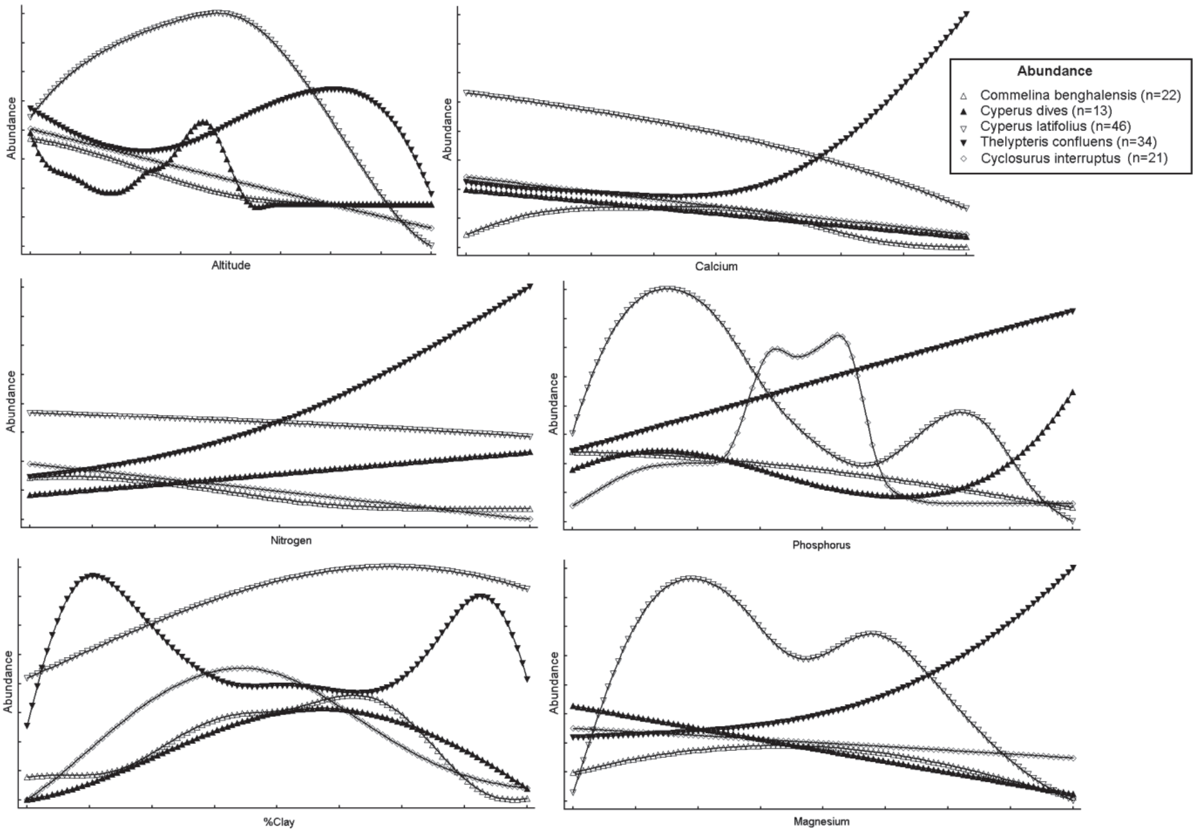


Figure 3.19 Species response curves for five species common in typical subtropical wetlands.

The five species that are displayed in Figure 3.19 are the main species in subtropical valley bottom wetlands that are found for example in coastal KwaZulu-Natal. They become dominant in Communities 3.18, 3.19, 3.20, 3.22, 3.25 and 3.26. The fern *Thelypteris confluens* becomes dominant at higher altitudes, but when any of the major nutrients or cations increases. *Cyperus latifolius* becomes dominant at high levels of clay contents in the soil, but requires low levels of Phosphate. The fern *Cyclosorus interruptus* becomes dominant at intermediate levels of Phosphate. *Cyperus dives* has more or less the same habitat characteristics as *Cyperus latifolius* but is everywhere less dominant except under conditions of high Phosphate.

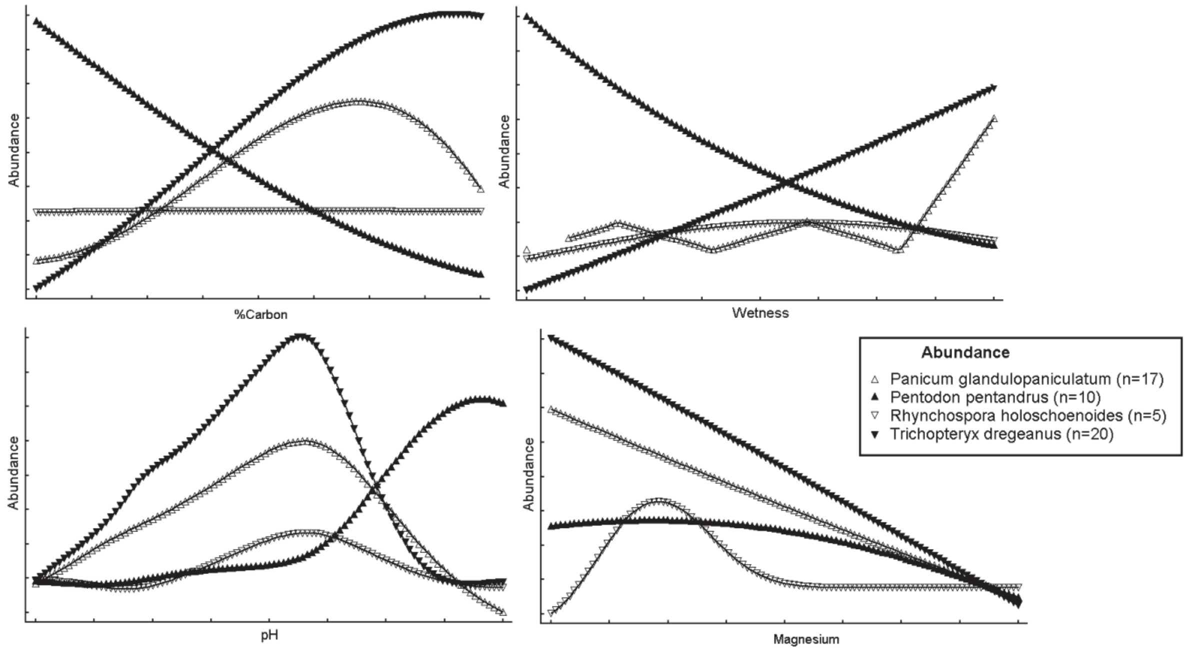


Figure 3.20 Species response curves for four species typical for nutrient-poor coastal sands or peatlands in Maputaland.

In Figure 3.20 some species are displayed that are associated with extremely nutrient-poor conditions of the coastal sands of Maputaland. These species are interesting but poorly represented in the plots with soil samples so these response curves are based on a poor amount of data. They become dominant in Communities 3.29, 3.47 and 3.49. *Panicum glandulopaniculatum* and *Trichopteryx dregeanus* become dominant in conditions of high wetness and high carbon, whereas *Rhynchospora holoschoenoides* seems indifferent but this is probably an artefact of the small sample size. The creeping forb *Pentodon pentandrus* has an opposite response to the other three, and likes slightly drier areas that also have a higher soil pH. In terms of the Magnesium contents, all four species have the same response.

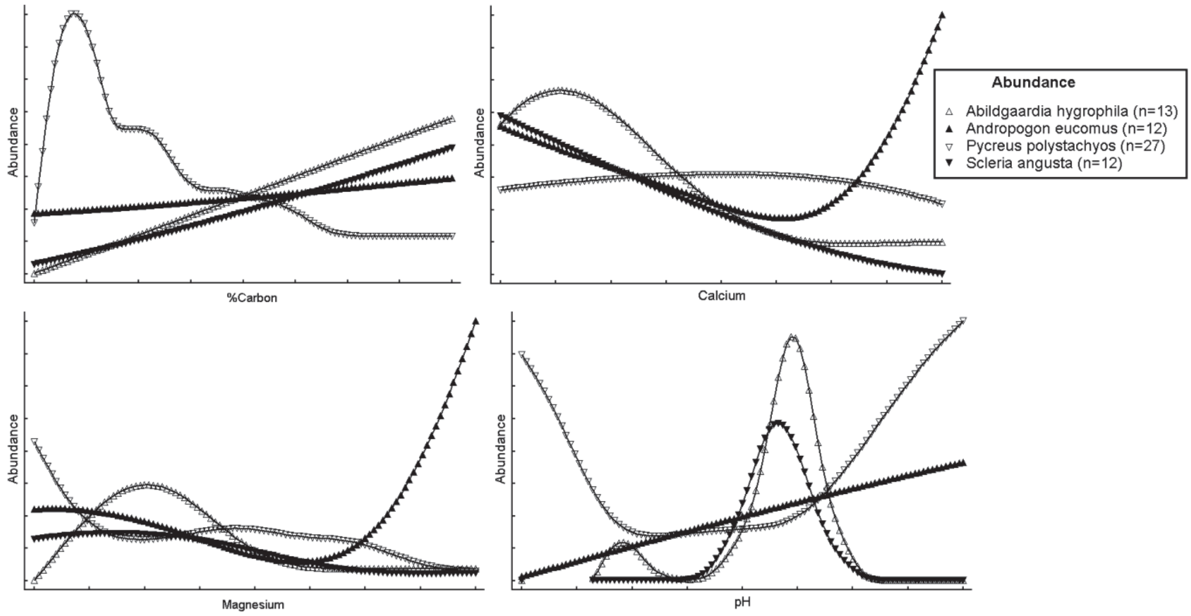


Figure 3.21 Species response curves for four species of grasses and sedges typical for peatlands and coastal sands derived from Pondoland.

Figure 3.21 deals with plants from similar nutrient-poor conditions, but this time the sandstone-derived soils from coastal Pondoland, where peat is also very common. *Abildgaardia hygrophila* becomes dominant in Community 3.33 whereas *Scleria angusta* also occurs in this community but is shared with Swamp Forest. Both of these species like high soil carbon, whereas the sedge *Pycreus polystachyos* occurs only in soils with low soil carbon. The grass *Andropogon eucomus* prefers conditions with high Calcium and Magnesium and steadily increases with alkalinity. In terms of soil pH, *Pycreus polystachyos* has a bimodal distribution and is absent from medium acidic soils, where *Abildgaardia hygrophila* and *Scleria angusta* have their peak.

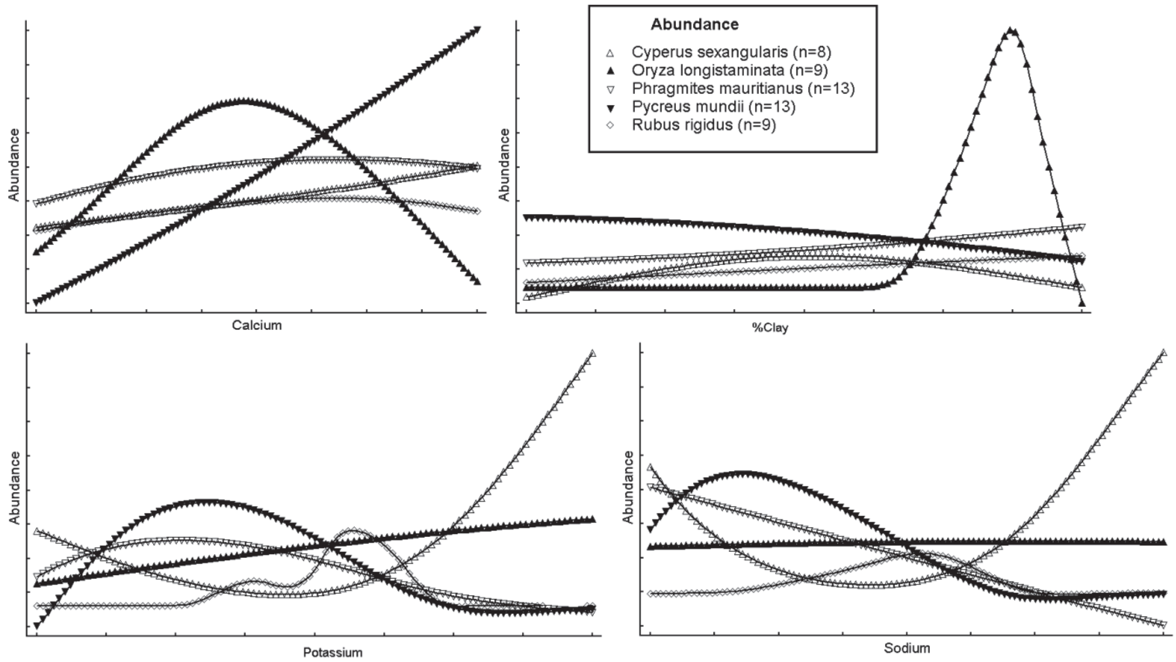


Figure 3.22 Species response curves for five species commonly occurring in wetlands in Limpopo province.

The northern parts of South Africa contain different types of wetlands, and five important species from these wetlands are presented in Figure 3.22. These species become dominant in Communities 3.12, 3.17, 3.21, 3.30 and 3.31. *Oryza longistaminata*, a grass that in South Africa is restricted to Nylsvley prefers medium levels of Calcium whereas the sedge *Pycreus mundii* prefers high levels of Calcium. The grass *Oryza longistaminata* also prefers high levels of clay contents in the soil, whereas the other species are more or less indifferent. The tall sedge *Cyperus sexangularis* is found in conditions with high levels of Potassium and Sodium, whereas the reed *Phragmites mauritianus* prefers low levels of these cations.

Figure 3.23 contains still a few more coastal species, among them the large sedge *Cladium mariscus*, which becomes dominant in some coastal wetlands, and it seems to prefer wetlands alkaline wetlands high in Calcium and a low percentage of silt.
It becomes dominant in Community 3.36.

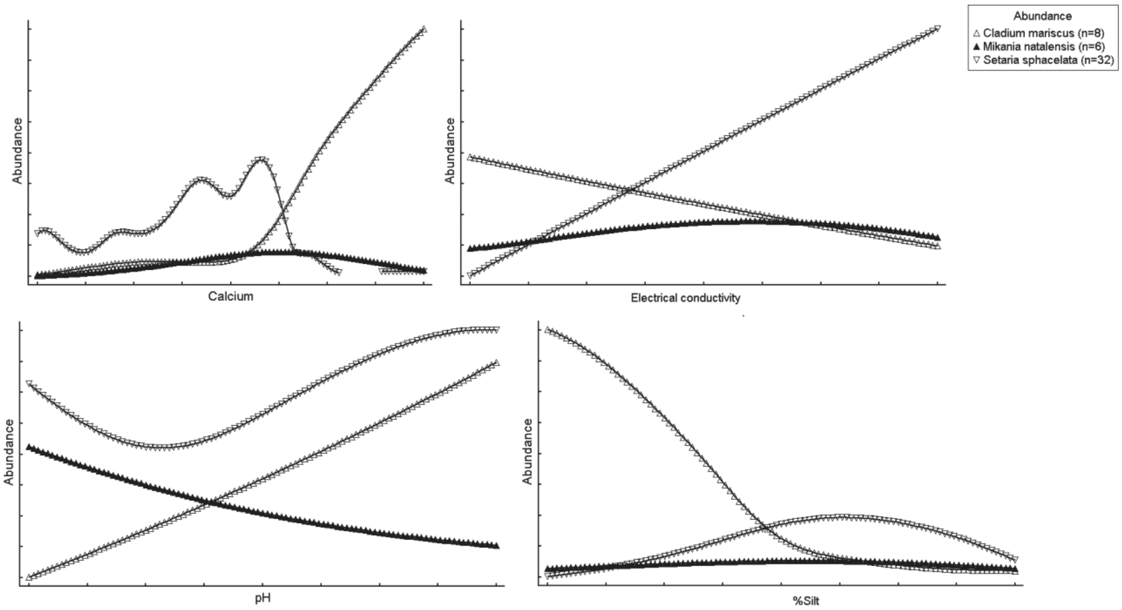


Figure 3.23 Species response curves for three species typically occurring in coastal wetlands along the Eastern Cape and KwaZulu-Natal coast.

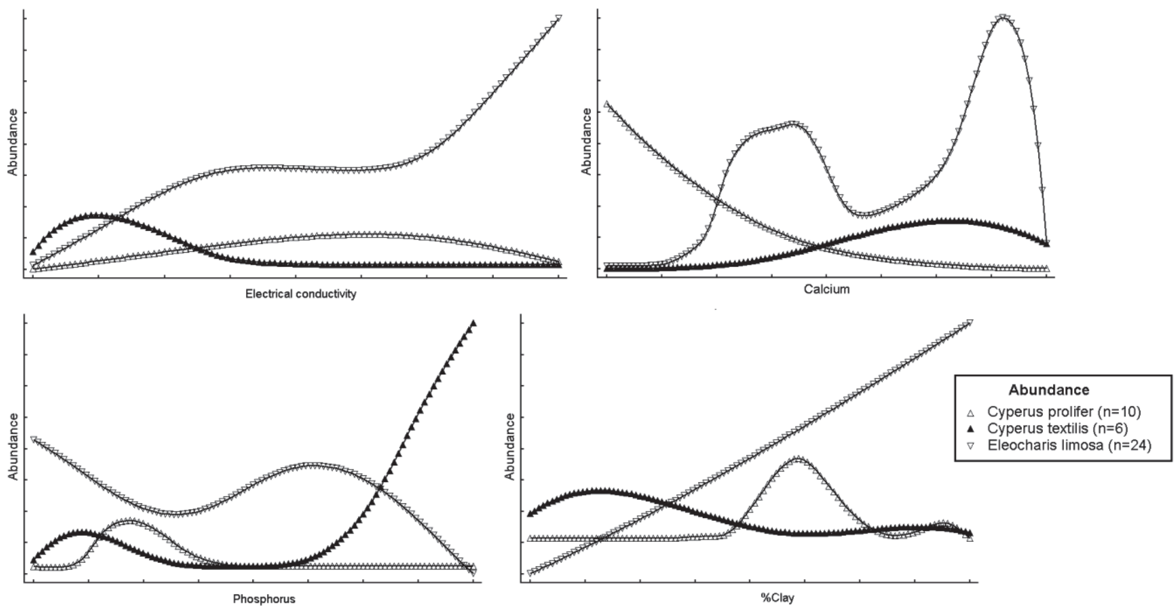


Figure 3.24 Species response curves for three species occurring in coastal wetlands on clayey substrates.

The species that are displayed in Figure 3.24 are widespread along coastal wetlands, particularly on clay substrates. They tend to become dominant in Communities 3.1, 3.9, 3.14 and 3.40. The sedge *Eleocharis limosa* becomes most dominant if the clay percentage and Electrical Conductivity becomes high. The tall sedge *Cyperus textilis*, which is restricted to the Cape, prefers substrates that are high in Phosphorus but generally peaks at a slightly lower clay percentage. The sedge *Cyperus prolifer*, occurring mainly in the tropical regions, is mostly bound to nutrient-poor substrate that are poor in Calcium, poor in Phosphorus but intermediate in clay percentage.

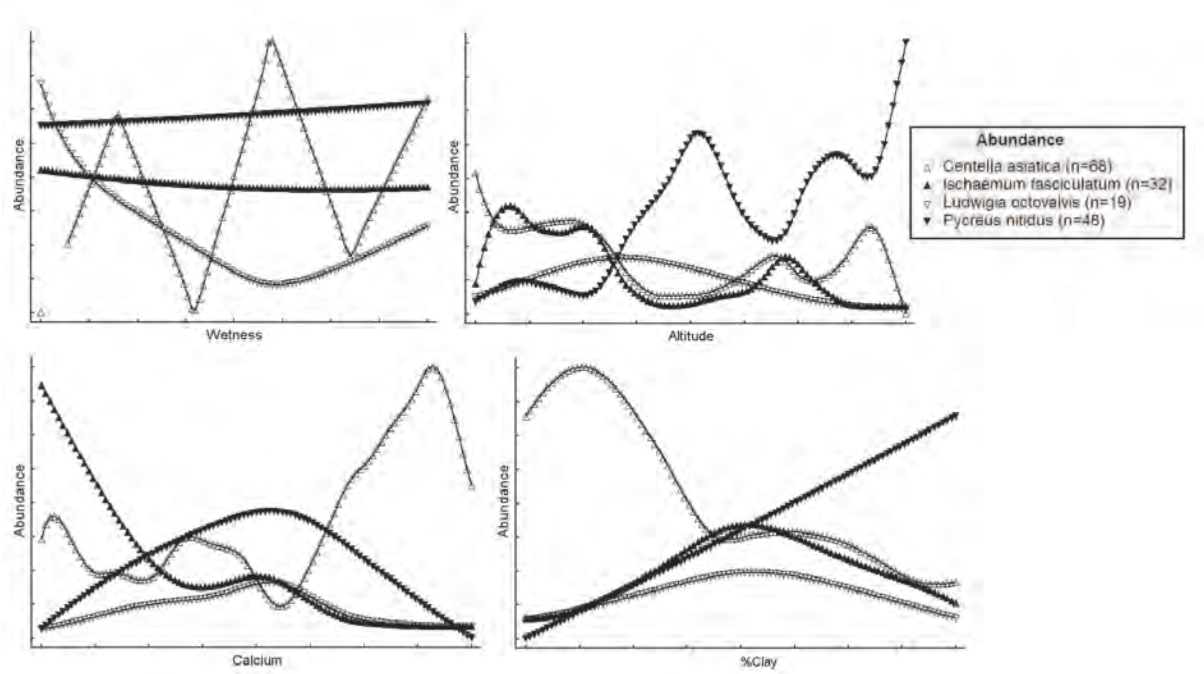
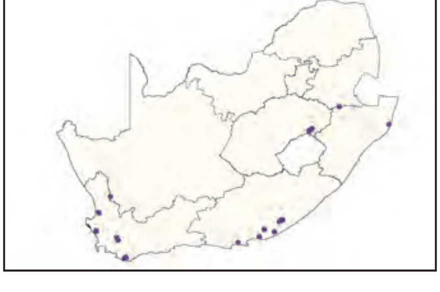


Figure 3.25 Species response curves for four widespread wetland species that are most abundant in the subtropical climate zone.

The species in Figure 3.25 are widespread in subtropical wetlands and much data is available on their distribution along gradients of soil variables. They are dominant in some communities, notably Communities 3.4, 3.23 ans 3.36, but they are shared with many others and even enter into communities from Main Cluster 6. All four species are quite indifferent to wetness, except *Ludwigia octovalvis* which clearly prefers the edges of wetlands where it is less wet. In terms of altitude, it is only *Pycreus nitidus* which actually increases with altitude and forms a mirror image response with *Ischaemum fasciculatum*, which decreases with altitude. *Centella asiatica* prefers situations where there is a high Calcium contents, *Pycreus nitidus* where it is intermediate, and *Ischaemum fasciculatum* where Calcium is very poor. *Pycreus nitidus* prefers soils that are very rich in clay, *Ischaemum fasciculatum* occurs in soils that have intermediate clay content, while *Centella asiatica* is bound to the most sandy soils with low clay content.

3.4.4 Description of communities

1. *Eleocharis limosa* Community



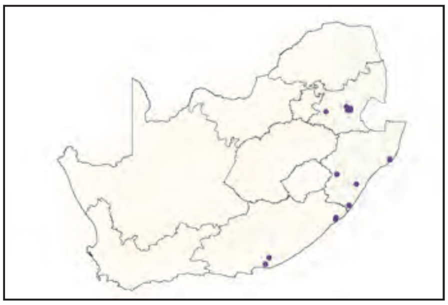
This is a community that is often found in warm coastal areas, particularly in the Cape, on grey clay soils that are seasonally to permanently inundated. The dominant species *Eleocharis limosa*, which often occurs in a monoculture, resembles the related species *Eleocharis dregeana*, that occurs in more temperate regions, although they can occur together in some places near the escarpment.

2. *Restio zuluensis – Andropogon appendiculatus* Community

This community, which is a bit under-sampled, is restricted to dry pans in dune depressions in Maputaland. The only plots of this community come from the eastern shores of Lake St. Lucia. A conspicuous element of the community is *Restio zuluensis*, which is the only species of Restionaceae in this part of KwaZulu-Natal.

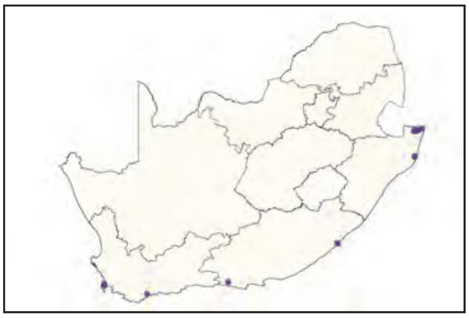
3. *Axonopus affinis - Centella asiatica* Community

This is a low weedy community at the edge of pans that contains a large number of common wetland species, but often includes the alien grass *Axonopus affinis*.



4. *Stenotaphrum secundatum – Centella asiatica* Community

This community is similar to the previous one but is restricted to coastal areas and has a large proportion of buffalo grass *Stenotaphrum secundatum*. It is therefore a bit transitional between the Subtropical wetlands and the Short Lawn Grassy Wetland Vegetation of Main Cluster 7.



5. *Sporobolus consimilis* Com-munity

This is a community confined to floodplains in tropical and subtropical areas, mainly in Kruger Park. It is dominated by tall grasses (predominantly *Sporobolus consimilis*) and is often extremely dry in the dry season, so the fluctuation in the water table is often quite extreme. The community often borders *Acacia xanthophloea* woodlands (Community 7.35)

6. *Typha domingensis* Community

This community is not very conspicuous in South Africa and it is suspected that in the past many of the occasions where *Typha domingensis* is dominant, it has been identified as *Typha capensis*. However, in many places on the Highveld, Limpopo and North-West Province, it is actually *Typha domingensis* and it is not even very difficult to differentiate between the two, as long as proper attention is paid.

7. *Cyperus sphaerospermus – Stenotaphrum secundatum* Community

This is another community of coastal grasslands in temporary wet zones, mostly found on the edge of pans, and it is dominated by the very variable sedge, often combined with Buffalo grass.

8. *Pycreus polystachyos – Cyperus sphaerospermus* Community

This community is often found in coastal areas and is particularly richly represented in freshwater seepages in Lake St. Lucia, but also occurs inland in Limpopo, where it is mostly dominated by the species *Pycreus polystachyos* and the grass *Andropogon eucomus.* In Lake St. Lucia it is often accompanied by the small sedge *Eleocharis caduca*. This community seems to be mostly adapted to fluctuations in salinity, as it occurs on the edge of estuaries.

9. *Cyperus prolifer* Community

The short sedge *Cyperus prolifer* ('Mini-papyrus') is common in many plant communities of the KwaZulu-Natal Coast, but as a dominant it is mostly restricted to Maputaland, where it occurs in peatlands.

10. *Cyperus solidus – Leersia hexandra* Community

This is another community that is restricted to Maputaland, although the component species are generally more widespread, especially the dominant *Leersia hexandra*. The large sedge *Cyperus solidus* is usually present but never in very large numbers.

11. *Eleocharis acutangula* Community

This community occurs on the wetter side of the wetlands gradient in subtropical pans and pools, and is probably a community that is more common and has more variation further north towards tropical Africa.

12. *Oryza longistaminata* Community

This plant community occurs only in a single wetland within South Africa, Nylsvley near Modimolle. The community is very common there but probably does not occur elsewhere in Limpopo because of the lack of large permanently wet wetlands in the region.

13. *Acacia xanthophloea – Brachiaria deflexa* Community

This community occurs in floodplains in Norhern KwaZulu-Natal and represents one of the few wetland plant communities where the tree layer is very prominent, in this case because of the presence of fever trees, *Acacia xanthophloea*.

14. *Cyperus textilis* Community

This community is found often in small patches around the edges of large pans or Valley bottom wetlands in the Cape. The species *Cyperus textilis* occurs in very dense stands and therefore the community does not harbor many other species, but the stands are often of limited extent. These communities occur on clay soils.

15. *Eriochloa meyeriana* Community

This is a community that is mostly found on the edges of wetlands in tropical lowland savanna areas, mostly in Kruger Park.

16. *Setaria incrassata – Ischaemum afrum* Community

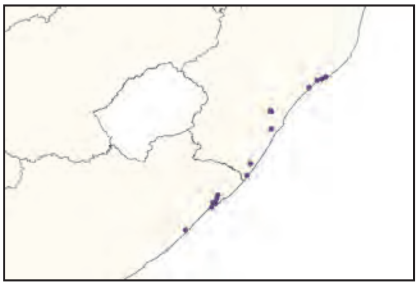
Another community largely confined to Kruger Park, although there is one deviant plot from near Bloemfontein that has *Setaria incrassata* dominant and therefore was grouped with this community. It seems to occur mostly on temporary wet areas with black clay soils.

17. *Cyperus sexangularis* Community

This community is relatively common in the northern tropical parts of the country and mostly occurs towards the drier edges of wetlands on clay soils. The tall sedge *Cyperus sexangularis* is dominant but often occurs in a rich mix of other species.

18. *Commelina benghalensis – Cyperus latifolius* Community

This is one of the most common plant communities on the Natal coast and closely resembles Community 3.19 and 3.20 which is also dominated by *Cyperus latifolius*. On the Natal coast however, this species occurs in a typical mix together with ferns, and herbs such as *Commelina benghalensis*.



19. *Cyclosorus interruptus – Cyperus latifolius* Community

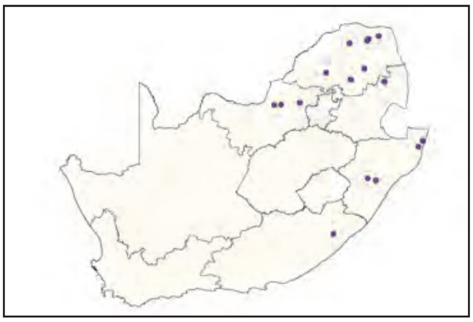
This is the second of *Cyperus latifolius* dominated communities, and it is a bit more common towards the northern parts of KwaZulu-Natal, with a few plots even in other parts of the country. This is a more shrubby type with a prominent role of ferns and may even represent a very early successional stage towards Swamp Forest.

20. *Cyperus latifolius* Community

This is the third and last of the wetland plant communities that are dominated by *Cyperus latifolius* and it seems to be restricted more towards the inland areas including Limpopo.

21. *Pycreus mundii* Community

This community is dominated by the small sedge of *Pycreus mundii,* which is mostly interspersed between larger sedges but occasionally becomes very dominant in itself. It is most common in the northern part of the country, with a few plots found in KwaZulu-Natal.



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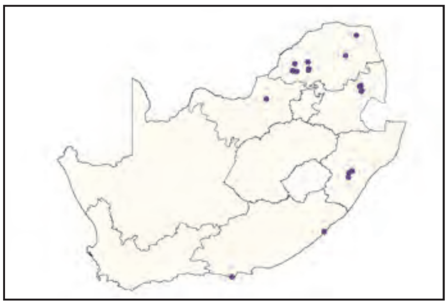
22. *Thelypteris confluens* Community

This community dominated by ferns is more common towards the inland areas on the border between Subtropical Wetland Vegetation and Temperate Grassy Wetland Vegetation.

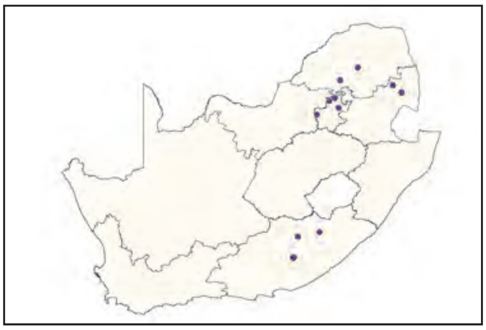


23. *Pycreus nitidus* Community

The sedge species *Pycreus nititus* is very common in temperate wetlands, but it tends towards dominance only in the warmer areas of the north of the country. It occurs in wet areas either on grey loam soils or black peat soils.

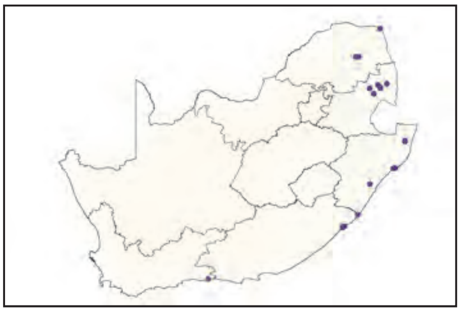
24. *Kyllinga erecta* Community

This community is common in higher lying areas, particularly around Gauteng. The species *Kyllinga erecta* is however particularly common in the warmer regions, although it does not always reach dominance.



25. *Echinochloa pyramidalis – Cyperus dives* Community

This is the first of two communities dominated by the giant sedge *Cyperus dives,* which occurs in slightly drier settings than *Cyperus latifolius,* but is distributed in more or less the same areas.



26. *Phragmites australis – Cyperus dives* Community

The second variant of *Cyperus dives* dominated communities is much more scarce and seems, for the most part, to be restricted to northern KwaZulu-Natal with a single plot in Limpopo.

27. *Brachiaria humidicola – Sida cordifolia* Community

This is a weedy community that is restricted to the Mkhuze floodplain in northern KwaZulu-Natal. It is relatively poor in species and it occurs only in the drier parts of the floodplain.

28. *Commelina diffusa -Ischaemum fasciculatum* Community

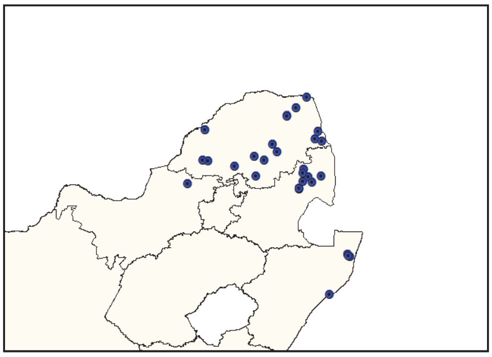
This community is restricted to the Mpumalanga escarpment region although it mainly contains widespread species so it can be regarded as a regional variant of the more widespread *Ischaemum fasciculatum* communities.

29. *Nidorella auriculata – Trichopteryx dregeana* Community

This is a second community that is restricted to the Mpumalanga escarpment area. The small grass *Trichopteryx dregeana* is common in various peatlands across the eastern part of the country but seems to get to high cover values in this particular region where it is also very common.

30. *Phragmites mauritianus* Community

The grass *Phragmites mauritianus* is the sister species of common reed and easily confused with it. It is mostly restricted to Limpopo where it is quite common but is also found on the Mpumalanga escarpment and the KwaZulu-Natal Coast. It is generally found in the drier parts of wetlands on hard clay soils, often in floodplains.



31. *Melanthera scandens – Phragmites mauritianus* Community

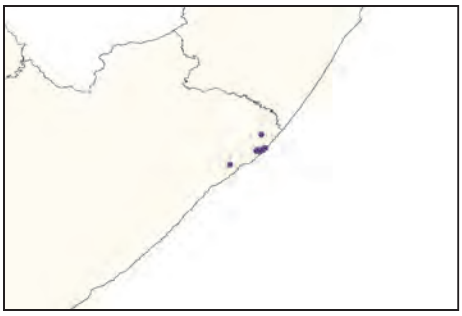
This is a variant of the *Phragmites mauritianus* Community but it is restricted to the Mkhuze River floodplains in northern KwaZulu-Natal.

32. *Rhynchospora holoschoenoides – Ischaemum fasciculatum* Community

The sedge *Rhynchospora holoschoe-noides* becomes very common on very nutrient-poor substrates in subtropical region and is therefore quite common on the Natal Group sandstones as well as the coastal sands of northern KwaZulu-Natal. Different communities with this same species are found in Mfabeni Swamp, the largest peatland in northern KwaZulu-Natal.

33. *Scleria angusta - Abildgaardia hygrophylla* Community

This community occurs in small coastal peatlands overlying the Natal Group Sandstone in Pondoland. It is a community very rich in species and containing many rare and special plant species, but the dominant species is the small and inconspicuous sedge *Abildgaardia hygrophylla*, together with species of *Xyris, Scleria, Panicum* etc. This type of sedgeland often borders Swamp Forest in this region.



34. *Scleria sobolifer – Abildgaardia hygrophylla* Community

This community is mostly restricted to coastal sands of the Maputaland coastal plain and tends to occur more towards the drier edges of *Cyperus latifolius* wetlands. It is dominated by the sedge *Scleria sobolifer*.

35.*Smilax anceps – Conostomium natalense* Community

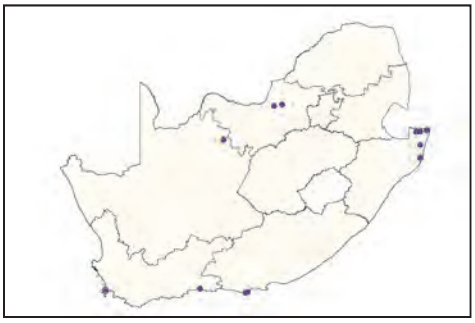
This community occurs mostly in those places that become a bit shrubby within *Cyperus latifolius* dominated wetlands and it is probably a first step towards the development of a Swamp Forest as there are several woody species entering this community or otherwise the vines that are common in Swamp Forest like *Smilax anceps*.

36. *Ischaemum fasciculatum* Community

The grass *Ischaemum fasciculatum* is very conspicuous in many subtropical wetlands, but in only a limited number of cases it really becomes dominant in an otherwise very species-poor community. This generally occurs in very wet circumstances.

37. *Cladium mariscus* Community

The large sedge *Cladium mariscus* is distributed worldwide and found generally dominant in coastal wetlands where they form quite impenetrable tall sedgelands. In South Africa they are particularly conspicuous in the Eastern Cape. A few plots of this community have been found in the heart of the country at the edge of the Kalahari.



38. *Mikania natalensis – Cyperus papyrus* Community

Papyrus swamps are well-known from all around Africa, including the banks of the Nile River where they played a role in providing the raw materials for the ancient Egypt for what later became known as 'paper'. In South Africa, they are mostly limited to northern KwaZulu-Natal where they are particularly extensive around the Mkhuze Swamps. There are three variants in Papyrus swamps and this first one is a more shrubby variant developing towards Swamp Forest.

39. *Cyperus papyrus* Community

This community represents a second variant of Papyrus swamps that consists of a real monoculture of *Cyperus papyrus* without any other species. This community is particularly well-known outside of South Africa from the Okavango Delta, where they have been described in detail by Ellery et al. (1995).

40. *Cyperus prolifer – Cyperus papyrus* Community

This is the last of the variants of Papyrus swamps. In this case, the cover of Papyrus is a bit less and interspersed with small sedges, the most important of which is *Cyperus prolifer* or 'Mini-papyrus'. Also, this community is restricted in South Africa to the Mkhuze Swamps.

41. *Ludwigia adscendens – Echinochloa pyramidalis* Community

The wettest parts of the Mkhuze swamps are covered with papyrus but the surrounding floodplains are dominated by the tall grass *Echinochloa pyramidalis*. This community represents the wetter part of these *Echinochloa pyramidalis* floodplains. Except for the Mkhuze River floodplains it is also found on the Pongola River floodplains.

42. *Sorghum bicolor – Echinochloa pyramidalis* Community

This community represents the second and the drier variant of *Echinochloa pyramidalis* grasslands and is restricted to the Mkhuze River floodplains.

43. *Scleria poiformis* Community

The large sedge *Scleria poiformis* can be found in wet dune slacks on the Eastern shores of Lake St. Lucia and also elsewhere in the coastal sands of Maputaland. The species often becomes quite dominant but there is still quite a mix of species growing in between.

44. *Eleocharis dulcis* Community

The wettest parts of Mfabeni Swamp are dominated by the aquatic sedge *Eleocharis dulcis* which can grow in water of up to a meter deep.

45. *Xyris natalensis – Sphagnum truncatum* Community

This is the first of five communities that is in its entirety restricted to the peatland of Mfabeni Swamp. This is regarded as the oldest peatland in South Africa. It is however quite possible that this particular community would occur elsewhere in the country on peat substrates.

46. *Fimbristylis bivalvis* Community

The second community endemic to Mfabeni Swamp is dominated by the leafless sedge *Fimbristylis bivalvis*.

47. *Panicum glandulopaniculatum* Community

The third community restricted to Mfabeni Swamp is dominated by the grass *Panicum glandulopaniculatum*.

48. *Rhynchospora corymbosa* Community

The large sedge *Rhynchospora corymbosa* is locally dominant in Mfabeni Swamp, mostly in the parts of the wetland that are slightly wetter.

49. *Rhynchospora holoschoenoides – Fimbristylis bivalvis* Community

The main body of Mfabeni Swamp is covered by the sedge *Rhynchospora holoschoenoides*, which grows in a rich mix of other sedges and grasses.

3.4.5 Discussion of Subtropical Wetland Vegetation

The subtropical wetlands represent a rich and diverse cluster but most of these wetlands are more or less restricted to KwaZulu-Natal, particularly Maputaland. The wetlands in this Main Cluster have the most evident links with wetlands elsewhere on the continent and since all rare and restricted community types of this Main Cluster are found somewhere on the border with neighbouring countries, the biogeography and rarity of these wetlands is difficult to assess until surveys have been carried out in neighbouring countries as well. This is particularly the case for Mozambique as this country will share many of the rare communities that are found in Maputaland as there are many coastal lakes and riverine marshes on the coast of this country that provide similar habitats as Kosi Bay or the Mkhuze Swamps.

Subtropical and tropical wetlands form the bulk of wetlands in Africa and many wetland species in Southern Africa are shared between Maputaland and the Okavango Delta, for example Papyrus (Cook 2004). This shows that many of the communities that have been described in this section are not as rare as they seem to be when they are considered at a continental scale. In South Africa, Maputaland stands out as it is the only subtropical area that is very rich in wetlands, but many more such areas exist elsewhere on the continent. It can be asked to what extent such regions drive evolutionary processes in wetland plants.

The wetlands in this Main Cluster are mostly located in areas that are grazed and trampled, for example by elephants. A quantification of these kinds of disturbances has not been included in the current study and is difficult to obtain. Especially when exclusion of large mammals is commonplace today as many wetlands are also located outside of large game reserves, it can be asked what its effect on plant composition will be. Another disturbance element that plays an important role in these communities is fire.

3.5 Main Cluster 4: Estuarine, Brackish and Saline Wetland Vegetation

The conditions in which salinity plays a role in wetlands are very diverse across the country, and brackish and saline wetlands can coarsely be subdivided into three main groups, which will be utilized during the ecological comparison of these communities. Most importantly, salinity plays a role in estuarine ecosystems. Estuarine ecosystems have not been an important focus in the database and the data is for a large part derived from a single study, that of Mucina et al. (2003) in the Western Cape and that of Sieben et al. (in prep.) in KwaZulu-Natal. Here the fluctuations in salinity and water level operate on a daily basis with the tidal regimes as opposed to inland saline wetlands where the fluctuations operate on a seasonal level. Within the inland saline wetlands, there are also two distinct regions in which these ecosystems are common, namely the Western Cape coastal forelands, where summer drought can be quite severe, and the inland areas of the Karoo, the Kalahari and the arid regions of the Highveld; both of these regions have their own distinct Saline Wetland Communities.

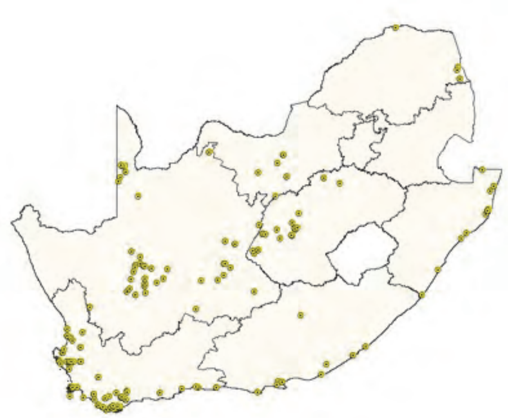


Figure 3.26 Distribution of Estuarine, Brackish and Saline Wetland Vegetation in the country and a picture that characterizes Inland Saline Wetland Vegetaion.

Especially in the Western Cape, there are a lot of transitions between estuarine systems and inland saline systems and they are generally dominated by the same groups of plants (chenopods of the genera *Sarcocornia* and *Atriplex*). The water and salinity regime in some areas such as the Hoop Vlei and the Agulhas Plain is also very complex and therefore a mixture of various communities of different salinity can often be found at close proximity to one another. The inland saline wetlands of the arid regions is more distinct and there is only a very limited number of species that is in common with all saline wetlands (mostly *Cyperus laevigatus* and *Sporobolus virginicus*, that are found both in estuaries and in inland salt pans). Inland saline wetlands are often also dominated by Chenopods, mostly by the genera *Salsola*, *Suaeda* and *Atriplex*, combined with a number of grasses, mostly of the genus *Sporobolus*. There is a transition between these communities and several communities of

Main Cluster 7 (dealt with in section 3.8) especially those with the various species of *Sporobolus*, *Eragrostis bicolor* and *Juncus rigidus*, which tend to occur in the drier regions. In Main Cluster 7 there is also a community characterized by *Paspalum vaginatum*, which is quite common in estuaries, as well as an *Atriplex* dominated community, characteristic for pans in the Southern Cape, which has certain affinities with these saline and brackish communities. The problem with the saline and brackish wetlands is mostly that there are still many taxonomic problems outstanding, although there have been a few recent studies that have resolved a few issues, for example around the genera *Sarcocornia*, *Salicornia*, and *Triglochin*. (Köcke et al. 2010; Steffen et al. 2009, 2010). The biggest taxonomic problem for now is still the genus *Salsola*, which is extremely rich, although the number of species in wetlands seems to be limited.

3.5.1 Classification and Indicator Species Analysis

The classification of Estuarine, Brackish and Saline Wetland Vegetation is based on 513 plots with a total of 533 species. One dummy species was added for the empty plots that were sampled in unvegetated areas in hypersaline flats in the inland arid regions, because it is important for environmental monitoring to see where the physiological barrier for plant growth in such habitats lies. This dummy species was added only when the total vegetation cover was less than 10%, and only took the values 7, 8 and 9 for total covers of 5-10%, 1-5% and 0-1 % respectively.

The classification led to the recognition of 35 plant communities, 15 of which are restricted to estuaries, 8 from cape saline flats, and 12 from inland saline flats. Those three main subdivisions do not really reflect in the dendrogram, most likely because the differences within plant communities from these three main saline plant community groups are larger than the differences between them. The subdivision does however make a lot of sense when making ecological comparisons. One cluster was characterized by unidentified specimens of *Sarcocornia*, but in most cases this should be either *Sarcocornia mossiana* or *Sarcocornia pillansii* as they are from the Cape coastal forelands.

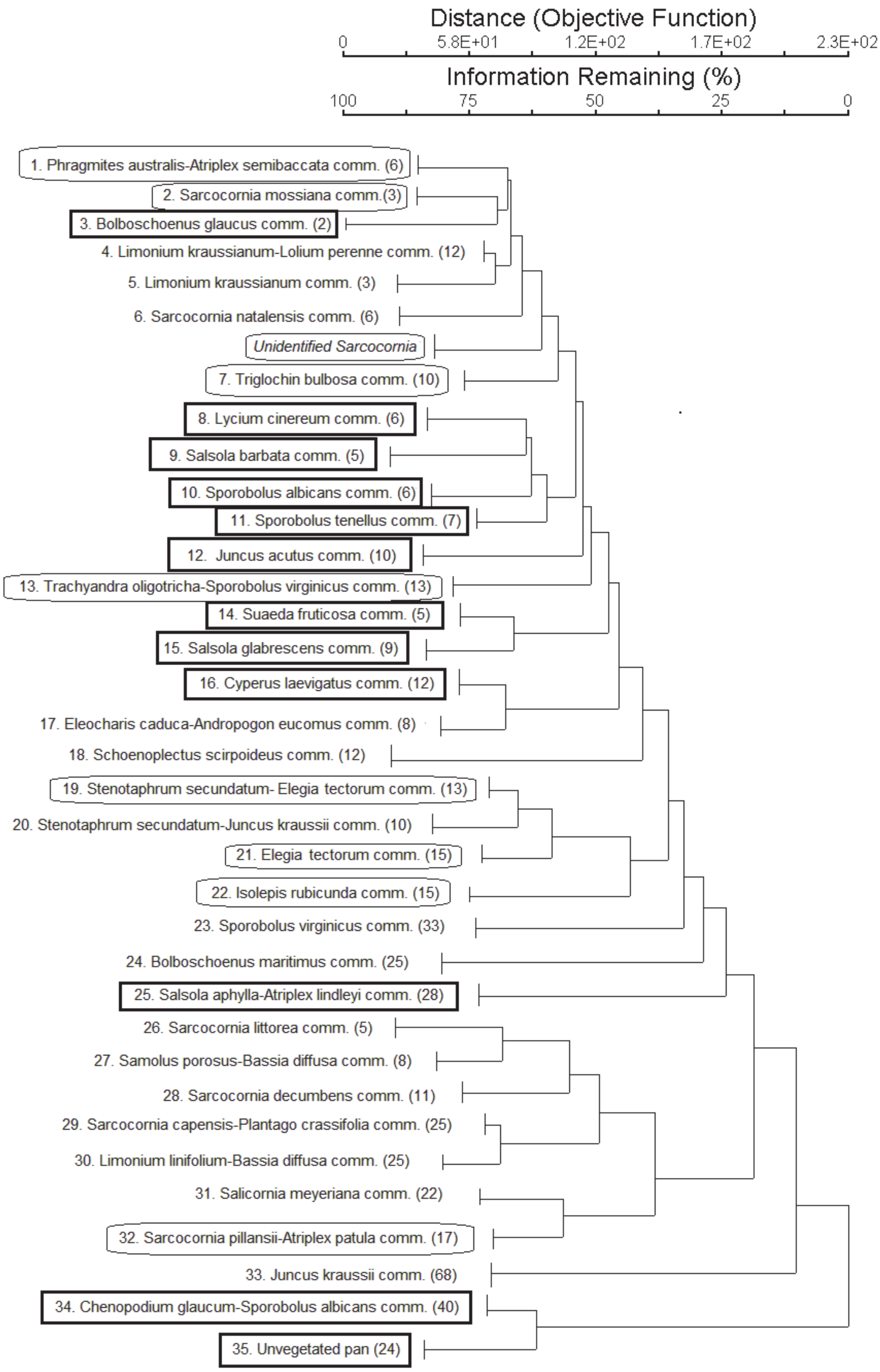


Figure 3.27 Dendrogram indicating affinities between the plant communities in Main Cluster 4 of saline wetlands. The thick square boxes represent inland wetlands from the arid regions, whereas the thin rounded boxes represent wetlands from the Cape coastal forelands and the unboxed communities represent those from estuaries.

Table 3.4 Plant communities and their indicator species for Estuarine, Brackish and Saline Wetland Vegetation.

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator value (IV)	p-value
1	6	*Sporobolus virginicus, Phragmites australis*	Inland pans Northwest	*Atriplex semibaccata*	41.3	0.001
				Acacia saligna	39.9	0.002
				Phragmites australis	38.3	0.003
				Acacia cyclops	28.5	0.014
				Drosanthemum floribundum	22.1	0.031
2	3	*Sarcocornia mossiana*	Inland valley bottoms Southern Cape	*Sarcocornia mossiana*	94.8	0.001
				Chaetobromus involucratus	33.3	0.01
				Ornithogalum species	33.3	0.01
				Parapholis incurva	26.7	0.02
				Berkheya rigida	21.7	0.028
				Manochlamys albicans	20.2	0.031
3	2	*Bolboschoenus glaucus*	Very scarce inland	*Bolboschoenus glaucus*	100	0.001
				Persicaria lapathifolia	50	0.004
				Verbena officinalis	50	0.004
				Xanthium strumarium	43.1	0.008
				Lactuca dregeana	40	0.006
4	12	Various grasses, *Lolium perenne*	Agulhas Plains	*Puccinellia fasciculata*	33.9	0.003
				Vellereophyton vellereum	23.9	0.023
				Limonium kraussianum	17.6	0.042
5	3	*Limonium kraussianum*	Western Cape estuaries	-		
6	6	*Sarcocornia natalensis*	Estuarine lakes East coast	*Sarcocornia natalensis*	65.3	0.001
7	10	Various	Saline grasslands Western Cape	*Triglochin bulbosa*	47.4	0.001
				Ficinia pygmaea	30	0.019
8	6	*Lycium cinereum, Prosopis glandulosa*	Karoo, edges of saltflats	*Lycium cinereum*	86.3	0.001
				Drosanthemum species	46.7	0.001
				Galenia sarcophylla	38.6	0.002
				Chloris virgata	36.1	0.004
				Prosopis glandulosa	33.3	0.006
9	5	*Salsola barbata*	Saline flats Kalahari	*Salsola barbata*	100	0.001
				Bassia salsoloides	23.6	0.026
				Sporobolus coromandelianus	20	0.036
				Galenia species	20	0.045
10	6	*Sporobolus albicans*	Pans Northwest and Free State	*Sporobolus albicans*	83.2	0.001
11	7	*Sporobolus tenellus*	Pans Free State	*Sporobolus tenellus*	100	0.001
				Portulaca oleracea	57.1	0.001
				Chenopodium album	43.8	0.002
				Cyperus usitatus	28.6	0.014
				Eragrostis obtusa	28.6	0.014
				Eragrostis trichophora	28.6	0.014
				Panicum coloratum	28.6	0.014
12	10	*Juncus acutus*	Inland valley bottoms Cape and Karroo	*Juncus acutus* ssp. *leopoldii*	90.7	0.001
				Conyza scabrida	23.6	0.03

Table 3.4 (continued)

Vegtype	No. of plots	Dominants	Description	Indicator species	Indicator value (IV)	p-value
13	13	*Romulea tabularis, Sporobolus virginicus*	West Coast	*Trachyandra oligotricha*	99.6	0.001
				Micranthus junceus	73.2	0.001
				Lolium multiflorum	53.8	0.003
				Romulea tabularis	48.2	0.001
				Ficinia indica	47.8	0.002
				Isolepis antarctica	46.2	0.001
				Isolepis levynsiana	46.2	0.002
				Schoenus nigricans	44.4	0.001
				Spiloxene aquatica	41.4	0.001
				Aponogeton angustifolius	39.9	0.003
				Jordaaniella dubia	38.5	0.006
				Bromus hordeaceus	36.2	0.002
				Zantedeschia aethiopica	32.1	0.005
				Wimmerella secunda	30.8	0.026
				Isolepis cernua	28.9	0.002
				Crassula natans	21.6	0.034
				Geissorhiza juncea	21.5	0.03
				Briza minor	20.4	0.035
14	5	*Suaeda fruticosa*	Saline flats Karroo	*Suaeda fruticosa*	95.9	0.001
				Zygophyllum simplex	60	0.001
				Atriplex erosus	52.1	0.001
				Sporobolus ioclados	27	0.017
15	9	*Salsola glabrescens*	Pans Free State	*Salsola glabrescens*	64	0.001
				Atriplex nummularia	22.2	0.022
16	12	*Cyperus laevigatus*	Inland salt pans Northwest and Free State	*Cyperus laevigatus*	45.7	0.001
17	8	*Juncus kraussii*	Places of freshwater seepage into Lake St. Lucia	*Lactuca inermis*	75	0.001
				Blumea species	50	0.001
				Eleocharis caduca	47.1	0.001
				Andropogon eucomus	36.5	0.011
				Paspalum vaginatum	26.9	0.005
				Cyperus natalensis	25	0.011
				Bacopa monnieri	25	0.017
				Pseudognaphalium luteo-album	20.2	0.041
18	12	*Schoenoplectus scirpoides*	Fringing estuarine lakes	*Schoenoplectus scirpoides*	99	0.001
				Aponogeton distachyos	17.5	0.046
19	13	*Elegia tectorum*	Coastal wetlands Western Cape	*Stenotaphrum secundatum*	32.5	0.002
				Cyperus sphaerospermus	30.4	0.013
				Plecostachys serpyllifolia	21.3	0.034
20	10	*Juncus kraussii*	Cape coast	*Ipomoea cairica*	20	0.027
21	15	*Elegia tectorum*	Agulhas Plains	*Elegia tectorum*	47.8	0.001
22	15	*Isolepis rubicunda*	Saline Flats Agulhas plains	*Isolepis rubicunda*	69.5	0.001
23	33	*Sporobolus virginicus*	Everywhere on coast	-		
24	25	*Bolboschoenus maritimus*	Fringing estuaries	*Bolboschoenus maritimus*	67.6	0.001

Table 3.4 (continued)

Vegtype	No. of plots	Dominants	Description	Indicator species	Indicator value (IV)	p-value
25	28	*Salsola aphylla*	Saline flats Karroo	*Salsola aphylla*	73.3	0.001
				Atriplex lindleyi	22.2	0.018
26	5	*Sarcocornia littorea*	Estuaries Cape	*Sarcocornia littorea*	97	0.001
27	8	*Bassia diffusa, Juncus kraussii*	Estuaries Cape	*Samolus porosus*	54.2	0.001
28	11	*Sarcocornia decumbens*	Estuaries Cape	*Sarcocornia decumbens*	54.1	0.001
29	25	*Sarcocornia capensis, Bassia diffusa, Limonium linifolium*	Estuaries Cape	*Sarcocornia capensis*	53.4	0.001
				Plantago crassifolia	47.7	0.001
				Silene clandestina	28	0.01
				Senecio rosmarinifolius	24	0.032
30	25	*Bassia diffusa, Sporobolus virginicus*	Estuaries Cape	*Limonium linifolium*	49.6	0.001
				Cotula filifolia	24.8	0.022
				Spergularia media	24.1	0.004
				Bassia diffusa	23.5	0.004
				Puccinellia angusta	20.1	0.01
31	22	*Salicornia meyeriana*	Estuaries Cape	*Salicornia meyeriana*	42.7	0.002
32	17	*Sarcocornia pillansii, Disphyma crassifolium*	Inland valley bottoms Southern Cape	*Atriplex patula*	47.1	0.002
				Sarcocornia pillansii	26.5	0.001
				Heliotropium curassavicum	21	0.014
				Disphyma crassifolium	19.8	0.028
33	68	*Juncus kraussii*	Everywhere on coast	-		
34	40	*Chenopodium glaucum, Cyperus laevigatus*	Saline flats Northwest province	*Chenopodium glaucum*	40	0.003
				Cyperus marginatus	25	0.013
				Spergularia rubra	20	0.033
35	24	none	Saline flats dry areas	empty		
Add.	7	*Sarcocornia* unidentified		*Sarcocornia* species		

3.5.2 Canonical ordination

The complication about saline wetlands is that the stress of salinity can be derived from very different causes. In the case of estuarine wetlands, the salinity stress is dependent on the tidal regime and this depends on daily fluctuations in the water level. In the case of inland saline wetlands, inundation by water is only very occasional and the cause of salinity is drought and deposition of solutes from the surrounding catchment. So the cause of high Sodium contents in soils can be very different in terms of the dynamics associated with it and in general it could be argued that this cluster of saline wetland vegetation should actually be split up into two Main Clusters: Estuarine Wetland Vegetation and Inland Saline Wetland Vegetation (generally saltpan vegetation). Estuarine wetlands have not been the focus of this project and a lot of variables that drive the dynamics in estuaries have not been recorded in detail, so it is worth considering doing a separate analysis on estuarine wetlands, but the current database is not well equipped to do this. What makes it complicated is that there are many transitional forms of Estuarine Wetland Vegetation, such as vegetation occurring in closed estuarine lakes that are more or less cut off from tidal influences and also in terms of species composition, some estuarine species do disperse further inland into other saline habitats. Therefore, Estuarine Wetland Vegetation has been included in the database, but not with sufficient data to understand them well in their own right and they will mainly be discussed in the light of comparison with inland systems. In a few cases, coastal catchments are subject to extremely complex dynamics such as in the case of the Nuwejaars River catchment on the Agulhas Plain or the Lake St. Lucia catchment on the KwaZulu-Natal Coast and these systems need to be investigated on their own to fully understand the interplay between hydrology, biogeochemistry and vegetation distribution. Again, within a national overview such as the current study, it is useful to include the vegetation types from these complex systems, but an explanation of all exact environmental conditions that determine these vegetation types is probably not going to be sufficient. In the following section, at first an overview of all wetland types of Main Cluster 4 will be given, those with soil data (Figure 3.28) (which are limited in extent, since most estuarine plots do not include soil data) and those without soil data (Figure 3.29). Secondly, the dataset will be split up in greater detail, with the estuarine and coastal saline wetlands separately shown in Figure 3.30, and the inland saline wetlands shown in Figures 3.31 (with soil data) and 3.32 (without soil data). The inland saline wetlands have been combined in their ordination diagram with several communities from Main Cluster 7, because the short grasslands of the semi-arid regions grade into the genuine saline pans and are often found in similar habitats. In terms of species composition however, communities of Main Cluster 4 tend to be dominated by succulent shrubs, whereas those of Main Cluster 7 are mainly dominated by grasses.

In **Figure 3.28** there are 19 communities represented, four of which only with a single plot (4.2 *Sarcocornia mossiana* Community, 4.5 *Limonium kraussianum* Community, 4.11 *Sporobolus tenellus* Community, and 4.18 *Schoenoplectus scirpoides* Community). The first axis is mostly associated with altitude with all inland wetland types on the right-hand side of the diagram (mainly 4.25 *Salsola aphylla-Atriplex lindleyi* Community, 4.34 *Chenopodium glaucum-Sporobolus albicans* Community, and 4.35 Unvegetated Pan) whereas the left-hand side of the diagram is mostly associated with estuarine wetlands of low-altitude. The percentage sand and wetness variables also point to the left along this axis and this is because the estuarine wetlands are generally the wettest in the saline context, as inland salt pans generally only have temporary inundation and also have mainly clay deposition in them. The second axis is mostly associated with Magnesium and Phosphorus but there are no vegetation types distinguished along this axis. The arrow for Electrical Conductivity is also mainly along the first axis and points towards the Highveld saline pans, which are often subjected to hypersaline conditions. The arrow for organic carbon is pointing negatively along the first axis but positively along the second axis. The only saline wetlands rich in organic matter are found in estuarine conditions, where inundation with salt water can be so common that organic matter does not decompose and peat develops. There is however not a specific plant community that is adapted to this situation and mostly it is the 4.33 *Juncus kraussii* Community that is found in these conditions. The Total Inertia for this ordination is 32.24 whereas the sum of all canonical eigenvalues is 6.18 so that means that about 19% of all variation can be explained by this ordination. This is not high but not surprising given the high variation within this cluster and the fact that estuarine systems are governed by much more variables than are given in the national database.

The CCA ordination of Figure 3.29 displays again the whole dataset, this time including also all plots where no soil data is available. Again, the main split is along the altitudinal gradient and the ordination basically has the same structure as the ordination in Figure 3.28. The most interesting thing that can be noted from this ordination diagram is Community 4.12, *Juncus acutus* Community, which is the only community shared between the coastal forelands and the inland karroo. This community can be found in both main ‘clouds’ of point in the diagram.

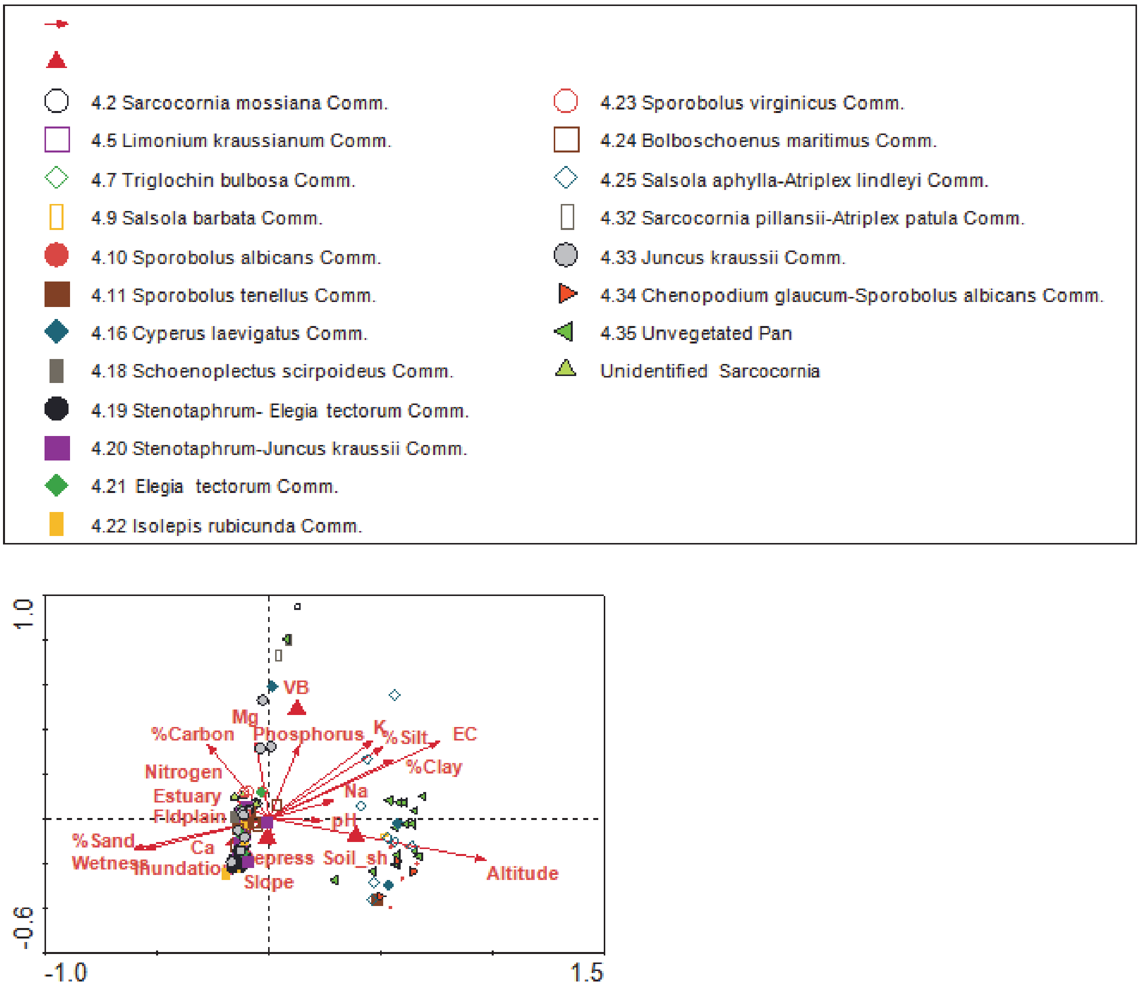


Figure 3.28 Canonical Correspondence Analysis of Main Cluster 4, including all soil variables. The main split between plots on the left (estuarine and coastal) and the right (inland saline) justifies the separate treatment of these wetlands in figures 3.30 to 3.31.

These first two ordinations both emphasize the main contrast between estuarine/coastal saline wetlands and inland saline wetlands and this justifies separate ordinations along this split. The ordination diagram for estuarine and coastal wetlands (**Figure 3.30**) does not show a very good differentiation of the different communities, because of the reasons mentioned above, but it is clear that the communities of 4.2 (*Sarcocornia mossiana* Community) and 4.32 (*Sarcocornia pillansii-Atriplex patula* Community) belong to the wetlands further inland which tend to be located around saline valley bottom wetlands or dead sea arms or closed estuaries. The only other distinction that can clearly be made is the wetter parts of the gradient in the lower left-hand corner of the ordination diagram, where the *Isolepis rubicunda* Community (Community 4.22) is particularly common. This community is ‘amphibious’, but tends to have relatively fresh water, but becomes dry and saline in summer. It is found in the deepest parts of coastal pans, for example on the cape flats or the Agulhas Plain.

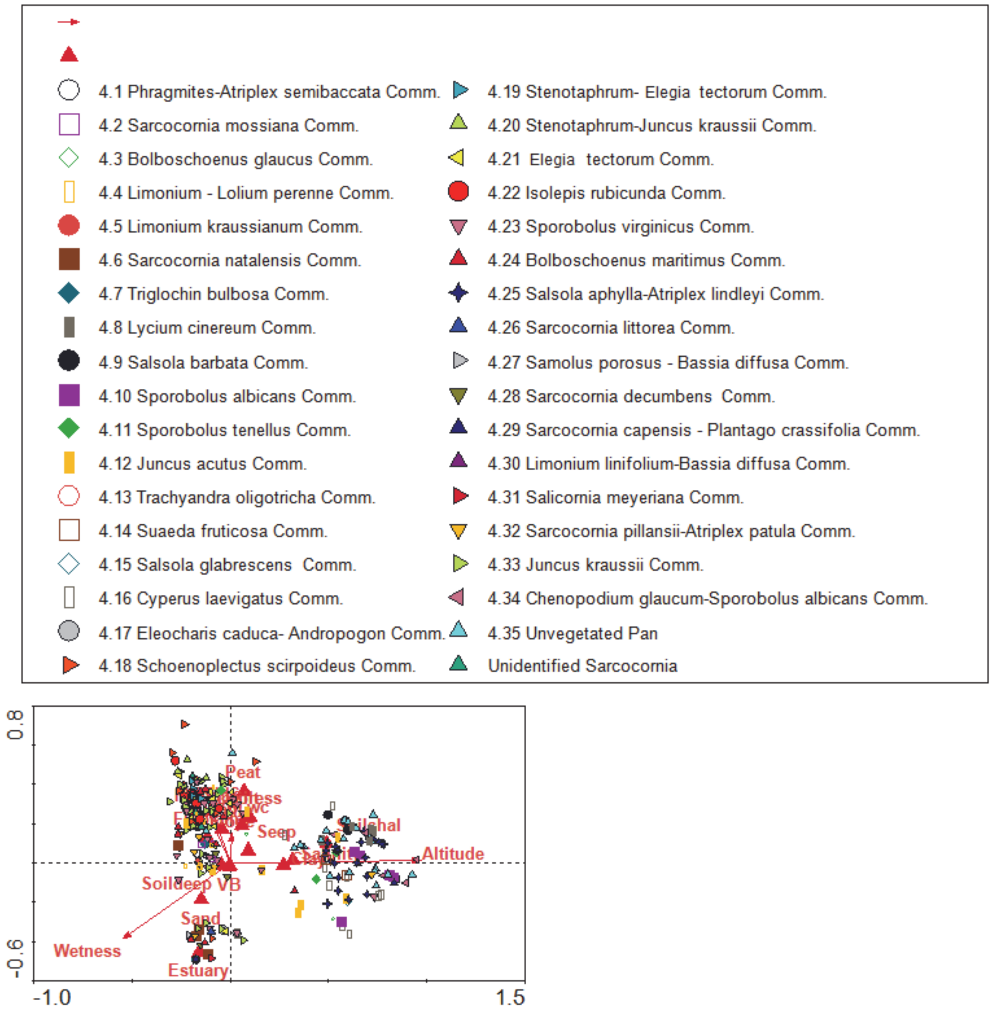


Figure 3.29 Canonical Correspondence Analysis for all communities of Main Cluster 4, with only a limited number of environmental variables, emphasizing the same split along an altitudinal gradient as displayed in Figure 3.28.

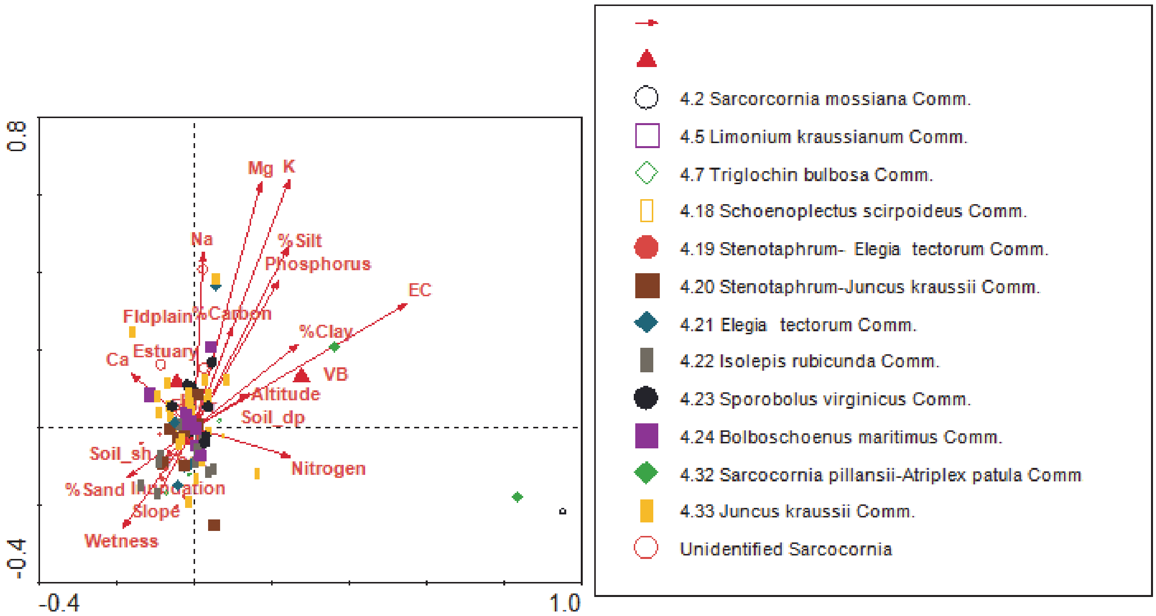


Figure 3.30 Canonical Correspondence Analysis for estuarine wetlands and Cape coastal wetlands. The distinction between many vegetation types cannot be made on the basis of the environmental variables that are supplied in the database.

Many other very common wetland vegetation types in estuaries, such as Community 4.33 *Juncus kraussii* Community, 4.23 *Sporobolus virginicus* Community and 4.24 *Bulboschoenus maritimus* Community cannot be distinguished based on the variables supplied in the database, yet they often have their own distinct places within the landscape of the estuaries, with *Bulboschoenus maritimus* and *Schoenoplectus scirpoideus* often fringing the waterbodies. Even the typical Western Cape salt pans with *Elegia tectorum* cannot be clearly differentiated in the ordination diagrams, but these are generally confined to salt pans further inland and do not occur directly in the estuary. Despite this, the total variation explained in the ordination displayed in Figure 4.13 is 36%. The *Sarcocornia*-dominated Communities (4.26 to 4.31) also all have their own place within the landscape of the estuary but for this we will have to refer to the original study that these data are derived from (Mucina et al. 2000).
Figure 3.30 shows the Canonical Correspondence Analysis ordination for the inland saline wetlands, combined with a number of communities of the semi-arid regions from Main Cluster which are found along the same environmental gradient. The Total Inertia for this ordination is 34.26 with the sum of canonical eigenvalues of 10.00, so that leads to Total Variation Explained of 29%. Both in the case of estuarine wetlands and in the case of inland saline wetlands the total variation explained has increased after dealing with the ordinations separately.
The first axis of this ordination is most clearly correlated with slope, although this variable is not very strong. The axis is also quite strongly correlated with Electrical Conductively (positively), Wetness (negatively) and Altitude (negatively), although EC and altitude are also positively correlated with the second axis. On the Highveld, the eastern part is higher and wetter and the western part is lower and drier. In the drier parts, there is more evaporation and higher salt contents in wetlands, so therefore therefore wetness and EC have opposite effects and most of the wetter wetlands are found at higher altitudes. The communities that

are found in these environments are 7.3 *Cynodon transvaalensis* Community and 7.1 *Schoenoplectus decipiens* Community Most of the saline pan communities from Main Cluster 4 are found in the right-hand side of the ordination diagram but some grassland communities are also found here, such as the *Eragrostis bicolor* Community (7.36) and *Sporobolus ioclados* Community (7.37).

The second axis of the diagram is mainly correlated positively with Sodium and negatively with Carbon contents. The communities that are on the lower end of this axis have the highest carbon contents and this is mostly Community 7.15 (*Panicum coloratum* Community) and Community 7.53 (*Schoenoplectus decipiens-Leptochloa fusca* Community). Both these communities seem to also occur much further towards the center of this gradient. The correlation between Sodium and Electrical Conductivity is evident, but some communities are occurring more in the direction of the Sodium, these are particularly Community 4.34 *Chenopodium glaucum-Sporobolus albicans* Community as opposed to Community 4.10 (*Sporobolus albicans* Community), which has probably a higher proportion of other solutes.

Along a typical salinity gradient, we find from brackish to hypersaline, typically first 7.3 *Cynodon transvaalensis* Community, then 7.36 *Eragrostis bicolor* Community, then 7.37 *Sporobolus ioclados* or 4.25 *Salsola aphylla-Atriplex lindleyi* Community, then 4.10 *Sporobolus albicans*, and lastly, 4.35 Unvegetated Pan. The difference between 7.37 (*Sporobolus ioclados* Community) and 4.25 *Salsola aphylla-Atriplex lindleyi* Community is not evident in terms of salinity but is clear in terms of their distribution ranges, (see the community descriptions) as the first community is more prominent further to the east, wheras the *Salsola aphylla* Community is spread throughout the Karroo.

In the ordination diagram of Figure 3.32 it becomes clear that without the data on soil chemistry, communities are much less clearly differentiated, although the altitudinal gradient is still quite clear. Community 7.52, *Leptochloa fusca*, is one of the most widely distributed communities over a wide range of altitudes.

Figure 3.31 Ordination diagram of Inland saline wetlands, combined with a number of clusters from Main Cluster 7.

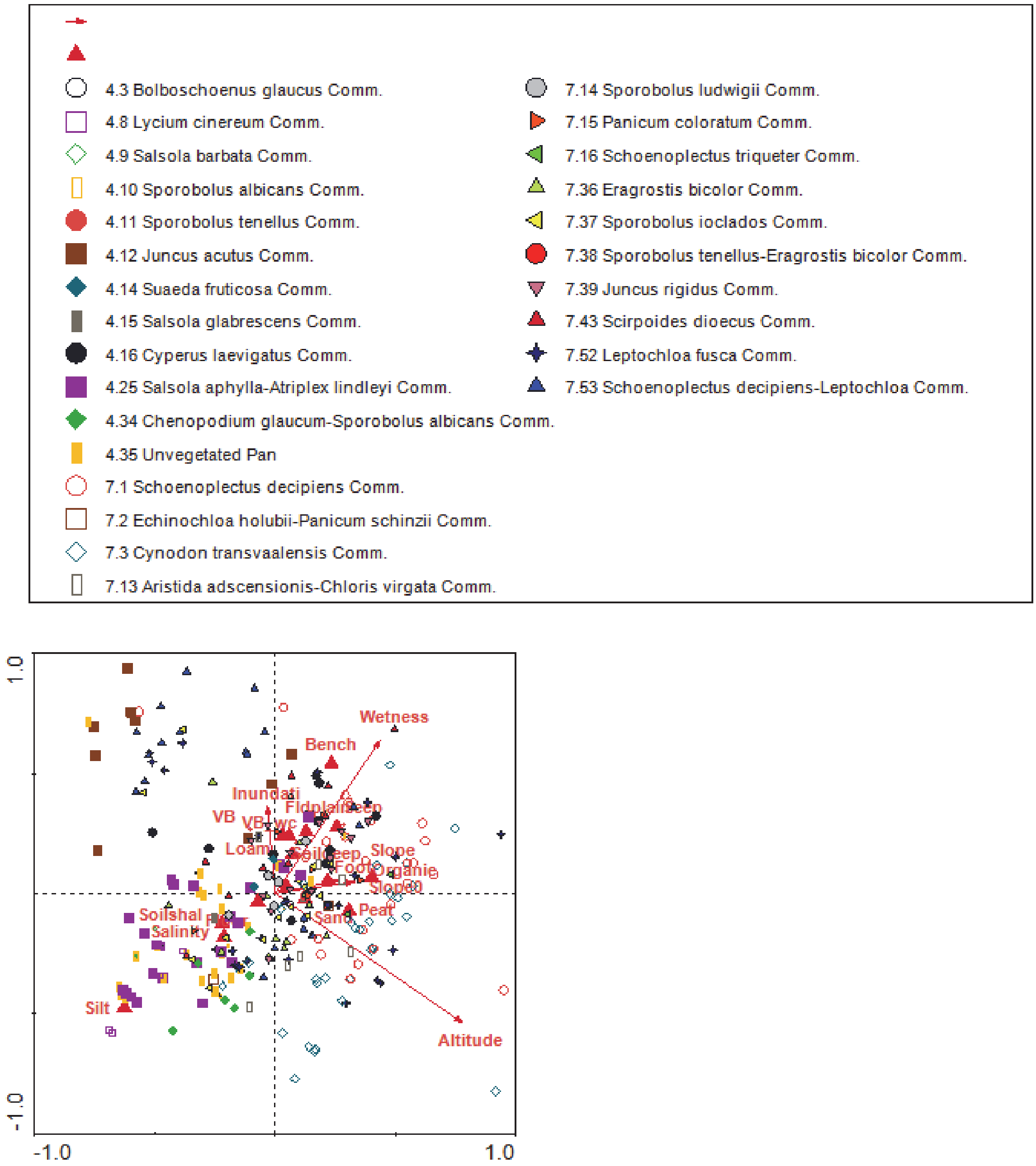


Figure 3.32 CCA Ordination of all communities of inland saline wetlands, including several communities from Main Cluster 7.

3.5.3 Species response curves

In terms of the species response curves, the dataset for Main Cluster 4 is again subdivided into the estuarine systems (which have been poorly sampled in terms of soils) and inland saline pans, which were combined with some of the more saline or brackish elements from Main Cluster 7.

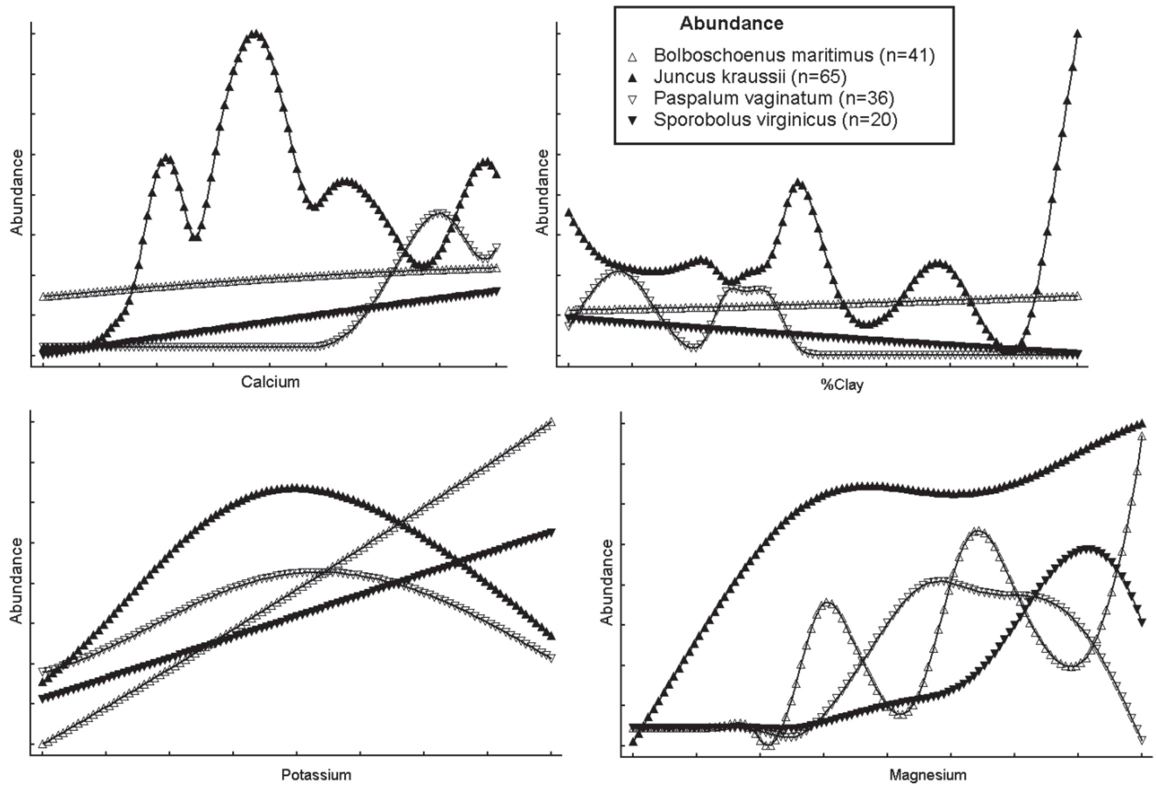


Figure 3.33 Species response curves for four common grasses and sedges occurring in estuarine ecosystems across the country.

In estuaries, the vegetation dynamics is dominated by a small number of species, for which the species responses are displayed in Figure 3.33. These species become dominant in Communities 4.23, 4.24, 4.33 and 7.23. The spiny rush *Juncus kraussii* prefers situations with an intermediate Calcium contents whereas *Paspalum vaginatum* shows a small positive response to higher Calcium. *Juncus kraussii* also responds strongly to Clay contents in the soil, although it is tolerant of sandy conditions, whereas *Paspalum vaginatum* prefers sandy conditions. Both species prefer intermediate levels of Potassium whereas *Sporobolus virginicus* and *Bolboschoenus maritimus* increase with higher levels of Potassium. All species respond positively to higher levels of Magnesium, but this response is strongest in *Juncus kraussii*.

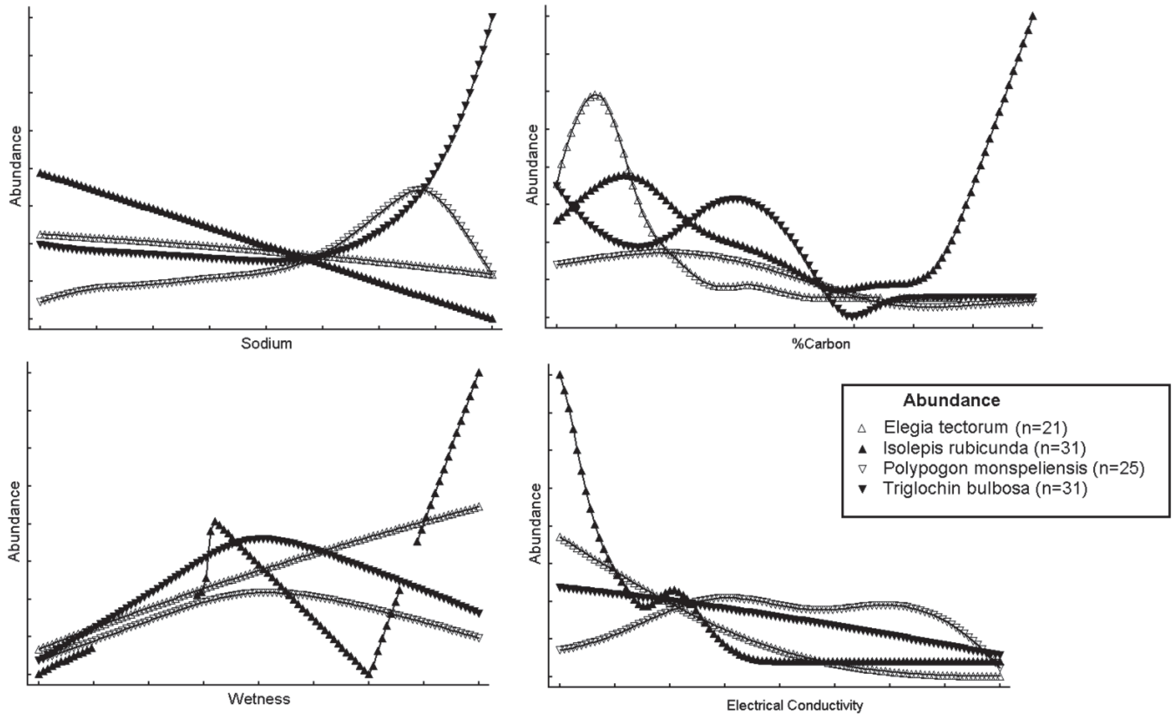


Figure 3.34 Species response curves for four species of graminoids occurring in inland saline wetland systems from the Cape coastal plains.

The four species of Figure 3.34 are all species that are common in the inland saline pans of the Western Cape. They become dominant in the Communities 4.7, 4.21 and 4.33. The species *Isolepis rubicunda* responds negatively to high levels of Sodium and Electrical Conductivity. This species is an annual aquatic sedge that grows in the wetter patches of salt pans that dry out in summer, so during its growing season it does not handle salinity very well, although in time, the influence of salinity will be felt. This species also responds most positively to soil carbon. The tuft-forming restio *Elegia tectorum* responds negatively to soil carbon but positively to wetness. It also has a negative response to Electrical Conductivity so it is also not strictly adapted to saline habitats, even though it often occurs in habitats where it needs to tolerate it. *Triglochin bulbosa* is the species that is best capable of handling high Sodium levels.

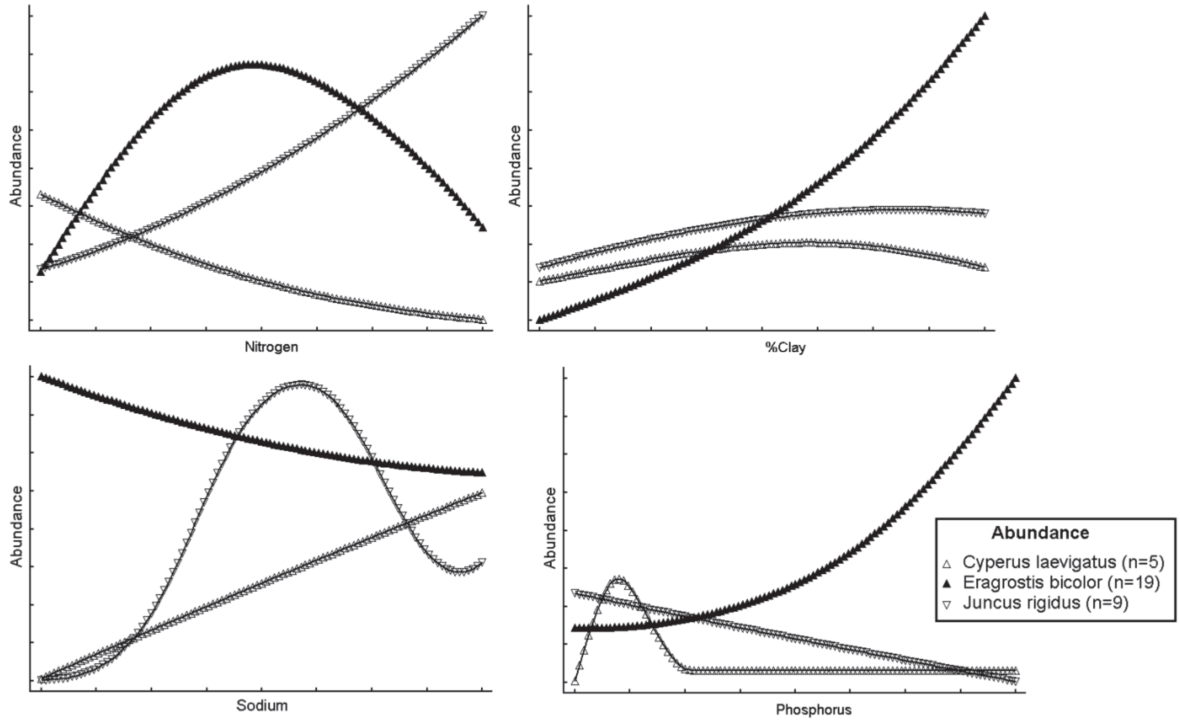


Figure 3.35 Species response curves for three species from inland saltpans from the edge of the arid regions.

Figure 3.35 displays the species response curves for three species that are more common in inland saline habitats, although *Cyperus laevigatus* is also found in estuaries. They become dominant in the Communities 4.16, 7.36 and 7.39. They show distinct responses to various soil variables, with *Eragrostis bicolor* having an affinity for heavy clay soils and intermediate Nitrogen levels. *Juncus rigidus* has a positive response to high Nitrogen levels while *Cyperus laevigatus* prefers low Nitrogen levels. In terms of Sodium, *Cyperus laevigatus* has a positive response to high Sodium levels, whereas *Eragrostis bicolor* decreases. *Juncus rigidus* peaks at intermediate Sodium levels.

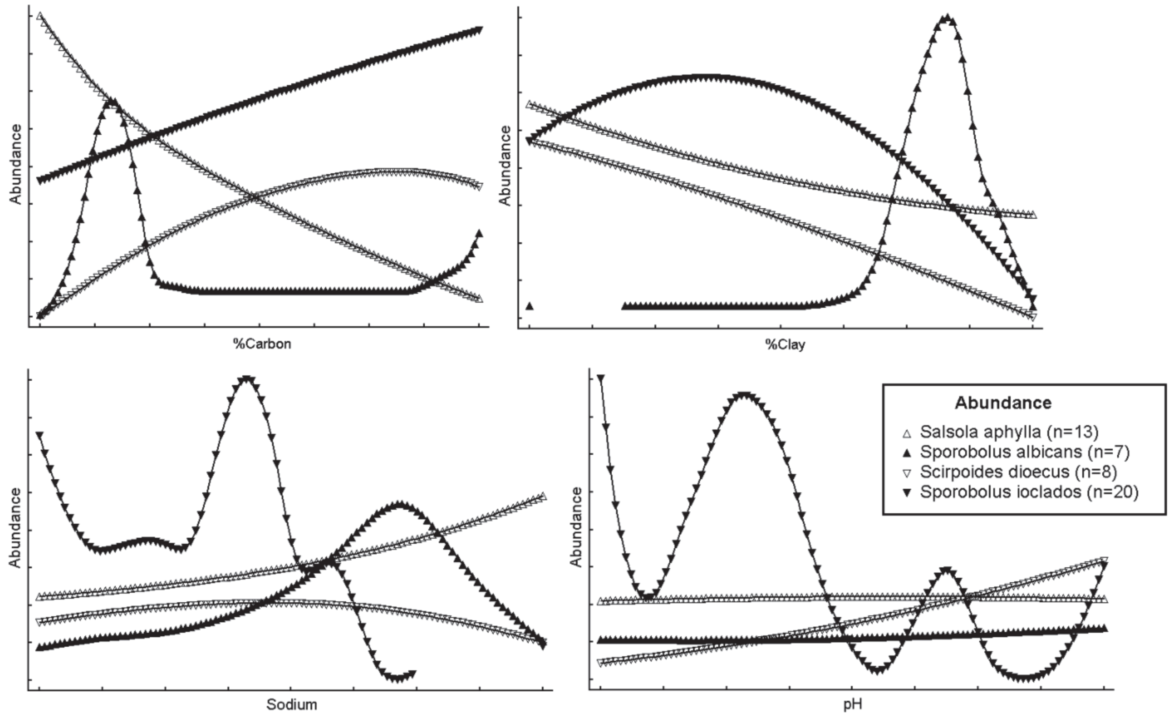


Figure 3.36 Species response curves for four species from inland saline pans from throughout the Karoo.

The four species in Figure 3.36 occur in inland salt pans, but generally in more saline habitats than the species in the previous graph. They become dominant in Communities 4.10, 4.25, 7.37 and 7.43. The succulent shrub *Salsola aph*ylla responds negatively to soil carbon and positively to Sodium and it still grows in quite hypersaline conditions. It is the only species to do so, and all other species eventually decrease at extreme Sodium levels, although the grass *Sporobolus albicans* still peaks at relatively high Sodium levels. This grass would also replace *Salsola aphylla* when clay levels in the soil are high. The grass *Sporobolus ioclados* prefers situations with high soil carbon and low pH and peaks at intermediate clay levels. The sedge *Scirpoides dioecus* shows the strongest negative response to high clay levels and occurs in the most sandy habitats, often in dry riverbeds.

3.5.4 Description of communities

1. *Phragmites australis-Atriplex semibaccata* Community

This community is restricted to the West Coast. All data to describe this community comes from a single study which used a plot size of 100 m^2, so it is not clear whether this community can only be defined at that particular spatial scale.

2. *Sarcocornia mossiana* Community

Sarcocornia mossiana is one of two species of Sarcocornia that can be found quite far outside of estuaries in the inland areas of the Western Cape. The other is *Sarcocornia pillansii*, with which it often grows together. It typically grows in saline 'rivers' or 'valley bottom' wetlands that are scattered over the Overberg landscape.

3. *Bolboschoenus glaucus* Community

This is a rather scarce and at the moment under-sampled community that is characterized by the dominance of *Bolboschoenus glaucus*. Otherwise, this community has also been noted from the lakeshores of Lake Chrissie in Mpumalanga.

4. *Limonium kraussianum-Lolium perenne* Community

This community represents a transition between saline environments and weedy grasslands in the Southern Cape, particularly around Cape Agulhas.

5. *Limonium kraussianum* Community

This community is under-sampled and also largely restricted to the Agulhas Plain. It may just be a variant of the previous community and more data needs to be collected.

6. *Sarcocornia natalensis* Community

Sarcocornia natalensis is the most widespread of all *Sarcocornia* species in South Africa and the only species becoming dominant is subtropical estuaries, although it is often found with a sparse cover.

7. *Triglochin bulbosa* Community

This community represents some brackish habitats that were found along the Western Cape coast. The species *Triglochin bulbosa* has recently received some taxonomic attention in the form of a revision but the 'typical' species is restricted to freshwater wetlands along the coast and never really becomes dominant. Some other species that have been split of from this species are restricted to estuaries in the Southern Cape but they have not been recorded in this project.

8. *Lycium cinereum* Community

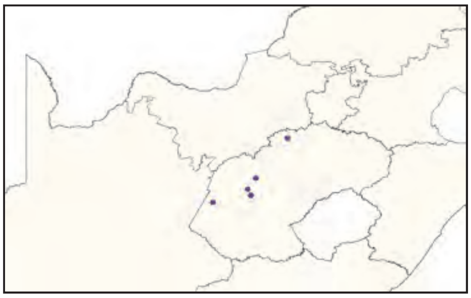
This community is found on the edge of large salt pans in the Karoo and represents the transition from the area where there is significant salt stress to the upland area where the main obstacle for plant growth is just drought. It is therefore quite marginal as a wetland community, but cracks in the clay indicate that this community does get inundated every now and then. It is replaced by the *Salsola aphylla-Atriplex lindleyi* Community (4.25) or the unvegetated pan (4.35) towards the center of the pan. It is structurally taller and denser than Community 4.25 and is dominated by woody shrubs and various succulents. It is also not as common as Community 4.25 and is sensitive to invasion by *Prosopis glandulosa*, which has been recorded in various plots, but is very extensive in certain areas of the Central Karoo vloere.

9. *Salsola barbata* Community

The species *Salsola barbata* replaces the much more common *Salsola aphylla* in the Karoo in the large pans at the southern edge of the Kalahari. It is likely that this community is much more common across the border in Namibia and Botswana. It is very sparsely vegetated and occurs on large open salt pans with and is in most aspects very similar to community 4.25, the *Salsola aphylla-Atriplex lindleyi* community.

10 *Sporobolus albicans* Community

This community is dominated by the grass *Sporobolus albicans*, which has its distribution mainly along the lowere reaches of the Vaal River, where it is found along saline edges of wetlands. It is particularly common in the western part of the Free State. The species *Sporobolus albicans* is distinct from all other *Sporobolus* species that can be found in pans in this area.

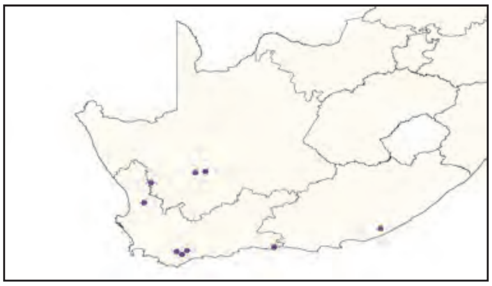


11 *Sporobolus tenellus* Community

This represents another community dominated by a small grass from the genus *Sporobolus*, and that is found slightly further to the south from the previous species. One record of this community was made from Maputaland, where another species, *Sporobolus subtilis*, is also common.

12 *Juncus acutus* Community

As its name implies, the large rush *Juncus acutus* is very sharp and this is a plant community that is difficult to move through. It is typical for Cape inland wetlands but it also enters into the southern parts of the Karoo and into the Eastern Cape.



13 *Trachyandra oligotricha*-*Sporobolus virginicus* Community

These represent species-rich communities from wet coastal fynbos on the Cape flats. The validity of this cluster needs to be assessed as it is dependent on an older study from the seventies (Boucher 1978) that used a plot size of 10 x 10 meters and it may therefore represent heterogeneous plots.

14. *Suaeda fruticosa* Community

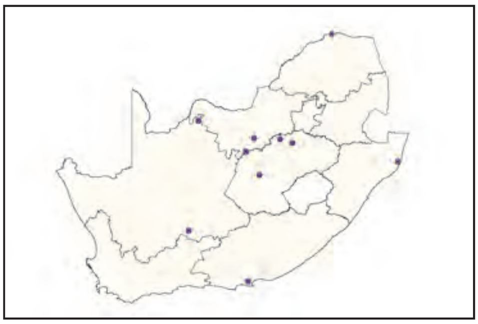
This community is dominated by the succulent shrub *Suaeda fruticosa*, and seems to be quite localized, although the species that dominates it is widespread throughout the arid regions of South Africa.

15. *Salsola glabrescens* Community

This community occurs mostly on the outer edge of saline pans dominated by *Salsola aphylla* in the Free State, but further west, this niche is more occupied by the *Lycium cinereum* community. The dwarf shrub *Salsola glabrescens* is very similar to *Salsola aphylla*, but much more common in upland situations.

16. *Cyperus laevigatus* Community

This is a community dominated by the sedge species, *Cyperus laevigatus*, that stands out for growing in quite saline conditions, unlike any other species of the genus *Cyperus*. The species is sometimes found in estuarine ecosystems, but mostly in estuarine lakes as it cannot deal with direct marine inundation. However, it becomes mono-dominant mostly in the inland salt pans of the Free State and North-West Province. It is one of the few species that can both occur in estuarine saline wetlands as well as inland saline wetlands.

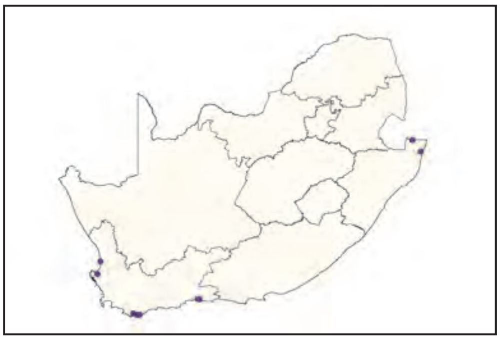


17. *Eleocharis caduca – Andropogon eucomus* Community

This community is found in a more or less unique situation along the eastern shores of Lake St. Lucia where freshwater seepage flows into a saline lake. The contact zone between freshwater and saline conditions creates a rich community with various saline species but a surprisingly mix with all kinds of rare and special plants in it.

18. *Schoenoplectus scirpoides* Community

This is a monospecific community consisting of dense stands of the tall sedge *Schoenoplectus scirpoides*, which is found mostly next to estuarine lakes (in one case it was found next to an inland lake), which are clayey and mostly strongly smelling of sulphuric gases.



19. *Stenotaphrum secundatum – Elegia tectorum* Community

In a few occasions the restio *Elegia tectorum* and the buffalo grass *Stenotaphrum secundatum*, both species that can deal well with drought as well as inundation, occur together to form a unique community. This community is mainly restricted to dune slacks.

20. *Stenotaphrum secundatum – Juncus kraussii* Community

Buffalo grass (*Stenotaphrum secundatum*) can also grow together with *Juncus kraussii* in a more grassy form of estuarine rushlands. This community and the previous one form a link with Main Cluster 7 where there is a community 7.31 where Buffalo grass grows as a monodominant.

21. *Elegia tectorum* Community

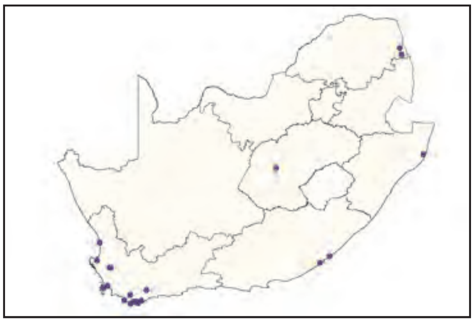
This is a unique community for the Western Cape where the hardy restio *Elegia tectorum* survives in conditions that are wet in winter and very dry and saline in summer. The community is rich in small annual grasses and forbs, most of which die in summer. The community is particularly common and conspicuous in the Agulhas plains.

22. *Isolepis rubicunda* Community

The swimming sedge *Isolepis rubicunda* occurs in parts of the wetlands of the Western Cape that contain a lot of water in early spring but dry out completely during the summer season, and are then subject to saline conditions.

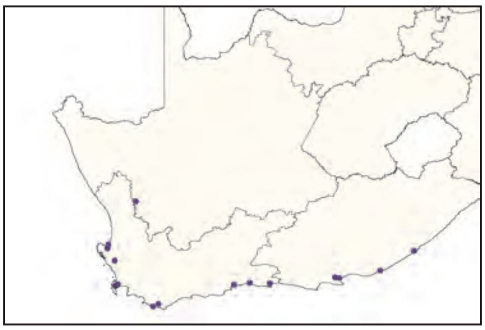
23. *Sporobolus virginicus* Community

The grass *Sporobolus virginicus* is very common in coastal areas, either on sand dunes or estuarine wetlands where it often occurs on the edges of estuaries. It is interesting that it also is found inland in some places, such as the Western Cape, Free State and Kruger Park. It is therefore one of the few species that provides a real link between all types of saline wetlands and it appears that it is just adapted to saline conditions and is quite indifferent to hydrodynamics.



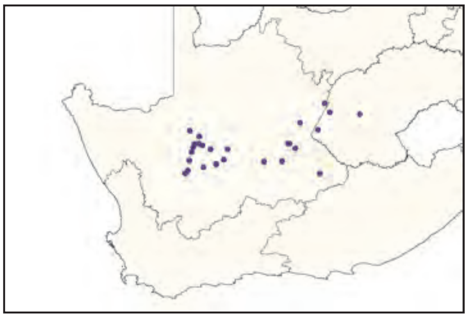
24. *Bolboschoenus maritimus* Community

Bolboschoenus maritimus is a conspicuous large sedge often occurring next to open water of estuaries. It occurs mostly in monospecific stands but it is sometimes mixed with common reed or other clonal species. It is rarely found inland and largely restricted to coastal areas.



25. *Salsola aphylla – Atriplex lindleyi* Community

This is the dominant community in salt pans in the central part of the Karoo, although its distribution extends all the way into the Free State. The community is very variable in terms of its species richness. In most cases, *Salsola aphylla* occurs as a sparse monoculture, but sometimes there is a mix of various grasses and succulent growing in between as well. The most common forb co-occurring in this community is *Atriplex lindleyi* which is an alien species. This community occurs in dry pans with cracked clay and the clay minerals often form a layer of shining mica at the surface, which gives an effect like it is a mirror.



26. *Sarcocornia littorea* Community

This community is dominated by a species of *Sarcocornia* that is usually more associated with rocky shores and generally occurs in the supratidal zone subjected with most salt stress originating from salt spray and less from inundation. It is probably more common than indicated on the distribution map but probably not very common.

27. *Samolus porosus – Bassia diffusa* Community

This community is probably much more common than just the Uilkraals estuary in the Western Cape, but this reflects the scarcity of estuarine studies within the database. It is often found near splash zones and drift lines in an estuarine ecosystem.

28. *Sarcocornia decumbens* Community

The succulent shrub *Sarcocornia decumbens* is one of the few species of *Sarcocornia* that can be found outside estuarine ecosystems and it has been found in several inland saline systems in the Western Cape. Unlike *Sarcocornia mossiana* or *Sarcocornia pillansii*, this species remain low to the ground and creeping producing thick fleshy stems. According to Mucina et al. (2003) this community occurs in more Nitrogen-rich conditions than any of the other *Sarcocornia*-dominated communities.

29. *Sarcocornia capensis – Plantago crassifolia* Community

This community is characteristic for the supratidal zone in Cape estuaries (probably much more widespread than indicated on the map). One aberrant plot dominated by *Plantago crassifolia* in a saline zone in a wetland in the Stormberg was also classified under this cluster.

30. *Limonium linifolium – Bassia diffusa* Community

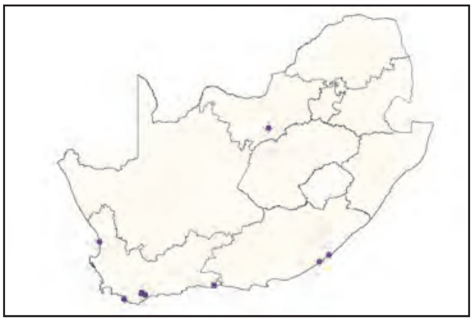
This community is poor in species and typical for Cape estuaries where it can tolerate a wide range of conditions in inundation. It is probably much more widespread and the distribution reflects the paucity of estuarine studies within the vegetation database.

31. *Salicornia meyeriana* Community

This community is restricted to the lower intertidal zone and is often very sparsely vegetated. The small succulent herb *Salicornia meyeriana* is an annual that can withstand inundation with salt water very well. The community is probably more widespread than indicated on the distribution maps.

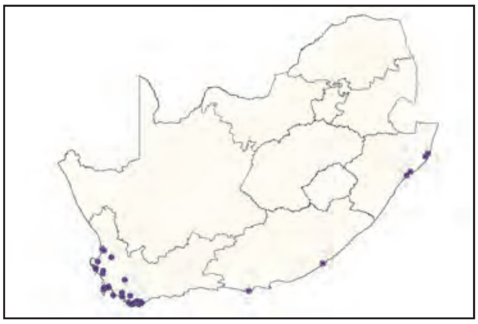
32. *Sarcocornia pillansii-Atriplex patula* Community

This community is characterized by the dominance of the shrubby species *Sarcocornia pillansii* which is very variable and occurs mostly in species-rich communities in the supratidal zone, but also in inland saline wetlands, particularly in the Overberg. One saline pan dominated by *Heliotropium curassavicum* from North-West Province was also classified with this community. Another peculiar wetland plant found in this community is the creeping vygie *Disphyma crassifolium*, which can locally dominate.



33. *Juncus kraussii* Community

This community represents the most important and widespread estuarine plant community and it is very variable in its composition. There are many plant species that can co-occur with the dominant *Juncus kraussii*, ranging from various Restionaceae in the Cape to subtropical grasses in Kwa-Zulu-Natal. In the Western Cape, communities dominated by *Juncus kraussii* still occur reasonably far inland, although it is also often replaced by the larger *Juncus acutus*. Just like this last species, *Juncus kraussii* is tough and spiky and therefore not pleasant to walk through, but the sedge is also harvested in KwaZulu-Natal for weaving material under the name iNcema.

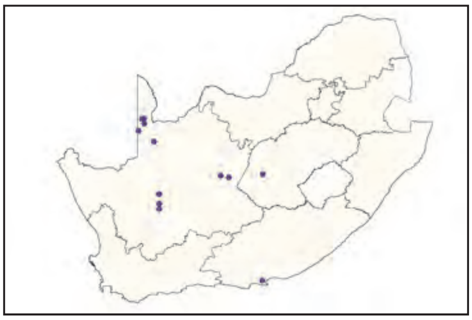


34. *Chenopodium glaucum – Sporobolus albicans* Community

This community represents the limit of the vegetated zone in salt pans on the western part of the Highveld. It consists largely of extremophiles as the community is mostly found at the edges of saline pans that are not vegetated at all. The vegetation only attains a cover of between 5% and 25%. The succulent forb *Chenopodium glaucum* and the grass *Sporobolus albicans* are the most common species, but a range of others are also found including various weeds.

35. Unvegetated pan

This community represents the unvegetated zones of the center of saline pans and was sampled within this project as it is assumed to be important when monitoring wetlands. Occasionally a small seedling of an extremophile can still be found but largely the area is empty covered by cracked clay and is inundated by water for only small periods every few years. Of course there are other wetland conditions in which there is no or very sparse vegetation cover for example when there is an unstable substrate or where the water column is too deep, but this community represents only the hypersaline conditions in the dry areas.
The actual conditions of this community can still differ widely as can be observed in the ordination diagrams.



3.5.5 Discussion of Estuarine, Brackish and Saline Wetland Vegetation

The wetlands of this Main Cluster are very diverse in their habitat requirements as the stress of salinity will be experienced in very different manners by the plant whether it comes daily due to tidal processes, or whether it comes seasonally due to drought. Hypersalinity is much more intense in the last situations, but inundation with salt water brings its own stresses. It should therefore not be surprising that there are only very few species shared between inland saline systems and estuarine saline systems (only *Sporobolus virginicus* and *Cyperus laevigatus,* even though the first one is certainly found more on the coast and the second one is found more inland.) For that reason it could be argued that the current Main Cluster is a bit artificial and should actually consist of two clusters.
The reason why this has not been done is mostly because Estuarine Wetland Vegetation is not particularly well represented in the current study. It was mainly included as a kind of afterthought, mainly to elucidate their relationships with other saline wetland vegetation, as some species seem to be not particularly estuarine but generally adapted to a saline environment. The South African Wetland Classification System mostly focuses on inland systems and most of the conservation issues concerning wetlands in South Africa are specific to inland wetland systems. These conservation issues are what informed the need for the current study, as does the need for a responsible management of South Africa's freshwater resources.
Often estuaries have their own experts, and there is not a lot of interaction between estuarine ecologists and wetland ecologists. However, for the sake of a general oversight, it is valuable to include estuaries so that their position in relation to other saline wetlands is

clear. A lot of estuarine vegetation types are indeed unique to estuaries, but there are certainly overlaps with other ecosystems, for example in terms of estuarine lakes, seepage zones flowing into estuaries and floodplains grading into estuaries. There may be little overlap in terms of species that occur in both estuaries and inland saline pans of the Karoo, but there are many estuarine plants that also occur in other saline systems that are in close proximity to the coast but not in direct contact with the sea. These are for example *Juncus kraussii, Sarcocornia pillansii, Bolboschoenus maritimus, Schoenoplectus scirpoideus* and *Triglochin bulbosa*. Note that there are also plants that are really strictly estuarine (*Sarcocornia capensis, Salicornia meyeriana, Bassia diffusa, Samolus porosus*).

A holistic overview of wetland types of all of South Africa should include estuarine types as well, even though these systems also require collection of their own types of explanatory variables, such as the influence of the tidal regime.

3.6 Main Cluster 5: Montane Grassy Wetland Vegetation

Montane Grassy Wetland Vegetation is centred on the Drakensberg region of South Africa and are found in the headwaters of the catchments that form the most important sources of freshwater in the industrial heartland of the country. They have affinity with the wetlands of the Highveld region (Main Cluster 6), but even though they are called 'grassy', they generally contain a higher number of forbs and the forbs also tend to cover more in the vegetation, especially at the higher altitudes (Sieben et al. 2010). With this variety of growth forms, the montane wetlands can be considered among South Africa's most species-rich wetlands. Many of the wetlands are seepage zones where groundwater discharges at the surface. The temporary wetlands at the edge of such zones grade into the surrounding mountain slope vegetation and it is often difficult to delineate wetlands in these areas, especially when soils are black.

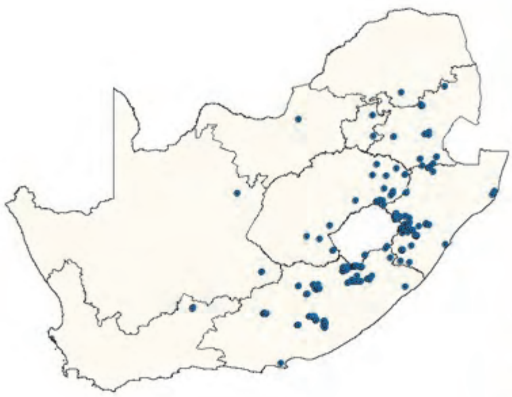


Figure 3.37 Distribution map of Montane Grassy Wetland Vegetation and a representative picture of a wetland in this Main Cluster.

The wetlands from this cluster are quite closely related to the Temperate Grassy Wetland Vegetation of Main Cluster 6 and there are many occasions where the communities in both Main Clusters are actually quite close to one another and it may be argued that some have been arbitrarily placed, as many communities in Main Cluster 6 are also particularly rich in the Drakensberg foothills. Furthermore, vegetation plots from Main Cluster 5 are also regularly occurring along the escarpment area and in some cases, aberrant plots from next to the coast even seem well placed within this cluster.

3.6.1 Classification and Indicator Species Analysis

The dataset that was used for cluster analysis consisted of 412 vegetation plots and 653 species. The outliers of the resulting classification were subjected to their own classification and dummy species were used to identify these clusters in the overall classification.

The optimal number of clusters was selected at the point at which the average p-value was less than 0.15, and the average indicator value at this stage was greater than 20. At this stage there were 32 plant communities that were identified. Indicator species analysis was used to test for well supported indicator species within each group. Only species with an indicator value of more than 20 and a p-value less than 0.05 were selected as well supported indicator species and displayed in Table 3.5.

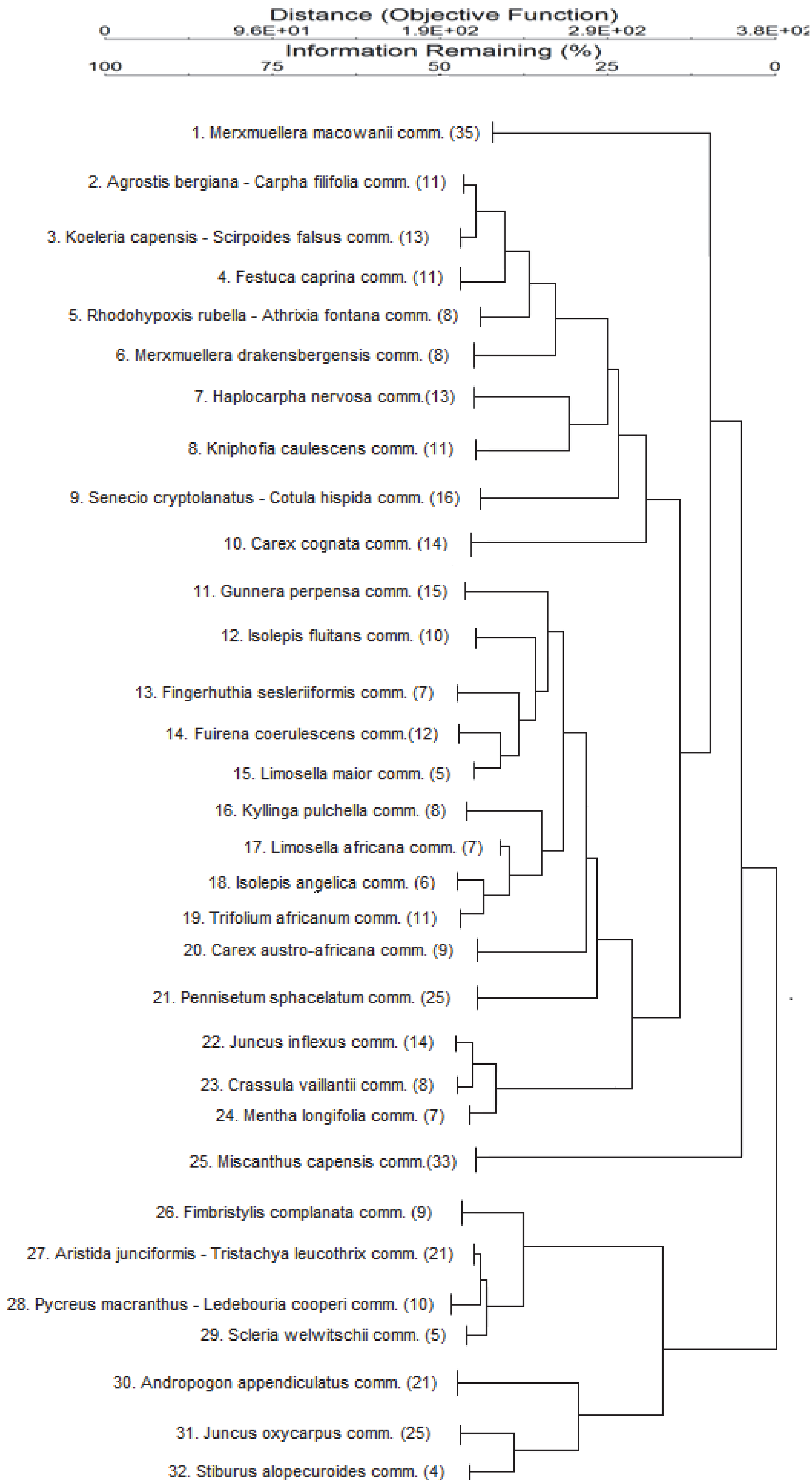


Figure 3.38 Cluster dendrogram for Montane Grassy Wetland Vegetation.

Table 3.5 Communities and associated indicator species for Montane Grassy Wetland Vegetation (Main Cluster 5).

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
1	35	*Merxmuellera macowanii*	Drakensberg, Sneeuberg High peaks	*Merxmuellera macowanii*	64	0.0002
2	11	*Carpha filifola, Restio sejunctus*	Highest altitudes	*Carpha filifolia*	36.4	0.001
				Dierama pauciflorum	34.4	0.001
				Wurmbea elatior	27.5	0.002
				Restio sejunctus	23.9	0.003
				Agrostis bergiana	20.7	0.002
				Alepidea natalensis	20	0.007
3	13	*Koeleria capensis, Festuca caprina, Dracoscirpoides falsus*	Highest altitudes	*Dracoscirpoides falsus*	38.5	0.001
				Merxmuellera disticha	26	0.001
				Poa binata	20.6	0.003
4	11	*Festuca caprina*	Mid and high altitudes	*Festuca caprina*	28	0.001
5	8	No clear dominant	High altitudes Drakensberg	*Rhodohypoxis rubella*	87.5	0.001
				Alepidea pusilla	87.5	0.001
				Schoenoxiphium filiforme	75.3	0.001
				Athrixia fontana	55.1	0.001
				Felicia species	50	0.001
				Rhodohypoxis baurii	30.2	0.001
				Ericaulon dregei	25.9	0.002
				Senecio natalicola	28.3	0.003
				Sebaea repens	22.3	0.005
				Senecio macrocephalus	20.2	0.005
6	8	*Merxmuellera drakensbergensis*	High altitudes Drakensberg	*Merxmuellera drakensbergensis*	83	0.001
7	13	*Haplocarpha nervosa*	High and middle altitudes	*Haplocarpha nervosa*	31.2	0.001
8	11	*Kniphofia caulescens*	Highest altitudes	*Kniphofia caulescens*	63.6	0.001
9	16	No clear dominant	Highest altitudes	*Senecio cryptolanatus*	87.5	0.001
				Limosella longiflora	74.1	0.001
				Agrostis subulifola	72.9	0.001
				Helichrysum bellum	68.8	0.001
				Thesium nigrum	50	0.001
				Bryum argenteum	49.5	0.001
				Cotula hispida	41.7	0.001
				Koeleria capensis	24.6	0.001
10	14	*Carex cognata*	High and middle altitudes Drakensberg	*Carex cognata*	55.1	0.001
11	15	*Gunnera perpensa*	High and middle altitudes Drakensberg, KZN Midlands	*Gunnera perpensa*	36.1	0.001
				Epilobium salignum	25	0.002
				Nidorella agria	20.5	0.01
12	10	*Isolepis fluitans*	Foothills Drakensberg	*Isolepis fluitans*	30.4	0.001
13	7	*Fingerhuthia sesleriiformis*	Eastern Cape Mountains	*Fingerhuthia sesleriiformis*	48.6	0.001
				Poa pratensis	24	0.003
14	12	*Fuirena coerulescens*	Eastern Cape Mountains	*Fuirena coerulescens*	70.4	0.001
				Lobelia flaccida ssp. *flaccida*	25.7	0.002
15	5	*Limosella maior*	Wet patches in seepages	*Limosella maior*	67.7	0.001
16	8	*Kyllinga pulchella*	Low and middle altitudes	*Kyllinga pulchella*	75.9	0.001
				Limosella inflata	21.3	0.006

Table 3.5 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
17	7	*Dracoscirpoides ficinioides*	Highest altitudes	*Limosella africana*	53.6	0.001
				Dracoscirpoides ficinioides	29.9	0.001
				Crassula gemmifera	21.8	0.008
18	6	*Isolepis angelica*	Highest altitudes	*Isolepis angelica*	44.9	0.001
				Juncus lomatophyllus	21.9	0.004
				Juncus bufonius	20.8	0.004
19	11	*Trifolium africanum*	Eastern Cape Mountains	*Trifolium africanum*	26.3	0.001
				Agrostis lachnantha	21.5	0.001
20	9	*Carex austro-africana*	Midlands, Drakensberg foothills	*Carex austro-africana*	81.3	0.001
				Phragmites australis	28.3	0.002
21	25	*Pennisetum sphacelatum*	Midlands, Drakensberg foothills	*Pennistum sphacelatum*	31.1	0.001
22	14	*Juncus inflexus*	Eastern Cape Mountains	*Juncus inflexus*	31.2	0.001
23	8	No clear dominant	Eastern Cape Mountains	*Crassula vaillantii*	68.1	0.001
				Pentaschistis densifolia	46.6	0.001
				Veronica anagallis-aquatica	35.4	0.001
				Juncus dregeanus	20.5	0.001
				Sebaea macrophylla	22.4	0.002
24	7	*Mentha longifolia*	Low and middle altitudes	*Mentha longifolia*	47.6	0.001
25	33	*Miscanthus capensis*	Low and middle altitudes	*Miscanthus capensis*	71.6	0.001
26	9	*Fimbristylis complanata*	Low and middle altitudes	*Fimbristylis complanata*	72.3	0.001
27	21	*Aristida junciformis*	Low and middle altitudes, KZN Midlands	*Tristachya leucothrix*	42.2	0.001
				Aristida junciformis ssp. *junciformis*	26.1	0.001
				Harpochloa falx	21.6	0.005
28	10	*Pycreus macranthus, Aristida junciformis*	Low altitudes and KZN Midlands	*Ledebouria cooperi*	57.8	0.001
				Pycreus cooperi	43.7	0.001
				Pycreus macranthus	34	0.001
				Xyris gerrardii	33.9	0.001
				Gladiolus papilio	45	0.002
				Bulbostylis schoenoides	21	0.003
29	5	*Scleria welwitschii*	Low altitudes and KZN Midlands	*Scleria welwitschii*	55.4	0.001
				Monocymbium ceresiiforme	53.1	0.001
				Helichrysum aureum	21.2	0.001
30	21	*Andropogon appendiculatus*	Low altitudes, KZN Coast	*Andropogon appendiculatus*	67.3	0.001
31	25	*Juncus oxycarpus*	Low altitudes, Midlands	*Juncus oxycarpus*	37.5	0.001
32	4	*Stiburus alopecuroides*	Mid and low altitudes	*Stiburus alopecuroides*	60.7	0.001

3.6.2 Canonical ordination

Two ordinations have been carried out, one ordination for all plots that have a full range of environmental variables included, as soil samples were collected, and a second ordination on the full dataset, but with less explanatory variables.
The CCA ordination that includes the soil variables is shown in Figure 3.39. This ordination has a Total Inertia of 25.30 and the sum of all canonical eigenvalues is 8.68 so about 34% of all variation can be explained by the environmental variables supplied.

Twenty-five of the 32 communities are represented here, and it must be noted that the soil samples have been effectively collected in the Eastern Cape Mountains and in the KwaZulu-Midlands, but not so much in the highest peaks of the KwaZulu-Natal Drakensberg. This is an important gap as these wetlands represent the highest extreme of the altitudinal gradient and there are a number of communities that exclusively occur here. Four communities are only represented by a single plot, namely Community 5.9 (*Senecio cryptolanatus – Cotula hispida* Community), 5.16 (*Kyllinga pulchella* Community), 5.20 (*Carex austro-africana* Community), 5.25 (*Miscanthus capensis* Community).

In the ordination of Figure 3.39 the first axis is most strongly correlated with altitude (negatively) while inundation is pointing in the opposite direction (meaning that low altitude wetlands have generally a deeper water column). Some of the communities that are found at the highest altitudes are 5.1 *Merxmuellera macowanii* Community, 5.4 *Festuca caprina* Community, 5.8 *Kniphofia caulescens* Community and 5.12 *Fuirena coerulescens* Community. Some of the low-altitude communities here are 5.21 *Pennisetum sphacelatum* Community, 5.27 *Aristida junciformis - Tristachya leucothrix* Community and 5.28 *Pycreus macranthus – Ledebouria cooperi* Community. Note that the communities from the highest altitudes, like 5.2 (*Agrostis bergiana – Carpha filifolia* Community), 5.3 (*Koeleria capensis – Dracoscirpoides falsus* Community), 5.5 (*Rhodohypoxis rubella – Athrixia fontana* Community) and 5.9 (*Senecio cryptolanatus – Cotula hispida* Community) which are confined to altitudes higher than 2500 meters are largely absent from the plots represented in this ordination diagram.

The second axis is mainly associated with wetness and with percentage silt in the soil. Interestingly, it seems here that the more sandy soils are the wettest; this is probably a consequence of having very shallow soils, so that the water does not drain quickly. Silt percentage and clay percentage are negatively associated with the first axis, as well as Electrical Conductivity. The community that stands out as the most extreme outlier along the second axis is the *Limosella africana* Community, which is found along the edges of lakes and pans at lower altitudes. For the rest, most low-altitude communities that were mentioned before seem to be restricted to the more clayey soils and have high values for Electrical Conductivity and Nitrogen contents.

The second ordination, dealing with the entire dataset, is displayed in Figure 3.40. Also this ordination has the first axis most strongly (negatively) associated with altitude, maybe not surprising given the large climatic and geological differences between the top and the bottom of the montane areas.

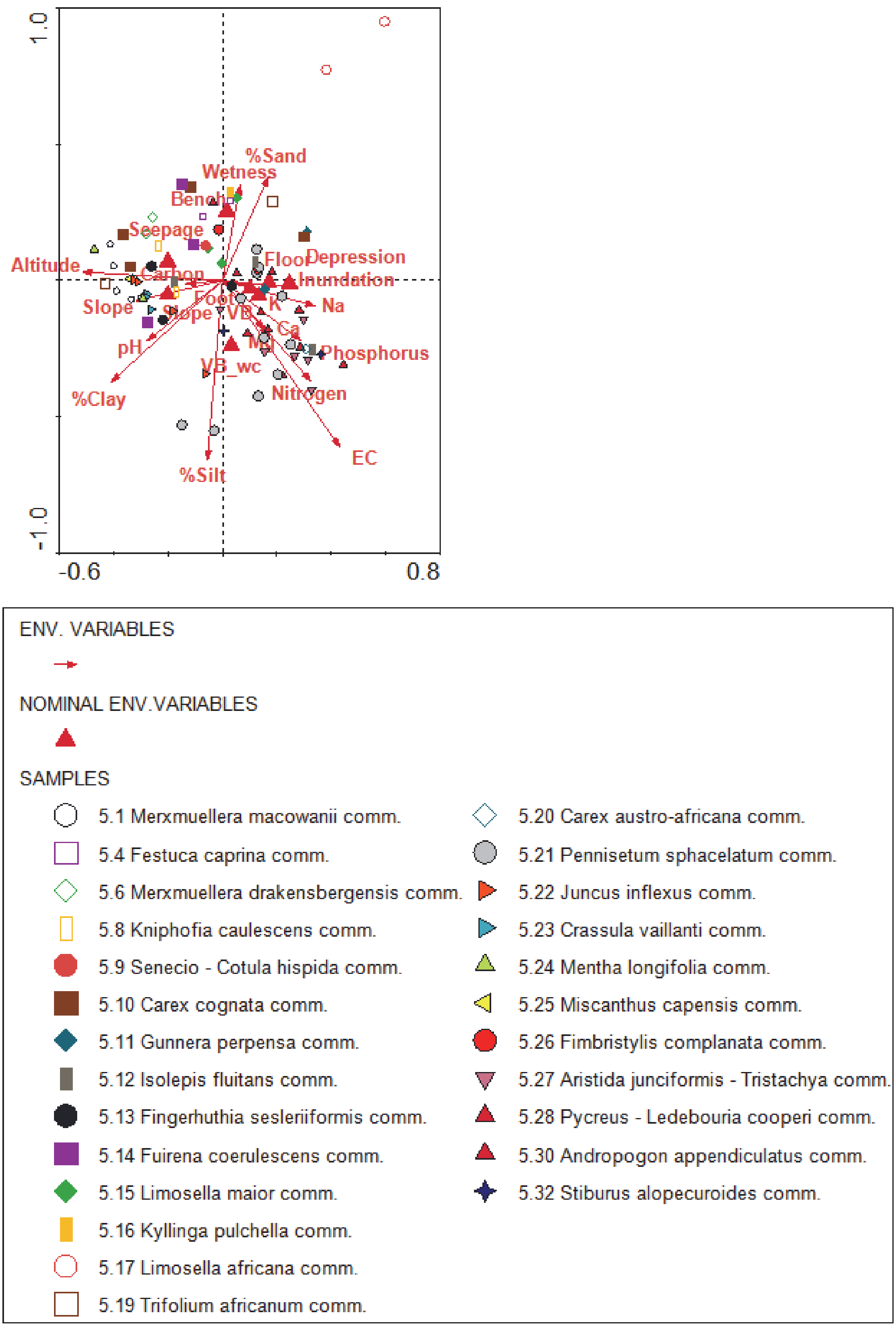


Figure 3.39 Canonical Correspondence Analysis for Montane Grassy Wetland Vegetation that include soil data.

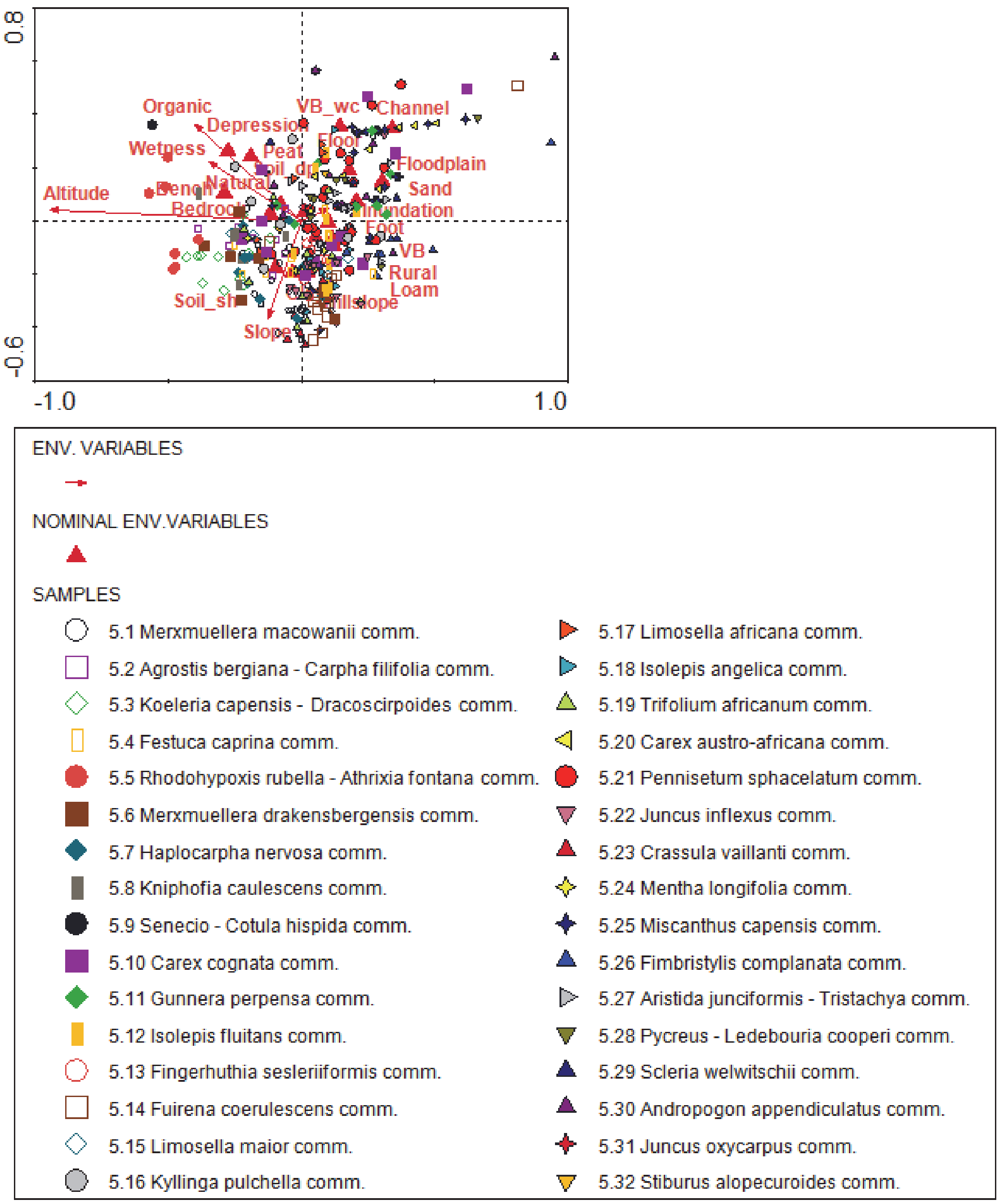


Figure 3.40 Canonical Correspondence Analysis for the entire dataset of montane wetland vegetation.

The Communities 5.2, 5.3, 5.5, 5.6 and 5.9 are found at the highest altitudes. These are for a large part communities that were not presented in Figure 5.39 as no soil data is available for them. For the rest, the altitudinal gradient largely reflects the same vegetational differences as in the previous ordination diagram.
The second axis is mostly associated with slope, with the steeper slopes on the negative side of the axis. The communities on steeper slopes also tend to have more shallow soils; these are typical slope seepages, while the plots towards the upper end of the second axis represent valley bottom wetlands and pans. The communities that are well represented at

the steeper slopes are 5.6 *Merxmuellera drakensbergensis* Community and 5.14 *Fuirena coerulescens* Community.

3.6.3 Species response curves

Species response curves are made from various groups of species in the Montane Grassy Wetland Vegetation in order to find whether there are contrasting responses between different species so that it can be known what it signifies when a certain species increases or decreases. These response curves are the output of the Programme Hyperniche and are displayed for small groups of species simultaneously.

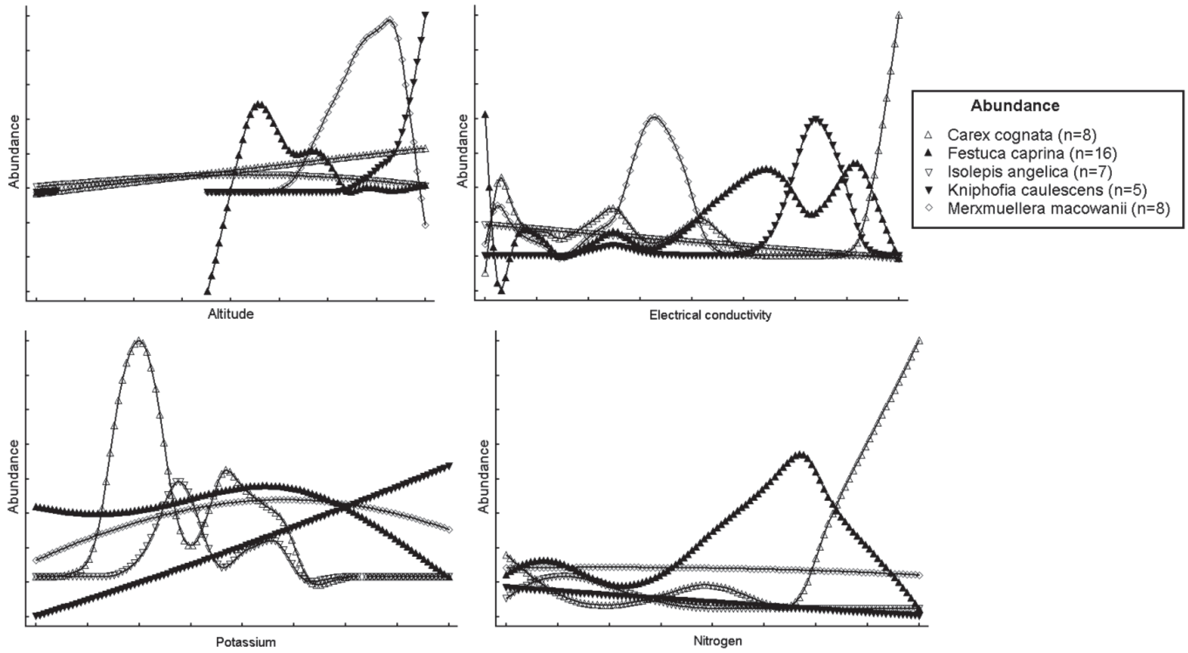


Figure 3.41 Species response curves of several species belonging to wetlands occurring at the highest altitudes of the Drakensberg.

The species shown in Figure 3.41 are occurring at the highest altitudes in the Drakensberg and become dominant in the Communities 5.1, 5.4, 5.8, 5.10 and 5.18. *Merxmuellera macowanii* and *Kniphofia caulescens* are peaking at the highest altitudes. *Carex cognata* increases a lot with high electrical conductivities while *Kniphofia caulescens* and *Festuca caprina* also peak at high conductivities in the soil. *Carex cognata* also grows abundantly under low levels of Potassium and high levels of Nitrogen. *Festuca caprina* also peaks under high Nitrogen levels, but slightly lower than those that are optimal for *Carex cognata*. *Kniphofia caulescens* increases most with Potassium, while *Festuca caprina*, *Isolepis angelica* and *Merxmuellera macowanii* peak at intermediate levels of Potassium.

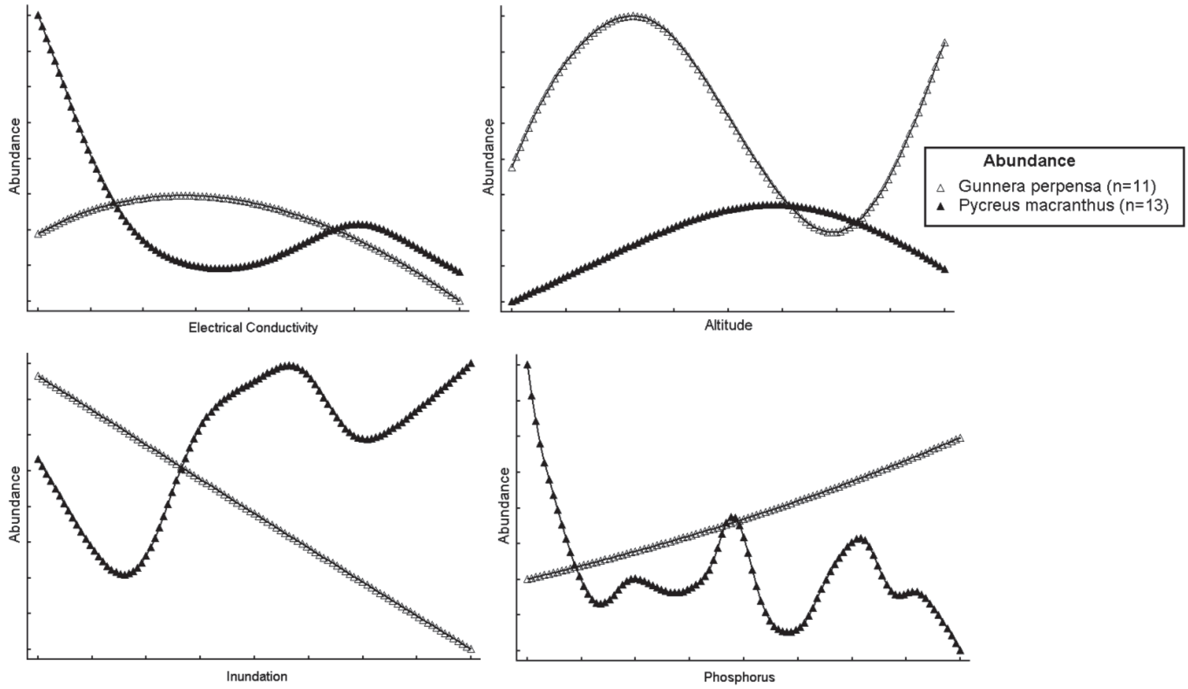


Figure 3.42 Species response curves of two species that are common in mid-altitude seepages

Figure 3.42 shows the contrasting responses of two species that are regularly found in the wettest parts of wetlands in the 'Mistbelt' zone of about 1800-2000 meters. They become dominant in Communities 5.11 and 5.28. The river pumpkin, *Gunnera perpensa* is growing optimally both at the lowest altitudes and at the very highest altitudes, while the sedge *Pycreus macranthus* performs best in between. *Pycreus macranthus* performs also better than *Gunnera perpensa* under low electrical conductivities and high inundation. The growth of *Gunnera perpensa* is stimulated by an increase in Phosphorus (because it is capable of fixing Nitrogen in its root nodules (Bergman et al. 1992). On the other hand, *Pycreus macranthus* decreases with an increase of Phosphorus.

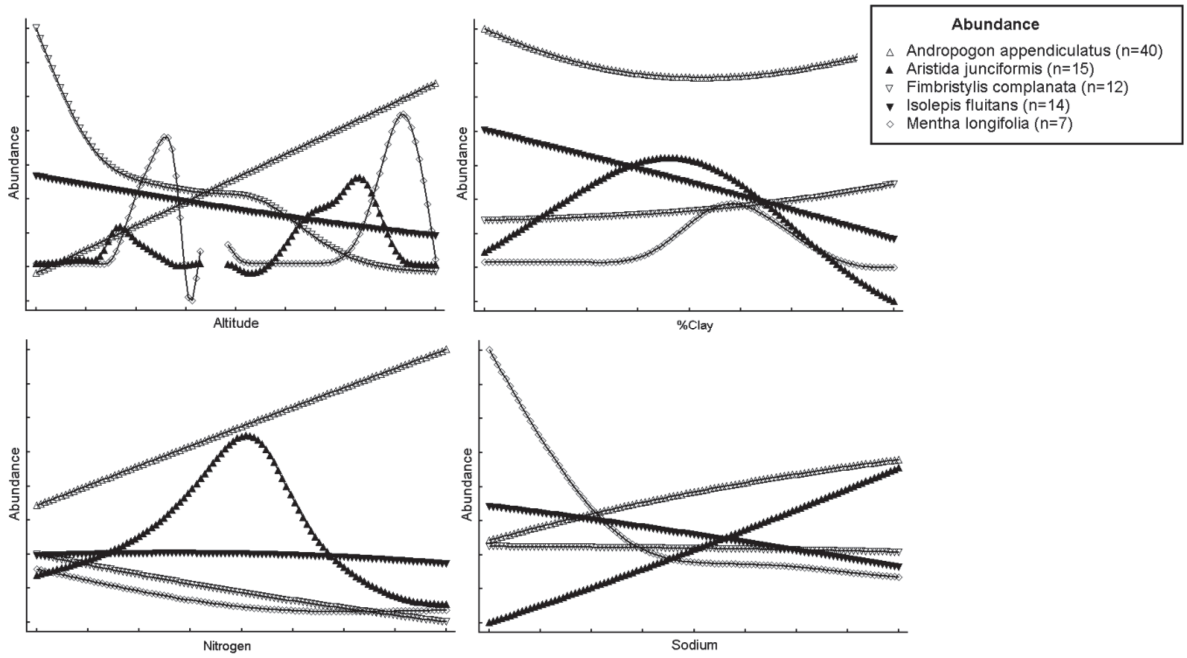


Figure 3.43 Species response curves for five species that are common across a wide range of altitudes but which are most common at mid-altitudes.

The five species in Figure 3.43 are occurring in a wide range of altitudes, although *Fimbristylis complanata* generally decreases and *Andropogon appendiculatus* generally increases with altitude. These species become dominant in Communities 5.12, 5.24, 5.26, 5.27 and 5.30. *Aristida junciformis* is the most sensitive to clay contents and has a peak at intermediate levels of clay, whereas all other species have only weak responses to clay contents. *Andropogon appendiculatus* does well under all levels of clay contents. Similarly, *Aristida junciformis* prefers intermediate levels of Nitrogen, while *Andropogon appendiculatus* increases with Nitrogen. The forb *Mentha longifolia* performs best when there is only a very low Sodium contents while the grasses *Aristida* and *Andropogon* increase with higher levels of Sodium.

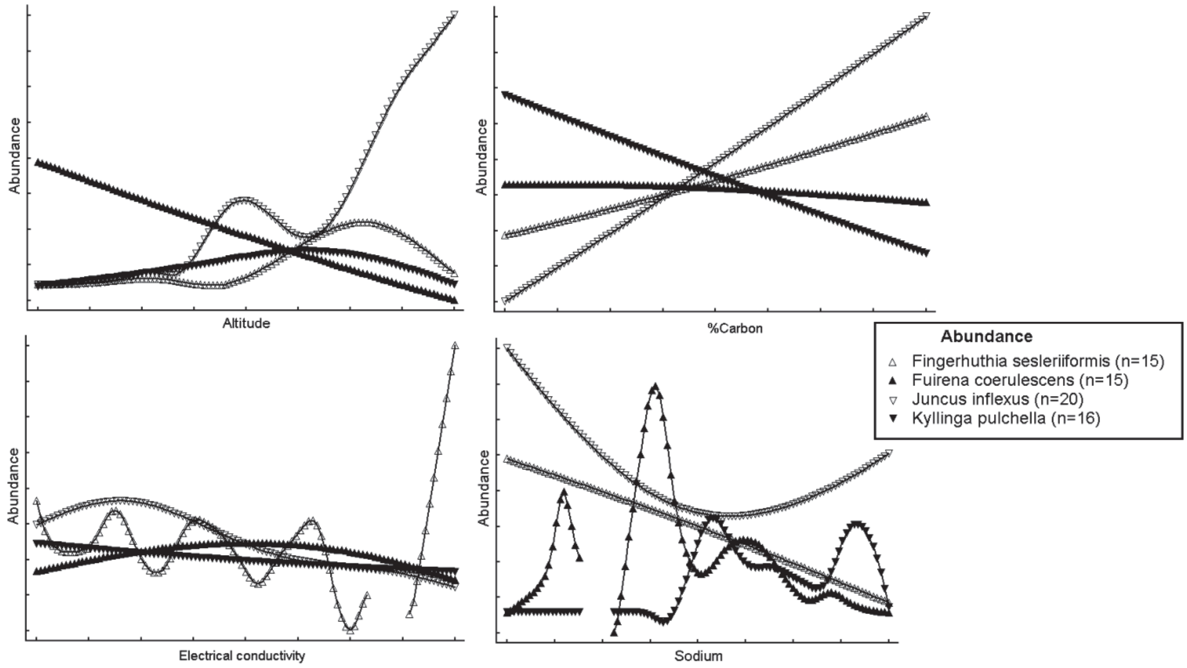


Figure 3.44 Species response curves of four species that are centered on the Eastern Cape mountains.

In Figure 3.44 we can see the species response curves for four species that are centered in the Eastern Cape Mountains. They become dominant in Communities 5.13, 5.14, 5.16 and 5.22. Of these four species, *Juncus inflexus* is most adapted to growing at high altitudes and it also has the most positive response to high soil carbon. *Fuirena coerulescens* decreases with altitude and *Kyllinga pulchella* decreases with soil carbon. The grass *Fingerhuthia sesleriiformis* has a strong positive response to Electrical Conductivity, but a negative response to Sodium concentration.

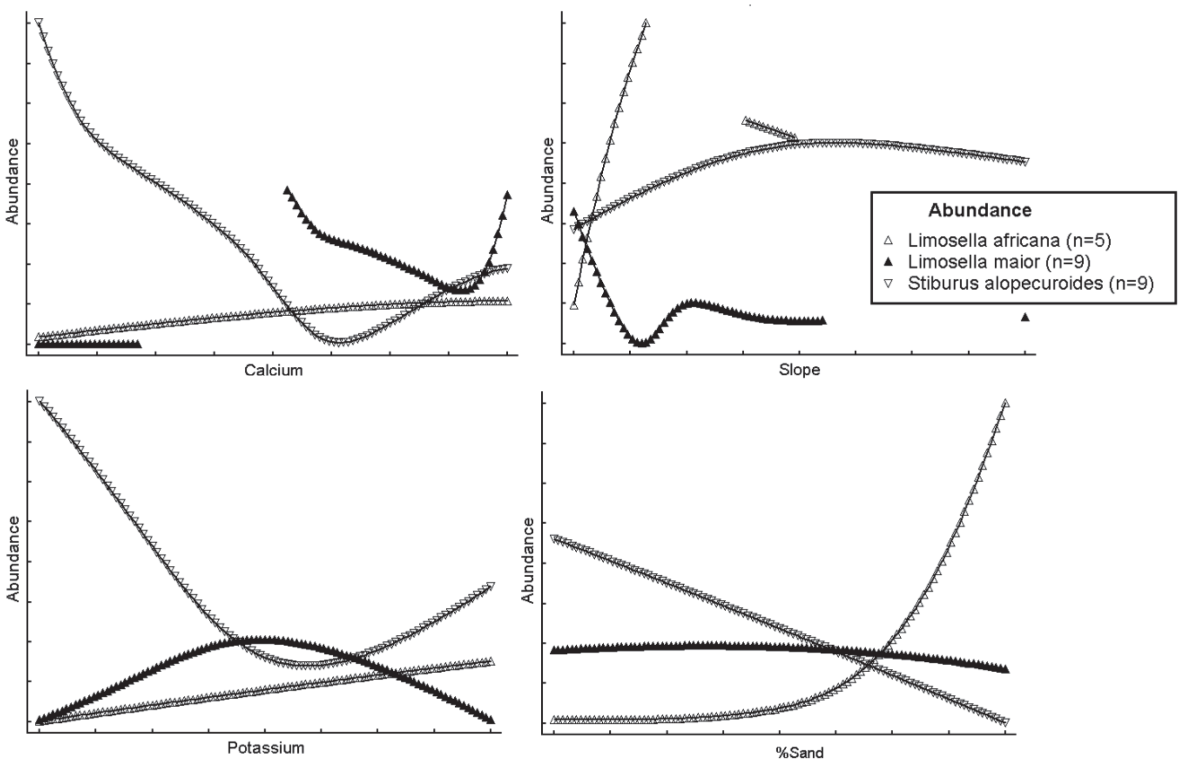
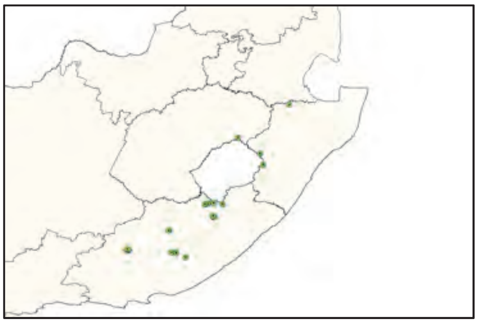


Figure 3.45 Species response curves for three species from mid-altitudes in the Drakensberg.

Figure 3.45 shows the response curves for three more species from mid-altitudes in the Drakensberg. These species become dominant in Communities 5.15, 5.17 and 5.32. The small forb *Limosella africana* is dominant in areas that have very slight slopes, high in sand fraction of the soil and low in Calcium. This is mostly along lakeshores of montane lakes, for example in the Stormberg in the Eastern Cape. *Limosella maior* occurs mostly in areas that are intermediate in Potassium and avoids slopes as it occurs in really wet patches in valley bottom wetlands. The grass *Stiburus alopecuroides* prefers steep slopes and avoids soils with a high sand fraction. It is typical for mistbelt grasslands, and occurs only marginally in wetlands.

3.6.4 Description of communities

1. *Merxmuellera macowanii* Community



This community is found throughout the Drakensberg and represents a tussock grassland dominated by a single species: *Merxmuellera macowanii*. It is mostly a seasonally or temporarily wet seepage community that contrasts strongly with the surrounding landscape. It is relatively low in species number.

2. *Agrostis bergiana - Carpha filifolia* Community

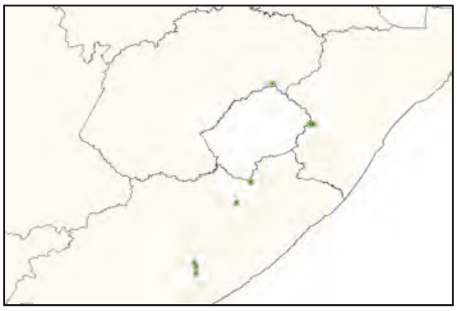
This community is rich in species but is sometimes dominated by a single species, the sedge *Carpha filifolia*. It is quite rich in species and restricted to the highest altitudes, where it is found in seepage zones. It is possible that this cluster is heterogeneous and it would be desirable to obtain more data

3. *Koeleria capensis – Dracoscirpoides falsus* Community

This community is another one that is restricted to the highest altitudes and that is very rich in species. It is restricted to temporarily to seasonally wet aread in valleyhead seepages.

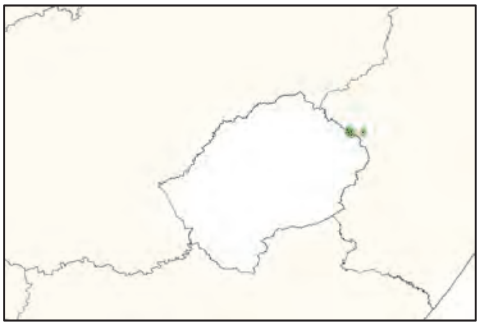
4. *Festuca caprina* Community

This is a more common wetland type in high altitude seepage zones, which is also regularly found at mid-altitudes. It is mostly dominated by a single tufted grass species *Festuca caprina* and is notably poorer in species than the preceding communities.



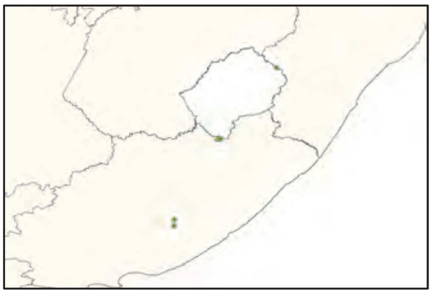
5. *Rhodohypoxis rubella – Athrixia fontana* Community

This is a wetland community restricted to the highest peaks in the Northern Drakensberg, where it is however quite common in seepage zones and it tends to occur on peat. It is very rich in species, mostly small creeping forbs, like *Alepidea pusilla* and *Sebaea repens*, as well as small sedges, such as *Carex monotropa*.



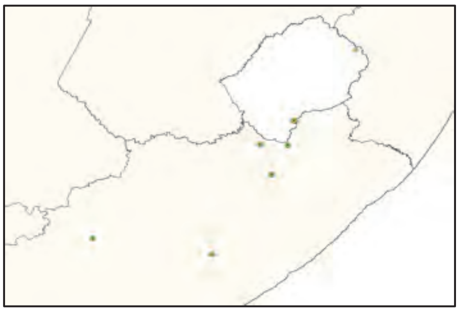
6. *Merxmuellera drakensbergensis* Community

This community resembles the *Merxmuellera macowanii* Community, but is less common and mostly restricted to the Eastern Cape. Similar to the *Merxmuellera macowanii* Community, it is low in species richness as it is dominated by a single tuft-forming species.



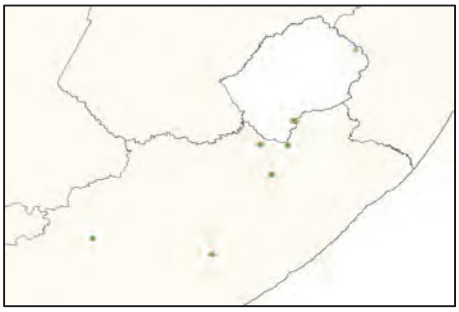
7. *Haplocarpha nervosa* Community

This community is dominated by the low creeping and rosette-forming forb *Haplocarpha nervosa*, which becomes dominant among various other low-growing forbs and grasses. It often occurs in peaty habitats in valleyhead seepages at high altitudes, although it is occasionally found at lower altitudes.



8. *Kniphofia caulescens* Community

This community is conspicuous because of its abundance of the red hot pokers which make this a very attractive plant community. It is quite a rare plant community in South Africa, but it is still quite common in Lesotho. It is typical for high altitude valley bottoms and valleyhead seepages which is also why it is more common in Lesotho where there are more high altitude valleys.

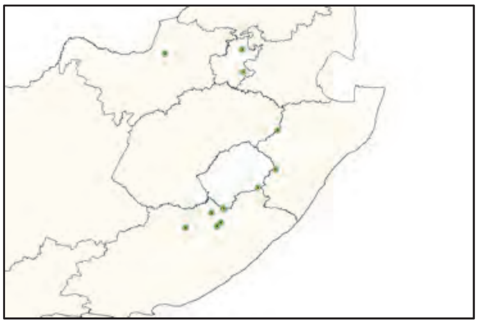


9. *Senecio cryptolanatus – Cotula hispida* Community

This is another type of high-altitude seepage that is rich in species. It occurs in valleyhead seepages and slope seepages at high altitudes, mostly on a peaty soil. Compared to other such communities (5.2, 5.3 and 5.5) the species diversity in this community is relatively low.

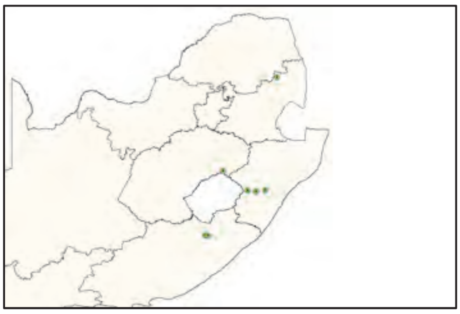
10. *Carex cognata* Community

This is a high-altitude form of a sedgeland, with the species *Carex cognata* which is very similar to *Carex acutiformis*, which commonly occurs on the Highveld. This community tends to occur more at higher altitudes, but is occasionally found on the Highveld, for example in Gauteng. It often occurs together with Community 5.8 *Kniphofia caulescens* Community.



11. *Gunnera perpensa* Community

The river pumpkin *Gunnera perpensa* is a conspicuous forb that dominates in seasonally to permanently wet seepage wetlands along the Drakensberg, the KwaZulu-Natal Midlands and even further up north along the escarpment. An interesting property of this species is that it forms a symbiotic relationship with a cyanobacterium that fixes Nitrogen so that it can enrich the soil. It normally occurs in species-rich communities.

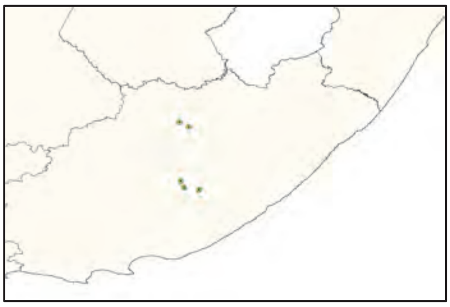


12. *Isolepis fluitans* Community

This community occurs in lowland wetlands, mostly in the wettest patches of valley bottom wetlands. It is relatively poor in species.

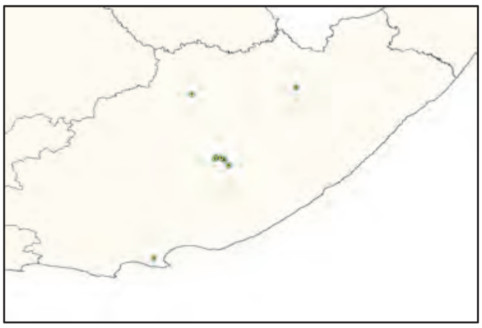
13. *Fingerhuthia sesleriiformis* Community

This community is largely restricted to the mountains of the Eastern Cape, where is occurs together with the exotic grass species *Poa pratensis*. It occurs mostly in valley bottom wetlands and is quite poor in species. In some cases it has been found in peatlands.



14. *Fuirena coerulescens* Community

This is a second community that is restricted to the Eastern Cape, although the species *Fuirena coerulescens* is much more widespread. It is mostly found on clay soils at mid altitudes.

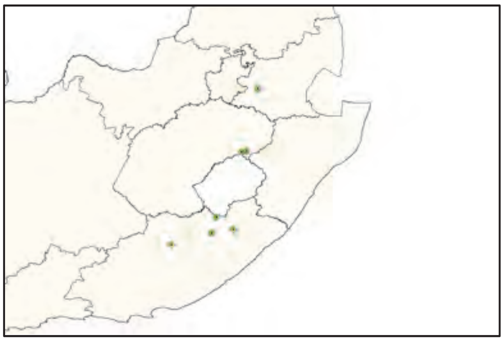


15. *Limosella maior* Community

This community is a mat-forming community occurring in very wet conditions on an unconsolidated substrate. Soils are generally low in Nitrogen and it is reasonably rich in species.

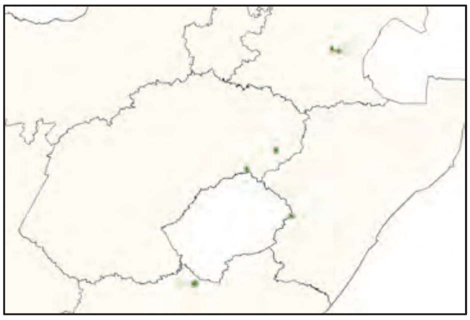
16. *Kyllinga pulchella* Community

This community is dominated by the short attractive sedge *Kyllinga pulchella*. It occurs mostly in depression wetlands, but it is also found in small disturbed wet patches. It is mostly found at the lower altitudes on the Highveld and the mountains in the Eastern Cape.



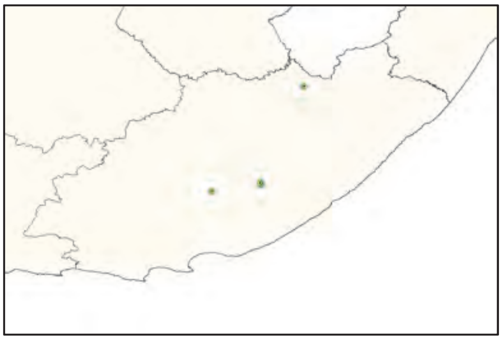
17. *Limosella africana* Community

This community mostly occurs on sandy soils next to depression wetlands where there is temporary or seasonal wetness. The species *Limosella africana* looks like a very short grass until it starts flowering, when it starts to develop an attractive carpet of small white flowers.



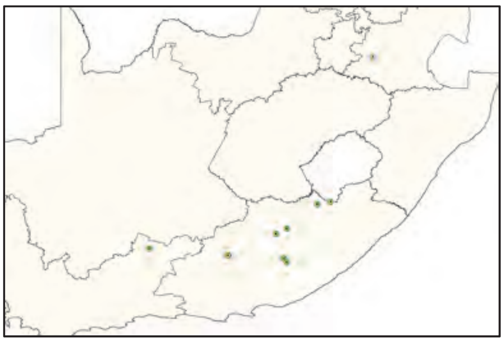
18. *Isolepis angelica* Community

This species-rich community dominated by short sedges which appears to be much more common in the Eastern Cape mountains than in the high altitudes of the Drakensberg, where it is quite rare.



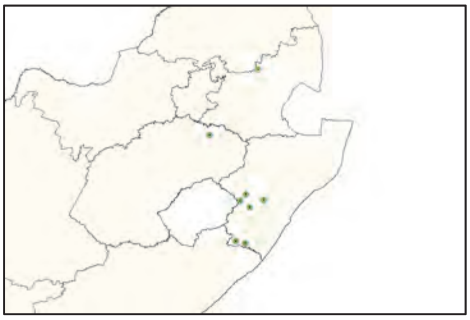
19. *Trifolium africanum* Community

This community is a species-rich mix between clover *Trifolium africanum* and various species of grasses, occurring in temporary or seasonal zones of the wetlands. It is very widespread in the Eastern Cape but also found outside of it.



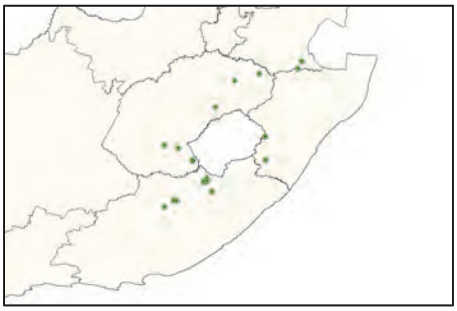
20. *Carex austro-africana* Community

This is a community dominated largely by monospecific stands of *Carex austro-africana* which generally remains lower in stature than the two other *Carex* species that regularly become dominant. It is widespread along the Eastern escarpment area, although it is only common in southern KwaZulu-Natal. It is generally found in soils rich in nutrients.



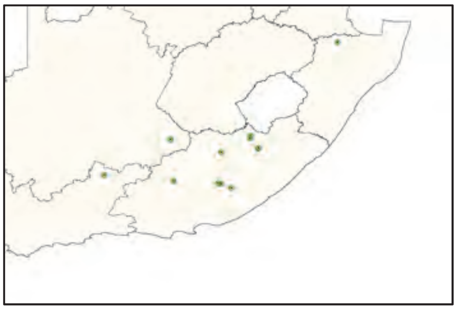
21. *Pennisetum sphacelatum* Community

This community is a tall grassland with moderate species richness but with a dominance of the grass *Pennisetum sphacelatum*. It is common at the lower altitudes in the Maloti-Drakensberg stretching over the whole escarpment area.



22. *Juncus inflexus* Community

The rush *Juncus inflexus* is one of the species of Juncacecae for which it is not clear whether the species is indigenous or alien, as the species also occurs in Europe. It is common in the Eastern Cape mountains from the Drakensberg stretching into the Karoo. It is typical for seasonal wetlands on clay or loam soils, where it can reach monodominance.

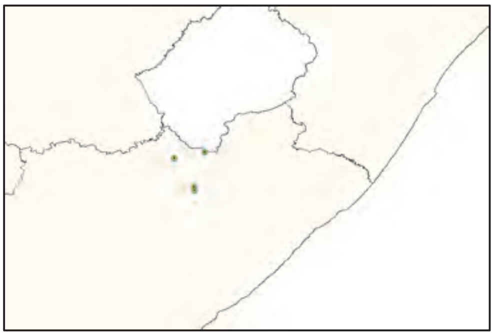


23. *Crassula vaillantii* Community

This community is found mostly at mid altitudes in the drier mountains of the Eastern Cape stretching into the Nuweveld Mountains of the Western Cape, where it occurs in seasonally wet slope seepages on South facing slopes. It is a rich community consisting of various types of forbs and rushes including *Juncus dregeanus* and the small annual *Crassula vaillanti*.

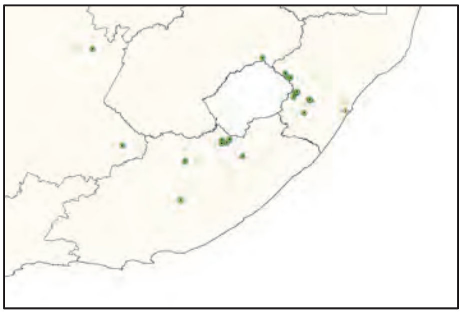
24. *Mentha longifolia* Community

This community is dominated by a single perennial herb and occurs mostly at mid altitudes in the Eastern Cape Drakensberg. It occurs mostly in the temporarily and seasonally wet zones of south facing slope seepages, that are rich in organic matter, so it prefers similar habitats to the previous community.



25. *Miscanthus capensis* Community

This is a community dominated by a single species of large grass that tends to become quite much like a reed. It occurs mostly at the lower altitudes in various areas of the Drakensberg area, but surprisingly it can also be found in various areas of the Karoo. It occurs in temporarily wet zones of different types of wetlands. The grass species *Miscanthus capensis* grows in large tufts and rises above the rest of the vegetation because of its height.

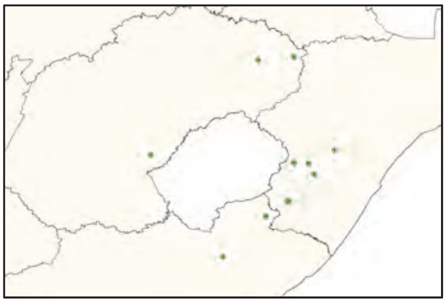


26. *Fimbristylis complanata* Community

This type of wetland occurs at the lower altitudes in various areas along the Escarpment, and is even found in one location along the coast. It prefers seasonally wet wetlands with highly organic soils. It is dominated by the sedge *Fimbristylis complanata*.

27. *Aristida junciformis -Tristachya leucothrix* Community

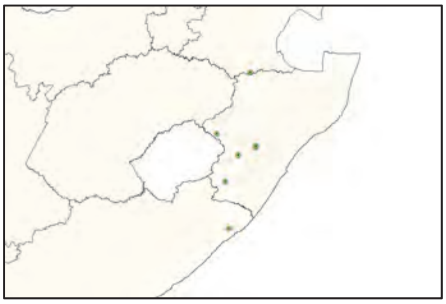
This grassland type coincides with the mistbelt grasslands of the KwaZulu-Natal, which can extend into the wetter parts of the wetlands that are located within the mistbelt region. This community and the next one are typically very rich in species. It is dominated by *Aristida junciformis* but accompanied by other montane grasses such as *Harpochloa falx*, *Tristachya leucothrix* and *Festuca caprina*. The soils are often peaty.



28. *Pycreus macranthus -Ledebouria cooperi* Community

This is a second wetland plant community typical for the mistbelt region and one of the most species-rich wetland plant communities in the country. It is dominated by various species of sedges and grasses of which *Pycreus macranthus* is the most conspicuous one. The undergrowth of the vegetation is dominated by the bulbous species *Ledebouria cooperi*.

It occurs on permanently wet soils with a peaty substrate.

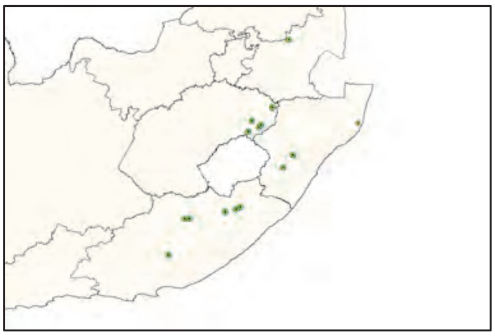


29. *Scleria welwitschii* Community

This is a third community typically found in the mistbelt region but the plots are generally located a bit closer to the mountains. It is poorer in species than the previous two communities but as a community it is also rarer. It occurs on permanently wet soils.

30. *Andropogon appendiculatus* Community

This is the last community that is common and widespread throughout the mistbelt region although a single plot is also known from the coast near Lake St. Lucia. It is found from mid-altitudes to high altitudes on seasonally to permanently wet soils with a peaty substrate.



31. *Juncus oxycarpus* Community

The species *Juncus oxycarpus* is commonly found in wetlands, but seldom as a dominant. On one locality along the escarpment in Mpumalanga several vegetation plots have been made which had this species as a dominant which makes this a distinct community. It is probably more common than this.

32. *Stiburus alopecuroides* Community

This grassland type is dominated by a single grass species occurring in the mistbelt regions in the Drakensberg and the Mpumalanga escarpment. The conspicuous grass *Stiburus alopecuroides* is also quite common outside wetlands but prefers very moist environments and can therefore also be found in actual wetlands. The soils are often black, but this does not necessarily mean they are very wet.

3.6.5 Discussion of Montane Grassy Wetland Vegetation

The communities in Main Cluster 5 are mainly associated with the mountains, but the reason why plant communities should be different in montane areas can be manifold.
Firstly, the mountains have two climatic effects on the community composition of wetlands, namely in terms of the temperatures which are much colder than in the rest of South Africa, and secondly by means of the moisture, as most of these mountains produce orographic rainfall in the areas directly below them. Because of this rainfall, there are also many springs and seepage zones as much of the water is stored underground for prolonged periods of time. This habitat also produces unique habitat types as the wetlands in these situations are located on a slope, which is very different from most wetlands in the lowlands.
It could be argued that the only strictly montane wetlands are those wetlands that are either found on the summits, where temperatures are very cold, or in seepage zones, where water originates as groundwater discharge with unique properties. As it is however, many of the communities in this Main Cluster also belong to those areas below the Drakensberg that benefit from the orographic rainfall that is produced because of the mountains. These communities are not very different from the plant communities in Main Cluster 6 and some could have been comfortably placed there as well in terms of their ecology, as the Temperate Grassy Wetland Vegetation also have a preference for the more moist climates. An example of these are the ‘mistbelt’ communities such as 5.27, 5.28, 5.29 and 5.30. These communities occur in dark peaty soils that are mainly there because the climate is conducive in terms of rainfall and evaporation. They are generally on high locations, but not much higher than the Highveld areas of the Free State and Mpumalanga. Many of these kinds of communities are also distributed more widely along the Free State and Mpumalanga escarpments, as these are also generally areas with high orographic rainfall and little evaporation.
The strictly montane wetlands from the high altitudes and the seepage zones are standing out more from the low-altitude wetlands because of the higher diversity of growth forms, which are more varied here as many communities are dominated by forbs, bulbs and C_3 plants. This can also be seen as one of the many environmental gradients across the landscape, which has been explored largely by Sieben et al. (2010). In that sense, it is only reasonable to expect that communities from Main Cluster 5 will also grade into communities from Main Cluster 6.

3.7 Main Cluster 6: Temperate Grassy Wetland Vegetation

These wetlands represent the most widespread and common type of wetlands in the country and they are often the wetlands that are the most familiar to wetland practitioners. Although the cluster is centered on the Highveld region and the sub-escarpment grasslands of KwaZulu-Natal and the Eastern Cape, it is far more widespread than that as the most common wetland plants such as *Typha capensis*, *Phragmites australis*, *Eragrostis plana* and *Leersia hexandra* are also found in this cluster. These are generally species with wide ecological amplitudes and very effective dispersal (probably by waterbirds) and they are therefore found virtually everywhere in the country where wetlands are found, except maybe some extreme environments such as the Western Cape mountains (too nutrient-poor), the peaks of the Drakensberg (too cold) or the arid expanses of the Karoo (too dry and saline), even though reedlands with Phragmites australis are found regularly in this last habitat. The vegetation mostly consists of medium to tall sedges and grasses, although occasionally forbs and bulbous species may become dominant.

Some of these species, particularly *Typha capensis,* are also dealing particularly well with eutrophication and pollution and these communities are therefore also very common in urban areas. In general, these wetlands are very prone to invasion and even though they are the most common wetland vegetation types in the country, they are also facing particular threats as they represent the wetlands found in the most utilized landscapes of the country. A number of vegetation types have been characterized by a dominance of alien species. The communities of this group grade into the Montane Grassy Wetland Vegetation of Main Cluster 5 and the highest diversity of Temperate Grassy Wetland Vegetation can be found in the foothills of the Drakensberg.

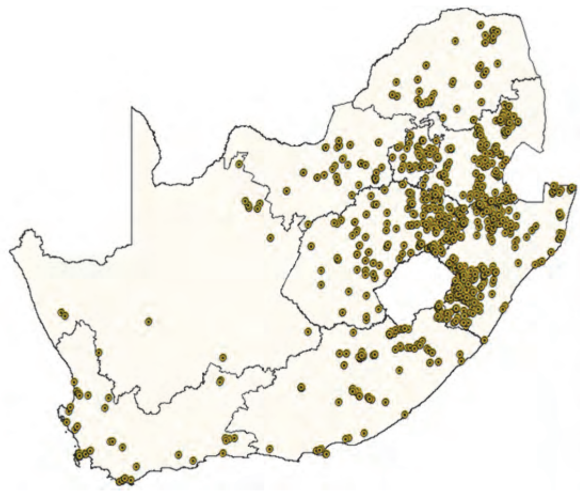


Figure 3.46 Distribution of Temperate Grassy Wetland Vegetation and an example of one of these wetlands in Ntabamhlope wetland in the KwaZulu-Natal midlands.

3.7.1 Classification and Indicator Species Analysis

The Temperate Grassy Wetland Vegetation of Main Cluster 6 originally contained 1617 plots and 1349 species, but a complication arised that made it clear that it would be better to remove a large number of plots from the analysis. In a first attempt of clustering, it became evident that a large number of old historical studies separated out as distinct clusters. Most of these plots came from several studies that were conducted by the University of Pretoria in the nineties that provided an overview over the grassland biome in South Africa. The problem with these studies was that they did not focus on wetlands specifically and the sample size for the vegetation plots was more geared towards landscape level studies: 10 by 10 meters. Because of this large sample size it makes comparison with more usual sample sizes (2 x 2 meters or 3 x 3 meters) difficult and there is a suspicion that many of these large plots are actually heterogeneous. In any case, they contain an unusual amount of species and it is these species that make each of these studies stand out as a separate community type. Therefore, each of the plots with a sample size of 10 x 10 meters was checked and most of these plots were removed from the analysis, except when they contained a clear dominant and a limited number of species, so that it is less likely that they are heterogeneous. The removal of these plots is not likely to lead to a missing out of communities in the dataset as the species composition of these plots generally consisted of the same plots that were present in the other communities of Main Cluster 6. It just leads to a general streamlining of the classification process; in the end therefore a dataset of 1366 plots and 1263 species was utilized.

A hierarchical cluster analysis resulted in the recognition of 26 clusters, one of which was clearly heterogeneous. A number of small communities could be recognized by visual inspection of this heterogeneous cluster whereas other plots within this cluster were rather removed from the analysis or added to other clusters. These small communities within the heterogeneous cluster represent the rarer and under-sampled communities within the Temperate Grassy Wetland Vegetation. Several attempts to use dummy species to make the cluster algorithm recognize also these small communities did not lead to a more comprehensive classification and so it was decided to leave it like it is and the ‘small’ communities in the heterogeneous cluster are just described in order to stimulate further sampling of these communities in the future. They are listed below in the table with indicator species (**Table 3.6**). It is one of the weaknesses of the clustering algorithm that was used that if a large part of the dataset is represented by a small number of very large clusters, it is very difficult to recognize the smaller clusters and they are usually all lumped together. **Figure 3.47** displays to dendrogram of this classification, displaying the 25 recognized communities and one branch representing the heterogeneous cluster.

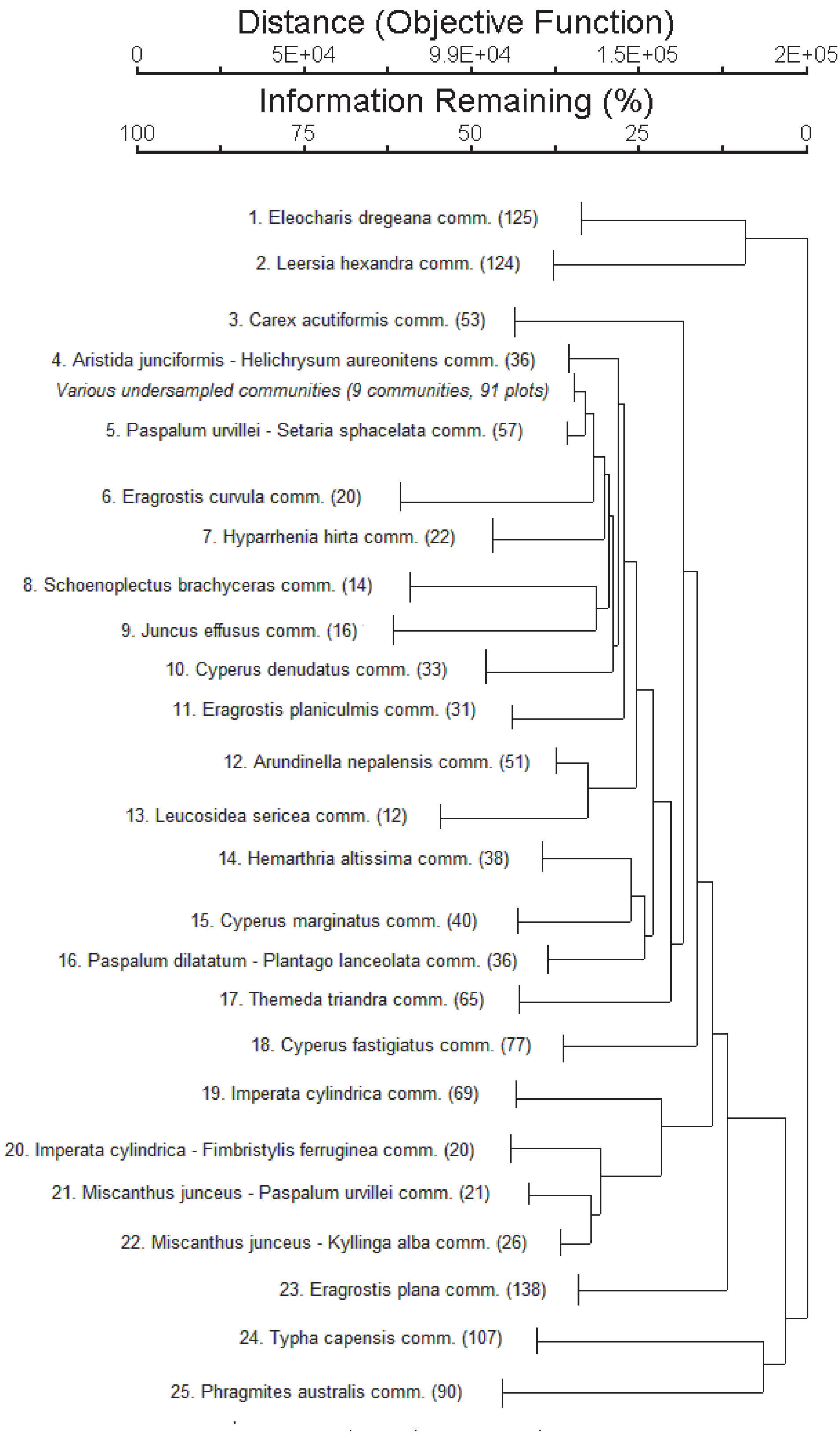


Figure 3.47 Cluster dendrogram for Temperate Grassy Wetland Vegetation.

Table 3.6 Plant communities and associated indicator species for Temperate Grassy Wetland Vegetation (Main Cluster 6).

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator value (IV)	p-value
1	118	*Eleocharis dregeana*	Highveld, Eastern Cape	*Eleocharis dregeana*	47.7	0.001
2	124	*Leersia hexandra*	Throughout the country	-		
3	53	*Carex acutiformis*	Highveld, Kwazulu-Natal	*Carex acutiformis*	75	0.001
4	36	*Aristida junciformis, Helichrysum aureonitens*	Highveld, Kwazulu-Natal	*Fuirena pubescens*	40	0.001
				Aristida junciformis	32.7	0.001
				Helichrysum aureonitens	24.3	0.001
5	57	*Cyperus congestus, Verbena bonariensis*	Highveld, urban and disturbed areas	*Hyparrhenia rufa*	14.8	0.001
				Hyparrhenia tamba	14.7	0.001
				Setaria sphacelata	12.5	0.001
				Cyperus congestus	11.8	0.001
6	20	*Eragrostis curvula*	Highveld	*Eragrostis curvula*	46.7	0.001
7	22	*Hyparrhenia hirta*	Highveld	*Hyparrhenia hirta*	50.3	0.001
8	14	*Schoenoplectus brachyceras*	Throughout the country	*Schoenoplectus brachyceras*	88.8	0.001
9	16	*Juncus effusus*	Eastern highveld, Transkei	*Juncus effusus*	63.8	0.001
10	33	*Cyperus denudatus*	Highveld	*Cyperus denudatus*	62.3	0.001
11	31	*Eragrostis planiculmis*	Highveld	*Eragrostis planiculmis*	56.7	0.001
12	51	*Arundinella nepalensis*	Highveld	*Arundinella nepalensis*	33.7	0.001
13	12	*Leucosidea sericea*	Around Drakensberg	*Leucosidea sericea*	79.7	0.001
				Searsia dentata	52.8	0.001
				Cliffortia nitidula	36.9	0.001
				Euclea crispa	29.2	0.001
				Mysine africana	22.9	0.001
				Halleria lucida	20.4	0.001
				Rhamnus prinoides	20.3	0.001
14	38	*Hemarthria altissima*	Throughout the country	*Hemarthria altissima*	37.6	0.001
15	40	*Cyperus marginatus*	Drakensberg and arid zones	*Cyperus marginatus*	63.8	0.001
16	36	*Paspalum dilatatum*	Highveld	*Cynodon dactylon*	30.6	0.001
				Plantago lanceolata	29.7	0.001
				Paspalum dilatatum	26.4	0.001
				Trifolium repens	26.2	0.001
				Cichorium intybus	21.1	0.001

Table 3.6 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator value (IV)	p-value
17	65	*Themeda triandra*	Highveld	*Themeda triandra*	52.4	0.001
18	77	*Cyperus fastigiatus*	Throughout the country	*Cyperus fastigiatus*	62.8	0.001
				Echinochloa pyramidalis	21.1	0.001
19	69	*Imperata cylindrica*	Throughout the country	*Imperata cylindrica*	41.1	0.001
20	20	*Imperata cylindrica*	NW KwaZulu-Natal	*Senecio achilleifolius*	54.2	0.001
				Pulicaria scabra	47.3	0.001
				Andropogon eucomus	42.2	0.001
				Fimbristylis ferruginea	41.6	0.001
21	21	*Miscanthus junceus*	NW KwaZulu-Natal	*Paspalum urvillei*	34.9	0.001
				Pycreus betschuanus	26.8	0.001
				Chamaecrista stricta	26.4	0.001
				Conyza species	21.3	0.001
22	26	*Miscanthus junceus*	Highveld, Limpopo	*Kyllinga alba*	31.8	0.001
				Miscanthus junceus	28.9	0.001
				Phymaspermum athanasioides	26.6	0.001
				Wahlenbergia undulata	26.4	0.001
				Oxalis purpurea	22.7	0.001
				Senecio affinis	21.7	0.001
				Verbena brasiliensis	21.3	0.001
				Melinis repens	21.2	0.001
23	138	*Eragrostis plana*	Throughout the country	*Eragrostis plana*	29.8	0.001
24	107	*Typha capensis*	Throughout the country	*Typha capensis*	51.9	0.001
25	90	*Phragmites australis*	Throughout the country	*Phragmites australis*	39.5	0.001
Add.		Various Undersampled				
	4	*Schoenoplectus paludicola*		KZN, Eastern Cape		
	9	*Hyparrhenia dregeana*		Around Drakensberg		
	3	*Cyperus eragrostis*		Northwest		
	3	*Pennisetum natalense*		Eastern Cape		
	9	*Schoenoplectus corymbosus*		Highveld		
	6	*Juncus punctorius*		Highveld		
	3	*Catalepis gracilis*		Around Drakensberg		
	5	*Carex glomerabilis*		Highveld		
	2	*Cliffortia linearifolia*		Escarpment		

3.7.2 Canonical ordination

The section of the data matrix for Main Cluster 6 where soil variables had been collected consists of 249 plots containing a total of 483 species. Canonical Correspondence Analysis of this part of the dataset led to an ordination with a Total Inertia of 47.69, whereas the sum of all canonical eigenvalues is 7.245, so more than 15% of all the variation in the dataset is explained by the environmental variables provided. This is quite low, despite the amount of data, but probably there are some variables that are not measured here, such as grazing intensity which has quite an important impact on these wetlands. Nearly all communities in the dataset are represented here, although there are only two of the under-sampled communities represented (both by 2 plots each) and Community 1.16 (*Paspalum dilatatum-Plantago lanceolata* Community) is represented by only two plots. The communities 6.20 and 6.21 (*Fimbristylis ferruginea-Imperata cylindrica* Community and the *Miscanthus junceus-Paspalum urvillei* Community) are both known only from historical studies in northern KwaZulu-Natal and are not represented in the ordination diagram at all, as no plots with soil data are available. The ordination diagram for this ordination is displayed in Figure 3.48.

The first axis in this ordination is mainly represented by altitude, which is negatively associated with this axis, showing that most communities are restricted to the higher altitudes on the Highveld, whereas others are also relatively common at lower altitudes, particularly Communities 6.2, *Leersia hexandra* Community, 6.19, *Imperata cylindrica* Community and 6.25, *Phragmites australis* Community, which represent pockets of widespread wetland vegetation types that still occur regularly within subtropical wetlands. The communities that are really restricted to the lower altitudes are found in Main Cluster 3 discussed in section Several other species occur occasionally at these lower altitudes (for example in the Cape coastal plains, the KwaZulu-Natal Coast or the Lowveld region).

The second axis is ecologically more interesting as there are several environmental variables that are involved here. The most important one of these is wetness, which is positively associated with the second axis, and it is also associated positively with organic carbon contents, and clay percentage, which both make perfect sense in terms of general wetland ecology, as the wetter parts of wetlands are usually sinks for both fine sediments and for organic carbon. The second axis is also negatively associated with sand percentage and Phosphorus contents. It is quite obvious that soils with a high sand percentage drain more quickly and are therefore negatively associated with wetness. Phosphorus is generally more attached to soil particles and therefore less likely to be washed out and deposited in the wetter parts of the wetlands, and therefore also it seems that the drier parts of the wetlands are generally richer in Phosphorus. Interestingly, also the major cations, as well as Electrical Conductivity point in the negative direction along axis 2, so the drier parts of the wetlands are more nutrient-rich.

The community types that are found in the wettest sections of the wetlands are Communities 6.8 (*Schoenoplectus brachyceras* Community), 6.9 (*Juncus effusus* Community), 6.10 (*Cyperus denudatus* Community) and 6.12 (*Arundinella nepalensis* Community). The communities towards the drier part of the gradient are mainly Communities 6.6 (*Eragrostis curvula* Community), 6.17 (*Themeda triandra* Community), 6.19 (*Imperata cylindrica* Community) and 6.23 (*Eragrostis plana* Community), whereas communities like 6.2 (*Leersia hexandra* Community), 6.11 (*Eragrostis planiculmis* Community), 6.24 (*Typha capensis* Community) and 6.25 (*Phragmites australis* Community) find themselves at intermediate positions.

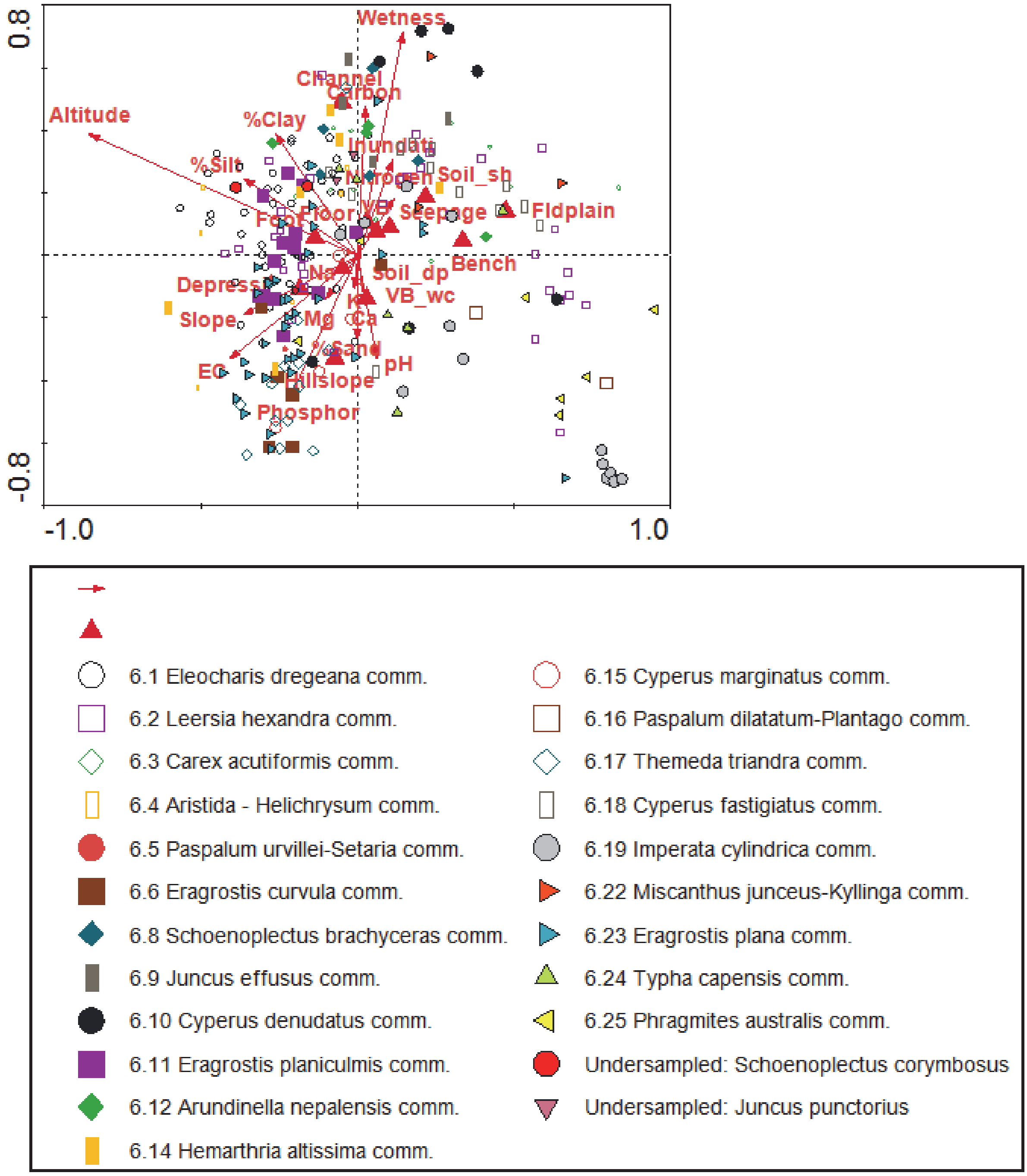


Figure 3.48 Ordination diagram for Canonical Correspondence Analysis for wetlands plots that included soil variables of Main Cluster 6.

The communities with the highest values for Electrical Conductivity seem to be the *Eragrostis plana* Community (6.23) and the *Themeda triandra* Community (6.17). It is conspicuous that there is still a very wide range in the scores along axis 2 for most of these communities, but that may reflect the fact that hydrological parameters were not measured but assessed and that proper measurements of soil-water characteristics would give a more accurate value.

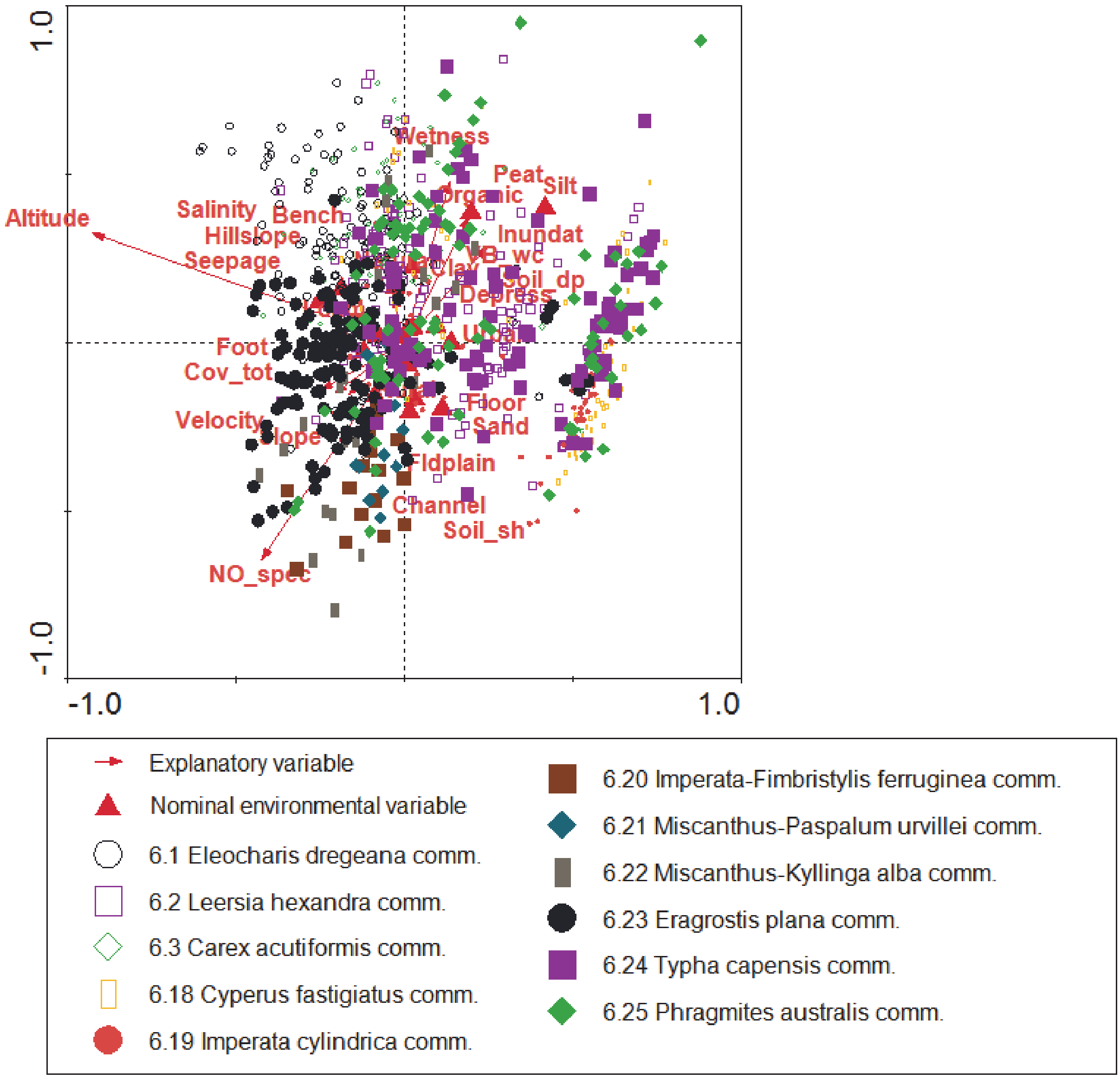


Figure 3.49 CCA ordination of 11 communities in Main Cluster 6, representing the most common communities.

The ordinations for the full dataset (Figures 3.49 and 3.50) including those plots where no soil data is available reflects more or less the same story, with altitude and wetness being the most important explanatory variables. For the first half of the dataset, displayed in Figure 6.22, total variation explained is 6.2 % and for the second half, displayed in Figure 6.23, the variation explained is 7.2 %, so they are both quite weak in explaining patterns in the data. We can conclude that many variables that determine the vegetation pattern in the Temperate Grassy Wetland Vegetation have not been captured. These may for example be more detailed measurements of hydrology, or assessments of grazing pressure or fire regime.

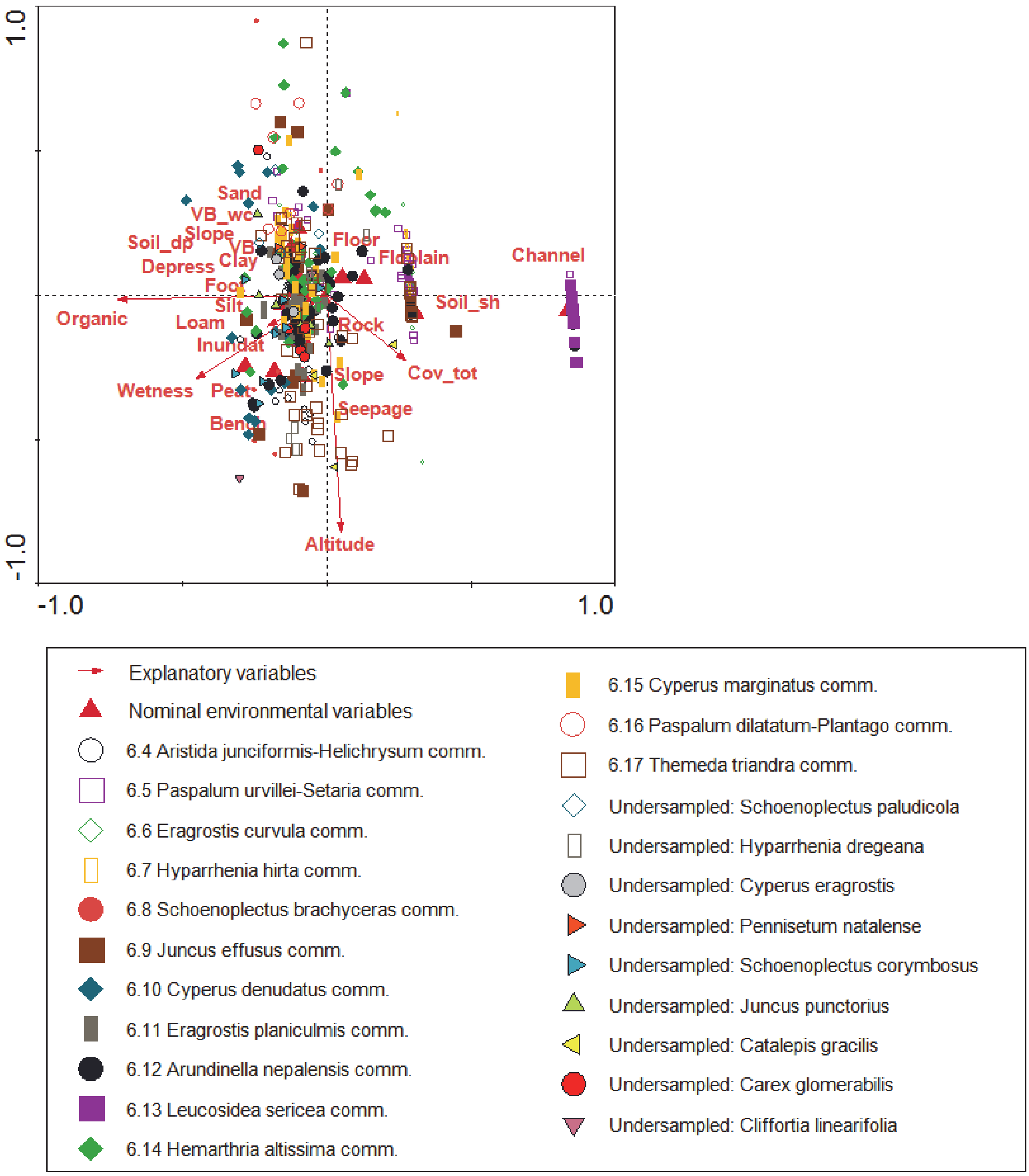


Figure 3.50 CCA ordination of the second part of all plots of Main Cluster 6, representing the more rare and restricted communities, including the under-sampled communities.

3.7.3 Species response curves

The wetlands in Main Cluster 6 are the ones that are most likely to be encountered in any urban area or region used for intensive agriculture and therefore they will also be the wetlands that are most likely to be subjected to a monitoring programme. It is therefore valuable that there is a lot of data about soil conditions for each individual indicator species, so that the models for the species response curves will be quite reliable. Most of these species have wide distributions across a broad spectrum of habitats and many species combinations are found together in the same plot, but for the purpose of presenting response curves the species are subdivided into small groups.

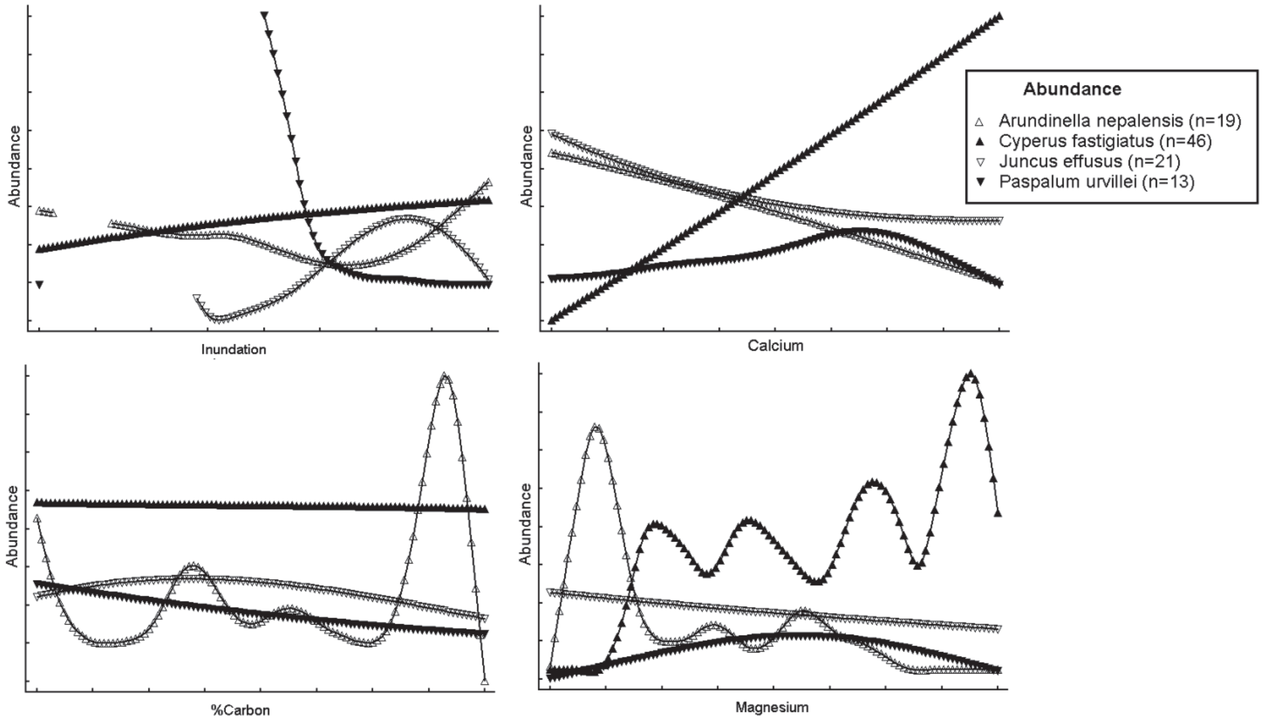


Figure 3.51 Species response curves for four graminoids found regularly in the foothills of the Drakensberg.

The species represented in Figure 3.51 show those species that become dominant in Communities 6.5, 6.9, 6.12 and 6.18. The species response curves show that the alien grass *Paspalum urvillei* does not deal well with high inundation, whereas the indigenous sedge *Cyperus fastigiatus* does very well. Similarly, this sedge becomes very competitive when there is a lot of Calcium in the soil, while both *Juncus effusus* and *Arundinella nepalensis* prefer low Calcium levels. A similar pattern is seen with Mangnesium, where *Cyperus fastigiatus* becomes more competitive at high levels. The grass *Arundinella nepalensis* performs well at high levels of soil carbon.

Figure 3.52 shows three species occurring more at the drier edge of wetlands with *Eragrostis curvula* becoming prominent in cluster 6.6, and *Helichrysum aureonitens* in Community 6.4. This last species, a daisy that colours the grasslands bluish grey, becomes prominent under conditions with low Calcium but also under high Sodium. *Eragrostis chloromelas* prefers higher wetness while the other two species decline under wetter conditions. *Eragrostis chloromelas* does decline on slopes, where *Eragrostis curvula* is more common.

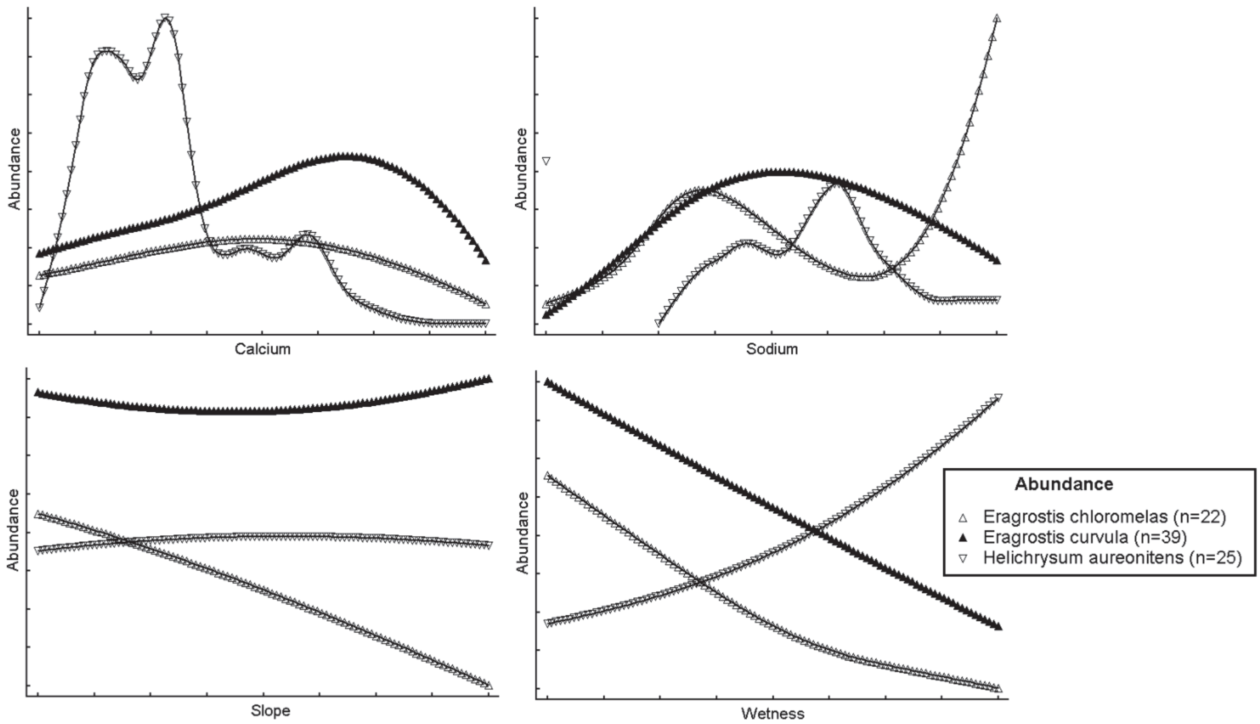


Figure 3.52 Species response curves of three species commonly occurring in hygrophilous grasslands of the Drakensberg and surroundings.

Figure 3.53 shows three other grass species, of which particularly *Miscanthus junceus* is important as it becomes dominant in Communities 6.21 and 6.22. It becomes dominant at mid-altitudes, at high clay levels and low Phosphorus levels. *Pennisetum thunbergii* is however even more dominant under low Phosphorus levels and also dominates under low Sodium levels.

The species in Figure 3.54 are mostly shared with the subtropical wetlands of Main Cluster 3 and become dominant in the Communities 6.11, 6.19, 3.24 and 6.8. *Imperata cylindrica* declines fastest with altitude whereas *Eragrostis planiculmis* increases with altitude. Kyllinga erecta peaks at low wetness and *Eragrostis planiculmis* peaks at high wetness. *Schoenoplectus brachyceras* gradually increases with wetness. All of these species decline with soil carbon, except for *Schoenoplectus brachyceras* which shows a slight increase. *Imperata cylindrica* declines with clay contents, but *Eragrostis planiculmis* shows a peak at a high clay contents.

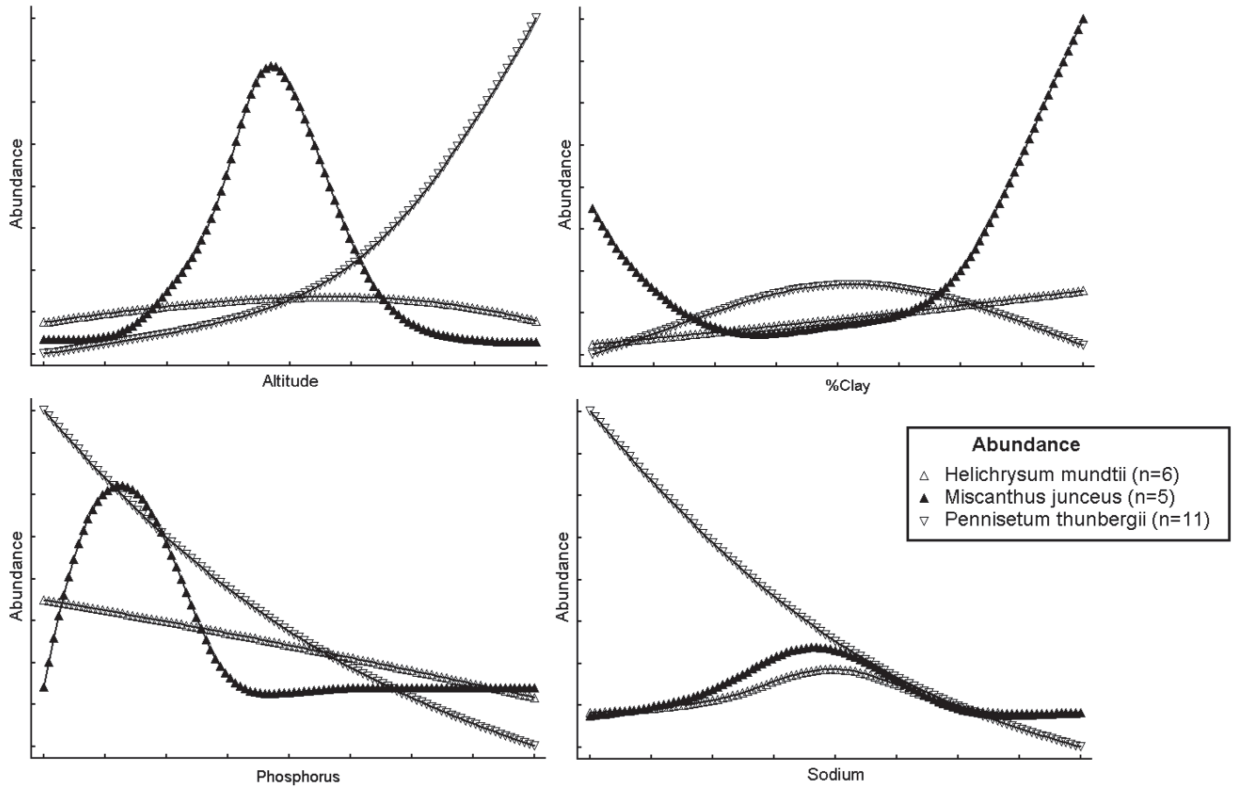


Figure 3.53 Species response curves for three species commonly found in the foothills of the Drakensberg.

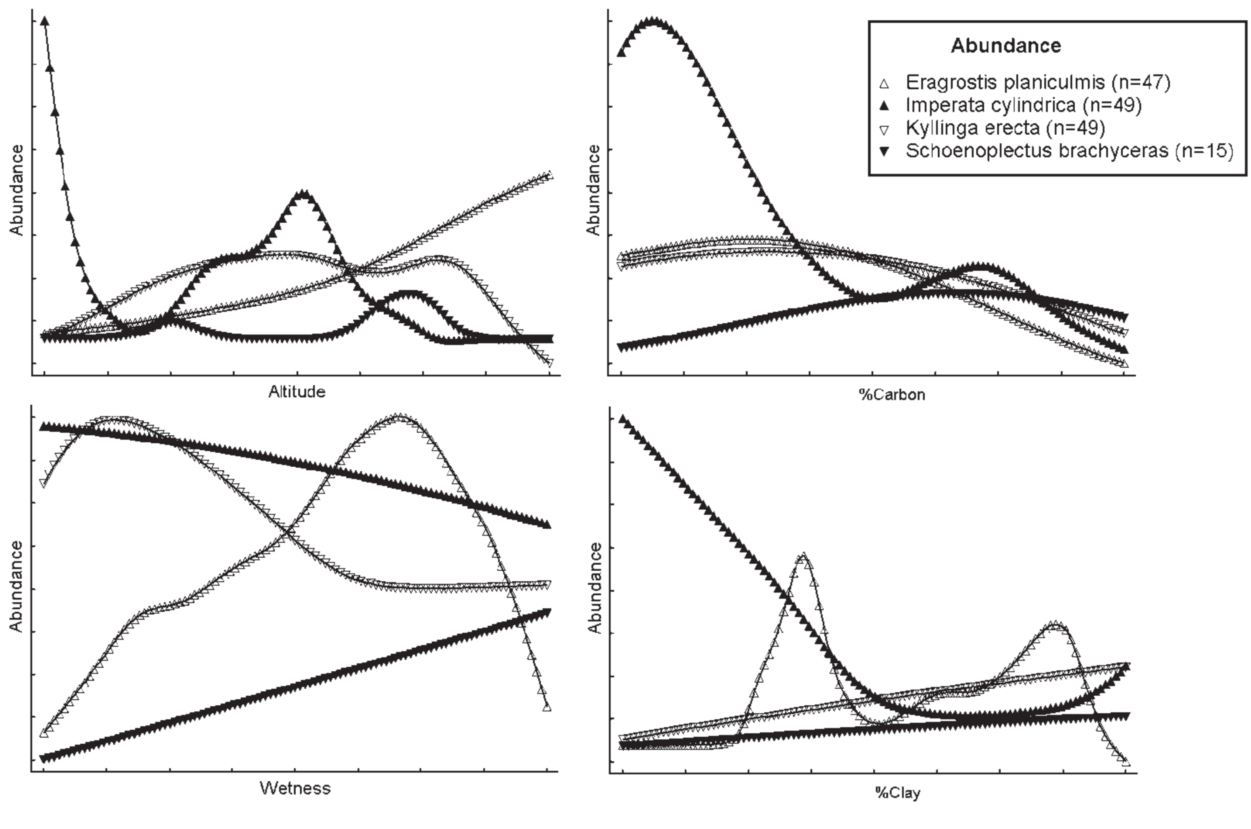


Figure 3.54 Species response curves for four species that are widespread across the temperate as well as the warm regions of South Africa.

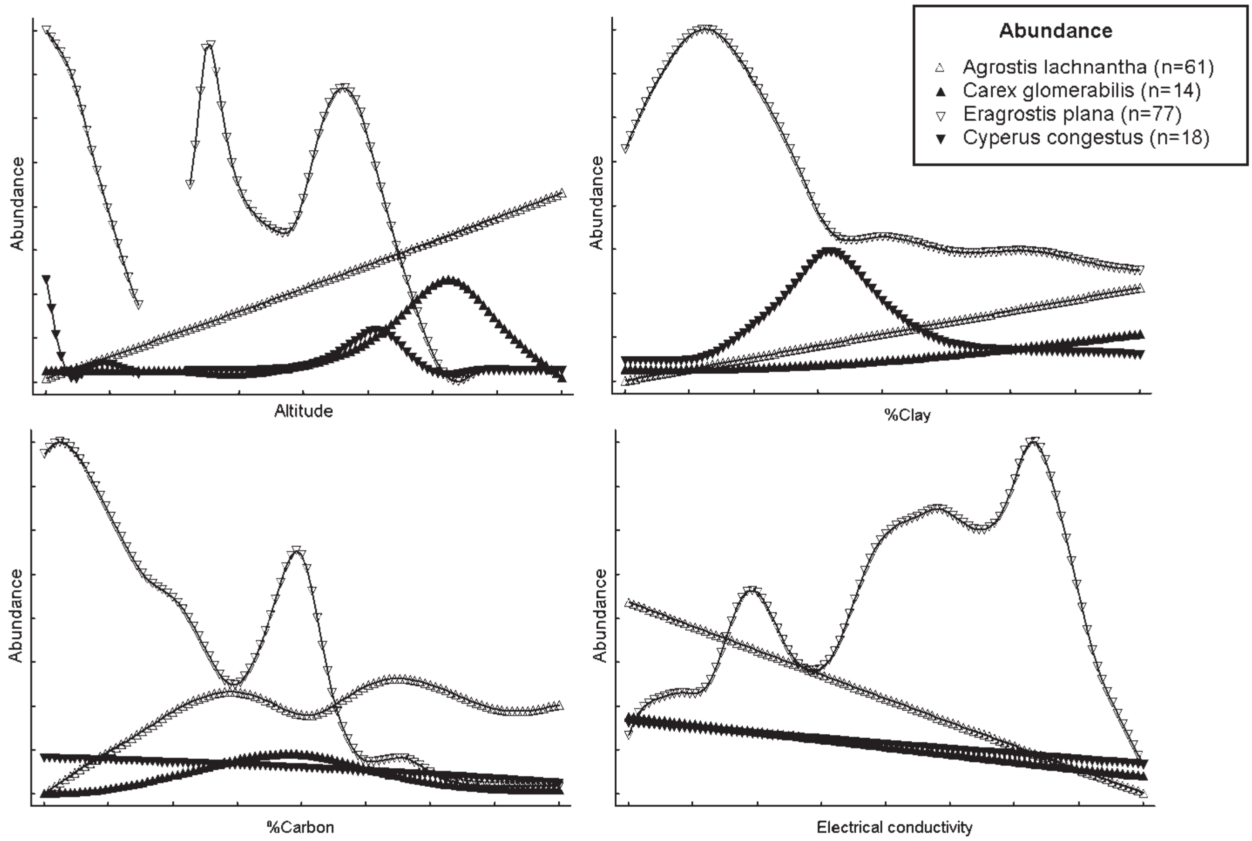


Figure 3.55 Species response curves for four species that occur regularly in slightly disturbed wetland conditions across the Highveld region.

The species in Figure 3.55 are all mostly bound to disturbed conditions for example where there is trampling. Only *Eragrostis plana* does become dominant and has a community named after it, Community 6.23. This happens in conditions with a relatively low clay fraction, low soil carbon and high Electrical Conductivity. *Cyperus congestus* peaks at higher clay fractions than *Eragrostis plana*. The very common grass *Agrostis lachnantha* increases with altitude, with soil carbon and slightly with clay percentage. It decreases however with Electrical Conductivity.

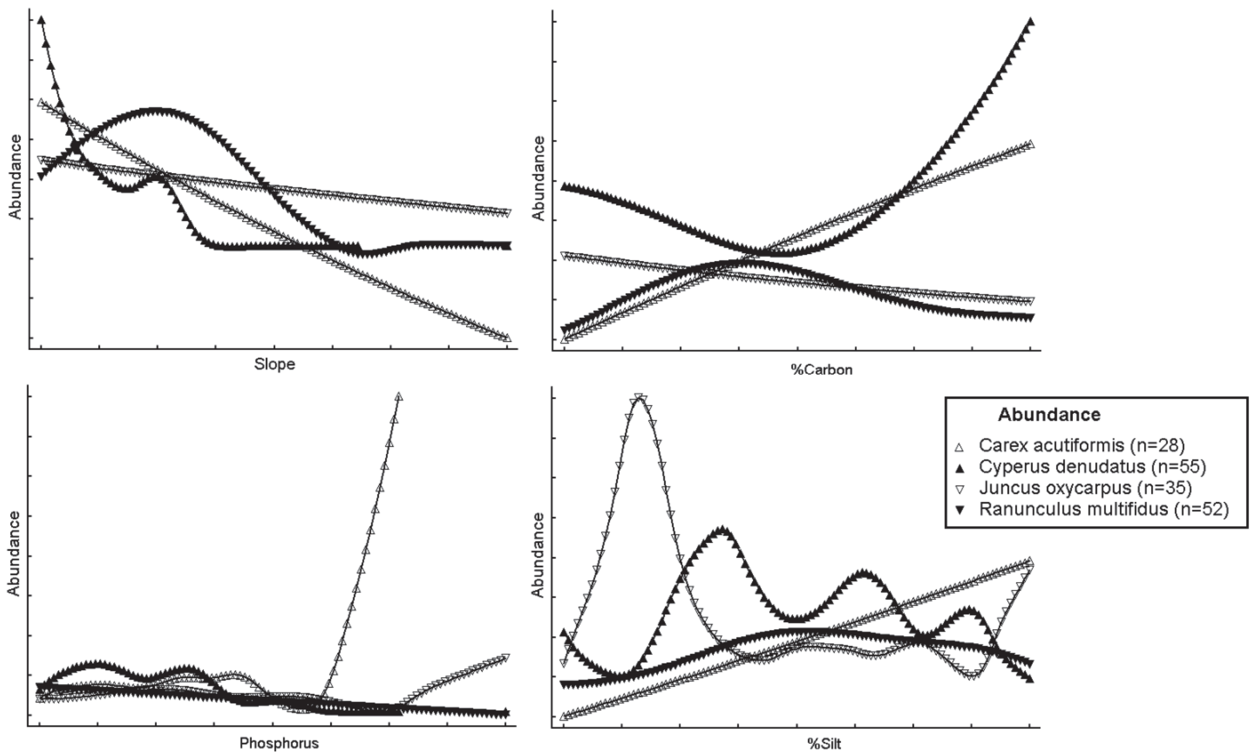


Figure 3.56 Species response curves for four species that are occurring mostly in the Drakensberg foothills but also at mid-altitudes.

In Figure 3.56 we find the species response curves for four species that are common in wetlands in the Drakensberg foothills. Of these species, *Juncus oxycarpus* and *Ranunculus multifidus* are the most likely to be found in seepages against mountain slopes, with *Carex acutiformis* and *Cyperus denudatus* occurring exclusively in the valley bottoms. These two species also perform best in those places where carbon accumulates in the soil. They become dominant in Communities 6.3 and 6.10. *Carex acutiformis* performs best when Phosphorus levels are high. *Juncus oxycarpus* peaks in soils where silt levels are low, and *Carex acutiformis* increases with silt level.

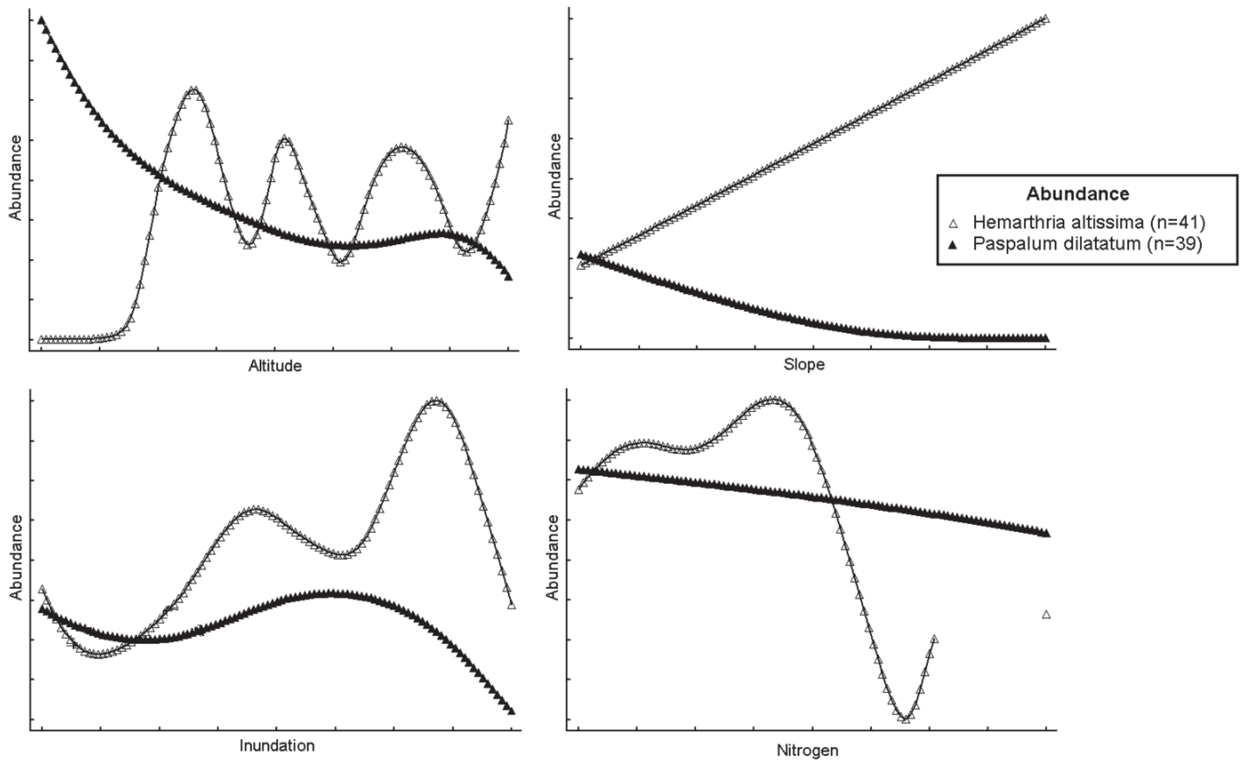


Figure 3.57 Species response curves for two weedy species commonly occurring around edges of pans in the Highveld region.

In Figure 3.57 the response curves of two species that are regularly found around the edges of pans in the Highveld region. They can become dominant in some cases, namely in Communities 6.14 and 6.16. *Paspalum dilatatum* is the most common alien invader in wetlands while *Hemarthria altissima* is an indigenous species. Both species decrease with higher Nitrogen levels, but *Hemarthria altissima* does so more quickly than *Paspalum dilatatum*. It can however deal better with inundation while at the same time it grows more on slopes, mostly on the edges of pans, whereas *Paspalum dilatatum* prefers flat ground.

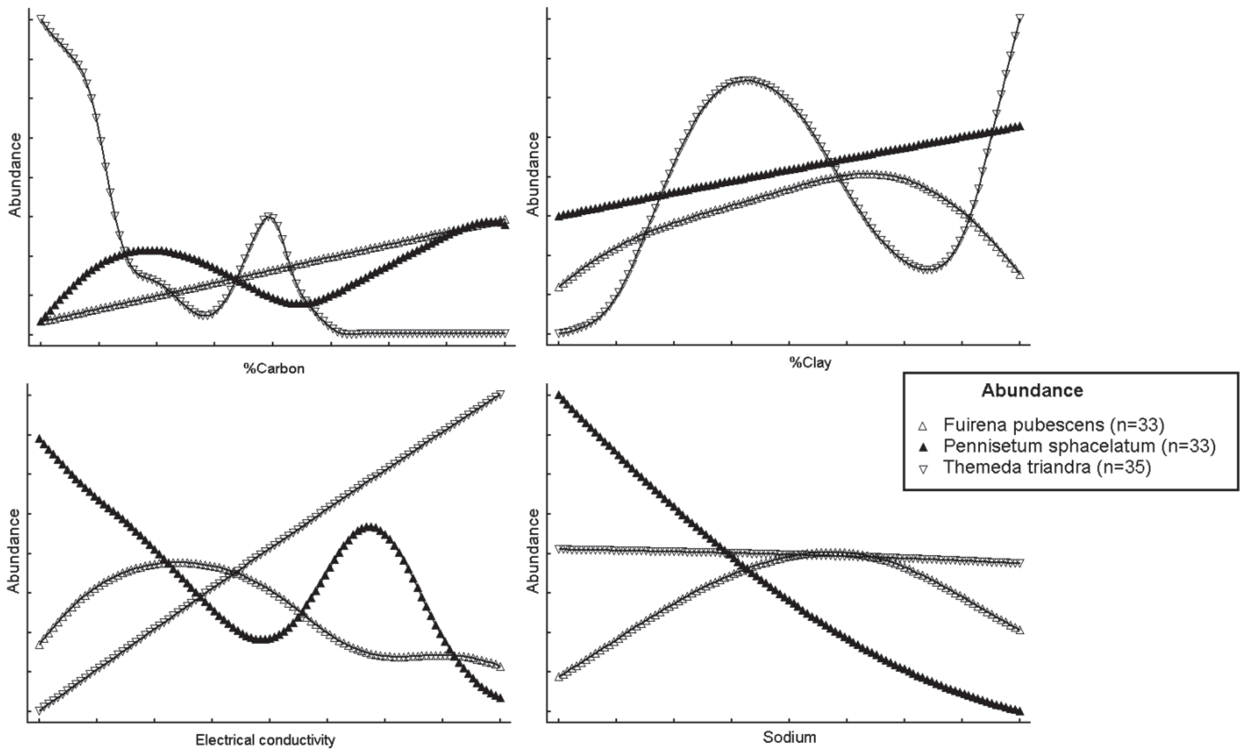


Figure 3.58 Species response curves of three species commonly occurring in various wet grasslands across the Highveld and Drakensberg foothills.

Figure 3.58 displays the species response curves for three species that are common in temporary zones in the wetlands of the Drakensberg foothills or Highveld regions. They become dominant in Communities 5.21 and 6.17. *Themeda triandra* is most dominant in conditions with low soil carbon, which are also the driest conditions. This species is basically a dryland species that is very common in Highveld grasslands. This species and *Pennisetum sphacelatum* increase with clay contents, whereas *Fuirena pubescens* prefers intermediate levels of clay. *Themeda triandra* increases with increasing Electrical Conductivity whereas the other two species decrease. *Pennisetum sphacelatum* decreases with increasing Sodium contents, whereas *Fuirena pubescens* prefers intermediate levels of Sodium. *Themeda triandra* seems indifferent to Sodium levels.

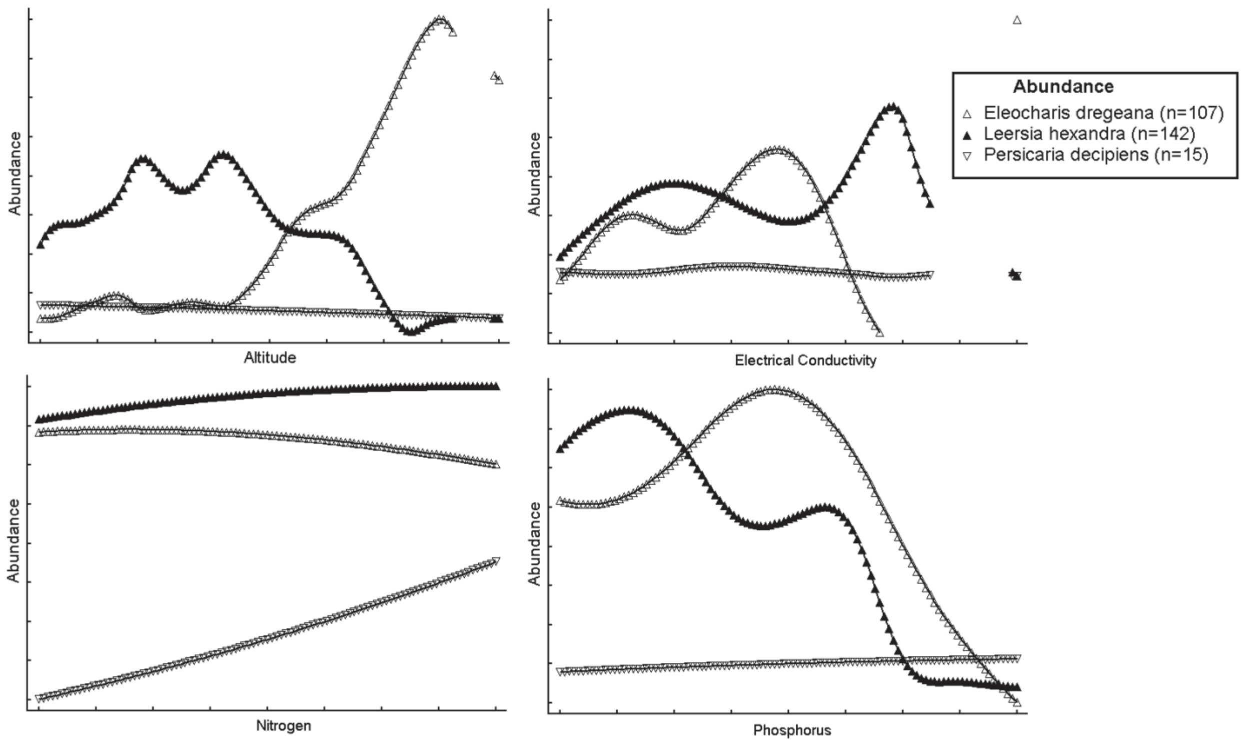


Figure 3.59 Species response curves of the three most common species of pans across the central part of South Africa.

In Figure 3.59 the species response curves of three very common species from pans on the inland plateau are displayed. They become dominant in Communities 6.1 and 6.2. *Eleocharis dregeana* is the species that is mostly adapted to higher altitudes, as it grows on the top of many of the koppies in the Highveld, whereas *Leersia hexandra* is more adapted to the lowlands. *Leersia hexandra* peaks at conditions with a high Electrical Conductivity whereas *Eleocharis dregeana* is more common in places with intermediate Electrical Conductivity. *Leersia hexandra* prefers conditions with low Phosphorus contents, but it will be replaced by *Eleocharis dregeana* under conditions with intermediate Phosphorus. The third species in these graphs, *Persicaria decipiens*, is not very responsive to the aforementioned factors, but is does slightly increase with an increase in Nitrogen, whereas the two other species are barely responsive to that.

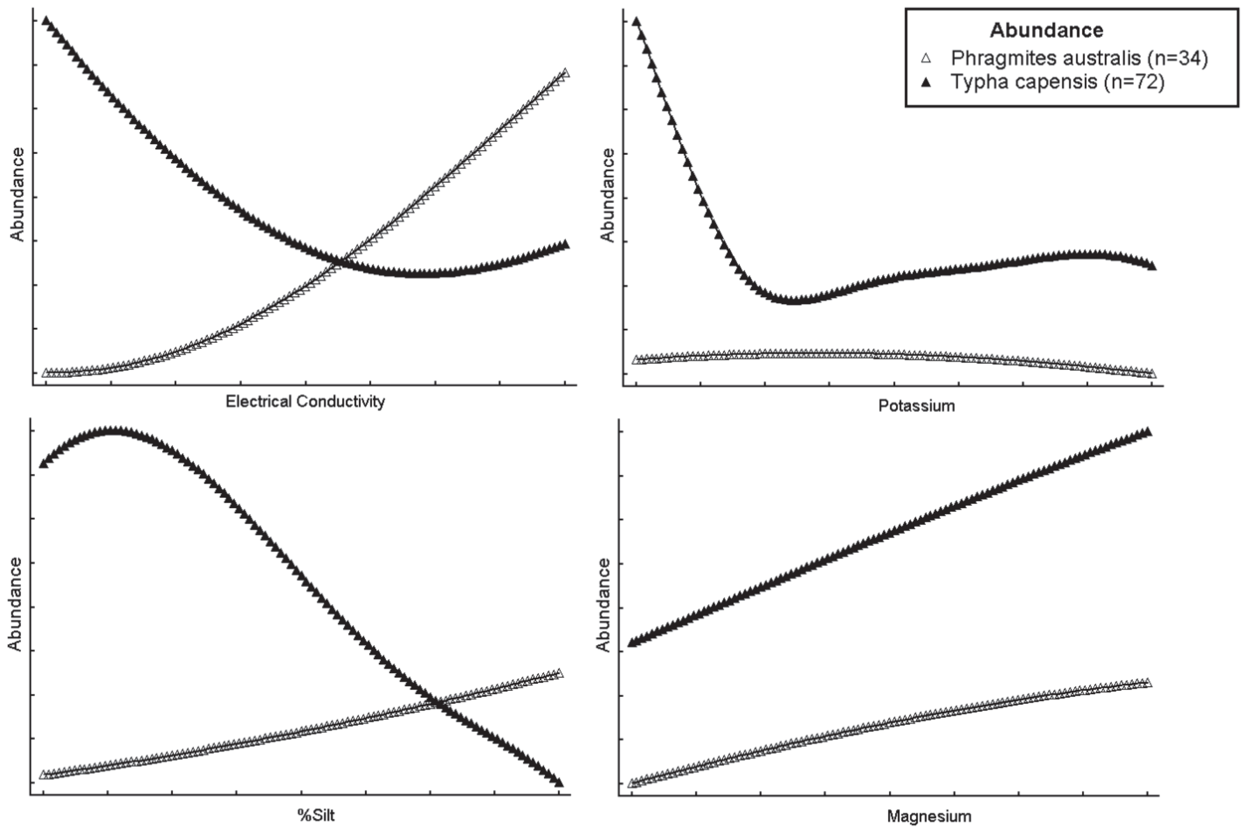


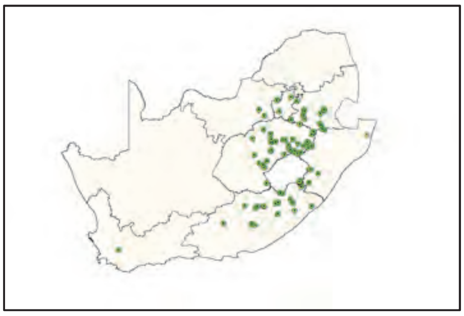
Figure 3.60 Species response curves for the two very well-known species of Common reed and Bullrush.

The species response curves that are shown in Figure 3.60 belong to the very common species of *Phragmites australis* and *Typha capensis*, which become dominant in Communities 6.24 and 6.25. From these graphs it becomes clear that *Phragmites australis* becomes dominant in conditions with a high Electrical Conductivity, and a very high silt percentage, while it is mostly indifferent to Potassium. On the other hand, *Typha capensis* becomes dominant in situations which are low in silt fraction and that are low in Potassium. Both species increase steadily with an increase in Magnesium, but *Typha capensis* reponds faster to such an increase.

3.7.4 Description of communities

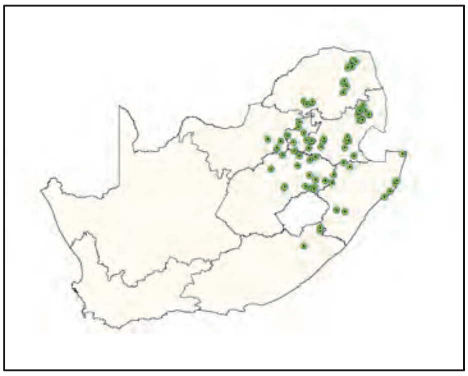
1. *Eleocharis dregeana* Community

This community is the most typical community for pans in the Highveld region, which can be found either in the lowlands, or on top of the sandstone koppies in the Free State. It is often the only plant community in the pan. The community grades into the *Leersia hexandra* Community (6.2) on the one hand, especially in the warmer regions, and into the *Schoenoplectus decipiens* Community (7.1) on the other hand, especially in the drier regions. *Eleocharis dregeana* often occurs with either of them, but it can also be a part of more species-rich communities, especially in the Eastern Cape.



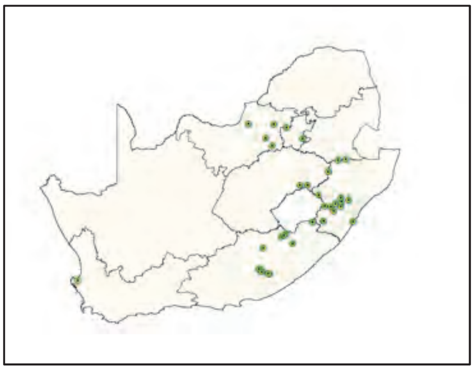
2. *Leersia hexandra* Community

This plant community is dominated by the most common wetland plant of South Africa, but in most cases, *Leersia hexandra* occurs interspersed within a matrix formed by other species and it occurs as a dominant only in the north of the country and in the warmer regions. In some cases it can grow to a very tall grass of reed-like stature, but in most cases the vegetation is low and permanently or seasonally wet.



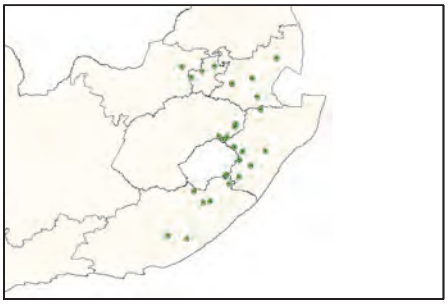
3. *Carex acutiformis* Community

This is a conspicuous plant community often occurring on peat soils or clay soils, with a monoculture of the sedge *Carex acutiformis*, which has a conspicuous glaucous shine on the leaves. It is unclear how this species arrived in South Africa and whether it is relatively new to the South African flora, as it is globally very widespread.



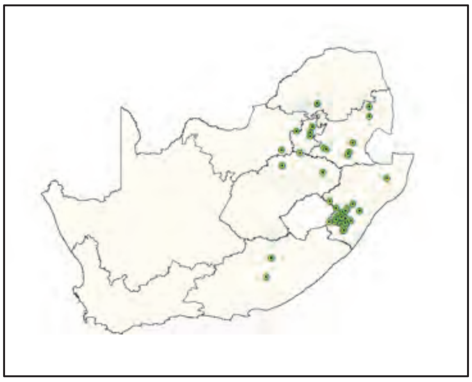
4. *Aristida junciformis – Helichrysum aureonitens* Community

This community is very common in the Highveld areas, mistbelt regions and the escarpment area. It is a temporarily wet part of the grassland that is conspicuous because of the silvery-grey shoots of *Helichrysum aureonitens* which occurs interspersed with the grasses, which are mainly *Aristida junciformis*.



5. *Paspalum urvillei – Setaria sphacelata* Community

This is a tall grassland community occurring in temporarily inundated grassland. It is invaded by the tall alien grass *Paspalum urvillei*.

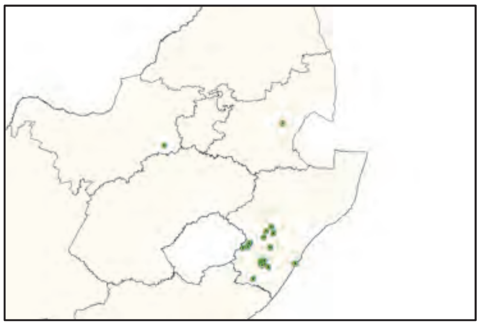


6. *Eragrostis curvula* Community

This is a marginal wetland community and is dominated by grasses that are also common outside of wetlands. *Eragrostis curvula* usually becomes dominant when a grassland is slightly overgrazed and the species is quite tolerant to inundation.

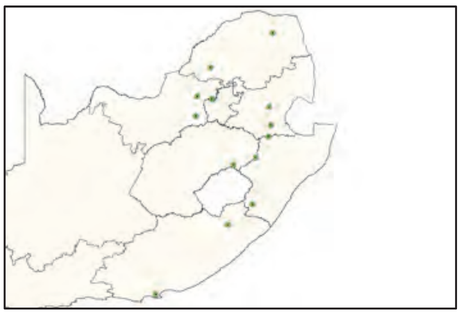
7. *Hyparrhenia hirta* Community

The grass *Hyparrhenia hirta* is an upland grass that becomes dominant mostly in undergrazed grasslands, but that can deal quite well with temporary inundation.



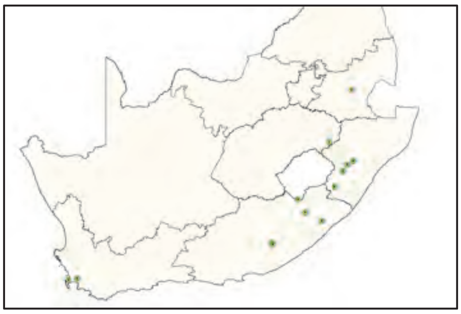
8. *Schoenoplectus brachyceras* Community

The species *Schoenoplectus brachyceras* occurs often in small clumps within *Cyperus fastigiatus* or *Carex acutiformis* wetlands, mostly in the wettest patches. It is not very common as a dominant over large areas, although this has been found across the entire eastern part of the country.



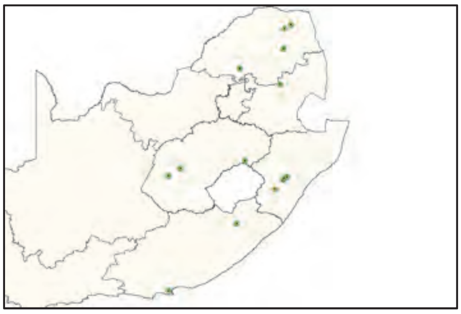
9. *Juncus effusus* Community

The species *Juncus effusus* is a globally distributed species that is found in many wetlands in South Africa. However it is not clear whether this species is originally from here. The species is very variable and occurs in permanently wet valley bottom wetlands on clay or loam soils.



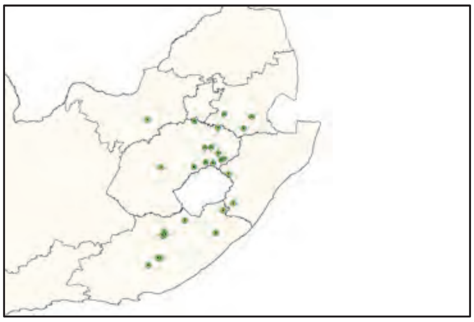
10. *Cyperus denudatus* Community

This is a community from permanently wet wetlands rich in short sedges, the most important of which is the leafless *Cyperus denudatus*. It occurs in clay or peat soils, mostly in areas with a high rainfall.



11. *Eragrostis planiculmis* Community

The grass *Eragrostis planiculmis* is an attractive grass which gives many wetlands in the Highveld a bit of a 'woolly' appearance. It occurs in clay soils, mostly in the Highveld area but can occasionally also be found in warmer regions.

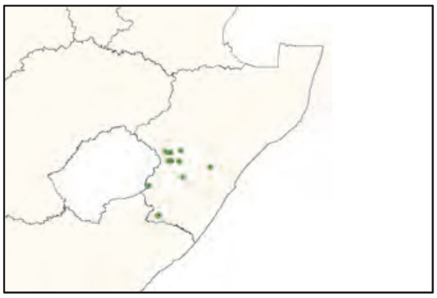


12. *Arundinella nepalensis* Community

The grass *Arundinella nepalensis* is mostly a riverine grass which can also regularly be found in wetlands, especially in the Drakensberg foothills. It is quite often monodominant.

13. *Leucosidea sericea* Community

The shrub *Leucosidea sericea* (Ouhout) is quite common in the Drakensberg foothills and tends to 'invade' grassland where there are disturbances but also where there are seepage zones of floodplains. It is an attractive shrub that can grow into a very large tree, but usually it does not grow large in wetlands. It occurs in temporary wet conditions in hygrophilous grasslands that can be quite rich in species.

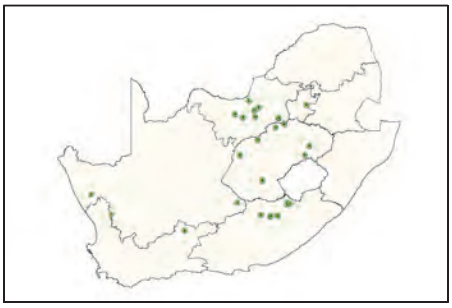


14. *Hemarthria altissima* Community

Hemarthria altissima, also called Red Vlei Grass, is a stoloniferous grass that commonly occurs around the edges of pans, particularly in the Highveld, but also in some tropical areas. Although it generally occurs in temporarily or seasonally wet areas, it can deal with high inundation as well. In many cases it achieved monodominance.

15. *Cyperus marginatus* Community

The sedge *Cyperus marginatus* is a leafless sedge that is very variable in its appearance and is found generally from the Drakensberg westwards. It likes the more arid regions and can be found also in the Cape where it can resemble *Cyperus textilis*. In the drier parts of its distribution range it grades into a community with *Cynodon dactylon* that is described under Community 7.44.

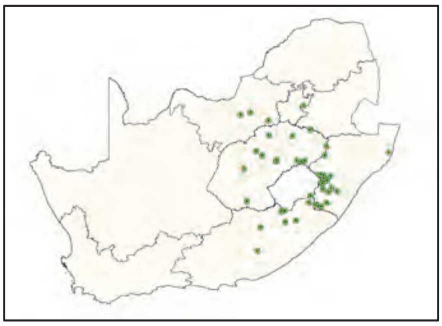


16. *Paspalum dilatatum – Plantago lanceolata* Community

This community is found in the temporary zones around Temperate Grassy Wetland Vegetation that is often quite disturbed and invaded by the alien species *Paspalum dilatatum*. It is also a type that is a transition towards the vegetation types of Main Cluster 7, as this community experiences intensive trampling and grazing. The grass *Cynodon dactylon* is also regularly found in this community.

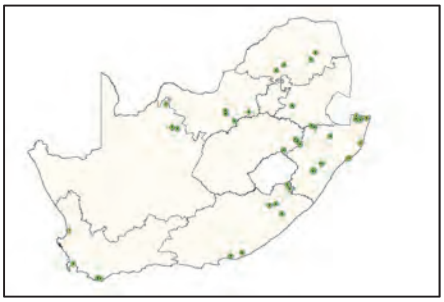
17. *Themeda triandra* Community

The red grass *Themeda triandra* is one of the most common grasses in South Africa, it is very palatable for grazers and it dominates in many grassland types across the eastern part of the Highveld. It is marginally also occurring in wetlands, but only in the temporary zone.



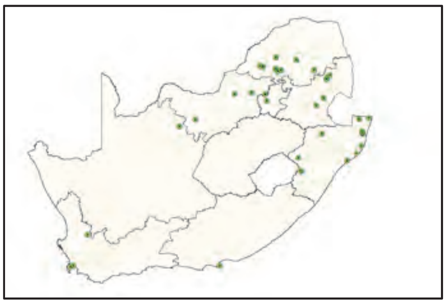
18. *Cyperus fastigiatus* Community

This is a very common and typical wetland plant community of seasonally to permanently wet soils on loam or clay soils and it can be found throughout the entire country including tropical or winter rainfall regions, but it is scarcer in the drier parts of the inland plateau. It occurs mostly in valley bottom wetlands and can deal with some water flow. It is generally poor in species and it is common as a monoculture of a single species.



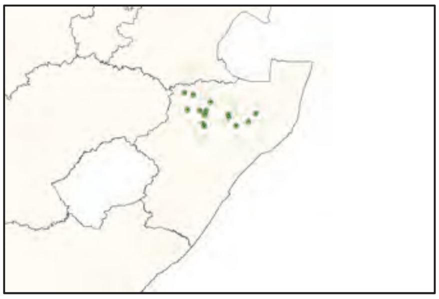
19. *Imperata cylindrica* Community

The grass *Imperata cylindrica* is conspicuous because of the white plumes of the infloresscense and is generally known as a grass that likes disturbances. It is mostly found in wet sandy soils, but also in generally disturbed areas such as road verges.



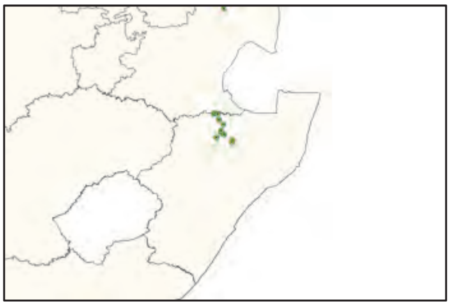
20. *Imperata cylindrica-Fimbristylis ferruginea* Community

The vegetation plots making up this community are from a single historical study that used a 10 by 10 meter sampling design, but these plots have nevertheless been included since there are no reasons to suspect that they are certainly heterogeneous. What makes this community stand out is the common presence of *Fimbristylis ferruginea*. For the rest, this community occurs in more or less similar habitats than the previous community, but it is restricted to northern KwaZulu-Natal.



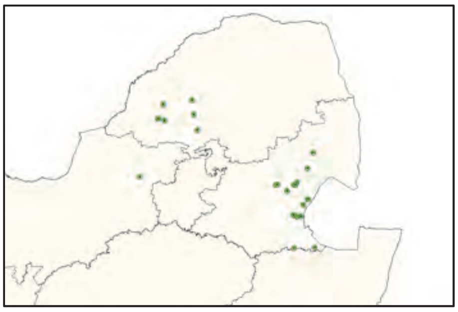
21. *Miscanthus junceus-Paspalum urvillei* Community

This is a community with a dominance of *Miscanthus junceus*, a tuft-forming grass that grows in temporary to seasonal wetlands and which conspicuously stands out in the landscape. The community is very similar to Community 6.23, but the tall grass *Paspalum urvillei* seems to have invaded these wetlands in northern KwaZulu-Natal much more than elsewhere.



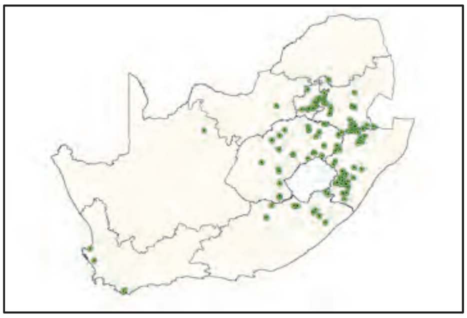
22. *Miscanthus junceus-Kyllinga alba* Community

This is a second community with a dominance of *Miscanthus junceus*, but this time without alien invaders. It borders the previous community in the south. It is particularly common in the Waterberg and along the Mpumalanga escarpment. It occurs in temporary to seasonal seepage and valley bottom wetlands in the mountains.



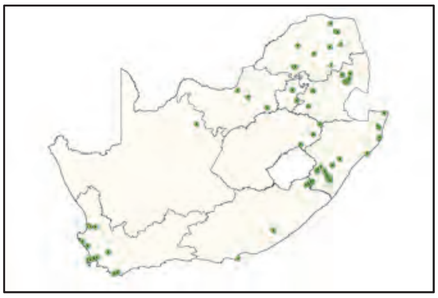
23. *Eragrostis plana* Community

This community is found in the temporary zone of many Temperate Grassy Wetland Vegetation, and is even found in the Western Cape associated with different types of wetlands. The dominant grass *Eragrostis plana* is dealing well with trampling but is generally not well grazed as it is quite unpalatable. Even though it is mostly confined to the temporary zone of wetlands, it can cope very well with inundation.



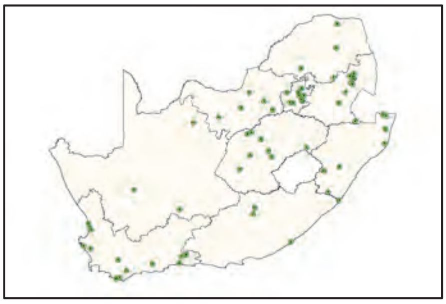
24. *Typha capensis* Community

The common bulrush *Typha capensis* is well-known as a species that is very tolerant of polluted situations that can sequester large quantities of toxic materials in its tissues. As such it is often found in urban wetlands. On the inland plateau it is mostly replaces by *Typha domingensis* with which it has often been confused.



25. *Phragmites australis* Community

Common reed (*Phragmites australis*) is a species with a worldwide distribution which is excellently adapted to wetland situations where it is very competitive. It can handle drought situations quite well and often becomes very dominant. It is the only type of ordinary wetland plant community which is still regularly encountered in the Karoo.



Under-sampled community 1: *Schoenoplectus paludicola*

These are four plots, mainly in the Eastern Cape, dominated by the short sedge *Schoenoplectus paludicola*, in seasonal to permanent wetlands.

Under-sampled community 2: *Hyparrhenia dregeana*

These are nine plots, mainly around the Drakensberg, dominated by the tall grass *Hyparrhenia dregeana*, which occurs in floodplains and seepage zones with temporary wetness.

Under-sampled community 3: *Cyperus eragrostis*

These are two plots, mainly around Gauteng, in permanently wet wetlands on clay, which have been invaded by the alien sedge *Cyperus eragrostis*, which is occasionally very dominant.

Under-sampled community 4: *Pennisetum natalense*

These are three plots from the Mpumalanga escarpment, dominated by the tufted grass *Pennisetum natalense*.

Under-sampled community 5: *Schoenoplectus corymbosus*

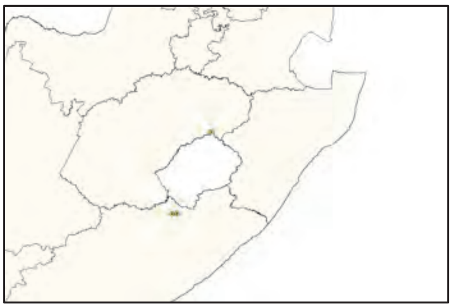
These are nine plots, from various places on the Highveld, mostly on the muddy banks of pans and lakes, dominated by the tufted sedge *Schoenoplectus corymbosus*.

Under-sampled community 6: *Juncus punctorius*

These are five plots dominated by *Juncus punctorius*, a tall rush species which is commonly found in wetlands, but only reaches dominance in North-West Province, in permanent wetlands.

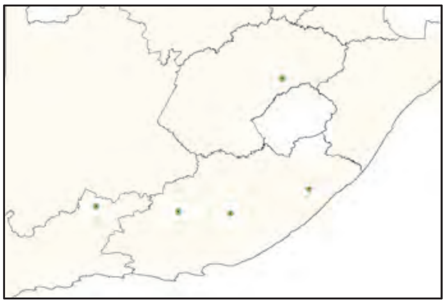
Under-sampled community 7: *Catalepis gracilis*

These are three plots, dominated by the lawn grass *Catalepis gracilis*, occurring in high altitude seasonally wet grasslands in the Drakensberg



Under-sampled community 8: *Carex glomerabilis*

These are three plots, dominated by the sedge *Carex glomerabilis*, which is very common, but seldom reaches dominance. When this happens it is in permanently wet wetlands with clay soils.



Under-sampled community 9: *Cliffortia linearifolia*

These are two plots quite far apart, one in the Drakensberg and one in the Mpumalanga escarpment, which are dominated by the tall shrub *Cliffortia linearifolia*. This species is usually riverine, but can also grow in valley bottom wetlands.

3.7.5 Discussion of Temperate Grassy Wetland Vegetation

Even though there is more data available for this cluster than for any of the other Main Clusters, the results of the ordination in explaining vegetation differences within this cluster remains quite limited. This may reflect that in the grassland biome, there are several pressures playing an important role that has not been captured in the database very well, such as fire and grazing. It is well understood that grazing affects the species composition of grassland vegetation, with a distinction between decreaser species (species that are dominant only when grasslands are optimally grazed), increaser 1 species, (species that increase when a grassland is undergrazed), and increaser 2 species (species that increase when a grassland is overgrazed, so that unpalatable species become dominant) (Tainton 1999). Grasses of each of these categories are represented in the vegetation classification presented above, with 6.17 *Themeda triandra* Community representing a community dominated by decreaser species that is optimally grazed, 6.7 *Hyparrhenia hirta* Community representing a community dominated by increaser 1 species that is undergrazed and 6.6 *Eragrostis curvula* Community representing a community dominated by increaser 2 species that is overgrazed. In that respect, there is no reason to expect that the dynamics of vegetation composition is different between wetland vegetation (of the temporarily wet zone) and upland vegetation. However, grazing may also affect vegetation in the wetter parts of a wetland, as cattle regularly forage deeper into the wetlands. It is not known how these species, that belong mostly to the families Cyperaceae and Juncaceae, respond to grazing and whether some species are becoming more dominant when the wetland is undergrazed or overgrazed.

Otherwise, the vegetation seems reasonably well explained by the environmental variables that were provided and many of the species had sufficient data available to produce reliable species response curves. This is valuable as these communities represent the most common but also the most vulnerable wetland plant communities in the country, and it seems that monitoring them will be realtively straightforward as there is only a limited number of species that play an important role.

3.8 Main Cluster 7: Short Lawn Grassy Wetland Vegetation

The communities of Main Cluster 7 are generally short lawn grasslands, mostly on floodplains that are inundated only temporarily or in pans located in semi-arid regions. The one species that tends to dominate these wetlands is *Cynodon dactylon* (Kweek), a grass species which tends to become dominant also in strongly grazed areas and is often associated with disturbance. It can be argued that such disturbance-prone environment can come into existence either by hydrogeomorphic settings (floodplains subject to irregular flooding) or by climatic conditions (semi-arid regions where rainfall is scarce and where wet areas are subjected to grazing and trampling).

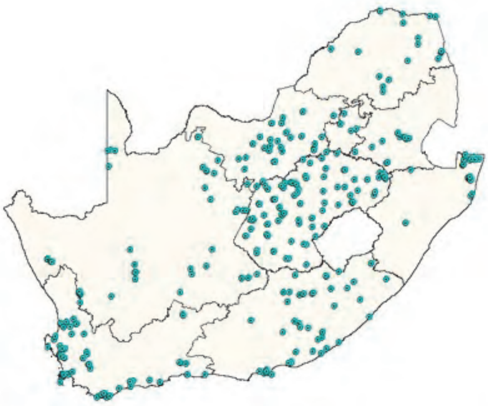


Figure 3.61 Distribution map of Short Lawn Grassy Wetland Vegetation and a picture representing a typical example of wetlands of this type.

Short Lawn Grassy Wetland Vegetation is particularly common in the Western Cape renosterveld areas (often subjected to severe summer drought), the semi-arid regions on the edge of the Karoo and the Kalahari, where they form a transition towards the saline wetlands of Main Cluster 4, and in the floodplains of subtropical regions of Northern KwaZulu-Natal and Limpopo. They are conspicuously absent in the main part of KwaZulu-Natal that has a humid climate. The wetter communities of this Main Cluster are often dominated by *Leptochloa fusca*, a grass with a very wide ecological amplitude occurring in near-saline conditions in the western Free State and in very wet and productive environments in the eastern Free State and Mpumalanga as well as the sedge *Schoenoplectus decipiens*.

3.8.1 Classification and Indicator Species Analysis

The cluster analysis for this cluster was carried out on a database with 948 plots containing a total of 1217 species. The classification using the classification criterion of Dufrene & Legendre (1997) resulted in an initial grouping into 49 clusters but four of these groups were regarded as heterogeneous and have been subjected to cluster analysis a second time which resulted in thirteen new clusters, resulting in a total of 58 clusters. Two of these clusters could be merged with existing clusters, whereas a third consists of a heterogeneous mix of several under-sampled communities, and lastly one of them was characterized by unidentified specimens of the genus *Sporobolus*. This grass genus proved to be the most difficult constraint on successful classification within this cluster because the grasses in the semi-arid regions of the western Free State, North-West and the eastern Karoo, are often in a very bad condition and can only be recognized properly after good growth and good rains.

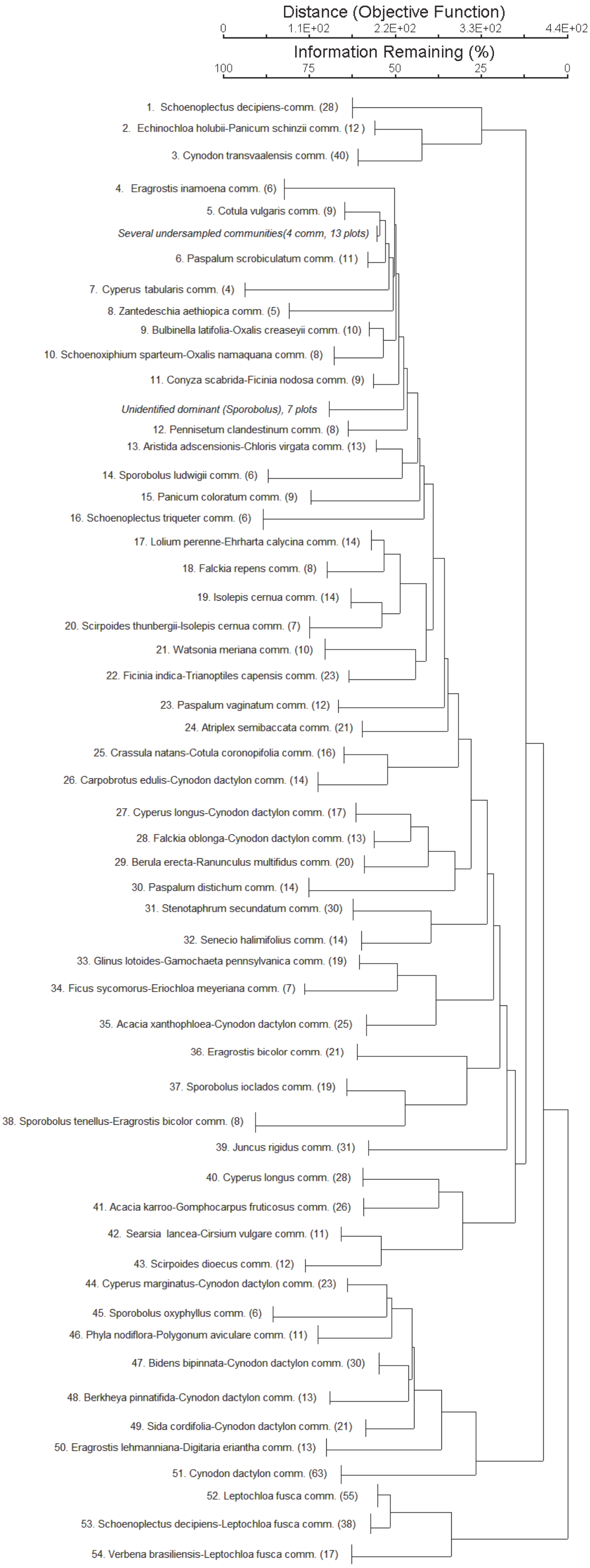


Figure 3.62 Cluster dendrogram for Short Lawn Grassy Wetland Vegetation.

Table 3.7 Plant communities and associated indicator species of Short Lawn Grassy Wetland Vegetation (Main Cluster 7).

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
1	28	*Schoenoplectus decipiens*	Seasonal to permanent in dry areas	*Schoenoplectus decipiens*	49	0.001
2	12	Various	Edge of dry areas	*Echinochloa holubii*	58	0.001
				Panicum schinzii	33.8	0.001
3	40	*Cynodon transvaalensis*	Pans in Free State	*Cynodon transvaalensis*	37.8	0.001
4	6	*Eragrostis inamoena*	Subtropical pans	*Eragrostis inamoena*	93.1	0.001
				Ischaemum fasciculatum	27.4	0.002
				Fimbristylis complanata	24.3	0.002
5	9	Various	Temporary pans in W Cape	*Cotula vulgaris*	50	0.001
				Puccinellia fasciculata	46.8	0.001
				Spergularia media	34.2	0.001
				Heliophila meyeri	22.2	0.003
				Drosanthemum parvifolium	20.1	0.004
6	11	*Paspalum scobiculatum*	Wet parts of pans	*Paspalum scrobiculatum*	41.5	0.001
7	4	*Cyperus tabularis*	Dry pans western Cape	*Cyperus tabularis*	98.7	0.001
				Merxmuellera stricta	33.7	0.001
				Panicum maximum	32.4	0.001
				Thesium funale	25	0.005
8	5	*Zandesceschia aethiopica*	Nutrient-rich pans Cape flats	*Zantedeschia aethiopica*	75.8	0.001
				Typha capensis	20.2	0.002
				Galium spurium ssp. *africanum*	20	0.01
				Carpha glomerata	20	0.011
				Juncus punctorius	20	0.011
				Villarsia capensis	20	0.011
9	10	Various, several *Oxalis*, *Carex divisa*	Namaqualand rocky pans	*Oxalis creaseyii*	50	0.001
				Bulbinella latifolia	40	0.001
				Carex divisa	31.2	0.001
				Hesperantha pauciflora	30	0.001
				Oxalis adenodes	30	0.001
				Moraea species	23.9	0.002
				Androcymbium burchelli	20	0.006
				Felicia merxmuelleri	20	0.006
				Pentzia species	20	0.006
				Holcus lanatus	20	0.007
				Ursinia cakilefolia	20	0.007
10	8	Various *Oxalis*, *Elytropappus rinocerotis*	Namaqualand rocky pans	*Schoenoxiphium sparteum*	84.8	0.001
				Oxalis namaquana	50	0.001
				Romulea citrina	37.5	0.001
				Trifolium glomeratum	37.5	0.001
				Cotula macroglossa	35.7	0.001
				Diascia namaquensis	25	0.001
				Zaluzianskya benthamiana	25	0.001
				Crassula species	25	0.002
				Elytropappus rhinocerotis	20.2	0.003

Table 3.7 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
11	9	*Ficinia nodosa*	Edges of wetlands in Cape	*Conyza scabrida*	51.2	0.001
				Helichrysum nudifolium	33.3	0.001
				Ficinia nodosa	27.8	0.001
				Calpurnia villosa	22.2	0.004
				Mentha longifolia ssp. *capensis*	22.2	0.004
				Pelargonium zonale	22.2	0.004
				Thelypteris confluens	22.2	0.008
12	8	*Pennisetum clandestinum*	Very disturbed wetlands often in urban areas	*Pennisetum clandestinum*	81.4	0.001
				Modiola caroliniana	46.9	0.001
				Datura stramonium	37.5	0.001
				Ipomoea purpurea	34.4	0.001
				Commelina benghalensis	25	0.001
				Sorghum halepense	25	0.001
13	13	*Cynodon polevansii, Eragrostis trichophora, Chloris virgata*	Dry pans or floodplains in karoo that are not saline	*Aristida adscensionis*	34.8	0.001
				Kyllinga alata	23.1	0.002
				Eragrostis trichophora	21.4	0.003
14	6	*Sporobolus ludwigii, Atriplex lindleyi*	Dry pans Karroo	*Sporobolus ludwigii*	85	0.001
				Atriplex lindleyi	33.3	0.001
				Salsola aphylla	24.9	0.002
				Lycium cinereum	24.7	0.001
15	9	*Panicum coloratum*	Pans and valley bottoms dry regions	*Panicum coloratum*	58	0.001
				Sonchus dregeanus	29.3	0.001
16	6	*Schoenoplectus triqueter*	Edges dry pans inland	*Schoenoplectus triqueter*	99.3	0.001
17	14	Annual grasses	Summer-dry grasslands West Coast	*Tribolium hispidum*	28.6	0.001
				Atriplex lindleyi	26.6	0.001
				Lolium perenne	21.5	0.001
				Lachenalia elegans	21.4	0.002
				Moraea tripetala	21.4	0.002
				Babiana vanzyliae	21.4	0.003
18	8	*Falckia repens*	Pans southern Cape	*Falckia repens*	79.4	0.001
				Parapholis incurva	25	0.001
19	14	*Isolepis cernua*	Pans and valley bottoms Southern and Western Cape	*Isolepis cernua*	21	0.001
20	7	*Isolepis cernua*	Pans and valley bottoms Southern and Western Cape	*Scirpoides thunbergii*	100	0.001
				Bromus madritensis	28.6	0.001
				Elegia tectorum	22.1	0.002
21	10	*Watsonia meriana*	Sandy plains Western Cape	*Watsonia meriana*	100	0.001
				Stipagrostis zeyheri	20	0.006
				Carpha capitella	20	0.007
				Restio tetragonus	20	0.007

Table 3.7 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
22	23	Various	Wetlands Cape Flats and inland plateaus Western Cape	*Trianoptiles capensis*	34.8	0.001
				Micranthus junceus	31.7	0.001
				Babiana stricta	25.1	0.001
				Ursinia anthemoides	23.7	0.001
				Hesperantha falcata	23.6	0.001
				Drosera trinervia	23.3	0.001
				Wachendorfia paniculata	23	0.002
				Isolepis marginata	22.4	0.001
				Triglochin striata	21.7	0.003
23	12	*Paspalum vaginatum*	Often saline, estuarine settings	*Paspalum vaginatum*	68	0.001
24	21	*Atriplex semibaccata* and other chenopods	Dry pans Southern Cape	*Atriplex semibaccata*	44.8	0.001
				Chenopodium mucronatum	21.1	0.001
				Salsola kali	20.1	0.003
25	16	Various	Annual grasslands Southern cape	*Crassula natans*	59.3	0.001
				Cotula coronopifolia	48	0.001
26	14	*Cynodon dactylon, Cyperus longus*	Grasslands Western Cape	*Carpobrotus edulis*	15.5	0.008
				Melilotus indica	14.3	0.038
27	17	*Cynodon dactylon, Cyperus longus*	Floodplains	*Carex schlechteri*	23.8	0.002
				Ranunculus multifidus	17	0.002
28	13	*Falckia oblonga, Cynodon dactylon*	Dry pans inland	*Falckia oblonga*	51.9	0.001
29	20	*Berula erecta*	Wet parts highveld pans	*Berula erecta* ssp. *thunbergii*	33.9	0.001
				Veronica anagallis-aquatica	27	0.001
				Juncus dregeanus	20	0.003
				Mentha longifolia ssp. *longifolia*	20	0.004
30	14	*Paspalum distichum*	Wet parts highveld pans	*Paspalum distichum*	56.9	0.001
				Persicaria hydropiper	21.4	0.002
				Cotula nigellifolia	21.4	0.003
31	30	*Stenotaphrum secundatum*	Wet coastal sands	*Stenotaphrum secundatum*	37.1	0.001
32	14	*Senecio halimifolius*	Wet coastal sands	*Senecio halimifolius*	80.9	0.001
33	19	*Cynodon dactylon*	Subtropical floodplains	*Gamochaeta penssylvanica*	79.2	0.001
				Glinus lotoides	51.9	0.001
				Grangea maderaspatana	47.3	0.001
				Caperonia stulhmannii	31.6	0.001
				Persicaria senegalensis	31.6	0.001
				Cotula anthemoides	24.3	0.001
				Heliotropium ovalifolium	22.7	0.001

Table 3.7 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
34	7	*Ficus sycomorus, Eriochloa meyeriana*	Riverine floodplain forests	*Ficus sycomorus*	93.8	0.001
				Cissampelos mucronata	88.4	0.001
				Jasminum fluminense	71.4	0.001
				Eriochloa meyeriana	59.3	0.001
				Echinochloa pyramidalis	54.6	0.001
				Ficus capreifolia	42.9	0.001
				Commelina africana	42.7	0.001
				Cardiospermum halicacabum	38.7	0.001
				Ipomoea mauritiana	38.2	0.001
				Ageratum conyzoides	37.8	0.001
				Trichilia emetica	28.6	0.001
				Sida alba	26.4	0.001
				Eriochloa parvispicula	25.1	0.001
				Grewia caffra	24.6	0.002
				Dyschoriste depressa	23.3	0.001
				Senecio madagascariensis	22.9	0.001
				Kraussia floribunda	21.9	0.003
35	25	*Cynodon dactylon, Acacia xanthophloea*	Floodplains northern KZN, Limpopo	*Acacia xanthophloea*	65.4	0.001
36	21	*Eragrostis bicolor*	Karroo	*Eragrostis bicolor*	47	0.001
37	19	*Sporobolus ioclados*	Brackish pans	*Sporobolus ioclados*	41.8	0.001
38	8	*Sporobolus ioclados, Eragrostis bicolor*	Brackish pans	*Sporobolus tenellus*	87.5	0.001
				Salsola glabrescens	70.9	0.001
39	31	*Juncus rigidus*	Dry pans or valley bottoms, Karroo	*Juncus rigidus*	36	0.001
40	28	*Cyperus longus*	Western parts Highveld	*Cyperus longus*	28.7	0.001
				Equisetum ramosissimum	23.4	0.002
41	26	*Acacia karroo*	Shrubby floodplains edge of karroo	*Acacia karroo*	34.5	0.001
				Gomphocarpus fruticosus	34.5	0.001
				Cynodon incompletus	24.9	0.001
42	11	*Searsia lancea*	Shrubby floodplains edge of Karroo	*Searsia lancea*	39.9	0.001
				Cirsium vulgare	30.5	0.001
				Cyperus laevigatus	28.5	0.001
				Lobelia thermalis	27.9	0.001
43	12	*Scirpoides dioecus*	Valley bottoms in Karroo	*Scirpoides dioecus*	50.3	0.001
44	23	*Cynodon dactylon*	Dry pans edge of Karroo	*Cyperus difformis*	11.4	0.043
				Senecio reptans	11.2	0.03
45	6	*Sporobolus oxyphyllus*	Dry pans Northwest around Vaal	*Sporobolus oxyphyllus*	83.7	0.001
				Sporobolus festivus	33.3	0.001
46	11	Various	Subtropical floodplains	*Phyla nodiflora*	40.1	0.001
				Polygonum aviculare	21.5	0.001
47	30	*Cynodon dactylon, Cyperus longus*	Weedy parts floodplains	*Cichorium intybus*	33.3	0.001
				Sesbania bispinosa	21.2	0.002

Table 3.7 (continued)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
48	13	*Cynodon dactylon*	Weedy parts inland wetlands	*Selago saxatilis*	60.5	0.001
				Berkheya pinnatifida	58.4	0.001
				Lepidium bonariense	46.2	0.001
				Felicia muricata	42.6	0.001
				Urochloa panicoides	39.2	0.001
				Solanum incanum	21.3	0.003
49	21	*Cynodon dactylon*	Subtropical floodplains	*Sida cordifolia*	60.2	0.001
				Indigofera velutina	28.6	0.001
				Brachiaria humidicola	28.6	0.002
				Brachiaria serrata	27.1	0.001
				Cyperus dives	25.5	0.001
				Justicia flava	23	0.002
				Lantana rugosa	23	0.003
				Chloris gayana	21.3	0.001
				Brachiaria eruciformis	21	0.001
50	13	Various	Dry edges inland wetlands	*Eragrostis lehmanniana*	70	0.001
				Digitaria eriantha	34.8	0.001
				Chrysocoma ciliolata	21.1	0.003
				Sporobolus fimbriatus	20.4	0.001
51	63	Cynodon dactylon	Floodplains anywhere	-		
52	55	*Leptochloa fusca*	Pans in Free State	*Leptochloa fusca*	37.6	0.001
53	38	*Leptochloa fusca, Echinochloa holubii, Schoenoplectus decipiens*	Pans in areas, between highveld and Karroo	*Leptochloa fusca*	30.2	0.001
54	17	*Leptochloa fusca*	Disturbed sites inland wetlands	*Verbena brasiliensis*	59	0.001
				Schkuhria pinnata	38.2	0.001
				Cotula hispida	35.3	0.001
				Ammocharis coranica	34.2	0.001
				Pseudognaphalium luteo-album	27.3	0.001
				Alternanthera nodiflora	26.7	0.001
				Amaranthus hybridus	25.9	0.001
				Chenopodium album	25.1	0.001
				Persicaria lapathifolia	24.1	0.001
Add.1	13	various	Heterogeneous, consisting of four: *Elegia nuda*, W Cape, *Echinochloa jubata*, highveld, *Eragrostis heteromera*, tropics *Cyperus durus*, E Cape			
Add. 2	7	Unidentified *Sporobolus*	Western part Highveld			

3.8.2 Canonical ordination

When looking at Canonical Correspondence Analysis for the cluster of Short Lawn Grassy Wetland Vegetation, we have to remember that part of the communities involved have also been included in the ordination of inland saline wetlands and have therefore also been used to compare communities between the Main Cluster. This was done because some of the communities in this Main Cluster occur in the semi-arid regions of the Western Highveld and form a transition towards the saline communities in the arid regions. Therefore, the CCA ordination for Main Cluster 7 using all available soil variables has been carried out twice, once with the entire dataset and once excluding those communities that have been already utilized in the ordinations of Main Cluster 4 (Figures 3.31 and 3.32). The first ordination, shown in Figure 3.63 includes 244 vegetation plots and 40 communities, seven of which only represented by a single plot (7.2 *Echinochloa holubii-Panicum schinzii* Community, 7.4 *Eragrostis inamoena* Community, 7.12 *Pennisetum clandestinum* Community, 7.14 *Sporobolus ludwigii* Community, 7.24 *Atriplex semibaccata* Community, 7.45 *Sporobolus oxyphyllus* Community, and 7.46 *Phyla nodiflora-Polygonum aviculare* Community). The second ordination (Figure 3.64) utilizes 244 plots and 24 communities, three of which among the communities mentioned above with only a single plot.

The ordination in Figure 3.63 has a Total Inertia of 63.5, while the sum of all canonical eigenvalues amounts to 11.5, so this means that the total fraction of variation explained by the environmental variables is about 18%.

The first axis is correlated with soil particle composition with a positive correlation with percentage sand and a negative correlation with percentages of clay and silt. Within this cluster it seems that plots with a higher percentage of clay and silt are located at the higher altitudes and the low-lying communities are mostly located on coastal sands. It is particularly communities like 7.19 *Isolepis cernua* Community, and 7.31 *Stenotaphrum secundatum* Community that are mostly restricted to the right-hand side of the diagram and therefore more or less confined to the coastal, sandy areas. The left-hand side of the diagram is dominated by communities such as 7.3 *Cynodon transvaalensis* Community and 7.52 *Leptochloa fusca* Community, and both these communities have also been included in the ordinations for Main Cluster 4. It is conspicuous that the most abundant plant community of Main Cluster 7, which is the *Cynodon dactylon* Community (7.51) is scattered everywhere across the ordination diagram and it could therefore be argued that this community is not only widespread but also has a wide ecological amplitude, as it occurs both on sandy and on clayey soils.

The second axis is mostly correlated with Electrical Conductivity, although this variable is for a part also correlation with percentage clay on the first axis. The communities that lie towards the negative extreme of this axis are all those communities that have been included in the ordination in section 3.5.2., such as 7.37 *Sporobolus ioclados* Community and 7.39 *Juncus rigidus* Community. This axis is also slightly correlated Nitrogen with Nitrogen contents, although this correlation is quite weak. Towards the positive extreme of this axis lie the communities with shallow soils.

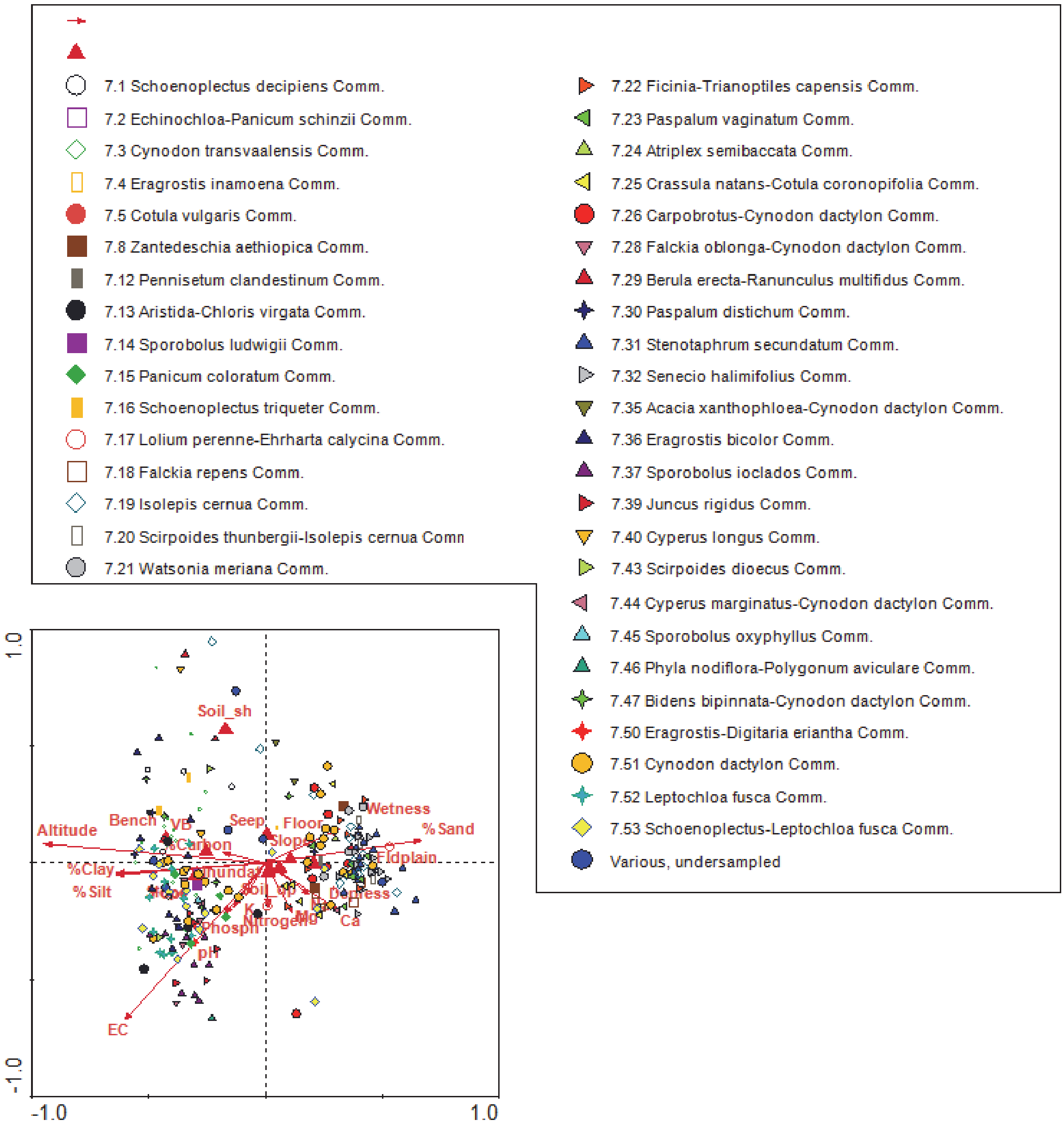


Figure 3.63 CCA Ordination diagram including soil variables for all communities in Main Cluster 7. A part of these plots have also been used in ordination of inland saline wetlands in section 3.5.2 and these are mostly found on the left-hand side of the diagram.

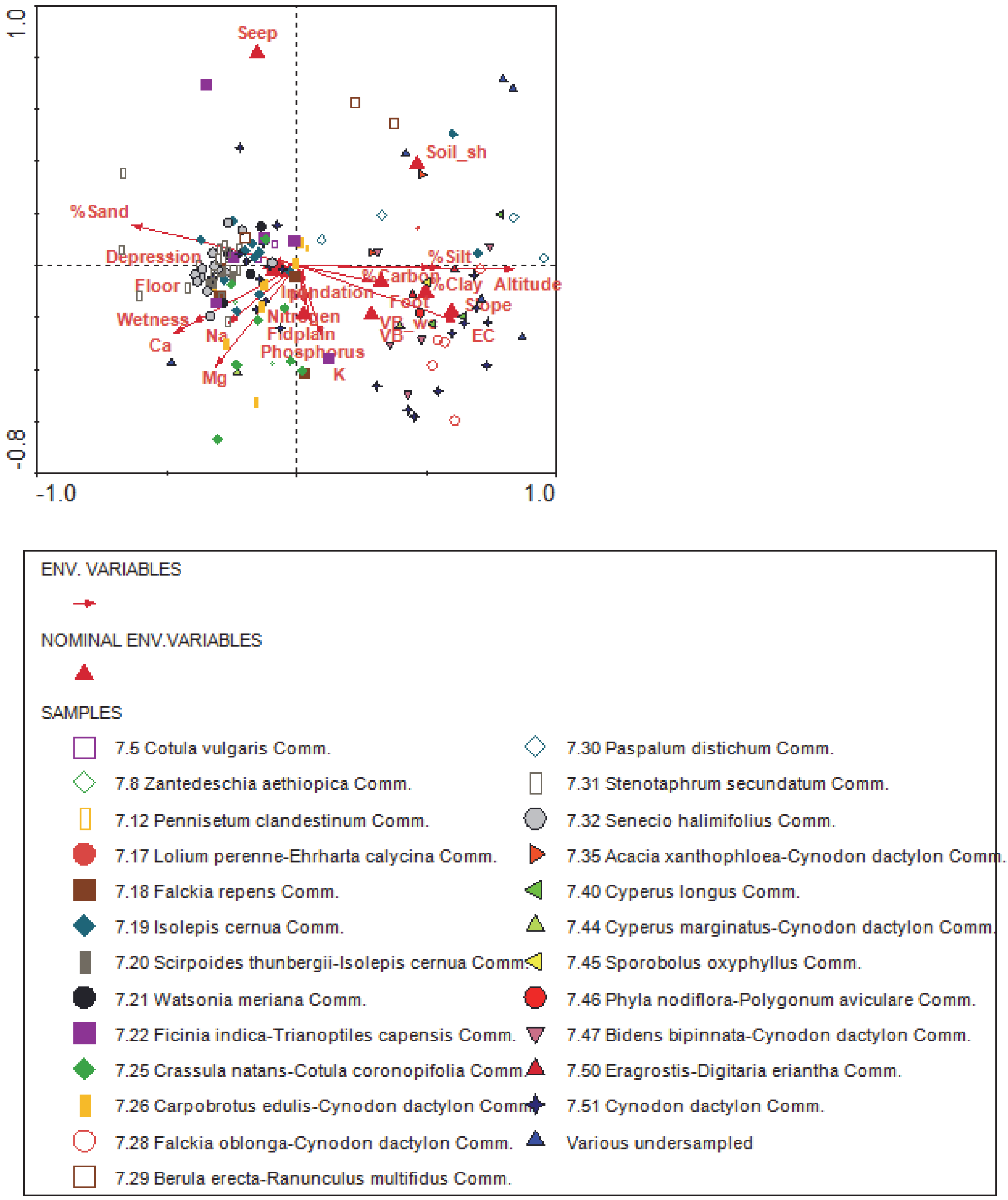


Figure 3.64 CCA ordination diagram for the communities of Main Cluster 7 excluding the ones associated with saline and brackish soils.

When Figure 3.63 is compared with Figure 3.64 that excludes the most saline communities, we see the difference in that the second axis is no longer associated with Electrical Conductivity and the effect of Magnesium is becoming more conspicuous along the second axis. The two communities that are mostly associated with these Magnesium-rich conditions are Communities 7.25 (*Crassula natans-Cotula coronopifolia* Community) and 7.26 (*Carpobrotus edulis-Cynodon dactylon* Community)

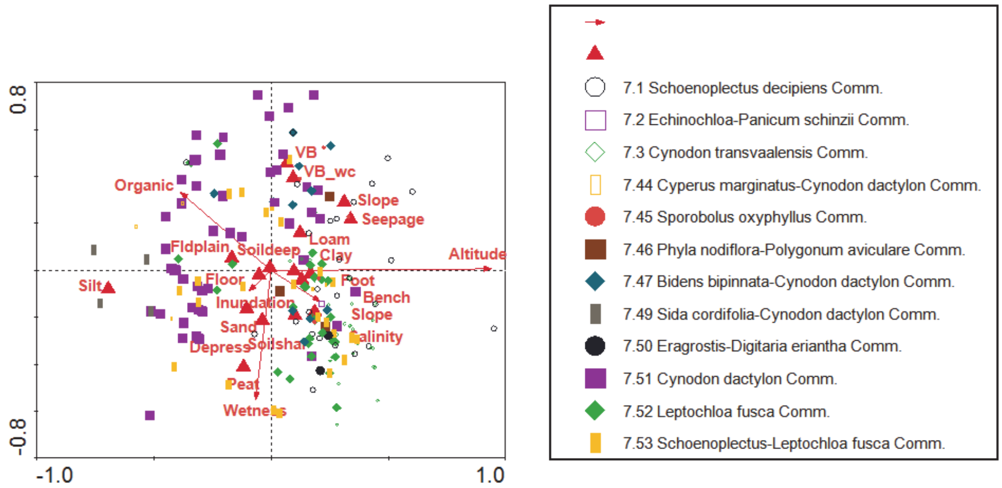
For the rest, the configuration of the ordination diagram is quite similar with that of Figure 3.31, except that the first axis here is switched around, with sandy communities to the left and clayey communities to the right. The total Inertia in this ordination is 46.3 and the sum of all canonical eigenvalues is 11.3 which means that the Total Variation Explained is about 24% which is an improvement compared with the previous ordination diagram, so leaving out these saline communities is a meaningful thing to do when interpreting this data.

Canonical Correspondence Analysis was also carried out on the complete dataset, that is including those plots where no soil data was available. This dataset was split into three sections, because of its size and is shown in Figure 3.65.

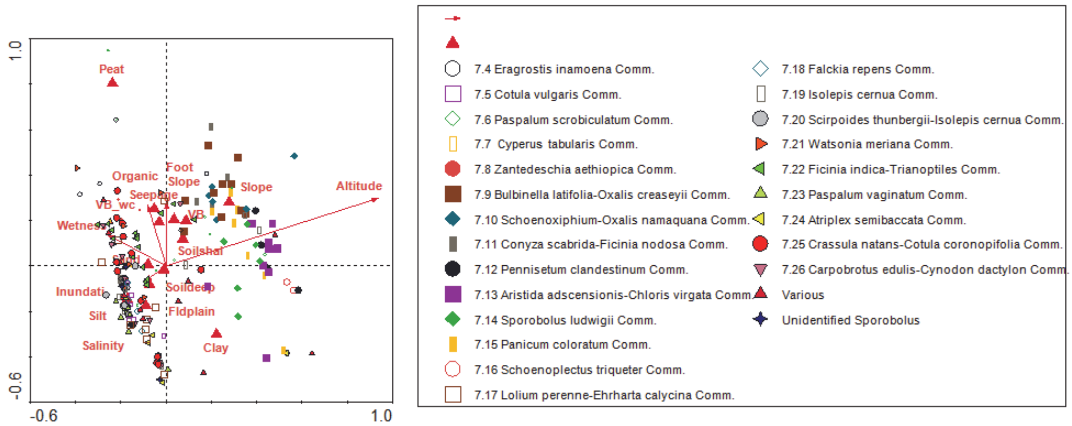
The first diagram shows the twelve communities that could be regarded as the most 'outlying' communities in the dendrogram of Figure 3.61. In the ordination diagram of Figure 3.65a the first axis is strongly correlated to altitude and the second axis with wetness. The *Cynodon dactylon* Community (Community 7.51) seems to be scattered all over the diagram but is a bit more scarce at higher altitudes and higher wetness. Here they are mostly replaced by the *Leptochloa fusca* Community (7.52), the *Schoenoplectus decipiens* Community (7.1) and *Cynodon transvaalensis* Community (7.3).

The second ordination diagram in Figure 3.65b shows also the first axis mainly corresponding to altitude and the data seems to be mostly split into two groups, namely the types confined to the highveld and the community types from the Cape coastal forelands. The second axis is mostly correlated to organic matter, and with slope (more slope seepages) but this correlation is not very strong. The two communities from the mountains in Namaqualand, the *Bulbinella latifolia-Oxalis creaseyii* Community (7.9) and the *Schoenoxiphium sparteum-Oxalis namaquana* Community (7.10) are found in the upper part of the diagram, at intermediate altitude, and at intermediate levels of organic matter.

a)



b)



c)

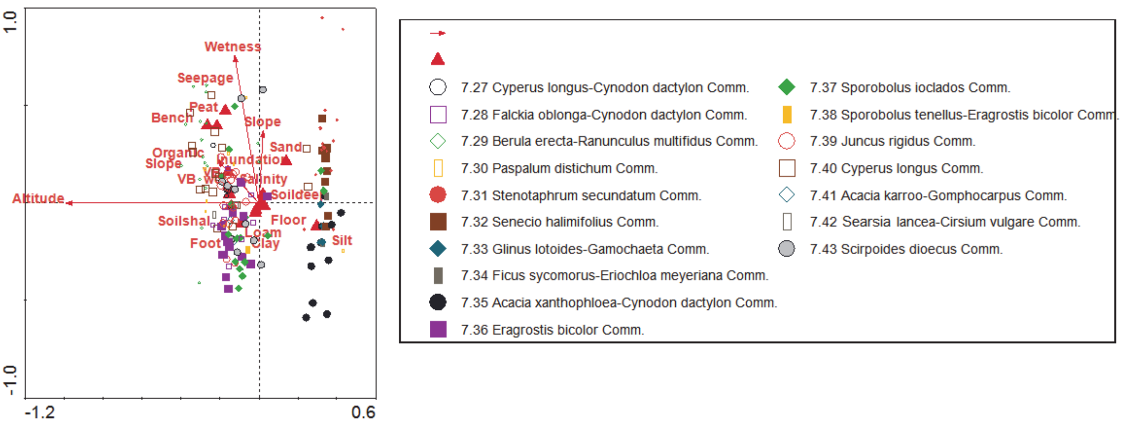


Figure 3.65 Three ordination diagrams for all vegetation plots, including those that have no soil data available. This provides a general oversight of all communities of Main Cluster 7, especially with regards to altitude and wetness.

The third ordination diagram in Figure 3.65c shows again a first axis mostly corresponding to altitude and the second axis mostly corresponding to wetness. The split into two parts between communities from the coastal forelands and those from the highveld is again evident. In the right-hand section of the ordination diagram we find the communities from tropical floodplains, such as the *Acacia xanthophloea-Cynodon dactylon* Community (Community 7.35) as well as some of the communities in coastal sands of *Stenotaphrum secundatum* Community (7.31) and the *Senecio halimifolius* Community (7.32). These are directed more towards the upper parts of the diagram along the wetness gradient. At the higher altitudes, two communities that are very prominent are the *Eragrostis bicolor* Community (7.36) and the *Scirpoides dioecus* Community (7.43). There are also two communities that straddle different altitudes, namely the *Sporobolus ioclados* Community (7.37) and the *Cyperus longus* Community (7.40).

3.8.3 Species response curves

The wetlands in this Main Cluster occur in a wide variety of habitats and many of the indicator species in these wetlands have narrow distributions with a limited number of plots containing them. Still, it is valuable to look at the different species response curves for a series of species that were recorded in these wetlands as they are particularly common in areas that are particularly prone to disturbance and environmental changes and are therefore important for monitoring. In the Western Cape and the Karoo groundwater use and climate change will affect many wetlands in the region and there is the additional threat of urbanization in the Western Cape.

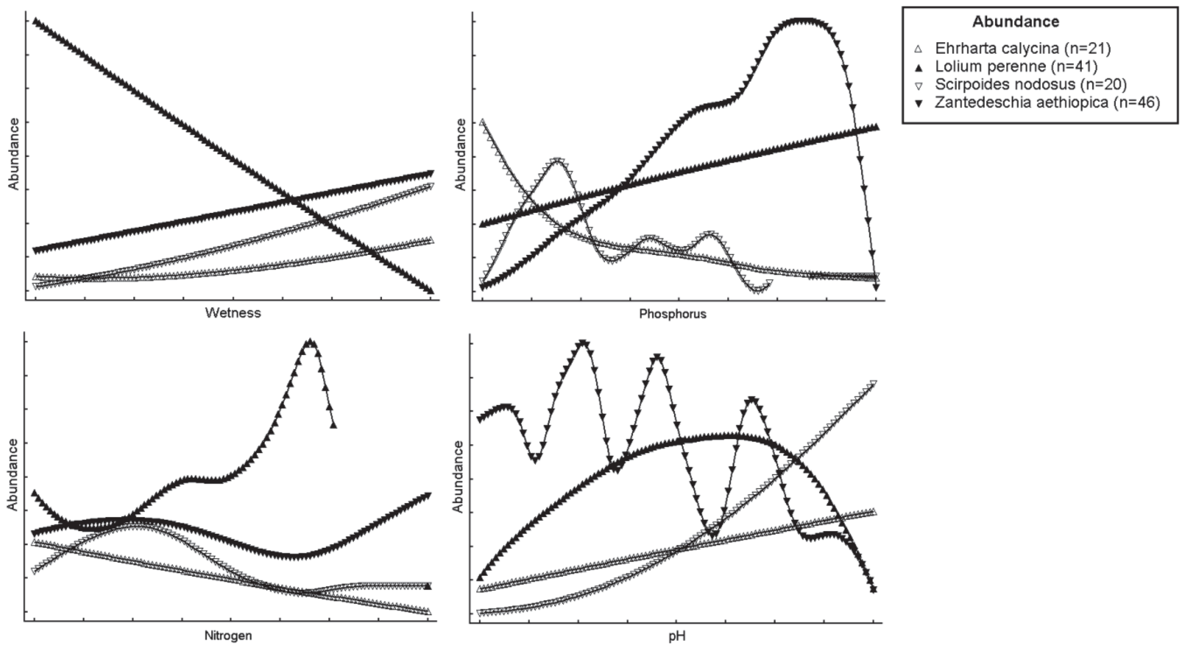


Figure 3.66 Species response curves for four species common in the wetlands of the Western Cape lowlands.

The four species of Figure 3.66 are common in lowland wetlands in the Western Cape and they become dominant particularly in Communities 7.8, 7.11 and 7.17. *Erhharta calycina* and *Lolium perenne* often co-exist in the same Community (7.8) but each has a very distinct response to wetness – with *Lolium perenne* decreasing with wetness and *Ehrharta calycina* increasing. *Lolium perenne* also responds strongly positive to Phosphorus and Nitrogen while *Ehrharta calycina* decreases. This is a special community representative of renosterveld communities and the presence of the alien invasive *Lolium perenne* in this community is not desirable so it is clear that the health of this community improves if it remains relatively nutrient-poor and wet. The Arum lily (*Zantedeschia aethiopica*) also has a positive response to Phosphorus but less strongly to Nitrogen, while its response to a higher pH is very erratic. The coastal sedge *Scirpoides nodosus* responds most strongly to alkaline conditions where it becomes dominant.

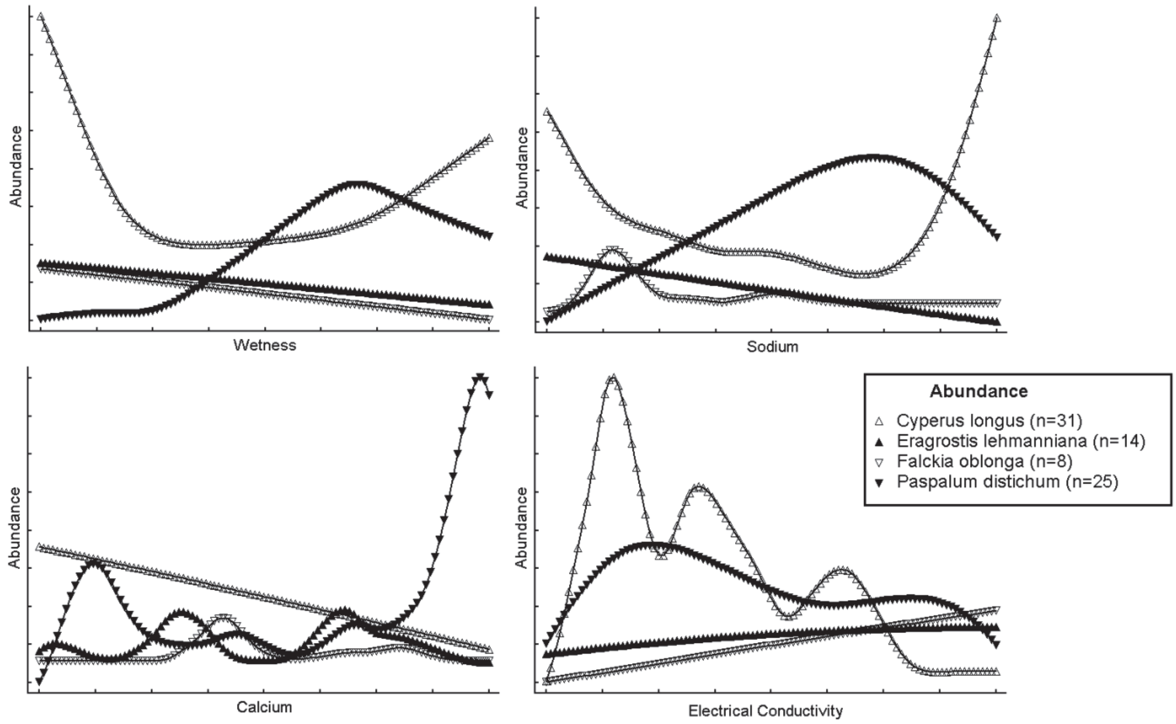


Figure 3.67 Species response curves for four species commonly occurring in wetlands of the drier regions of the Highveld region.

In Figure 3.67 four species from the drier regions of the Highveld are shown and these species tend to become dominant in Communities 7.27, 7.28, 7.30, 7.40 and 7.50. For the common sedge *Cyperus longus* and the alien species *Paspalum distichum* the responses are each other’s mirror images for wetness and Sodium content, with *Cyperus longus* being least dominant in intermediate positions on the gradient where *Paspalum distichum* takes over. For the other two species, *Falckia oblonga*, a creeping forb typical from dry pans, and *Eragrostis lehmanniana*, a common grass in the uplands, the responses are generally quite weak but they seem to prefer conditions with a low Sodium contents and a high Electrical Conductivity. In cases with a high Calcium contents, *Paspalum distichum* increases, but *Cyperus longus* decreases.

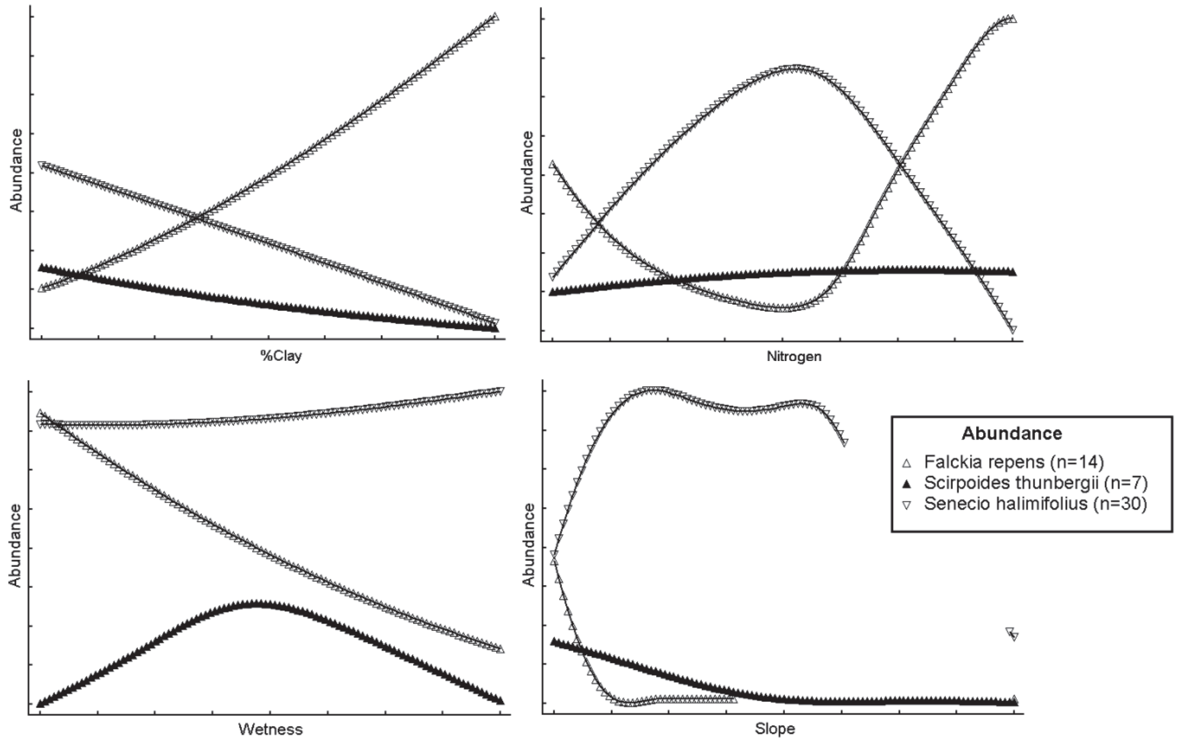


Figure 3.68 Species response curves of three species commonly occurring in coastal wetlands in the Cape.

In Figure 3.68 three species are shown that occur in coastal wetlands of the Cape. The sedge *Scirpoides thunbergii* shows the weakest response to environmental variables, but seems to prefer situations with intermediate wetness, it is not often dominant, but does occur in Community 7.20. *Senecio halimifolius* and *Falckia repens* have opposite responses with *Senecio halimifolius* being dominant when there is low clay contents and *Falckia repens* taking over when clay contents is high. *Falckia repens* prefers conditions that are either very low or very high in Nitrogen contents while *Senecio halimifolius* becomes dominant in intermediate Nitrogen levels. *Falckia repens* responds negatively to wet conditions while *Senecio halimifolius* seems to be completely indifferent to wetness. This suits the conditions where it grows quite well as it grows in coastal dune wetlands that are drained very quickly, represented by Community 7.32. *Falckia repens* is typical for clay flats that dry out quickly, represented by Community 7.18 and is for example often found in road verges.

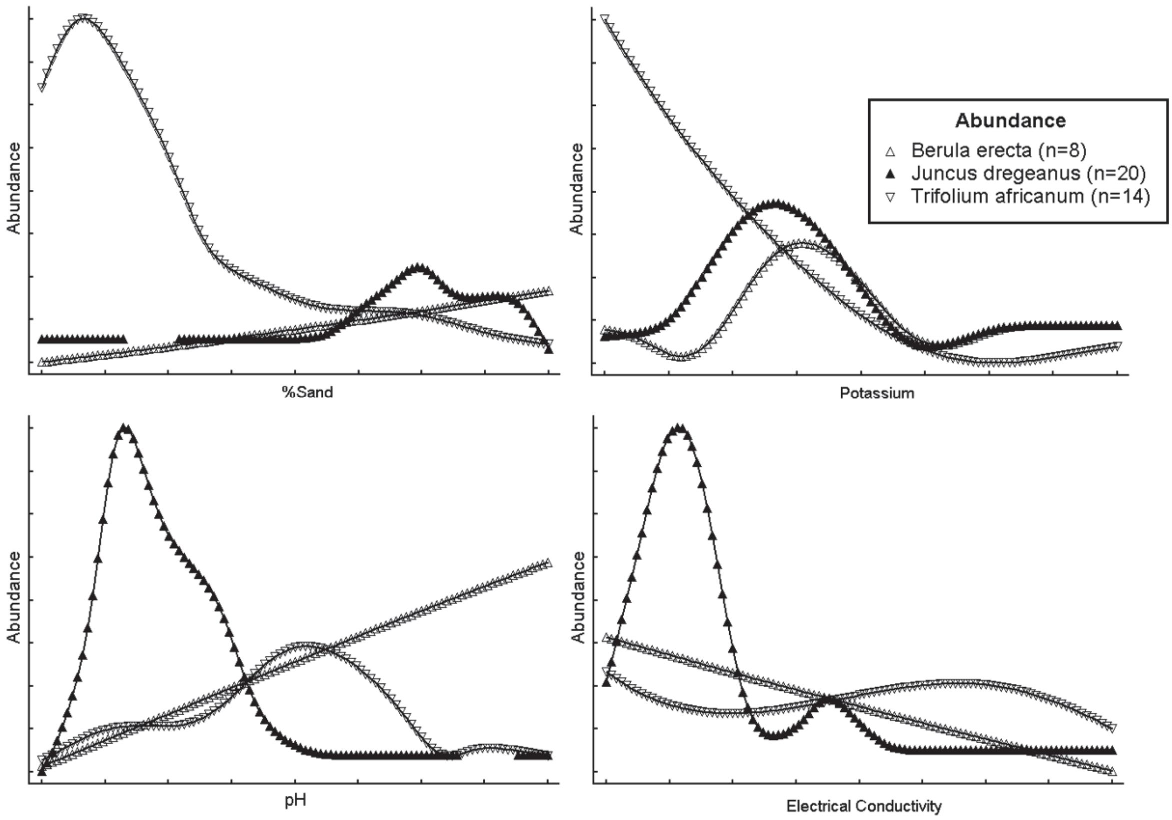


Figure 3.69 Species response curves for three species occurring in the wetter habitats of Main Cluster 7.

The species that are shown in Figure 3.69 represent species that are common in the wetter conditions, for example wet patches in floodplains, or in the western foothills of the Drakensberg. The most typical community where these species would become dominant is Community 7.29 as well as Community 5.19, which are however occurring in quite close proximity to one another. *Berula erecta* prefers conditions which are slightly alkaline, and have a low Electrical Conductivity. The species also has a slight peak at intermediate Potassium, but otherwise it does not display any clear responses to environmental variables. The clover *Trifolium africanum* becomes particularly dominant in conditions with a low fraction of sand and with low levels of Potassium. The last species shown here *Juncus dregeanus* clearly has more a preference for conditions that are more acidic and that have low Electrical Conductivity: it is mostly found in very nutrient-poor conditions.

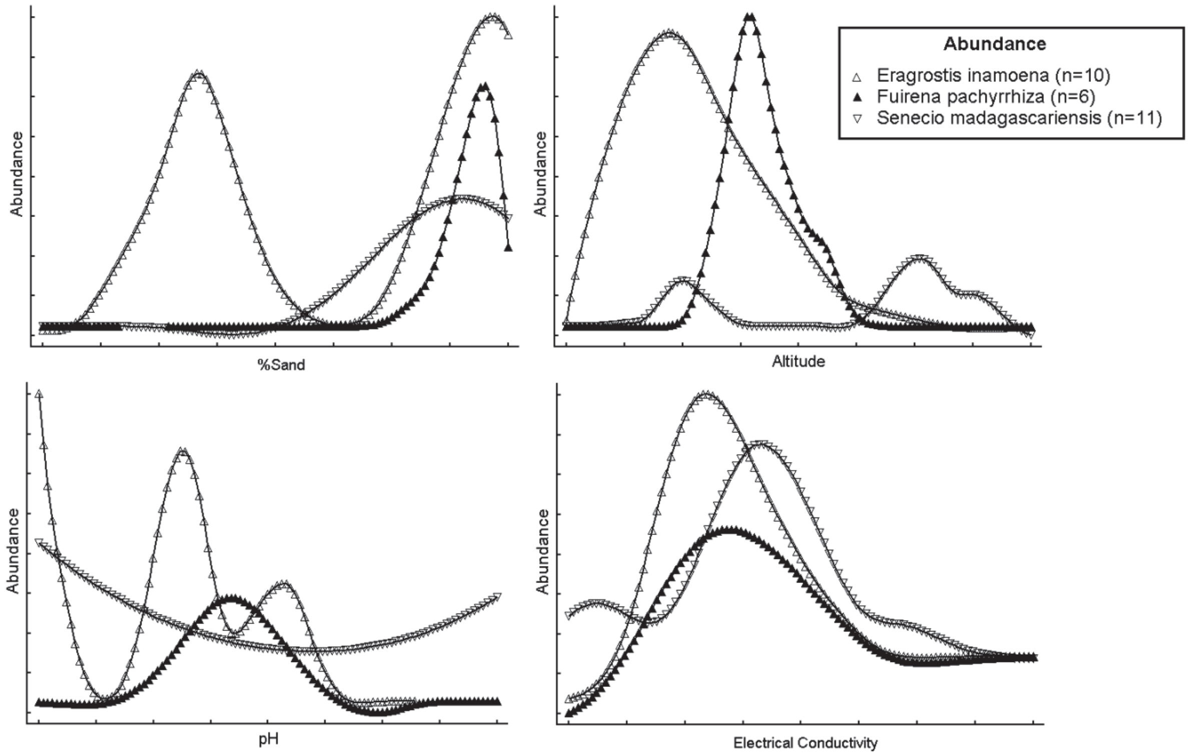


Figure 3.70 Species response curves of three species commonly occurring in weedy patches of subtropical wetlands.

The response curves that are shown in Figure 3.70 belong to species that are not often dominant but become common in subtropical floodplain wetlands. They become dominant in Communities 7.4 and in one of the under-sampled communities of Main Cluster 6. In terms of Electrical Conductivity all three species have more or less the same peak, and all three species seem to prefer very sandy conditions, even though *Eragrostis inamoena* also has a peak at low sand fractions. In terms of pH Eragrostis inamoena seems to do well in conditions with a very low pH but the peak at intermediate pH is also shared with *Fuirena pachyrrhiza*. Only *Senecio madagascariensis* has a real distinct response here, preferring either very low or very high pH. The most distinct responses of these three species are in terms of altitude, with *Eragrostis inamoena* particularly common at the low altitudes (Lowveld), *Fuirena pachyrrhiza* at intermediate altitudes (Limpopo Highveld) and *Senecio madagascariensis* with a small peak at the highest altitudes, as it gets more common on the highveld.

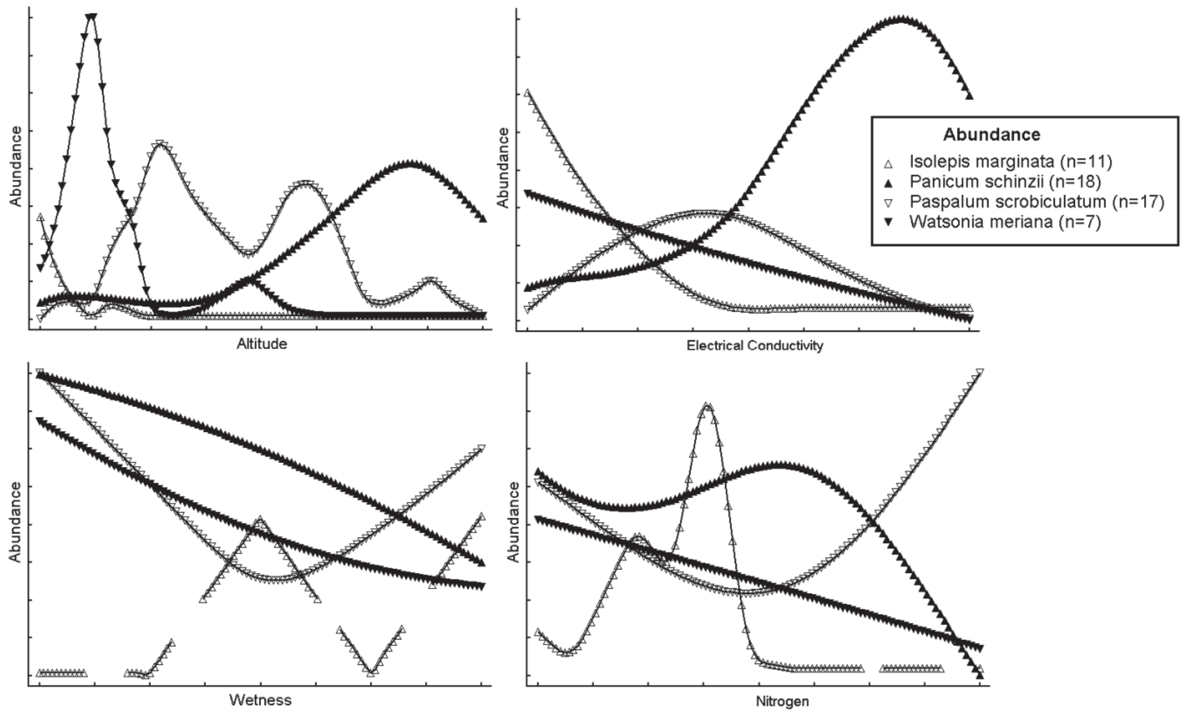


Figure 3.71 Species response curves of four wetland species commonly associated with valley bottom wetlands in the Cape Fold region.

Figure 3.71 shows the responses of four species occurring in Western Cape Valley bottom wetlands. They become dominant in Communities 7.2, 7.6 and 7.21. Both *Watsonia meriana* and *Isolepis marginata* prefer conditions with a low Electrical Conductivity whereas *Panicum schinzii* becomes dominant when Electrical Conductivity increases. The grass *Paspalum scrobiculatum* prefers intermediate conditions. In terms of altitude, *Isolepis marginata* and *Watsonia marginata* seem to prefer the lowest altitudes, with *Paspalum scrobiculatum* occurring on mid-altitudes, and *Panicum schinzii* preferring the highest altitudes. These last two grasses are not restricted to the Western Cape but also occur on the Highveld. Both *Watsonia meriana* and *Panicum schinzii* decrease with higher Nitrogen levels, whereas *Paspalum scrobiculatum* increases with higher Nitrogen levels. *Watsonia meriana* and *Panicum schinzii* also decrease with wetness, whereas *Isolepis marginata* and *Paspalum scrobiculatum* increase when it gets wetter.

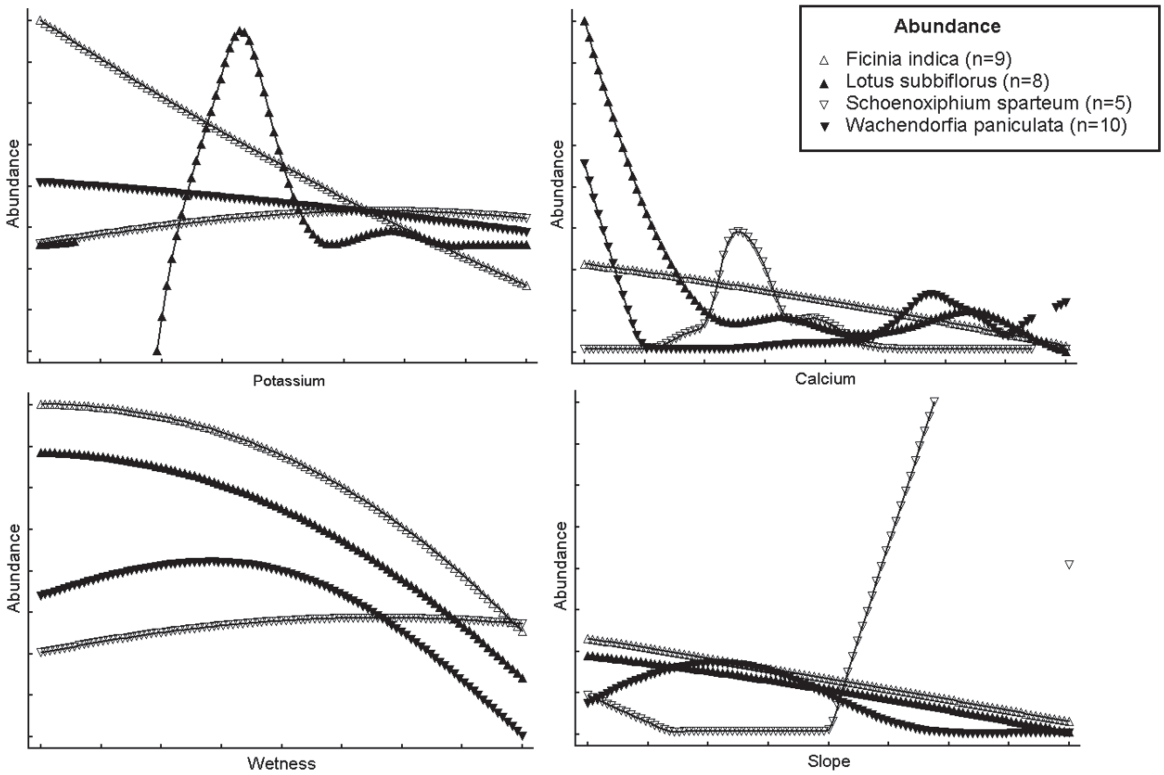


Figure 3.72 Species response curves for four other species commonly associated with valley bottom wetlands in the Western Cape.

The species in Figure 3.72 occur in similar habitats in the Cape and Figures 3.70 and 3.71 could be studied together as many of these species can co-occur. They become dominant particularly in Communities 7.10 and 7.22. All species decrease with wetness, except *Schoenoxiphium sparteum* which seems indifferent to wetness. *Ficinia indica* decreases with higher levels of Potassium, whereas *Lotus subbiflorus* peaks at intermediate levels of Potassium. Most of these species prefer low levels of Calcium, but particularly *Lotus subbiflorus* and *Wachendorfia paniculata* do very well under these conditions. *Schoenoxiphium sparteum* does very well on mountain slopes as it is found mostly in wetlands in the Khamiesberg, but also in other montane areas in the country.

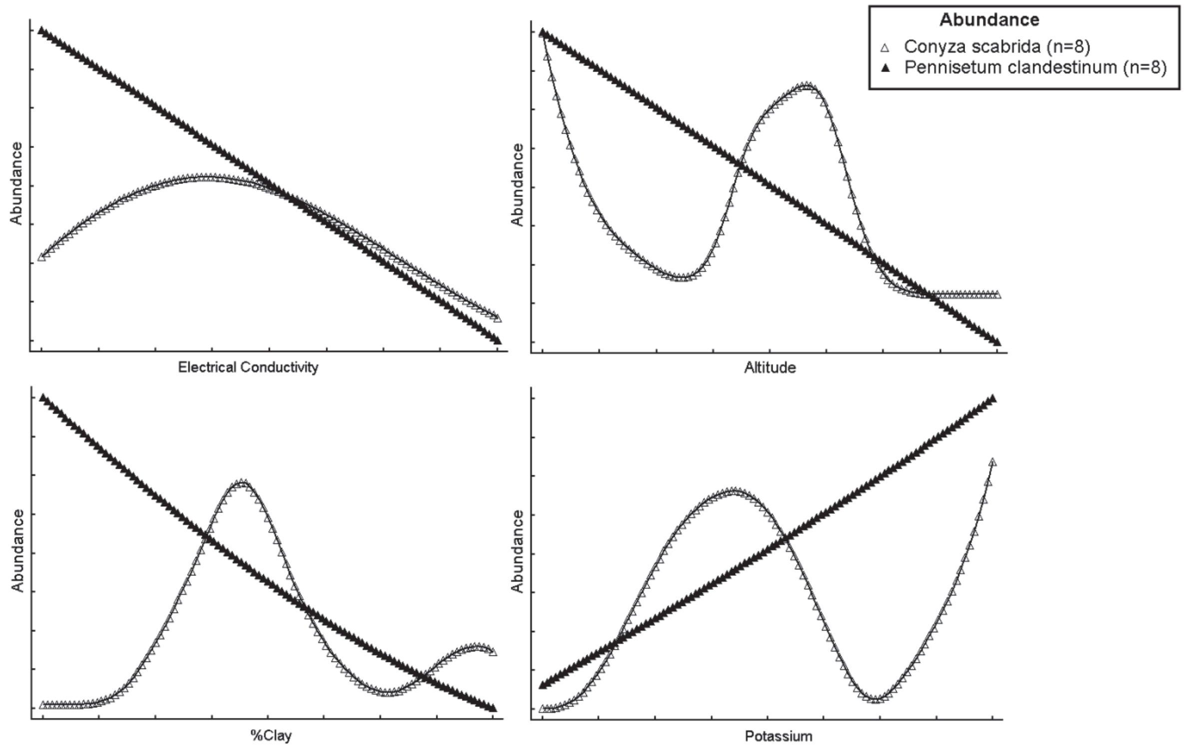


Figure 3.73 Species response curves of two species commonly associated with disturbed edges of wetlands, particularly in the Cape.

The two species that are shown with their response curves in Figure 3.73 are poorly represented in the database but are important disturbance species. One of them, Kikuyu grass, *Pennisetum clandestinum*, becomes only dominant in wetlands in completely destroyed wetlands in urban areas (Community 7.12) whereas the other one, the shrub *Conyza scabrida*, is common at the edges of wetlands in the Western Cape (Community 7.11). *Pennisetum clandestinum* decreases with Electrical Conductivity and clay contents while *Conyza scabrida* peaks at intermediate levels of Electrical Conductivity and clay contents. In terms of Potassium, both species seem to increase with higher levels of Potassium. The response curve for altitude probably represents an artefact of the small amount of data as Kikuyu grass is certainly also common in the Highveld.

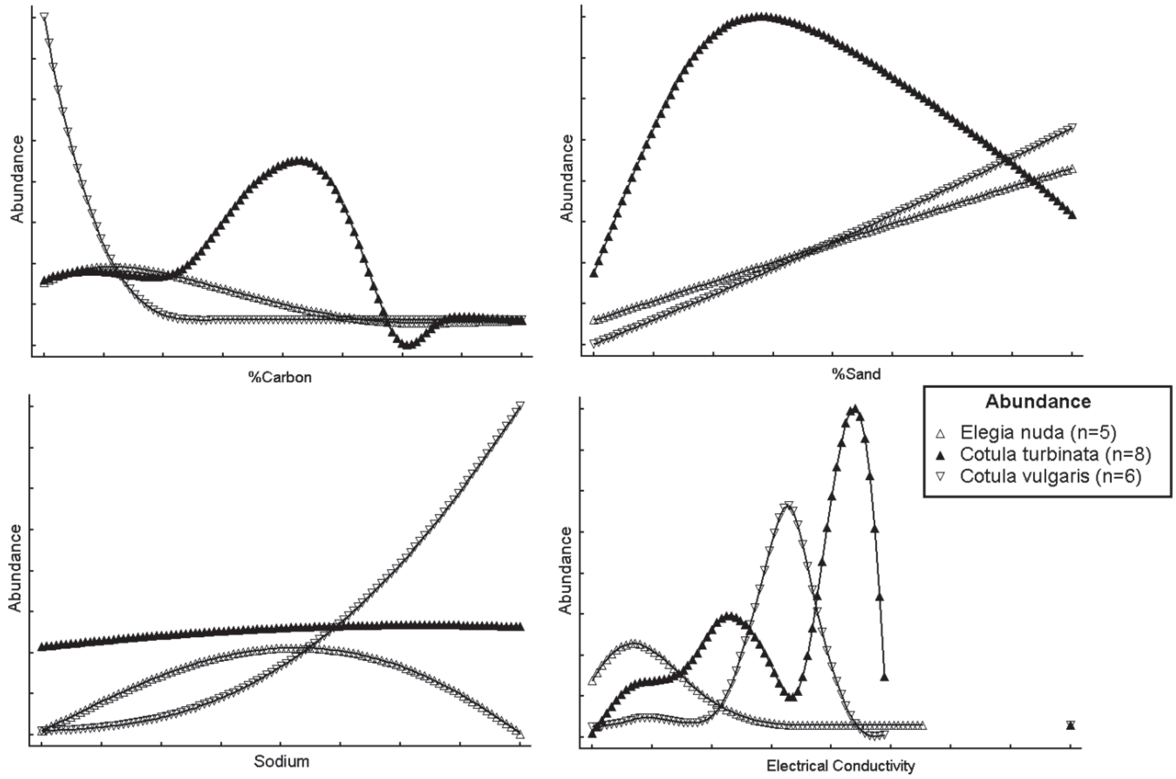


Figure 3.74 Species response curves for three not very common species associated with the wetlands of the Overberg region.

The species in Figure 3.74 represent a few of the less common species from wetlands in the Overberg region in the Western Cape. They are all quite poorly sampled so for proper information on these species, more intense sampling still needs to take place. They become mostly dominant in Community 7.9 and one of the under-sampled communities. The restio *Elegia nuda* requires very low levels of soil carbon and prefers very sandy soils, just like *Cotula vulgaris*. *Cotula turbinata* peaks at low sand contents. *Cotula vulgaris* increases with Sodium contents, whereas *Elegia nuda* prefers intermediate levels of Sodium. When it comes to Electrical Conductivity, *Cotula turbinata* prefers the highest levels of Electrical Conductivity, whereas *Cotula vulgaris* peaks at slightly lower levels.

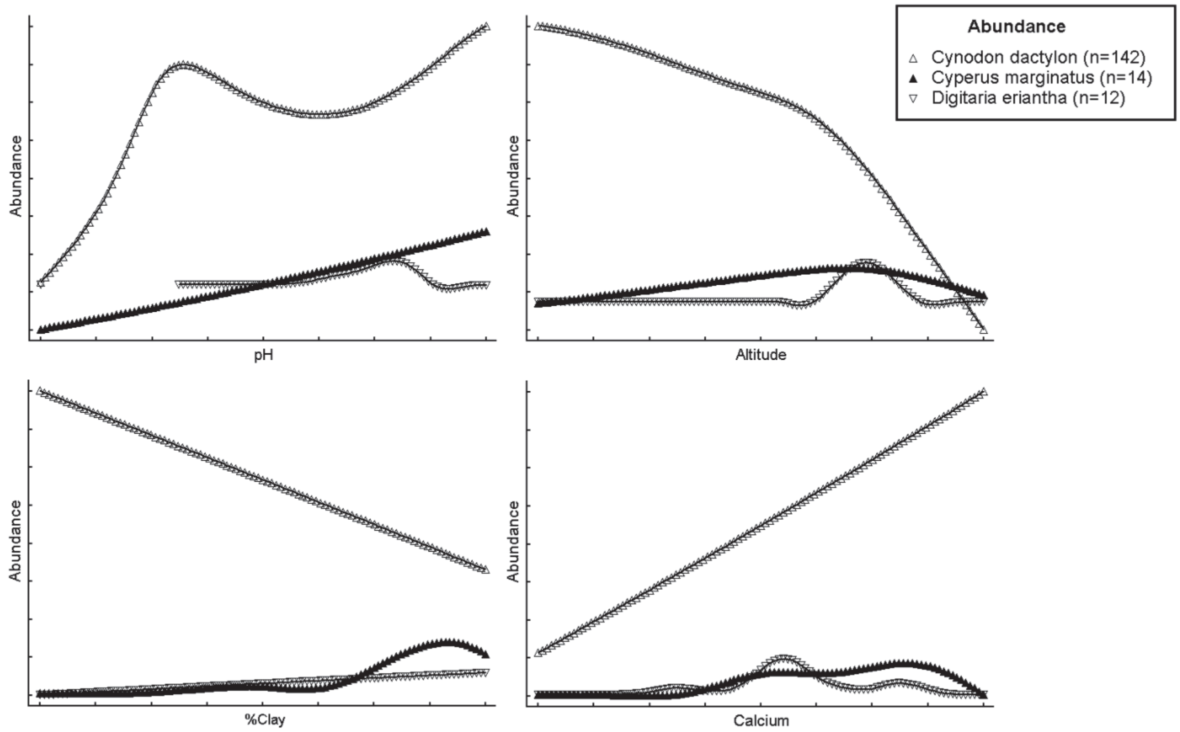


Figure 3.75 Species response curves for *Cynodon dactylon* (Kweekgras) and two other widespread species from the dry regions of the Highveld.

The species response curves in Figure 3.75 include one of the most common wetland grass species in the country together with two other species that are common in the drier parts of the highveld. They tend to become dominant in Communities 7.26, 7.35, 7.44, 7.47, 7.48, 7.49, 7.50 and 6.15. *Cynodon dactylon* becomes dominant in nearly all situations but decreases with high altitudes, high clay contents, acidic conditions and low Calcium contents of the soils. *Cyperus marginatus*, which can also become a dominant sedge in some conditions, but which is mostly found together with *Cynodon dactylon*, prefers a high clay contents, a high pH and high levels of Calcium.

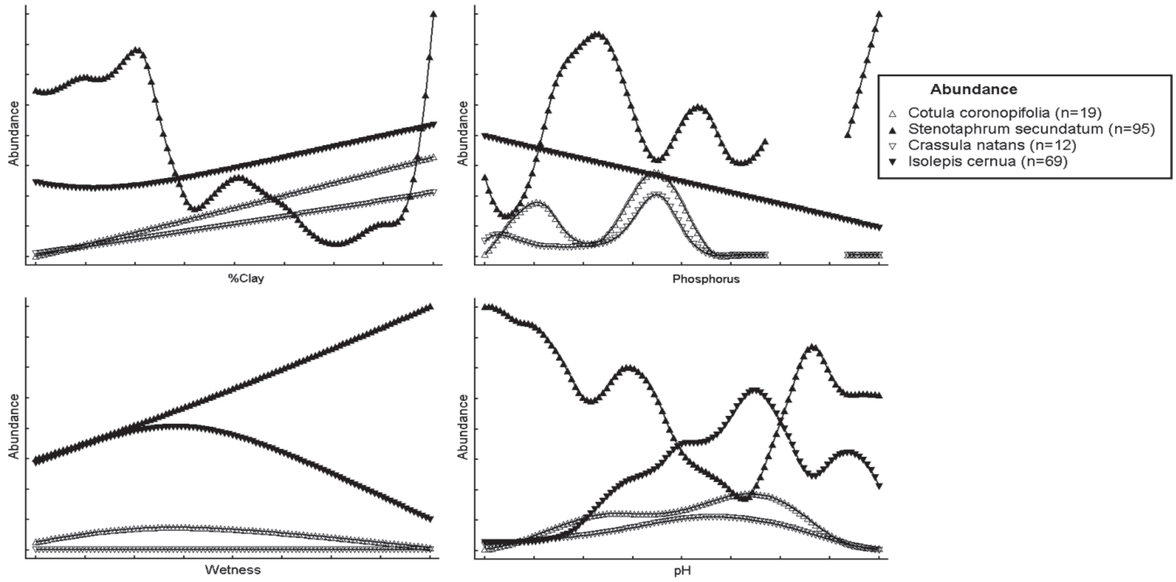


Figure 3.76 Species response curves for four common species from wetlands on the coastal plains of the Western Cape.

In Figure 3.76 the species response curves of four species occurring in wetlands from the coastal plains in the Western Cape are shown. They become dominant in Communities 7.19, 7.20, 7.25 and 7.31. All these species steadily increase with a higher clay contents, although Buffalo grass *Stenotaphrum secundatum* also shows a peak at a low clay contents. *Isolepis cernua* responds negatively to an increase in Phosphorus and also *Stenotaphrum secundatum* peaks at a low Phosphorus contents. *Stenotaphrum secundatum* is the only species that responds positively to an increase in wetness, while a short sedge like *Isolepis cernua* decreases with increasing wetness, because it can not deal with too much inundation since it is so short. *Stenotaphrum secundatum* has a bimodal distribution in terms of pH and its growth is suppressed when there are neutral values of pH, which is where the other three species have their peak.

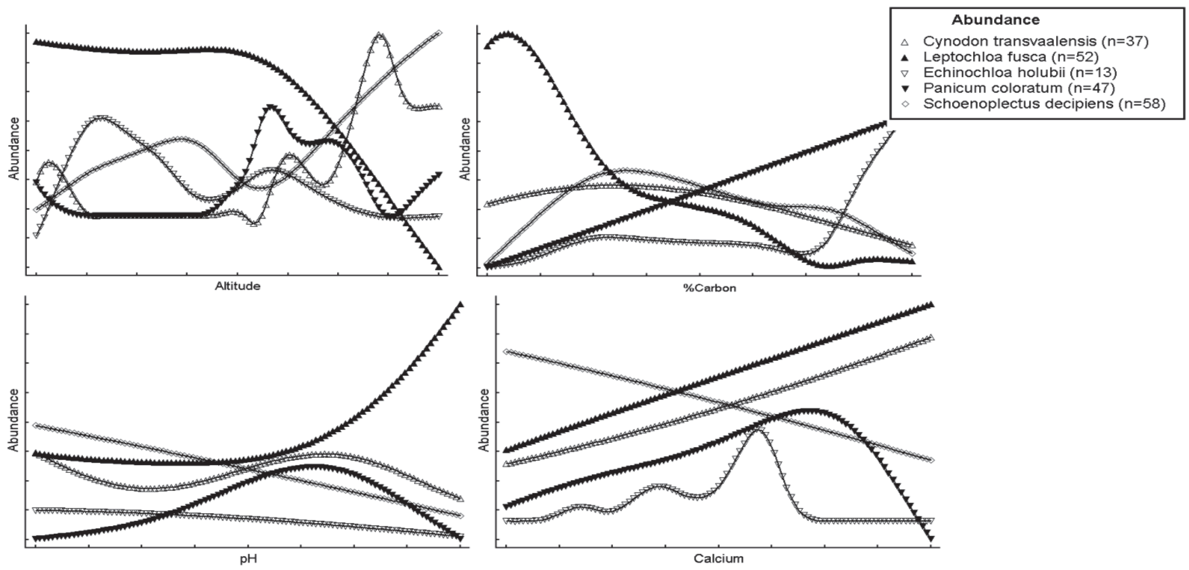


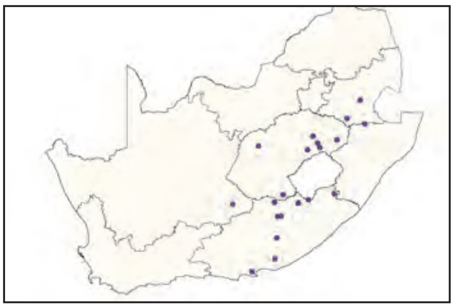
Figure 3.77 Species response curves for five species of inland pans of the drier parts of the highveld.

Figure 3.77 shows five species that are common in seasonal pans in the drier parts of the highveld, including two very common species: *Leptochloa fusca* and *Schoenoplectus decipiens*. These species become dominant in Communities 7.1., 7.2, 7.3, 7.15, 7.52, 7.53 and 7.54. Most of these species decrease with altitude, except for *Schoenoplectus decipiens* and *Cynodon transvaalensis*, which are still regularly found in the highest parts of the highveld. The common and widespread species *Leptochloa fusca* decreases with organic carbon in the soil, whereas *Panicum coloratum* and *Echinochloa holubii* increase in more organic soils. *Leptochloa fusca* also prefers the more alkaline soils, which explains why it is often still doing very well in saline pans. *Panicum coloratum* and *Cynodon transvaalensis* also have a small peak at alkaline soils, but they do not perform as well as *Leptochloa fusca* in extreme situations. *Schoenoplectus decipiens* actually prefers the more acidic soils. *Cynodon transvaalensis* and *Leptochloa fusca* both increase with an increase of Calcium in the soil, whereas *Schoenoplectus decipiens* decreases. The two grasses *Echinochloa holubii* and *Panicum coloratum* both peak at intermediate levels of Calcium in the soil.

3.8.4 Description of communities

1. *Schoenoplectus decipiens* Community

This community occurs in the wetter parts of wetlands, especially pans, in the Highveld and particularly the inland parts of the Eastern Cape. The sedge *Schoenoplectus decipiens* often occurs together with *Eleocharis dregeana*, which it superficially resembles from a distance.

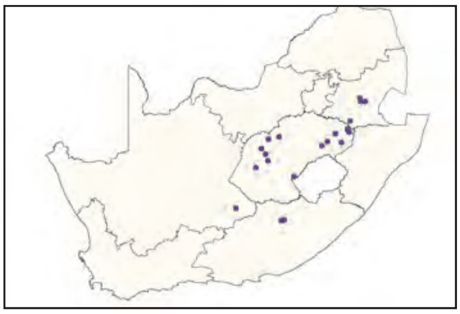


2. *Echinochloa holubii- Panicum schinzii* Community

The species *Echinochloa holubii* and *Panicum schinzii* often occur together with more common species, but occasionally become dominant in their own right, particularly on the Western side of the Highveld.

3. *Cynodon transvaalensis* Community

This wetland community represents a short grassland community occurring at the edges of pans in the Highveld. The grass *Cynodon transvaalensis* is more delicate than the more widespread *Cynodon dactylon* and probably grazed by waterbirds.



4. *Eragrostis inamoena* Community

The grass *Eragrostis inamoena* is taller than most grasses in the communities of Main Cluster 7 but often co-occurs with short lawn grasses in sparse communities at the edge of lakes and pans. The community occurs in subtropical regions and is probably more widespread.

5. *Cotula vulgaris* Community

This is a variable community that is probably worth sampling more intensively. The only consistently occurring species is *Cotula vulgaris*, although this species is by no means dominant in the community.

6. *Paspalum scrobiculatum* Community

The grass *Paspalum scrobiculatum* is the only species of the genus *Paspalum* that is indigenous in South Africa but it is not common as a dominant. As a community dominant it occurs mostly in the wetter parts of wetlands in the drier regions.

7. *Cyperus tabularis* Community

This is a rare community from the Western Cape which is still under-sampled, mostly from temporary wet sandy areas. The sedge *Cyperus tabularis*, which is the dominant here, resembles another rare species from the Eastern Cape, *Cyperus durus*, which however tends to occur in wetter areas.

8. *Zantedeschia aethiopica* Community

The arum lily *Zantedeschia aethiopica* is one of the country's most well-known wetland plants and is in some cases harvested from wetlands as an ornamental plant. It often becomes dominant in eutrophic and disturbed wetland sites. The community probably is more widespread as indicated here as it was also observed in southern KwaZulu-Natal.

9. *Bulbinella latifolia-Oxalis creaseyii* Community

This is a heterogeneous community that is confined to Namaqualand where it occurs in temporary pools and requires more attention, as it might represent different communities, some dominated by various species of *Oxalis*, and some by the sedge *Carex divisa* and the bulbous plant *Bulbinella latifolia*. It is quite rich in species.

10. *Schoenoxiphium sparteum-Oxalis namaquana* Community

This is another community confined to Namaqualand that deserves more attention in the future. The sedge *Schoenoxiphium sparteum* is more widespread, particularly in montane areas like the Drakensberg but usually does not occur in wetlands.

11. *Conyza scabrida – Ficinia nodosa* Community

The shrub *Conyza scabrida* often occurs in temporary zones of wetlands or at the edge of pans in the Western Cape. It often co-occurs with the sedge *Ficinia nodosa*.

12. *Pennisetum clandestinum* Community

This community is much more common than indicated on the distribution map and represents extremely disturbed wetland communities overgrown by Kikuyu grass. This is mainly found in temporary parts of the wetland.

13. *Aristida adscensionis – Chloris virgata* Community

This community is a marginal wetland community as it is found mostly on the temporarily wet edges of wetlands in the dry regions at the edge of the Karoo and Kalahari. It is dominated by annual grasses and subject to disturbance and climatic fluctuations.

14. *Sporobolus ludwigii* Community

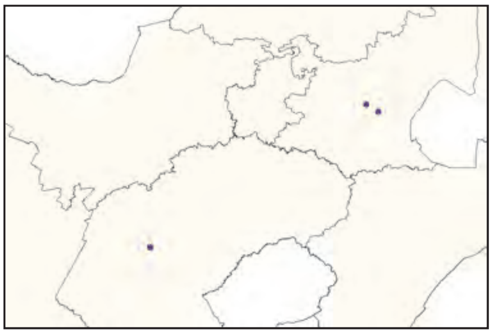
This community, dominated by the grass *Sporobolus ludwigii*, occurs along the western border of the Free State on the edge of the Karoo in temporarily wet wetlands. It often borders more shrub-dominated wetlands, for example *Salsola*.

15. *Panicum coloratum* Community

This community is restricted to organic soils in the drier parts of the country where it occurs in seasonally wet zones of wetlands. It is particularly common around the many springs that arise around the edge of the Kalahari such as the Kuruman eye. In these situations there is a sufficiently reliable source of freshwater in this otherwise very dry region.

16. *Schoenoplectus triqueter* Community

The sedge *Schoenoplectus triqueter* is a globally distributed sedge that is commonly known from estuaries in the Northern hemisphere. In South Africa it is restricted to inland saline pans and it has been found in only two locations in the country: in a saline valley bottom wetland near Florisbad in the Free State and around some pans in the Lake District of Mpumalanga.



17. *Lolium perenne-Ehrharta calycina* Community

This community represents a large part of the wetlands in the renosterveld in the Western Cape and was probably always dominated by annual grasses due to the extreme water fluctuations in the deep sandy soils of the West Coast. Historically these were probably grasses such as

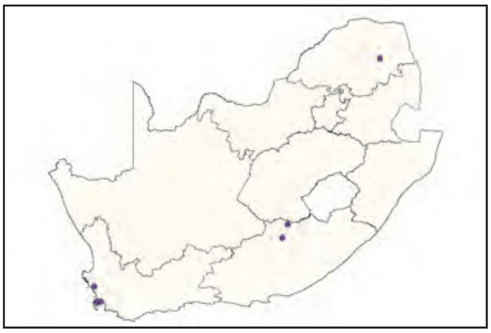
Ehrharta calycina and *Ehrharta longiflora*, but now they have been largely invaded by the alien species *Lolium perenne*. Despite this alien invasion these are certainly special wetland systems worthy of conservation and they regularly contain unique renosterveld species.

18. *Falckia repens* Community

The creeper *Falckia repens* occurs mostly on temporarily wet clay flats, often next to roads in ditches, but it can form an extensive community in various situations along the coast in the Western Cape. In such cases, the vegetation is relatively open and many other species grow in between *Falckia repens*.

19. *Isolepis cernua* Community

This community is typical for Western Cape lowland wetlands, although it has also been found in the mountains of the Eastern Cape and even in Limpopo. It is a very low growing community of clay flats that cannot deal with deep inundation.



20. *Scirpoides thunbergii – Isolepis cernua* Community

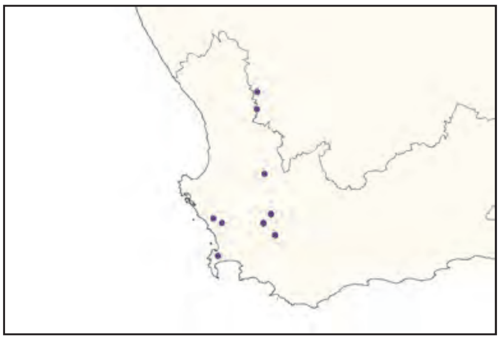
The largest part of the Western Cape plots with *Isolepis cernua* actually belong to this community which is also mixed with some taller sedges, such as *Scirpoides thunbergii*.

21. *Watsonia meriana* Community

This is one of the more attractive wetland communities in the lowlands of the Cape as it is dominated by the flesh-coloured lily *Watsonia meriana*. One interesting characteristic of this lily is that it produces cormlet above ground as a mechanism for asexual resporduction and dispersal. It occurs in seasonal zones of sandy to loamy parts of the wetland.

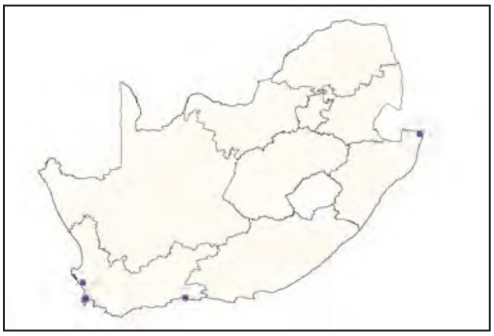
22. *Ficinia indica-Trianoptiles capensis* Community

This is one of the richest plant communities across the country and it occurs with many different growth forms growing together, particularly bulbous plants, small annual sedges and dwarf shrubs. It occurs in floodplains and flat wetlands in the Western Cape lowlands and this community is mostly characterized as renosterveld.



23. *Paspalum vaginatum* Community

This community is one of the estuarine communities but due to its poor similarity with the estuarine communities it has ended up in Main Cluster 7, even when ecologically it is more similar to the estuarine communities of Main Cluster 4. The species *Paspalum vaginatum* is an alien species which is standing out for invading such an extreme environment. It occurs along the entire South African coastline.

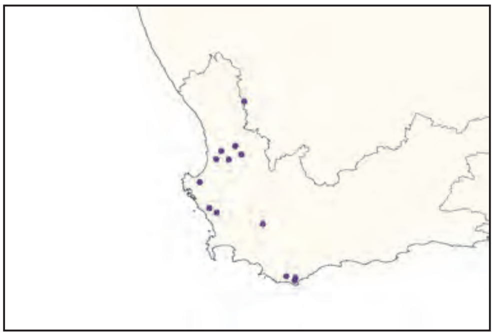


24. *Atriplex semibaccata* Community

This community is a relatively rich community dominated by the Chenopod *Atriplex semibaccata*, which is found in dry grassy pans at the edge of the Karoo, both in the Cape as well as in North-West Province. Most chenopods are adapted to saline conditions, but this species occurs only in those areas where the salinity is only very slight.

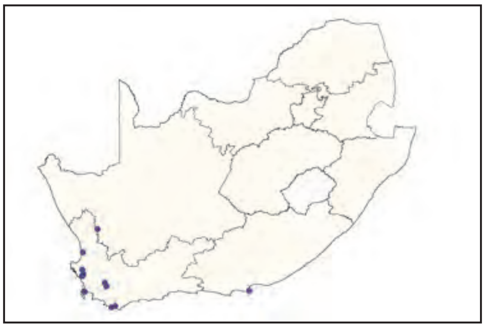
25. *Crassula natans – Cotula coronopifolia* Community

Both species that dominate this community (*Crassula natans* and *Cotula coronopifolia*) are truly amphibious species that are very plastic in their phenotypic response to the environment and are comfortable with growing on dry land as well as swimming in water more than a meter deep. For this reason, it is no surprise that this community does particularly well in the western part of the Western Cape where watertable fluctuations are particularly large.



26. *Carpobrotus edulis – Cynodon dactylon* Community

These wetlands represent the *Cynodon dactylon* wetlands of the winter rainfall region which have less of a tendency to become a monoculture than *Cynodon dactylon* grasslands in the inland regions. A conspicuous element is vygies, particularly *Carpobrotus edulis* which is a disturbance species common in road verges, but which can deal with a temporary inundation. In rare situations this vygie actually becomes dominant.



27. *Cyperus longus-Cynodon dactylon* Community

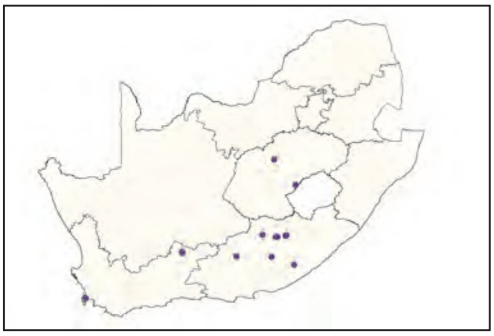
This community represents a mixture between *Cynodon dactylon* grasslands and *Cyperus longus* sedgelands, and is mostly restricted to North-West Province. It is however quite possible that this community is much more widespread.

28. *Falckia oblonga – Cynodon dactylon* Community

This community represents an attractive carpet of small white flowers that are found in temporarily inundated clayey or loamy flats, whether they are pans or floodplains, along the drier parts of the Highveld.

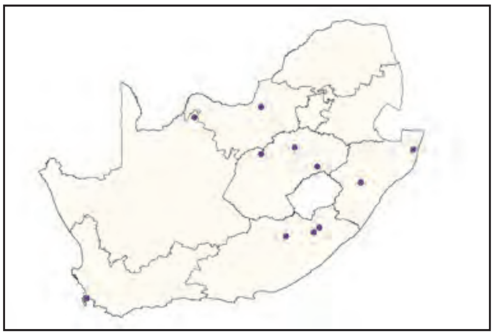
29. *Berula erecta – Ranunculus multifidus* Community

This community represents one of the wettest types of communities of this Main Cluster. There are affinities between these wetlands and the montane wetlands of Main Cluster 5 although it is mainly restricted to the Eastern Cape.



30. *Paspalum distichum* Community

The grass *Paspalum distichum* is an alien grass that often occurs in the wettest patches of wetlands, mostly in semi-arid regions. It seems to have a preference for an unstable substrate and some flow of water and therefore it often invades only local patches and not entire wetland. However it often does achieve monodominance in those patches.



31. *Stenotaphrum secundatum* Community

The buffalo grass *Stenotaphrum secundatum* is one of the weedy grasses that has the tendency to overgrow everything else and thereby one of the most important indigenous invaders. It occurs in sandy coastal soils mostly in temporarily wet conditions and often achieves monodominance. The one record inland in Potchefstroom is probably the result of planting of this grass in gardens because it is a suitable lawn grass.

32. *Senecio halimifolius* Community

The shrub *Senecio halimifolius* is common in wetlands on coastal sands and is found on the entire south coast of the cape but has been found as a monodominant only in the Cape flats. It is however possible that this community is more widespread or that the monodominance of this species represents a form an urban disturbance.

33. *Glinus lotoides – Gamochaeta penssylvanica* Community

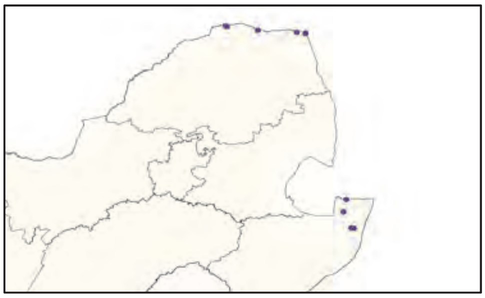
This community is only known from a historical study in the Pongola River floodplain (Furness 1981) and represents a typical disturbance-prone floodplain community from the subtropical regions. Most species in the community are annual species and the grass layer is very sparse. It is quiote likely that similar communities are found in floodplain areas further north, for example in the Kruger Park.

34. *Ficus sycomorus – Eriochloa meyeriana* Community

This plant community represents a more fully grown gallery forest than Community 7.35 below and its relationships to the proper gallery forest (Community 2.6) need to be more properly investigated. At present it has only been recorded in a historical study of the floodplain forest of the Pongola River, but it is known also to occur in the rivers in Kruger Park. However it is not certain how strongly the wetland characteristics are developed in these rivers which are generally smaller than the Pongola River.

35. *Acacia xanthophloea – Cynodon dactylon* Community

This community is of cultural importance as towering presence of fever trees (*Acacia xanthophloea*) along the banks and in the floodplains of the Limpopo River has been mentioned in many literary works describing journeys in Africa. It is also the plant community that gives the name to the Umkhanyakude Municipality in Northern Maputaland, where it can be found lining large pans in the coastal plain as well as in floodplains as in Limpopo. It is a structurally unique community with a sparse low grass layer and a very tall open tree layer. It seems that there are very strong seasonal aspects to this community and that many plants appear as ephemerals in the community during episodic floods and high rainfall. This variation has not been captured well in the database as all plots were made during dry episodes.

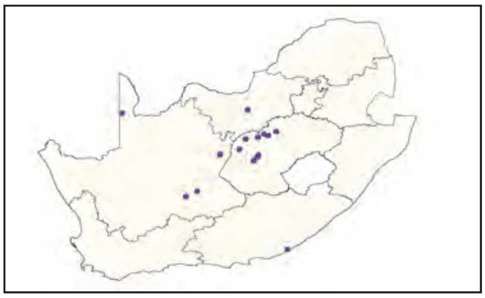


36. *Eragrostis bicolor* Community

This community, dominated by the grass *Eragrostis bicolor*, occurs in temporarily wet areas at the edge of salt pans. It is most common in the southern Free State but extends into the Karoo.

37. *Sporobolus ioclados* Community

This is one of the most characteristic wetland vegetation types of the drier parts of the Highveld dominated by the grass *Sporobolus ioclados* which regularly occurs in brackish and saline pans at the edge of the Karoo.



38. *Eragrostis bicolor* Community

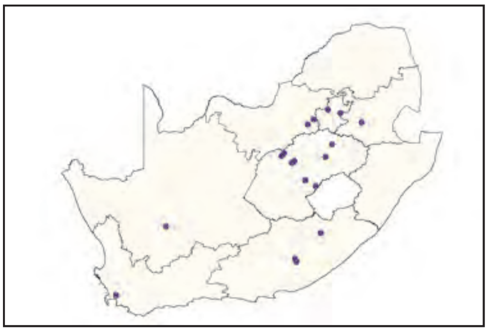
This community represents a link between Community 7.36 and Community 4.11 and is therefore in between two of the Main Clusters. The community is quite rare, occurring in the western Free State.

39. *Juncus rigidus* Community

Juncus rigidus is the twin species of *Juncus kraussii* that occurs in estuaries and coastal wetlands, whereas *Juncus rigidus* is restricted to the drier parts of inland South Africa.

40. *Cyperus longus* Community

Cyperus longus is a sedge that looks like a miniature version of *Cyperus fastigiatus* and it generally grows in drier parts of the country than *Cyperus fastigiatus*. It also has more affinity to the short lawn grasslands, as it often co-occurs with *Cynodon dactylon*. Yet it stands out within this Main Cluster by being dominated by a sedge of up to 50 cm high.



41. *Acacia karroo-Gomphocarpus fruticosus* Community

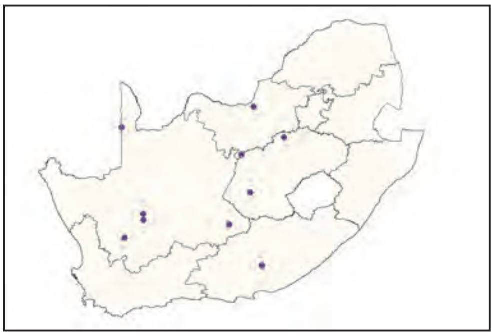
This community is probably more widespread than indicated on the distribution map as it represents a disturbed type of wetland in the dry regions. The shrub *Acacia karroo* is quite common in river floodplains in the drier regions of South Africa and in most cases these have not been clearly recognized as wetlands, as they are quite marginal.

42. *Searsia lancea – Cirsium vulgare* Community

This is another weedy community in the Karoo, but it is a bit more widespread than the previous community. Wetlands in the Karoo seem to be quite susceptible to invasion if their environment is not too saline.

43. *Scirpoides dioecus* Community

Most wetlands in the driest parts of the country look very unlike the familiar wetlands in temperate or subtropical regions, and it is therefore surprising to find still one species of sedge that does very well in valley bottom wetlands or dry river beds in the middle of the Karoo. *Scirpoides dioecus* is the best adapted sedge to the arid climates of the Karoo as it is a tough and hardy sedge.

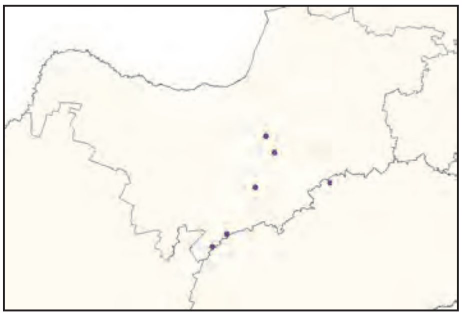


44. *Cyperus marginatus – Cynodon dactylon* Community

This community is transitional between Main Clusters 6 and 7, as the sedge Cyperus marginatus can become fully dominant in the wetter regions in the country, but more typically it is found as a sparse taller species occurring in a mat of *Cynodon dactylon* grassland.

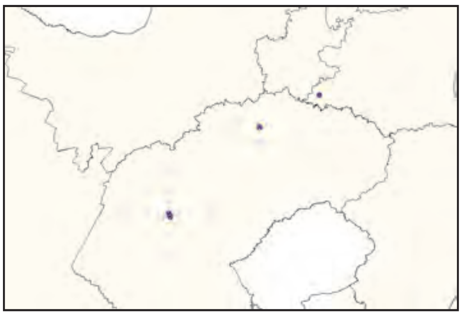
45. *Sporobolus oxyphyllus* Community

The grass *Sporobolus oxyphyllus* was only recently described as a new species and during this study it was actually found to be quite a common grass in the Free State / North-West border area. This community is quite typical for slightly brackish edges of wetlands where the grass *Sporobolus oxyphyllus* co-occurs with *Cynodon dactylon* which it resembles in terms of its vegetative parts.



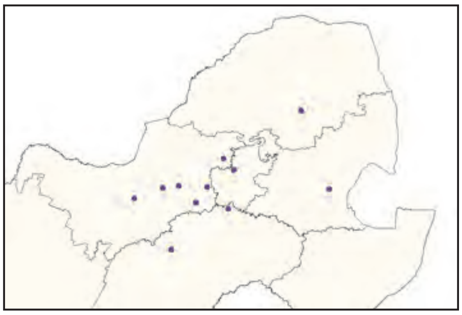
46. *Phyla nodiflora – Polygonum aviculare* Community

This represents a small community found in various pans in the Free State and Mpumalanga that consists mostly of low-growing creeping weedy species.



47. *Bidens bipinnata – Cynodon dactylon* Community

This community represents one of the many variations of *Cynodon dactylon* grasslands that are invaded by various weedy species such as *Bidens bipinnata*. It is conspicuous that the plots are all centered around Gauteng, particularly to the west of it, which may have something to do with the dispersal pattern of alien invasive species.



48. *Berkheya pinnatifida – Cynodon dactylon* Community

This represents another 'enriched' form of the *Cynodon dactylon* grasslands, but this form seems to be restricted to relatively dry parts of the Free State.

49. *Sida cordifolia – Cynodon dactylon* Community

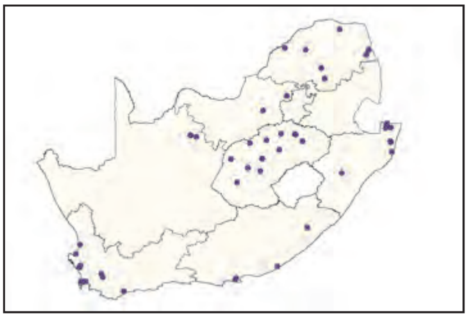
This is a specific type of floodplain grassland dominated by *Cynodon dactylon*, but including a lot of forbs of *Sida cordifolia*. It has only been sampled in the Mkhuze floodplain in northern KwaZulu-Natal but it is most likely much more common, for example in other low-lying areas such as Kruger Park.

50. *Eragrostis lehmanniana – Digitaria eriantha* Community

This community represents marginal wetland areas of temporarily wet zones at the edge of pans in the western Free State. *Eragrostis lehmanniana* is one of the most dominant upland grasses in this area, but as with many grass species, this grass is quite tolerant to temporary inundation.

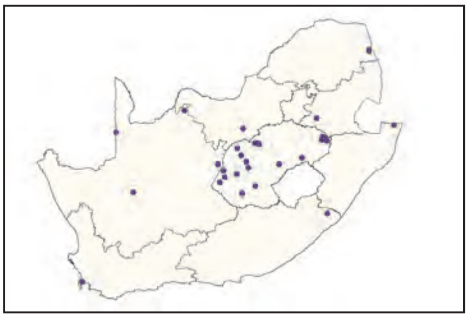
51. *Cynodon dactylon* Community

This community represents the very broad community of the proper *Cynodon dactylon* grasslands, which under many circumstances can achieve monodominance but is most often accompanied by various weeds. This community is coping very well with disturbances of various kinds and is commonly found in floodplains, dry pans and around the edges of other wetlands.



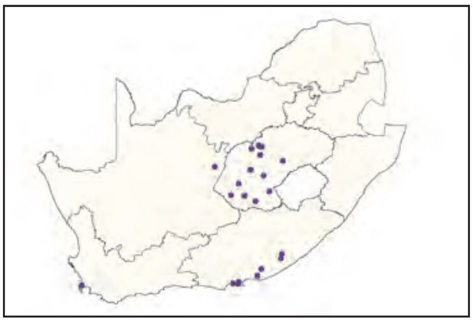
52. *Leptochloa fusca* Community

The grass *Leptochloa fusca* (old name *Diplachne fusca*) is one of the most variable grasses occurring in wetlands and it can occur in extremely different forms. It can appear as a tall reed-like grass on peatlands, to a swimming grass in pans in the Highveld, but most of the time it occurs in a stunted form growing on salt pans in the western part of the Free State.



53. *Schoenoplectus decipiens – Leptochloa fusca* Community

This community is particularly common in the pans of the Albany district of the Eastern Cape, but it is also found in the western Free State, where it occurs in wetlands in a similar dry climate. In the Albany district several other plants co-occur in this community, such as *Crassula inanis* and *Crinum campanulatum*. This may represent a separate form of this community with particular conservation importance.



54. *Verbena brasiliensis – Leptochloa fusca* Community

This community is a degraded form of the *Leptochloa fusca* grasslands that are common in the western Free State. It is only known from around the Panveld in the western Free State.

3.8.5 Discussion of Short Lawn Grassy Wetland Vegetation

The wetlands in this section are very diverse but have one characteristic in common, which is that they are driven by disturbance. The problem is that in this project we have not been paying much attention to the quantification of this general term ‘disturbance’. It can mean that plants are intensively grazed, it can mean that they are sometimes violently disrupted because of major flood events or it can mean that droughts can subject the plants growing in these communities to soil loss due to wind erosion. All three of these kinds of disturbances certainly play a role in shaping these communities, but it is difficult to quantify them. We would like to discuss the disturbance due to climatic conditions here a bit further as this provides, probably, the most straightforward manner in which to quantify at least part of these disturbances.

Except for the widespread communities in this Main Cluster, the communities are centered in three areas of the country: the Western Cape, the Western part of the Highveld fringing the Karoo, and in subtropical floodplains, such as the Limpopo, Pongola and Mkhuze Rivers.

The disturbance effect from the climate in the Cape is mostly due to the fact that this is a winter rainfall region, where the hot season often results in severe drought conditions and therefore watertable fluctuations are very high. This means that plants could either be annuals avoiding growth in the dry season (as in Community 7.17) or have traits that facilitate an amphibious lifestyle (as in Community 7.25). There are many other forms of Short Lawn Grassy Wetland Vegetation here, especially in communities that have a more reliable source of water, such as a connection to a groundwater discharge area or a river network.

Secondly, the disturbance effect from the regions fringing the Karoo in the Eastern Cape, Northern Cape, Free State and North-West Provinces, comes from the fact that droughts here are common and plants need to survive conditions where there is an accumulation of salts in the soil, where soil blows away because of wind erosion etcetera. There are many different communities here and especially the genus Sporobolus seems to be specialized in dealing with the conditions in wetlands in these areas.

Lastly, the floodplains in subtropical areas are often located in areas that can also receive small amounts of rainfall and are therefore nearly entirely dependent on waters from the flooding of the river with which they are associated. This flooding is in itself also a disturbance, so plants need to be adapted to that.

The most common species in these communities, *Cynodon dactylon*, is adapted to disturbance because of its clonal growth form which makes it very flexible in adjusting to new soil levels if soil is washed away, stresses during summer drought and removal of biomass from grazing.

The communities that are first split off from the dendrogram, those with *Schoenoplectus decipiens*, *Cynodon transvaalensis* and *Leptochloa fusca* stand out within this Main Cluster as these are the only ones that are still growing in relatively wet conditions, even though they seem to be able to cope with drier climates as well. They however do show the most affinities with communities in Main Cluster 6.

These are mainly speculations but it is relatively easy to test these assumptions by analysing the dataset with climatic data. Disturbance is a very general term, but if disturbances are tied to climatic factors, they can be more easily quantified.

3.9 Main Cluster 8: Hydrophytic Vegetation

The last Main Cluster represents the hydrophytic (submerged and floating) vegetation which is found in areas with deep clear waters. The dynamics in the water column are very different than the vegetation dynamics in terrestrial vegetation and the light regime is dependent on the suspended material in the water column. Many of the plants in the water column take their nutrients directly from the water and various species are not even rooted in the substrate. In some cases, when there is floating vegetation, it hampers the growth of vegetation below this floating layer in the water column.

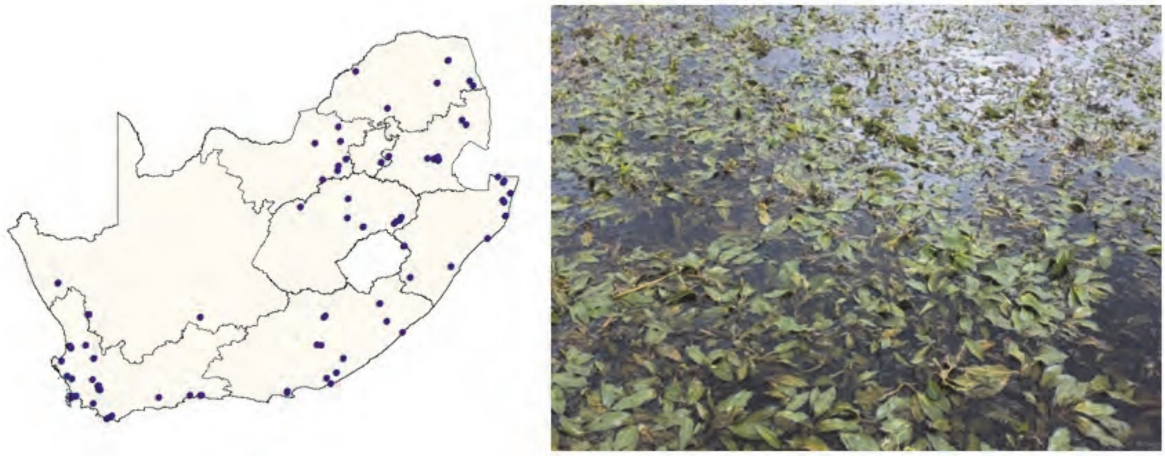


Figure 3.78 Distribution map of Hydrophytic Vegetation plots in the database with a photograph of a typical community.

Vegetation of this cluster is very poor in species and adaptation to permanent inundation can be seen as an adaptation to extreme conditions that not just any species can handle. Aquatic species from families like Hydrocharitaceae, Potamogetonaceae, Aponogetonaceae, Lentibulariaceae, Menyanthaceae and Araceae tend to become dominant, with occasionally still an aquatic grass or sedge. The vegetation in this cluster is regarded as azonal, and therefore independent of climate and bioregion but a number of communities are restricted to the Cape, as it seems that the Cape is an 'island' of temperate climates separated from the rest of the continent and a distinct aquatic flora has developed in the Western Cape, particularly in the family Aponogetonaceae which has three endemic species.

3.9.1 Classification and Indicator Species Analysis

Classification was carried out on a data matrix containing 129 vegetation plots and 178 species. After the first clustering it became clear that there was a need to use two dummy species to aid in classification and to lump some species together because too little data was available for some communities. Therefore some species sharing the same genus, were lumped together as a genus, this happened with *Nymphoides* spp., *Nymphaea* ssp and *Persicaria* ssp. This resulted in a classification into 21 communities, but the community with Persicaria ssp. was regarded as a 'leftover' cluster with many under-sampled communities. Of these and various other hydrophytic communities it is still necessary to collect more data as many communities in this cluster have not been collected very intensively as presently these communities are mostly occurring in farm dams and not so much in wetlands.

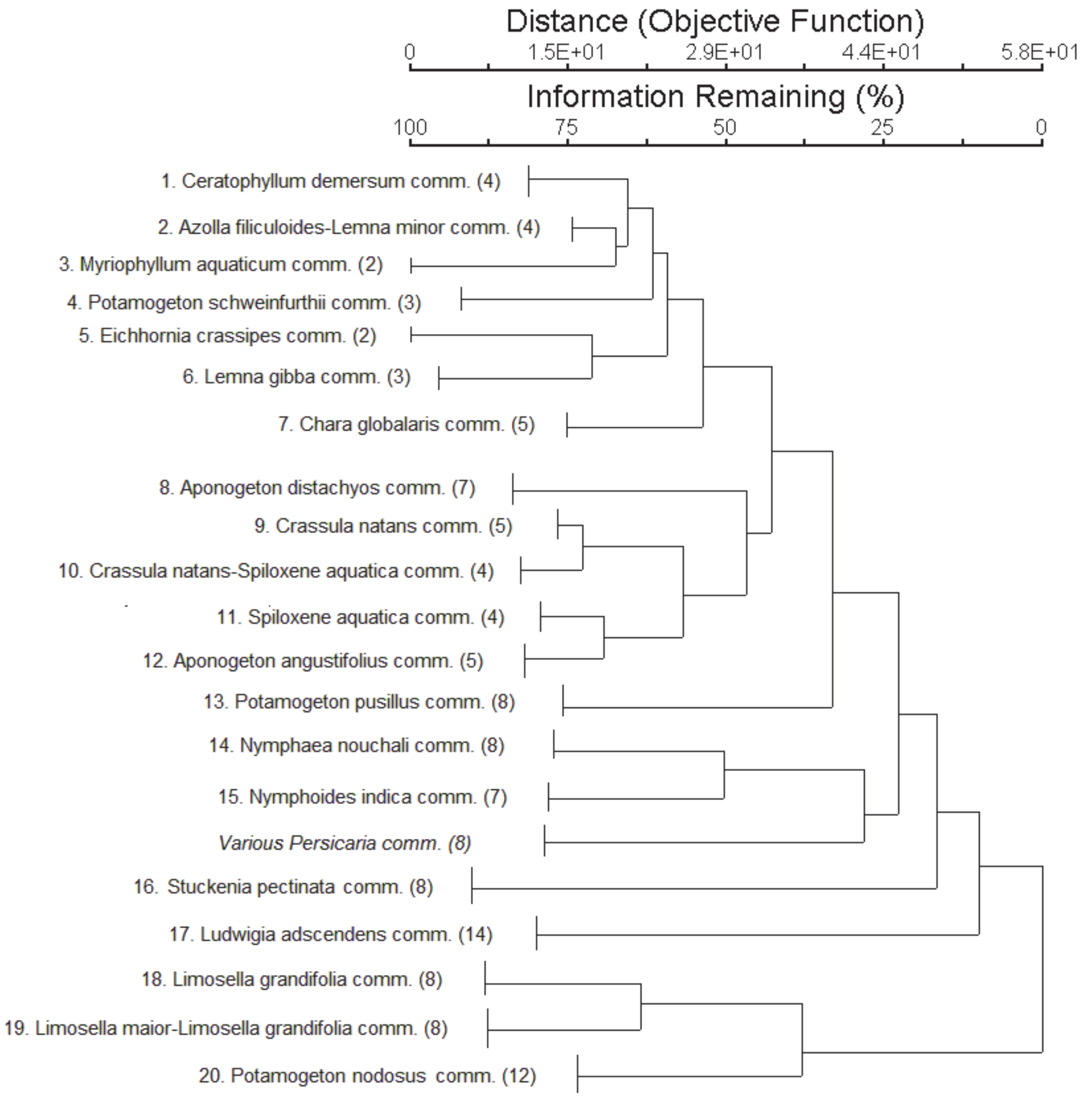


Figure 3.79 Cluster dendrogram for the Hydrophytic Vegetation.

Table 3.8 Plant communities and associated indicator species for Hydrophytic Vegetation (Main Cluster 8)

Vegtype	No. of plots	Dominants	Where	Indicator species	Indicator Value (IV)	p-value
1	4	*Ceratophyllum demersum*	Highveld	*Ceratophyllum demersum*	88.4	0.001
2	4	*Azolla filiculoides, Wolffia arrhiza*	polluted areas	*Azolla filiculoides*	57.5	0.005
				Wolffia arrhiza	48.5	0.007
				Lemna minor	44.4	0.008
3	2	*Myriophyllum aquaticum*	Coast ?	*Myriophyllum aquaticum*	100	0.001
4	3	*Potamogeton schweinfurthii*	Everywhere	*Potamogeton schweinfurthii*	100	0.001
5	2	*Eichornia crassipes*	tropics, polluted areas	*Eichhornia crassipes*	100	0.001
6	3	*Lemna gibba*	Everywhere	*Lemna gibba*	68.8	0.002
7	5	*Chara globularis*	Cape, polluted areas	*Chara globularis*	82.4	0.001
8	7	*Aponogeton distachyos*	Cape, various	*Aponogeton distachyos*	69.2	0.001
9	5	*Crassula natans*	Cape	*Isolepis hystrix*	40	0.037
				Juncus exsertus	40	0.039
				Limosella africana	40	0.045
				Crassula natans	31.9	0.005
10	4	*Spiloxene aquatica, Crassula natans*	Cape	*Spiloxene aquatica*	60.1	0.001
				Pennisetum macrourum	50	0.005
				Triglochin bulbosa	50	0.006
				Rumex crispus	30.5	0.044
11	4	*Spiloxene aquatica*	Cape	Unknown species strap-leaves	75	0.002
				Limosella inflata	50	0.005
12	5	*Aponogeton angustifolius*	Cape	*Aponogeton angustifolius*	97.9	0.001
				Nitella spec.	80	0.001
				Sporobolus virginicus	44.6	0.008
				Cyperus thunbergii	40	0.038
				Sarcocornia capensis	40	0.038
				Romulea tabularis	40	0.042
				Trachyandra oligotricha	33.1	0.04
13	8	*Potamogeton pusillus*	Everywhere	*Potamogeton pusillus*	56.2	0.001
14	8	*Nymphaea nouchali*	Tropics, coastal	*Nymphaea* species	57.1	0.001
				Utricularia species	37.5	0.015
				Eleocharis dulcis	32.4	0.02
15	7	*Nymphoides* species	Coastal areas	*Nymphoides* species	100	0.001
16	8	*Stuckenia pectinata*	Shallow areas highveld	*Stuckenia pectinata*	75.3	0.001
17	14	*Ludwigia adscendens*	Tropics, shallow areas	*Ludwigia adscendens* ssp. *diffusa*	88.3	0.001
18	8	*Limosella grandiflora*	Shallow areas highveld	*Limosella grandifolia*	100	0.001
19	8	*Limosella major*	Shallow areas highveld	-		
20	12	*Potamogeton nodosus*	Highveld	*Potamogeton nodosus*	78.7	0.001
Add.	8	Various *Persicaria*	Everywhere, shallow, disturbed areas	*Persicaria decipiens*	71.7	0.001
				Persicaria attenuata		
				Persicaria limbata		
				Persicaria senegalensis		
				Persicaria lapathifolia		

3.9.2 Canonical ordination

The ordination of the data for the submerged vegetation (Figure 3.80) needs to take into account that plants growing in the water column are more affected by water quality than by soil quality. However, only a limited number of water quality variables were measured, namely pH and Electrical Conductivity. Selection of those plots where these variables were measured led to a data matrix of 58 plots counting a total of 65 species. The environmental data file consisted of the ordinary environmental data plus water pH and Conductivity, but without soil data, as this was only available for a very limited number of plots. The resulting dataset included all community types from this Main Cluster, as only community 8.9 and 8.12 were not represented. However, a large number of communities (eight) were represented by only a single plot, namely Communities 8.2 (*Azolla filiculoides-Lemna minor* Community), 8.3 (*Myriophyllum aquaticum* Community), 8.5 (*Eichhornia crassipes* Community), 8.10 (*Crassula natans – Spiloxene aquatica* Community), 8.11 (*Spiloxene aquatica* Community), 8.14 (*Nymphaea nouchali* Community), 8.17 (*Ludwigia adscendens* Community), and 8.18 (*Limosella grandifolia* Community).

Canonical Correspondence Analysis on this dataset led to an ordination with a Total Inertia of 17.95 while the sum of all canonical eigenvalues was 6.14, which means that about 35% of all variation is explained by the environmental variables supplied.

The first axis of the ordination is clearly explained by both Electrical Conductivity (negative association) and altitude (positive association), which means that open water at higher altitudes is generally lower in solutes and Electrical Conductivity than open water at lower altitudes. A community that tends to grow at higher altitudes is for example Community 8.20 (*Potamogeton nodosus* Community) and a community that is common at lower altitudes is Community 8.15 (*Nymphoides indica* Community).

The second axis is less clear and seems to be most strongly associated with organic matter contents of the soil (assessed from soil colour). There is also a distinction between wetlands from Natural, Rural and Urban wetlands so this may signify a pollution gradient. The *Lemna gibba* wetlands (or at least two of them) stand out as wetlands that are high in organic matter and that are most located in the ‘Urban wetlands’ direction. In completely the opposite direction, there is the *Myriophyllum aquaticum* Community, consisting of an alien invasive species, which is however found in very natural habitats. For the rest, there is not much that can be interpreted from this ordination diagram, mainly because most communities are only represented from only one plot, but also because some communities are scattered over the whole diagram. It would also be better to know more water quality variables, so that the second gradient could be interpreted better.

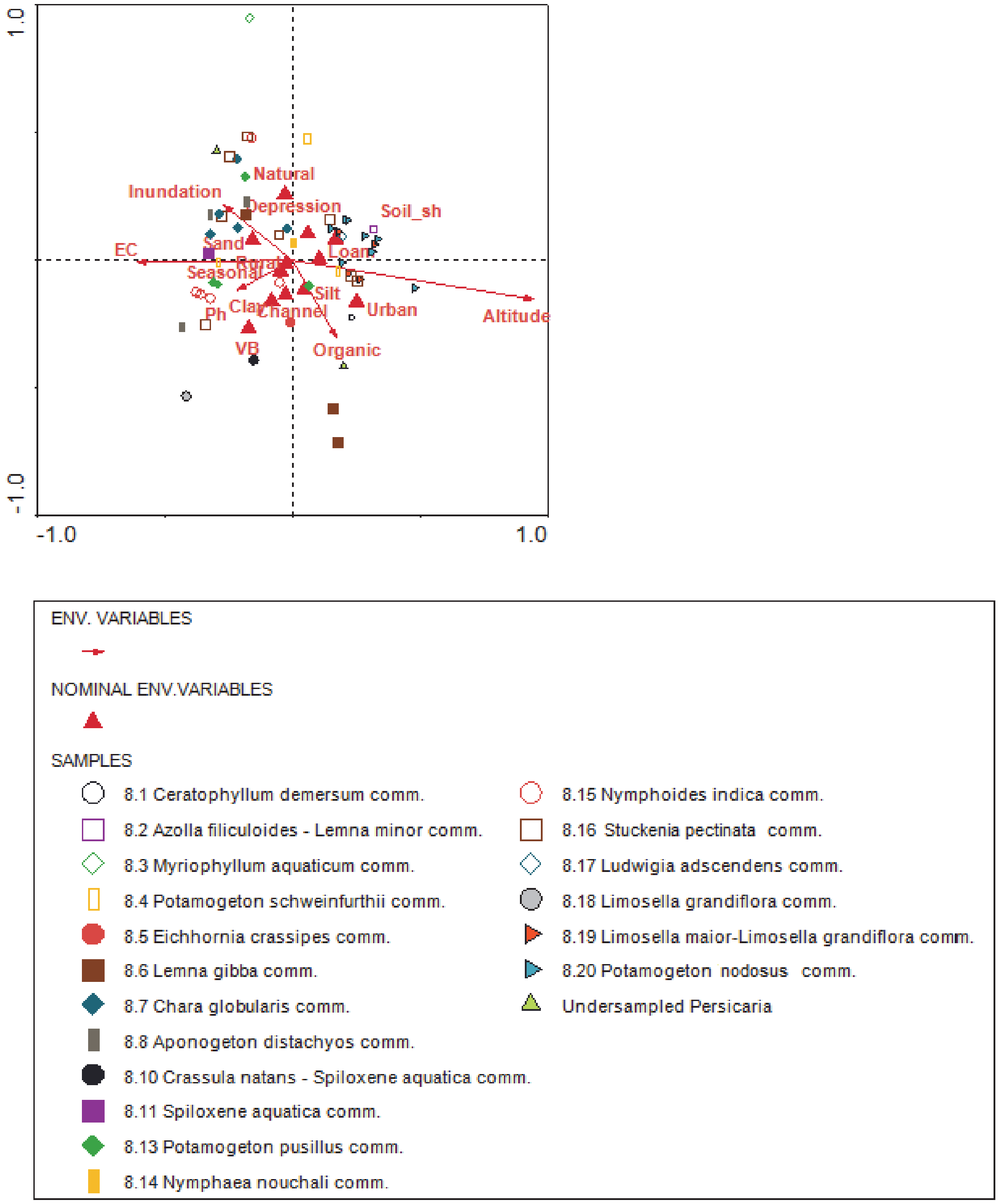


Figure 3.80 CCA ordination diagram of the hydrophytic communities.

3.9.3 Species response curves

The data available to determine species response curves for submerged species is very poor and mostly based on soil data, which is ambiguous. It is still necessary to get more detailed water quality data in those places where submerged vegetation is sampled, to obtain more exact measures to explain the distribution of submerged vegetation. For example, turbidity is known to explain a lot of patterns of the distribution of aquatic vegetation, as it impacts the light regime in the water column.

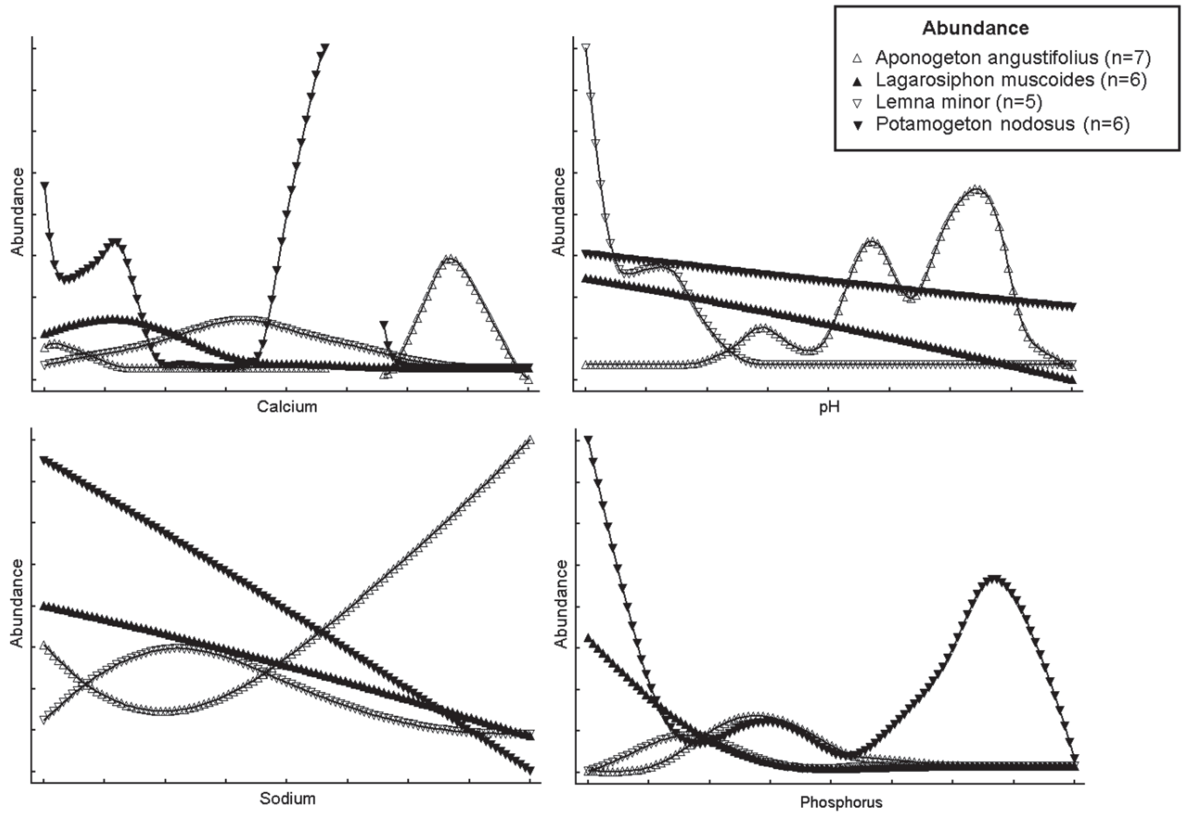


Figure 3.81 Species response curves for four submerged species.

The species displayed in Figure 3.81 are represented by only a very small number of plots so the data is quite poor to make a proper interpretation but some trends can be detected. It seems that the species *Aponogeton angustifolius* is the species most adapted to a high content of Sodium and Calcium, as well as high alkalinity. This species is found in wetlands in the Cape flats and the groundwater may well be affected by sea water infiltration. *Lemna minor* is adapted to very acidic conditions. *Potamogeton nodosus* has a peak at high Phosphate concentrations.

3.9.4 Description of communities

1. *Ceratophyllum demersum* Community

This community is dominated by *Ceratophyllum demersum*, a submerged aquatic plant that is not rooted in the substrate. It has not been found as a monodominant very often but it occurs both on the Highveld as well as on the coast. It often occurs mixed with many other species in eutrophic waters that can be either flowing or standing still (Cook 2004).

2. *Azolla filiculoides – Lemna minor* Community

This community is probably much more common than indicated on the map and represents the situations where *Azolla filiculoides*, an alien floating aquatic species that can be easily recognized by the typical reddish colour that it gives the water surface. It is often accompanied by an indigenous but cosmopolitan species *Lemna gibba*. The indigenous species of Azolla, *Azolla pinnata*, has not been found in the course of this project.

3. *Myriophyllum aquaticum* Community

The aquatic forb *Myriophyllum aquaticum* is an alien invader that grows submersed in the water but has emergent inflorescenses. It forms a dense monoculture in the waters that are invaded. The species occurs mostly in shallow coastal waters, but is at present only in the database from two localities. One of these localities is Lake Sibaya, a pristine coastal freshwater lake that is part of the Isimangaliso Wetland Park.

4. *Potamogeton schweinfurthii* Community

This community is an entirely aquatic community that is often still doing quite well in relatively turbid waters. It is probably found throughout the entire country but has not been picked up very often during the current project.

5. *Eichhornia crassipes* Community

This is an under-sampled community with only two samples, and it is much more widespread than is indicated on the distribution map, with many occurrences also in the coastal Provinces. The water hyacinth *Eichhornia crassipes* is a very aggressive alien invader that invades the water surface and shades the water column below it.

6. *Lemna gibba* Community

This is one of the communities which are probably much more common than its distribution map suggests, as it occurs mainly on eutrophic farm dams. It consists of a single species of floating aquatic that deprives the entire water column below it of any light.

7. *Chara globularis* Community

Chara globularis is a stonewort, not a vascular plant, and becomes in some cases dominant in polluted waters in the Western Cape. It is the only community based on stoneworts that is recognized here, and there may be more, as most stoneworts are actually adapted to very clean waters.

8. *Aponogeton distachyos* Community

This is the most characteristic aquatic community from the Western Cape and the floating-leaved aquatic *Aponogeton distachyos* is even grown commercially to be sold as 'waterblommetjies' a characteristic Cape culinary dish. It occurs in open waters, mostly dams or lakes.

9. *Crassula natans* Community

Crassula natans is an amphibious species that takes a different form when it is inundated and it occurs from the Cape to the Drakensberg. It is mostly found in places with a highly fluctuating water table.

10. *Crassula natans – Spiloxene aquatica* Community

This community is a rich community of aquatic and amphibious species combined in shallow waters in the inland parts of the Cape. One of the most conspicuous elements of this community is the white-flowered lily *Spiloxene aquatica*.

11. *Spiloxene aquatica* Community

In this community, the white-flowered *Spiloxene aquatica* occurs in open water, virtually by itself as just a single monodominant species.

12. *Aponogeton angustifolius* Community

This community is restricted to the area around Cape Town in the Western Cape and is endemic to this area because the floating aquatic species *Aponogeton angustifolius* is endemic to this area. The species in itself is quite rare and the community is probably under threat as well. This is the only species of *Aponogeton* that is capable to deal with brackish conditions.

13. *Potamogeton pusillus* Community

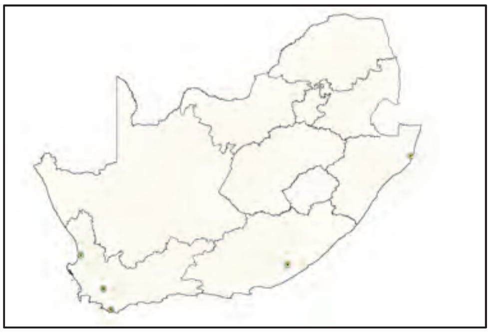
This is a submerged community dominated by the small pondweed *Potamogeton pusillus*. It is restricted to the Cape and it has been found in coastal lakes.

14. *Nymphaea nouchali* Community

The blue water lily *Nymphaea nouchali* is a floating-leaved aquatic plant that occurs in natural open waters or farm dams in the subtropical regions. It is sometimes replaced by *Nymphaea lotus*, which is white, and the species also occur together sometimes. Not enough data is available to split this community for the two species separately, but the blue water lily is certainly the most common.

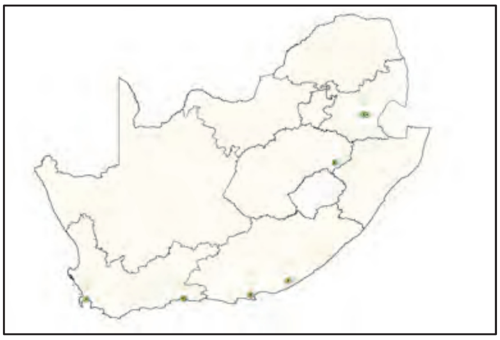
15. *Nymphoides indica* Community

This community has been combined with communities dominated by the less common *Nymphoides occidentalis*, for the sake of oversight, but in the future the communities with both of these species may become better differentiated if more data becomes available. Both of them are floating-leaved aquatics that occur in shallow open waters.



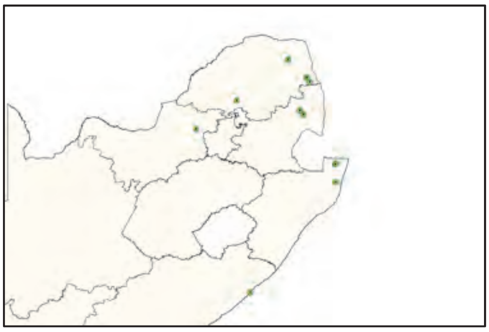
16. *Stuckenia pectinata* Community

This community is dominated by the pondweed *Stuckenia pectinata* which is slightly larger and seemingly more widespread than the similar species *Potamogeton pusillus*. One of the plots includes a record from Lake Chrissie with a very peculiar pondweed which was in the end classified as *Stuckenia pectinata*, but it seems quite an aberrant form.



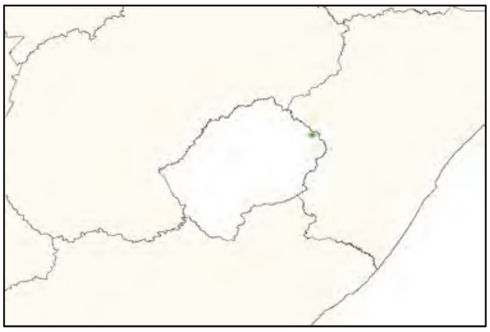
17. *Ludwigia adscendens* Community

The creeping / floating species *Ludwigia adscendens* becomes common in shallow wetlands in the subtropical regions and it forms one of the most species-rich communities from this Main Cluster. Strictly speaking, the species *Ludwigia adscendens* is not a floating species like a waterlily, because it encroaches onto the water surface from the edge of the water, instead of growing from the floor of the pond.



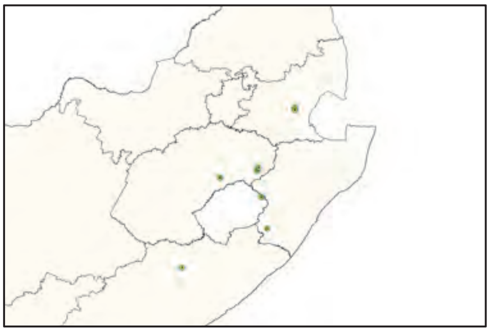
18. *Limosella grandiflora* Community

This community is only known from a very old study carried out in Lesotho and it also seems to be under-sampled. It occurs in open pools at the very high altitudes of eastern Lesotho.



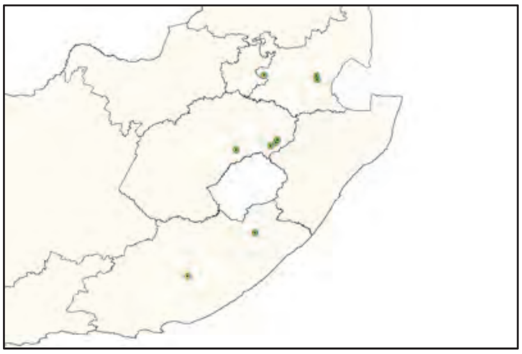
19. *Limosella maior – Limosella grandiflora* community

This community represents the shallow pools vegetated with various species of *Limosella* in the Highveld and at the foothills of the Drakensberg.



20. *Potamogeton nodosus* Community

This is, at least for a submerged plant community, a relatively rich community with commonly more than four species in it, and it represents the most common aquatic plant community in the eastern part of the Highveld, It is dominated by the floating-leaved *Potamogeton nodosus*, mostly floating over a dense layer of *Lagarosiphon major*. The species *Potamogeton thunbergii*, as this species was previously named, was recently split up into two species, so the taxonomic identity of each record needs to be verified. Of the two new species identities, *Potamogeton nodosus* is the most common one in the eastern Free State where the main part of the samples were made.



3.9.5 Discussion of Hydrophytic Vegetation

Several historical studies have looked into hydrophytic plant communities but have not used a plot-based approach as is common in terrestrial vegetation (Musil et al. 1973; Howard-Williams 1980). Because of the general shortage of vegetation data of these communities, it may however be desirable to look into comparing this historical data with the data present in the database and resolve the issues around compatibility.

Submerged plant communities are subjected to different environmental drivers as the communities in the other Main Clusters. This is mainly because there is a mixture between plants that are rooted in the substrate and plants that take their nutrition from the water column. Even when plants are rooted in the substrate, they can still acquire significant amounts of nutrients through the water column as these plants generally do not have a cuticula and water and nutrients diffuse freely (Cronk & Fennessy 2001).

Communities with emergent plants can also co-exist with a floating aquatic species, such as *Lemna*, and it can be argued that both types of plants each represent their own communities, because the emergent species will take its nutrition from the soil compartment and the floating species will take its nutrition from the water column.

In the course of this project, the focus has been mostly on the emergent species and the explanatory variables that have been collected have suited this aim, but for submerged species, the explanatory variables should focus more on the nutrients and conditions of the water column. A small number of variables have been collected in this water column, but it is certainly not enough to get a sufficient understanding of how these communities work. The first variables that are missing are the concentrations of Nitrogen, Phosphate and the major cations in the water column, because the nutrients in the water column and the nutrients in the soil compartment can be of a different source. One other aspect that is important to know about water is its turbidity. Floating aquatic plants and emergent species do not utilize light penetrating through the water column but submerged species generally do and therefore they require at least some level of clarity in the water column. Temperature of the water column can also play a role, because the temperatures in the water are much more stable than temperatures of the air.

More on a positive note, most of these communities are not very complex as they consist of only one or two main dominants. Submerged plant communities belong to the most species-poor wetland communities and therefore an understanding of the autecology of the individual species is often sufficient in understanding the ecosystem as a whole. Information about specific requirements of individual aquatic species is often already available in taxonomic literature, for example Cook (2004) and therefore it may not always be necessary to have precise field data available.

4 DISCUSSION: OVERALL ANALYSIS AND COMPARISONS

The analysis that was carried out in Chapter 3 results in an overview of wetland vegetation types within South Africa. There are certain connections between the Main Clusters that have been highlighted in the text, but additional data can still provide more refined insights. In terms of species response curves, it is useful to contrast response curves among various species with each other, as these represent visible trends that will be detected during monitoring of a wetland. Community shifts provide an indication that something is happening to the ecosystem before expensive measurements take place. In that sense, it is not a problem that interactions between environmental factors have not been taken into account. It is a goal of scientific development to model the complexity of the real world, but it is a different matter to develop a workable method that people in the field can use to detect and interpret changes. Therefore, it is important to keep things simple for the sake of a monitoring programme. Except for the results per Main Cluster and the results for each community, there are also some general insights that emerge from the database that has been developed. Those general insights stretch from species lists of the most common species, species diversity per wetland, and regional diversity in wetland community types. These are the topics that will be discussed in the following sections.

4.1 Species diversity in South African wetlands

The overall species list of the National Wetlands Vegetation Database is informative in terms of the typical species composition of wetlands in South Africa and the taxonomic identity of the largest groups of wetland plants. Unlike previous overviews of South African wetland plants (Cook 2004; Van Ginkel et al. 2010) it is now possible to make assessments in terms of abundance as well. In this section we will focus on several questions, firstly, what are the most common wetland plant species in South Africa, secondly which are the most important families and their representative species. Special attention is paid to alien species, the number and types of the most common alien species are indicated and the question of which wetland types are most susceptible for alien invasion.

Firstly, the fifteen most common wetland species of the country are listed in Table 4.1. This listing is based on the assumption that the wetland database is representative of the real wetland vegetation in the country. This is a difficult assumption to test and will be further addressed in Section 4.2 where the spatial distribution of wetland vegetation plots will be addressed.

Table 4.1 The list of the 15 most commonly occurring wetland plants in South Africa, listed with the plant family to which they belong, as well as the percentage of plots in the database in which they are present.

1	*Leersia hexandra* Sw.	POACEAE	15.1%
2	*Cynodon dactylon* (L.) Pers.	POACEAE	12.7%
3	*Phragmites australis* (Cav.) Steud.	POACEAE	10.0%
4	*Paspalum dilatatum* Poir.	POACEAE * alien	9.1%
5	*Eragrostis plana* Nees	POACEAE	8.4%
6	*Typha capensis* (Rohrb.) N.E.Br.	TYPHACEAE	8.1%
7	*Agrostis lachnantha* Nees	POACEAE	7.0%
8	*Eleocharis dregeana* Steud.	CYPERACEAE	6.3%
9	*Ischaemum fasciculatum* Brongn.	POACEAE	6.2%
10	*Hemarthria altissima* (Poir.) Stapf & C.E.Hubb.	POACEAE	6.1%
11	*Centella asiatica* (L.) Urb.	ARALIACEAE	5.9%
12	*Ranunculus multifidus* Forssk.	RANUNCULACEAE	5.6%
13	*Andropogon appendiculatus* Nees	POACEAE	5.5%
14	*Eragrostis curvula* (Schrad.) Nees	POACEAE	5.2%
15	*Cyperus fastigiatus* Rottb.	CYPERACEAE	5.1%

When looking at Table 4.1, we notice that 10 out of fifteen of the most common wetland plant species are grasses (family Poaceae). This is interesting because in most common wetland delineation guides (for example DWAF 2008), one of the characteristics of wetlands that is commonly mentioned is that wetlands tend to be dominated by sedges (Cyperaceae) and the uplands are more dominated by grasses (Poaceae). This represents a gross simplification as it becomes clear now that wetland grasses (which represent only a very small fraction of the overall grass family) actually happen to be very common in wetlands and the five most common wetland plants in South Africa are all grasses. The Cyperaceae family appears only two times in this list and sedges may often be dominant in the wettest parts of the wetlands, there are only few species that are very widespread and occur in large numbers of wetlands.

Another thing that is revealed by Table 4.1 and that is of concern for conservation is that among this list of common wetland plants, an alien species is featured. The current study certainly did not focus on extremely disturbed wetlands and there is actually a bias towards natural and pristine systems as the aim of the study was to find reference conditions, but even so, there are alien species that have become so prominent in South Africa’s wetlands that they start belonging to one of the most common wetland species of the country. The list of the most common alien species in the database is given in Table 4.6 below.

One reason why grasses may appear as the most important wetland plant family is that the database represents both the permanently wet habitats as well as temporarily wet habitats which are more like upland dry habitats in any case. The picture may change if we split up the database in temporarily, seasonally and permanently wet habitats and this is shown in Table 4.2. It appears that the number of plots of temporarily, seasonally and permanently wet habitats is more or less equal in the overall database.

In this Table, we can see that Temporary and Seasonal wetland habitats are very similar to the picture shown above for the overall wetlands database, in that grasses dominate and top the list, even though the individual species that tops the list is different in the case of temporary wetlands. We can also see that in the temporarily wet habitats there are even two alien species in the list, which makes it clear that temporarily wet habitats are the most prone to invasion.

The last table, of the permanently wet habitats shows a bias because five Swamp Forest species are represented. This actually represents a very rare vegetation type that has been over-represented in the current database as there have been various historical studies showing a particular interest in this type. These species should actually be disregarded in the overall list of most common wetland plants as Swamp Forest itself is quite a rare community type that does not occur just anywhere in the country. Otherwise, the list of common wetland plants of permanently wet habitats is the only one among the three where the sedge family is actually well represented with six species among the top 15 with only five grasses. Still, even here, the list is still topped by grasses with *Leersia hexandra* and *Phragmites australis* being the most common wetland plants in permanently wet habitats.

Table 4.2 Most common wetland plants split up according to the period of inundation. (*) represents alien species. (**) Swamp Forest species, shaded as they represent a bias in the database.The percentages refer to the number of plots in that kind of habitat that contain the species.

	Plants from temporary wet habitats			
1	*Cynodon dactylon* (L.) Pers.	POACEAE		17.4%
2	*Eragrostis plana* Nees	POACEAE		14.6%
3	*Paspalum dilatatum* Poir.	POACEAE	*	13.4%
4	*Eragrostis curvula* (Schrad.) Nees	POACEAE		12.0%
5	*Themeda triandra* Forssk.	POACEAE		9.9%
6	*Verbena bonariensis* L.	VERBENACEAE	*	8.1%
7	*Leersia hexandra* Sw.	POACEAE		7.6%
8	*Arundinella nepalensis* Trin.	POACEAE		7.5%
9	*Helichrysum aureonitens* Sch.Bip.	ASTERACEAE		7.4%
10	*Agrostis lachnantha* Nees	POACEAE		7.1%
11	*Cyperus marginatus* Thunb.	CYPERACEAE		7.1%
12	*Hemarthria altissima* (Poir.) Stapf & C.E.Hubb.	POACEAE		6.8%
13	*Cyperus congestus* Vahl	CYPERACEAE		6.5%
14	*Ranunculus multifidus* Forssk.	RANUNCULACEAE		6.5%
15	*Andropogon appendiculatus* Nees	POACEAE		6.1%
	Plants from seasonally wet habitats			
1	*Leersia hexandra* Sw.	POACEAE		14.8%
2	*Cynodon dactylon* (L.) Pers.	POACEAE		13.3%
3	*Paspalum dilatatum* Poir.	POACEAE	*	9.9%
4	*Eragrostis plana* Nees	POACEAE		9.5%
5	*Phragmites australis* (Cav.) Steud.	POACEAE		8.2%
6	*Typha capensis* (Rohrb.) N.E.Br.	TYPHACEAE		8.1%
7	*Centella asiatica* (L.) Urb.	ARALIACEAE		8.1%
8	*Eleocharis dregeana* Steud.	CYPERACEAE		8.0%
9	*Agrostis lachnantha* Nees	POACEAE		7.8%
10	*Hemarthria altissima* (Poir.) Stapf & C.E.Hubb.	POACEAE		7.7%
11	*Ranunculus multifidus* Forssk.	RANUNCULACEAE		7.4%
12	*Ischaemum fasciculatum* Brongn.	POACEAE		6.8%
13	*Cyperus fastigiatus* Rottb.	CYPERACEAE		6.5%
14	*Arundinella nepalensis* Trin.	POACEAE		6.1%
15	*Eragrostis planiculmis* Nees	POACEAE		6.1%
	Plants from permanently wet habitats			
1	*Leersia hexandra* Sw.	POACEAE		24.3%
2	*Phragmites australis* (Cav.) Steud.	POACEAE		13.8%
3	*Typha capensis* (Rohrb.) N.E.Br.	TYPHACEAE		12.2%
4	*Pycreus nitidus* (Lam.) J.Raynal	CYPERACEAE		9.9%
5	*Persicaria decipiens* (R.Br.) K.L.Wilson	POLYGONACEAE		8.3%
6	*Syzygium cordatum* Hochst.	MYRTACEAE	**	8.2%
7	*Voacanga thouarsii* Roem. & Schult.	APOCYNACEAE	**	7.5%
8	*Cynodon dactylon* (L.) Pers.	POACEAE		7.3%
9	*Ficus trichopoda* Baker	MORACEAE	**	7.2%
10	*Bridelia micrantha* (Hochst.) Baill.	EUPHORBIACEAE	**	6.9%
11	*Eleocharis dregeana* Steud.	CYPERACEAE		6.9%
12	*Panicum glandulopaniculatum* Renvoize	POACEAE		6.9%
13	*Cyperus prolifer* Lam.	CYPERACEAE		6.6%
14	*Schoenoplectus brachyceras* (A.Rich.) Lye	CYPERACEAE		6.1%
15	*Cyclosorus interrupta* (Willd.) H. Ito	THELYPTERIDACEAE		6.0%
16	*Agrostis lachnantha* Nees	POACEAE		5.8%
17	*Juncus oxycarpus* E.Mey. ex Kunth	JUNCACEAE		5.6%
18	*Cyperus fastigiatus* Rottb.	CYPERACEAE		5.0%
19	*Tarenna pavettoides* (Harv.) Sim	RUBIACEAE	**	5.0%
20	*Rhynchospora corymbosa* (L.) Britton	CYPERACEAE		4.9%

As a matter of fact, sedges tend to dominate in the wettest parts of the wetlands, but with their rhizomatous growth form they often tend towards monodominance and it is not as common that many species of sedge co-exist in the same way as many species of grasses co-exist in the temporary zones. Another effect of this is that the overall number of species in wetlands decreases with wetness, as in Figure 4.1. Sedges tend to be more dominant (but with less species) in the wetter and therefore more species-poor habitats. The most common sedges are shown in Table 4.3.

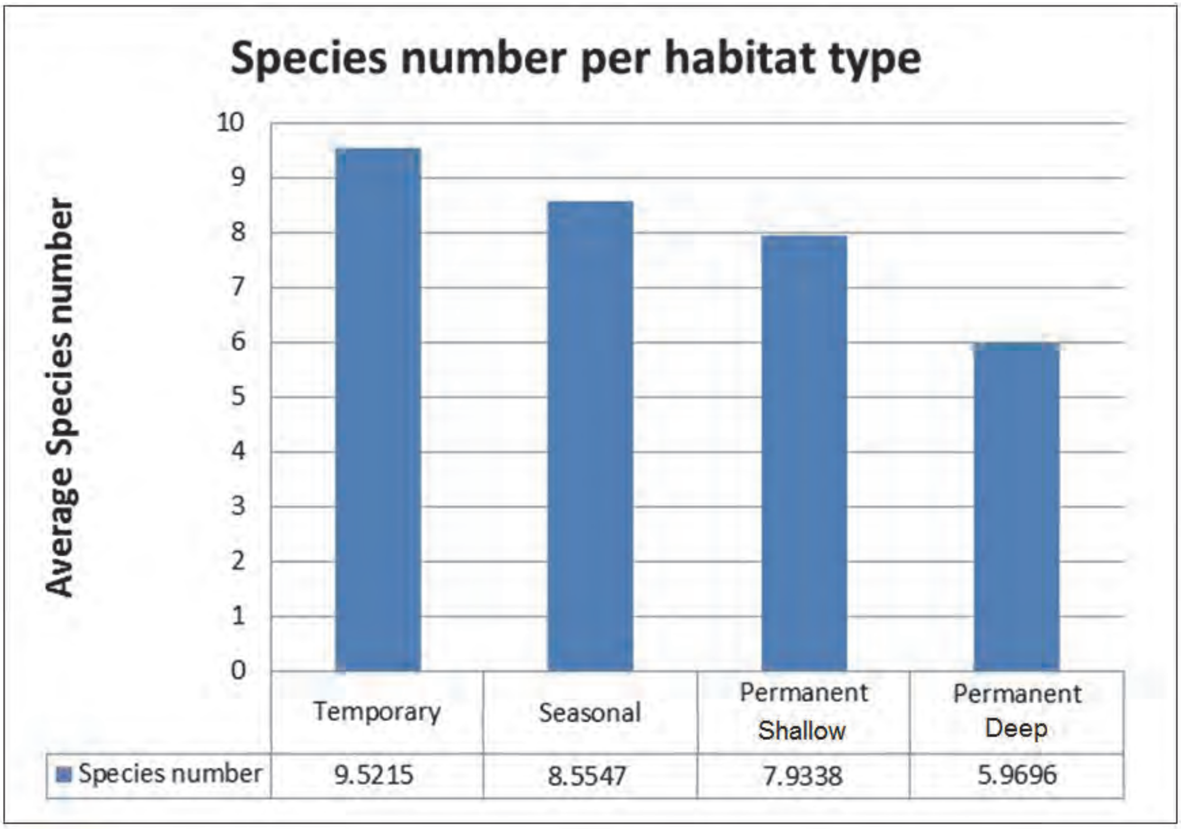


Figure 4.1 Average number of species versus wetness. The category Permanent deep refers to wetlands that are permanently wet and have a water column of at least 30 cm.

Since sedges nevertheless are typical wetland species and often represent the dominant growth form in the wettest part of the wetlands (see also section 4.3 where we will look at functional composition of a wetland and where sedges are regarded as a distinct growth form), it is justified to also present a separate list with the ten most common sedge species in wetland habitats.

We are particularly interested in the sedges, but what about a general overview of plant families in wetlands? There are three levels on which the prominence of a family can be assessed, namely the number of species by which it is represented, the number of occurrences by which a member of that family has been recorded, or the overall cover of the members of that family in individual plots. The last question will be addressed in section 4.3 which deals with the functional composition of wetland vegetation plots, but the twenty most prominent plant families in terms of number of occurrences as well as in number of species is represented in Table 4.4. It is clear that the three most important families between number of occurrences and number of species are similar, Poaceae, Cyperaceae and Asteraceae, although their order differs between the two tables. Further in the table there are however more important differences, with some families being prominent in terms of number of occurrences, but with very few species, for example Typhaceae (2 species), Araliaceae (7 species), Verbenaceae (10 species), Onagraceae (14 species), Juncaceae (17 species) and Polygonaceae (22 species).

Table 4.3 List of the ten most common wetland sedges (Cyperaceae) in the country, together with the fraction of plots they appear in as well as their ranking in the overall list of most common wetland plants (Table 4.1).

Rank	Species	Overall rank	Percen-tage
1	*Eleocharis dregeana* Steud.	8	6.3%
2	*Cyperus fastigiatus* Rottb.	15	5.1%
3	*Pycreus nitidus* (Lam.) J.Raynal	21	4.5%
4	*Cyperus congestus* Vahl	22	4.5%
5	*Cyperus longus* L.	25	4.4%
6	*Cyperus denudatus* L.f.	27	3.8%
7	*Kyllinga erecta* Schumach.	28	3.8%
8	*Fuirena pubescens* (Poir.) Kunth	29	3.7%
9	*Cyperus marginatus* Thunb.	32	3.7%
10	*Cyperus prolifer* Lam.	38	3.4%

Table 4.4 Prominence of the various plant families occurring in wetlands in South Africa, both in terms of the number of occurrences as well as in terms of the number of species in each family. The list for the non-wetland species is derived from Huntley (1995) but adjusted to modern taxonomic changes.

	Commonest	Number of occurrences in database		Most species-rich	Number of species		Non-wetland species (derived from Huntley 1995)
1	POACEAE	13760	1	ASTERACEAE	387	1	AIZOACEAE
2	CYPERACEAE	7943	2	POACEAE	338	2	ASTERACEAE
3	ASTERACEAE	5801	3	CYPERACEAE	229	3	FABACEAE
4	JUNCACEAE	1199	4	FABACEAE	139	4	IRIDACEAE
5	FABACEAE	1166	5	IRIDACEAE	80	5	ERICACEAE
6	POLYGONACEAE	1142	6	RESTIONACEAE	78	6	POACEAE
7	AMARANTHACEAE	1018	7	AMARANTHACEAE	57	7	APOCYNACEAE
8	RUBIACEAE	536	8	RUBIACEAE	46	8	SCROPHULARIACEAE
9	RESTIONACEAE	518	9	SCROPHULARIACEAE	42	9	CYPERACEAE
10	VERBENACEAE	513	10	ERICACEAE	41	10	EUPHORBIACEAE
11	ONAGRACEAE	499	11	AIZOACEAE	40	11	ORCHIDACEAE
12	ARALIACEAE	497	12	GERANIACEAE	39	12	PROTEACEAE
13	ROSACEAE	473	13	ORCHIDACEAE	38	13	ACANTHACEAE
14	TYPHACEAE	470	14	LAMIACEAE	36	14	RUTACEAE
15	LOBELIACEAE	467	15	HYACINTHACEAE	33	15	RESTIONACEAE
16	EUPHORBIACEAE	455	16	ROSACEAE	32	16	GERANIACEAE
17	RANUNCULACEAE	439	17	EUPHORBIACEAE	31	17	LAMIACEAE
18	IRIDACEAE	433	18	GENTIANACEAE	27	18	RUBIACEAE
19	LAMIACEAE	395	19	LOBELIACEAE	25	19	CRASSULACEAE
20	APOCYNACEAE	395	20	MALVACEAE	23	20	POLYGALACEAE

On the other hand, there are also some families that are very well represented in terms of number of species, but with no significant number of occurrences overall: these are for example the Iridaceae, Ericaceae, Scrophulariaceae, Aizoaceae, Orchidaceae. It is also interesting to compare the last table with number of species per family in wetlands with the same data that is available for the South African flora in general. Graminoid taxa, such as Poaceae, Cyperaceae and Restionaceae are much better represented in wetlands than they are in the overall South African flora, while other families such as Aizoaceae, Apocynaceae, Euphorbiaceae, Proteaceae and Acanthaceae are under-represented in wetlands when compared with the overall flora.

At last, there is an interest in the number of alien invasives that occur in wetlands. There were already two alien invasive species that were mentioned in Tables 4.1 and 4.2 but in Table 4.5 the ten most common alien species in South African wetlands are mentioned. We must mention here that there was, in the current study, a certain bias towards natural and pristine wetlands, as one of the goals of the project was to obtain an overview of reference community types for South African wetlands. Therefore the picture portrayed here is still quite optimistic. Aquatic invasives, such as *Azolla filiculoides*, *Pistia stratiotes* and *Eichhornia crassipes* are not very common in natural wetlands, but can be quite common in farm dams, which were not very well sampled in this project. The problem with herbaceous invasives in temporary zones seems to be much more serious in South African wetlands. Most wetland invasives in Table 4.5 are either grasses (from the genus *Paspalum*) or weedy daisies. The wetland areas that are susceptible to invasion are mostly in grassy wetland vegetation (temperate or Short Lawn Grassy Wetland Vegetation) and largely in the temporary zone, with only one species, *Paspalum distichum*, becoming dominant in seasonal to permanent zones.

Table 4.5 Ten most abundant alien invasives in South African wetlands.

	Species	Abundance in plots	Ranking in overall list	Type of habitat invaded
1	*Paspalum dilatatum* Poir.	9.1%	4	temperate and short lawn grassy wetlands, temporary to seasonal zone
2	*Verbena bonariensis* L.	4.9%	18	temperate grassy wetlands, temporary zone
3	*Cirsium vulgare* (Savi) Ten.	3.0%	46	short lawn grassy wetlands, temporary zone
4	*Conyza albida* Spreng.	2.9%	47	temperate grassy wetlands, temporary zone
5	*Paspalum distichum* L.	2.9%	50	short lawn grassy wetlands, seasonal to permanent zone
6	*Paspalum urvillei* Steud.	2.8%	52	temperate grassy wetlands, temporary zone
7	*Oenothera rosea* L'Herit. ex Aiton	2.7%	56	temperate grassy wetlands, temporary zone
8	*Conyza bonariensis* (L.) Cronquist	2.2%	72	temporary grassy wetlands, temporary zone
9	*Hypochaeris radicata* L.	2.1%	75	short lawn grassy wetlands, temporary zone
10	*Tagetes minuta* L.	2.1%	76	temporary grassy wetlands, temporary zone

Very few of the wetland plants in this table are listed nationally as declared weeds or are regarded as priorities in terms of combating alien invasives in the country. Only *Cirsium vulgare* is listed as a category 1 declared weed and *Oenothera rosea* is proposed as a category 3 invasive species (Henderson 2001). The national list of alien invasive plants set up by the Department of Agriculture contains mostly woody plants and relatively few herbaceous or ruderal species, presumably because it is assumed that these species do not affect ecosystem processes to the same extent as woody plants. However, this should maybe be reconsidered given the prominence of some of these species in wetlands, which represent an important part of South Africa's freshwater resources.

4.2 Biogeography of South African wetlands

This section will investigate generalizations regarding the biogeography of South African wetlands. Wetlands are not equally divided across the land surface of South Africa (Nel et al. 2011) and this is one of the reasons why a systematic overview of South African wetlands and their vegetation took such a long time. The questions that we will answer in this section deal with the number of plots per Province and the number of vegetation types per Province.

We will try to assess whether there is a bias towards certain areas in terms of wetland vegetation and what the current database indicates in terms of where the highest diversity lies in terms of wetland plants, or wetland community types. This is not an easy question as the sampling design of the database was not really designed to get a similar number of plots from similar areas, as firstly there are not an equal number of wetlands across the country, and secondly, the sampling protocol was geared more towards capturing diversity as well and therefore large, but relatively homogeneous wetlands, are represented by a small number of plots, whereas small wetlands with strong environmental gradients can be represented by many plots. Then at last, there is also a bias in terms of historical studies, because the first part of the database was based on historical studies that mostly focused on just a single wetland, that can however have hundreds of plots. The later fieldwork in the course of this project was more geared towards covering large areas so no extensive attention has been paid to single wetlands that may be very interesting for a detailed study.

Table 4.6 Number of vegetation plots made per Province split up according to the source of the data.

	Historical data (up to 2005)	Recent studies	Current study	Total
Western Cape	267	418	305	**990**
Eastern Cape	139	-	487	**626**
KwaZulu-Natal	1646	59	125	**1830**
Mpumalanga	177	-	276	**453**
Free State	388	278	53	**719**
(Lesotho)	28	-	-	**28**
Gauteng	48	-	57	**105**
Limpopo	17	-	258	**275**
Northwest	225	-	122	**347**
Northern Cape	16	-	181	**197**
Grand Total	**2951**	**755**	**1864**	**5570**

An overview of the source of data for all Provinces is given in Table 4.6. Historical data in the first column represents data directly from literature, while the second column represents several recent large studies that contributed to the database in terms of sampling protocol. The third column represents fieldwork carried out in the current study as part of the process of 'filling the gaps' while the last column (bold) sums it up for all Provinces. If we look at Table 4.6 we can see that there is indeed a slight bias in the database, mainly because of the historical studies, that were mostly carried out in areas known to be rich in wetlands and in close proximity to the universities and large cities. This resulted particularly in a very large number of plots in KwaZulu-Natal where both the Drakensberg and Maputaland have received a lot of attention. This bias should be considered real as many wetland studies, for example on Swamp Forest, resulted in only seven clusters of Swamp Forest and some data in the database had to be abandoned because of incompleteness of the data or an unsuitable plot size. KwaZulu-Natal is certainly a very diverse Province in terms of wetlands, contains many wetlands as it has a moist climate, but the density of data here is certainly more than in the other Provinces. It could be considered to actually visit some of the old sites again with a proper sampling protocol, so that a better comparison with more modern data can be carried out. In terms of soil samples, KwaZulu-Natal is actually a bit underrepresented, as the historical data generally did not have detailed soil data analyses and could therefore not be used in ordinations.

Except for a very high number of plots in KwaZulu-Natal we can also see other differences in terms of number of plots per Province. For example, Gauteng has a low number of plots, but this is also a small Province with wetlands that are very similar to other places in the Highveld, so a small number of plots can be justified. Similarly, the Northern Cape has a low number of wetland plots, but this is because there are not many wetlands in the Province and many of the large wetlands in the Province are very homogeneous over large stretches of area.

In the end, it is also the diversity of wetlands that matters when the number of plots in a Province needs justification. Table 4.8 shows the number of communities that were recorded in each Province. It shows that the coastal Provinces of the Western Cape, Eastern Cape and KwaZulu-Natal are the richest in wetland vegetation types. These are indeed the 'wettest' Provinces with high rainfall and extensive wetland areas. The Western Cape will probably still have a higher number of communities as the Cape Fold mountains have largely been ignored in gathering data here. What we can also see here is that each of the Main Clusters has its own 'centers' of diversity, with Sclerophyllous Wetland Vegetation and Estuarine, Brackish and Saline Wetland Vegetation centered in the Western Cape, Swamp Forests and Subtropical wetlands centered in KwaZulu-Natal, Montane Grassy Wetland Vegetation centered in the Eastern Cape, Temperate Grassy Wetland Vegetation centered in the whole grassland region (KwaZulu-Natal, Mpumalanga, Free State and North-West), Short Lawn Grassy Wetland Vegetation centered on the edges of the dry regions in the Western Cape, Northern Cape, Free State and North-West, and Hydrophytic Vegetation centered in the Western Cape, the only area that has hydrophytic plant species endemic to it.

Table 4.7 Number of communities per Province in each of the Main Clusters of Chapter 3. The number in brackets represents under-sampled communities that are not yet well represented in the current database. The bold number in the first column represents the total number of communities.

		Main Cluster 1: Fynbos wetlands	Main Cluster 2: Swamp Forest	Main cluster 3: Subtropical wetlands	Main cluster 4: Saline and estuarine wetlands	Main Cluster 5: Montane grassy wetlands	Main Cluster 6: Temperate grassy wetlands	Main Cluster 7: Short lawn grassy wetlands	Main Cluster 8: Submerged vegetation
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Western Cape	**118**	27 (+3)	-	10 (+1)	23 (+1)	4	10 (+3)	24 (+1)	10 (+1)
Eastern Cape	**124**	13	1	14 (+1)	12 (+1)	29	19 (+4)	20 (+1)	8 (+1)
KwaZulu-Natal	**125**	1	7	41 (+1)	8	20	23 (+3)	13 (+1)	5 (+2)
Mpumalanga	**72**	2	-	17 (+1)	1	13	21 (+3)	9	5
Free State	**82**	-	-	3	9	12	19 (+4)	29 (+1)	3 (+2)
Gauteng	**27**	1	-	2	-	1	14 (+2)	5	2
Limpopo	**48**	4	-	17 (+1)	2 (+1)	1	12	7 (+1)	2
Northwest	**62**	-	-	6 (+1)	3 (+1)	1	19 (+3)	21	3 (+3)
Northern Cape	**56**	5	-	3	9	2	9 (+1)	24	3

The concentration of wetland vegetation types in certain areas can be defined in better terms than just by the provincial boundaries. A number of 'hotspots' in terms of wetland community and species diversity can be recognized and these centers of diversity could be investigated in more depth in order to understand the exact drivers of diversity in these areas. In some cases, regions with a complex hydrology create many different niches within a single wetland system and it can be asked whether places like this are important drivers of wetland plant evolution. An estimate of seven such areas can be identified in South Africa, and these areas are indicated in Figure 4.2. A short description follows:

1. **Western Cape:** This area is the heart of the Fynbos Biome and many of the wetland plants that are present in this area have been derived from several groups of typical fynbos plants, particularly in Restionaceae, Ericaceae and Iridaceae. The wetlands from Main Cluster 1 are for a large part confined to here, but there is also a large group of communities from Main Cluster 4 and 7 here. The lowlands of the Western Cape are not vegetated by Fynbos as they are generally much more rich in nutrients, but they are either very saline (such in the Overberg region) or very prone to disturbance (due to high water level fluctuations). Communities of this last type are renosterveld wetlands that are mostly part of Main Cluster 7. This area is much more rich in wetlands than has been revealed up to now, as most montane wetlands have yet to be explored and several of the wetlands dominated by bulbous species are very rare and have not been recorded very often yet.

	Region of endemism	Number of communities	Number of endemic communities
1	Western Cape	79	24
2	Southern Cape / Port Elizabeth	46	2
3	Pondoland/ KZN Coast	19	2
4	Maputaland	61	27
5	Drakensberg	45	7
6	Panveld / Ghaap Plateau	43	6
7	Namaqualand	8	2

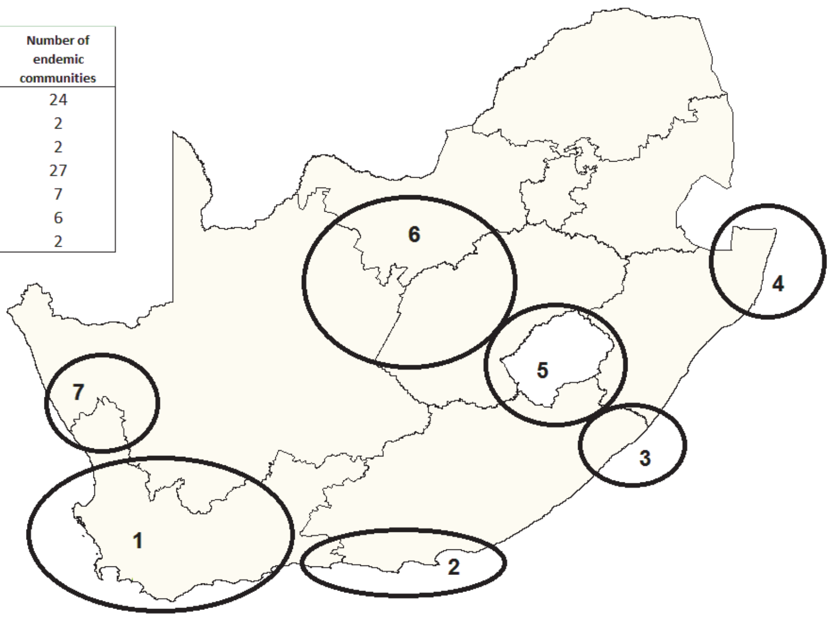


Figure 4.2 Map indicating areas with a high diversity of wetland vegetation types.

2. **Southern Cape / Port Elizabeth:** This area is very rich as there are many different terrestrial biomes converge here and there are strong environmental gradients. Sclerophyllous Wetland Vegetation have a local center of diversity here in the Tsitsikamma region which is very rich in wetlands and many Sclerophyllous Wetland Vegetation are found here, particularly those dominated by various species of Cliffortia. Around Port Elizabeth there is a high diversity, between dune pans, saline wetlands and the pans in the succulent thicket which are mostly dominated by *Schoenoplectus decipiens*, but with some local variations. An example of a wetland type not yet in the database here are those dominated by the bulbous species *Crinum campanulatum*.

3. **Pondoland / Southern KwaZulu-Natal:** This area is not very rich in wetlands, but the ones that are there are quite special. The southernmost Swamp Forest (which is different in composition to more northern types) meets the Northernmost Palmiet wetlands here (which are also quite different to the more southern types). The special wetlands here are mostly found on the Msikaba Group Sandstone, but the Cyperus latifolius wetlands from Southern KwaZulu-Natal are also quite distinct.
4. **Maputaland:** This seems to be one of the richest areas of wetlands in the country, not only in terms of the various types, but also in terms of sheer extent, and it has been one of the first areas where research on wetland vegetation types took place. The area is particularly rich in subtropical wetlands of Main Cluster 3, but mostly from a distinct group that is mostly restricted to very nutrient-poor soils and that are dominated by sedges of the genera *Rhynchospora* and *Scleria*. Swamp Forest is also particularly diverse here and all types can be found here. It is not yet clear how many of the wetland communities in this region are actually common in Mozambique, and some tropical wetland types, like Papyrus swamps, are occurring from here further northwards but then this is the only place where they are found within South Africa.
5. **Maloti-Drakensberg:** This area is rich in wetlands as it is the upper parts of the catchment of the major rivers, such as the Tugela, Vaal and Orange Rivers. There are also steep rainfall gradients and a high variety of montane wetlands is found here, particularly in the Eastern Cape part of this area. They are different from most other wetlands in the country as they are dominated by C_3 grasses and rosette-forming daisies.
6. **Panveld / Ghaap Plateau:** The lower reaches of the Vaal River are rich in wetlands which are concentrated in clusters for example in the Panveld near Wesselsbron. The wetlands here are mostly from Main Cluster 7 and dominated by short grasses, mostly from the genus *Sporobolus*. The Ghaap Plateau contains very special wetlands that show some similarities with the montane wetlands from the Drakensberg, for example being dominated by the Red hot pokers, *Kniphofia ensifolia*, as well as wetlands from drier areas, dominated by *Cynodon polevansii*. This area still deserves more attention in the future.
7. **Namaqualand:** This area is poor in wetlands, but those that are there are unique. They have mostly shared with types of wetlands that are found in the Fynbos Biome, for example being dominated by *Pennisetum macrourum*, but there are various wetlands here dominated by various species of Oxalis, which certainly deserve more attention.

- Some additional areas could also contain rare wetland types limited in their extent in South Africa, but are mostly located near border areas, such as the Limpopo lowveld (no unique community types, but a number of special species, various *Fuirena, Schoenoplectus, Eleocharis, Cyperus*), and the Kalahari region near Namibia (one endemic community dominated by *Salsola barbata*). Just as in the case of Maputaland, it is not clear how extensive these communities would be across the border. More research needs to be carried out in these areas as well, because wetlands are not very common here.

Another aspect of biogeography of wetland vegetation in South Africa is the local species richness in a particular community. Species richness is a characteristic for different vegetation types and in the case of wetlands, much of the vegetation dynamics is driven by the fact that the plants are clonal species that can very effectively colonize an area and keep other species out. The mix of species in the matrix is very different for different community types. In other cases, the environment is too extreme and only a limited number of species are adapted to it.

Table 4.8 Some of the most species-poor wetland communities and their median species number.

Hydrophytic communities		**Median species number**
V8.7	*Chara globularis* comm.	1
V8.16	*Stuckenia pectinata* comm.	1.5
V8.1	*Ceratophyllum demersum* comm.	2.5
V8.13	*Potamogeton pusillus* comm.	2.5
V8.2	*Azolla filiculoides - Lemna minor* comm.	3
V8.20	*Potamogeton nodosus* comm.	3
Salt pans		
V4.15	*Salsola glabrescens* comm.	1
V4.35	Unvegetated pan	1
V4.10	*Sporobolus albicans* comm.	2
V4.9	*Salsola barbata* comm.	2
V7.16	*Schoenoplectus triqueter* comm.	2.5
V4.34	*Chenopodium glaucum-Sporobolus albicans* comm.	3
V7.36	*Eragrostis bicolor* comm.	3
V7.52	*Leptochloa fusca* comm.	3
Estuarine communities		
V4.18	*Schoenoplectus scirpoides* comm.	2
V7.23	*Paspalum vaginatum* comm.	2
V4.22	*Isolepis rubicunda* comm.	3
V4.24	*Bolboschoenus maritimus* comm.	3
V4.6	*Sarcocornia natalensis* comm.	3
Other communities		
V3.5	*Sporobolus consimilis* comm.	2.5
V3.12	*Oryza longistaminata* comm.	3
V3.14	*Cyperus textilis* comm.	3
V8.18	*Limosella grandiflora* comm.	3
V8.19	*Limosella maior - Limosella grandiflora* comm.	3

Table 4.8 shows some communities that have an extremely low median species number (lower than 3), which are mostly extreme environments, such as salt pans, estuaries or submerged communities. The most species-rich communities are listed in Table 4.9 and these occur mostly in the montane areas of the Drakensberg, the KwaZulu-Natal Coast, the

mistbelts of the midlands, and the renosterveld areas of the Western Cape. In some cases, a high number appears for the median species number but samples were actually taken in a 10 x 10 meter plot, so they can actually not be compared with other plant communities, this is the case for example with Swamp Forest types and some fynbos communities.

Table 4.9 The most species-rich communities and their median species number.

Montane communities		**Median species number**
V5.2	*Agrostis bergiana-Carpha filifolia* comm.	21
V5.5	*Rhodohypoxis rubella - Athrixia fontana* comm.	15.5
V5.15	*Limosella maior* comm.	16
Renosterveld communities		
V7.22	*Ficinia indica - Trianoptiles capensis* comm.	18
V7.17	*Lolium perenne - Ehrharta calycina* comm.	15
V4.4	*Limonium kraussianum - Lolium perenne* comm.	14
Mistbelt communities		
V5.28	*Pycreus macranthus - Ledebouria cooperi* comm.	17.5
V5.27	*Aristida junciformis - Tristachya leucothrix* comm.	14
Subtropical communities		
V3.35	*Smilax anceps - Conostomium natalense* comm.	17
V3.33	*Scleria angusta - Abildgaardia hygrophila* comm.	16
V3.8	*Eleocharis caduca - Lactuca indica* comm.	15
V3.3	*Axonopus affinis - Centella asiatica* comm.	15
V6.22	*Miscanthus junceus - Kyllinga alba* comm.	14
Plots from historical studies mostly studied in 10 x 10 m (Artefact)		
V4.13	*Trachyandra oligotricha - Sporobolus virginicus* comm.	17
V1.27	*Elegia mucronata - Restio subtilis* comm.	15.5
V7.34	*Ficus sycomorus - Eriochloa meyeriana* comm.	15
V2.4	*Voacanga thouarsii - Macaranga capensis* comm.	14
V2.7	*Ficus trichopoda - Psychotria capensis* comm.	14
V2.2	*Voacanga thouarsii - Bridelia micrantha* comm.	14
V6.20	*Imperata cylindrica - Fimbristylis ferruginea* comm.	14
V6.21	*Miscanthus junceus - Paspalum urvillei* comm.	14

4.3 Vegetation structure and functional composition

Instead of looking at the exact species identity within wetland plant communities, we can also focus on plant functional types, which represent a summary of plant diversity into functional groups. In such classifications, it is assumed that the exact species identity is not as important in terms of the niche it occupies in the ecosystem, as would be the evolutionary adaptations in terms of form and function, which are often shared by different species of entirely different taxonomic groups. Examples of functional groups are ‘graminoids’, for grass-like plants, ‘succulents’ for plants storing water in their leaves or other tissues, ‘trees’ or ‘annuals’. Functional classifications of wetland plants can be based on many different characters of these plants and are mostly based on a systematic measurement of traits (Boutin & Keddy 1992; Sieben 2012). In the case of the current vegetation database, detailed measurements of traits are largely absent and a tentative classification of wetland plants can only be based on a coarse classification in terms of plant form, such as grasses, forbs and shrubs. The advantage of such classification is that it will largely reflect what a wetland 'looks like' in terms of a lay person observing it and thereby also help in describing the vegetation structure. The composition of a wetland in terms of the functional types (10 classes were tentatively defined) is combined with the vegetation structure (cover and height of the various strata) and species diversity in order to classify all wetland vegetation types of the country into a more 'simplified' classification. Then also an ordination was carried out in order to try to find the drivers that determine the abundance of these functional groups.

In order to classify the vegetation structure, fractions of each functional group were calculated as a part of the total biomass/cover (an estimate was obtained by adding all cover values in the vegetation plot). If the total biomass/cover value was less than 100% then the value for each functional group was indicated as part of 100%, but when the total biomass/cover value was higher than 100%, then the value was indicated as a fraction of the whole biomass/cover value, so it was divided by this overall value.This means that 'vacant space' in the vegetation plot was accounted for in the assessment of functional composition. The different functional groups are indicated in **Table 4.10**. The height of the tree layer, shrub layer and herb layer was subdivided into different classes as well, as indicated in **Table 4.11.**

Species diversity was log-transformed before the entire dataset (about 5000 plots, as in some historical data, vegetation structure was not properly recorded) was subjected to a hierarchical cluster analysis with Euclidean distance as a distance measure and Ward's method as a linkage method.

The resulting classification is shown in Table 4.12 together with an explanation. The functional classes are discussed shortly and their distribution ranges in the country are shown. This classification is very coarse and many subcategories are not very well represented, such as the structural types with a dominance of dwarf shrubs (in Fynbos) or communities dominated by bulbous species (there's not many, but there are a few). Another problem is the category 'Other graminoids', which is a very artificial category, as it implies both Rushes (Juncaceae), Bullrushes (Typhaceae), Restio's (Restionaceae) and yellow-eyed grasses (Xyridaceae) which are functionally very different families.

Table 4.10 Functional groups of plants occurring in South African wetlands. This is a tentative classification and could still be supplemented by a more detailed classification based on measured traits.

No.	Functional group	Explanation
1	Grasses	All species from family Poaceae
2	Sedges	All species from family Cyperaceae
3	Other graminoids	Other families from Poales, for example Restionaciaae, Juncaceae, Thurniaceae, Typhaceae, Xyridaceae, Eriocaulaceae
4	Bulbs	All other (non-woody and non-aquatic) Monocots, especially Asparagales and Liliales, mostly bulbous species
5	Forbs	All Dicotyledonous plants that are not woody or succulent, except at the base

No.	Functional group	Explanation
6	Dwarf shrubs	Low woody shrubs, especially Ericaceae, Fabaceae, Rosaceae, not growing taller than 1.5 meter.
7	Woody plants	All tall woody plants that grow higher than 1.5 meter
8	Succulent shrubs	Succulent shrubs, mostly halophytes, especially from families Chenopodiaceae and Aizoaceae
9	Aquatics	Monocotyledonous and dicotyledonous plants growing submerged in or floating on the water column, for example Hydrocharitaceae, Potamogetonaceae and Araceae, also including stoneworts
10	Mosses	All mosses and liverworts, usually species not recorded.

In the end however, we should not forget this is only a preliminary search for patterns in the functional ecology of wetlands; in the long term, functional classifications will need to be made on the basis of the measurement of functional traits, so that a more fine-grained as well as a more scientifically justifiable functional classification can be made.

Table 4.11 Height classes of strata to describe vegetation structure

Height class		
Tree layer		
6-15 m	1	Low
15-30 m	2	Medium
Shrub layer		
1.5-2.5 m	1	Low
2.5-6 m	2	High
Herb layer		
0-1 cm	1	Short moss layer / submerged
2-5 cm	2	Tall moss layer
5-10 cm	3	Very short
10-25 cm	4	Short
25-50 cm	5	Medium short
50-100 cm	6	Medium
100-150 cm	7	Tall
150-400 cm	8	Very tall

Table 4.12 Structural classification of South African wetland vegetation, based on the vegetation cover, the main functional groups, the vegetation height, and the species diversity.

Structural type	Name	Main functional groups	Openness	Height	Diversity
1	Mixed closed medium grasslands	Grasses + herbs	50-100%	50-100 cm	±10
2	Mixed closed medium short grasslands	Grasses + herbs	70-100%	25-50 cm	10 to 30
3	Poor mixed closed medium short grasslands	Grasses + herbs	70-100%	25-50 cm	2 to 10
4	Poor mixed closed very short grasslands	Grasses + herbs	50-100%	5-10 cm	2 to 10
5	Mixed closed tall grasslands	Grasses + herbs	50-100%	100-150 cm	±10
6	Mixed closed short grasslands	Grasses, sedges, herbs	50-100%	10-25 cm	±10
7	Monodominant closed medium grasslands	Grasses + sedges	50-100%	50-100 cm	1 to 5
8	Monodominant closed short grasslands	Grasses	50-100%	10-25 cm	1 to 5
9	Monodominant open very short grasslands	Grasses	10-25%	5- 10 cm	1 to 5
10	Monodominant closed medium short grasslands	Grasses	90-100%	25-50 cm	1 to 5
11	Poor closed very tall grasslands	Grasses	70-100%	150-300 cm	2 to 10
12	Moderately rich closed very short grasslands	Grasses	50-100%	2-5 cm	2 to 15
13	Poor closed medium sedgelands	Sedges	90-100%	50-100 cm	2 to 10
14	Moderately rich closed medium short sedgelands	Sedges	80-100%	25-50 cm	5 to 10
15	Rich closed medium short sedgelands	Sedges	80-100%	25-50 cm	8 to 30
16	Poor closed tall sedgelands	Sedges	70-100%	100-150 cm	1 to 10
17	Moderately rich closed short sedgelands	Sedges	60-100%	10-25 cm	5 to 10
18	Poor closed medium short sedgelands	Sedges	90-100%	25-50 cm	1 to 5
19	Moderately rich closed medium rushlands	Graminoids	60-100%	50-100 cm	±10
20	Poor closed tall rushlands	Graminoids	70-100%	100-150 cm	1 to 10
21	Poor closed very tall rushlands	Graminoids	70-100%	150-300 cm	2 to 10
22	Rich closed medium short rushlands	Graminoids	90-100%	25-50 cm	5 to 20
23	Poor closed medium short rushlands	Graminoids	90-100%	25-50 cm	1 to 5
24	Rich medium short mixed shrublands	Graminoids + Shrubs	70-100%	25-50 cm / 2m	10 to 20
25	Rich medium mixed shrublands	Graminoids + Shrubs	70-100%	50-100 cm / 2m	10 to 20
26	Moderately rich closed medium herblands	Herbs	70-100%	50-100 cm	±10
27	Moderately rich closed medium short herblands	Herbs	70-100%	25-50 cm	2 to 20
28	Moderately rich closed short succulent shrublands	Succulent shrubs	50-100%	10-25 cm	±10
29	Poor open medium short succulent shrublands	Succulent shrubs	10-80%	25-50 cm	2 to 10
30	Rich closed medium short parklands	Woodys + Grasses	90-100%	25-50 cm / 10 m	5 to 20
31	Rich open medium short parklands	Grasses + Trees	25-50%	25-50 cm / 10 m	5 to 15
32	Rich closed medium parklands	Grasses, shrubs + Trees	70%	50-100 cm / 15 m	±10
33	Rich closed forest	Trees + forbs	50-100%	50 cm / 15 m	10 to 30
34	Poor closed emergent aquatic vegetation	Aquatics	90-100%	25-50 cm	1 to 5
35	Poor closed submerged aquatic vegetation	Aquatics	50-100%	1 cm	1 to 5

In Table 4.13 it can be seen how the structural classification fits in with the classification based on floristics that was discussed in Chapter 3. There is certainly not a one-on-one match between communities that are recognized on the basis of floristics and the structural classification as there is a lot of variation within each community in terms of structure, for example in the form of different successional stages, fire and disturbance, or adverse environmental conditions that result in a stunted growth form. In the table, the most 'typical' form of each community is indicated, but it is certainly possible that shorter or more open forms of a certain vegetation type are found.

It is clear that each of the Main Clusters are particularly well represented among specific structural types: the Sclerophyllous Wetland Vegetation are mostly shrublands and 'rushlands' (dominated by restios), the Swamp Forest is mostly forest, Saline Wetland

Vegetation is represented mostly by succulent shrublands, and the Hydrophytic Vegetation is mostly dominated by various types of aquatic plants. Among the grasslands and sedgelands it is conspicuous that the subtropical wetlands contain much more types of sedgelands than the montane and temperate wetlands. Lastly between Main Clusters 5, 6 and 7 there is a differentiation in the typical height of vegetation, with the Temperate Grassy Wetland Vegetation of Main Cluster 6 containing more of the tall grasses while both the Montane Grassy Wetland Vegetation and Short Lawn Grassy Wetland Vegetation containing more short vegetation.

Table 4.13 Plant communities discussed in chapter 3 and the structural types that they fall under. The numbers refer to the community numbers as were used in the discussion of the communities. The cells that are boxed represent structural types that are particularly common within that Main Cluster.

		Fynbos wetlands	Swamp Forest	Subtropical wetlands	Saline and estuarine wetlands	Montane grassy wetlands	Temperate grassy wetlands	Short lawn grassy wetlands	Submerged vegetation
	Structural type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Mixed closed medium grasslands			16, 28, 29, 32, 33		8, 13, 21, 26, 27, 30	4, 5, 17		
2	Mixed closed medium short grasslands	19				4		17, 50	
3	Poor mixed closed medium short grasslands			10, 36, 47		2,		13, 14, 15, 36, 37, 38, 47, 48, 49, 53, 54	
4	Poor mixed closed very short grasslands			4		5, 7, 9, 12, 17, 18, 19, 23		45	6
5	Mixed closed tall grasslands	3		41, 42			20, 21, 22		
6	Mixed closed short grasslands			3	4, 5, 13	32	14, 15, 16	2, 6, 26, 27, 28	
7	Monodominant closed medium grasslands	23		12, 15		1, 6, 25	6, 7, 11, 12, 19		
8	Monodominant closed short grasslands				23			12, 30, 51	12
9	Monodominant open very short grasslands							24, 44,	
10	Monodominant closed medium short grasslands				10, 11		23	23, 31, 52	11
11	Poor closed very tall grasslands			5, 30, 31	1		25		
12	Moderately rich closed very short grasslands							3, 25	
13	Poor closed medium sedgelands	13, 24		17, 23, 24, 43	24	10, 20	1, 3	40, 43	
14	Moderately rich closed medium short sedgelands	4, 9		7, 9, 18, 19, 45, 46, 48, 49		3		1, 7	
15	Rich closed medium short sedgelands			8, 11, 34, 35		14, 16, 28, 29	10	22	
16	Poor closed tall sedgelands	6		14, 20, 25, 26, 37, 38, 39, 40	18		8, 18	16	
17	Moderately rich closed short sedgelands			21	17			19, 20	
18	Poor closed medium short sedgelands			44	16, 22				
19	Moderately rich closed medium rushlands				33		9	39	
20	Poor closed tall rushlands	1, 8, 14, 22, 25			12	22, 31			
21	Poor closed very tall rushlands			6			24		
22	Rich closed medium short rushlands	10, 11, 12		2	21			21	
23	Poor closed medium short rushlands				20				
24	Rich medium short mixed shrublands	15, 26						11, 41, 42,	
25	Rich medium mixed shrublands	2,5,7, 16, 17, 18, 21, 27	1		8			32	
26	Moderately rich closed medium herblands	20		22		11, 24		8, 46	
27	Moderately rich closed medium short herblands			27				5, 9, 10, 29	
28	Moderately rich closed short succulent shrublands				6, 26, 27, 28, 29, 30, 31				
29	Poor open medium short succulent shrublands				2, 9, 14, 15, 25, 32 34, 35				
30	Rich closed medium short parklands			13			13		
31	Rich open medium short parklands							33, 35	
32	Rich closed medium parklands		6						
33	Rich closed forest		2,3,4,5,7					34	
34	Poor closed emergent aquatic vegetation								3,9
35	Poor closed submerged aquatic vegetation								1,5,7,10, 20
		11	3	18	15	11	12	21	5

In order to understand the prevalence of certain functional types in wetland vegetation plots, a Canonical Correspondence Analysis was carried out on the entire dataset with the environmental variables as explanatory variables and the prevalence of functional groups as a response variable. Two more response variables were included, namely species number, and the proportion of alien species in each plot. This ordination, applied to the portion of the whole dataset that has soil variables available (1053 plots) is shown in **Figure 4.3.**

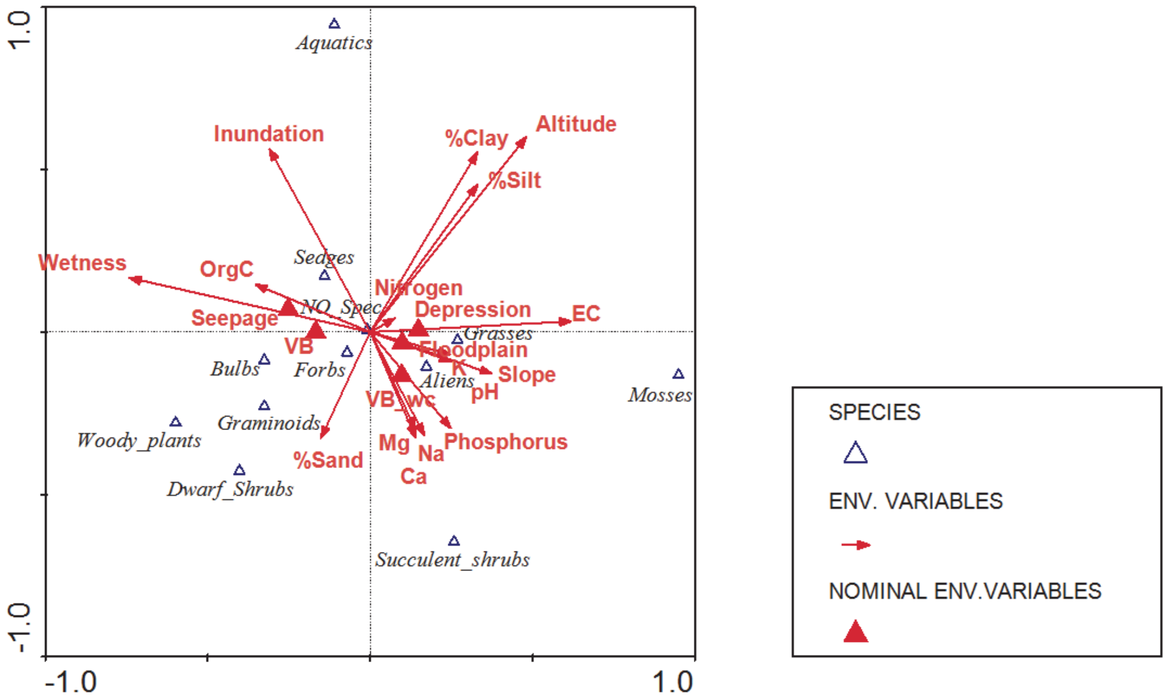


Figure 4.3 CCA ordination diagram explaining the occurrence of the various functional types (Table 4.1), as well as the fraction of alien species and overall species diversity in terms of soil and environmental variables for the entire dataset (1053 plots where soil variables were available).

The first axis of this ordination is associated most strongly with the variables EC (Electrical Conductivity, positively) and Wetness (negatively). The second axis is positively associated with both Inundation and Altitude, although both these variables also have correlations with the first axis. Interestingly, percentages clay and silt point in the same direction as altitude, while percentage sand points in the opposite direction. This is counterintuitive as along a rivercourse, the finer sediment is washed out in the higher reaches and deposited in the lower reaches. However, if we take the pans into consideration, most of them in the Highveld are sinks for clay sediments and most of them in coastal flats such as in the Cape or in Maputaland are underlain by sand. Most of the major cations are negatively associated with the second axis. It is clear that not all patterns will reveal themselves clearly in such a large ordination. For example, the variable species number is indicated in the middle of the diagram, but this does not mean that there are no meaningful trends in species number across the environmental gradients in wetlands. It is however possible, that positive effects on species number can be in any direction and that it ‘averages out’ to produce a point in the middle. Another seeming contradiction in the diagram is that the arrow for slope points in the opposite direction as where the nominal variable ‘Seepage’ is shown. This is probably the result of a bias in the places where soil samples were taken. Not surprisingly, the highest proportion of aquatics is found under conditions of high inundation and the highest proportion of succulent shrubs is found under conditions with high concentrations of cations. The proportion of sedges tends to be highest in those places where wetness and inundation are high and the proportion of grasses is higher where Electrical Conductivity and the concentrations of cations is highest. These last conditions are also the conditions where a higher proportion of aliens are to be expected. These habitats coincide with the drier and more temporary parts of wetlands that can be regarded as ‘disturbance-prone’ habitats. The proportion of graminoids and dwarf shrubs is highest in those parts of the ordination diagram where the soils are most sandy and this is probably an effect of substrates found on sandstone-derived soils where many Erica’s, Brunia’s and Restio’s are present. Woody plants are most prominent in those areas with a high proportion of sand and a high wetness; that last condition, especially, describes the conditions in which Swamp Forest is found.

5 CONCLUSIONS

The collation and comparison of data from large areas and widely differing plant communities is certainly useful as it reveals patterns that would not become evident from small-scale studies. In that regard, the present database forms a very useful tool in the management and planning around wetlands and other freshwater resources in the country. It is however also clear that the most useful data in the present study is made by the recent round of data collection where the environmental data was recorded in a standardized form and where many plots included soil variables. Data that was 'coincidentally' collected in historical studies for an entirely different purpose often needed to be left out in the analysis and regularly blurred the picture, for example because it was collected with a different plot size. Therefore, the current database should be regarded only as a starting point, and there are new gaps to be filled. Even so, this is the first time an attempt was made at collating all South African wetland vegetation and it is therefore a major step forward.

In the current study, 244 plant communities have been described and there are certainly hints that more plant communities could be recognized if more data were to be collected, mostly because of the occurrence of several 'under-sampled' communities as they were referred to in the current study. The problem with sampling rare communities is that one only stumbles upon them once in a while and in the case of wetlands often quite unpredictably so. A point in case is the community dominated by *Bolboschoenus glaucus*, which was recorded only two times, one time in the Kruger Park, and one time near Vrijburg in North-West Province. It is certain that there will be many places in between those localities where the same community can be found, but if one would want to do a directed search for this community, it is difficult to predict where it could be expected. Today ecologists can make use of sophisticated statistical tools such as Maximum Entropy modelling in order to predict the occurrence of a species or a community, based on a limited amount of existing information, but if one would want to apply this, the amount of data that is required should be more than just two plots. The problem is that many wetland plants occur with quite an erratic distribution as they are dispersed by birds. In some cases, a rare species, that is however clonal, may disperse to a suitable wetland, become monodominant due to clonal growth and that means a new community.

Hubbell (2000) speculated that species abundance distributions are a 'fractal' phenomenon, which means that the tail of the species abundance curve representing the rarest species is 'infinitely' long. In other words, more intensive sampling will always lead to the discovery of new species or in our case, new plant communities. However, it is not only the rare communities that should be of concern to ecologists, but particularly also the common communities, as they could also become rarer in the face of environmental and land use changes. Therefore as the database gets more populated, it is particularly important to get an understanding of the differentiation between the optimal conditions for different species and to determine their species response curves. In that way, community shifts can be interpreted when they are observed and the link with the underlying environmental changes can be made, which in turn informs management.

The database, as it is presented in the current report, shows clearly that it is possible to use wetland plants as indicators for environmental conditions and many correlations between the presence of plant species and environmental conditions have been found. In nature, there is an interplay between stochastic (random) and deterministic processes (Shipley 2010) so different plant communities could have arisen in the same locality, but in most cases, the presence and abundance of certain species can be linked to specific environmental conditions.

Except for more community composition data, there are also more explanatory variables that should be considered for inclusion in the database in order to obtain a better interpretation of the differences between different communities. An obvious gap in the current analysis is the lack of climatic data, but this can easily be obtained from climate records when the geographical coordinates are known. The wetland conditions that plants respond to are mostly driven by local hydrological processes but climatic processes such as precipitation and evaporation have indirectly also an important impact on local conditions. This impact will however be stronger in the temporarily wet sections of the wetland than in the permanently wet parts of the wetland.

Another gap in the explanatory variables that were used in this study is represented by the hydrological parameters. It is clear that the variable wetness is an important variable in differentiating between different wetland habitats, but unfortunately this variable is actually a coarse assessment based on soil hydromorphic features and not an exact measurement. More accurate measurements of hydrology, such as soil moisture content, or the fraction of time that an area is inundated, are difficult and expensive to obtain and therefore not recommended for a large-scale screening programme such as the current project. Also, there are various aspects of hydrology that have not been captured and that could possibly explain more variation in the canonical ordinations, for example the range of watertable fluctuation or the season in which the watertable is at its highest peak. However, it is very well possible to make more detailed measurements like these in specific wetland study sites and to use these specific study sites to predict what will be happening in comparable sites. In many cases, it has also been possible to use the redox potential of a soil as a measure of wetness, which may represent a cheaper alternative (Schlesinger & Bernhardt 2013).

Another variable that has been recorded during this study but that has not been optimally used is the time aspect. The vegetation in South Africa has changed drastically in the last century and wetlands are undoubtedly very different today than what they looked like historically. However, the oldest data in our database at present is from the early seventies and this is only available in a few very specific locations. The number of variables that were recorded in those wetlands was quite limited and generally the scale of plots was also very large compared with the plot sizes used today. It is therefore unlikely that time trends in wetland vegetation will be detected in the current database and the current database should rather be seen as a baseline study for the wetlands in South Africa for the beginning of the 21st century. Unfortunately we will never know exactly what wetlands historically looked like, except that the number of alien species was much smaller in the past. By comparing physical environmental variables between invaded and uninvaded wetlands it can however, in most cases, be established what a reference type of a certain type of invaded wetland would have looked like.

One aspect that can be investigated more closely about the wetland plant communities is the ‘zonality’ of these vegetation types. Rutherford & Mucina (2006) referred to wetlands as ‘azonal vegetation types’, which means that they are more determined by edaphic (local environmental) factors than by climatic variables. On the other hand, Nel et al. (2011) used the zonal vegetation in which the wetlands were embedded as a coarse estimate of a wetlands’ conservation value in classification, which suggests that they assumed (because of a lack of data) that wetland vegetation is correlated to vegetation occurring in the uplands. This actually contradicts the view of wetlands as ‘azonal vegetation’, but we can regard ‘zonality’ as a continuum, in which the wettest habitats of Hydrophytic Vegetation represent the most ‘azonal’ aspect of the vegetation and the temporarily wet habitats are more similar to the upland ‘zonal’ vegetation. It still needs to be investigated more closely whether the assumption that wetland vegetation is closely linked to the vegetation growing in the uplands holds true, and this may vary between many different wetland types. In the Western Cape, Corry (2011) already challenged the view of wetlands as ‘azonal’ and maintained that regional diversity has a huge impact on the composition of wetland plant communities, but this may differ between regions and between wetland types.

6 RECOMMENDATIONS

It is important that the efforts around the wetland vegetation database are continued, and that it is maintained and supplemented by a public institution with a mandate of maintaining information on biodiversity. Discussions need to be held with various of such institutions that are in existence in South Africa, such as SANBI or SAEON, for the housing of the database. However, just as a herbarium with plant species needs to be curated, similarly also a vegetation database needs maintenance and updating, especially if it grows and if there are taxonomic changes in the constituent species. At present, a National Wetland Map (AWL or Advanced Wetland Layer) is maintained at SANBI, and a wetland vegetation database can be linked to such a map, but in our view, a wetland vegetation database should rather be maintained within the framework of a general vegetation map or general vegetation database.

Except for the extension of data from more localities, it is also recommended to acquire different kinds of data that, in combination with the database, can lead to new insights that are beneficial for wetland management. Examples were already mentioned in the previous chapter and include acquiring additional environmental data such as climatic data or detailed hydrological data. Another field of enquiry should be towards the functional traits of wetland plants, which refers to the morphological and physiological traits that make species adapted to a specific environment. Data on functional traits can be used in making predictions on community assembly (Weiher & Keddy 1999; Shipley 2010) and may have an indicator value by themselves, since functional traits represent adaptations to specific stressors. A comprehensive database on functional plant traits combined with compositional data for wetlands across the country will represent the first steps towards predictive modelling of wetland vegetation in South Africa.

If we can confidently link species occurrences to environmental conditions then it is also possible to monitor wetlands by means of satellite imagery. The advantage of vegetation as a biological indicator is that it can be observed from space and different vegetation types will have different emission spectra and texture on satellite images. Several indices, based on the spectral signature of vegetation, can be used to detect vegetation changes on large scales by means of satellite imagery. The most well-known of these is the Leaf Area Index, which measures the abundance of chlorophyll and is an important indicator for the productivity of an environment. It can be explored to what extent spectral properties of different wetland species can be used to differentiate the community types in which they are dominant at the landscape level. This is probably not an easy matter, as there are many different factors that have an influence on the spectral signature, for example the nutrient contents of a plant, its health, or the time of the year. Additionally, many communities consist of a mixture of different species and there is also the water surface which blurs the overall spectral signature further. Despite these difficulties, there are several studies that indicate that this approach may be fruitful (Adam & Mutanga 2009). Investigating this option further will pay off in the long term because it gives national conservation authorities the possibility to monitor all wetlands of the country simultaneously without spending much effort for going into the field. The database can then be used to interpret community shifts and these community shifts can be linked to environmental changes. If individual species can not be recognized, broad functional types may be recognized and there are also steps towards developing models for recognizing broad strategy types using satellite imagery (Schmidtlein et al. 2012).

In most cases however, monitoring of wetlands will be conducted by people in the field, and by monitoring wetland vegetation changes in the field, data can be generated for populating the database further. This work can be facilitated by producing a field guide to assist wetland practitioners with the identification of the most common wetland plants. When the most common wetland plants are known, wetland practitioners can be involved in monitoring these ecosystems and this will increase our understanding of wetland ecosystems in the long term including their dynamism, responses to environmental degradation and to restoration work.

An updated field guide such as the one by Van Ginkel et al. (2011) would certainly help in making wetland vegetation sampling more accessible and user-friendly for a wider audience. There are many people involved in wetland conservation today, from provincial departments, Working for Wetlands staff, land owners and civil society, and a fieldguide that emphasizes the indicator value of certain species would go a long way in providing the right tools to people with an interest in wetland conservation. As previous literature has always emphasized the sedges and grasses, it has become clear that these are certainly not the only wetland plants that play a role in these plant communities. Large-scale monitoring programmes are more viable if citizen science is involved and large numbers of volunteers get involved. Equipped with the right tools, these volunteers can be visiting sites to obtain data on plant communities in wetlands and thereby collect useful data for the monitoring of wetland health. It is the task of scientists, environmental managers and policy-makers to ensure that the data obtained by citizen scientists is subjected to quality control and provide a framework in which it can contribute to an assessment on the state of wetlands in the country.

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APPENDIX A: Vegetation form

This provides a standardized format for the collection of wetland vegetation data

South African Wetland Vegetation Survey - Field Dataform

Releve number:	Date:	Area / Study
Surveyor(s):	Latitude:	Wetland name:
	Longitude:	Slope
Plot size:	Altitude:	Aspect

Vegetation structure:

Layer:	Cover:	Av. Height	Dominants	Growth form
Total cover:				

Wetland and habitat description:

HGM Unit:	Hydroperiod:	Water velocity:
Landscape setting:	Inundation depth:	Salinity:
Urban/Rural/Pristine	Groundwater table:	Water source:
Disturbance		
		Geology:

Soil description:

Texture of top soil	Mottling present:	Soil sample taken:
Colour of top soil:	Soil depth:	yes/no
Soil form:	Deep layer:	

Braun-Blanquet cover-abundance scale
r = 1-2 ex, **+** = 3-10 ex, **1** = 11-100 ex, **2m** = > 100 ex, <5%, **2a** = 5 - 12.5%, **2b** = 12.5 - 25%, **3** = 25 - 50%, **4** = 50 - 75%, **5** = 75 - 100%

Vegetation sample:

Species	Layer	Cover	Coll. Number	**Species**	Layer	Cover	Coll. Number
				Total number of species:			

Notes:

APPENDIX B

Historical datasets that were entered into the dataset.

Publication / dataset	Area	No. of plots	Comments
Van Zinderen Bakker & Werger (1974)	Montane wetlands of Lesotho	28	Coordinates not known, based in Lesotho
Boucher (1978)	West Coast	72	Vegetation plots of 10 x 10 m,
Furness (1981)	Pongola floodplain	106	Vegetation plots 10 x 10 m
Fuls, Bredenkamp & Van Rooyen (1992)	Pans of Northwestern Free State	29	No coordinates, poor environmental data
Fuls (1993)	Grasslands Northern Free State	52	Vegetation plots of 10 x 10 m
Bloem, Theron & Van Rooyen (1993)	Verlorenvlei, Mpumalanga	47	Vegetation plots of 10 x 10 m
Coetzee, Bredenkamp & Van Rooyen (1993)	Belfast- Wakkerstroom- Barberton- Piet Retief	22	No exact coordinates available, unpublished
Eckhardt, Van Rooyen & Bredenkamp (1993a,b)	Wetlands Northeastern Free State	44	Vegetation plots of 10 x 10 m
Coetzee, Bredenkamp & Van Rooyen (1994)	Wetlands of Heidelberg, Witbank, Pretoria area	36	Vegetation plots 10 x 10 m
Malan (1995)	Wetlands of Southern Free State	33	No coordinates, poor environmental data
Bezuidenhout (1995)	Graspan-Holpan section Vaalbos National Park	16	Two wetlands, often low in cover
Guthrie (1996)	Hlatikhulu, Mooi River, Ntabamhlophe	177	Three large wetlands, cover values not in same format
Eckhardt, Van Rooyen & Bredenkamp (1996)	Wetlands of Northwestern KwaZulu-Natal	87	Vegetation plots of 10 x 10 m
De Frey (1996)	Southeastern Mpumalanga	52	Vegetation plots 10 x 10 m
Wessels (1997)	Swamp Forest Lake St. Lucia	59	No herb layer recorded
Smit, Bredenkamp, Van Rooyen, van Wyk & Crombrinck (1997)	Witbank Nature reserve	6	Very small amount of wetland plots, mostly terrestrial vegetation
Cilliers, Schoeman & Bredenkamp (1998)	Urban wetlands in Potchefstroom	86	Three wetlands in detail
Perkins, Bredenkamp & Granger (2000)	Southern KwaZulu-Natal	184	Vegetation plots of 10 x 10 m
Burgoyne, Bredenkamp & Van Rooyen (2000)	Northeastern Mpumalanga	29	Vegetation plots large, 20 x 10 m, heterogeneous
Schoultz (2000)	Mkhuze Swamps	115	Plots on transects, no wetness data
Taylor (2000)	Mdlanzi Pan, Zululand	77	Plots on transects, no wetness data
Neal (2001)	Mkhuze floodplains	187	Plots on transects, no wetness data
Goge (2002)	Eastern shores Lake St. Lucia	175	Poor IDs in Swamp Forest
Venter (2002)	Mfabeni Swamp, Eastern	203	One large wetland sampled
Siebert, Van Wyk, Bredenkamp & Du Plessis (2002)	Sekhukhuneland	17	No coordinates, plots large 20 x 10 m, heterogeneous

Publication / dataset	Area	No. of plots	Comments
Kareko (2002)	Middelvlei Wetland, Stellenbosch	16	Plots of only 1 x 1 meter
Venter, Bredenkamp & Grundling (2003)	Rietvlei in Gauteng	22	Many plots in pioneer stage after disturbance
Mucina, Janssen & Callaghan (2003)	Salt marshes of Uilkraals Estuary, Western Cape	76	Many plots only 1 x 1 meter, but some larger
Malan (2003)	Cookes Lake recreational area, Mmabatho	56	One urban wetland, largely disturbed
Janecke, DuPreez & Venter (2003)	Soetdoring Nature Reserve	54	Two wetlands
Cilliers & Bredenkamp (2003)	Pans in Northwest Province	83	Four large pans, many plots with very poor cover
Cleaver, Brown & Bredenkamp (2004)	Kamanassie Mountains	29	Maybe not all clear wetlands, small springs, plot size variable
Sieben, Boucher & Mucina (2004)	Montane wetlands of Hottentots Holland	35	Vegetation plots 10 x 10 m
Kotze, Sieben & Morris (2006)	Maloti-Drakensberg Transfrontier Park	265	
Sieben, Ellery, Garden & Grenfell (2006)	Wetlands South of Richards Bay	17	Unpublished consultancy
Fouche (2008)	Florisbad	25	One wetland
Grobler (2009)	Swamp Forest Kosi Bay	65	Many different stages of succession and disturbance
Van Aardt (2010)	Vet River	82	No coordinates, poor environmental data
Sieben, Ellery, Dullo & Grootjans (submitted)	Catalina Bay, KwaZulu-Natal	39	Vegetation sampled twice in permanent quadrats
Cowden, Kotze, Ellery, Hill & Sieben (in prep.)	Rehabilitated wetlands in KwaZulu-Natal	51	Many disturbed sites, not yet published
Modern studies that include detailed soil data			
Collins (2011)	Free State pans and Valley bottoms	284	Soil data and many other variables available
Corry (2012)	Western Cape lowlands	418	Soil data and many other variables available for most plots
Pretorius & Grundlingh (2013)	Wetlands Nothern Maputaland	77	Results not yet published and soil data not yet available

APPENDIX C: Statistical algorithms

Sorensen similarity index

The distance measure equations uses the following conventions: data matrix **A** has *q* rows, which are the sample units, and *p* columns, which are the species. Each cell in the matrix, a_{ij}, represents the abundance of species *j* in sample unit *i*. The distance between sample units *i* and *h* is calculated by considering the number of species and their abundances that they have in common. It is calculated in the following manner: shared abundance among sample units is divided by the total abundance.

Sorensen similarity index: $D_{i,h} = \frac{\sum_{j=1}^{p} |a_{ij} - a_{hj}|}{\sum_{j=1}^{p} a_{ij} + \sum_{j=1}^{p} a_h}$

The Sorensen similarity index is calculated for all pairs of sample units, creating a similarity matrix that can be used for subsequent analyses.

Cluster analysis

In order to cluster objects, a similarity measure is needed to express the level of similarity between objects (the Sorensen distance measure was used in this research project), but additionally a linkage method is required in order to provide a criterion by which to join the sample units. Such a linkage method determines in which case two existing clusters (which both consist of a cloud of points in multidimensional space) should be joined on a branch, in terms of the two furthest members in a group, the closest neighbours, or a cluster centroid. In this study, Ward's method was the method of choice, and this method calculates the error sum of squares as the sum of squares of distances from each individual to the centroid of its group. Two groups S_p and S_q are chosen so that the fusion of groups S_p and S_q yields the least increase in the error sum of squares. After joining all items, the procedure is complete. (McCune & Grace 2002).

The following represents the basis of hierarchical cluster analysis using Ward's method in PC-Ord: an *n* x *n* (*n*= number of entities) dissimilarity matrix is calculated and each of the elements in this matrix is squared. The algorithm then performs *n* – 1 loops (clustering cycles) to join each element up with another one. In each of these loops the following steps are taken:

- The smallest element (d_{pq^2}) in the dissimilarity matrix is sought (the groups associated with this element are S_p and S_q).
- The objective function E_n (the amount of information lost by linking up to the cycle *n*) is incremented according to the rule $E_n = E_{n-1} + \frac{1}{2d_{pq}^2}$ where n is the step in the loop and E_0 (the objective function at the start of the procedure) is equal to 0.
- Group S_q is replaced by $S_p \cup S_q$ by recalculating the dissimilarity between this new combined group and all the other groups.
- Group S_q is rendered inactive and all of its elements are assigned to group S_p.

Dendrograms or cluster trees are conveniently used to show the structure of 'relatedness' between objects such as vegetation plots because similar plots end up on the same branch of the dendrogram. The distance between two plots on a dendrogram can be expressed as the distance of 'travelling' along the branches of the tree that needs to happen in order to get

from one plot to another: the deeper you have to travel back to the main stem of the tree, the more dissimilar two plots are.
The final clustering shows a tree with branches together with the distances at which certain branches differ from each other. As the structure of the dendrogram is determined, it is not yet clear how many clusters need to be recognized in the final analysis since the clustering starts with each individual plot in the dataset. In this regard, Indicator Species Analysis, discussed below provides useful guidance by providing a criterion for the most optimal number of clusters that should be recognized in a dendrogram (McCune & Grace 2002).

Non-Metric Multidimensional Scaling (NMDS)

NMDS is an ordination method that seeks as far as possible an ordination in which the distances between all pairs of sample plots are in rank-order agreement with their dissimilarities in species composition and does so by trying out several dimensionalities (Peck 2010). Unlike other ordination methods, nonmetric multidimensional scaling (NMDS) makes few assumptions about the nature of the data, since it does not assume a specific type of response curve of variables to the gradient. NMDS can be used for a range of data types and allows the use of any distance measure, because it only looks at the rank order of the distances. There are two specific disadvantages, firstly, NMDS is very time-consuming and therefore it has only become popular now that computers have become faster, secondly NMDS has to start out with a randomized configuration before it looks for an optimized solution and these solutions are not always stable. Since NMDS could not find stable solutions for all of the analyses in this research project, the method has been abandoned.

Canonical Correspondence Analysis (CCA)
The matrix of response variables is stated as Y (vegetation composition) and the matrix of explanatory variables as X.
The steps that the algorithm for Canonical Correspondence Analysis takes are as follows. First the Chi-square distance for every cell is calculated, this distance measure is based on the expected frequency with which each cell should be scored, given the column totals (total abundance of all species in a plot), and row totals (total abundance of that species in all plots). This can be expressed mathematically as:

$$\bar{Q} = [\bar{q}_{ij}] = \left[\frac{p_{ij} - p_{i+}p_{+j}}{\sqrt{p_{i+}p_{+j}}}\right]$$

Where p represents the relative frequency p_{ij} of each cell in row i and column j, which is the absolute value in that cell divided by the sum of all values in all cells of the original data matrix. Hereby p_{i+} represents the total sum of all entities in that row divided by the total sum of values in the entire matrix and represents the weight of that row. Similarly, p_{+j} represents the total sum of entities in each column divided by the total for the entire matrix and represents the weight of that column. The value *p* represents the relative frequency (divided by the total sum for the entire matrix) whereas the values *f* represent the absolute frequency, based on the original entries in the matrix.

The explanatory matrix X is standardized by dividing by weights $D(f_{i+})$ to make a matrix X_{stand}. Weighted multiple regression is used to calculate the estimates for the response variable based on this standardized explanatory matrix. The matrix $\hat{Y}$ containing these estimates is calculated by a complex formula of matrix algebra that is fortunately calculated by a computer algorithm.

$$\hat{Y} = D(p_{i+})^{1/2} X_{stand} [X'_{stand} D(p_{i+}) X_{stand}]^{-1} X_{stand}' D(p_{i+})^{1/2} \bar{Q}$$

The matrix of residuals, which is the original value minus the estimate is then calculated as $\bar{Q}_{res} = \bar{Q} - \hat{Y}$.

The matrix $\hat{Y}'\hat{Y}$ is then subjected to eigenvalue decomposition, a standard procedure in matrix algebra that finds a number of vectors (eigenvectors) and their associated eigenvalues that make a diagonal vector that is equivalent to the original vector. Again, this procedure will be solved by a computer algorithm and will produce a diagonal matrix with eigenvalues Λ and a vector U with eigenvectors. This procedure of eigenvalue decomposition is the actual CCA procedure.
After the solution to this problem has been found, the site scores in an ordination diagram still need to be found to illustrate the solution. This can happen through various types of scaling, which will not be discussed in detail here, but generally follow another matrix multiplication: $V = D(p_{+j})^{-1/2} U$.

The result is an ordination plot where site scores on various axes are plotted along these axes (with similar plots ending up close to one another), but are constrained by the environmental information that is supplied, so that the impact of these environmental variables on vegetation composition can be assessed. The environmental variables themselves can be plotted together with the site scores in a biplot, indicated as arrows for numerical variables or points for nominal variables (classes that each plot is allocated to), with the length of the arrow indicating the strength of the correlation and the direction of the arrow indicating the direction in which that environmental variable increases.

The advantage of the procedure of eigenvalue decomposition is that the first eigenvalue represent the axis of largest variation within the dataset, and subsequent eigenvalues represent less of that variation. Therefore it is generally sufficient to study the first two axes, or sometimes up to the first four axes of variation, as the higher axes do not represent important parts of variation within the dataset.

Indicator Species Analysis (ISA)
In order to calculate the indicator value the following steps are taken (McCune & Grace 2002):

- The proportional abundance of a particular species in a particular group relative to the total abundance of that species in the whole dataset is calculated
  Let **A =** sample unit x species matrix
  $a_{ijk=}$ abundance of species *j* in sample unit *i* of group *k*
  n_k = number of sample units in group *k*
  g = total number of groups
  RA_{jk}= Relative abundance
  RF_{kj}= Relative frequency
  B = matrix of absence-presence

The mean abundance of x_{kj} of species *j* in group *k* is calculated as follows

$$x_{kj} = \frac{\sum_{j=1}^{n_k} a_{ijk}}{n_k}$$

From here one can calculate the relative abundance RA_{kj} of species *j* in group *k*

$$RA_{jk} = \frac{x_{kj}}{\sum_{k=1}^{g} x_{kj}}$$

- The proportional frequency of species in each group is calculated. For this purpose, firstly **A** is transformed into a matrix of presence-absence, **B:** $b_{ij} = a_{ij}^{o}$

  The relative frequency RF_{kj} of species *j* in group *k* is then calculated as follows:

$$RF_{\boldsymbol{kj}} = \frac{\sum_{i=1}^{n_k} b_{ijk}}{n_k}$$

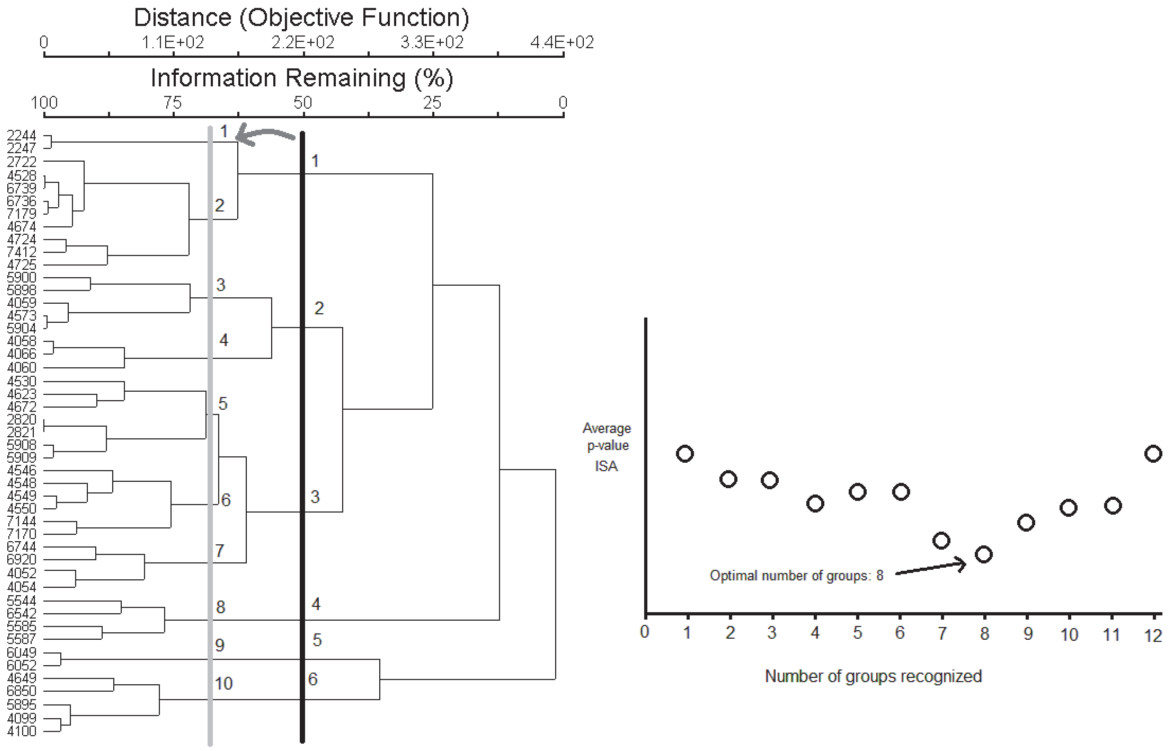
- The two proportions RA_{jk} and RF_{kj} calculated above are combined into a single statistical indicator by multiplying them. The results are presented as a percentage, yielding an indicator value (IV_{kj}) for each species *j* in each group *k.*

$$IV_{kj} = 100\ (RA_{kj} \times RF_{kj})$$

- The highest indicator value $(IV_{\max})$ for a given species across all groups is stored as a summary of the overall indicator value of that species. This means that each indicator species only appears once in the list of indicator species, so if a particular species occurs nearly equally abundant in more than one group, it will only be listed as an indicator for that group where the IV_{max} is highest.
- The statistical significance of $IV_{\max}$ is evaluated by means of a randomization test using a Monte Carlo permutation procedure, where sample units are randomly assigned to groups for a 1000 times. For each permutation, the IVmax is calculated and the proportion of times that these calculated IVmax values equal or exceed the value from the actual dataset is reported as the p-value for the randomization test. If that proportion is less than the threshold level of 0.05 then the IVmax value is significant and it will be reported in the table of indicator values.

The species that will be characterized as indicator species are ecologically important species in terms of recognizing wetland communities although they are not always necessarily the most conspicuous species in the community. For this reason, when reporting on the description of a wetland plant community, both the indicator species as well as the dominant species are reported. These last species are the species that may have a low indicator value because they are shared between several communities, but that reach a high cover value and stand out as the most conspicuous element in the community. They are generally the species with a wide ecological amplitude that go across many different communities. Both the indicator species and the dominant species will be selected at a later stage to plot species response curves.

Indicator species analysis (ISA) is used in combination with agglomerative cluster analysis in order to decide how many clusters should be recognized. A dendrogram resulting from a classification ends with all individual plots at the end of the branches so it requires 'pruning' to determine which main branches should be recognized as clusters. We can draw a vertical line through the dendrogram to this, but the position of this vertical line is not clear beforehand. Indicator Species Analysis can assist in finding the optimal number of clusters by considering that each cluster must be sufficiently distinct from the other clusters in terms of indicator species. For each run of Indicator species analysis, an average p-value and an average Indicator Value for the whole range of species in the dataset can be calculated. These values give an indication of how well the clusters are defined in terms of indicator species and therefore the cluster analysis which provides the minimum average p-value for the randomization test of Indicator Species Analysis is the one with the optimal number of clusters. This means that by means of trial and error, a number of classifications need to be carried out with different numbers of clusters, an Indicator Species Analysis needs to be calculated for each of them, and the minimum number of the average p-value needs to be sought. This process is illustrated in the figure below, where the average p-value has been calculated for twelve different rounds of clustering, two of which are illustrated in the dendrogram.



Dendrogram showing the various ways in which a dendrogram can be ‘pruned’ in order to define the number of clusters. Two different ways of pruning are shown in the dendrogram, one with 6 clusters and one with 10 clusters. If the average p-value for each of these clusterings in ISA is calculated and the outcomes are shown in a graph, it appears that the average p-value is lowest with eight clusters so therefore this is the optimal number of clusters, based on the indicator species.

Non-metric Multiplicative regression

Species response curves do not always resemble normal bell-shaped curves, even though much of ecological modelling is based on that assumption (Austin 1987). In most cases where a variable is modelled as a function of another variable in a flexible and dynamic way, Generalized Linear Models (GLM) and Generalized Additive Models (GAM) are used to find the best model that explains the correlation function between the two variables. These GLM’s are an extension of linear models that allow for regression in situations where the error terms are not normally distributed. Generalized Additive Models are modifications of Generalized Linear Models where explanatory variables are included in the model as non-parametric smoothing functions. This allows for a wider range of types of response curves than can be found by normal linear regression and therefore it provides a more realistic model that explains the correlation between the variables.

The programme HyperNiche uses yet another type of habitat model that is built on the basis of the environmental variables that are provided. The regression method that is used in Hyperniche to build these habitat models is Non-parametric Multiplicative Regression models (NPMR, McCune 2009). Habitat models identify the relationship between a species and the factors that determine its abundance, using a Gaussian weighting function with a local mean estimator. This means that the shape of the response in a particular region of the explanatory variable is only determined by values in a specific small window, not by the entire dataset, as in many non-parametric regression functions using splines or kernels (McCune 2009).

NPMR can be regarded as a form of Generalized Additive Modelling where a single term using multiplicative weights for all predictors is used. It is therefore particularly well adjusted to explore interactions between environmental factors.

- When the response variable is quantitative, the model quality is evaluated in terms of the residual sum of squares (*RSS*) in relationship to the total sum of squares (*TSS*).
- The value 1 – (RSS/TSS) is called the "cross R^2" (xR^2) because the calculation incorporates a cross validation procedure.
- When the model is weak it is common for *RSS* > *TSS* and xR^2 becomes negative. These models should not be considered as valid.
- For the quantitative data the model estimates abundance of a species at a certain point as the mean abundance of the species in the whole data set. The model quality is evaluated by the cross-validated R^2 value (xR^2) as the models with the highest values provide the best fit to the explanatory data. The maximum possible value for xR^2 is 1.0.

In order to get started with Hyperniche, the programme provides the option to use a free search method, in which all possible models are explored. The best models can then be selected by finding the highest xR^2 for each number of predictors. All explanatory variables included in this project are quantitative.

The method whereby the best model is selected in Hyperniche is known as a leave-one-out form of cross validation. Each model is characterized by two statistical indicators. Tolerance corresponds to the smoothing parameter for each quantitative parameter. Sensitivity evaluates the importance of individual variables by expressing the factor by which a change in the predictor has an effect on the response (McCune 2009).