Developing a classification system for Western Cape wetlands

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Abstract

Although broad wetland classifications systems are available internationally, a comprehensive wetland classification system, which can be used for both desktop and field analyses, is lacking in South Africa but is required by the South African National Water Act (36 of 1998). Wetlands within the Western Cape were selected from different bioregions and wetland regions. In this project geomorphological characteristics (drainage patterns, landform), hydrological pattern and timing of water availability, were recorded during winter and summer for each studied wetland. Water samples were also collected at the wetlands and analysed for ion and nutrient concentrations and samples of organisms were collected for identification. Multivariate cluster and multidimentional scaling analyses of the chemical and biotic data were used to aid identification of wetland groups. A hierarchical classification system was developed using drainage patterns (endorheic or exorheic systems) as the primary defining characteristic, followed by wetland landform and hydrological regime as the secondary and tertiary characteristics for identifying wetlands. Water chemistry and biotic characteristics were found to be less stable and less reliable than the physical wetland characteristics and have not been included into the higher levels of the classification system, but are recommended for use as wetland descriptors at lower levels in the hierarchical classification system. A classification key is provided in order to facilitate use of the classification system and to ensure that it is available for both wetland biologists and non-wetland experts. Intensive investigation of aquatic invertebrates, vegetation and water chemistry characteristics (particularly pH, conductivity and turbidity) over a few years might reveal the usefulness of these characteristics for wetland classification. Thus, more data are required to determine the water quality requirements of different wetland types, but the classification system will prove useful for the determining the quantity of water required by wetlands.

Chapter One
Introduction

1.1 Introduction

The first step in investigating wetlands is recognising them as wetlands and identifying the different types, and for this we need a suitable classification system. Further, such a classification system should use a standardized terminology, allowing a uniform understanding between scientists studying wetlands; this would assist in identifying types of wetlands recorded in an inventory and it should also allow for generalizations to be made of the types of wetlands present within a region. A classification system should provide a universal means of communication. Further more, information gained will be valuable for management and academic purposes as it provides an initial catalogue of existing wetlands to which further information may be methodically added (Findlayson and van der Valk, 1995).

Wetland classification systems have been developed and are available in countries such as the United States (Cowardin *et al.*, 1979 and Mitsch and Gosselink, 1986) and Australia (Semeniuk and Semeniuk, 1995) but these classification systems are based on characteristics that render them unsuitable for application to South African wetlands (detailed in Sections 2.4.2 and 3.6). A South African classification system is required to facilitate the management of wetlands by the South African National Water Act (No 36) of 1998. The Act requires determination of the "ecological reserve" defined as "the quantity and quality of water required to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource". A classification system is required in order to determine the "ecological reserve" since quantity and quality of water required by wetlands varies depending on wetland type. The present project attempts to develop such a classification system for wetlands of the Western Cape province of South Africa in response to the requirements of this Act.

Wetlands types should not be distinguished on the basis of single characteristics, but should rather incorporate the suit of characteristics that affect wetland processes and patterns. Further, wetland structures and processes cannot be represented at a single scale and are thus investigated, in this thesis, at as many different scales as possible, from geomorphological characteristics through to macroinvertebrate characteristics. These characteristics are investigated in conjunction with each other (using multivariate techniques) in order to find multi-characteristic patterns of wetland types. Thus descriptions of wetland types are based at different scales and wetlands are considered to be distinguished by many characteristics (multi-causal).

Classifying landscapes is frequently reduced to descriptive and consequently ambiguous and sometimes subjective grouping of landscape types. Through the use of multivariate techniques I attempt identify characteristics that indicate patterns of wetland types in an objective and rigorous manner. These characteristics are used to group wetland types, which are incorporated into a classification system, and are available for further testing.

1.2 Objectives

This dissertation reports on a project which has been funded by World Wildlife Fund- South Africa. The particular aim of the project is to develop a hierarchical classification system for Western Cape wetlands, which will be of use for quantifying the 'ecological reserve' defined in the South African National Water Act (No 36, 1998). In order to reach this goal three objectives were identified:

1. Reviewing and testing of some existing South African and other wetland classification systems.

2. Beginning an inventory of the biodiversity of selected Western Cape wetlands by collecting and analysing physical, chemical and biotic data from a variety of wetlands of different types.

3. Application of the data so generated to describe physical, chemical and biological features of the wetlands and to identify categories for a wetland classification system in the study area.

A detailed literature review of wetland classification systems is given in Chapter 2. Different types of wetlands from the area are described in Chapter 3, methods used during the study are described in Chapter 4 and information collected from wetlands within the Western Cape are presented in Chapters 5 and 6. Characteristics useful for classification of these wetlands are selected from the investigated physical, chemical and biological features, and are then used to create categories of wetland types, and to develop a wetland classification system and key in Chapter 6.

Chapter Two
Wetlands and systems used for their classification

2.1 Introduction

This chapter identifies features that differ between wetlands and can therefore be used in a classification system. Different approaches to classification and types of classification systems that have been proposed are then reviewed.

Wetlands are commonly known as features in a landscape which are inundated with water and are home to fish, frogs and waterfowl as well as supporting different types of specifically adapted plants. Yet there is more to wetlands than this generalised depiction and some go unrecognised. Wetlands from different continents vary considerably and there is certainly an enormous variation within South Africa. Because of this variability it is not always easy to define and identify them as wetlands or to distinguish wetland types and delineate their boundaries. Cowardin *et al.* (1979) define wetlands as "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water". The definition is broad enough to include almost all wet areas. The definition adapted by the Ramsar convention is more specific and excludes open-ocean aquatic environments: "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Peck, 1999). Both of these definitions include a broad spectrum of aquatic environments but this dissertation deals with a subset of wetlands: inland aquatic environments (excluding rivers) and some inland wetlands connected to the sea.

Wetlands are ecologically, socially and economically valuable, yet they are threatened by a variety of human activities. At present there is little knowledge of the numbers and types of wetlands occurring in South Africa, let alone about their physical, chemical and biotic characteristics or the ways in which they function. They perform vital services, of which storage of water is primary, but reduced surface water flow, reduced impact of flash floods, increased groundwater recharge, and provision of a perennial supply of water to downstream wetlands, are also significant. Wetlands also purify water that flows through them by retaining sediments, nutrients and bacteria (*e. g.* Wilen and Bates, 1995). They support diverse biotas that differ from those of terrestrial environments (*e. g.* Howard-Williams, 1985).

2.2 Wetland processes

Walmsley (1988) suggests that wetlands be identified and classified in terms of environmental determinants (geomorphological, hydrological *etc*), biotic composition and ecological functions in the landscape (for example water storage) and evaluated in terms of conservation value and status. Biotic, chemical and physical processes occurring in wetlands mould other characteristics which may then be used to define wetlands. In this way, processes occurring in wetlands cause some of the differences between them. It is obvious that information on wetland structures (physical, chemical and biotic characteristics), processes (the interactions between different components of the physical, chemical and biotic characteristics) and the functions or services they perform in the landscape (such as flood attenuation and groundwater recharge) (Maltby *et al.*, 1994) is required in order to classify and evaluate wetlands.

2.2.1 Geomorphological, hydrological, chemical and biological interactions in wetlands

Climate, in the form of temperature, wind, and precipitation, shapes the hydrological regime of an entire river catchment. Wetlands occur in the catchments of rivers and these catchments shape the structure of wetlands and affect their functions. Catchment geomorphology affects frequency and timing of rainfall and determines duration of inundation, and water depth at specific sites in a catchment. Hydrology in turn shapes the geomorphology of a wetland through processes such as erosion and sedimentation (Gordon *et al.*, 1992). Both geomorphological and hydrological characteristics influence proportions and quantities of nutrients entering downstream areas (Allan, 1995). All these factors control the biotas that characterise wetlands as recognisable ecosystems.

2.2.1.1 Wetland geomorphology

The geomorphology of a landscape is a primary and historically more stable feature than hydrological, chemical and biological features. Geomorphology moulds the shape and the drainage pattern of the wetlands. Landscape shape affects water retention time. For instance, a deep basin is more likely to retain water throughout a year than is a wetland on a mountain slope (Semeniuk and Semeniuk, 1995). It is obvious that landscape morphology controls not only wetland shape and size but, together with climate, affects the hydrological regime of aquatic systems. Since geomorphology determines the hydrological regime of the wetland, which in turn has an effect on the type of organisms, geomorphology indirectly affects wetlands biota (Gordon *et al.*, 1992).

The position of a wetland in the landscape also determines its source of water. For example, wetlands on slopes usually receive water in the form of overland flow, whereas those in depressions at the bottom of slopes are more likely to receive groundwater (Mitsch and Gosselink, 1986). Water from different sources contains different concentrations of nutrients and ions and has different pH, conductivity and turbidity levels (Silberbauer and King, 1991b). Since it influences the source of water moving into wetlands, topography also has an indirect effect on the chemistry of the water entering wetlands, which in turn affects the type of organisms living in them.

2.2.1.2 Hydrological regime of wetlands

The hydrological regime of wetlands in southern Africa is controlled by a variable climate, particularly with regard to precipitation (Rogers, 1997), so that wetlands vary from permanently to seasonally to irregularly inundated or saturated. Some wetlands support only standing water, but relatively slow currents flow through others, particularly those connected to rivers. Wetlands thus store water, allowing it to infiltrate the soil and replenish groundwater, in this way reducing surface water flow and reducing destruction caused by flash floods. A greater water storage time in wetlands compared to the connected rivers means that wetlands even out discharge and thus create a perennial water supply for downstream wetlands. However, wetlands are often small and a single small wetland is unlikely to result in regulated water flow on its own. It is, instead, the cumulative effect of a number of wetlands within a catchment that results in water regulation (Mitsch and Gosselink, 1986).

Water may enter wetlands as precipitation, from runoff or overland flow, *via* stream flow, from underground springs and as a result of underground water tables rising to expose water at the surface. Water entering a wetland adds nutrients and ions to the wetland (Mitsch and Gosselink, 1986).

Water loss from wetlands may be due to physical and biotic processes. Physical water loss is due to flow to downstream wetlands, to percolation to ground water aquifers and to surface evaporation (which is effected by climate conditions). Biotic processes cause water loss by plant evapotranspiration, but vegetation cover also acts to decrease the rate at which water evaporates because plant cover shades wetlands and protects surface water from wind and direct sun heat which increase evaporation rates (Mitsch and Gosselink, 1986).

Natural erosion of bedrock in the catchment results in particles being carried into downstream aquatic environments where they are deposited. Over time, such deposits create a substratum on which vegetation may establish and faunal communities develop. At times of fast flow, sediments may be flushed out, causing the cycle to start again. Wetlands are generally characterised by sluggish flow, however, and sediments have the potential to build up to such an extent that water is forced to flow beneath the surface (McCarthy *et al.*, 1986).

2.2.1.3 The hydric soils of wetlands

Inundation and waterlogging result in the "hydric" anaerobic soils of wetlands. Oxygen diffusion through soil is reduced when water fills the pore spaces. The reduced oxygen levels in the soils means that aquatic plants need to be adapted to these anaerobic conditions as aerobic root respiration is hampered. Further, the degree of oxidation conditions affect plant nutrient availability. Anaerobic organisms, adapted to the soil conditions, result in transformation of the chemicals stored in wetland soils through processes such as microbial respiration. Wetland soils are divided into two groups: organic soils (such as peat which are highly organic) and mineral soils (Mitsch and Gosselink, 1986). Soil type may thus be used to define a wetland. The period of inundation or waterlogging affects chemical processes as well as factors (*e. g.* quantity of organic carbon in soils) that determine soil colour, mottling, texture and degree of humification or decomposition of organic particles. These visual characteristics allow identification of hydric soils even when they are dry and, as certain soils have a characteristic profile, we may infer other information, such as extent of inundation (Kotze and Marneweck, 1999 and Kotze *et al.*, 1994).

2.2.1.4 Effects of water chemistry on the interactions occurring in wetlands

Water characteristics include physical variables (temperature, turbidity and suspensoids) and chemical variables (pH, nutrients, dissolved oxygen and conductivity, salinity or total dissolved solids; TDS). Temperature has a direct influence on organisms in wetlands as different communities of organisms are only able to survive in certain temperature ranges. Temperature also affects chemical processes and has the potential to alter variables such as pH, thereby indirectly affecting aquatic organisms. Turbidity affects light penetration into the water. Increased turbidity levels can result in decreased primary production (Dallas and Day, 1993) thus, a reduction in the amount of dissolved oxygen in the water, which has an indirect affect on organisms. In addition, suspended solids may impair their breathing and the vision of predators (Dallas and Day, 1993).

Three major factors controlling the ion content of a wetland are geology, rainfall and evaporation. Silberbauer and King (1991b) found that wetlands along the Western Cape coast are characterised by sodium and chloride and the inland wetlands by carbonate. Sodium and chloride are evaporation- and rainfall-controlled ions, whereas carbonate is controlled by the geology of the area. This indicated to Silberbauer and King (1991b) that the inland wetlands are "rock-dominated", whereas the coastal wetlands are dominated by precipitation and evaporation. They suggest that sodium and chloride are carried from the sea onto land by the frontal rainfall systems predominant in the area. The total dissolved solids or ion content may be measured in terms of conductivity or salinity. In South Africa there are many saline wetlands (Dallas and Day, 1993) and wetlands may be grouped according to differing salinity ranges (*e. g.* Cowardin *et al.*, 1979). Increased salinity levels affect the type of organisms found in wetlands as most organisms tolerate only a limited range of salinity.

Wetlands of the Western Cape are known for their acidity (*e. g.* the humic acid sponges of the southern Western Cape referred to by Noble and Hemens, 1978) and thus pH is likely to be an important characteristic for describing some of the different types of wetlands in the area. Silberbauer and King (1991b), in an investigation of the south-western Cape, found a wide pH range (from 4 to greater than 10) in these wetlands. The osmotic and ionic balances of aquatic organisms are affected by pH and some organisms are adapted to specific pH ranges (Dallas and

Day, 1993). Thus a change in a wetlands pH is likely to affect the community of organisms in the wetland.

Although the underlying rock type is the ultimate source of nutrients, the hydrological regime controls the rate at which nutrients enter a wetland and in this way controls its functions (Howard-Williams, 1985). Groundwater entering a wetland will carry nutrients from underlying rocks but nutrients are also gained from water entering *via* overland flow and precipitation (Mitsch and Gosselink, 1986). Since the topography and geomorphology of an area control hydrological processes, they will also affect the type and amounts of nutrients entering a wetland.

Nutrients flow through exorheic wetlands (wetlands which release water downstream), but some may be stored in water, sediment, biomass and dead organic matter. Nutrients used by the biota will pass through their bodies either returning to the water or being released from the wetland into the atmosphere by the process of volatilisation. Nutrients cycle through physical, chemical and biological interactions and may be lost from a wetland by downstream water movement. Downstream exports of nutrients may exceed inputs and exorheic wetlands therefore function as nutrient sources in the landscape. Endorheic wetlands are closed drainage environments, in which nutrients are stored since there is no outflow of water. These wetlands are generally richer in nutrients than exorheic wetlands are. Other wetlands act as nutrient sinks since particles and solutes in the water settle and are retained by sediments which allows vegetation to develop (Mitsch and Gosselink, 1986). The roots of hydrophilic plants prevent sediments from being flushed out and the vegetation and sediments together allow retention of water and solutes in the wetland.

Wetlands are known to transform chemicals. For instance some heavy metals are transformed from toxic to non-toxic, more stable species under wetland conditions (Mitsch and Gosselink, 1986). Wetlands also purify water moving through them. For instance, excess nitrogen may be taken up by plants or removed by microbial nitrification/denitrification (Rogers *et al*, 1991) and toxic chemicals may be retained in the sediment. Wetlands are thus used for treatment of polluted or sewage effluents. Excessive quantities of nutrients in a wetland have the potential to increase plant production to such an extent that some species of plants cannot compete. When they die and decay, more nutrients are released into the wetland. This positive feedback of nutrients into the wetland may alter the natural nutrient cycle and ultimately change the composition of both floral and faunal communities (Mitsch and Gosselink, 1986).

2.2.1.5 Biological interactions occurring within wetlands

The different hydrological regimes displayed by wetlands result not only in physical differences but also in different biotic communities. Certain kinds of organisms (such as fish) require permanently flooded wetlands and others (such as notostracans, anostracans and other branchiopods) have life cycles dependent on wetlands that dry out seasonally because the organisms diapause during the dry season as cysts in the dried substratum.

Water chemistry is a major determinant of the type of organisms that a wetland will support, and the organisms, in turn, affect water chemistry. Each taxon has differing water quality tolerance limits and some require specific conditions for survival, for instance, the anostracan, *Artemia* species that survive in temporary, highly saline, wetlands. The presence of certain species can be used as an indication of the conditions in their host wetlands through methods such as a biomonitoring system like the South African Scoring System is used for rivers (SASS, Dallas 1997). Besides the obvious wetland animals such as water fowl and aquatic mammals, inundated wetlands support many different types of macro and microinvertebrates.

Bacteria living in the anaerobic substratum and rooted aquatic vegetation have adaptations that allow them to continue in these conditions (Mitsch and Gosselink, 1986). Bacteria and vegetation play an important role in cycling of nutrients by wetland specific processes such as denitrification, ammonium volatilization and oxidisation as well as transforming other chemicals (Mitsch and Gosselink, 1986).

Denny (1985) classifies hydrophytes (aquatic plants) into microphytes and macrophytes. Three types of aquatic macrophytes are recorded: surface-floating macrophytes (*e. g.* duckweeds and *Azolla* spp), emergent macrophytes (*e. g. Phragmites* spp), and euhydrophytes. Euhydrophytes may be submerged (*e. g. Potamogeton* spp) or anchored to the substratum but with floating leaves (*e. g. Nymphea* spp) and are found in deeper parts of wetlands than those occupied by emergent species. Emergent macrophytes are rooted in wetland substratum and dominate in marshes (wetlands dominated with low lying bushy vegetation) or swamps (tree dominated wetlands) while surface-floating species have evolved in such a way that they do not need to be rooted and their distribution is dependent on wind and water movement. Plant species are also adapted to particular hydrological and nutrient regimes. *Potamogeton crispus* on the Pongola flood plain, for example, is dependent on the irregular flooding regime for reproduction and continued existence (Mitchell and Rogers, 1985) while other species (such as. mangrove trees) are suited to tidal saline conditions.

2.3 The value of wetlands in the landscape

Wetlands are important features in a landscape since they function in ways that benefit not only their adjacent ecosystems but also the human population associated with them. Begg (1990) highlights the major benefits of wetlands to humans:

- Wetland processes cause flood attenuation as a result of water storage. A reduction in flash floods results in regulated downstream flow. Furthermore, stored water seeps into the substratum and replenishes groundwater aquifers. Since these processes reduce the overland flow of water, erosion will be decreased, thereby decreasing soil and sediment movement through a catchment.
- Through filtration of particles and adsorption of some solutes in water entering wetlands, nutrients, toxic substances and sediment are removed from the water. Thus water flowing into a down stream wetland is "purified" and potentially more useful for human consumption than water entering the wetland upstream.
- Wetlands provide habitat for many species, some of which are rare and endangered, and support a high biodiversity.
- Wetlands are used as a source of food (such as fish and edible aquatic plants), for agriculture and aquaculture and are also appreciated for their aesthetic value by humans.

Historically, wetlands were regarded as nuisance areas and were often used for dumping or were reclaimed through draining or transformation. Dam construction, erosion, and agricultural and urban development are identified as the major causes of wetland loss, but other anthropogenic activities such as road construction, afforestation, and dumping of solid, mining or toxic waste also negatively impact on wetlands. Catchment conditions, such as erosion causing sedimentation in wetlands, and disruption of upstream flow regimes, also have the potential to cause loss of wetlands. The available data, though limited, indicate that there has been a high percentage of wetland loss in some areas of South Africa (Kotze *et al.*, 1995). At present, wetlands are progressively being considered socio-economically valuable, and there has been movement towards conservation and wise usage of wetlands through developments such as the South African National Water Act (36 of 1998). Understanding of the different types of wetlands and their biogeochemical processes is essential for wetland users in order to prevent processes such eutrophication. While we are aware of the importance of wetlands, it is necessary to know more about their specific processes so that they can be better conserved and managed.

2.4 Classification

A classification system permits division of wetlands into groups that share common features. Such a system is useful in that it allows an inventory (a list of wetlands including information on their type and other data) of different types of wetlands. Further, groups of wetlands that share common features may be managed with common strategies, since management techniques found to be beneficial to one type of wetland may be used for others with similar characteristics. This dissertation describes the development of a classification system that may be used by both managers and scientists and that facilitates communication between them. As shown in the previous section, wetlands vary in physical, chemical and biological attributes. These attributes may be used as criteria for characterising wetlands and defining the classes into which they fall. Some criteria are more easily assessed than others, some provide more information regarding the processes occurring than others, and some may be used to predict other characteristics, but the requirements of a classification system defines which criteria are selected for grouping wetlands.

2.4.1 Approaches to developing classification systems

Classification systems are designed to meet specific needs and there is no one correct classification system. A classification system aimed at management and conservation of wetlands might best be based on landscape features, for instance, although it might be appropriate to consider biotic features as well, because they are an integral part of and reflect aspects of wetland functioning.

South Africa, being a fairly arid country, supports particular types of wetlands which perform vital services for the human population. Many of these have already been lost or transformed and conservation and management of the remaining wetlands will benefit the population. Wetland inventory, classification, and research is required for knowledge-driven conservation and management.

A South African classification system needs to be practical and inexpensive, and it should be possible for non-specialists to provide data for the classification system. A classification system is required by legislation but should be as multi-purpose as possible. If these criteria are met, then wetland researchers may be better inclined to use the classification system. This would assist with developing a detailed wetland inventory as information from these researchers may be assembled with ease if the wetlands have been classified using the same classification system.

As South African wetland classification is a relatively young aspect of the science there is a paucity of information regarding methods used for developing such a classification systems. River classification systems, on the other hand, are well developed (*e. g.* Eekhout *et al.*, 1997 and Wadeson and Rowntree, 1994) and the literature gives some useful information regarding different approaches that can be used. The following points review different approaches to classification of natural wetlands and their useful attributes (O'Keeffe *et al.*, 1994 and Naiman *et al.*, 1992).

- "Hierarchical" versus "single-scale" classification systems

  Hierarchical classification systems consist of levels at which the subjects of the classification system are grouped. At the primary levels the subject is usually divided into broadly separated groups and then divided into subgroups at the next more detailed level, and so on. They are popular because they consist of logically structured groups and are practical to apply (*e. g.* the hierarchical classification system by Cowardin *et al.*, 1979). Single-scale classification systems are usually in the form of descriptions of a number of different categories (*e. g.* Noble and Hemens, 1978). The latter classification systems are useful and necessary but can lead to ambiguous and inconsistent use of criteria as no logical format for assigning the subject to different categories is defined (O'Keeffe *et al.*, 1994).

- "Top-down" versus "bottom-up" classification systems

"Top-down" classification systems use independent physical characteristics such as climate and geomorphology as initial characteristics. For instance, the Cowardin *et al.* (1979) classification system uses hydrological characteristics at the first level. Subsequently, the subject may be further classified using dependent changeable characteristics such as aspect of the biota. The "bottom-up" approach, on the other hand, initially depends on characteristics such as water chemistry and biota and only after that does it group the subject using the independent physical characteristics. The independent physical characteristics such as landscape morphology are often more readily available (on maps for instance) than biotic and water chemistry data. Thus the "top-down" approach is easier to apply but it is likely to result in less detailed classification systems since the independent physical characteristics provide less information about the wetland than biotic and water chemistry data. A "bottom-up" approach can be labour intensive since it uses attributes such as species composition, and collection of data for these characteristics is time consuming and requires scientific expertise. However, these attributes provide more ecological knowledge than independent physical characteristics and the use of the "bottom-up" approach results in a more detailed classification system. It is assumed that a "bottom-up" approach using living organisms should integrate physical aspects in the classification system. Data availability and the logistics of data collection are frequently factors that decide whether a classification system is to be based on a "top-down" or "bottom-up" approach (O'Keeffe *et al.*, 1994).

- "Structural" versus "functional" characteristics

Structural characteristics include geology, geomorphology, vegetation, and fauna, characteristics that shape the overall appearance of the wetland. Functional attributes such as nutrient cycling and sediment transport are less easily assessed than structural characteristics, but reveal detailed information regarding processes. Wetlands are defined by both of these types of characteristics and both are useful to different degrees for different users (O'Keeffe *et al.*, 1994).

- Extent of human alteration

If one requires a "natural" classification system (for wetlands which have not been anthropogenically disturbed) then the extent of human disturbance needs to be taken into account. Wetlands affected by human activities often tend to become more similar to each other than they were in an unaltered state. If one requires a classification system for wetlands in their natural state selection criteria should be based on data from undisturbed rather than disturbed or man made wetlands. Features that have been modified should not be chosen for "natural" classification systems if they result in wetlands of different kinds being grouped together. Modified features may be remodified and have the potential to return to their natural state and are thus not stable features in a human time frame. For instance, artificially salinized wetlands should not be classified with natural saline ones simply because they have similar salinity levels as salinity concentrations may change with a change in management. A naturally-based classification system will allow better inventory and management of undisturbed wetlands than one based on artificially altered characteristics. It may also be more useful to managers of slightly altered or urban wetlands and help to ensure that they remain as natural as possible if this is their management goal.

Naiman *et al.* (1992) note that a good classification system should integrate structural and functional characteristics under various regimes of human disturbance. This may be difficult to accomplish in wetlands since human disturbance rapidly changes both structure and functioning and it is difficult to identify the original condition. Depending on the degree and type of disturbance, some wetlands have been irreversibly altered and it is arguable whether they should be classified according to their present or original characteristics (O'Keeffe *et al.*, 1994). Altered wetlands require management in the present rather than their "natural" state, and a classification system based on artificially altered features could be more appropriate for such management regimes.

- Classification may be applicable over different spatial and temporal scales

A classification system which labels a wetland consistently over a long time period is usually more useful than one which results in wetlands being labelled differently through time. For this reason it is desirable to classify wetlands using characteristics such as geomorphology and the hydrological regime of the area, which change slowly in comparison with biological and chemical characteristics. Developers of a classification system in arid areas are faced with a specific problem in that the wetlands are subject to an unpredictable climate, frequently resulting in hydrologically ephemeral wetlands. Such wetlands are often dominated by irregularly changing structural characteristics, so that developing a classification system that is applicable on a broad temporal scale is not simple (Naiman *et al.*, 1992).

Different regions are usually characterised by their particular geological, biotic and climatic regimes, which means that these regions support different types of wetlands. This has been a dominant problem with wetland classification and has resulted in many different classification systems being developed all over the world (Cowardin *et al.*, 1979; Noble and Hemens; 1978, and Semeniuk and Semeniuk, 1995). An international classification system, which groups wetlands into broadly defined categories, can be used for international inventories (such as the classification system developed for the Ramsar convention). But, for smaller geographical areas, a more detailed classification system may be required because areas of differing complexity are dominated by different features. These features which vary from area to area need to be incorporated when developing a classification system for local management and inventory. Thus, while it may be possible to develop a single coarse classification system for international use, it is unlikely that a single detailed wetland classification system (such as one based on biota) will be available for wetlands on an international scale.

- Information revealed by a classification system

Different classification systems provide different types of information. Some classification systems may provide a means of grouping wetlands, which is useful for inventory purposes. By default, a classification system based on underlying characteristics (such as geomorphological and hydrological characteristics) that shape wetland structure and indirectly affect wetland functions, will reveal information about the mechanisms controlling wetlands as well as the processes occurring in them (Naiman *et al.*, 1992). A classification system grouping wetlands according to their geographical positions might not provide information about their structure, but one based on shape and hydrological regime is likely to do so. A classification system revealing information such as species composition and water chemistry is useful for knowledge-driven management of specific wetland types, for scientific knowledge and for inventorying purposes. The user also benefits if the name given to wetland types yields information about their structure and functioning. For instance, a wetland labelled "floodplain" has the obvious connotations for both scientific and lay readers. Detailed information regarding size, water chemistry and other characteristics could also be gained from the name of the wetland and from additional descriptors, depending on the characteristics applied by the original author in his classification system.

- Attributes gained at a low cost and uniform understanding amongst users

Classification systems which require expensive technical equipment, a high level of expertise and a great deal of time are only useful to investigators who are specifically interested in wetlands and have financial support. Specialists investigating amphibians, waterfowl or vegetation, for example, may not be inclined or even able to use such a classification system. These researchers have often created their own simpler and more applicable classification systems. Unfortunately, these classification systems are specific to the researchers and can result in poor communication between scientists in differing fields. If a single classification system is practical and easy to use it will be accessible to many and this will facilitate amalgamation and correlation of information (Naiman *et al.*, 1992).

2.4.2 Existing wetland classification systems

Wetland classification systems have been in development in the Northern Hemisphere since the early twentieth century (Davis, 1907 and Weber, 1908 *in* Mitsch and Gosselink, 1986) and a great deal of work has been done in this field in the United States (Shaw and Fredine, 1956 *in* Mitsch and Gosselink, 1986; Cowardin *et al.*, 1979). Wetlands in the northern hemisphere differ from those in the southern hemisphere as well as from continent to continent due to their different climates. Thus, application of ecological theories and classification systems developed in other parts of the world to South African wetlands is difficult and sometimes inappropriate. However, a knowledge of methods and characteristics used previously assists with developing a useful classification system for South African wetlands. The following sections review some well known international classification systems as well as some classification systems that have been proposed for use in South Africa. The glossary may be referred to for definitions of terms used in the different classification systems.

2.4.2.1 The Unites States Fish and Wildlife Services Wetlands classification (Cowardin *et al.*, 1979)

A number of classification systems are available worldwide, but the Cowardin *et al.* (1979) classification system (hereafter called "the Cowardin system') is widely recognised. These authors define wetlands as "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" and use a hierarchical classification system. This classification system (Figure 2.1) is relatively easy to apply and was designed to include wetlands in marine, deltaic, estuarine, riverine, lacustrine, and palustrine systems at a primary level. Once these wetlands have been identified at this primary level, which Cowardin *et al.* (1979) refer to as Systems level, they are divided into Subsystems using hydrological characteristics and are then further into Classes and Subclasses on the basis of substratum material, flooding regime and plant life forms or lack thereof. Subclasses are further divided into groups of Dominance types (based on types of the dominant plant or animal form). At the lowest level of the classification system Modifiers (or descriptors of water regime, chemistry and soil) may be applied.

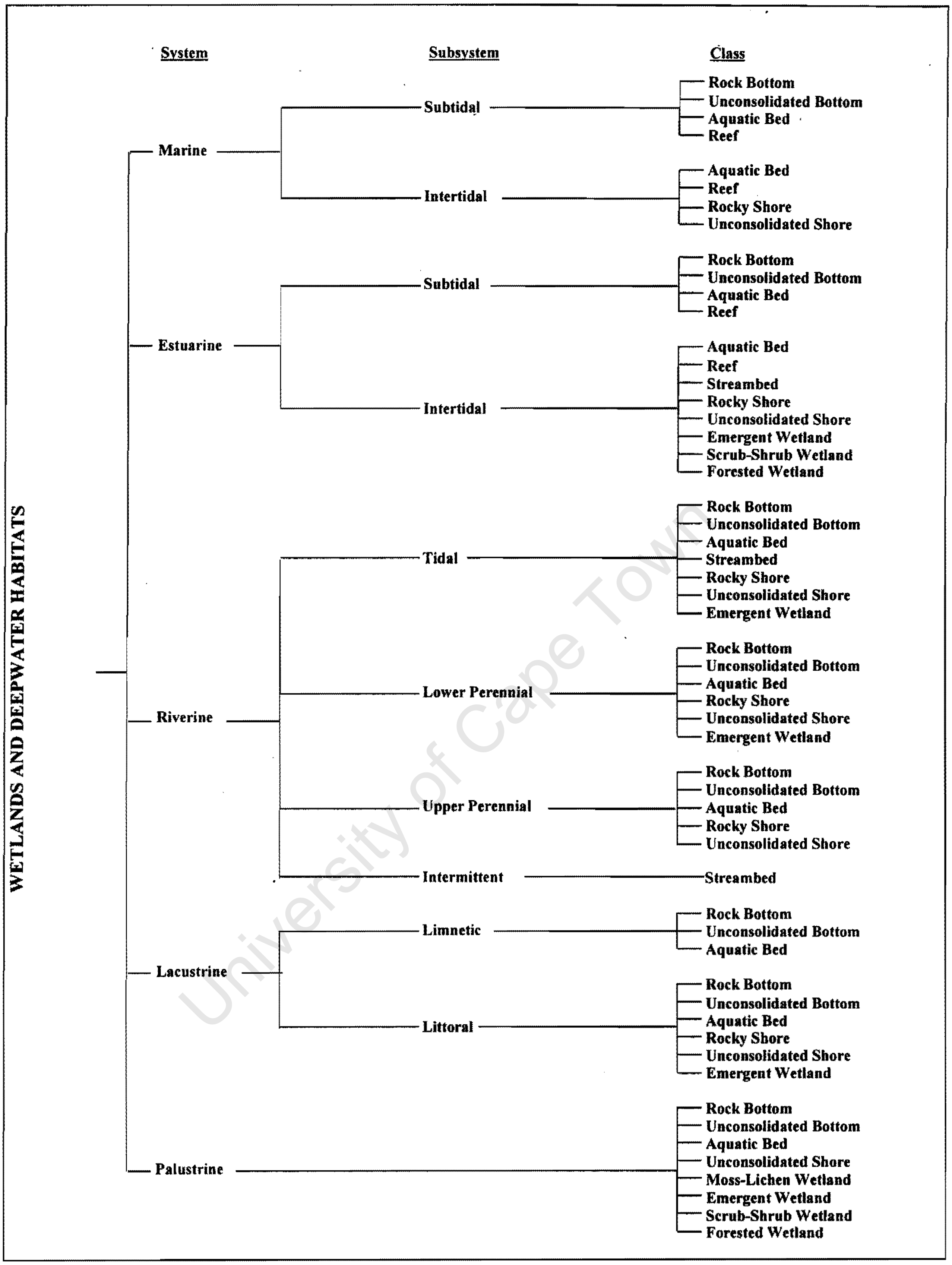

Figure 2.1 Wetland classification reproduced from the hierarchical classification system developed by Cowardin *et al.* (1979).

Cowardin *et al.* (1979) describe the different types of habitats of the classification system. The Palustrine system, for instance, groups vegetated wetlands (such as those called bog, fen, marsh, mire, prairie and swamp), including small shallow wetlands with permanent or intermittent hydrological regimes. The definition of these wetlands includes non-tidal vegetated systems as well as tidal systems which have less than 0.5 parts per thousand ocean-derived salts. Non-vegetated Palustrine systems are defined as wetlands with less than 8 ha, less than 2m deep at low water, less than 0.5 parts per thousand ocean-derived salinity (although it is not mentioned how they know whether the salinity is ocean-derived or not) and without active wave-formed or bedrock shoreline (Cowardin *et al.*, 1979). From the definition it can be seen that Palustrine systems include a wide variety of wetland types. Lacustrine systems are defined as wetlands with a total area exceeding 8 ha and situated within a topographic depression or dammed river channel, with less than 30% areal vegetation coverage, and less than 0.5 parts per thousand ocean-derived salinity. Estuaries are considered to be deepwater and tidal habitats that are connected to the open ocean but are also fed by a freshwater source such as a river or by precipitation (Cowardin *et al.*, 1979).

The Cowardin system, being hierarchical, is easily understood and this has made it internationally accepted. Using such a classification system would allow the inclusion of important wetlands from areas such as South Africa into an international inventory and on a global wetland map. Furthermore, quantitative distinctions have been developed for defining wetlands of different categories. For instance, an aquatic environment with higher than 0.5 parts per thousand ocean-derived salinity may be considered estuarine, but those with less than that fall into another category. Quantitative distinctions can be useful and may remove some ambiguities when assigning wetlands to different categories.

My evaluation of the Cowardin system for use in South Africa has indicated that it is inappropriate in its unmodified form for the following reasons. The classification system deals with large wetlands but does not include small ephemeral endorheic wetlands which, in large parts of South Africa, are the most important, and sometimes the only, wetlands that exist. The classification system relies primarily on hydrological characteristics of wetlands and puts biotic and water chemistry data at secondary levels. Wetland hydrological regimes are extremely variable in South Africa due to a variable climate regime and some wetland scientists (*e. g.* Dini *et al.,* unpublished draft (1998), Silberbauer and King (1991b) and J.A. Day (personal communication, Freshwater Research Unit, University of Cape Town, 2001) believe that hydrological characteristics cannot always be used as the major defining characteristic of South African wetlands without ambiguity. The annual average rainfall for South Africa is about 500mm, but the average annual rainfall within the Western Cape may vary from 200mm to 3000mm. Further, the percentage deviation from the mean annual rainfall is fairly high throughout the country. The Cape Peninsula, for instance, has a mean annual precipitation of 400mm to 600mm but the percentage deviation of the mean annual precipitation ranges from 20% to 30% (Department of Water Affairs, 1986). The wetlands investigated in the present project mostly fall within the Palustrine system, although some fall within the Lacustrine and Estuarine systems. However, distinctions between the different types of Palustrine systems are not identifiable as indicated in section 3.6. The Cowardin system is particularly useful for identification using remote sensing techniques. This is beneficial for a nation-wide inventory, but it does not allow identification of the different types of known wetlands in South Africa because many South African wetlands are ephemerally and seasonally wet and may not show on remote sensing images. A more detailed classification system is required for local management as important features of South African wetlands are not evident at the scale for which the Cowardin system has been designed.

2.4.2.2 Adaptations of the Cowardin system

Most authors acknowledge the difficulty of creating completely inclusive wetland classification systems and encourage updating of their classification systems. The Cowardin system has been modified several times, for example for the Mediterranean Wetland Inventory (Hecker *et al*,. 1996) and for South African use (Morant, 1983 and Cowan and van der Riet, 1998).

After testing the practicality of the Cowardin system for South African wetlands, Morant (1983) proposed a number of modifications.

- In addition to classifying the wetlands themselves, an initial classification of the climate (Schulze, 1965 in Morant 1983) and ecological system in terms of Veld Type (Acocks, 1975 in Morant 1983, latest edition is Acocks, 1988) were to be carried out as collection of "essential ancillary information".

- Morant's (1983) suggestions of an "addition of cover classes (of vegetation cover types) for use in a whole basin". The Cowardin system as it stands classifies parts of wetlands separately, while Morant suggest they should be classified as a single wetland supporting different vegetation cover types and illustrates this with the example of Rondevlei a small coastal lake in Cape Town. This wetland is fringed with emergent vegetation (usually reeds) and is classified into different categories by the Cowardin system: emergent vegetation, mud flats and open, unvegetated water. Morant suggests that Rondevlei be classified as a single wetland and that cover type be included as a level in the classification system. He labels the wetland as

    > "lacustrine, fine bottom, organic, emergent vegetation cover type 7, permanently flooded, slightly saline"

  rather than the two wetland types of the Cowardin system

    > "reeds fringe...palustrine, emergent wetland, semipermanently flooded, slightly saline"

  and

    > " open water...lacustrine, profundal, fine bottom, organic, permanently flooded, slightly saline"

Single bodies of water are known to support different habitats that may be used by different faunal groups. While it is important to identify different habitats within wetlands, classifying single water bodies as one wetland is not only simpler but removes clumsiness in map labelling and communications regarding the wetland. Morant (1983) also notes that using cover type is practical for smaller scale remote sensing techniques (1: 50 000 topographic maps rather than 1:10 000 orthophotos), since wetland cover type may be recorded from maps.

As vegetation cover is included in Morant's 1983 classification system, a record of wetland biological characteristics is also incorporated, which means that the classification system is biologically useful. In these ways Morant (1983) attempts to make the classification system applicable to the South African context and to make it more detailed, which is necessary for management purposes. Rather than providing a name for a wetland Morant (1983) provides a method for coding each wetland and suggests that this coded legend be used for inventory purposes and on maps, as it allows concise representation of detailed information. Application of the classification system is subjective to the different users as Morant (1983) does not specifically define some of the categories used. As Morant's (1983) classification system is based on the original Cowardin system, other problems associated with it are retained, and the classification system still does not incorporate endorheic, temporary wetlands in a comprehensive manner (as discussed further in section 3.6). Breen (1988) suggests that Morant's (1983) approach be adopted, but that the classification system should be tested in the field and, evaluated, and that a national classification, inventory and mapping program be implemented. In the 1980s a wetland program was initialised and funded by the Foundation for Research Development. One of the major aims was to develop a wetland classification system and inventory, but funding was withdrawn and the project was not completed. The two Silberbauer and King (1991a and b) papers represent the initial work that was done.

2.4.2.3 The Ramsar wetland classification system

The Ramsar classification system is a hierarchical one which allows coarse classification of the different types of international wetlands (Dugan, 1990). All countries contracted to the Ramsar convention use the same classification system for identification of listed wetland sites. Although wetlands may only be classified very coarsely, these countries will more easily communicate on wetland issues as they will be using the same classification terminology. Some categories are similar to those defined by Cowardin *et al.* (1979), but the available documents do not provide a key or detailed description of all wetland types (Dugan, 1990) which means that application of the classification system may be subjective to the different users.

A classification system that has already been applied in South Africa (such as the Ramsar classification system: Cowan and Marneweck, 1996) may group and name certain wetlands in a particular way. A new classification system may not do this in the same way. There is an obvious trade-off between using an original, possibly less adequate, classification system and a newer, more comprehensive, classification system, because mapped and other information collated using the original classification system may not be easily related to the new classification system's categories and names. This is particularly relevant in South Africa where there is a paucity of wetland data and what are available is therefore of particular value.

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2.4.2.4 Adaptation of the Ramsar and Cowardin classification systems for use in South Africa

Cowan and van der Riet (1998), who have adapted the Ramsar wetland categories and sorted them into the Cowardin system's broad categories in a manner more applicable for the South African situation, use the Ramsar definition of wetlands: "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres". The definition includes marine, estuarine and inland aquatic systems but is more specific than the one used by Cowardin *et al.* (1979) (indicated in the glossary). For instance Cowan and van der Riet (1998) categorise Marine and Estuarine wetlands as "coastal wetlands" and Endorheic, Riverine, Lacustrine, Palustrine and Man-made wetlands as "interior wetlands". Alterations to the Cowardin system include the addition of man-made and Endorheic wetlands (at the Systems level) and the division of Palustrine wetlands into two vegetation subclasses, emergent and forested. These alterations make the classification system more comprehensive than the Cowardin system (Figure 2.2) and more useful for application in South Africa as it permits inclusion of some common South African wetland types. By sorting the Ramsar wetland categories into a hierarchical format similar to that of the Cowardin system, Cowan and van der Riet (1998) have made the South African classification system more accessible to non-specialists. Some of the categories, particularly the Endorheic wetlands, which incorporates four separate Ramsar categories, may be further subdivided to give a more comprehensive classification of South African wetlands.

While South African wetlands may be broadly grouped into the major categories of the Cowan and van der Riet (1998) classification, the lower levels of the classification system are not easily applied, because of the variable hydrological regime. Thus, the classification system requires further alteration and the addition of a key will facilitate its use.

Cowan and van der Riet (1998) have made a start at wetland inventory by classifying a large number of South African wetlands using their classification system, but the wetlands have been classified at the Systems level only which provides limited information about the wetlands themselves. While the inventory (wetlands list) is useful for identifying major South African wetlands, a more detailed classification system is required for management purposes.

Classification of wetlands habitats adapted from that approved by the Ramsar Convention 1990.

COASTAL WETLANDS			
Marine	**subtidal**	1	*sea bays, straits*
		2	subtidal aquatic vegetation
		3	*coral reefs*
	intertidal	4	rocky marine shores, including *cliffs, rock shores*
		5	shores of *mobile stones* and *shingle*
		6	intertidal *mud, sand* or *salt flats*
		7	intertidal *salt marshes*
		8	intertidal *mangroves*
Estuarine	**subtidal**	9	estuarine waters
	intertidal	10	intertidal *mud, sand* or *salt flats*
		11	intertidal marshes
		12	intertidal forested wetlands
(Lagoonal)		13	*brackish to saline lagoons*
INTERIOR WETLANDS			
Endorheic		14	Permanent and season, *brackish, saline* or *alkaline lakes, flats, pans* and *marshes*
Riverine	**perennial**	15	rivers and streams including waterfalls
		16	inland deltas
	seasonal	17	seasonal rivers and streams
		18	riverine floodplains
Lacustrine	**permanent**	19	permanent freshwater *lakes* (≥ 8ha)
		20	permanent freshwater *ponds, pans* (≤ 8ha)
	seasonal	21	seasonal freshwater *lakes* (≥ 8ha)
		22	seasonal freshwater *ponds, pans* (≤ 8ha)
Palustrine	**emergent**	23	permanent freshwater *marshes* and *swamps*
		24	permanent *peat-forming freshwater swamps*
		25	seasonal freshwater *marshes*
		26	*peatlands* and *fens*
		27	*Alpine* and *polar* wetlands
		28	*springs* and *oases*
		29	*volcanic fumaroles*
	forested	30	*shrub swamps*
		31	freshwater *swamp forest*
		32	*forested peatlands*
MAN-MADE WETLANDS			
Aquaculture/mariculture		33	*aquaculture ponds*
Agriculture		34	*irrigated land* including rice fields
		35	seasonally flooded agricultural land
Salt exploitation		36	*salt pans* and *evaporation pans*
Urban/industrial		37	*excavations*
		38	*wastewater treatment areas*
Water storage area		39	*resevoirs* (*sic*)
		40	*hydro-dams*

Figure 2.2 Wetland classification reproduced from Cowan and van der Riet (1998) for use in South Africa.

Dini *et al.* (unpublished draft 1998) have simplified Cowardin systems "modifier" characteristics in order to make classification possible using remote sensing techniques. While a classification system based on desk-top analysis is less expensive and time consuming than field identification, it cannot replace a field classification system, since desktop tools are not available to all users and desktop analysis does not provide a full record of wetland characteristics, particularly chemistry and biology. Further, aerial photography provides a momentary record and does not indicate whether a wetland is permanently, seasonally or irregularly inundated.

Dini *et al.* (unpublished draft 1998) have also adapted the Cowardin system by dividing Palustrine systems into a number of Subsystems on the basis of geomorphological rather than less stable hydrological characteristics to include the categories of flat, slope, valley bottom and floodplain. Since all the other subsystems are grouped according to hydrological regime, there is a loss of consistency. Despite this technical difference the classification system may prove to be more useful in a South African context than the unmodified Cowardin system, since geomorphology is a more stable characteristic than hydrological regime.

2.4.2.5 A global geomorphic classification system for inland wetlands

Semeniuk and Semeniuk (1995) adopted the following definition of wetlands: "areas of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline". Their classification system excludes deltaic, estuarine, and marine wetlands but includes inland wetlands such as lakes, rivers and floodplains. They have not specified a clear distinction between estuarine and inland wetlands, although it is stated that wetlands should be classified according to their dominant characteristics (Figure 2.3).

These authors note that, globally, the distribution and abundance of wetlands are controlled by climate: the more humid the climate, the more numerous and abundant the wetlands. Landform and hydrological characteristics are selected as the two characteristics that determine the existence of wetlands regardless of 'climate settings, soil type, vegetation cover, geomorphic settings, or origin'. The characteristics are not dependent on biological characteristics, which change with geographical position. Landform and hydrological characteristics may be used in regions with different climates because they are stable characteristics, and Semeniuk and Semeniuk (1995) believe that they incorporate global variability in wetlands.

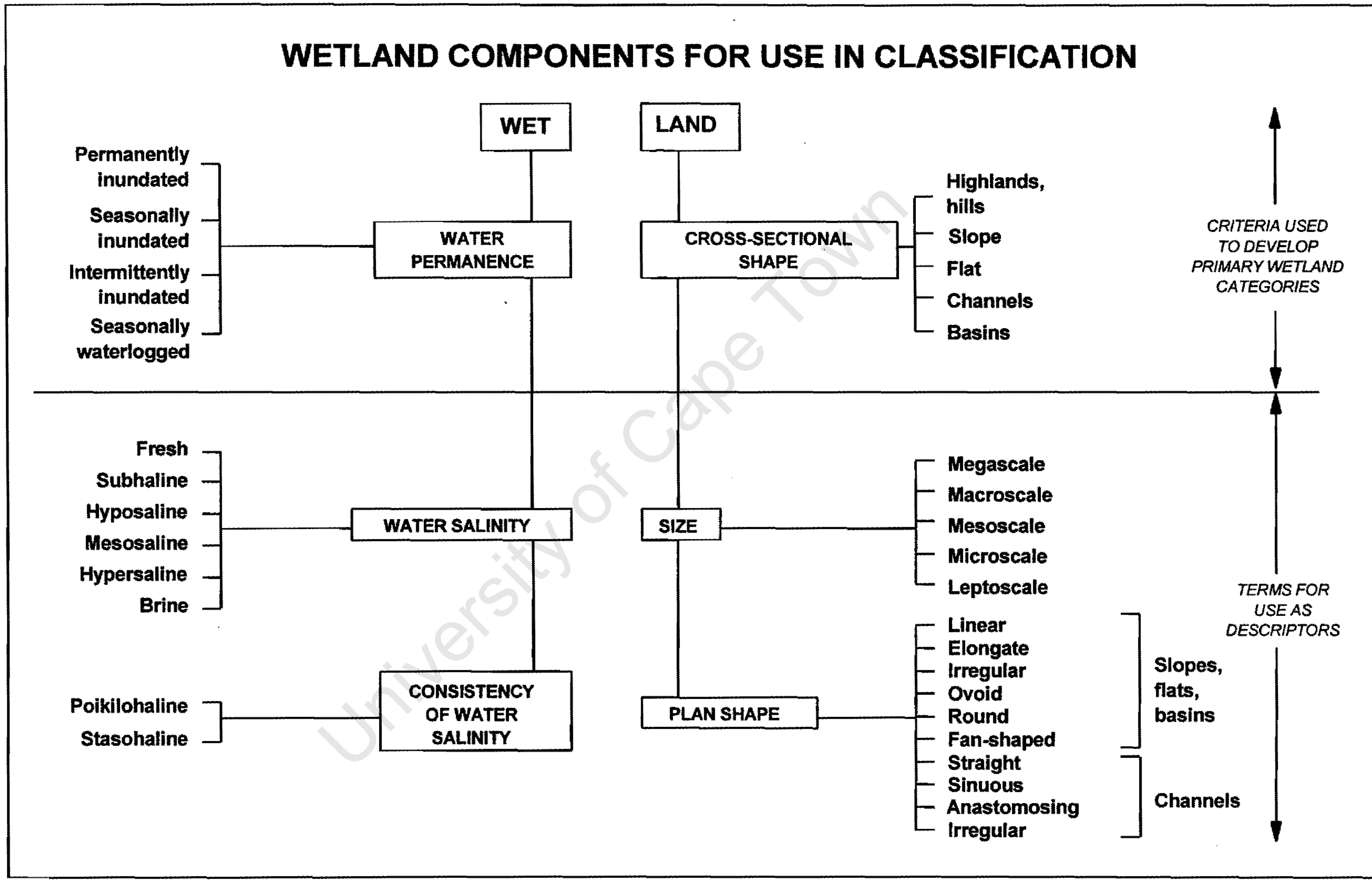


Figure 2.3 Framework for wetland classification prepared by Semeniuk and Semeniuk (1995). Wetlands may be grouped according to characteristics of water permanence and cross-sectional shape which are used to classify the wetlands into the different categories shown in Table 2.1. The landform characteristics (size and plan shape) and water (salinity and consistency of salinity) may be used to describe the hydrological and morphological features of the wetland.

Five landforms that support wetlands are illustrated in Figure 2.4. They are described as:

- **basins**, which generally support lakes and increase in depth from the perimeter to a central area of greatest depth;
- **channels** that are valley shaped and support rivers;
- **flats**, which are often floodplains and have a gradient of less than one degree;
- **slopes**, which support wetlands on gradients higher than one degree and are often mountain side seeps; and
- **highlands or hills**, which are waterlogged mountain top areas.

Semeniuk and Semeniuk (1995) specifically note that the shape of the land that results in the formation of a wetland, rather than the surrounding landscape, is considered to be the landform of that wetland. So if a wetland is in a shallow depression within a flat landscape, the wetland is classed as a depression rather than as a flat. They also divide hydrological regime into four categories (Figure 2.3):

- **permanent inundation** when water covers the surface throughout the year except in times of extreme drought;
- **seasonal inundation** when flooding occurs during the growing season, but the land is dry or waterlogged at the end of the season;
- **intermittent inundation** when brief flooding occurs during the growing season or for variable periods unrelated to seasonality; and
- **seasonal waterlogging** when soils are saturated with water during the growing season.

These physical characteristics are used together to classify 13 basic wetlands units (Table 2.1).

Once wetlands have been grouped into the 13 primary categories using landform and hydrological regime, they may be qualified by "descriptor terms", of which there are four categories (Figure 2.3). These are salinity, consistency of water salinity (whether variable or constant), wetland size and plan shape (such as linear, fan-shaped or rounded etc) (Semeniuk and Semeniuk 1995).

Semeniuk *et al.* (1990, *in* Semeniuk and Semeniuk, 1995) proposed a classification system for wetland vegetation based on areal extent and pattern of plant cover. Semeniuk and Semeniuk (1995) suggest that this wetland vegetation classification system be used as descriptors in their geomorphic classification system. Semeniuk and Semeniuk's (1995) system does not, however, incorporate aquatic fauna.

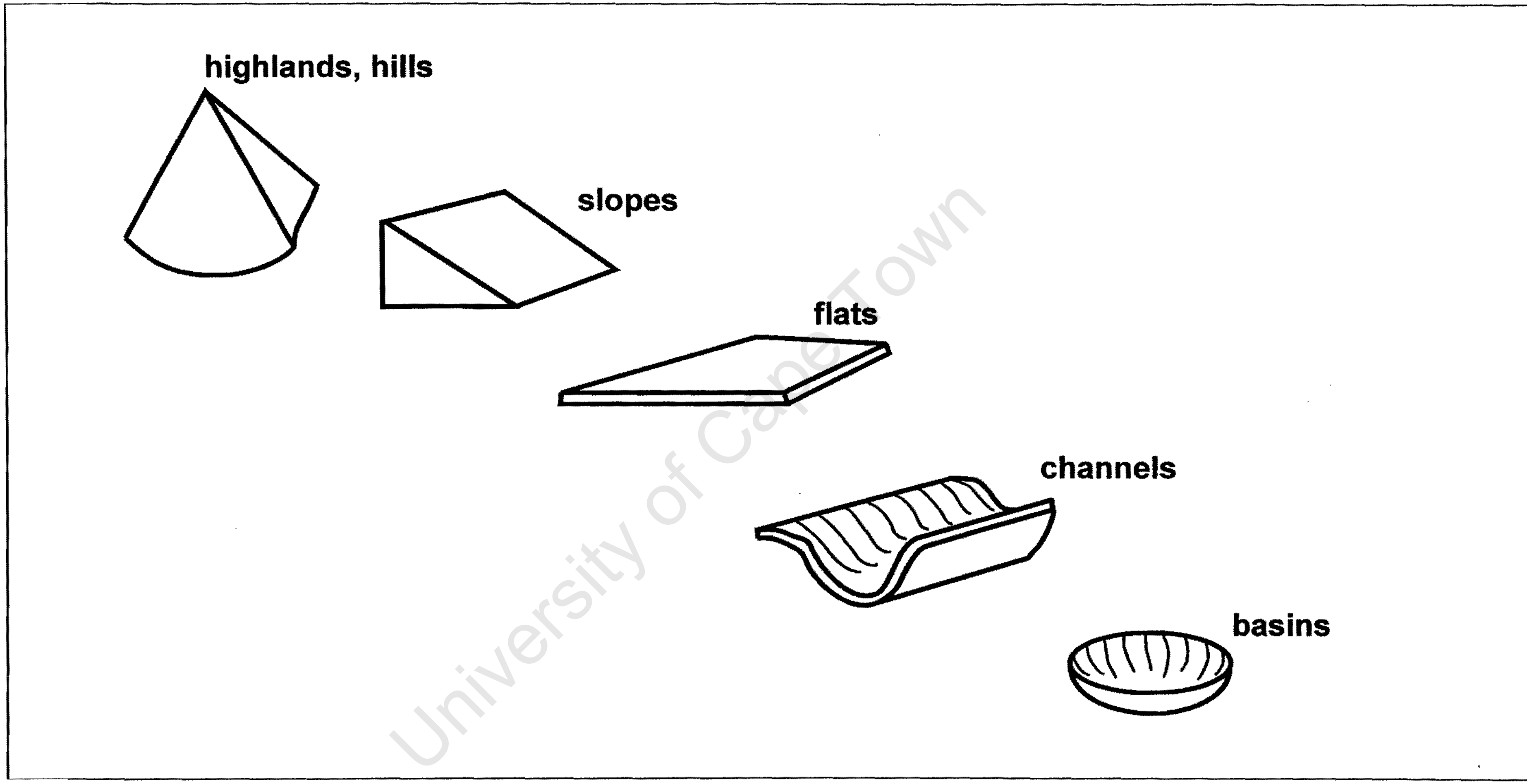


Figure 2.4 The continuum of landforms, from hill tops to basins which support wetlands (reproduced from Semeniuk and Semeniuk, 1995).

The above classification system only includes categories of wetlands known to exist in Australia and additional categories may exist elsewhere. For example, Semeniuk and Semeniuk (1995) know of no wetland exhibiting intermittent or permanent waterlogging, and suggest that such categories should be created if required.

Table 2.1 Basic wetland units described by Semeniuk and Semeniuk (1995)

Hydrological regime	Landform				
	Basin	Channel	Flat	Slope	Highland
Permanent inundation	Lake	River			
Seasonal inundation	Sumpland	Creek	Floodplain		
Intermittent inundation	Playa	Wadi	Barlkarra		
Seasonal waterlogging	Dampland	Trough	Palusplain	Paluslope	Palusmont

Semeniuk and Semeniuk (1995) recognise that there may be a number of zones within a single standing water body that might represent different wetland types. For example, a lake may include a sumpland. They tried to overcome the problem of labeling a single water body with different names by introducing a percentage separation. For example, if ten percent or more of a water body is a permanently inundated basin ("lake") and the rest is a seasonally inundated basin ("sumpland") the waterbody is classified as a lake. Quantifiable distinctions prevent discrepancies in classification between scientists but could make data collection more time consuming.

Since the classification system was developed in Australia, which has a climate more similar to that of South Africa than most parts of the United States and Europe do, it may be useful to apply locally. It is designed to include those wetlands dependent on variable climate (*e. g.* small shallow temporary endorheic wetlands) that are not comprehensively included in classification systems from Europe and the United States. The classification system is presented in the form of a hierarchical key, which facilitates its use and understanding, and also makes modification relatively easy. The classification system is not as widely known and accepted as the Cowardin system, possibly because it was developed 16 years later. This means that the terms are not globally accepted, and communication regarding wetlands classified according to the Semeniuk and Semeniuk's (1995) classification system may be difficult. Despite the obvious problems associated with applying a new classification system, this classification system may be easily adapted for use in South Africa and the categories used to define wetlands are more useful for grouping South African wetlands than those created in other classification systems (discussed further in section 3.6). However, the classification system only provides useful information for broad-scale classification, and finer detail is required to usefully group wetlands for biologists, managers and especially for the 'ecological reserve' which is specified in the South African National Water Act No 36 (1998).

2.5 Wetlands in South Africa

Authors such as Noble and Hemens (1978), Geldenhuys (1982) and Rogers (1995) have described a variety of South African inland aquatic ecosystems types, some of which are specific to the region. Although these descriptions do not all follow the hierarchical classification system format, they provide a fairly comprehensive data base of the different types of South African wetlands for which a classification system should be developed.

2.5.1 South African inland water ecosystems described by Noble and Hemens (1978)

Noble and Hemens (1978) described six categories of inland aquatic ecosystems in South Africa: rivers; vleis and floodplains; endorheic pans and other lakes of the interior; man-made impoundments; coastal and estuarine lakes; and estuaries and estuarine lagoons (Table 2.2). This subdivision was as an initial attempt to put order to the chaos of wetlands types in South Africa and, although it is a single-scale wetland description rather than a true classification system it has been useful in identifying the variability of South African wetlands. A hierarchical key facilitates use of any classification scheme and Breen and Begg (1989) have modified the Noble and Hemens (1978) classification system to present it in a hierarchical format similar to that shown in Table 2.2. Since it was an initial step to describing wetlands of South Africa rather than a classification system, it is not always possible to assign wetlands to single categories (as shown in section 3.6) . The categories Vleis and Floodplains; Endorheic Pans and Lakes of the Interior;

Table 2.2 Inland water ecosystems described by Nobel and Hemens (1978).

Ecosystem	**Wetland Type**	
Rivers		
Vleis and Floodplains	River source sponges	
	Marshes and Swamps	Sedge marshes Restio marshes Reedbed marshes Reedswamps Papyrus swamps Cape seasonal wetlands Swamps forests Salt marshes Mangrove swamps
	Floodplains	Karoo salt flats Floodplain vleis Storage Floodplains
Endorheic Pans and lakes of the interior		Salt pans Temporary pans Grass pans Sedge pans Reed pans Semi-permanent pans
Impoundments (man-made)		
Coastal and Estuarine lakes	Coastal lakes	Brackish, seepage outflow Fresh or Brackish, outflow to sea Fresh or Brackish, outflow to sea, occasionally tidal
	Estuarine	Fresh to saline, shallow Fresh to saline, deeper, stratified Fresh to hypersaline
Estuaries and Estuarine lagoon		Estuaries forming temporary lagoons Embayment estuaries Estuaries connected to coastal/estuarine lakes Typical estuaries River mouths

Rivers are not grouped into different types, but Noble and Hemens (1978) present a table indicating the different zones that make up a entire river.

and Coastal and Estuarine Lakes are the specific wetlands investigated in the present project."Vlei" is a common South African term used to refer to many types of wetlands, including endorheic wetlands, floodplains and deep coastal lakes. While the word may be used colloquially, it should be avoided for use in a classification systems because it gives rise to ambiguities.

2.5.2 Riparian wetlands identified by Rogers (1995)

Rogers (1995) deals with the classification of riparian wetlands, which are distinguished from other wetlands by three main features: (1) they have linear form, (2) energy and materials from the surrounding landscape pass through the wetlands in greater proportions than through other ecosystems, (3) the wetlands are hydrologically connected to upstream and downstream ecosystems, at least intermittently. Riparian wetlands are thus defined as : "... open ended (exorheic) systems which occur adjacent to river and stream channels, where plant species distribution and growth is determined by, at least intermittent, soil (root zone) saturation or inundation as a consequence of fluctuation in flow." Rogers (1995) describes five types of riparian wetlands: storage floodplains, floodplain vleis, karoo salt flats, riparian swamp forests, and riparian fringes. To some degree these riparian wetlands coincide with the ecosystem category "Vleis and Floodplains" described by Noble and Hemens (1978) and the Palustrine systems in the Cowardin system. Although these systems are connected to and dependent on rivers, they are distinct from rivers and need to be included in a wetland classification system. The difference between these and other wetlands (such as endorheic wetlands described in the next section) in South Africa is considerable and they are easily identified by non-scientists.

2.5.3 Endorheic wetlands of South Africa

Endorheic wetlands are common in South Africa. Noble and Hemens (1978) describe them as being of closed drainage and either permanently or periodically filled with water. The terminology of such wetlands is not uniform worldwide. Some authors have viewed them as a type of lake (Shaw, 1988); they are frequently referred to as "pans" and "vleis", and Allan *et al.* (1995) cite Neal (1975) as claiming that "the most commonly used name for these features in world geomorphological literature is playa." However, a "playa" generally is considered to be specific kind of endorheic wetland, usually a large temporary saline wetland which often ends in a terminal lake. "Pan" is probably a suitable local term. In their review of endorheic pans, Allan *et al.* (1995) define pans as having the following characteristics

- their shape is typically circular to oval and where two or more pans have spread or combined they are kidney- or lobe- shaped and
- they are shallow, usually less than 3m deep, even when fully inundated.

Allan *et al.* (1995) also refer to the Goudie and Thomas' (1985) definition of pans as "small closed basins". There are differences in opinion regarding the definitions of pans, but for the purpose of this project "pans" may be described as shallow, endorheic circular, oval or lobe-shaped wetlands.

Allan *et al.* (1995) note that the largest pans may exceed 1 000 ha and suggest a cut-off point of 1ha as the smallest pan size to be inventoried. This cut-off point was probably suggested in order to facilitate remote sensing analysis since it is not always possible to identify small wetlands from maps and orthophotographs, but this would result in a large number of small and functionally important wetlands being neglected.

Allan *et al.* (1995) indicate that these wetlands are "characteristically ephemeral" but describe three types of inundation:(1) "many years between temporary flooding", (2) "pans may contain water seasonally" and (3) "some larger pans have been never known to dry up". These authors suggest that this last category might better be "...classified as lakes since they are large, deep, permanent and have rooted vegetation". Endorheic pans may gain water from precipitation or stream flooding, but water is lost from them almost entirely by evaporation. They usually hold water because they are clay-bottomed and therefore well sealed, which also results in very little infiltration into the groundwater.

South African endorheic wetland classification

Probably because pans are prevalent and important in South Africa there has been a long history of pan classification. This is summarised by Allan *et al.* (1995). Du Toit (1927) classified pans as either inland or coastal (flats or in sand dunes). Hutchinson *et al.* (1932) developed this classification system and divided the inland wetlands into three geographical categories: pans of the Transvaal (which now includes Gauteng, Northern Province and Mpumalanga) the south-central Transvaal (now, more or less the Gauteng province) and the south-eastern Transvaal (more or less Mpumalanga). Leistner (1967) identified two types of pans in the Kalahari: rock pans (depressions in solid rock) and dune pans (those in sandy flats or between dune ridges). Pans have also been classified according to vegetation type for example *Scirpus* pans, reed (*Phragmites*) pans, *Melosira*-Cyanophyceae pans, *Potamogeton livingstonei* pans, *Nodularia* pans and vegetationless pans (Geldenhuys, 1982). Geldenhuys (1982) developed a classification system for pans of the Free State based on the presence of emergent vegetation; the types discussed are sedge pans, scrub pans, mixed grass pans, and closed and open *Diplachne* pans. Geldenhuys (1982) noted, however, that differentiation between pans is seen most clearly two months after flooding, which means that wetlands can be identified only in a specific season.

While a vegetation-based classification system for wetlands in the Free State is unlikely to be useful elsewhere, it provides information about wetland functioning in the area and details required for management. Such studies should also include classification according to an internationally or nationally accepted classification system to facilitate compilation of inventories.

2.5.4 Coastal lakes

Although extensive natural deep open water or lacustrine wetlands (such as the Great Lakes of the United States) are not common in southern Africa (Lake Fundudzi being the only example in South Africa), numerous coastal water bodies exist. These wetlands are called coastal or estuarine lakes by Noble and Hemens (1978) and Hart (1995) distinguishes between coastal lakes connected to the sea and isolated coastal lakes that may vary in salinity from fresh to supersaline. Hart (1995) identifies the Cape Peninsula and south-western Cape as an area supporting coastal lakes. These include wetlands such as the Langvlei and Eilandvlei (Wilderness Lakes) that are occasionally connected to the sea and Groenvlei (also a Wilderness Lake) which is endorheic.

2.5.5 Classification system for wetland soils in South Africa

Anaerobic conditions of inundated soils result in hydromorphic features or signs of wetness in the soil, and both give an indication of the moisture regime of the wetland (Kotze *et al.*, 1994).

Signs of wetness within 500mm of the soil surface are used as a wetland indicator and the type of hydromorphic feature is used to determine the type of wetland.

Kotze *et al.* (1994) could not use the Cowardin system in their wetland classification system because there are too many categories for categorization of hydric soils and because classes of the Cowardin system are not clearly defined in terms of some variables such as water table depths. Instead, they provided a "provisional water regime classification" which includes the following subdivisions: Class1a - permanently flooded or saturated wetlands, Class 1b - semi-permanently flooded/saturated wetlands, Class 2 - seasonally flooded/saturated wetlands, and Class 3 - temporarily saturated/flooded wetlands. This classification system was developed for classification of Kwazulu/Natal wetland soils and allows identification of these water regime classes. Kotze *et al.* (1994) noted that the hydromorphic soil characteristics and water regime studies only apply to local soils and thus their classification system cannot be applied universally. However, a classification system of this kind is valuable in that it allows localised management of wetlands and their soils and this is of particular importance in agricultural areas such as Kwazulu/Natal.

Chapter Three
Selection of wetlands for field analysis

3.1 Introduction

The study was carried out within the Western Cape province of South Africa. Within the Western Cape, geographical regions have been identified from biotic communities, climate and geomorphological features. Since wetlands within a region share climatic, geomorphological and biotic characteristics, wetlands within a region will be more similar to each other than wetlands of different regions. In order to include a variety of different types of wetlands, study sites were selected from as many different parts of the Western Cape as possible.

3.2 Western Cape province

Investigation of wetlands was confined to the political boundary of the Western Cape for a number of reasons:

- A reasonable proportion of an area of this size could be investigated within the time available.

- The area is managed by a single governing body (Western Cape Nature Conservation Board), which means that the final result will cover areas of relevance for this governing body. This is likely to be more beneficial than partial coverage of areas governed by different management organisations since it will allow one management body to maintain the area using a management regime based upon a single classification system.

- The geographical boundary of the Western Cape is similar to that of the Cape Floral Kingdom and includes a specific number of distinct climatic, geomorphological and biotic areas. The Cape floral kingdom is the smallest of the Earth's six floral kingdoms and the only one to be found within a single country (Cowling and Richardson, 1995).

The Western Cape is at the southernmost part of the African continent. The coast is bounded to the east by the warm Indian Ocean and to the west by the cold Atlantic Ocean, which results in a strong marine influence on many coastal wetlands. On the north western side of the country, the area is bounded by the Orange River, but the arid Karoo region makes up large parts of the interior (Figure 3.1).

The main geological type of the south western Cape is the Sandstones of the Table Mountain Group, but Malmesbury shales and alluvial areas do occur (Silberbauer and King, 1991a). Although some areas within the province rise to altitudes of 1500m (Silberbauer and King, 1991a), the coastal plain, which extends far inland, reaches an average altitude of 500m. The province is comprised of areas that support different climatic regimes and vegetation types and the diversity of aquatic systems is related to these areas.

Considering the size of this area, there is a relatively high diversity in types of landscape and a corresponding biotic diversity and endemism. The floral biodiversity of the area has been well documented, particularly the South Western Cape that supports the Cape Floral Kingdom (Cowling *et al.*, 1992), as well as high diversity and endemism of the aquatic fauna (Wishart and Day, in press). Compounds such as tannins and other polyphenolics derived from fynbos vegetation (a dominant floral type of the Cape Floral Kingdom) leach into the freshwater wetlands and result in the black or "peat-stained" waters that are characteristic of the south western Cape (*e. g.* Britton, 1991).

Wetlands studied for this project were selected from the west coast (Berg River), east coast (Agulhas Plain, Gouritz River and Wilderness), Cape Peninsula (including Cape Point and Bettys Bay), farmland near Vanrhynsdorp, Cederberg (Koue and Warm Bokkeveld) and wetlands in the Ceres and Worcester farmlands (Table 3.1). This range ensured that wetlands were investigated from the west (Berg River), east (Wilderness) and south western (Cape Peninsula) coast of the Western Cape as well as in the more arid inland Karoo (Figure 3.1).

3.3 Bioregions of the Western Cape

Bioregions are geographical regions distinguished by differences in biotic composition. Using presence/absence data for selected taxa (limited checklists of taxonomic data were available), Brown *et al.* (1996) identified eleven bioregions in southern Africa, six of which are in the

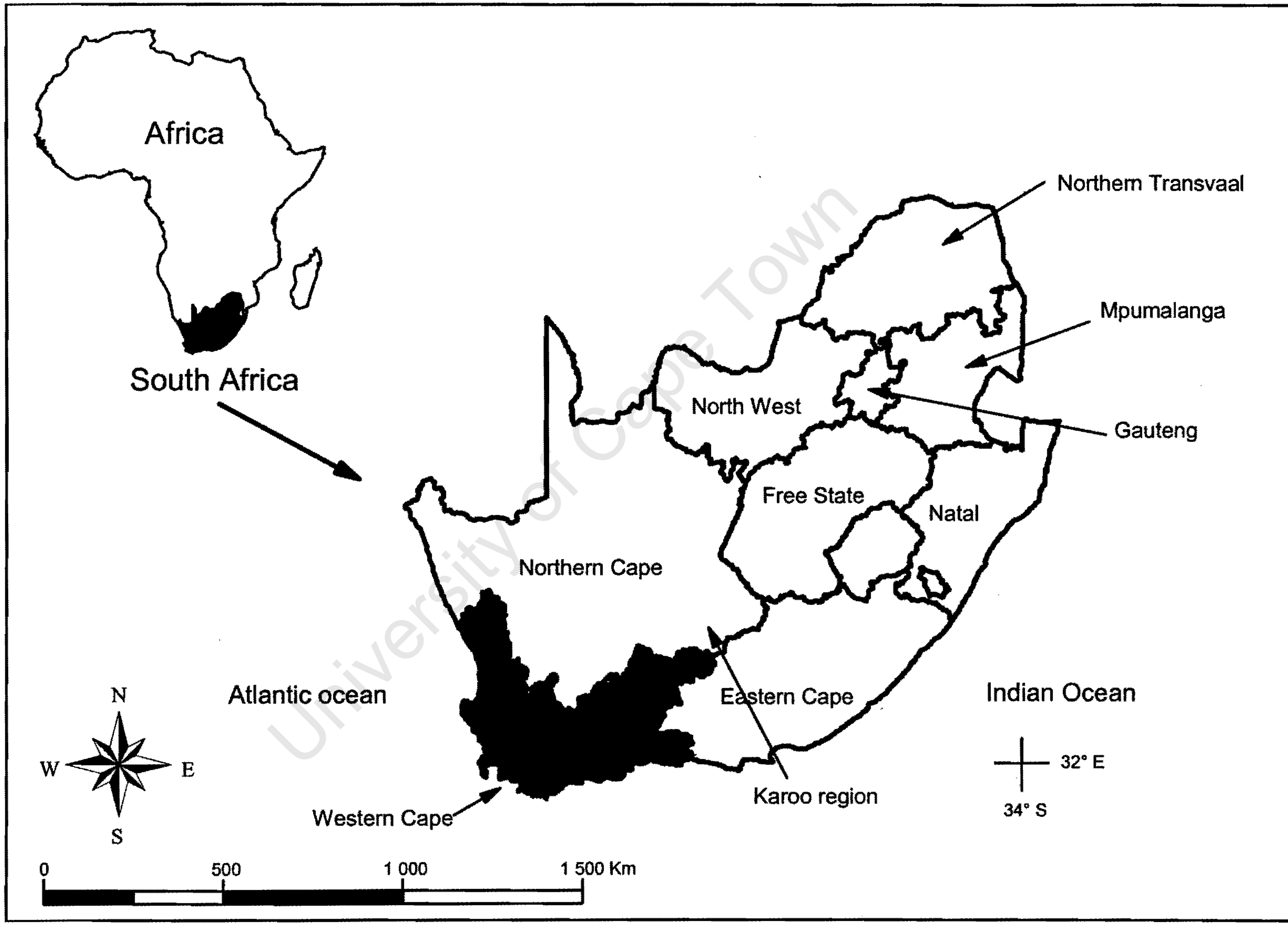


Figure 3.1 The provinces of South Africa reproduced from the surveyor-general republic of South Africa. The area of study is within the Western Cape Province boundary. The Karoo region is not limited to to specific provinces, but covers a large proportion of the interior of the country.

Table 3.1 Characteristics of areas at which wetlands were investigated. Bioregions and Wetland Regions are shown on the maps of Figures 3.2 and 3.3.

Area	Number of wetlands investigated	Altitude range [1] (m)	Average rainfall [1] (mm)	Bioregions [2]	Wetland regions [3]
Berg River and Verlorenvlei	9	0 - 500	0 - 400	Fynbos	Western Coastal Slope
Agulhas Plain	17	0 - 500	401 - 800	Fynbos	Western Coastal Slope
Gouritz River	4	0 - 500	401 - 800	Alkaline Interior	Southern Coastal Slope
Wilderness	4	0 - 500	200 - 6000	Southern Coastal	Southern Coastal Slope
Cape Peninsula and Betties Bay	12	0 - 500	401 - 1200	Fynbos	Cape Fold Mountains
Vanrhynsdorp	4	0 - 500	0 - 400	Arid Interior	Western Coastal Slope
Cederberg	8	1000 - 1500	401 - 1200	Fynbos	Cape Fold Mountains
Ceres and Worcester	4	500 - 1500	401 - 1200	Fynbos	Cape Fold Mountains

1 Silberbauer and King (1991); 2 Brown *et al.* (1996), Figure 2.2; 3 Cowan (1995), Figure 2.3.

Western Cape. Wetlands were investigated from four of these six bioregions: the fynbos, the alkaline interior, the southern coastal and the arid interior bioregions (Figure 3.2).

The Fynbos Bioregion is characterised by a mediterranean, winter-rainfall climate and has a variable average rainfall average from 600 to 2000 mm y^{-1}. The water in rivers is oligotrophic, peat stained and acidic which appears to be the situation in both riverine and endorheic wetlands (Van Niewenhuizen and Day, 2000).

The Southern Coastal Bioregion receives between 600 and 2000 mm y^{-1} of aseasonal rainfall. The dominant underlying rock type is the Table Mountain Group, which usually results in peat-stained, clear, NaCl-dominated and acidic aquatic environments (Van Niewenhuizen and Day, 2000). Three of the four wetlands investigated in the bioregion are indirectly and temporarily connected to the sea, however, and their water show some marine influences.

The Alkaline Interior Bioregion is dominated by seasonal or ephemeral alkaline aquatic environments. Although it falls within a winter rainfall climate the climate is arid (Van Niewenhuizen and Day, 2000) .

The Arid Interior Bioregion supports ephemeral rivers and wetlands as the annual average rainfall is low. The area has been severely impacted by agricultural activities (Van Niewenhuizen and Day, 2000). Study wetlands in this Bioregion were all in farmlands but were investigated despite possible human disturbance since an initial assessment of maps indicated that these endorheic wetlands might be different from others in the Western Cape.

3.4 Wetland Regions of South Africa

Cowan (1995) divides South Africa into four broad areas based on the morphology of the country. Geomorphology and climatic characteristics, temperature and humidity zones, were then used to further divide these areas into Regions (Cowan, 1995). The Western Cape includes mainly

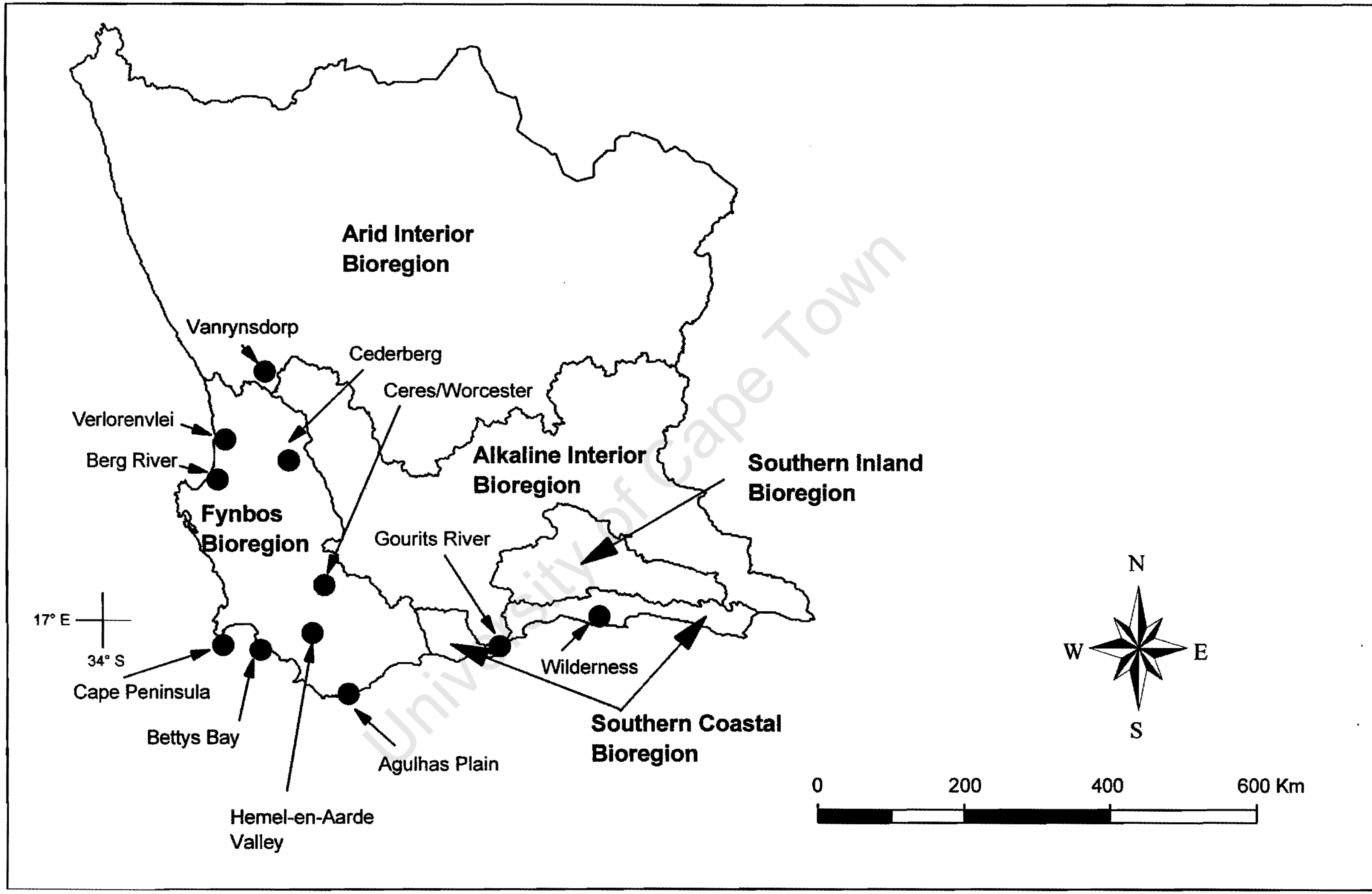


Figure 3.2 Wetland study areas within the bioregions of the Western Cape from Brown *et al.* (1996).

the Cape Fold Mountain Regions and the Western Coastal Slope Region but also parts of the Southern Escarpment Region, Southern Coast and the Karoo Regions (Figure 3.3).

Wetlands selected for this study fall into the Cape Fold Mountain, the Western Coastal Slope and the Southern Coast Regions (Table 3.1). Cowan (1995) notes that wetlands typical of a region are not necessarily found only in that region, but wetlands within a specific region will be affected by similar climate and geomorphological features.

The Cape Fold Mountain Region of the study is characterised by a Mediterranean climate (winter rainfall and dry summers). Cowan (1995) also identifies restioid marshes as typical wetlands of the region. Study wetlands of Cape Peninsula, Bettys Bay, Cederberg and Ceres/Worcester areas fall within the Cape Fold Mountain Region.

Wetlands from two Western Coastal Slope Regions were investigated; one is a desert climate region and the other is a mediterranean climate region. The wetlands investigated near Vanrhynsdorp fall within the Western Coastal Slope, desert region. The area is characterised by "low, unreliable rainfall of up to 250mm " per annum from summer and autumn showers. Winter precipitation occurs along the coast, and a wide range of seasonal and daily temperatures occur. Small coastal pans and salt marshes are dominant in the area (Cowan, 1995).

Rainfall of the Western Coastal Slope mediterranean region ranges from "250mm on the plains to 2 500mm on the mountains". Wetlands of the area are coastal lakes, salt-marshes, hygrophilous and restioid marshes (wetlands vegetated with short bushy vegetation, particularly of the Restionaceae) (Cowan, 1995). Verlorenvlei, the Berg River Estuary and Agulhas Plain study areas fall within this region.

The Southern Coast temperate region includes the wetlands investigated at Wilderness and Gouritz river areas and Cowan (1995) notes that the area is characterised by coastal lakes. The climate of the region is warm and humid, with hot, dry berg winds and rainfall varies from 380mm y^{-1} to 1140mm y^{-1} (Cowan, 1995).

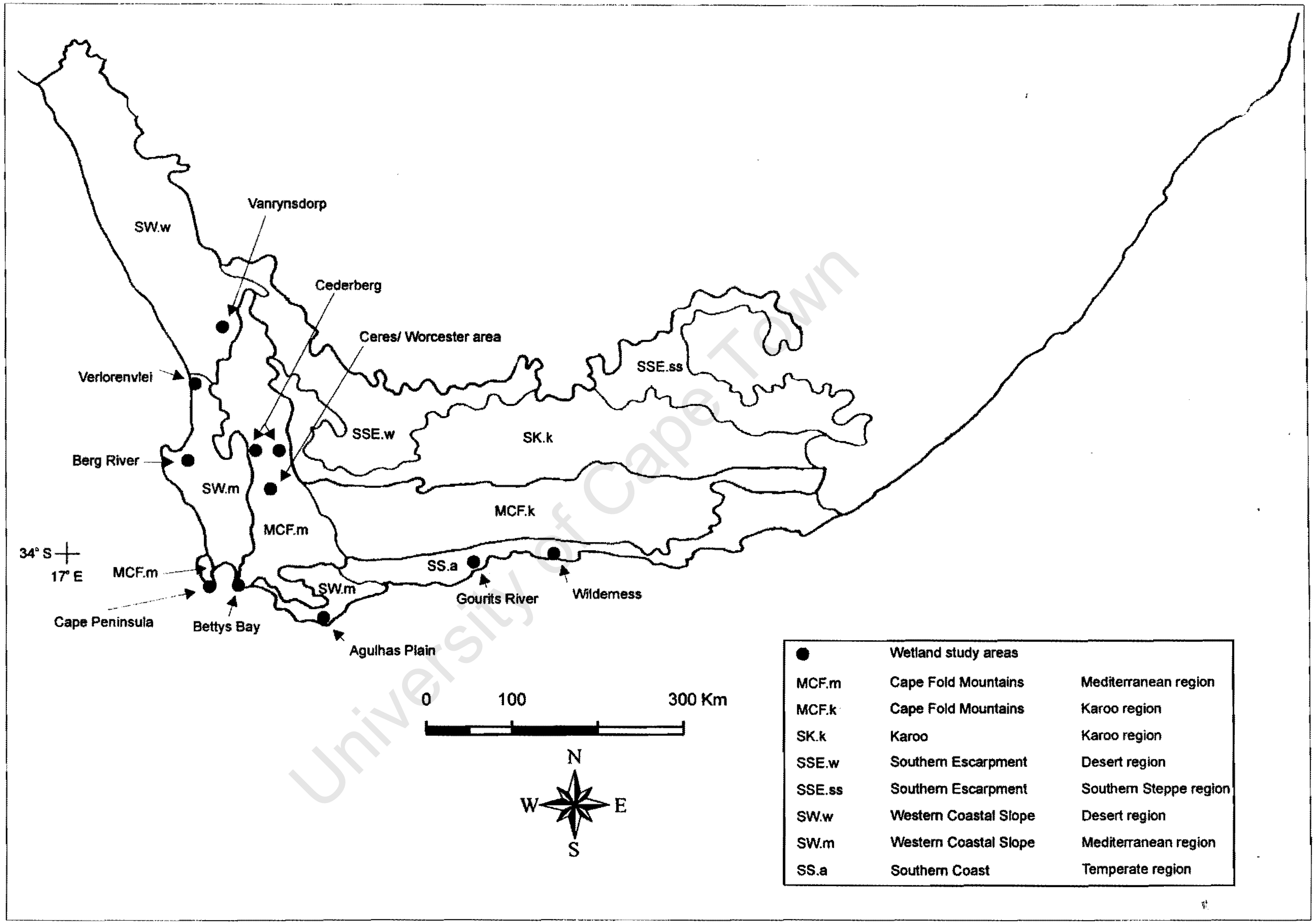


Figure 3.3 Wetland study areas within the different wetland regions defined by Cowan (1995). Map reproduced from Cowan (1995).

3.5 Wetland study sites

Wetlands were chosen for investigation using existing data bases (Cowan and van der Riet, 1998 and Silberbauer and King, 1991a) as well as 1:50 000 maps. It may be noted that a large portion of the wetlands investigated are endorheic; such wetlands are common in the Western Cape. Where possible, relatively undisturbed wetlands were selected for field analysis. This ensured that wetland characteristics investigated at each site were representative of wetlands in their natural condition so that the developed classification system would be based on natural rather than disturbance created characteristics. Geographical position and altitude were recorded using a GPS Magellan Tracker (accurate to 5 - 50 m) and the wetlands names or the name of the farm on which they were situated were also recorded (Figure 3.4). Each wetland was visited and investigated during the 2000 winter/spring (post rainfall) season (August to October) and again during the 2001 dry summer months (January and February). The code, location and name of each wetland is recorded in Table 3.2 and Figure 3.4.

3.6 Classification of study wetlands using existing wetland classification systems

An attempt was made to categorise the study wetlands using the Morant (1983) adaptation of the Cowardin system and the Semeniuk and Semeniuk (1995) classification system (Table 3.3a). Although Semeniuk and Semeniuk (1995) do not provide quantitative specifications for each category it is fairly easy to group wetlands using their method and coarse geomorphological and hydrological wetland categories. Due to the low rainfall during the winter field study some wetlands were recorded as seasonally saturated or waterlogged rather than seasonally inundated. This means that some flats (such as sites C11, D13 and E7) that in years of average rainfall might be classified as "floodplains" are now classified as "barlkarras". A number of shallow wetlands, which are commonly termed pans in South Africa were classified as "lakes" merely because they are "permanently inundated basins". As these wetlands are less than 500mm deep, and the word "lake" usually refers to deep waters, some confusion may arise by classifying them as "lakes" .

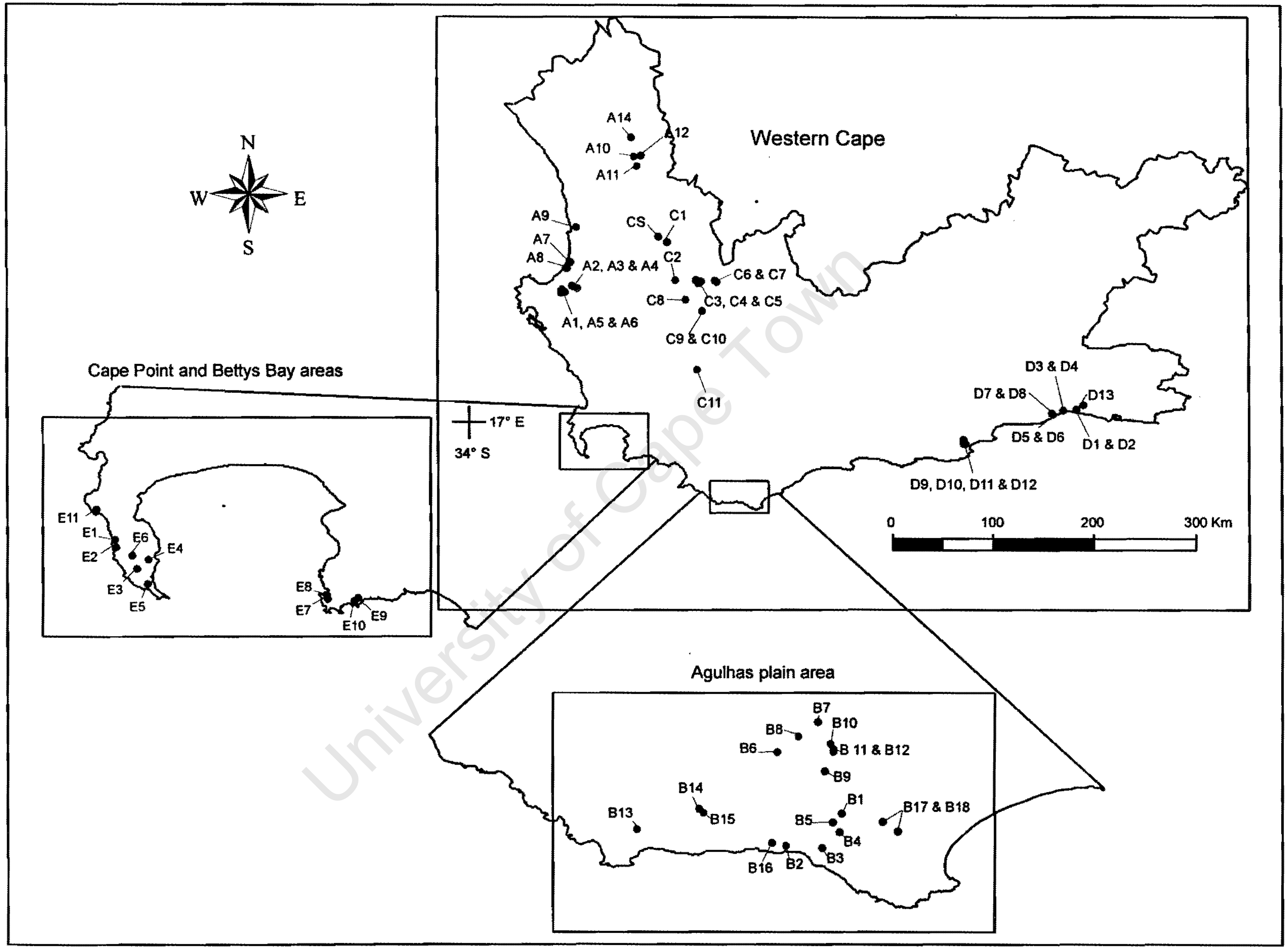


Figure 3.4 Points indicating wetland study sites within the Western Cape boundary.

The Morant (1983) classification system uses the Cowardin classification's key and some definitions developed there, such as the salinity and pH regime modifier. Morant (1983) seems to have altered some categories, such as the salinity regime modifier, but as these altered categories are not specifically defined by him I have referred to categories and definitions supplied by Cowardin *et al.* (1979; Table 3.3b). Using the wetlands water regime modifier proved to be difficult as the one years field study does not allow one to accurately fit the wetlands to the water regime modifier categories, particularly as the winter of this study was much drier and warmer than average winters and the wetlands' water regime recorded during this study would be a recording of their drier extreme rather than a recording of their average degree of wetness. For these reasons wetlands have not been designated a water regime category. Occasionally, it is problematic assigning wetlands to specific categories from field studies since percentage aerial cover of characteristics such as substratum and emergent vegetation cannot be easily obtained. But the Cowardin system was developed for remote sensing use and these characteristics may be obtained from fine scale aerial photographs and orthophotographs.

As Morant (1983) uses the Cowardin system most of the wetlands are classified as palustrine. In order to indicate the differences of these wetlands the descriptions from Noble and Hemens (1978) that may be associated with the wetlands have been included in Table 3.3. Since specific details informing the reader on how to assign wetlands to their categories is lacking, grouping wetlands according the Noble and Hemens (1978) descriptions is ambiguous and occasionally it was felt that certain wetlands could be described by more than one category.

Table 3.2 List of study sites and their codes, altitude and geographical coordinates.

Site	Farm or wetland	Altitude (m)	Latitude	Longitude	Area	Landscape type	Bioregion	Wetland Region
A1	Kruispad 1	9	32° 51' 39"	18° 14' 10"	Berg River catchment	Coastal plain	Fynbos	Western Coastal Slope
A2	Doornfontein 1	7	32° 51' 12"	18° 17' 13"	Berg River catchment	Coastal plain	Fynbos	Western Coastal Slope
A3	Doornfontein 2	0	32° 50' 54"	18° 18' 48"	Berg River catchment	Coastal plain	Fynbos	Western Coastal Slope
A4	Doornfontein 3	18	32° 51' 2"	18° 18' 33"	Berg River catchment	Coastal plain	Fynbos	Western Coastal Slope
A5	Kruispad 2	1	32° 52' 13"	18° 15' 23"	Berg River catchment	Coastal plain	Fynbos	Western Coastal Slope
A6	Kruispad 3	0	32° 52' 7"	18° 15' 16"	Berg River catchment	Coastal plain	Fynbos	Western Coastal Slope
A7	Rocher Pan	9	32° 36' 17"	18° 18' 8"	West coast	Coastal plain	Fynbos	Western Coastal Slope
A8	La Rochelle	16	32° 39' 16"	18° 16' 26"	West coast	Coastal plain	Fynbos	Western Coastal Slope
A9	Verlorenvlei	11	32° 19' 22"	18° 22' 51"	West coast	Coastal plain	Fynbos	Western Coastal Slope
A10	Ronderug	159	31° 39' 47"	18° 52' 25"	Vanrhynsdorp	Inland plateau	Arid interior	Western Coastal Slope
A11	Blinkvlei	199	31° 44' 20"	18° 55' 23"	Vanrhynsdorp	Inland plateau	Arid interior	Western Coastal Slope
A12	Sandvlei	204	31° 40' 7"	18° 55' 45"	Vanrhynsdorp	Inland plateau	Arid interior	Western Coastal Slope
A14	Palmiet Fontein	165	31° 30' 6"	18° 51' 20"	Vanrhynsdorp	Inland plateau	Arid interior	Western Coastal Slope
B1	Soutpan	14	34° 43' 27"	19° 55' 21"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B2	Brandfontein 1	22	34° 45' 42"	19° 51' 29"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B3	Brandfontein 2	21	34° 45' 49"	19° 53' 53"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B4	Springfield 1	21	34° 44' 41"	19° 55' 6"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B5	Springfield 2	15	34° 44' 15"	19° 54' 40"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B6	Vogel Valley	22	34° 39' 15"	19° 50' 38"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B7	Langpan	17	34° 36' 58"	19° 53' 30"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B8	Haze Vlakte	14	34° 37' 55"	19° 52' 4"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B9	Wiesdrif	9	34° 40' 30"	19° 54' 15"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B10	Rooiwal	16	34° 38' 33"	19° 54' 31"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B11	Honing Rug	15	34° 38' 47"	19° 54' 42"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B12	Rattelrivier 1	13	34° 38' 47"	19° 54' 42"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B13	Rattelrivier 2	12	34° 44' 28"	19° 40' 42"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B14	Melkbospan 1	34	34° 43' 4"	19° 45' 18"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B15	Melkbospan	37	34° 43' 14"	19° 45' 29"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B16	Rietfontein	20	34° 45' 33"	19° 50' 22"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B17	Soetendalsvlei a	0	34° 43' 59"	19° 58' 15"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope
B18	Soetendalsvlei b	2	34° 44' 57"	19° 59' 8"	Agulhas Plain	Coastal plain	Fynbos	Western Coastal Slope

Site	Farm or wetland	Altitude (m)	Latitude	Longitude	Area	Landscape type	Bioregion	Wetland Region
CS	Cederberg	2	32° 24' 36"	19° 6' 36"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C1	Driehoekvlei	903	32° 26' 10"	19° 9' 5"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C2	Wagenboomsrivie	845	32° 47' 34"	19° 14' 46"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C3	Zuurvlakte 1	952	32° 46' 58"	19° 28' 27"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C4	Zuurvlakte 2	971	32° 46' 50"	19° 27' 8"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C5	Zuurvlakte 3	985	32° 47' 52"	19° 27' 7"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C6	Zwartrug 1	1137	32° 46' 30"	19° 35' 24"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C7	Zwartrug 2	1129	32° 46' 44"	19° 35' 52"	Cederberg	Mountain escarpement	Fynbos	Cape Fold Mountains
C8	Wagen Drift	948	33° 1' 32"	19° 19' 22"	Ceres	Mountain escarpement	Fynbos	Cape Fold Mountains
C9	Odessa	975	33° 7' 15"	19° 25' 43"	Ceres	Mountain escarpement	Fynbos	Cape Fold Mountains
C10	Groot Vlakte	970	33° 7' 15"	19° 25' 43"	Ceres	Inland plateau	Fynbos	Cape Fold Mountains
C11	Bokke Kraal	188	33° 40' 23"	19° 22' 57"	Ceres	Inland plateau	Fynbos	Cape Fold Mountains
D1	Groenvlei a	190	34° 2' 1"	22° 51' 7"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D2	Groenvlei b	0	34° 1' 33"	22° 51' 1"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D3	Rondevlei a	14	33° 59' 24"	22° 43' 3"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D4	Rondevlei b	4	33° 59' 45"	22° 42' 13"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D5	Langvlei a	5	33° 59' 29"	22° 41' 41"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D6	Langvlei b	5	33° 59' 29"	22° 41' 41"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D7	Eilandvlei a	1	33° 59' 15"	22° 38' 40"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D8	Eilandvlei b	3	33° 59' 40"	22° 38' 6"	Wilderness	Coastal plain	Southern Coastal	Southern Coastal
D9	Voelvlei	7	34° 15' 57"	21° 50' 11"	Gouritz River	Inland plateau	Alkaline Interior	Southern Coastal
D10	Zoutpan 1	5	34° 16' 45"	21° 50' 22"	Gouritz River	Inland plateau	Alkaline Interior	Southern Coastal
D11	Zoutpan 2	21	34° 16' 47"	21° 50' 12"	Gouritz River	Inland plateau	Alkaline Interior	Southern Coastal
D12	Ou Soutpan	6	34° 16' 44"	21° 50' 40"	Gouritz River	Inland plateau	Alkaline Interior	Southern Coastal
D13	Rachmere	7	34° 0' 15"	22° 49' 28"	Wilderness	Inland plateau	Southern Coastal	Southern Coastal
E1	Grootrondevlei	7	34° 14' 18"	18° 22' 57"	Cape Peninsula	Coastal plain	Fynbos	Cape Fold Mountains
E2	Kleinrondevlei	17	34° 14' 56"	18° 22' 55"	Cape Peninsula	Coastal plain	Fynbos	Cape Fold Mountains
E3	Cape Peninsula 1	124	34° 17' 39"	18° 25' 52"	Cape Peninsula	Coastal plain	Fynbos	Cape Fold Mountains
E4	Cape Peninsula 2	139	34° 16' 23"	18° 27' 6"	Cape Peninsula	Coastal plain	Fynbos	Cape Fold Mountains
E5	Skulpadvlei 1	85	34° 19' 39"	18° 27' 3"	Cape Peninsula	Coastal plain	Fynbos	Cape Fold Mountains
E6	Sirkelsvlei	103	34° 16' 9"	18° 24' 56"	Cape Peninsula	Coastal plain	Fynbos	Cape Fold Mountains
E7	Pringle Bay	6	34° 21' 30"	18° 49' 17"	Hangklip/Bettys Bay	Coastal plain	Fynbos	Cape Fold Mountains
E8	Skulpadsvlei 2	7	34° 21' 44"	18° 49' 7"	Hangklip/Bettys Bay	Coastal plain	Fynbos	Cape Fold Mountains
E9	Bettys Bay 1	8	34° 22' 0"	18° 53' 20"	Hangklip/Bettys Bay	Coastal plain	Fynbos	Cape Fold Mountains
E10	Bettys Bay 2	6	34° 22' 3"	18° 53' 2"	Hangklip/Bettys Bay	Coastal plain	Fynbos	Cape Fold Mountains
E11	Soetwater	2	34° 10' 28"	18° 20' 49"	Cape Peninsula	Coastal plain	Fynbos	Cape Fold Mountains

Table 3.3a Classification of wetlands using existing classification systems.

	Wetlands classified according to Morant (1983)					Wetland categories (Noble and Hemens, 1978)		Semeniuk and Semeniuk (1995)
Site	System	Subsystem	Class	Subclass	Water chemistry			
A1	Palustrine		Unconsolidated bottom	Mud	Subsaline	Floodplain	Floodplain pan	Floodplain
A2	Palustrine		Unconsolidated bottom	Mud	Subsaline	Floodplain	Floodplain pan	Sumpland
A3	Palustrine		Unconsolidated bottom	Mud	Brackish	Endorheic	semi-permanent pan / Reed pan	Sumpland
A4	Palustrine		Unconsolidated bottom	Mud	Brackish	Endorheic	Salt pan	Sumpland
A5	Palustrine		Emergent vegetation	Narrow-leaved	Brackish	Floodplain/Marsh	Floodplain pan/ Restio marsh	Lake
A6	Palustrine		Unconsolidated bottom	Mud		Floodplain	Floodplain pan	Barlkarra
A7	Palustrine		Aquatic vegetation	Submerged vascular	Moderately brackish	Endorheic	Temporary pan	Lake
A8	Palustrine		Unconsolidated bottom	Mud	Subsaline	Endorheic	Salt pan	Floodplain
A9	Estuarine	subtidal	Emergent vegetation	Narrow-leaved	Oligohaline	Coastal lake	Brackish, outflow to sea	Lake
A10	Palustrine		Unconsolidated bottom	Mud	Alkaline fresh	Endorheic	Temporary pan	Sumpland
A11	Palustrine		Unconsolidated bottom	Mud	Slightly brackish	Endorheic	Temporary pan	Sumpland
A12	Palustrine		Unconsolidated bottom	Mud	Alkaline fresh	Endorheic	Temporary pan	Sumpland
A14	Palustrine		Unconsolidated bottom	Mud	Slightly brackish	Endorheic	Temporary pan	Sumpland
B1	Palustrine		Unconsolidated bottom	Mud	Saline	Endorheic	Salt pan	Floodplain
B2	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic/Marsh	Temporary pan	Sumpland
B3	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic/Marsh	Temporary pan	Sumpland
B4	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic	Temporary pan	Sumpland
B5	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic	Semi-permanent pan	Lake
B6	Palustrine		Unconsolidated bottom	Mud	Brackish	Endorheic	Temporary pan	Floodplain
B7	Palustrine		Unconsolidated bottom	Mud	Subsaline	Endorheic	Salt pan	Lake
B8	Palustrine		Emergent vegetation	Narrow-leaved	Moderately brackish	Floodplain/Marsh	Floodplain vlei/ Restio marsh	Floodplain
B9	Palustrine		Unconsolidated bottom	Mud	Slightly brackish	Floodplain/Marsh	Floodplain vlei/ Restio marsh	Floodplain
B10	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic	Semi-permanent pan	Lake
B11	Palustrine		Emergent vegetation	Narrow-leaved	Brackish	Floodplain/Marsh	Floodplain vlei/ Restio marsh	Floodplain
B12	Palustrine		Emergent vegetation	Narrow-leaved	Brackish	Coastal lake	seepage outflow	Lake
B13	Palustrine		Emergent vegetation	Narrow-leaved	Slightly brackish	Floodplain/Marsh	Floodplain vlei/ Restio marsh	Floodplain
B14	Palustrine		Unconsolidated bottom	Mud	Subsaline	Endorheic	Salt pan	Sumpland
B15	Palustrine		Aquatic vegetation	Submerged vascular	Slightly brackish	Endorheic	Temporary pan	Sumpland
B16	Palustrine		Aquatic vegetation	Submerged vascular	Subsaline	Endorheic	Temporary pan	Sumpland
B17	Palustrine		Emergent vegetation	Narrow-leaved	Slightly brackish	Coastal lake	Brackish, outflow to sea	Lake
B18	Palustrine		Emergent vegetation	Narrow-leaved	Moderately brackish	Coastal lake	Brackish, outflow to sea	Lake

	Wetlands classified according to Morant (1983)					Wetland categories (Noble and Hemens, 1978)		Semeniuk and Semeniuk (1995)
Site	System	Subsystem	Class	Subclass	Water chemistry			
CS	Palustrine		Emergent vegetation	Narrow-leaved		River source sponge		Paluslope
C1	Palustrine		Emergent vegetation	Narrow-leaved	Acid fresh	Floodplain/Marsh	Floodplain vlei	Floodplain
C2	Palustrine		Emergent vegetation	Narrow-leaved	Circumnuetral fresh	Floodplain	Floodplain vlei	Floodplain
C3	Palustrine		Unconsolidated bottom	Mud	Brackish	Marsh/Endorheic	Temporary pan	Sumpland
C4	Palustrine		Emergent vegetation	Narrow-leaved	Alkaline fresh	Endorheic	Temporary pan	Sumpland
C5	Palustrine		Unconsolidated bottom	Mud	Circumnuetral fresh	Endorheic	Temporary pan	Sumpland
C6	Palustrine		Unconsolidated bottom	Mud	Slightly brackish	Endorheic	Temporary pan	Sumpland
C7	Palustrine		Unconsolidated bottom	Mud		Endorheic	Temporary pan	Playa
C8	Palustrine		Emergent vegetation	Narrow-leaved	Circumnuetral fresh	Floodplain/Marsh	Floodplain vlei	Floodplain
C9	Palustrine		Emergent vegetation	Narrow-leaved		Floodplain/Marsh	Floodplain vlei	Floodplain
C10	Palustrine		Emergent vegetation	Narrow-leaved	Circumnuetral fresh	Floodplain/Marsh	Floodplain vlei	Floodplain
C11	Palustrine		Emergent vegetation	Narrow-leaved	Slightly brackish	Floodplain/Marsh	Floodplain vlei	Palusplain
D1	Palustrine		Emergent vegetation	Narrow-leaved	Moderately brackish	Coastal lake	Brackish, seepage outflow	Lake
D2	Palustrine		Emergent vegetation	Narrow-leaved	Moderately brackish	Coastal lake	Brackish, seepage outflow	Lake
D3	Estuarine	subtidal	Emergent vegetation	Narrow-leaved	Mesohaline	Coastal lake	Brackish, outflow to sea	Lake
D4	Estuarine	subtidal	Emergent vegetation	Narrow-leaved	Mesohaline	Coastal lake	Brackish, outflow to sea	Lake
D5	Estuarine	subtidal	Emergent vegetation	Narrow-leaved	Mesohaline	Coastal lake	Brackish, outflow to sea	Lake
D6	Estuarine	subtidal	Emergent vegetation	Narrow-leaved	Mesohaline	Coastal lake	Brackish, outflow to sea	Lake
D7	Estuarine	subtidal	Emergent vegetation	Narrow-leaved	Mesohaline	Coastal lake	Brackish, outflow to sea	Lake
D8	Estuarine	subtidal	Emergent vegetation	Narrow-leaved	Mesohaline	Coastal lake	Brackish, outflow to sea	Lake
D9	Palustrine		Aquatic vegetation	Submerged vascular		Floodplain	Floodplain vlei	Barlkarra
D10	Palustrine		Unconsolidated bottom	Mud	Moderately brackish	Endorheic	Semi-permanent pan	Lake
D11	Palustrine		Rock		Moderately brackish	Endorheic		Lake
D12	Palustrine		Aquatic vegetation	Submerged vascular		Floodplain	Floodplain vlei	Barlkarra
D13	Palustrine		Emergent vegetation	Narrow-leaved		Floodplain	Floodplain vlei	Barlkarra
E1	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic	Temporary pan	Sumpland
E2	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic	Temporary pan	Sumpland
E3	Palustrine		Emergent vegetation	Narrow-leaved		Marsh	Restio marsh	Barlkarra
E4	Palustrine		Emergent vegetation	Narrow-leaved		Marsh	Restio marsh	Palusplain
E5	Palustrine		Aquatic vegetation	Submerged vascular	Moderately brackish	Endorheic	Temporary pan	Sumpland
E6	Palustrine		Unconsolidated bottom	Mud	Subsaline	Endorheic	Temporary pan	Sumpland
E7	Palustrine		Emergent vegetation	Narrow-leaved		Marsh	Restio marsh	Barlkarra
E8	Palustrine		Aquatic vegetation	Submerged vascular	Brackish	Endorheic	Temporary pan	Sumpland
E9	Palustrine		Emergent vegetation	Narrow-leaved	Slightly brackish	Endorheic	Temporary pan	Sumpland
E10	Palustrine		Emergent vegetation	Narrow-leaved	Subsaline	Endorheic	Temporary pan	Floodplain
E11	Palustrine		Emergent vegetation	Narrow-leaved	Moderately brackish	Endorheic	Semi-permanent pan	Lake

More than one sample was collected at some wetlands, thus the number study sites investigated is large the number of actual wetlands investigated.

Table 3.3b Definitions used to classify waccording to Morant (1983) in Table 3.3a.

Categories of pH used in the Cowardin system (reproduced from Cowardin *et al.*, 1979)

Modifier	pH of Water
Acid	<5.5
Circumneutral	5.5 - 7.4
Alkaline	>7.4

Definitions of classes used (Cowardin *et al.*, 1979)

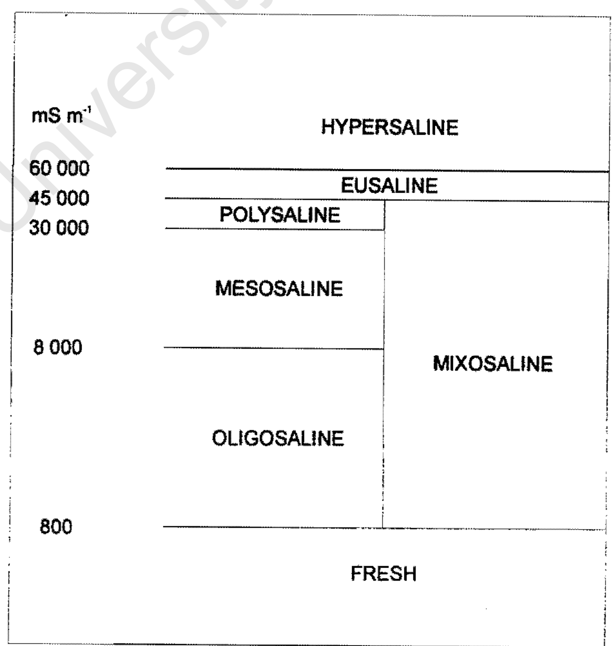
Aquatic Bed Class includes wetlands and deepwater habitats dominated by plants that grow principally on or below the surface of the water for most of the growing season in most years.

Emergent Wetland Class is characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. This vegetation is present for most of the growing season in most years. These wetlands are usually dominated by perennial plants.

Rock Bottom Class includes all wetlands an deepwater habitats with substrata having an areal cover of stones, boulders or bedrock 75% or greater and vegetative cover of less than 30%.

Unconsolidated Bottom Class includes all wetlands an deepwater habitats with at least 25% cover of particles smaller than stones and a vegetative cover less than 30%.

Categories of salinity concentrations used in the Cowardin system



Chapter Four

Methods

4.1 Field data collection

A range of physical, chemical and biotic data were collected at a variety of wetland sites in the Western Cape. Appendix 1 contains datasheets that were created for use in this project and that provide an indication of the type of information collected for each wetland site.

4.1.1 Observed abiotic features of these wetlands

Some geomorphological features are not specific to wetlands and have been regarded as relatively slow-changing characteristics (such as landscape shape, which changes over a geological time frame rather than annually, as biotic characteristics do). Slow changing, non-specific characteristics are good features for use in a classification system (Semeniuk and Semeniuk, 1995). Semeniuk and Semeniuk (1995) describe landform as the "container" of a wetland, that delimits its shape, size and depth. Landform types recorded in this dissertation were initially based on the five landform types suggested by Semeniuk and Semeniuk (1995) (basin, channels, flats, slopes and highlands or hills: Figure 2.4) but subsequently another category was added- depressions which are basins that only reach a water depth 500mm. This final category was included once field work had commenced as it was noticed that a large number of temporary wetlands were shallow and apparently different from wetlands in deep basin.

Besides geomorphological characteristics, hydrological characteristics also play a dominant role in shaping wetlands, a fact that has, logically, lead to many classification systems (such as the Cowardin system and those based on it) defining wetlands according to their different hydrological regimes. Hydrological characteristics recorded at each wetland include the degree of inundation (whether or not water covers the substratum). Degree of inundation was recorded at the wetlands during both winter and summer field studies. Substratum covered with water was indicated as "**inundated**", waterlogged substratum as "**saturated**" and dry substratum as "**dry**"

Table 4.1 Abiotic characteristics recorded at each wetland.

Inundation period	Degree of inundation	Water source	Water outlet	Landform	Landscape position
permanent	inundated	stream inflow	stream outflow	flat	mountain top
seasonal	saturated	stormwater	seepage	slope	mountain slope
ephemeral	dry	seepage	evaporation	basin	foothill
		rain	sea connection	channel	coastal plain
		sea connection		shallow depression	coastal dunes
		industrial discharge		highlands and hills	inland plateau
		sewerage			mountain valley

(Table 4.1). The inundation period (or the length of times that surface water persisted during a year) was estimated from the winter and summer field visits. Wetlands inundated during both field visits are **"permanent"** and wetlands which change from inundated to saturated or dry are "**temporary**'. For the purpose of this dissertation "**temporary**" wetlands inundated during the rainy season (winter) but "dry" or "saturated" at other times of the year were regarded as "**seasonal**" and those which are usually dry but broken with short periods of inundation were regarded as "**ephemeral**" (Table 4.1). Wetlands inundated during both winter and summer field studies were grouped as "**permanent**". Wetlands inundated during the winter and saturated or dry during the summer were grouped as a "**temporary**" and "**seasonally inundated**". Those wetlands which were saturated during the winter but dry during the summer were grouped as "**temporary**" and "**seasonally saturated**". Wetlands that were dry during both visits are called "**temporary ephemeral**", since they are believed to be wet for short infrequent and irregular periods. These characteristics incorporate the four types of water permanence described by Semeniuk and Semeniuk (1995).

At each wetland records were made of the water source (including stream or river flow, storm water, seepage (high groundwater table), industrial discharge, sewage and rain) and water outlet (including stream or river flow, seepage, and evaporation) (Table 4.1). It is not always possible to determine whether wetlands derive their water from rain or from a rising water table and whether it is lost through seepage or evaporation. Wetlands with a clay substratum are likely to be rainfall/evaporation dominated since the clay prevents inflowing seepage of a rising water table and outflowing seepage into groundwater aquifers. Thus water source and loss from clay bottomed wetlands is discernable from those losing and gaining water due to seepage. Clay bottomed wetlands were recorded as rainfall/evaporation dominated, but others were recorded as both seepage and rainfall/evaporation wetlands. Evidence of whether or not the wetlands were indirectly (temporarily or permanently) connected to the sea was also recorded (Appendix 1). These data indicate the degree to which a wetland may be riverine or estuarine and will assist in making the decision as to whether or not they are palustrine, riverine or estuarine. Water sources recorded in other wetland studies include industrial discharge and sewage but our aim was to investigate natural wetlands with low anthropogenic disturbance so these categories were not recorded during this study.

General notes of water colour (*e. g.* colourless, brown-tinged, green and yellow) clarity (*e. g.* clear, cloudy and muddy), current (*e. g.* still, or running), and smell (*e. g.* sulphur or algal smells) were made. The substratum of the shoreline was used as an indicator of the wetlands substratum (including characteristics such as bedrock, boulders, stones, gravel, pebbles, sand, mud, clay and detritus). Signs of anthropogenic modifications were recorded at each site and included characteristics shown in Appendix 1.

4.1.2 Physical attributes and chemical constituents

Day *et al.* (1998) indicated that water chemistry differs due to geology and climate and that rivers can be grouped according to their position on chemical gradients. Water chemistry is useful for grouping similar inundated wetlands but is also important because water chemistry affects wetland biotic communities and functioning. At each inundated wetland site salinity, conductivity, pH and turbidity were measured and water samples were collected for ion and nutrient analysis.

Measurements of salinity were taken with an Atago S/Mill Hand Refractometer graduated as parts per thousand which had been standardised to zero with distilled water. Conductivity in mS cm^{-1} at 25°C (Crison conductivity meter 524 with an accuracy of ±0.05% of the reading) were taken at each wetland site. The conductivity meter was calibrated using KCL 0.010mol l^{-1} for the resolution range from 0.1 S cm^{-1} to 0.1mS cm^{-1}. pH was measured at the wetland sites with a Hanna pH meter H1 8424 (accuracy 0.01pH) calibrated for pH 4 and 7 and compensated for temperature. Turbidity was measured in NTUs (Nephelometric Turbidity Units) using a Hach 2100 Turbidimeter (no indication of accuracy provided by the makers) and standardised using Gelex Secondary Turbidity Standards 0 -10, 0 - 100, 0 - 1000 NTU. In cases where water at the wetlands was too turbid for the turbidimeter to produce readings, the turbidity was recorded as "1000+ NTU".

Collection of water for analysis for soluble water chemicals

All bottles used to collect water samples from inundated wetlands were submerged in (500ml/20l) hydrochloric acid (6-24 hours), rinsed four times with deionised water, then submerged in Contrad TM® or Extrad TM® (6-24 hours), similarly rinsed with deionised water and finally given two rinses in distilled water of at least six hours each. Filtered sample water was used to rinse the containers before water collection.

Water filtered through an Advantec GF75 glass microfibre filter (diameter 47mm and pore size 1micron) using a filter and receiver under a pressure ranging from 20 to 50 bar. The filtrate was collected in glass Polytop TM® bottles for ammonia analysis and plastic bottles for nitrate, nitrite, phosphate and major ions analysis.

4.1.3 Sampling of the biota

4.1.3.1 Vegetation

Vegetation has traditionally been used to describe different types of wetlands- particularly in the northern continents. While this wetland characteristic is relatively changeable it is an obvious wetland feature that cannot be neglected since plant material is relatively easily identified and grouped into functional types by non-specialists. Vegetation may also provide information about water chemistry and animal communities of wetlands.

At small wetlands (approximately 30m x 30m or smaller) plant samples of all visible species were collected. At larger wetlands it was not possible to collect all plant species so samples of plants were taken only at the specific study site. Records were made of three different vegetative types; emergent macrophytes; submerged and surface-floating plants (referred to as submergent); and riparian vegetation (plants surrounding the wetland which are not inundated).

4.1.3.2 Fauna

Zooplankton or aquatic animals were qualitatively sampled by sweeping an 80 μm net through the water for three to five minutes. Samples were collected from as many different habitats as possible, usually including, the water column, the marginal vegetation, water surface and water/substratum interface. All animal samples were immediately preserved in 4% formalin for approximately a week and subsequently stored in 70% alcohol.

Although aquatic animals were sampled from as many habitats as possible, large wetlands could only be sampled at specific study sites as it would have to time consuming to sample, sort and identify more samples from all the larger wetlands. As samples were collected once from seasonally inundated wetlands, or twice from permanent wetlands invertebrates maturing between sampling times may not have been collected and would therefore not be represented.

4.2 Laboratory methods

Water, animal and plant samples, which had been collected in the field were analysed and identified in the laboratory.

4.2.1 Chemical analysis

Water samples were stored frozen for up to ten months before they were analysed. Since all samples analysed for nutrients had been filtered, the results show concentration of soluble ions and nutrients, specifically ammonia (NH_3-N), nitrate (NO_3-N), nitrite (NO_2-N) and phosphate (PO_4-P). Concentrations of major ions (chloride, sulphate, calcium, potassium, sodium and magnesium) were measured using a Dionex Ion Chromatograph (calcium and potassium accurate to ±0.01 mmol l^{-1} chloride, magnesium, and sulphate to ±0.1 mmol l^{-1} and sodium to ±1 mmol l^{-1}). Ammonium was measured by the indophenol method scaled to size (accurate to 0.1 mg l^{-1}: Grasshoff *et al.*, 1983), nitrite was determined spectrophotometrically after diazotation (Nydahl, 1976) and nitrate was determined in the same manner once the sample had been reduced in a cadmium column (accurate to $\pm 0.01 mg\ l^{-1}$). Soluble reactive phosphate using the Grasshoff *et al.* (1983) ascorbic acid method scaled to size (accurate to $\pm 0.01 mg\ l^{-1}$). Nutrients were analysed by P. Kuun (University of Cape Town).

On the assumption that the sum of the positive cations is equal to the sum of the negative cations, potassium, sodium, calcium, magnesium, chloride and sulphate were used to calculate rough alkalinity values in terms of HCO_3^-. All these variables were entered into a spreadsheet for creating Maucha symbols provided by M. Silberbauer (Institute for Water Quality Studies, Department of Water Affairs and Forestry) and P. Kuun assisted in producing the symbols. Maucha symbols summarise the major ions (potassium, sodium, calcium, magnesium, sulphate, chloride and carbonate) of each wetland and facilitates comparison between water samples. Each ion is represented by an spike on the star of the ionic diagram. Spikes of large areas indicate dominant ions in the wetland.

For purposes of multivariate analysis, soluble ammonium, nitrate and nitrite were added together as a measure of total soluble nitrogen. Sodium and potassium were added as a measure of monovalent cations and magnesium and calcium as divalent cations.

4.2.2 Species identification

4.2.2.1 Vegetation

Plant samples were identified by the National Botanical Institute. Some specimens could be identified to species, but most could only be identified to genus or family level and a number of specimens were not identifiable as many plants were not flowering during sampling periods. For an accurate species list to be developed, plants should be sampled regularly throughout the year which suggests that identification of wetlands flora is too time consuming for use in a classification system.

4.2.2.2 Fauna

The animal samples were subsampled, usually 1/16th of the initial sample, although those with few organisms were completely sorted. Each sample was then sorted by eye to ensure that all larger organisms were picked out for identification. Notostracans and cladocerans were identified by the author from Brendonck (2000) and Raynor (2000) respectively, anostracan were identified by M. Hamer (University of Natal), cladocerans by A. Kotov (El Colegio de la Frontera Sur, Mexico), copepods by N. A. Rayner (University of Durban-Westville), ostracods by K. Martins (Royal Belgium Institute of Natural Sciences, University of Ghent: but the ostracods were excluded from the analysis as not all specimens could be identified) and amphipods and isopods were identified by the author under the supervision of C. L. Griffiths (University of Cape Town) from Griffiths (1976), Griffiths and Stewart (2001), Kensley (1978) and Kensley (2001). Chironomids were identified by A. D. Harrison (Freshwater Research Unit, University of Cape Town), culicids by myself (Coetzee, in press) and other diptera were identified by J. A. Day (Freshwater Research Unit, University of Cape Town) who also identified the coleoptera to different morphs. P Reavell (University of Zululand) identified the aquatic hemiptera, F. De Moor (Albany Museum) the tricopteran and lepidopteran larvae and I identified the ephemeropterans using an unpublished key by H.M. Barber James (Albany Museum) and Lehmkuhl (1979) and odonates using Samways and Wilmot (in press) and Samway and Whiteley (1997) with the assistance of M. Picker (University of Cape Town). Identification of gastropods were checked by C. Appleton (University of Natal, Durban) and mytilids were identified by the author with assistance from B. R. Davies (Freshwater Research Unit, University of Cape Town) using Davies (1980). A Dipennaar-Schoeman (ARC-Plant Protection Institute, Pretoria) identified the aquatic spiders and I grouped the hydracarines into morphological similar taxa using Jansen van Rensburg (1976). Turbellaria were identified by the author (Prudhoe, 1989). Fish fry were identified by R. Bills and N. Strydom (South African Institute for Aquatic Biodiversity, formally the JLB Smith Institute) and tadpoles by A. Channing (University of the Western Cape).

4.3 Statistical analysis

Multivariate analyses by means of Plymouth Routines In Multivariate Ecological Research (PRIMER, Clarke and Warwick, 1994) were used in an attempt to identify groups of chemically and biotically similar wetlands.

Water chemistry samples collected in winter and summer were analysed separately as samples could only be collected from the permanently inundated sites during the summer. The analyses require that the variables are normally distributed and that the variables do not correlate. Chemical variables for the summer and winter data sets were plotted and as some variables were not normally distributed the data required transformation. In order to create consistency all chemical variable data were logged transformed (using the equation log $(x + 1)$), except pH, which is measured in a log scale. Once the data had been logged and replotted it was found that total soluble nitrogen was not normally distributed for both winter and summer data sets and phosphate for the winter data set. Despite this, these variables were included in the analysis as they were considered important as they were only measures of nutrients in the analysis. Regressions of the log-transformed data were plotted and indicated that the variables to be analysed were not correlated with each other. Water chemistry information was standardised so that the different variables had equal status when the different wetland sites were compared. Euclidean distance was selected as the measure suited to analysis of similarity for abiotic variables. Two multivariate analyses were run on water chemistry variables: the first analysis included conductivity, pH, total soluble nitrogen, soluble reactive phosphate, divalent cations, monovalent cations, chloride and sulphate and the second conductivity, pH and turbidity.

Animal summer and winter data were also analysed separately but the plant data sets were amalgamated since most plant species persist throughout the year. The presence/absence animal data were analysed for similarity at species, genera and family levels using the Bray Curtis measure of similarity, while the vegetation data were analysed only at genera and family levels because not all specimens could be identified to species.

Group-average linkage clusters were used to create dendrograms that were analysed in conjunction with an ordination processed from 50 restarts of multi-dimensional scaling analysis (MDS).

SIMPER was run in order to determine which chemical variables from the water chemistry analysis and which taxa for the biotic analyses contributed most to the groups identified from the cluster and MDS analyses. SIMPER also provides a percentage measure of the similarity between pairs of samples within the groups. The greater the percentage similarity the more similar are the wetlands in the group.

In order to investigate correlations between aquatic animals and water chemistry the BIO-ENV programme was run on the water chemistry groups identified from the dendrogram mentioned above. BIO-ENV provided an indication of taxa that are related to groups identified from water chemistry clustering.

Chapter Five

Results

5.1 Introduction

Data collected at each site were synthesised and the wet winter season and dry summer season data sets have been dealt with separately. Appendix 2 provides details regarding the physical characteristics of each wetland and appendices 3 and 4 are the concentrations of variables measured at inundated sites. A list of animal species identified from each site has been compiled in appendix 5 and of the plant species in appendix 6. All data are available electronically and are stored in the Freshwater Research Unit at the University of Cape Town. Discussed wetlands are listed in Table 3.2.

5.2 Hydrogeomorphological characteristics of the study wetlands

Almost three-quarters (73%) of the wetlands visited are temporary, characterised by either a seasonal or an ephemeral hydrological regime (Table 5.1). The remaining wetlands were permanently inundated.

Table 5.1 Some hydrological and landform features of the studied wetlands ("n" is the number of wetland sites investigated in each category).

		Basin n = 19	Depression n = 20	Flat n = 22	Slope n = 1
Permanent	Inundated year round n = 17	13	4		
Temporary seasonal	Winter inundated, summer saturated n = 2	2			
	Winter inundated, summer dry n = 31	4	15	12	
	Winter saturated, summer dry n = 4			3	1
Temporary ephemeral	Irregularly wet, usually dry n = 8		1	7	

Wetlands that were inundated in winter and were still saturated (with waterlogged soils but no surface water) in the summer are considered to be temporary since their seasonal hydrological change will affect their biotic functioning. Wetlands saturated in winter, but dry in summer are also classed as seasonal since their hydrological regime is altered seasonally.

From the data available it is not possible to determine whether ephemeral wetlands are normally inundated for extremely short periods (a couple of weeks) during the winter (and the field visits simply did not coincide with the inundation period) or if they only become inundated during seasons with higher than average winter rains. Some wetlands (such as Voelvlei near the Gouritz River site D9) have remained dry for a number of years (personal communication, P Zitzman, landowner). The lack of inundation may mean that this site is inundated only during infrequent flooding events.

More than half (69%) of the wetlands studied are endorheic and 24% are exorheic, and the remaining 7% were also exorheic but connected to the sea (Table 5.2). Endorheic wetlands are found in all of the landform categories except slopes since those on slopes drain into other aquatic wetlands and are thus unlikely to be endorheic. Six of the endorheic wetlands gain water from riverine wetlands during flooding events, but at other times depend on precipitation and seepage. These irregularly flooded wetlands are found in basins or on flats. Exorheic wetlands are found in all the landforms.

Table 5.2 The number of wetlands investigated from each water source category and the different landform categories ("n" is the number of wetland sites investigated in each category).

	Basin n = 19	Depression n = 20	Flat n = 22	Slope n = 1
Exorheic n = 15	1	1	13	1
Exorheic- sea connection n = 4	4			
Endorheic n = 43	14	19	9	

Endorheic wetlands experience a full range of hydrological regimes but the greater proportion (70%) of them are seasonal (Table 5.3). Both endorheic and exorheic permanently inundated wetlands were investigated. Although only one exorheic basin was investigated in this study (such as Voelvlei at Agulhas), more are present in the Western Cape. The estuarine wetlands are all permanently inundated despite temporary disconnection from the sea.

Table 5.3 The number of wetlands investigated from each water source category related to the different drainage categories ("n" is the number of wetland sites investigated in each category).

	Permanent	Temporary seasonal			Temporary ephemeral
	Inundated year round n = 16	Winter inundated, summer saturated n = 3	Winter inundated, summer dry n = 31	Winter saturated, summer dry n = 4	Irregularly wet, usually dry n = 8
Exorheic n = 15	2		6	3	5
Exorheic- sea connection n = 4	4				
Endorheic n = 43	11	2	25	1	3

5.3 Water chemistry

Detailed results of the measured water chemistry variables of the winter and summer collections are shown in appendices 5 and 6. Separate multivariate analyses were carried out on the winter and summer results which are indicated in the following sections.

5.3.1 Water chemistry recorded during the winter season

Figures 5.1 shows a grouped average dendrogram and the corresponding MDS (Multidimentional Scaling) of the variables conductivity, pH, chloride, sulphate, divalent and monovalent cations, total nitrogen and soluble reactive phosphate (SRP), from samples collected in the winter. Five

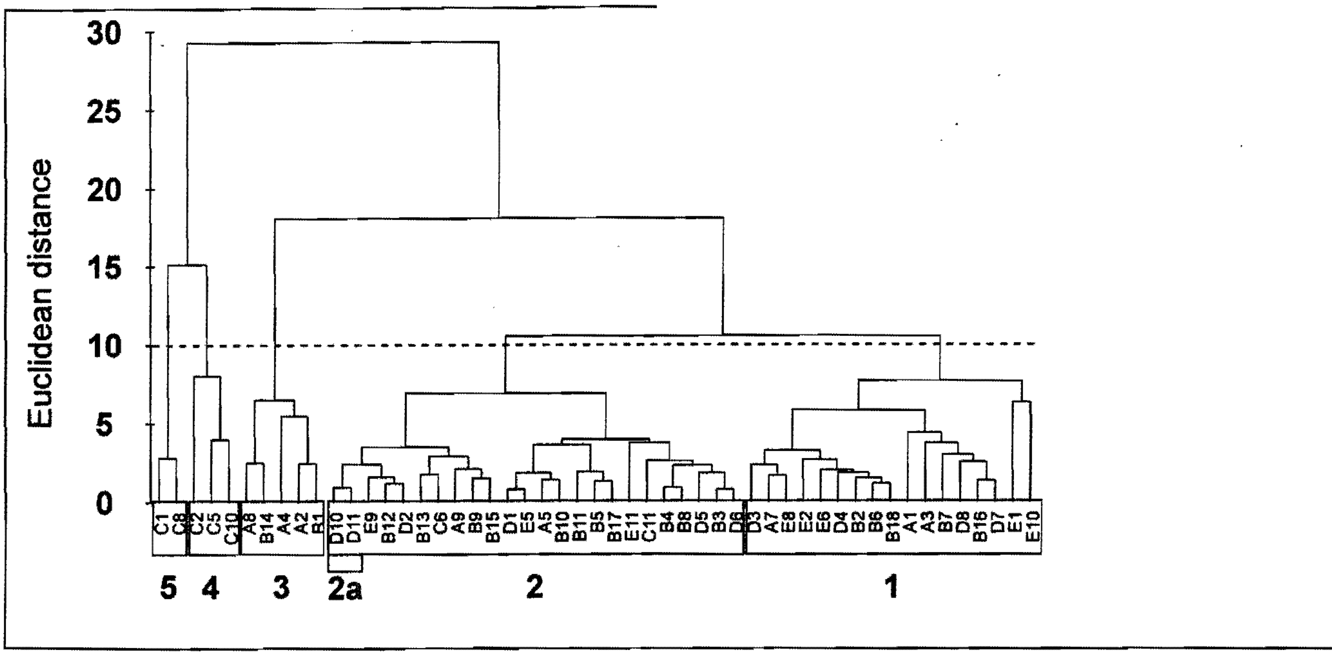


Figure 5.1a Five wetland groups at Euclidean distance 10 identified from the cluster analysis of SRP, total soluble nitrogen, chloride, sulphate, monovalent cations, divalent cations, pH and conductivity concentrations sampled from the different wetlands (indicated by site codes) from winter sampling.

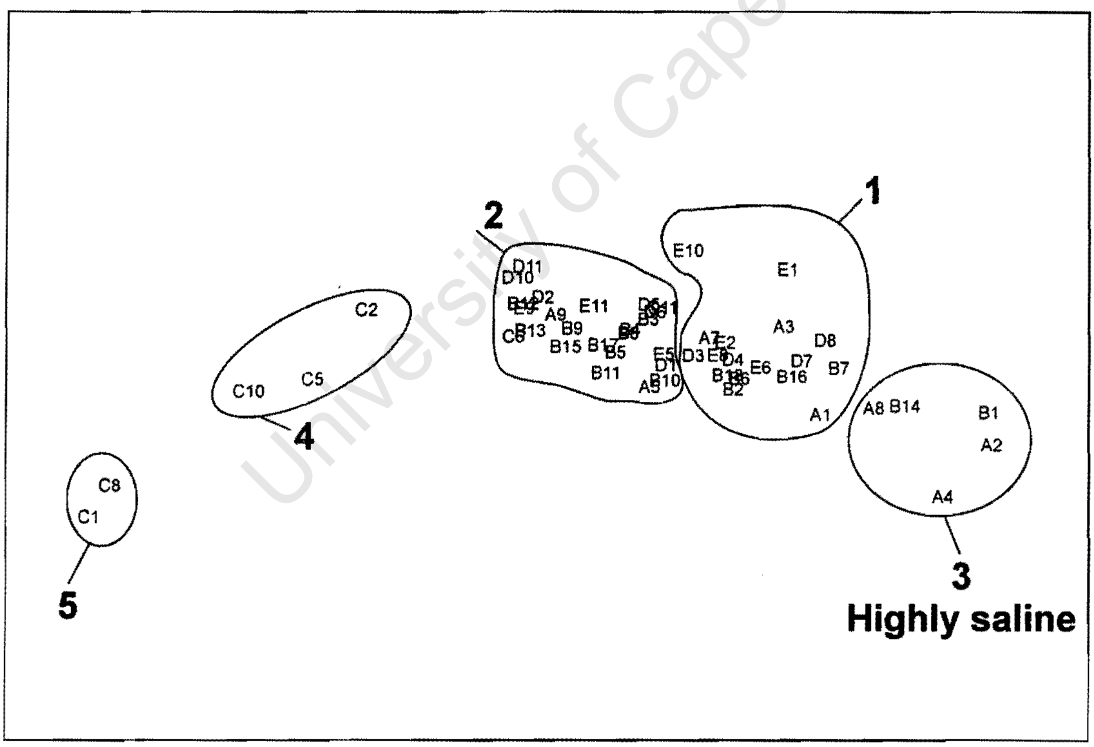


Figure 5.1b Multidimentional Scaling of SRP, total soluble nitrogen, chloride, sulphate, monovalent cations, divalent cations, pH and conductivity concentrations sampled at the different wetlands during winter (stress 0.01).Wetland groups indicated are identified at Euclidean distance 10 from the cluster analysis in Figure 5.1a. Wetlands may be identified by their site codes.

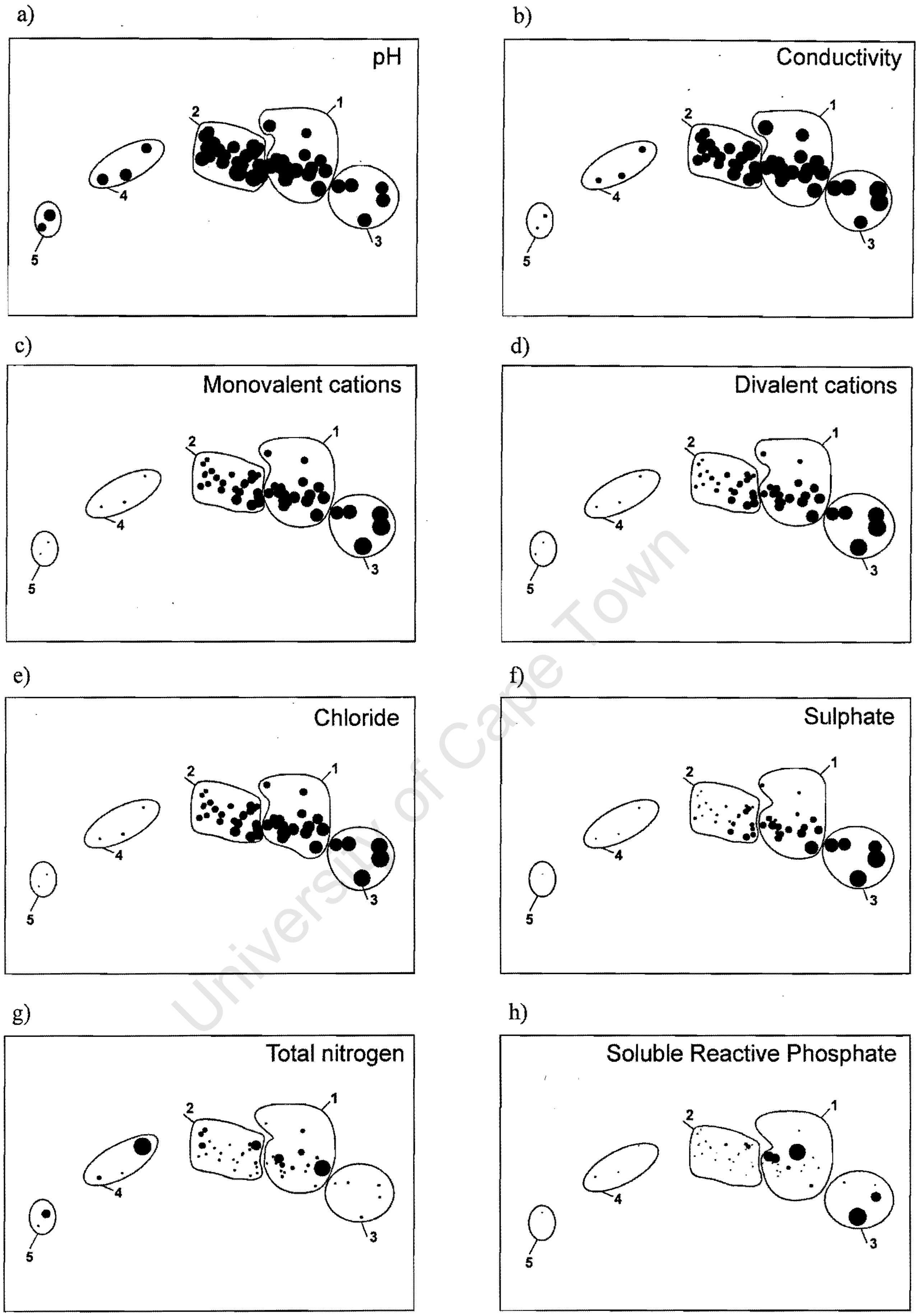


Figure 5.2a-h Conplots indicating, pH, conductivity and ion and nutrient concentrations of MDS, groups indicated on Figure 5.1 a and b.

groups are identified at a Euclidean distance of 10 (Figure 5.1a) and the low stress (0.01) of the corresponding MDS (Figure 5.1b) indicates that the two-dimensional illustration is good representation of groups.

Groups 4 and 5 cluster together at a Euclidean distance of 15. These wetlands are in the Cederberg and Ceres areas and are mostly exorheic seasonal wetlands on low-gradient landscape, except for C5 which is a permanent endorheic depression. The ionic concentrations of the wetlands in these two groups are low, as are the SRP concentrations and conductivity (Figure 5.2), the pH is neutral and the total nitrogen concentrations varied between the sites of the groups. Despite the fact that site D11 is polluted (it is used by local people for clothes washing) the two springs at the Gouritz River mouth are associated closely (group 2a). Conductivity is highest in group 3, lower in groups 1 and 2 and lowest in groups 4 and 5. This trend appears to be repeated by chloride, sulphate and the monovalent and divalent cations. Total nitrogen and SRP are variable throughout the groups, while pH is slightly higher in groups 1-3 and lower in groups 4 and 6.

SIMPER analysis identified pH followed by conductivity as the variables which contribute most to the identity of each group (Table 5.4). While concentrations of some ions were also identified as important, it is noticeable that sulphate, total nitrogen and SRP are not identified as important in contributing to the grouping of the wetlands (Table 5.4).

Table 5.4 Variables (contributing most to least) identified through SIMPER analysis as contributing to the groups identified in the dendrogram from the winter data (Figure 5.1a). The average percentage similarity is that of pairs of samples within a group.

	Average similarity	pH	Conductivity	Chloride	Monovalent cations	Divalent cations
Group 1	95%	1	2	3	4	
Group 2	95%	1	2	3	4	
Group 3	95%	1	2	3	4	5
Group 4	94%	1	2			
Group 5	97%	1	2			

5.3.2 Water chemistry recorded during summer

PRIMER similarity analysis was performed on conductivity, pH, chloride, sulphate, divalent and monovalent cations, total nitrogen and SRP recorded during the summer from the permanently inundated sites. The four groups, identified from the resultant dendrogram at Euclidean distance of 10 (Figure 5.3a), are clearly indicated on the MDS (at a low stress value of 0.02) (Figure 5.3b).

The pH of the groups is similar between sites and but a gradual change in conductivity is apparent between the different groups. The SRP and total nitrogen concentrations of groups 1 and 3 are variable (0.002 - 0.128 mg l^{-1}), while groups 2 and 4 are characterised by low nutrient concentrations. Group 3, includes site E11 which has singularly high total nitrogen (1.144 mg l^{-1}) and SRP (0.128 mg l^{-1}) concentration. The concentrations of monovalent cations, divalent cations, chloride and sulphate are low in groups 3 and 4, higher in group 1 and highest in group 2. An increase in ion concentrations occurs in the groups from right to left of the MDS indicating that ions play a noticeable role in the placement of wetlands into the different groups (Figure 5.4). Conductivity contributed most to the identification of groups of wetlands followed by chloride and monovalent cations. Once again nutrients and sulphate are found not to be important variables contributing to the identity of the different wetland groups (Table 5.5). SIMPER analysis cannot be run on "groups" consisting of single wetlands. Thus total nitrogen, SRP and sulphate may contribute to groups 2 and 4 but could not be included in this analysis.

Table 5.5 Variables (contributing most to least) identified through SIMPER analysis as contributing to the groups identified in the dendrogram from the summer data (Figure 5.3a). The average percentage similarity is that of the pairs of samples within a group.

	Average similarity	Conductivity	Chloride	Monovalent cations	Divalent cations	pH
Group 1	94%	1	2	3	4	5
Group 3	93%	1	2	3	5	4

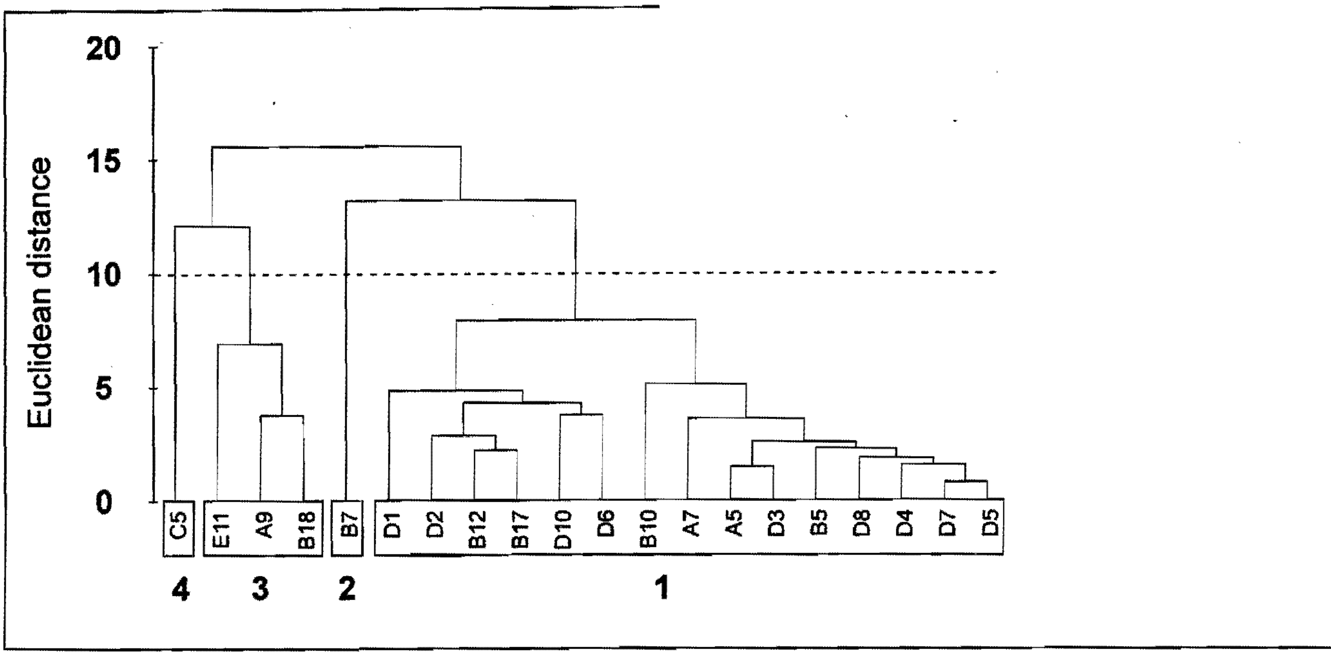


Figure 5.3a Four wetland groups at Euclidean distance 10 identified from the cluster analysis of SRP, total soluble nitrogen, chloride, sulphate, monovalent cations, divalent cations, pH and conductivity concentrations sampled from the different wetlands (indicated by site codes) from summer sampling.

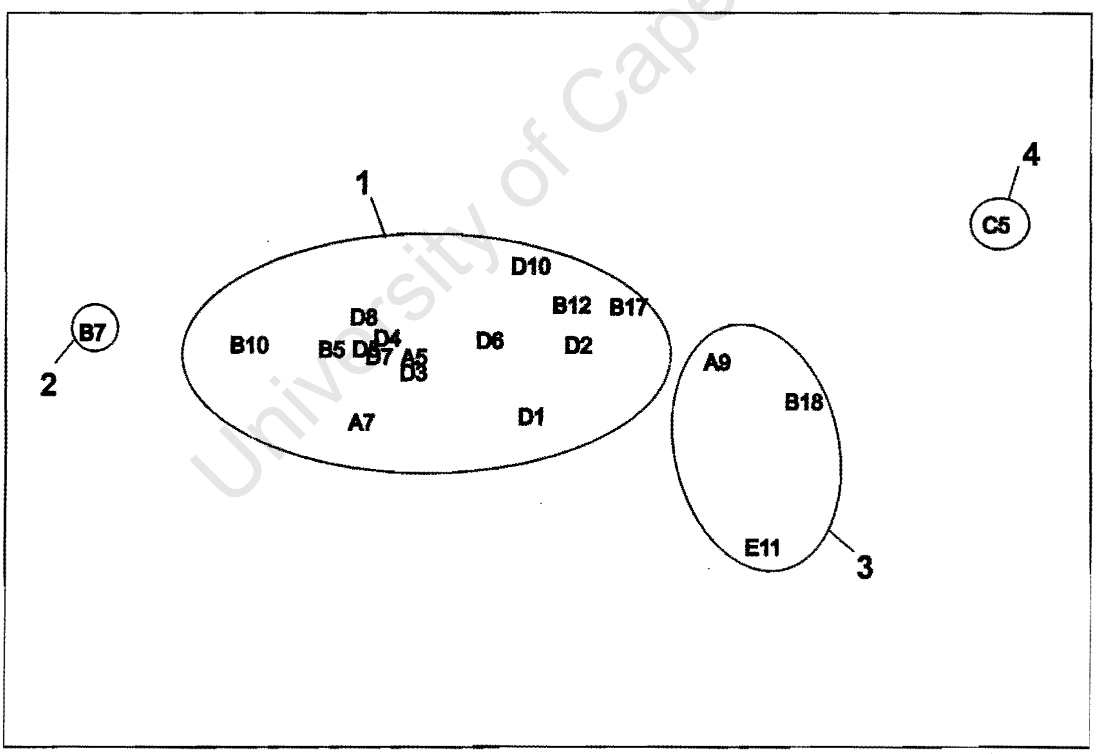


Figure 5.3b Multidimentional Scaling of SRP, total soluble nitrogen, chloride, sulphate, monovalent cations, divalent cations, pH and conductivity concentrations sampled at the different wetlands during summer (stress 0.02). Wetland groups indicated are identified at Euclidean distance 10 from the cluster analysis in Figure 5.3a. Wetlands may be identified by their site codes.

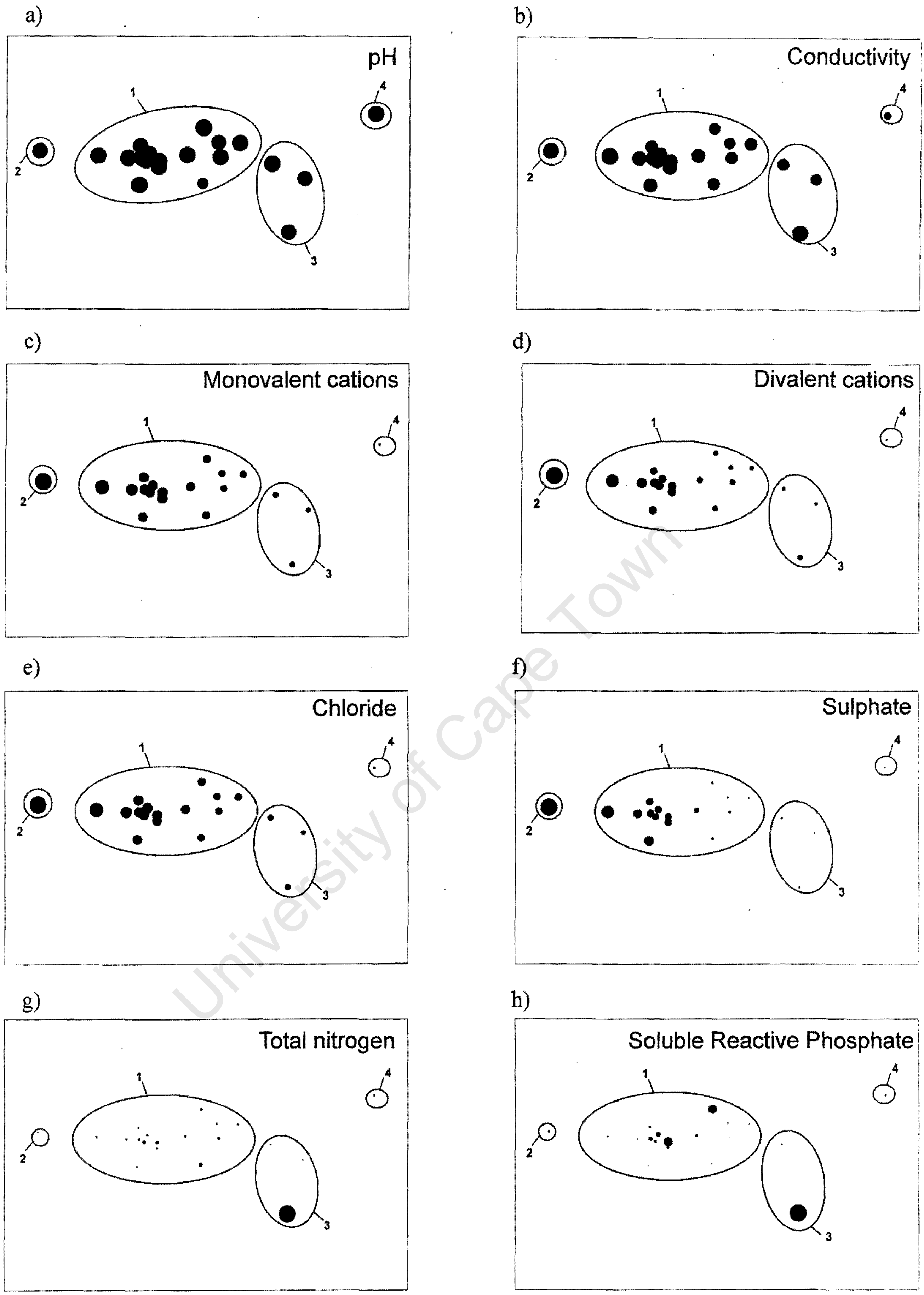


Figure 5.4a-h Conplots of pH, conductivity and ion and nutrient concentrations of MDS, groups indicated on Figure 5.3 a and b.

The clusters of the winter and summer nutrients do not group the permanently inundated wetlands together. For instance, the wetlands in group 1 of the summer analysis (Figure 5.3a) are divided into two different groups in the winter analysis (Figure 5.1a). In some cases two sites from the same wetland (*e. g.* sites B17 and B18 from Soetendalsvlei, Agulhas Plain) have clustered in different groups (Figure 5.1a and 5.3a).This indicates that nutrient composition, of the permanently inundated wetlands at least, varies from winter to summer and also suggests that the nutrient composition of these wetlands is variable throughout the year. Although water collected for nutrient analysis was routinely filtered to remove particulate matter, some seasonal sites (A10, A11, A12, A13, C3 and C4) from Cederberg and Vanrhynsdorp area have extremely turbid milky water that could not be filtered so nutrients and ion concentrations were not measured. This meant that only pH, conductivity and turbidity could be recorded at these sites. PRIMER similarity analysis using only these three variables was run on the winter sites. Six groups of wetlands are identified at a Euclidean distance of 10 in the resultant grouped average dendrogram and the MDS (with 0 stress). The extremely turbid sites cluster together in subgroup 6a (Figure 5.5). Site C6 and C3 are also highly turbid seasonal wetlands and are closely associated with group 6a, but site B17 which is clustered with sites C6 and C3, is a permanent basin that did not have the same milky muddy waters (Figure 5.5a). Group 2 clusters wetlands with the highest conductivity, indicating that these highly saline wetlands form a distinct group of wetlands. The other groups identified using this dendrogram are not the same as those identified previously (Figures 5.1a) although there are similarities and particular pairs of sites remain closely related (for instance sites D10 and D11 are in close proximity in both sets of dendrograms). These turbid and saline sites are all seasonal wetlands thus only the winter data set has been analysed.

5.4 Ionic proportions of the study wetlands

Figure 5.6 indicates that the water chemistry of most of the coastally distributed wetlands investigated is largely dominated by sodium and chloride ions. A number of highly saline wetlands (*e. g.* site A2 near the Berg River, site A8 on the western coast and site B1, Soutpan, on the Agulhas Plain) are represented by large maucha diagrams and sodium and chloride ions, that are responsible for the saline conditions, are most dominant ions. The Cederberg wetlands including Driehoekvlei (site C1) and sites C2, C5 and C6 and those in the Ceres/Worcester area

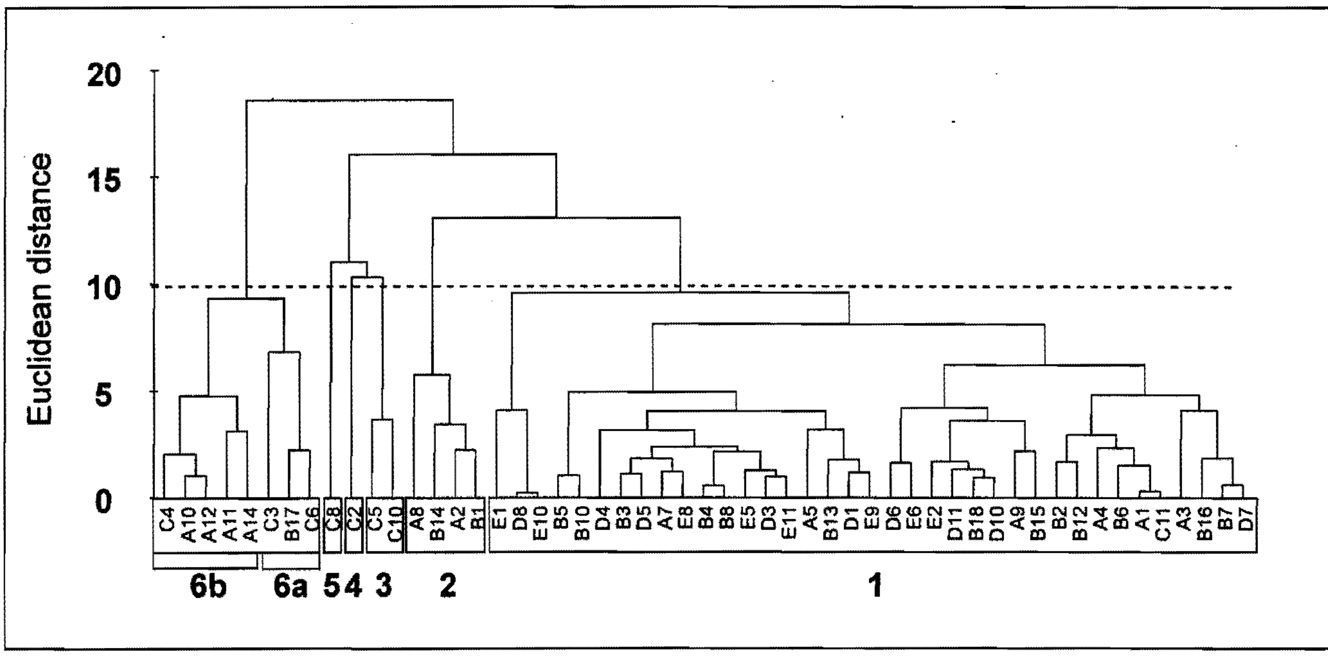


Figure 5.5a Six wetland groups at Euclidean distance 10 identified from the cluster analysis of turbidity, pH and conductivity concentrations sampled from the different wetlands (indicated by site code) from winter sampling.

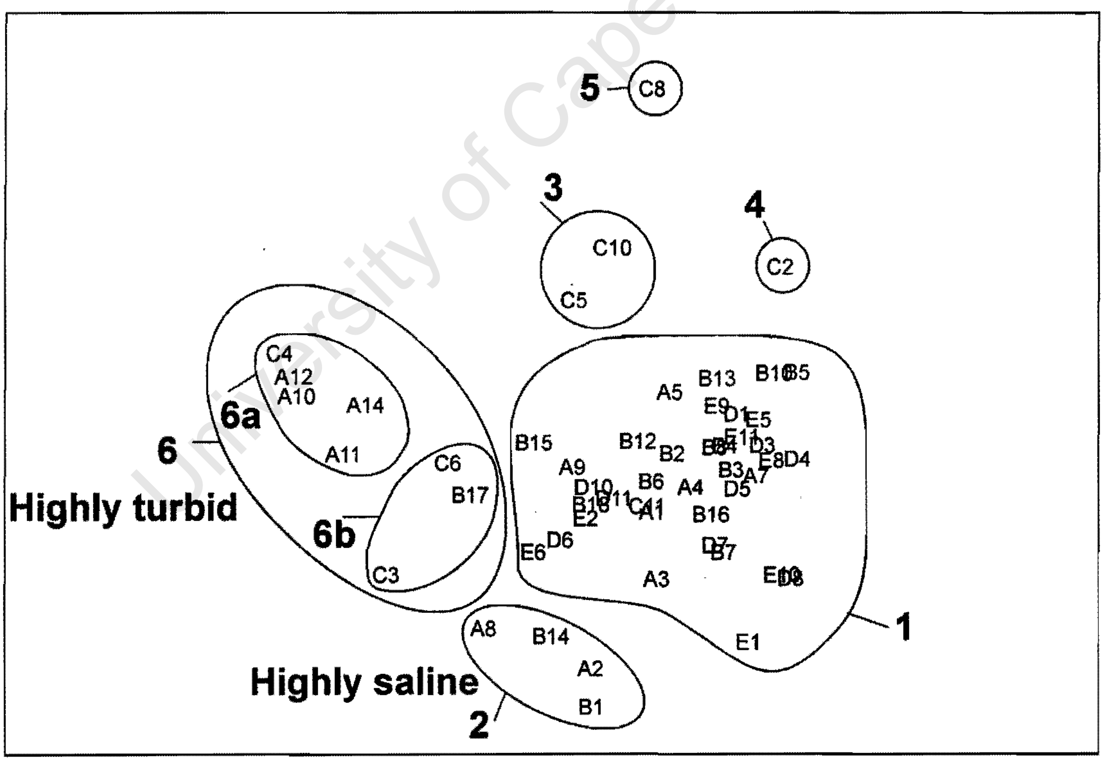


Figure 5.5b Multidimentional Scaling of turbidity, pH and conductivity concentrations sampled at the different wetlands during winter (stress 0).Wetland groups indicated are identified at Euclidean distance 10 from the cluster analysis in Figure 5.5a. Wetlands may be identifie by their site codes.

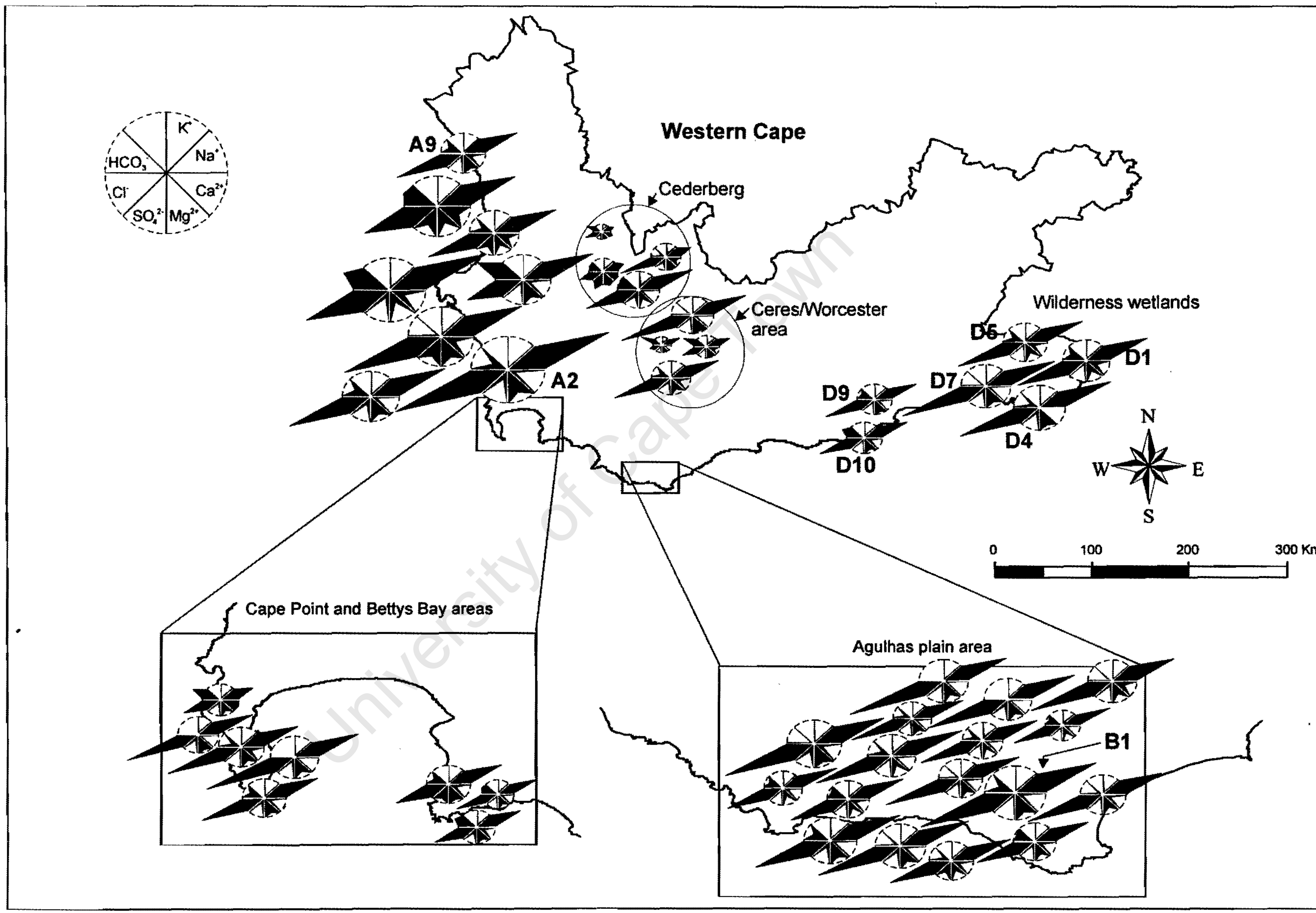


Figure 5.6 Mauche ionic symbols of inundated wetlands sampled during winter.

(sites C6 - C11) are dominated by sodium and chloride more than other ions, but to a lesser degree than the wetlands on the coast. Sites C2 and C8 are particularly different from the other wetlands as they do not appear to dominated by sodium and chloride. Magnesium, although not as dominant as sodium and chloride, is found in fairly high proportions in most wetlands. Of further interest are sites D9 and D10, which receive water from underground springs and also show similar ionic proportions. The Maucha diagrams of wetlands from similar areas indicate that wetlands in geographical proximity area characterised by similar ionic proportions.

5.5 Wetland groups identified from aquatic animals

5.5.1 Analysis of animal clusters at species level

Faunal clusters from samples collected during the winter season

Initial multivariate analyses indicate that Driehoekvlei (site C1) is entirely unlike the other sites at animal family, genus and species levels. Very little water was available for animal sample collection at Driehoekvlei due to the unusually dry winter season. As a result only one specimen (*Paramelita* sp) was identified from the site and furthermore the species was not recorded at any other site which resulted in the multivariate analysis indicating that the site is markedly dissimilar from other sites. After initial analysis this outlier site was removed.

At a Bray Curtis similarity of 20%, twelve wetland groups are identified from the grouped average dendrogram of the presence and absence of animal species (Figure 5.7a). The corresponding MDS plot indicates a fair stress of 0.17 but also shows that clear distinctions between groups 2 and 3 do not exist (Figure 5.7b). Similarly groups 8 and 9 are not clearly separated (Figure 5.7b).

All wetlands in group 1 are on the Agulhas plain. Sites B13 and B8, cluster together and are both restioid marshes temporally inundated due to flooding and although site B12 is a permanent basin

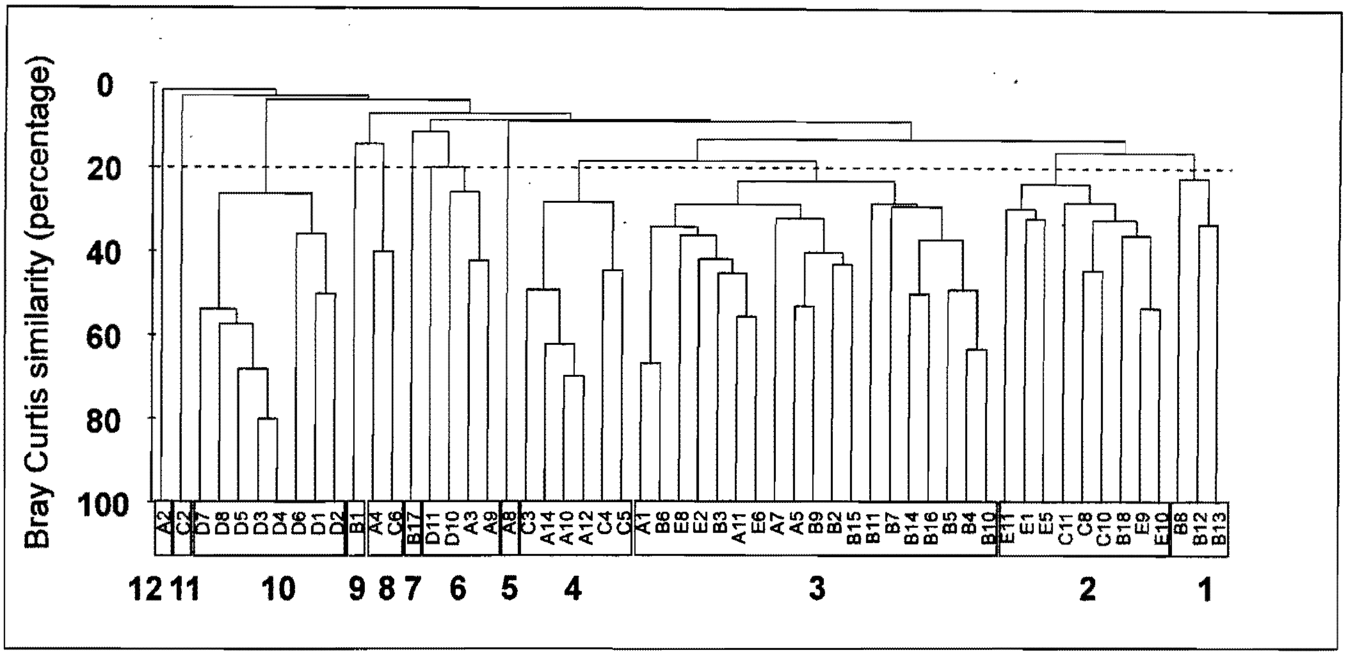


Figure 5.7a Twelve wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of animal species identified from the different wetlands (indicated by site codes) from the winter collections.

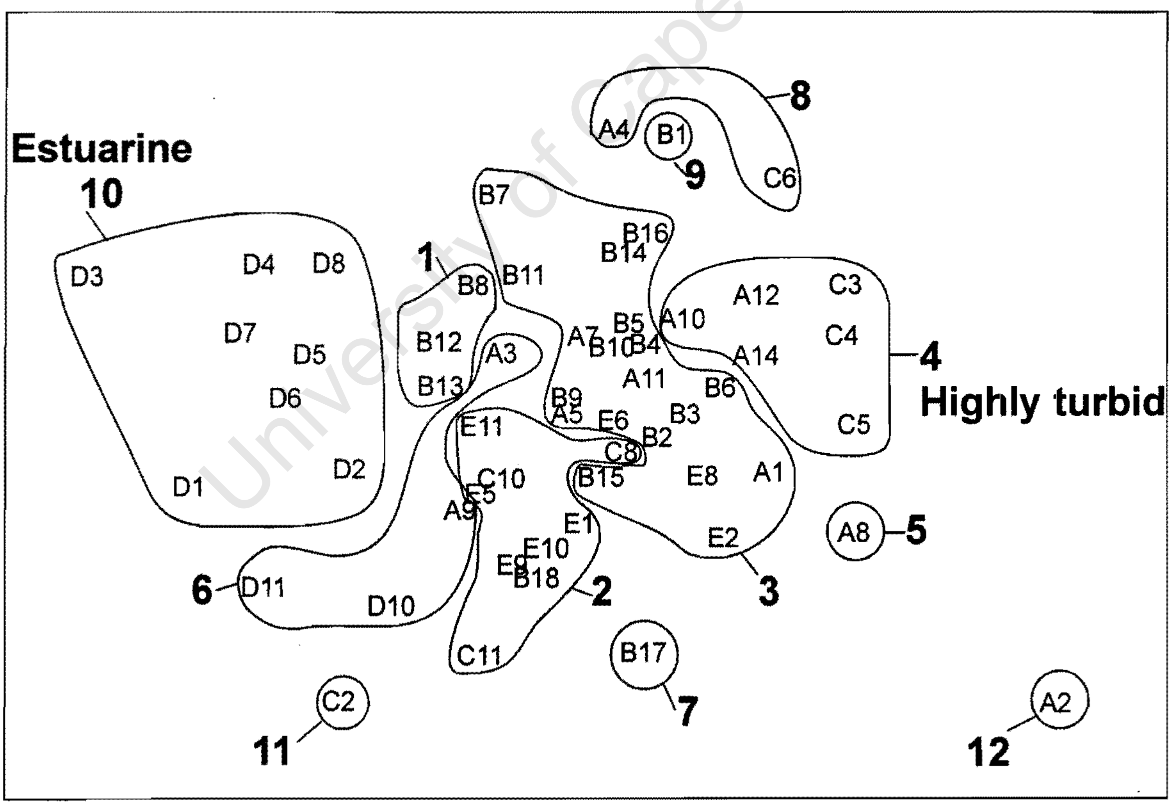


Figure 5.7b Multidimentional Scaling of the presence or absence of animal species identified from winter collections (stress 0.17).Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.7 a. Wetlands may be identified by their site codes.

Table 5.6 Animal (contributing most to least) identified through SIMPER analysis as contributing to the groups identified in the dendrogram from the winter collection (Figure 5.7). The average percentage similarity of pairs of samples within a group is noted in brackets .

Group 1 (26)	Group 2 (28)	Group 3 (29)	Group 4 (41)	Group 6 (26)	Group 8 (40)	Group 10 (40)
Corynoneura sp (Diptera)	*Metadiaptomus purcelli* (Copepoda)	*Metadiaptomus capensis* (Copepoda)	*Paradiaptomus lamellatus* (Copepoda)	*Chironomus formosipennis* (Diptera)	*Daphnia* similis-group (Cladocera)	*Atherina breviceps* (Fish)
Chydorus sphaericus-group (Cladocera)	*Macrothrix capensis s.str* (Cladocera)	*Lovenula simplex* (Copepoda)	*Metadiaptomus capensis* (Copepoda)	*Eucyclops gibsoni* (Copepoda)		*Pseudosphaeroma barnard* (Isopoda)
Daphnia similis-group (Cladocera)	*Ceriodaphnia reticulata* (Cladocera)	*Tomichia* spp (Gastropoda)	*Leptestheria rubidge* (Conchostraca)	*Cladotanytarsus capensis* (Diptera)		*Pseudiaptomus hessei* (Copepoda)
Dicrotendipes pilosimanus (Diptera)	*Psectrocladius viridescens* (Diptera)	*Macrothrix capensis s.str* (Cladocera)	*Streptocephalus purcelli* (Anostraca)	*Moina brachiata* (Cladocera)		*Arcuatula capensis* (Bivalvia)
Hydracarina sp E	*Alona* sp (Cladocera)	*Daphnia* similis-group (Cladocera)	*Lovenula simplex* (Copepoda)	*Anisops sardea* (Hemiptera)		*Exosphaeroma hylocoetes* (Isopoda)
Hydracarina sp D	Anisops sardea	Hydracarina sp D	*Turbellaria* spp			*Afrochiltonia capensis* (Amphipoda)
Tomichia spp (Gastropoda)	*Turbellaria* spp	*Cladotanytarsus capensis* (Diptera)	*Daphnia* similis-group (Cladocera)			*Melita zeylanica* (Amphipoda)
Galaxias zebratus	*Corynoneura* sp (Diptera)	*Daphnia carinata* (Cladocera)	Micronecta scutellaris (Hemiptera)			*Paracyclops poppei* (Copepoda)
	Simocephalus vetulus (Cladocera)	*Anisops* sp (Hemiptera)				
	Scapholebris kingi (Cladocera)	Hydracarina sp A				
	Hydracarina sp A	*Sigara meridionalis* (Hemiptera)				

surrounded by restioid vegetation. It may be hydrologically connected to site B13 during high-rainfall seasons.

Group 4 includes most of the turbid endorheic wetlands from the Cederberg and Vanrhynsdorp area. SIMPER analysis indicates that the five animal species which contribute most to this group of wetlands are all crustaceans. The crustaceans *Paradiaptomus lamellatus*, *Leptestheria rubidgei* and *Streptocephalus purcelli* are largely restricted to these wetlands (Table 5.6).

Group 6 includes two groundwater springs near the Gouritz River. The SIMPER analysis indicates that *Chironomus formosipennis* is the most important species contributing to the similarity of this group (Table 5.6).

Group 10 of the species cluster (Figure 5.7a) includes the four deep basins investigated in the Wilderness region. These wetlands, except for Groenvlei (sites D1 and D2) are temporarily and indirectly connected to the sea. A stream connects Rondevlei (sites D3 and D4) to Langvlei (sites D5 and D6) that in turn is connected to Eilandvlei, which is then connected to the sea *via* the Touws and Serpentine Rivers. The two sites investigated at Groenvlei (D1 and D2) are more similar (50% similarity) to each other than to the other Wilderness wetlands, possibly since Groenvlei, unlike the other Wilderness wetlands, is not connected to the sea and has only relict estuarine connection.

Fauna groups from samples collected during the summer season

The grouped average dendrogram and MDS (with a low stress of 0.01) were run on the animal samples collected during the summer (Figures 5.8), thus including only permanently inundated wetlands. At 20% Bray Curtis similarity eleven groups are identified. Most of the sites studied from the Wilderness wetlands cluster into groups nine, ten and eleven which cluster together at 5% Bray Curtis similarity. Grouping of the Wilderness wetlands is more clearly shown in the winter than the summer data set since two sites, one on Langvlei (site D6) and another on Eilandvlei (site D8), are distinctly separated from the other Wilderness wetlands when analysing the summer data.

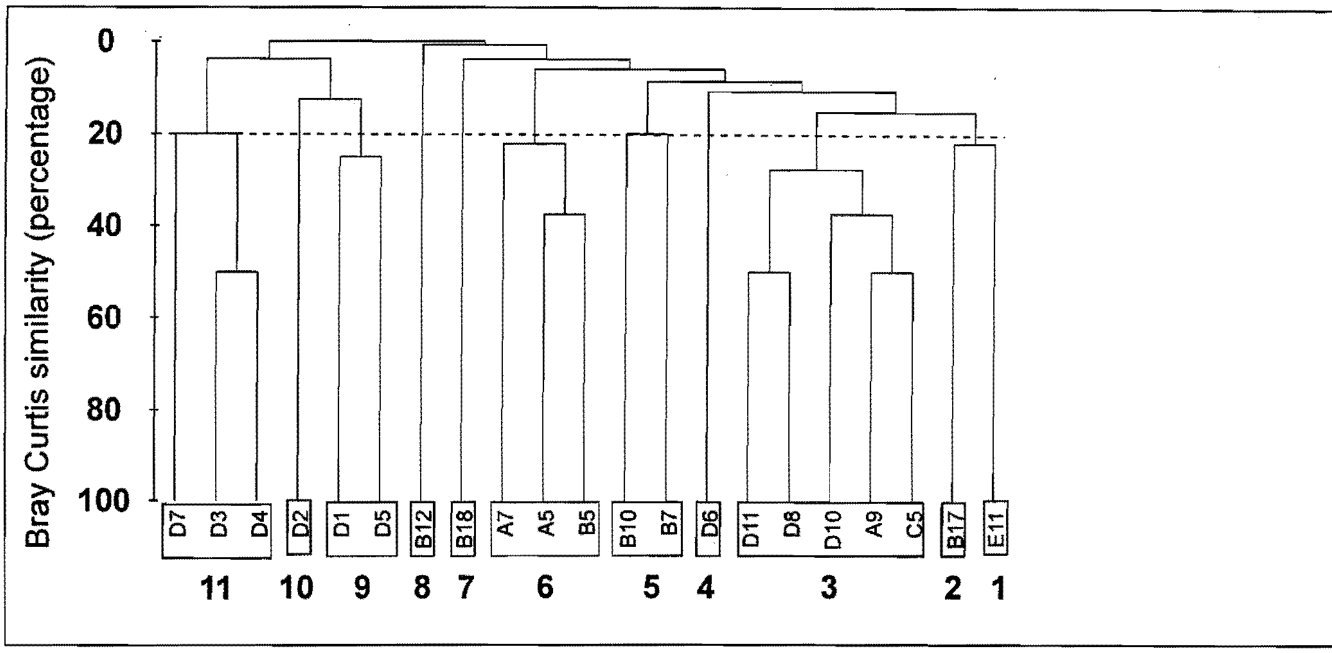


Figure 5.8a Five wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of animal species identified from the different wetlands (indicated by site cod from the summer collections.

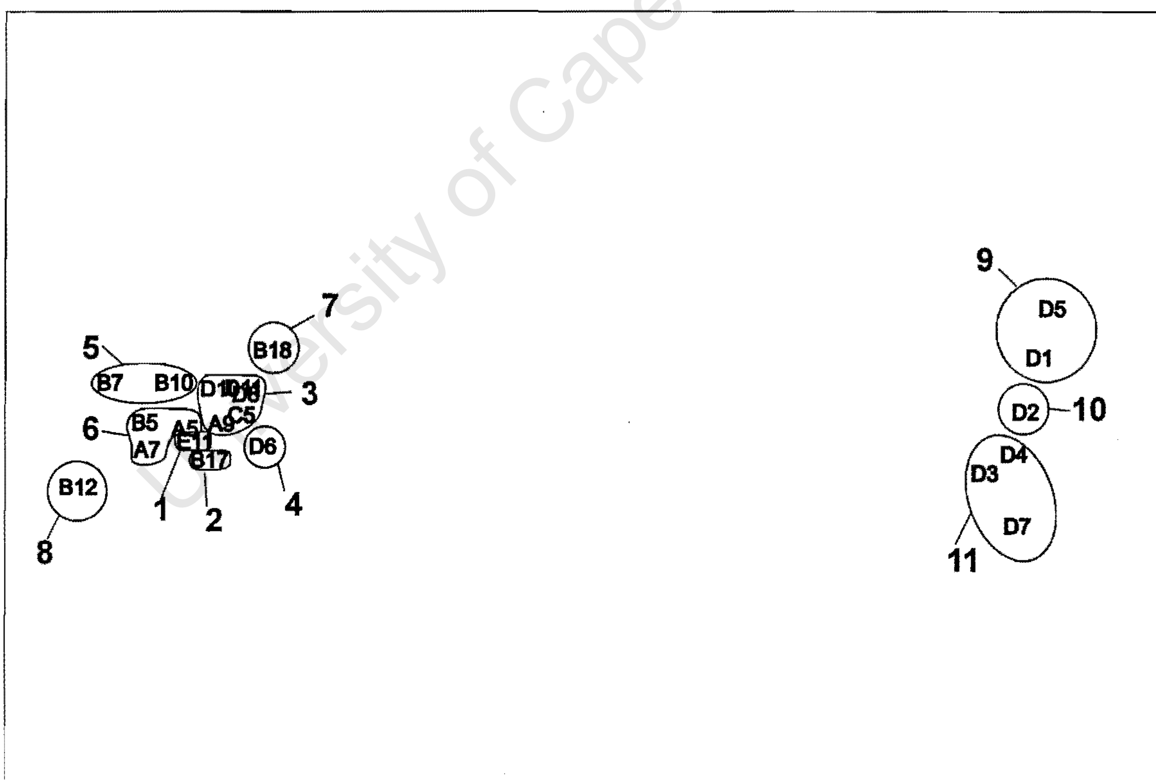


Figure 5.8b Multidimentional Scaling of the presence or absence of animal species identified from summer collections (stress 0.01).Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.8a. Wetlands may be identified by their site codes.

Table 5.7 Animal (contributing most to least) identified through SIMPER analysis as contributing to the groups identified in the dendrogram from the summer collection (Figure 5.8). The average similarity of pairs of samples within a group is noted in brackets .

Group 1 (29.68)	Group 2 (66.67)	Group 3 (33.33)	Group 5 (34.77)	Group 7 (40.00)	Group 9 (42.86)
Micronecta scutelllaris (Hemiptera)	*Microcyclops crassipes* (Copepoda)	*Tomichia* spp (Gastropoda)	*Metadiaptomus capensis* (Copepoda)	*Orchestia rectipalma* (Amphipoda)	*Arcuatula capensis* (Bivalvia)
Anisops sardea (Hemiptera)			*Anisops* sp (Hemiptera)		
Dicrotendipes pilosimanus (Diptera)			*Anisops debilis* (Hemiptera)		
Afrocyclops gibsoni (Copepoda)					

Animals contributing to the Wilderness wetland groups (9 and 11) include an amphipod *Orchestia rectipalma* (an estuarine species previously recorded in the area) and a bivalve *Arcuatula capensis*, which was also recorded as a species contributing to the Wilderness wetland grouping when the winter data was analysed (Table 5.7). The dendrograms from the separate winter and summer data do not group wetlands similarly.

5.5.2 Analysis of animal clusters at a generic level.

A grouped average cluster of the animals at genus level clusters five groups of wetland at 20% Bray Curtis similarity (Figure 5.9a) which correspond with the MDS plot (Figure 5.9b) providing a good representation of the groupings (stress 0,19). Group 2 (Figure 5.9a) includes all of the wetlands investigated in the farmlands around Vanrhynsdorp as well as four of the wetlands investigated in the Cederberg. All of these inland wetlands are very turbid, seasonal and shallow endorheic wetlands. Groenvlei and the estuarine wetlands from the Wilderness are clustered into group 4. The two springs (D10 and D11) investigated at Gouritz river do not cluster together, possibly because site D11 is much smaller than the other (D10) and is affected by human activities which has affected the animal composition.

Analysis of summer samples at genus level (Figures 5.10) does not group the permanent wetlands into the same groups as analysis of the animals at species level. Most of the Wilderness wetlands cluster fairly closely into groups 1 and 2, but some Wilderness sites (*e. g.* site D8 and D5, which had to be removed from this analysis) remain distinctly separated from the other Wilderness wetlands when analysed at genus level.

5.5.3 Analysis of animal clusters at the family level

Five groups of wetlands are shown at 20% Bray Curtis similarity from the dendrogram derived from animal families identified from the winter samples, (Figure 5.11a). Group 1 is divided into three sub-groups; 1a, 1b and 1c. The associated MDS, with a fair stress level of 0.21, illustrates the groups and sub-groups (Figure 5.11b).

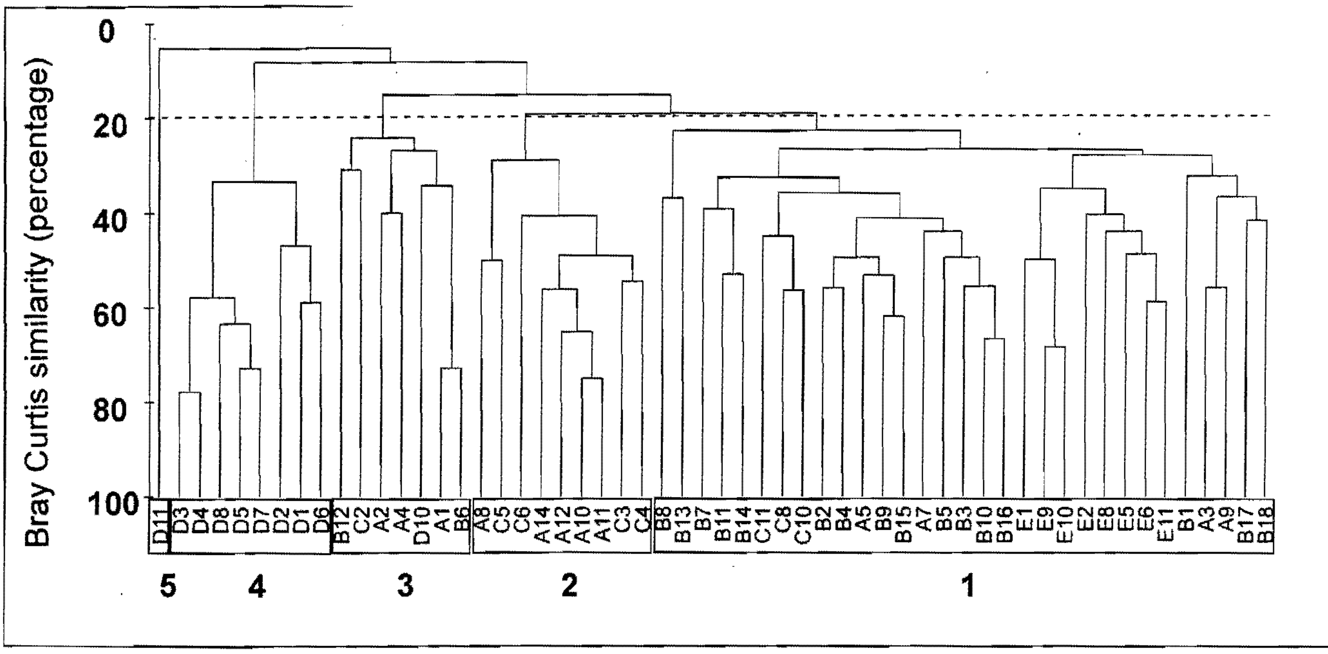


Figure 5.9a Five wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of animal genera identified from the different wetlands (indicated by site codes) from the winter collections.

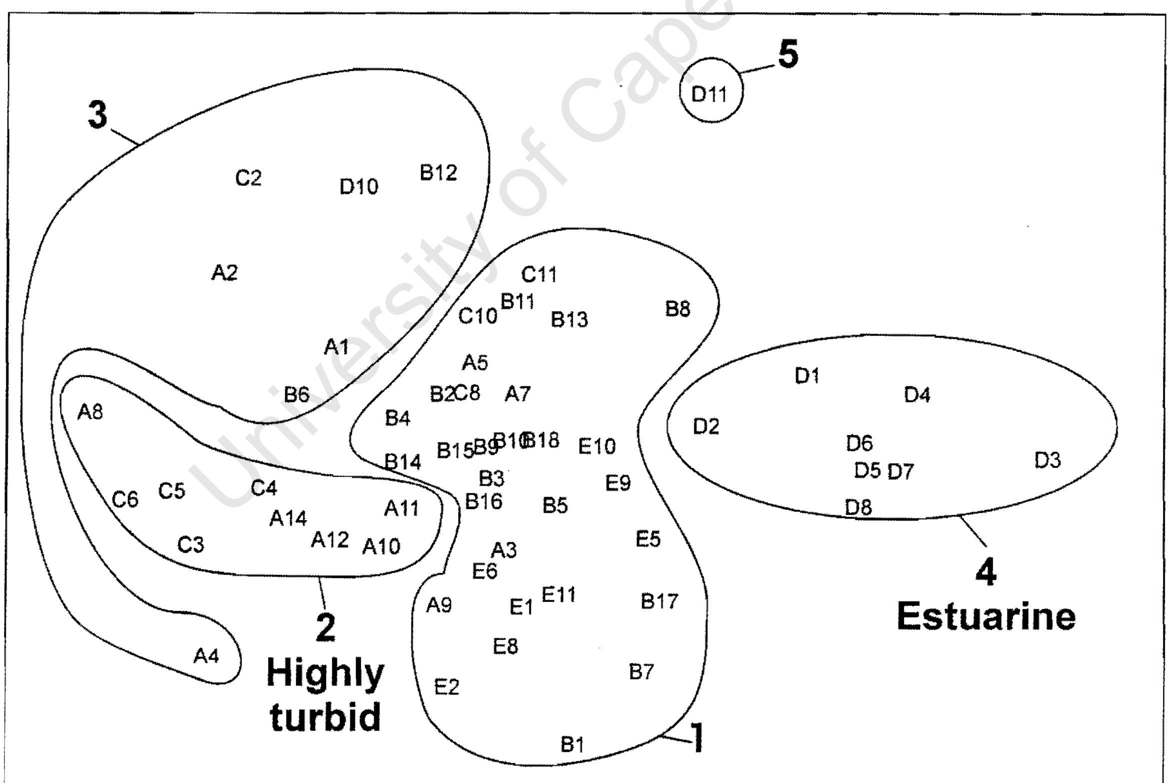


Figure 5.9b Multidimentional Scaling of the presence or absence of animal genera identified from winter collections (stress 0.19).Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.9a. Wetlands may be identified by their site codes.

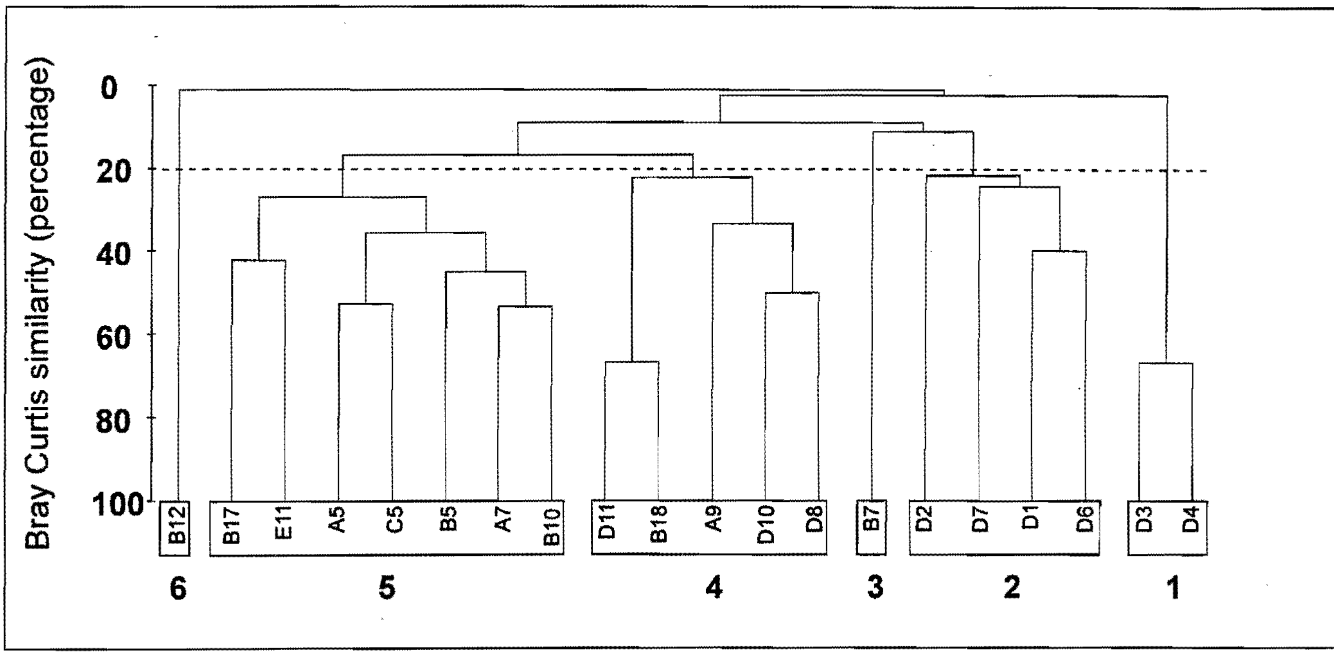


Figure 5.10a Five wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of animal genera identified from the different wetlands (indicated by site code from the summer collections.

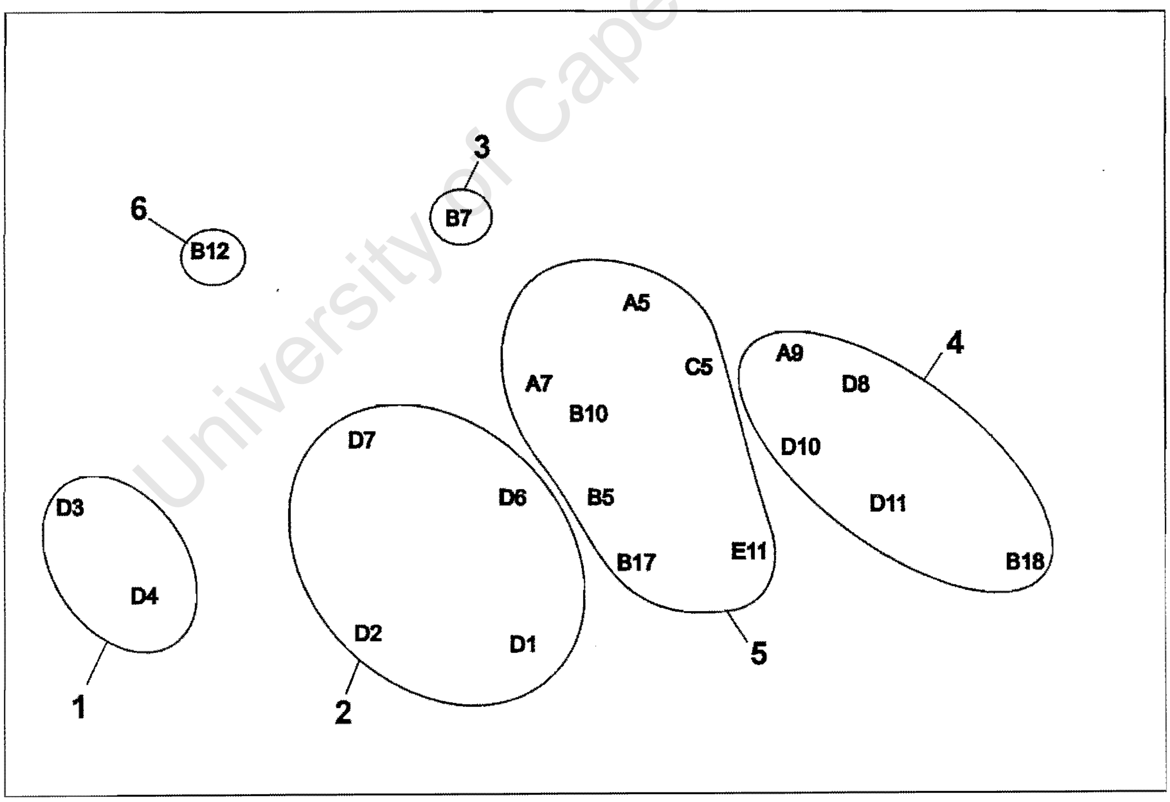


Figure 5.10b Multidimentional Scaling of the presence or absence of animal genera identified from summer collections (stress 0.19).Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.10a. Wetlands may be identified by their site codes.

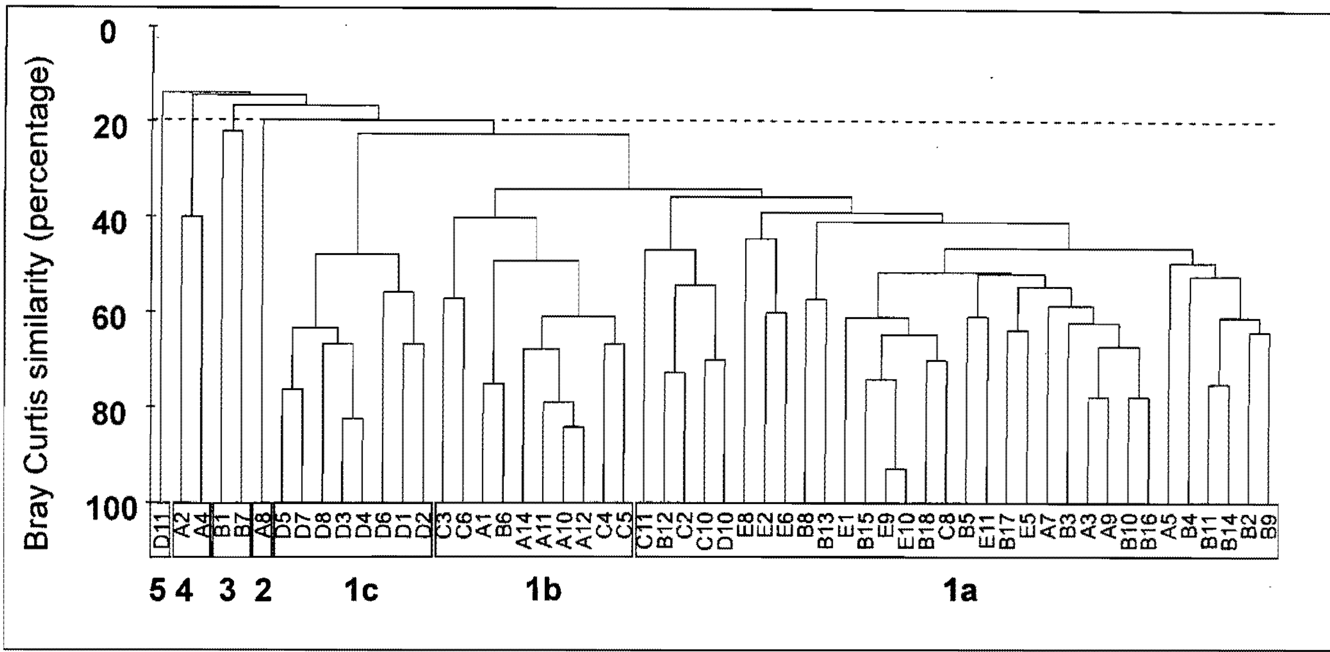


Figure 5.11a Five wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of animal families identified from the different wetlands (indicated by site codes from the winter collections.

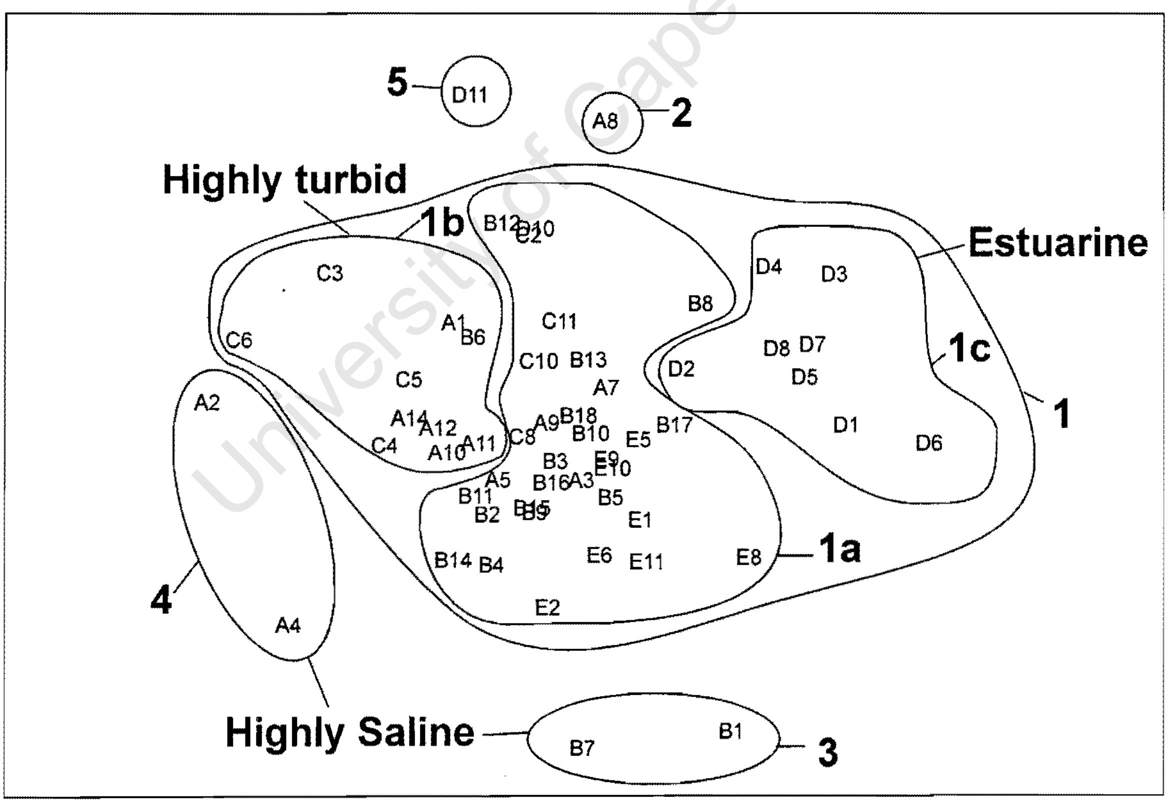


Figure 5.11b Multidimentional Scaling of the presence or absence of animal families identified from winter collections (stress 0.21). Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.11a. Wetlands may be identified by their site codes.

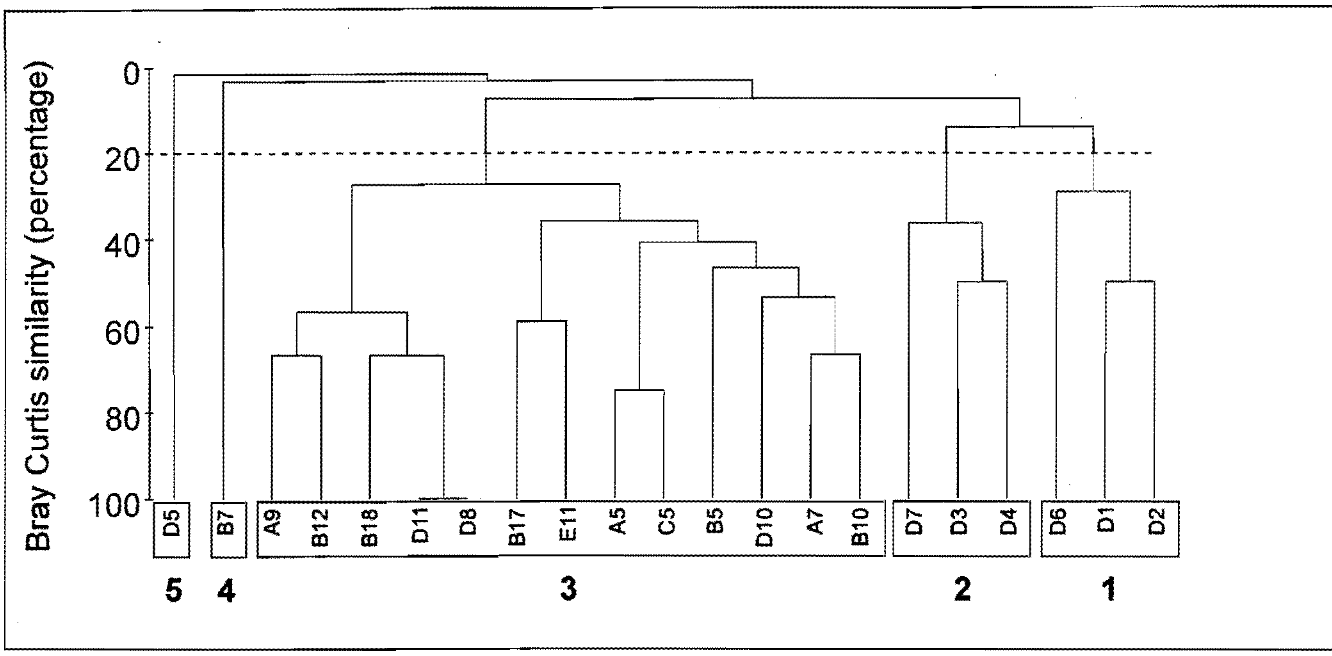


Figure 5.12a Five wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of animal families identified from the different wetlands (indicated by site co from the summer collections.

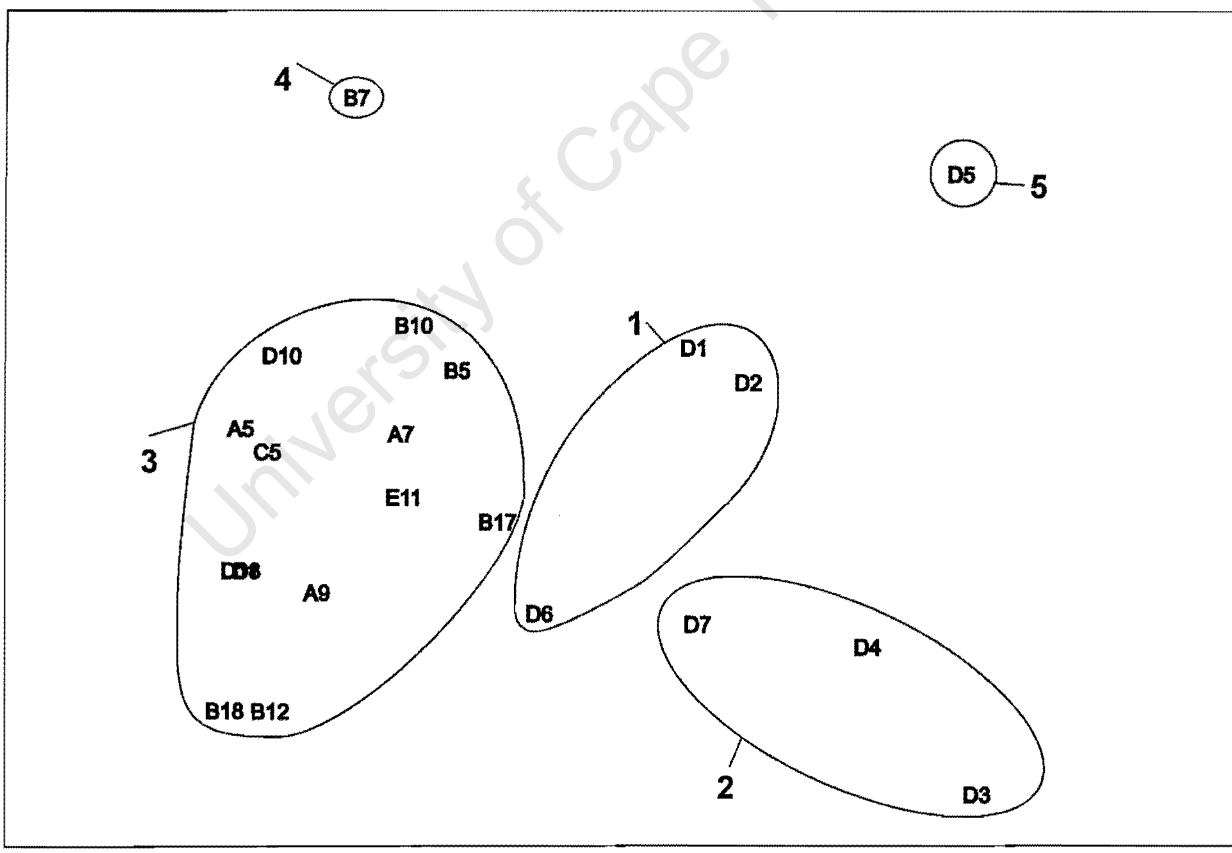


Figure 5.12b Multidimentional Scaling of the presence or absence of animal families identified from summer collections (stress 0.07). Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.12a. Wetlands may be identified by their site codes.

Group 1b includes the turbid wetlands from the Vanrhynsdorp and Cederberg area with addition of one from the Berg River (site A1) and another from the Agulhas Plain (site B6). The Wilderness wetlands are again distinctly indicated as a separated cluster in group 1c. Group 3 and 4 include four highly saline wetlands (765 mS $^{-1}$ to 9310 mS $^{-1}$), group 3 wetlands are from Agulhas Plain and group 4 from Berg River area . The spring, site D11 at Gouritz River, clusters into a group on its own as it did when the winter animal data was analysed at genus level.

Five groups are identified at 20% Bray Curtis similarity of the dendrogram formed from the faunal family similarities of the summer samples (Figure 5.12a). The MDS analysis clearly illustrates the five groups with a low stress of 0.07 (Figure 5.12b). Groups 1 and 2 include all but two of the sites investigated at the Wilderness wetlands. Group 5 includes only site D5, (Langvlei at Wilderness) which was removed from the analysis at genus level due to the lack of similarity between it and all other sites.

Groups identified from clusters using animal data

Analysis of the winter data at species, genus and family levels identify two distinctive groups of wetlands, but the remaining wetlands do not consistently separate into groups. The Wilderness wetlands are most distinctly clustered and the turbid wetlands of Vanrhynsdorp and the Cederberg are consistently grouped together.

The analyses of animals at generic level reveals similar wetland groups to those identified at family level, indicating that generic and family taxa may be of equal use for identifying wetland groups consistently. Although two groups are identified when the analysis is run at a species level the wetland groups identified at species level are slightly different from those identified at genus and family levels. At the more detailed species level the two Gouritz River springs (site D10 and D11) are grouped together.

Clusters of the animal data collected during the winter do not show the expected distinction between seasonally and permanently inundated wetlands. The analysis was repeated using only crustacean taxa, which also did not cluster these wetlands separately.

5.6 Relationships between aquatic animals and water chemistry

In order to discover which, if any, animal trends coincide with the water chemistry trends of the wetlands, the animal and chemical data were compared using BIO-ENV and the conplot function in PRIMER. Only sites with adequate chemical data could be used for these analyses. The cluster analysis including only these sites reveals twelve groups from the animal data at 20% Bray Curtis similarity (Figure 5.13a). The associated MDS (Figure 5.13b) with a low stress value of 0.16 is used for the conplot function, which superimposes the relative values of the chemical data onto the MDS created from the animal species identified from the winter collection. The log-transformed data are superimposed to produce a visually comprehensible representation of water chemistry variables of the groups identified from animal communities (Figure 5.14).

The concentrations of pH and conductivity appears to be uniform throughout the groups and there is not a particular group which can be identified by distinctive pH or conductivity levels (Figure 5.14). Turbidity values of the wetlands in groups identified from animal species data are not similar and turbidity seems to vary irrespective of animal wetland groups. However, the highly turbid wetlands were not included in this analysis as ion and nutrient data were not available for these wetlands but using the animal data (Figure 5.7a), these turbid wetlands cluster together. The nutrient concentrations of the wetland groups identified from animal species appear to be vary from group to group and there does not appear to be any particular trend in nutrients. The ionic concentrations are generally low in groups 9 and 10 (group 9 includes the two Gouritz River springs). Groups 1 - 4, 8 and 11 (the Wilderness wetlands) show slightly higher ionic concentrations, while groups 5 - 7 and 12 include wetlands with high ionic concentrations. The patterns of ion concentrations suggests that the investigated wetland animals may be affected by ionic concentrations more so than other water chemistry characteristics (Figure 5.14).

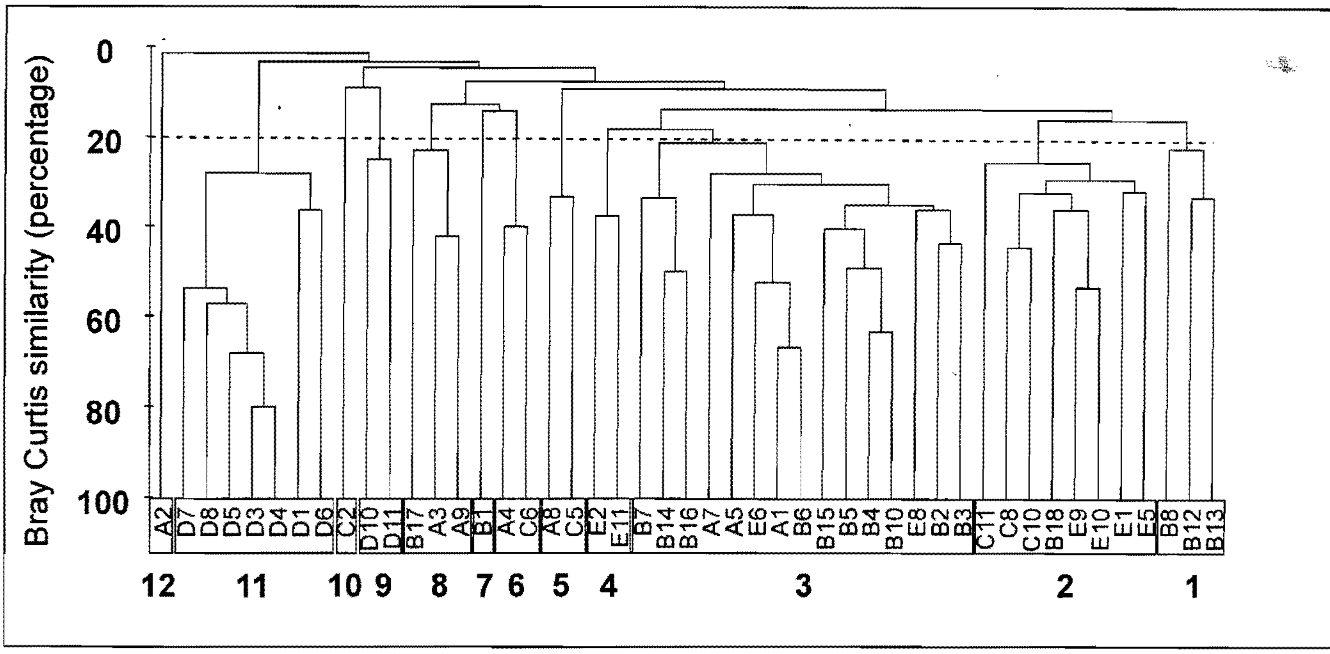


Figure 5.13a Twelve wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of animal species identified from the different wetlands (indicated by site codes) from the winter collections.

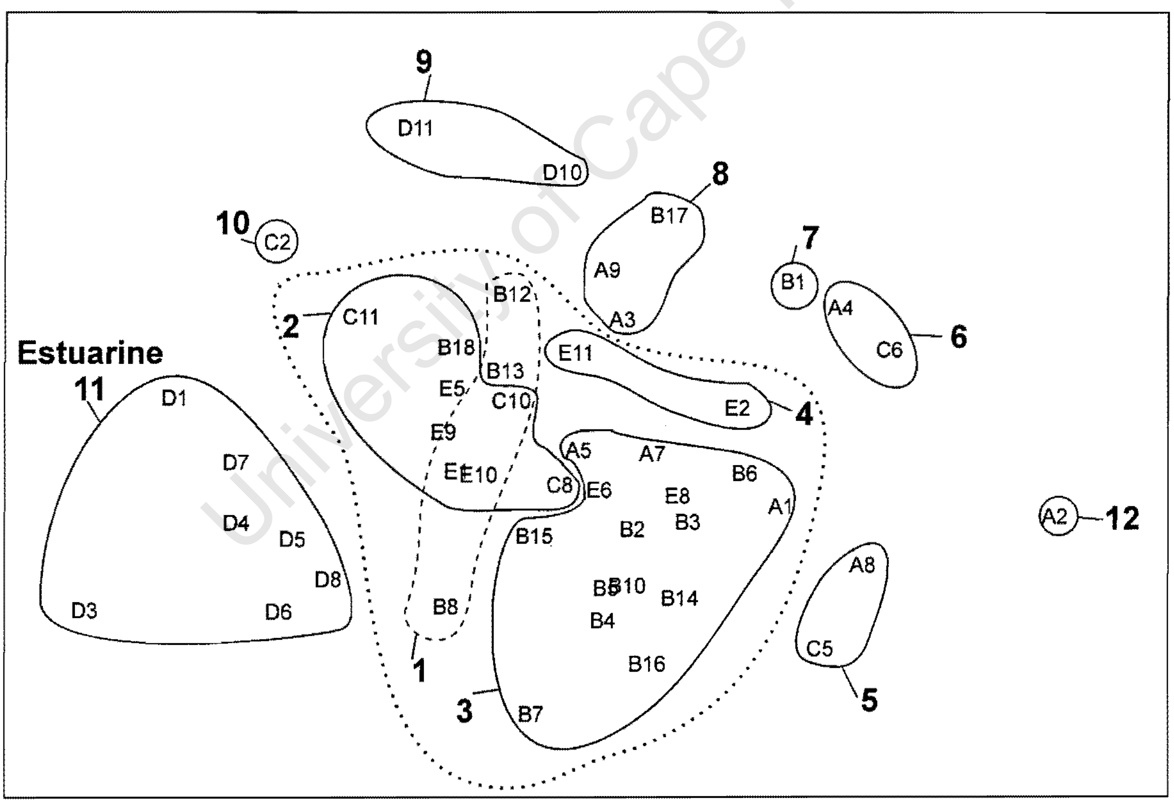


Figure 5.13b Multidimentional Scaling of the presence or absence of animal species identified from winter collections (stress 0.16).Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.13a. Wetlands may be identified by their site codes. Groups 1 to 4 do not separate clearly, particularly group 1 (marked with dashed lines). These groups have been amalgamted into a larger group marked with dotted lines.

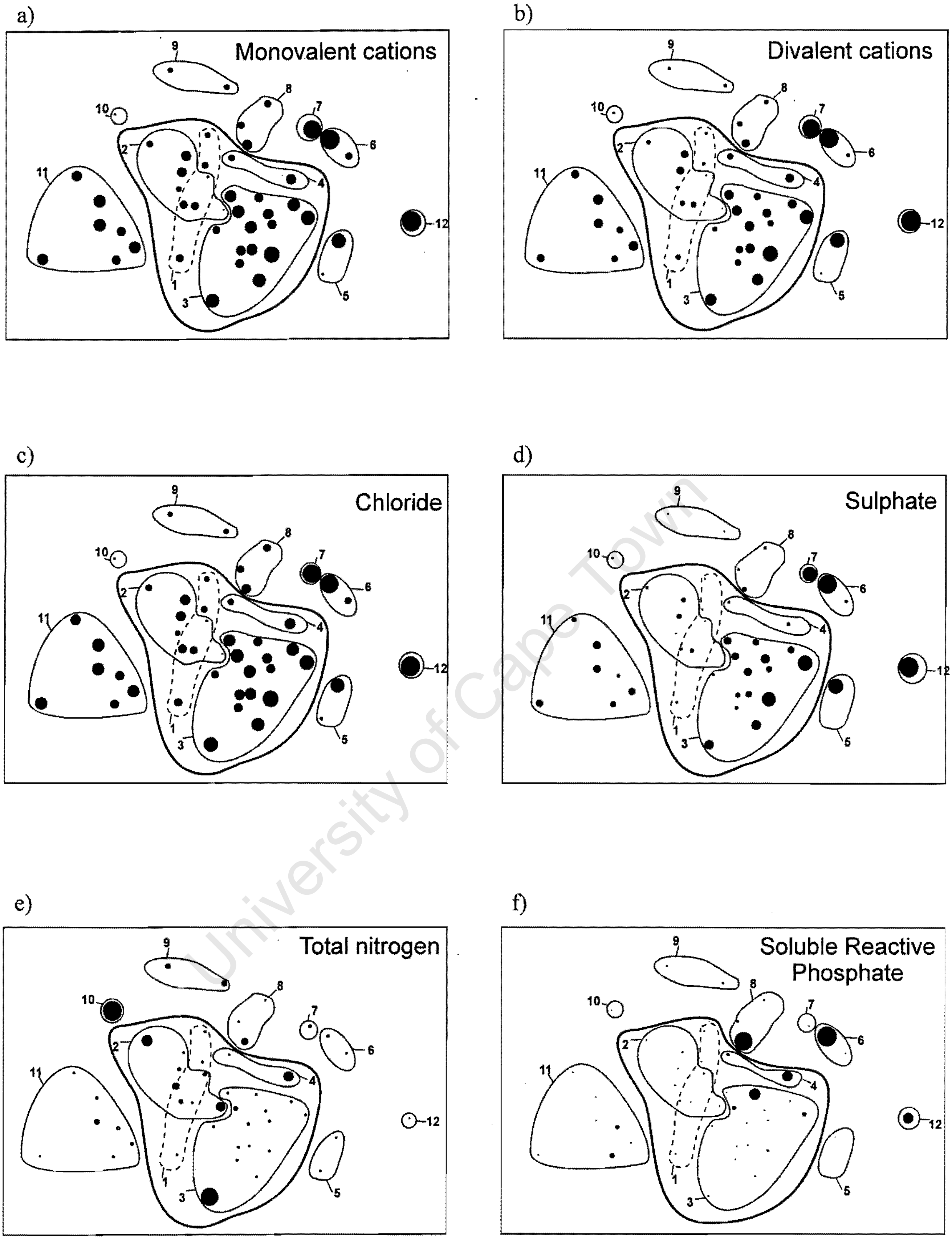


Figure 5.14a-f Conplots of nutrient and ion concentrations superimposed on MDS analyses of animals identified from winter collections, groups indicated on Figure 5.13 a and b.

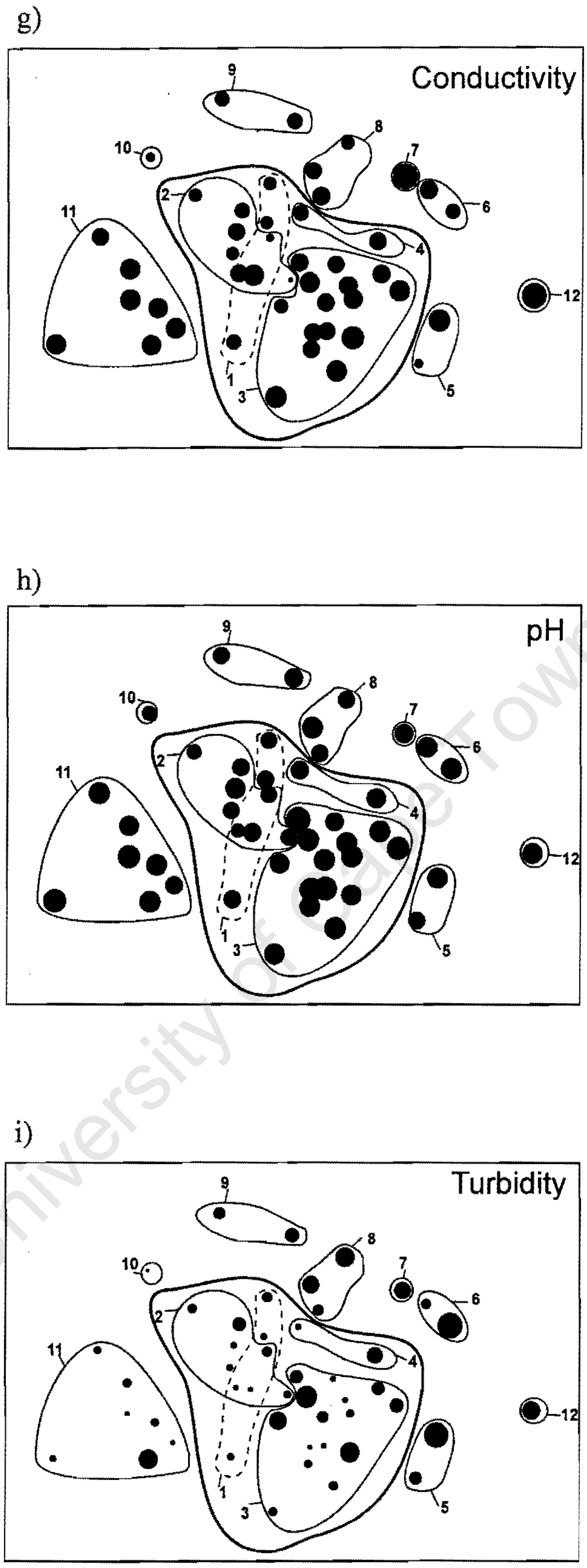


Figure 5.14g-i Conplots of conductivity, pH and turbidity superimposed on MDS analyses of animals identified from winter collections, groups indicated on Figure 5.13 a and b.

BIO-ENV indicates that a combination of three variables correlate best with the winter animal species clusters: total nitrogen, divalent cations and sulphate (Table 5.8).

Table 5.8 Winter water chemistry variables that best correlate with the animal groups identified in Figure 5.13 (BIO-ENV analyses excluding sites C1, C3, C4, D2 A10, A11, A12, A14, B9 and B11 where nutrient data were unavailable).

Number of variables	Best variable combinations
1	divalent cations (0.199)
2**	total nitrogen, sulphate (0.231)
3*	total nitrogen, divalent cations, sulphate (0.233)
4**	SRP, total nitrogen, divalent cations, sulphate (0.231)

*The combination of variables which best correlates with groups identified from animal data

**The second best combinations of variables which correlates with groups identified from animal data

Sulphate is identified as the variable which best correlates with the animal species clusters identified from the summer collections. A combination of soluble reactive phosphate and sulphate best correlate with the animal species clusters (Table 5.9).

Table 5.9 Summer water chemistry variables that best correlate with the animal groups identified in Figure 5.8 (BIO-ENV analyses excluding sites A3, D11 and E6 where nutrient data were unavailable).

Number of variables	Best variable combinations
1*	sulphate (0.087)
2**	SRP, sulphate (0.083)
3***	turbidity, divalent cations, sulphate (0.080)
4	turbidity, SRP, divalent cations, sulphate (0.079)

* Variable which best correlates with groups identified from animal data

**The second best combination of variables which correlates with groups identified from animal data

***The third best combination of variables which correlates with groups identified from animal data

Both the winter and summer BIO-ENV correlations include sulphate (as part of a group of variables or alone) as the variable which best corresponds with wetland animal species clusters.

5.7 Vegetation at the study sites

Of the 62 different wetlands investigated, 43 (69%) are considered vegetated since, they supported emergent macrophytes and/or submerged plants. The remaining 19 (30%) water bodies do not support emergent, submerged or floating plants (categorised as "no aquatic vegetation", Table 5.10). The vegetated wetlands were also surrounded by riparian vegetation which is associated with moist soil conditions. Some of the wetlands which did not support emergent macrophytes and submerged plants were surrounded by riparian plants (including members of the Restionaceae, Juncaceae and Cyperaceae families).

The extent of vegetation is not restricted to particular hydrological and landform categories (Table 5.11). Two of the permanently inundated basins do not support emergent macrophytes or submerged plants (Table 5.11), while the remaining 10 support emergent vegetation (*e. g.* the Wilderness wetlands, sites D1-D8 and Soetendalsvlei, sites B17 and B18 are surrounded by tall emergent plants).

Table 5.11 The number of vegetated and "no aquatic vegetation" wetlands associated with each hydrological and landform category ("n" is the number of wetland sites investigated in each category).

Hydrology		Landform	Vegetated n = 43	No aquatic vegetation n = 19
Permanent	Inundated year round n = 16	Basin	10	2
		Depression	2	2
	Winter inundated, summer saturated n = 3	Basin	2	1
Temporary seasonal	Winter inundated, summer dry n = 31	Basin	1	3
		Depression	10	5
		Flat	8	4
	Winter saturated, summer dry n = 4	Flat	3	
		Slope	1	
Temporary ephemeral	Irregularly wet, usually dry n = 8	Depression		1
		Flat	6	1

Table 5.10 Vegetation categories for each wetland.

Site Code	Vegetated/ No aquatic vegetation	Dominant plant functional types	Wetland descriptors	Notes on plant types
A1	No aquatic vegetation			*Sarcocornia* patches
A2	No aquatic vegetation		saline	*Sarcocornia* patches
A3	Vegetated	emergents		algae
A4	No aquatic vegetation		saline	
A5	Vegetated	emergents/submergents		algae
A6	No aquatic vegetation			*Sarcocornia* patches
A7	Vegetated	emergents/submergents		*Sarcocornia*
A8	No aquatic vegetation		saline	*Sarcocornia* patches/algae
A9	Vegetated	emergents		algae
A10	No aquatic vegetation		turbid	
A11	No aquatic vegetation		turbid	
A12	No aquatic vegetation		turbid	
A14	No aquatic vegetation		turbid	
B1	No aquatic vegetation		saline	*Sarcocornia*
B2	Vegetated	submergents		
B3	Vegetated	submergents		algae
B4	Vegetated	submergents		
B5	Vegetated	emergents/submergents		algae
B6	No aquatic vegetation	riparian vegetation present		algae
B7	No aquatic vegetation		saline	algae
B8	Vegetated	emergents		algae
B9	Vegetated	emergents/submergents		*Sarcocornia*
B10	Vegetated	submergents		algae
B11	Vegetated	emergents		
B12	Vegetated	emergents		algae
B13	Vegetated	emergents		
B14	No aquatic vegetation	riparian vegetation present	saline	
B15	Vegetated	emergents		
B16	Vegetated	emergents		algae
B17	Vegetated	emergents		
B18	Vegetated	emergents		algae
CS	Vegetated	inundated roots		
C1	Vegetated	emergents		
C2	Vegetated	emergents		algae
C3	No aquatic vegetation		turbid	
C4	Vegetated	submergents	turbid	algae
C5	Vegetated			algae/veg patches
C6	No aquatic vegetation	riparian vegetation present	turbid	algae
C7	No aquatic vegetation	riparian vegetation present		
C8	Vegetated	emergents		
C9	Vegetated	emergents		
C10	Vegetated	emergents		
C11	Vegetated	emergents		
D1	Vegetated	emergents		
D2	Vegetated	emergents		algae
D3	Vegetated	emergents		
D4	Vegetated	emergents		algae
D5	Vegetated	emergents		algae
D6	Vegetated	emergents		
D7	Vegetated	emergents		algae
D8	Vegetated	emergents		algae
D9	Vegetated	submergents		*Sarcocornia*
D10	No aquatic vegetation	riparian vegetation present		algae
D11	No aquatic vegetation			algae
D12	Vegetated	submergents		*Sarcocornia*
D13	Vegetated	emergents		
E1	Vegetated	submergents		algae
E2	Vegetated	submergents		algae
E3	Vegetated	inundated roots		
E4	Vegetated	inundated roots		
E5	Vegetated	submergents		algae
E6	No aquatic vegetation			
E7	Vegetated	emergents		
E8	Vegetated	submergents		algae
E9	Vegetated	emergents		
E10	Vegetated	emergents		
E11	Vegetated	emergents		

All exorheic wetlands are vegetated, but only 56% of the endorheic ones are (Table 5.12). Except for Langpan on the Agulhas Plain (site B7), which has submerged algae within the water body, there are no highly saline (water with salinity greater than 20 part per thousand) wetlands that support aquatic vegetation. One of the turbid wetlands in the Cederberg (site C4) is sparsely vegetated with emergent species, but the remaining turbid wetlands of Vanrhynsdorp (sites A10, A11, A12 and A14) and Cederberg (sites C3 and C6) are not vegetated. Although both sites are densely surrounded by plants, aquatic plants are not found within the Gouritz River springs (sites D10 and D11). Site D10, in particular, is a permanently inundated basin surrounded by members of the families Juncaceae and Cyperaceae which are associated with moist areas. Thus, wetlands that do not generally support emergent, submerged or floating vegetation include highly saline wetlands, highly turbid wetlands and the springs, although riparian vegetation may surround the springs.

Table 5.12 The number of vegetated and "no aquatic vegetation" wetlands associated with drainage categories.

	Vegetated n = 43	No aquatic vegetation n = 19
Exorheic n = 15	15	
Exorheic- sea connection n = 4	4	
Endorheic n = 43	24	19

A Bray Curtis similarity of the presence and absence of plant genera was run on identified plant samples, including plants collected from wetlands supporting emergent, submerged and floating macrophytes as well as riparian plants collected from the surrounding edges of the wetland. The species lists of plants collected during winter and summer seasons at each wetland have been amalgamated. At 20% Bray Curtis similarity, eight wetland groups are identified and indicated on the MDS (Figures 5.15) with a low stress of 0.07.

Group 2, which is characterised by wetlands supporting *Sarcocornia* and *Juncus* (Table 5.13), includes most of the wetlands recorded as "no aquatic vegetated" as well as others (Figure 5.15a). *Sarcocornia* is frequently associated with saline conditions and the highly saline wetlands are also

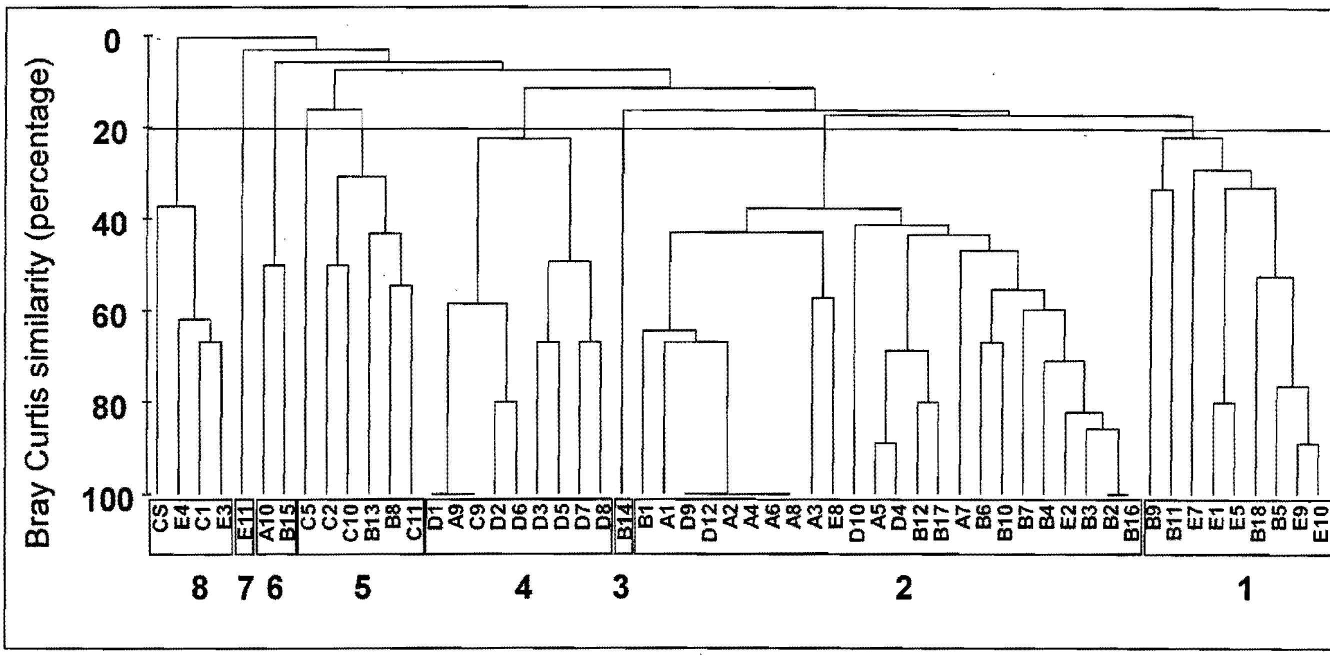


Figure 5.15a Eight wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of plant genera identified from the different wetlands (indicated by site codes)

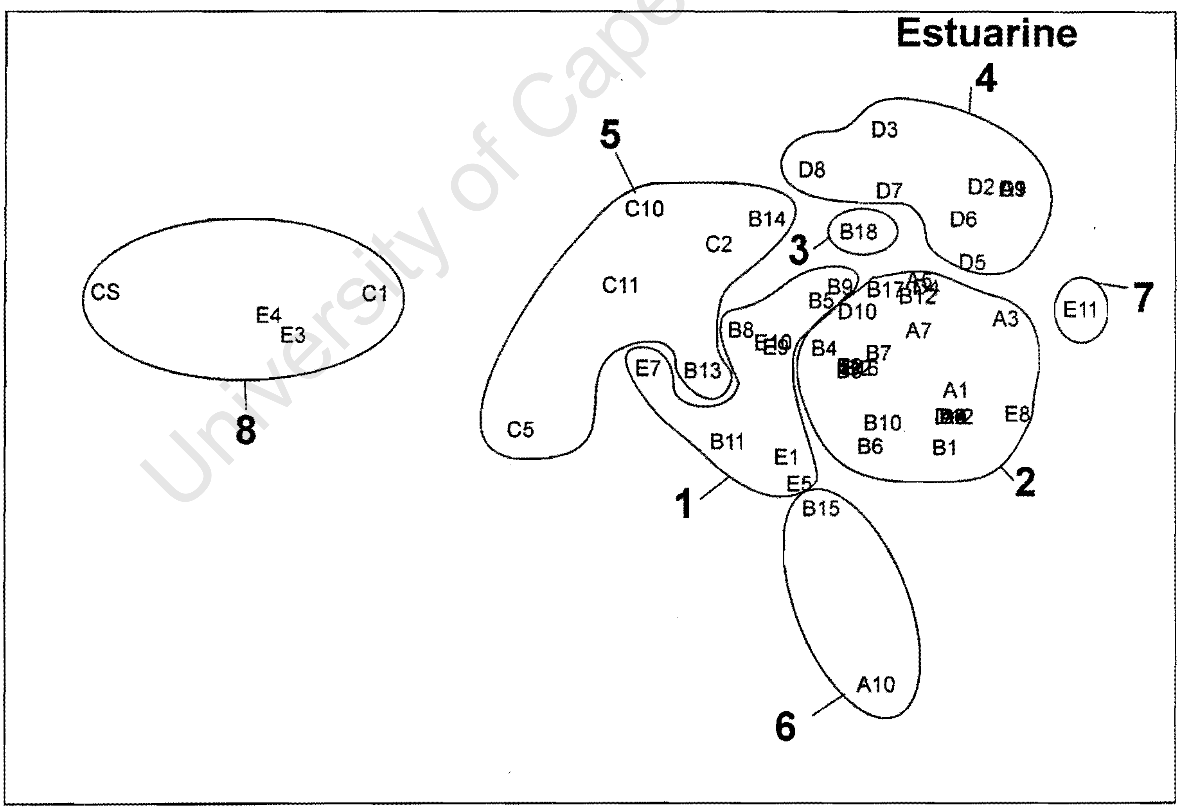


Figure 5.15b Multidimentional Scaling of the presence or absence of plant genera (stress 0.07). Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.15a. Wetlands may be identified by their site codes.

included within group 2. Group 3 separates Melkbosvlei (site B14), a saline wetland without emergent of submerged species, from the others of group 2 as *Sarcocornia* is not found at this site (Figure 5.15a).

Group 4 includes estuarine wetlands (most of the Wilderness wetlands and Verlorenvlei) as well as site C9 (Figure 5.15a). The estuarine wetlands are permanently inundated basins, but although site C9 is also dominated by *Phragmites*, it was dry throughout the year of this study and is dependent on flooding for inundation.

Group 8 includes wetlands which support winter saturated soils which are dry in summer although Driehoekvlei (site C1) is apparently temporarily inundated during years of average rainfall. The two plant genera that most contribute to the clustering of this group of wetlands, both of which belong to the family Restionaceae, are *Restio* and *Elegia* (Table 5.13).

Table 5.13 Plant genera (contributing most to least) identified through SIMPER analysis as contributing to the groups identified in the dendrogram (Figure 5.15). The average similarity of pairs of samples within a group is noted in brackets.

Group 1	Group 2 (47%)	Group 4 (42%)	Group 5 (30%)	Group 6 (50%)	Group 8 (50%)
Isolepsis Cyperaceae	*Sarcocornia* Chenopodiaceae	*Phragmites* Poaceae	*Aponogeton* Aponogetonaceae	*Oxalis* Oxalidaceae	*Restio* Restionaceae
Triglochin Juncaginaceae	*Juncus* Juncaceae	*Potamogeton* Potamogetonaceae	*Spiloxene* Empodium		*Elegia* Restionaceae
Juncus Juncaceae		*Schoenoplectus* Cyperaceae	*Juncus* Juncaceae		
Typha Typhaceae					

A Bray Curtis similarity analysis of plants identified to family (Figure 5.16a) revealed 6 groups at a similarity of 20% similarity which are illustrated at a low stress of 0.12 by the MDS analysis (Figure 5.16b). Group 1 is divided into two subgroups: groups 1a and 1b.

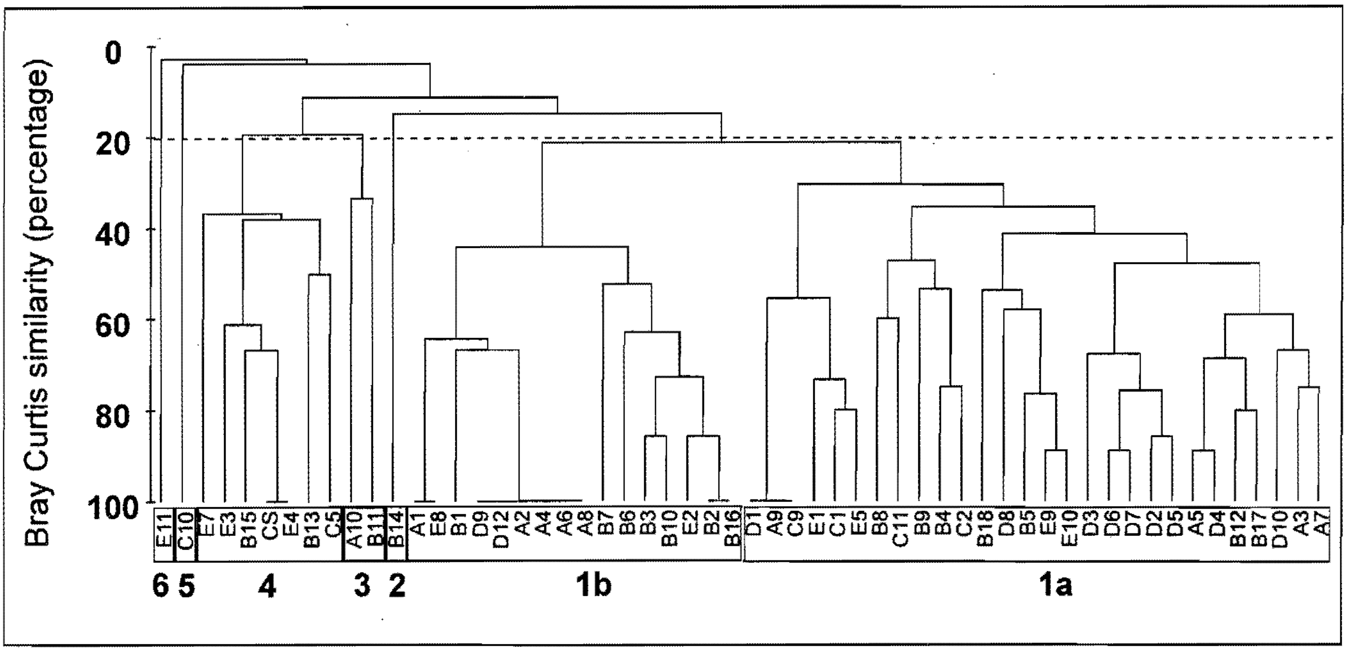


Figure 5.16a Six wetland groups at 20 % Bray Curtis similarity from the cluster analysis of presence or absence of plant families identified from the different wetlands (indicated by site code

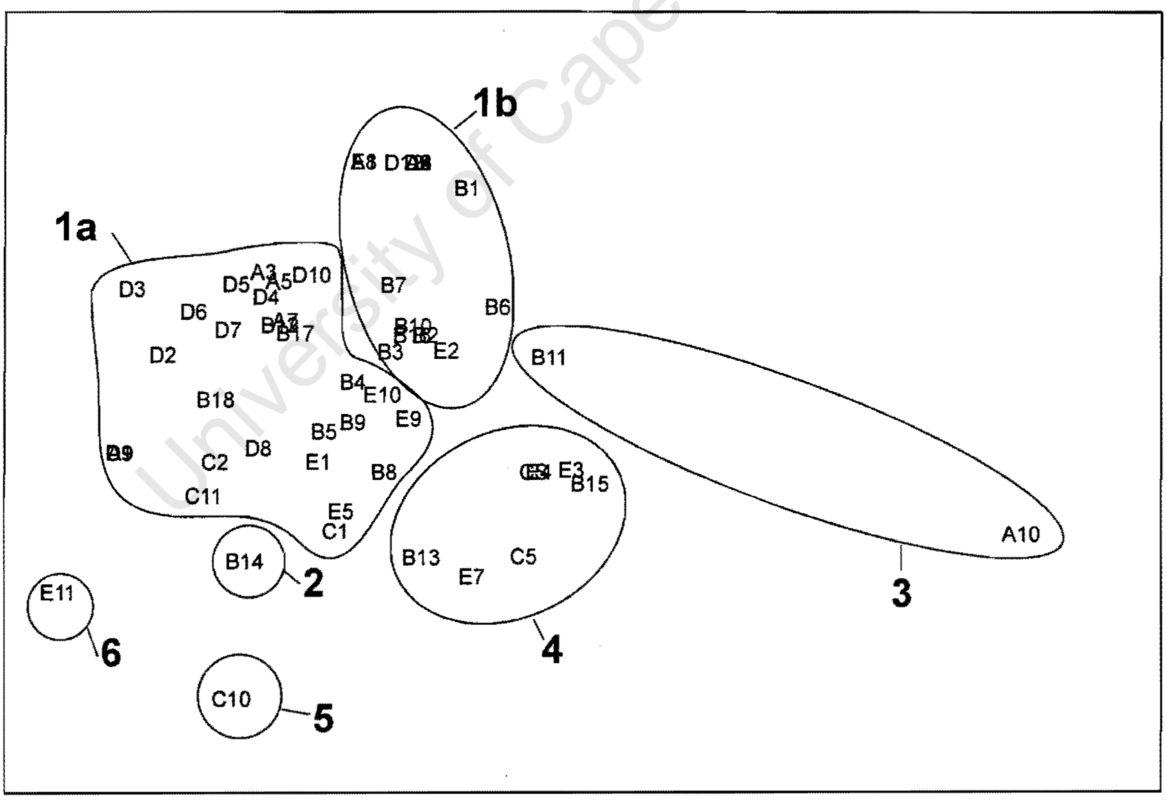


Figure 5.16b Multidimentional Scaling of the presence or absence of plant families (stress 0.12). Wetland groups indicated are identified at 20 % Bray Curtis similarity from cluster analysis in Figure 5.16a. Wetlands may be identified by their site codes.

Although the estuarine wetlands are not clustered into a group on their own, all the Wilderness wetlands and Verlorenvlei are included in group 1a. The greater portion of vegetated wetlands recorded as emergent wetlands (Table 5.10) are clustered into group 1a because the three families most responsible for the clustering of the wetlands in group 1a are the Poaceae, the Cyperaceae and the Juncaceae, which are taxa most characteristic of emergent wetlands (Table 5.14).

Group 1b includes most of the highly saline and wetlands not supporting emergent or submerged plants. *Sarcocornia* of the family Chenopodiaceae is once again the taxon most responsible for the grouping of these wetlands (Table 4.14).

Table 5.14 Plant families (contributing most to least) identified through SIMPER analysis as contributing to the groups identified in the dendrogram (Figure 5.16). The average similarity of pairs of samples within a group is noted in brackets.

Group 1a (41%)	Group 1b (59%)	Group 3 (33%)	Group 4 (47%)
Poaceae	Chenopodiaceae	Iridaceae	Restionaceae
Cyperaceae	Restionaceae		
Juncaceae			
Chenopodiaceae			
Restionaceae			

The plant analysis at genus level show that the Wilderness wetlands are different from the other wetlands investigated. The analysis groups these wetlands with Verlorenvlei which also has temporary connection with the sea. Since plant data associate all these estuarine wetlands, and animal data only the Wilderness wetlands, plants may be a slightly more reliable indicator of estuarine wetlands than animals are.

Group 1a from the plant family analysis (Figure 5.16) which includes the Wilderness wetlands is not as distinct as the Wilderness wetland group identified from plant genera (group 4, Figure 5.15).

5.8 Wetland categories from physical characteristics

Drainage, landform and hydrological regime are used to create a matrix containing 60 cells (Table 5.15) but only 16 are populated by wetlands found within the Western Cape during this study. These characteristics are used to create a hierarchical scheme of the wetlands within the Western Cape (Figure 5.17), which is to form a classification system for these wetlands. Wetlands connected to the sea have been considered estuarine and the remaining 15 are grouped as wetlands. Sites A3 near the Berg River and E6, Sirkelsvlei on Cape Peninsula are the only two that were recorded as winter inundated, summer saturated. Although these sites were saturated during the summer visit it is likely that they do dry up during the summer and that the time of the summer field study simply did not coincide with the times of dryness at these wetlands. For this reason, and because only two sites were found to fall within the category, they have been grouped with winter inundated, summer dry to form the "seasonally inundated" category indicated in Figure 5.17.

Table 5.15 Possible wetland categories. The site codes indicate which and "n" indicates the number of wetlands in this investigation that fit into each category.

		Permanent	Temporary seasonal			Temporary ephemeral
		Inundated year round **n = 16**	Winter inundated, summer saturated **n = 3**	Winter inundated, summer dry **n = 30**	Winter saturated, summer dry **n = 5**	Irregularly wet, usually dry **n = 8**
Exorheic sea connection	Basin **n = 4**	**n = 4** A9, D3 & 4, D5 & 6, D 7 & 8				
	Depression					
	Flat					
	Slope					
Exorheic	Basin **n = 1**	**n = 1** B17 & 18				
	Depression **n = 1**	**n = 1** A5				
	Flat **n = 13**			**n = 5** B8, B9, B11, C2, C8	**n = 3** C1, C10, C11	**n = 5** C9, D9,D12, D13, E3
	Slope **n = 1**				**n = 1** C5	
Endorheic	Basin **n = 14**	**n = 8** A7, A11, B5, B7, B10, B12, D1 & 2, E11	**n = 2** A3, E6	**n = 3** A10, C6, E8		
	Depression **n = 19**	**n = 3** C5, D10, D11		**n = 15** A4, A12, A14, B2, B3, B4, B14, B15, B16, C3, C4, E1, E2, E5, E9		**n = 1** C7
	Flat **n = 9**			**n = 6** A1, A8, B1, B6, B13, E10	**n = 1** E4	**n = 2** A6, E7
	Slope					

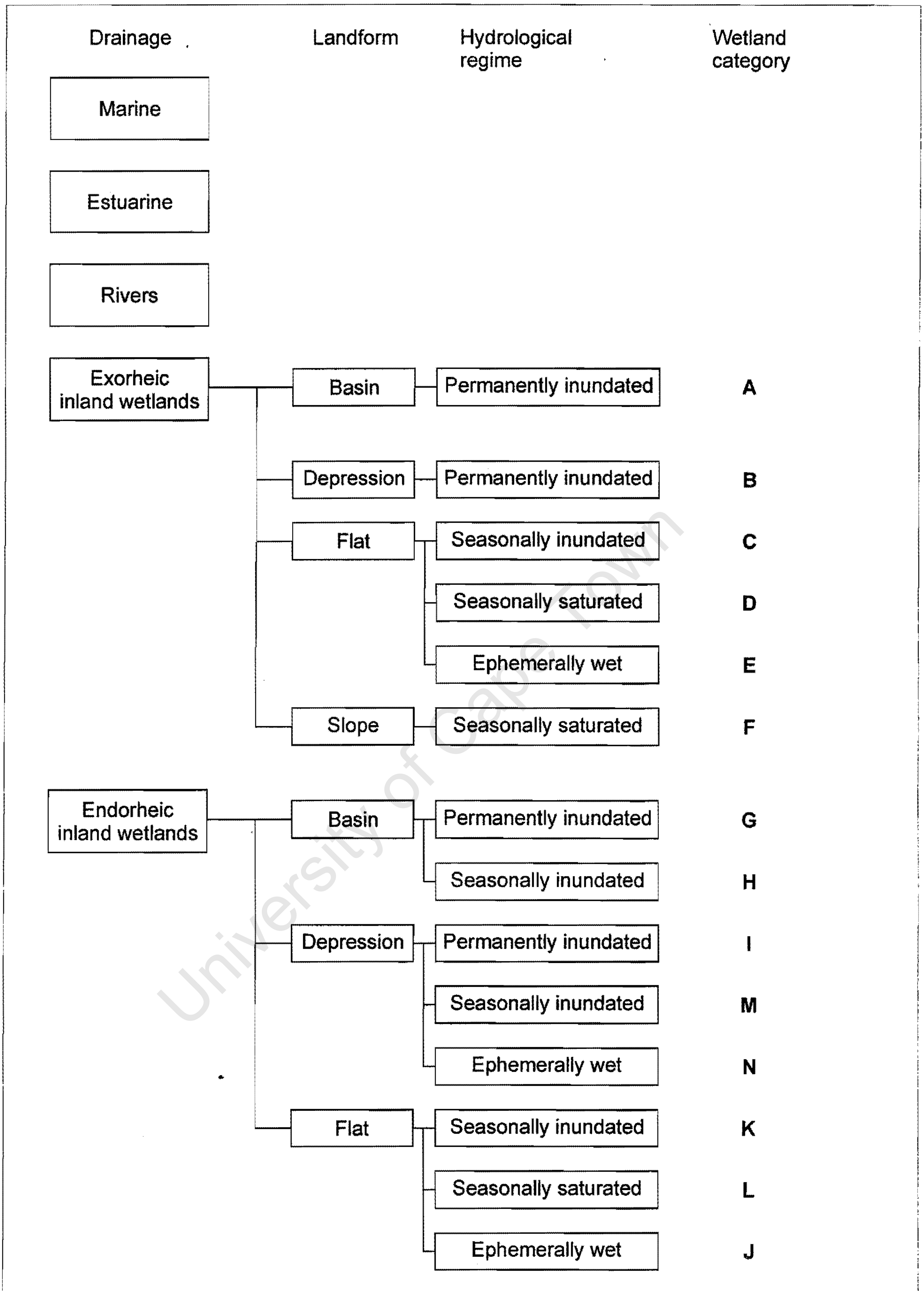


Figure 5.17 Hierarchical format of wetland categories found within the Western Cape.

Chapter Six

Discussion

6.1 Introduction

Wetland characteristics that might useful for developing a wetland classification have been analysed and wetland categories identified in Chapter 5. This chapter discusses the degree of usefulness of these characteristics and the ways in which they may be incorporated into a classification system. The studied wetlands fit into only some of the potential categories, in other words those represented in reality in the Western Cape. The categories are ordered into a hierarchical classification system which is considered to be a useful approach. Finally, a dichotomous key is presented for the proposed categories.

Classification systems differ depending on their purpose and resources available. A hierarchical classification system will be easy to use but descriptions of the different wetland types are also required. The use of visible structural characteristics will enable users to classify wetlands through observation, but may not represent the wetlands' functions. Wetlands will be classified consistently through time if the characteristics used in classification system are slow changing, but some slow changing characteristics (*e. g.* geomorphology) may not provide the detailed information that other characteristics would (*e. g.* animal community). Characteristics selected for the classification system are required to group wetland types with clarity and convenience for both scientists and non-scientists as the classification is required to facilitate communication between scientists and managers. Further, the classification system is required to assist with identification of the quantity and quality of water required to protect wetlands and to secure sustainable development (South African National Water Act (No 36) of 1988).

6.2 Wetland characteristics and their use in a classification system

Biotic and chemical processes occurring in wetlands are affected by their underlying characteristics, namely aspects of climate, lithology, geomorphology and hydrology. These characteristics shape the structure, and define the functions of, wetlands in the landscape (Maltby *et al.*, 1994). Although all of these characteristics are important for describing types of wetland and the processes taking place in them, not all of them are necessarily practical for classification purposes. For example, information on some characteristics (such as nutrient concentrations) are collected at high expense, while others may not even indicate distinctions between wetlands.

6.2.1 Geomorphology of the wetland

Landscape morphology is a useful characteristic for coarsely grouping wetlands since it is a slow changing wetland parameter in comparison to hydrological, chemical and biological features and neither technical expertise nor expensive equipment is required to provide a coarse description of geomorphology. Furthermore, some geomorphological aspects may be described using remote sensing techniques for some wetlands, although it may not be useful for others (such as small wetlands which may not be visible on low resolution images).

Winter-saturated wetlands were found only on flat or sloped landforms, while depressions or basins can hold water and are therefore more likely to be inundated throughout the year. Furthermore, while seasonal wetlands are found along the continuum of different landforms, from basins to slopes, permanent wetlands are only found within basins and depressions. This is not unexpected as Semeniuk and Semeniuk (1995), for instance, also found permanently inundated wetlands only within basins and channels. It is thus apparent that geomorphology shapes other wetland characteristics, particularly aspects of the hydrological regime.

Although landform has the advantage of being relatively stable, ambiguities may arise when this feature is used for grouping wetlands since it is not always possible to state precisely into which category a landform fits. It may be difficult, for instance, to distinguish between a flat and a slope or between a depression and a basin, because these terms are not defined quantitatively but fall in a continuum, as with most abiotic characteristics (Figure 2.4).

6.2.2 Drainage patterns

Exorheic and endorheic wetlands are easily identified because it is relatively simple to determine whether or not water flows out of a wetland. A distinction drawn between endorheic and exorheic wetlands allows us to make a primary separation between river-connected wetlands and non-riverine wetlands and permits division of wetlands into two groups at an initial stage in the hierarchical classification system presented here. This facilitates cross referencing with the Cowardin *et al.* (1979) classification system, which also makes a distinction between riverine and other wetlands at a primary level.

6.2.3 Hydrological regimes

The wetlands investigated were sorted into the five categories of water permanence: permanently inundated; winter inundated, summer saturated (seasonally inundated); winter inundated, summer dry (also seasonally inundated); winter saturated, summer dry (seasonally saturated) and ephemerally saturated or inundated (ephemerally wet). The rainfall of the Western Cape varies from year to year and the winter season during this study was the driest in many years. Although the wetlands identified as permanently inundated are likely to remain so from year to year, wetlands of the other categories may change depending on annual rainfall. For instance, a site found to be inundated in winter and dry in summer may be saturated or even inundated throughout summer in years of high rainfall. Furthermore, the inundation period of seasonal wetlands also depends on the amount of rainfall, the greater the rainfall the longer the drying process and the longer the period of inundation or saturation. Thus, if one was attempting to determine whether or not a wetland dried during summer, it might have to be monitored throughout the summer and over a number of years. The period of inundation is also likely to depend on the size of the wetland, larger deeper wetlands presumably remaining wet for longer. For these reasons it is unprofitable to measure lengths of inundation periods of seasonal wetlands.

Further, it is not always easy to ascertain whether a wetland is permanently inundated or otherwise, since an inundated wetland may only be classified as temporary once it has been seen to dry out at some time during a single year. Thus, an annual photographic record of a wetland cannot be used to indicate water permanence. In summary, since patterns of inundation or saturation are changeable, the overall hydrological regime is too changeable for primary or sole use in the classification system developed here. It also requires a full year of data before the wetland's hydrological regime can be accurately described, which is not practical.

The type of inundation affects biotic communities, for example, fish that exist in permanently inundated wetlands cannot survive in seasonally inundated wetlands. Permanent wetlands are more predictable than seasonal wetlands which are changeable, albeit often predictably so. The differences in hydrological regimes make the wetlands very different from each other and the different types need to be regarded separately for academic and management purposes. It is possible to draw the distinction between permanently inundated and other wetlands at initial levels in the classification system. Thus, as water permanence shapes the type of wetland and its processes, it should not be excluded from the classification system.

6.2.4 Wetland soils

Distinguishing characteristics of wetland soils were not examined in the present investigation. A reconnaissance-level investigation did, however indicate both the usefulness of soil characteristics with regard to delineating (determining the wetlands boundaries) and the difficulties in identifying the different soil types (particularly within the studied area and possibly in other areas of the Western Cape).

The appearance of hydric soils is mostly due to the anoxic conditions caused by waterlogging. Organically rich humus shows mottling and a matrix of colours which may be used to determine soil characteristics such as the degree and extent of waterlogging. Thus, soil characteristics (together with vegetation characteristics) may be used as a wetland boundary indicator (Kotze *et al.*, 1994 and Kotze and Marneweck, 1999). Some areas, such as Bettys Bay, support well leached sandy soils (podsols) that do not show the mottling and typical gleying of waterlogged soils. Sandy soils lack organically rich humus, and anoxic conditions do not always develop in the shallow and temporary wetlands on these podsols. Thus, the soil chroma and mottling typical of inundated soils does not develop in wetlands on sandy substrata. In this instance soil moisture may be the only indicator of wetland existence and, since these soils dry out during the summer, soils are of limited value for wetland delineation in summer months.

This investigation revealed not only the difficulty of using soil characteristics but also the variability of soil types found in the Western Cape wetlands. I recommend that further investigations are made into the soils of these wetlands in order to ascertain the degree to which they may be useful for wetland classification in the area.

6.2.5 Conductivity, pH and turbidity

Of the water chemistry variables, conductivity, pH and turbidity contributed most to wetland groupings. The pH values measured during the study were surprisingly high as wetlands in the Western Cape are known for their acidity (Noble and Hemens, 1978) and this may have been a result of the unusually low rainfall during the 2000 winter season. The cluster and MDS analysis using pH, conductivity and turbidity (Figure 5.5) identified a group of turbid seasonal endorheic wetlands near Vanrhynsdorp and Cederberg, which can easily be recognised in the field by their muddy waters. Since pH, conductivity and turbidity are frequently recorded and can be measured *in situ*, and because the data are likely to be comparable with data sets collected by different scientists, they are arguably the most practical chemical parameters for use in the classification system. Conductivity, pH and turbidity are included in the classification system, but as descriptors of the different types of wetlands rather than as specific criteria for classifying wetlands.

6.2.6 Major ions and nutrients

In the present study, wetland groups defined by pH, conductivity, ions and nutrients did not correspond with groups defined by geographical, animal, plant or abiotic categories. Further, the clusters identified from winter and summer analyses of these variables did not consistently group wetlands (Figure 5.1 and 5.3) which suggests that the variables cannot be reliably used to identify different types of wetlands. Wetlands groups were distinguished only at a Euclidean distance of 20 indicating that they are not well separated.

Nutrient patterns in this study appeared to be random and could therefore not be used to group wetlands. More intensive investigation might reveal wetland groups, but it is possible that nutrients do not indicate different wetland types on the spatial scale investigated. Since many of the wetlands were within agricultural areas, their water chemistry may be altered through human impacts such as run-off from agricultural irrigation which would mask 'natural' patterns. Furthermore, nutrient fluxes are complex and can be considerable from season to season (e. g. Britton *et al.*, 1993). Despite the value of understanding nutrient composition this characteristic is unlikely to be useful for distinguishing wetland types since nutrients are expensive and time consuming to measure.

Figure 5.6 indicates that most wetlands of the Western Cape coastal areas are $NaCl^-$ dominated wetlands, some salt pans such as Soutpan, site B1, on the Agulhas plain and A2 near the Berg River to a much greater degree than others. As sodium and chloride are generally the last ions to settle as wetlands evaporate, they may be present in high concentrations in wetlands that have less water than in a usual. Due to the low rainfall in the winter, there was less water in the sampled wetlands which may also account for the fact that some wetlands are strongly dominated by $NaCl^-$. The ionic content of coastal wetlands is affected by on-shore winds which bring in precipitation laden with salt. Thus coastal wetlands are more likely to be dominated by $NaCl^-$ than inland systems (Day and King, 1995). Sodium and chloride are less dominant in the inland wetlands of the Cederberg and Ceres areas and the ionic content of waters of these areas are likely to be influenced by the lithology of the Karoo. This suggests that water chemistry is related to geographical location rather than to specific types of wetlands (Day and King, 1995).

6.2.7 Wetland animal communities

The unusually low rainfall in 2000 resulted in few temporarily inundated wetlands being available for study and in their being inundated for shorter periods. This reduced the time available for invertebrate maturation (it is not always possible to identify juvenile specimens) as well as for collection and also meant that invertebrate emergence from eggs or cysts may have been stalled during this season. For instance some crustaceans such as anostracans might have been expected to be present in more sites than was actually the case in this project. Previous aquatic invertebrate data collected by M.J Silberbauer and J.M King during 1989 (Freshwater Research Unit, University of Cape Town, personnel communication) showed a limited ability to distinguish wetland groups and not all investigated wetlands could be consistently associated with specific groups (B.E. Day Freshwater Research Unit, University of Cape Town, personnel communication). The aquatic fauna of the western Cape is known to be highly speciose. It is possible that the high number of species and endemics and the low number of species common to different wetlands prevent the biota from providing a useful grouping all the wetlands. For the purpose of the classification system it has to be assumed that the animals samples collected are representative of the wetlands. In fact, more intensive animal sampling (more collections at more wetlands over longer time periods) might be expected to produce more complete lists of species for the different types of wetlands, and this might in turn permit identification of invertebrate communities specific to wetland types. Since intensive sampling is financially expensive and time consuming, the use of aquatic animal communities may not be practical in a system designed for easy classification of wetlands.

Cluster analyses of the samples of aquatic animals (Figures 5.7 - 5.12) at each taxonomic level repeatedly distinguished certain groups of wetlands. For instance, a group of the Wilderness wetlands, and a group of highly turbid seasonal wetlands of the Cederberg and Vanrhynsdorp areas, are distinguished on each dendrogram. The clustering associated with the Vanrhynsdorp and Cederberg wetlands and the Wilderness wetlands indicates that animal community characteristics do have the potential for identifying different types of wetlands. However, other wetlands could not be grouped consistently using faunal characteristics and furthermore, clusters from the separate winter and summer analyses do not group wetlands similarly.

Analyses of animal data cluster wetlands from similar areas. For instance, all of the Wilderness wetlands are grouped together, the Cape Peninsula and Bettys Bay wetlands are closely associated, and wetlands of Cederberg and Vanrhynsdorp areas repeatedly group together. River organisms are geographically specific (*e. g.* King and Schael, 2001) and the data suggests that wetland animal communities are also geographically specific. Further investigations into wetland biodiversity would be valuable, since the geographical specificity implies that there may be local endemism of wetlands within the Western Cape area. This may indicate that rather than grouping specific types of wetlands, faunal samples will only be similar in geographically close wetlands.

An attempt was made to specify the taxa associated with different wetland groups using SIMPER analyses, but results did not indicate taxa specific to wetland types. The turbid seasonal Vanrhynsdorp and Cederberg wetlands (Table 5.6, group 4) are characterised by certain crustaceans (copepods, conchostraca, and anostracans) indicating that these taxa may be used to group this wetland type. However, these temporary wetlands share some of these taxa (*e. g.* copepods) with permanently inundated wetlands.

The aquatic invertebrate data did not group permanent and temporary wetlands separately despite the fact that some species require temporary inundation and others require permanent inundation. Some crustacean taxa (anostracans, conchostracans, notostracans and cladocerans, Table 6.1) are usually associated with temporary wetlands, since certain crustaceans produce eggs or cysts that may withstand, or even require, desiccation, and emerge when the wetland becomes inundated (Davies and Day, 1998). Some amphipod, isopod and decapod taxa are specific to estuaries, while other taxa have been found only in rivers. Thus different crustacean species were not identified as specific to wetlands types in this project, although different taxa may indicate differences in wetland type.

Although the Wilderness wetlands are neither permanently nor directly connected to the sea, the animals supported by these wetlands are typically estuarine (*e. g.* Griffiths, 1974), indicating a strong marine influence. Groenvlei (also one of the Wilderness wetlands) is not connected to the other wetlands or to the sea, yet the animals are also of estuarine origin because it was once connected to Swartvlei (Hill, 1975), another of the Wilderness wetlands that is presently connected to the sea. Verlorenvlei, on the west coast, still functions infrequently as an estuary in its lower reaches but the animal data did not group this wetland with the other estuarine wetlands. Verlorenvlei is subject to more agricultural disturbances than the Wilderness wetlands and the connection with the sea has been severely degraded by reclamation and is largely blocked by a road crossing. Langvlei, Eilandvlei and Rondevlei (sites D3 - D8) are annually connected to the sea (Hill, 1975) whereas Verlorenvlei is connected infrequently (Robertson, 1980). Although both freshwater and estuarine organisms are found in Verlorenvlei (Grindley and Grindley, 1987), the degree of historic separation of the wetland from the sea may have resulted in the less estuarine nature of its animal community.

Table 6.1 Crustacean taxa restricted to different types of aquatic systems.

	Temporarily inundated	Permanently inundated	Rivers
Anostracans Conchostracans Notostracans	Definitive for temporary waters	Not found	Not found
Cladocerans	Many species found	Many species found	Found occasionally Few species
Amphipods Isopods	Not found	Taxa specific and definitive for estuaries, not found in other wetlands	Definitive taxa for rivers
Decapods	Not found	Marine, estuarine taxa different to river taxa	Definitive taxa for rivers

The author would like to acknowledge J.A. Day (Freshwater Research Unit, University of Cape Town) with regard to development of the this table.

Animal communities were found to distinguish estuarine wetlands from all others and can be used at a primary level in the classification system. As riverine and lacustrine wetlands (*sensu* Cowardin *et al.*, 1979) were not investigated in this study, it is not possible to show how clearly faunal characteristics indicate a difference between rivers, lakes and other inland wetlands. However, animal taxa of these aquatic environments are different and several taxa are known to be specific to rivers or wetlands (*e. g.* Table 6.1). For instance, insects are more common invertebrates of rivers than of wetlands. Furthermore, some crustacean taxa (some cladoceran species, amphipods, isopods and decapods) are specific to rivers while other crustacean taxa (anostracans, conchostracans, notostracans and some cladocerans) are dominant in wetlands (Davies and Day, 1998).

Thus animal communities may be used to indicate differences between aquatic ecosystems at a coarse scale of marine, estuarine, riverine and other inland wetlands. Some taxa may also indicate differences at a finer scale such as between different types of inland wetlands. However, as the data do not conclusively show that the animal communities can be used to group the investigated wetlands, information regarding wetland animal communities is not used to classify wetlands in the classification system, but is rather used to describe the wetland types defined from geomorphological and hydrological characteristics.

6.2.8 Wetland vegetation

For an accurate species list to be developed, plants should be sampled regularly throughout the year which suggests that identification of wetland flora is too time consuming for use in the classification system. For this reason, and to obviate the need for identifying plants to species level, categories of functional (Denny, 1985) types of aquatic vegetation (in this study, plant categories of emergent macrophytes and submerged and floating plants) present at each wetland are used. At this level, vegetation is an easily perceived characteristic that many non-specialists can identify, and it is therefore a useful characteristic for wetland classification. However, studies investigating wetland vegetation in more detail might go a long way to improving the classification system developed here since aquatic plants may be used as indicators of conditions within the wetland (Goslee *et al.*, 1997) even if the plants are not identified to species level. During the dry months vegetation of the temporarily inundated wetlands is exposed. In some of these wetlands the vegetation dries out and dies, leaving behind mats of dried plants or algae and in others vegetation persists through the dry season. Plants left behind by drying of temporary wetlands are also useful indicators of types of wetlands, such as *Sarcocornia* which is indicative of saline conditions.

Emergent plants need to be rooted in the wetland substratum and as a result only exist to water depths of *ca* 3m or less (Denny, 1985). Thus the presence of emergent plants indicates wetland areas less than 3m in depth. Since tall emergents are established around the edges of most permanent basins, it was possible to deduce that central parts of the wetland are too deep for emergent plants and these wetlands thus exceed 3m in depth. Thus emergents, such as *Phragmites* and *Typha*, can be used as indicators of permanently inundated basins that have depths greater than 3m since water depth limits the spread of emergents into the centre. As emergent plants may be seen on some aerial and orthophotographs, emergents may be used for a remote-sensing classification of wetlands.

The analyses of plant data do not identify specific wetland groups. However, it is possible to describe wetlands as either supporting aquatic vegetation (vegetated) or lacking in emergent macrophytes and submerged plants (no aquatic vegetation). Further, the vegetation may be described according to functional type. Through a human time frame plant type and distribution changes (McCarthy *et al.*, 1986) which suggests that vegetation characteristics are not stable enough features for use at higher levels of a classification system. However, vegetation characteristics may be used to describe wetlands at lower levels in the classification system.

6.3 Characteristics selected for use in the hierarchical classification system

Figure 6.1 illustrates the hierarchy of characteristics, firstly drainage patterns, then landform followed by hydrological regime that are used to classify wetlands at the first three levels of the classification system. Other characteristics including water chemistry, animal communities and plant functional types will be used as "descriptors" to indicate detailed information on the wetlands once they have been classified according to geomorphological and hydrological characteristics.

Drainage patterns determine whether or not nutrients, ions and particles are retained in a wetland and whether organisms are moved out of a wetland or not. Drainage thus plays a major role in controlling the chemical and biotic processes occurring in different wetlands and therefore

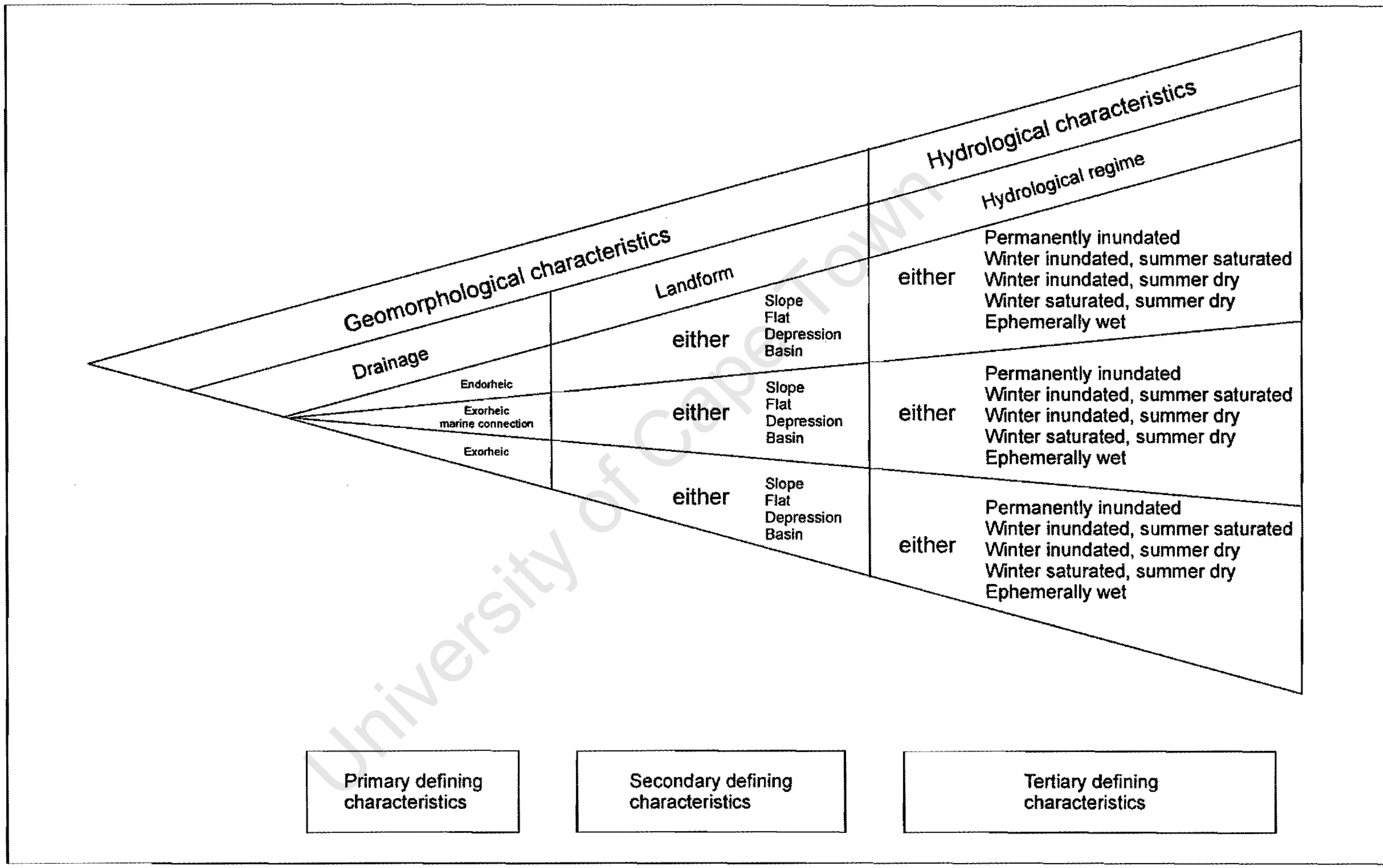


Figure 6.1 The hierarchical method whereby the selected characteristics may be applied to wetland classification. Wetlands may be assigned to a category using the primary defining characteristic, and then may be further categorised using the secondary characteristics, and again categorised using the tertiary characteristics. The hierarchy will allow coarse classification of wetlands.

determines the functioning and type of wetland. Because drainage patterns are controlled by the geomorphology of the surrounding landscape, they are less likely to be altered by human activity and are slower to change than hydrological, biotic and chemical characteristics. Geomorphological characteristics are therefore stable over long time periods. For these reasons, drainage pattern is used as the primary characteristic for distinguishing between unimpacted wetlands (Figure 6.1).

Landforms within which a wetland is located are selected as the secondary characteristics for the hierarchical classification system since they are also slowly changing morphological features (Figure 6.1). Landform not only shapes a wetland but also determines its hydrological regime. For instance, basins and depressions are the only landforms that support permanently inundated wetlands, while slopes support wetlands with saturated soils, since surface water flows away as overland flow. Since landform controls aspects of hydrology and can create habitats, it has an effect on the biotas of wetlands. For instance, a deep-water wetland will support benthic and pelagic species while a shallow wetland may consist of open waters interspersed with vegetated regions inhabited by different suites of species.

As the presence of water defines the very existence of wetlands, it should be incorporated into the classification system at a high level (Figure 6.1). Not only is availability of water changeable in South Africa due to the unpredictable climate, but the hydrological regime is also more likely to be altered by anthropogenic forces than morphological characteristics because humans require water and are easily able to drain or dam wetlands. So, while the hydrological regime is not the primary characteristic used to distinguish wetland types in this classification system, it is used at the tertiary level.

As the chosen characteristics (geomorphology, hydrological regime and drainage patterns) are physical attributes of wetlands, the hierarchical classification system is "top-down" rather than "bottom-up". A "bottom-up' approach to classification would be based on aspects, such as the aquatic fauna, the vegetation and water chemistry (Naiman *et al.,* 1992). Physical characteristics are more easily assessed than biotic communities and water chemistry are. Although the underlying physical characteristics may not provide information as detailed as one based on the

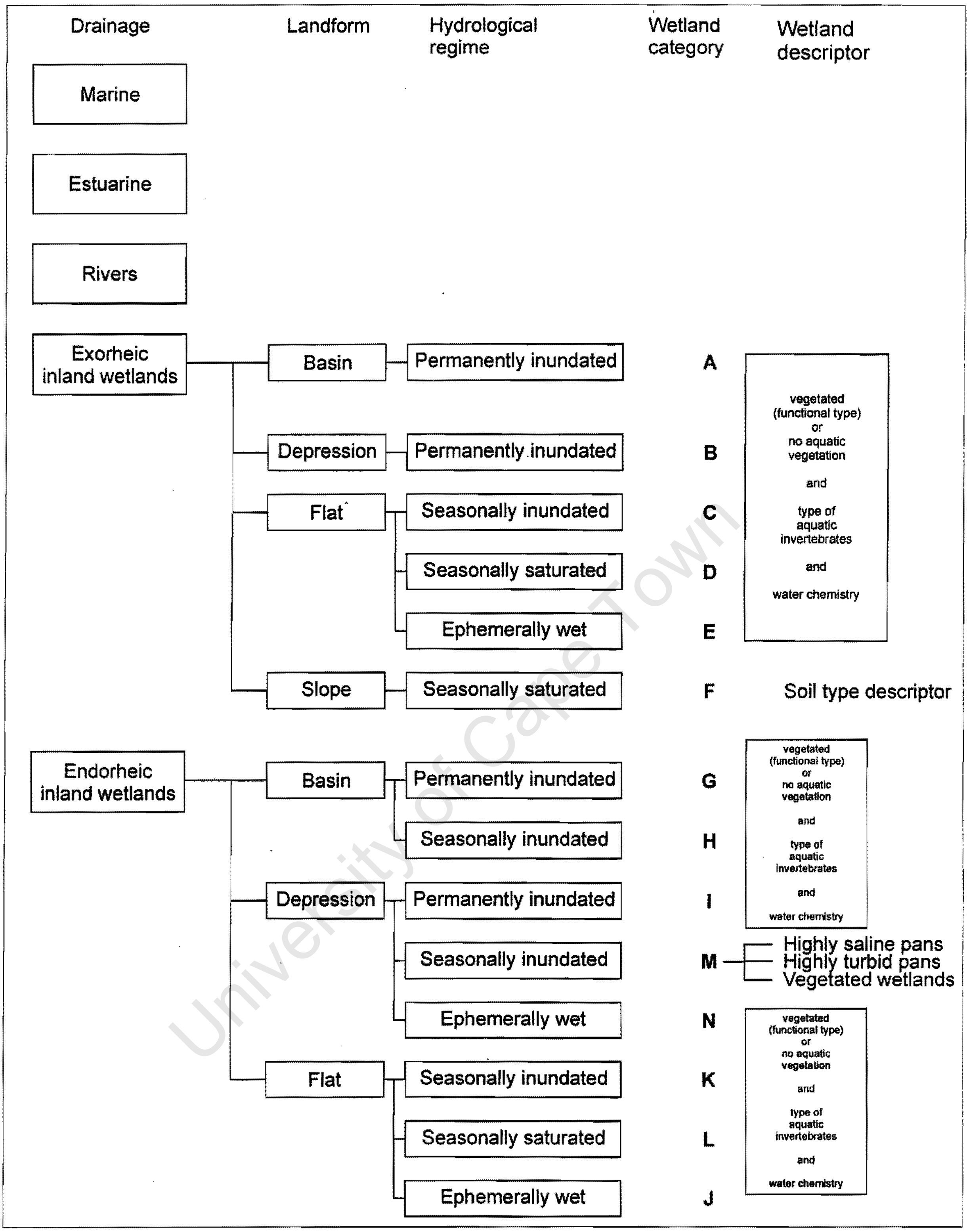


Figure 6.2 Hierarchical format of wetland categories found within the Western Cape with possible descriptors included at a lower level.

biotic communities and water chemistry, a classification system based on physical rather biotic and chemical characteristics may be more applicable for remote sensing and large scale wetland inventories as physical characteristics are visible on aerial and othophotographic material. If, in future, pH is found to group wetlands, particularly in the Cape acid waters described by Noble and Hemens (1978), it can be built into the classification system. For the purposes of the presented classification system, both pH and conductivity will be used as descriptors. Since a group of highly turbid and another of highly saline wetlands were identified in both the chemical and animal analyses, the turbid and saline seasonal endorheic wetlands are also considered a distinct group. Turbidity and salinity are good distinguishing characteristics, particularly as they are easily identifiable (Figure 6.2).

Aquatic animals and water chemistry data are easily collected from inundated wetlands, and some aquatic invertebrates can be hatched in the laboratory from the dried soils of temporary wetlands. Wetlands with saturated soils do not support aquatic macroinvertebrates as inundated sites do, and collecting water samples from them is time consuming and impractical. Thus, aquatic animals and water chemistry are useful as wetland classification characteristics only for wetlands that are inundated at some time during the year. For this reason, they should only be used as descriptors of inundated wetlands but not as primary distinguishing features in an hierarchical classification system (Figure 6.2). On the other hand, characteristics such as vegetation and soil type can be used as descriptors of saturated and dry wetlands. Vegetation usually persists in saturated wetlands and is thus available for describing wetlands throughout the year. Soil types of saturated and dry wetlands have been classified for certain areas and it is possible that a soil classification system may be developed specifically for the hydric soils of Western Cape too. Soil characteristics are less easily applied to inundated wetlands since it is more difficult to core samples from inundated wetlands than from saturated ones. Thus soil characteristics cannot be applied to all wetland types identified in the hierarchical classification system presented here (Figure 6.2).

The three initial levels in the hierarchy provide a coarse classification system of wetlands that may be used for remote techniques and for some management and scientific purposes. A more detailed classification system will probably be required by wetland ecologists and other scientists as they may require more detailed information. Wetlands may be further subdivided, but characteristics such as aspects of the fauna and of water chemistry cannot be applied to all categories of wetlands identified to the tertiary level. Clearly, some wetland types identified at this level may not support aquatic animals while water chemistry cannot be used as some wetlands are not inundated with standing water. Soil and biotic characteristics may not be universally useful, but they may be applied as descriptors to particular wetland groups within specific geographical areas.

6.4 Types of wetlands found in the Western Cape

The characteristics identified in Figure 6.1 are used to create a hierarchical classification system for Western Cape wetlands. Although various wetland types are identifiable from the hierarchy given in Figure 6.1, not all actually exist. Table 5.15 indicates the types of Western Cape wetlands which may be classified using this hierarchy and a key for the classification of these characteristics is given in Table 6.2.

The fact that only 16 wetland categories were investigated does not imply that wetlands in the other categories do not exist. They may not have been investigated in the present study or they may not exist within the Western Cape. For example, flats that are connected to the sea, such as the Berg River tidal flats, were not investigated as they were considered to be estuarine rather than an inland aquatic environment. These wetlands may be permanently inundated flats, a category not represented in Table 5.15.

Basins and depressions are more likely to store water than flats and slopes, which means that these landforms are likely to support inundated wetlands. While categories of "winter saturated, summer dry" and "ephemeral" wetlands were not found within basins in this study, it is possible that they do exist elsewhere. For instance, Semeniuk and Semeniuk (1995) identified "seasonally waterlogged (saturated) basins" as "damplands". In contrast, some of the categories may not be possible at all. For example, "inundated endorheic slopes" are unlikely to occur since water on

Table 6.2 Key to wetlands based on the first three primary levels of the hierarchical classification. Letters indicate the different wetland categories shown in Figure 6.2.

1	Exorheic	2
	Endorheic	9
2	Connected at least temporarily to the sea; salinity and faunal characteristics should indicate a marine influence	Estuarine
	Not connected to the sea; fauna and salinity not influenced by sea water	3
3	Landform in which water is stored in a channel	Riverine
	Water is stored on a flat, slope, basin or depression	4
4	Permanently inundated basin or depression (lakelets and coastal lakes)	5
	Flat or slope not permanently inundated	6
5	Permanently inundated basin	A
	Permanently inundated depression	B
6	In a flat landscape	7
	Seasonally saturated, on a slope (river source sponges and seepages)	F
7	Seasonally inundated or saturated	8
	Ephemerally wet	E
8	Seasonally inundated flat (floodplains)	C
	Seasonally saturated flat	D
9	Endorheic, situated within a basin	10
	Endorheic, not situated within a basin	11
10	Permanently inundated (lakelets, and coastal lakes)	G
	Seasonally inundated	H
11	Water is stored within a depression	12
	Water is stored on a flat landform	13
12	Permanently inundated depression (permanent pans)	I
	Temporarily inundated	15
13	Ephemerally wet flat	J
	Seasonally wet flatl	4
14	Seasonally inundated flat (floodplains)	K
	Seasonally saturated flat	L
15	Seasonally inundated depression (temporary pans, playas, salt pans, turbid pans, floodplain pans)	M
	Ephemerally wet depression	N

a slope flows down hill and out of the wetland, which therefore can not be endorheic.

Contrary to what might be expected in an arid region, few ephemeral wetlands were found during the study. Seasonally inundated wetlands were most common, according with the fact that many wetland types in the Western Cape are controlled by the rainfall regime.

6.4.1 Exorheic wetlands

Exorheic wetlands include both rivers and other inland wetlands from which water flows, but rivers are excluded form this study. Exorheic wetlands are often considered riverine or palustrine systems and include floodplains, river source sponges and dammed or drowned basins within river catchments. Nutrients, aquatic animals and plants may be transferred out of these wetlands, which are thus sources of nutrient and biota for downstream reaches. The exorheic nature of these wetlands causes them to be both structurally and functionally different from endorheic ones.

6.4.1.1 Exorheic permanently inundated basins and depressions

Two types of permanent exorheic basins were identified in this study: those connected to the sea (including three Wilderness wetlands, sites D3 - D8 and Verlorenvlei, site A9); and Soetendalsvlei (sites B17 and B18, in the Agulhas Plain), which is fed by the Nuwejaars River and flows into the Heuningnes River. All of these wetlands supported emergent vegetation on their shorelines, but Verlorenvlei supports only small patches of vegetation. The geomorphological approach to wetland classification (Semeniuk and Semeniuk, 1995) labels these wetlands as lakes, and Hart (1995) identifies them as coastal lakes. Those that are connected to the sea are classified as Estuarine by the Cowardin system since their ocean derived salinity is greater than 0.05‰. Soetendalsvlei would be classified into separate parts (the littoral and limnetic zones) by the Cowardin system, but it is classified as Palustrine by Morant (1983) because the aerial coverage of emergent vegetation is greater than 30%.

Generally, the end points of South African rivers are their estuarine connections with the sea. Perusal of a wetland's drainage patterns does not always provide an indication of the extent of estuarine influence upriver. Although one can sometimes identify tidal influences on these wetlands, it is not possible in all circumstances. All the studied wetlands connected to the sea, even temporarily or indirectly, showed estuarine qualities (such as salinity levels and animal communities) which suggests that these wetlands should be grouped with estuaries rather than with other inland waters.

Wetlands described by Cowardin *et al.* (1979) as lacustrine are large (8 ha or 20 acres) deep (usually greater than 2 m) permanently inundated wetlands. Semeniuk and Semeniuk (1995) describe lakes as permanently inundated basins but these authors do not place restrictions on the wetland size or depth. Although Southern Africa lacks natural deep lacustrine systems such as the American Great Lakes, smaller shallower wetlands, some of which are coastal lakes, would fit into the category of permanently inundated basins. The coastal lakes may be described as permanently inundated basins. The hierarchy developed here (Figure 6.1) separates coastal lakes into three groups: those that are exorheic and connected to the sea (the Wilderness wetlands, sites D2 - D8); exorheic wetlands flowing into rivers (such as Soetendalsvlei); and those (such as Groenvlei) that are endorheic. Although these wetlands are not separated in other classification systems the differences in water chemistry, in the animals they support and in the habitats provided indicate that they are functionally different and that they should therefore be distinguished for management purposes.

A single wetland was recorded as a permanently inundated exorheic depression (Table 5.15), site A5 adjacent to the Berg River. It is a marsh or floodplain pan (Noble and Hemens, 1978) inundated by the Berg River. This wetland is grouped as a lake using the Semeniuk and Semeniuk (1995) classification system and as Palustrine when using Morant (1983). Vegetated floodplain pans store pockets of water when other parts of the floodplain have dried. This type of wetland is fairly common in South Africa, other examples including pans on the Pongola and on the Okovango floodplains. These wetlands provide different habitats to the basins described above as they do not have deep open waters. Thus the depth of the basin is likely to affect biotic habitats.

6.4.1.2 Exorheic flats

The five seasonally inundated flats identified were sites B8, B9 and B11 on Agulhas Plain, Waboomsrivier (C2) and site C8 near Ceres. As they are usually inundated from flooding of adjacent wetlands or rivers, their extent, and period of inundation, depend entirely on the amount of water in their source areas. These wetlands are generally referred to as floodplains (Noble and Hemens, 1978 and Semeniuk and Semeniuk 1995) and are classified as vegetated Palustrine systems by Morant (1983). Large floodplains like the Okovango occur around the globe, and smaller floodplains frequently occur along rivers. While smaller floodplains may include only exorheic flats, larger floodplains usually include a complex of different wetland types. At times of high floods a floodplain may appear to be a single waterbody, but as the flooding recedes the floodplain forms into a number of different smaller water bodies. If the full value of floodplains is to be recognised, these wetlands need to be identified as part of a larger floodplain as well as individual wetlands.

Driehoekvlei in the Cederberg (site C1) and site C11 in the Worcester area are identified as seasonally saturated flats, or palusplains (Semeniuk and Semeniuk, 1995). Once again, these wetlands are classified as vegetated Palustrine systems (Morant, 1983). They apparently become inundated during years with higher winter rainfall than that received in 2000. They may be described as floodplains as they are fed from flooded rivers during high-rainfall years.

Six flats were dry throughout the year of study and were recorded as ephemeral; they are sites C9 and C10 (near Ceres/Worcester area), site D9 and D12 (near the Gouritz River mouth area), site D13 (near Wilderness) and site E3 (on the Cape Peninsula). The wetlands may become inundated or saturated during very wet years, but could also be in a process of transition from a wetland to dry land. They would be classified as barlkarras by Semeniuk and Semeniuk (1995) which assumes that they are intermittently inundated. In reality, they may also be intermittently saturated, which does not coincide with any of the Semeniuk and Semeniuk (1995) categories. They are classified as vegetated Palustine wetlands in the Morant (1983) classification system. Although these wetlands were dry they are identified as wetlands from topographical maps. Plants such as *Sarcocornia* at sites D9 and D12 (near Gouritz River) and *Phragmites* at sites C9 (near

Ceres) and D13 (near Wilderness) indicated that soil saturation does occur. Sites such as D12 are characterised by cracked clay soils interspersed with patches of *Sarcocornia,* and soil analyses should indicate whether or not they can be described as wetlands. Living *Phragmites* certainly indicates saturated soils and *Sarcocornia* is typical of salt flats that would be inundated seasonally or tidally (Day, 1981). Ephemeral wetlands such as these are not uncommon in arid countries but are likely to hold water for longer in countries with more mesic climates.

6.4.1.3 Seasonally saturated exorheic wetlands on slopes

Site CS in the Cederberg is on a slope and is saturated during the winter but dry during the summer. It may be described as a river source seepage (Noble and Hemens, 1978), a paluslope (Semeniuk and Semeniuk, 1995) and a vegetated palustrine wetland (Morant, 1983). Wetlands on slopes do not become inundated unless some type of depression forms on the slope. For example, although site B16 is on a gradual mountain slope, water is stored in a depression, which allows the wetland to become inundated. Thus sloped wetlands are unlikely to support submerged and emergent macrophytes and do not support aquatic invertebrates, but the vegetation is nonetheless very distinctive of "seepage" areas all year round. These wetlands may easily be identified by saturated soils in winter, but during summer, vegetation and other soil characteristics such as peat, organic soils or gleyed soils would have to be used to identify the wetland (Kotze and Marneweck, 1999). These characteristics could be used to describe these wetlands and possibly divide them into subgroups of the winter saturated, summer dry wetlands. These saturated wetlands may be identified on slopes of escarpments, such as the Hottentots Hollands Escarpment outside Cape Town as well as in other mountainous areas of South Africa.

6.4.2 Endorheic wetlands

In South Africa endorheic wetlands are a recognised group (Noble and Hemens, 1978 and Allan *et al.,* 1995). The present study revealed that the Western Cape supports many of these wetlands and that they are of different types. Endorheic wetlands are found in basins and depressions and on flats, and include all five hydrological categories. While a few receive water from rivers, most gain water from precipitation and runoff or from groundwater seepage and springs.

6.4.2.1 Permanently inundated endorheic basins

All of the permanent endorheic wetlands were formed in basins or depressions. The permanent endorheic basins include wetlands such as Groenvlei at Wilderness (sites D1 and D2) described as a coastal lakes by Hart (1995). Smaller wetlands in this category include some on the Agulhas Plain (Springfield b, Langpan, Rooiwal and Rattelrivier a, sites B5, B7, B10 and B12), Rocherpan near Veldrift (site A7) and one of the highly turbid wetlands in the Vanrhynsdorp area (site A11). The smaller wetlands may be known colloquially as either pans or coastal lakes (but their surface areas are much less than those of other wetlands considered to be coastal lakes) and are classified as palustrine (Morant, 1983).

While sites A7 and A11 had some parts (less than 10%) deeper than 500mm (which classified them as basins), and they were inundated during the summer, the greater portion of each of these wetlands is described as a seasonally inundated depression. For the purposes of their classification system, Semenuik and Semenuik (1995) specify that if more than 10% of a basin is permanently inundated, the wetland is classified as a permanently inundated basin (a lake) but at less than 10% it is defined as seasonally inundated (a sumpland). On the basis of these criteria sites A7 and A11 might best be classed as a seasonally inundated depressions rather than permanent basins.

Thus, sites B5, B7, B10, B12, D1 and D2 are lakes and sites A7 and A11 are sumplands (*sensu* Semeniuk and Semeniuk, 1995). Further, based on animal and water chemistry criteria, site A11 is clustered with other seasonally inundated wetlands (group 6a, Figure 5.5) which supports the argument for classifying it as a seasonally inundated depression. This supports arguments for adopting Semeniuk and Semeniuks' (1995) criteria of using a quantitative distinction for determining whether or not a wetland should be classified as permanently or seasonally inundated. Thus if more than 10% of a basin or depression remains permanently inundated the wetland is referred to as permanent

Sites A7, B5, B7, B10, B12, D1 and D2 were mostly vegetated wetlands. Groenvlei and Ratelriver are surrounded by tall emergent plants and Springfield, while not completely surrounded, supports patches of tall emergents, as well as submerged beds of *Chara* sp. Langpan (site B7) had a non-vegetated sandy shore and did not support emergents, although submerged patches of algae were present in the water body. Site A11 is a non-vegetated clay-bottomed pan and is thus likely to gain water mainly through rainfall and loss through evaporation.

6.4.2.2 Permanently inundated endorheic depressions

Three sites, C5 (in the Cederberg) and D10 and D11 (near the Gouritz River), were identified as permanent endorheic depressions. All are classified as palustrine by Morant (1983) and lakes by Semeniuk and Semeniuk (1995). Site C5 may also be described as a marsh or vegetated pan (Noble and Hemens, 1978) but sites D10 and D11 are springs.

Two groundwater seeps or springs (sites D10 and D11) near the Gouritz River clustered together in the analysis of water chemistry (Group 2a, Figure 5.1) and of animals at species level (Group 6, Figure 5.7). Both these wetlands may be classified as permanently inundated wetlands but site D10 is in a depression and site D11 is a small (1m in diameter) circular rock-bottomed 1m deep hole or well in the ground, the smallest wetland investigated. Despite the fact that site D11 has been used for washing clothes these two wetlands share chemical characteristics. Because these wetlands are in close proximity to each other they are on similar rock forms and will derive their ions and nutrients from similar sources, resulting in similar chemical regimes. *Chironomus formosipennis* is the most important species contributing to the similarity of this group (Group 6, Table 5.6). The Laingsburg floods which occurred in 1981 markedly affected the environment by depositing river sediment which covered and sealed numerous springs, as well as altering the conditions of other wetlands near the Gouritz River mouth by deposition of large amounts of sediments.

The results indicate that the ground water springs should be grouped together and so for the purposes of this classification system site D11 will be grouped with site D10 as a spring and in the "permanently inundated depression" category. These wetlands are distinguished from basins as they are much smaller and too shallow to support the same organisms as deeper basins and are thus structurally dissimilar.

6.4.2.3 Seasonal endorheic depressions

All three endorheic landforms (basins, depressions and flats) support seasonal wetlands. Seasonally inundated endorheic wetlands within basins and depressions are commonly known as temporary endorheic pans, a group which in this study included a variety of highly saline pans, some extremely turbid pans, and vegetated pans with clear waters. These wetlands are classified as sumplands by Semeniuk and Semeniuk (1995) and palustrine by Morant (1983). The group includes almost a quarter (24%) of the wetlands investigated, which indicates that they are an important wetland type in the Western Province.

Seasonally inundated turbid wetlands

A group of turbid seasonally inundated wetlands was repeatedly clustered by some water chemistry and the winter animal analyses (Sites A10, A11, A12, A14, C3, C4 and C6 near Vanrhynsdorp and in the Cederberg). These wetlands mainly support crustaceans (of the orders copepoda, conchostraca and anostraca) and were located in extremely arid parts of the Western Cape. Turbid, seasonally inundated wetlands exist in other arid areas of South Africa, such as in the Kimberly area of the Free State. Future investigation into wetlands outside the boundary of this project may increase our knowledge and confirm the distinctiveness of these seasonally inundated turbid wetlands.

Seasonally inundated saline wetlands (Salt pans)

Highly saline seasonal endorheic wetlands exist throughout South Africa and are commonly referred to as "salt pans". Saline wetlands that dry up leave a surface layer of salt, while less saline wetlands may occasionally leave small crusty patches of salt crystals. Only certain invertebrate species are able to survive extremely saline conditions. An example is the anostracan *Artemia salina*, which was recorded in the Soutpan of the Agulhas Plain (at a salinity of 87) and *Sarcocornia* species which is commonly associated with saline wetlands. Although it is not usually inundated it is found on saturated soils surrounding saline wetlands and typically on estuarine flats (Day, 1981). Although chemical and animal data did not repeatedly cluster the saline wetlands, they were easily identified in the field (*e. g.* sites A4 and A8 near Berg River and B1, B7 and B14 on Agulhas plain).

6.4.2.4 Seasonal endorheic flats

Flats include floodplains (Noble and Hemens, 1978 and Semeniuk and Semeniuk, 1995) and rainfall-inundated areas. Sites A1, A8, B1, B6, B13, C10 and E10 are seasonally inundated flats. Some can be described as floodplains as they receive water from adjacent rivers; others hold rain water for short periods; and others are clay-bottomed. Site E4 (on the Cape Peninsula), a winter-saturated flat or palusplain (*sensu* Semeniuk and Semeniuk, 1995), may also be considered as ephemerally saturated as the saturation period is fairly short. All of these wetlands would be classified as palustrine by Morant (1983).

6.4.2.5 Ephemerally wet endorheic depressions and flats

Three endorheic wetlands were classified as ephemeral: site C7 (in the Cederberg), an ephemeral depression labelled a pan (*sensu* Noble and Hemens, 1978) or playa (*sensu* Semeniuk and Semeniuk, 1995); and sites E7 (near Bettys Bay) and A6 (on the Berg River), ephemeral flats labelled barlkarras by Semeniuk and Semeniuk (1995). They are dependent on rainfall for inundation or saturation, the shape of the land and the low rainfall resulting in the ephemeral hydrological regime of these wetlands.

6.5 Comments on the developed classification system

This classification system is based on characteristics similar to those suggested by Semeniuk and Semeniuk (1995). A new landform type has been included (depression) and another has not been used (highlands and hilltops). The "depression" category has been included so that shallow permanent depressions (*e. g.* some permanent pans common in South Africa) may be classified differently from the deeper permanent basins (*e. g.* coastal lakes). While wetlands were found in high mountainous areas (highlands and hilltops) all wetlands investigated were formed within other landform types (slopes, flats, basins, or depressions) within these areas. Thus highlands and hilltops was not found to be a landform type within which wetlands form, but rather a description of the surrounding wetland landscape. The landform category "channels" also suggested by Semeniuk and Semeniuk (1995) is not used here merely because river wetlands were not investigated in this study.

Figure 2.4 illustrates different landforms along a continuum of gradual change from flat to hill/highlands. Although the landform categories of depression and basin were separated in the classification system presented here to better enable distinction between different wetland types, occasionally it is problematic to assign wetlands to each group as the distinction between the two is not clear and in real field situations one is likely to encounter intermediate wetland landforms rather than specific basins and depressions. Thus there may be intermediate forms between wetlands grouped as basins or depressions, and clearly distinguishing between endorheic depressions or pans and endorheic basins or lakes may be problematic. For the sake of consistency between different users, depressions have been limited to 500mm in depth and basins are therefore wetlands deeper than 500mm.

The permanently inundated and seasonally inundated categories corresponds with that described by Semeniuk and Semeniuk (1995) and the ephemerally wet category described here corresponds with their "intermittently inundated" category. Their "seasonally waterlogged" category corresponds with that described as seasonally saturated (or winter saturated, summer dry) in the classification system developed here.

As the winter of this study was drier than normal the recorded hydrological regime of the wetlands represented the driest extreme. This provided valuable information since it would allow identification and inclusion of these hydrological extremes, such as permanent wetlands which very occasionally dry out or inundated wetlands which occasionally become saturated, into the classification system. On the other hand, information regarding the wetter end of the spectrum could not be collected, and the results also have the potential to created a distorted idea of the usual hydrological regime of some wetlands.

Table 6.2 Relationship between water permanence categories used in the classification system presented and Semeniuk and Semeniuk (1995) classification system.

Hydrological regime categories used in this dissertation	Water permanence categories used by Semeniuk and Semeniuk (1995)
Permanently inundated	Permanently inundated
Seasonally inundated *(Winter inundated, summer saturated)*	Seasonally inundated
Seasonally inundated *(Winter inundated, summer dry)*	Seasonally inundated
Seasonally saturated *(Winter saturated, summer dry)*	Seasonally waterlogged
Ephemerally wet	Intermittently inundated

An additional modification to the Semeniuk and Semeniuk (1995) classification system is the initial separation of endorheic and exorheic wetlands. Drainage affects both biotic and water chemistry characteristics of wetlands and results in structurally different wetland at biological and limnological levels. As this geomorphic feature controls these characteristics, using it at a primary level in the classification system will ensure to a degree that wetlands with different water chemistry and biotic communities will be classified separately. Further, endorheic and exorheic wetlands are functionally different; endorheic wetlands retain and may gradually accumulate sediments that are moved into them (aggrading) while sediment is moved through and out of (eroding) exorheic wetlands (Wilkinson, 1988).

The classification system developed here does differ slightly from that proposed by Dini *et al.* (unpublished draft, 1998). Interior wetlands named "Endorheic", "Lacustrine" and "Palustrine" by Dini *et al.* (unpublished draft, 1998) were investigated in this study. These wetlands are grouped methodically in the classification system developed here which, I suggest, should be incorporated into that proposed by Dini *et al.* (unpublished draft, 1998). This may be done by overlaying the classification of "exoheic and endorheic inland wetlands" developed here over the categories "Endorheic", "Lacustrine" and "Palustrine" proposed by Dini *et al.* (unpublished draft, 1998).

Most wetland classification systems (*e. g.* the Cowardin system and Semeniuk and Semeniuks' (1995) geomorphic approach) are based on physical characteristics. Some biologists and limnologists believe that wetland species assemblages and water chemistry reflect the functioning of the ecosystem and that these characteristics should, therefore, also be used in wetland classification systems. As aquatic invertebrates are speciose it was expected that they would indicate significant wetland groups at the specific scale. The Western Cape is known for its large numbers of aquatic endemics (Wishart and Day, in press). The high degree of endemism results in a large number of species in the area and may also mean that there are fewer species common to the wetlands. The lack of shared animal species would result in animal data indicating less similarity between wetlands and thus fewer relationship between wetlands and therefore less distinct wetland groups would be identified.

Although it had been expected that invertebrate taxa would provide more useful information for wetland categories than they did, the animal data revealed only a limited number of wetland groups and did not reveal which aquatic animals are specific to different wetland types. Only two kinds of chemically distinct wetland types were identified, the highly saline and highly turbid wetlands. These wetland grouping characteristics have been included as descriptors below the tertiary level in the classification system and in this way touch on determining water quality (required for determining the ecological reserve: South African National Water Act (No 36) 1998). It is probable that more detailed data of wetlands with acid waters would indicate another chemically distinct wetland group, this chemical characteristic can then be included in the classification as another wetland descriptor.

More detailed information regarding chemical and species assemblages might group more wetland types with greater distinction. Thus further investigations might increase the number of wetland categories identifiable from chemical and biotic data. If more categories are revealed it is possible that these characteristics may be used at higher levels in the classification system. For instance, if it is conclusively found that endorheic temporary waters support certain crustaceans and permanent waters do not, the presence of these animals may be used to distinguish these wetland types at a higher level in the classification system.

The classification system developed retains benefits of the Semeniuk and Semeniuk (1995) classification system, in that it is based on underlying slow-changing features. The characteristics used allow wetlands to be classified in areas of unpredictable climates. Since the classification system is based on geomorphological and hydrological characteristics it may be applicable on a scale greater than the Western Cape and should be tested for use throughout South Africa and use in conjunction with the classification system proposed by Dini *et al.* (unpublished draft, 1998).

The classification system uses degree and period of inundation or saturation as a classification characteristic to group wetlands and in this way wetland categories indicate the quantity of water required by wetlands for their sustained existence. Thus, the classification system may aid with determining the quantity of water required by the ecological reserve (South African National Water Act (No 36) of 1998).

Chapter Seven

Concluding statements

- A number of international wetland classification systems are available. These classification systems have been developed in areas of differing climate. As different climate zones support different types of wetlands, wetland classification systems tend to be specific to particular locations.

- Most developed wetland classification systems use geomorphological and hydrological features to categorise wetlands. Biological and limnological features are usually only used after the wetland has been classified to further describe it.

- Application of the available classification systems allowed a coarse classification of the studied Western Cape wetlands, but showed that the full diversity of wetlands in the area is not indicated using these classification systems. A classification system based on detailed biotic and water chemistry characteristics, as well as geomorphological and hydrological characteristics would allow recognition of the diversity of local wetlands.

- Wetlands could be allocated to a category of each of the physical characteristics investigated (drainage pattern, landform and hydrology). Geomorphological characteristics were identified as the most reliable characteristics for grouping wetlands since landscape morphology changes slower than hydrological, chemical and biotic characteristics. Although the aquatic fauna, vegetation and water chemistry control the process occurring, it was not possible to group all wetlands using these characteristics. Some wetland were associated with each other due to high salinity levels, others due to high turbidity, but the remaining wetland groups were not associated with identifiable characteristic. Thus wetlands of the Western Cape can be classified using geomorphological and hydrological features, but animal and plant communities and water chemistry did not group all the investigated wetlands with clarity.

- An intensive investigation into the biotic and water chemistry characteristics of the Western Cape wetlands over a few years is likely to indicate biotically and chemically distinct wetlands. Biotic and chemical information would provide a greater understanding of the wetland types in the area, but time required for these characteristics to be introduced into a classification systems renders them impractical for present use as classifying characteristics. However, it is recommended that these characteristics be used for describing the different wetland types and that they be reviewed for use in future classification systems.

- The geomorphological and hydrological features used in the developed classification system affect biota, and in this way the classification allows a degree of separation of biologically distinct wetlands.

- Sixteen different wetlands types were identified for the Western Cape using a hierarchical model of the geomorphological and hydrological characteristics.

- One wetland type, permanently inundated basins with surface connections to the sea, is considered to be estuarine rather than an inland aquatic wetlands. Although estuarine wetlands may also be classified using the hierarchical model, faunal communities and ocean-derived salinity levels indicate that these wetlands are distinctly different from others investigated.

- As the classification system developed for wetlands in the Western Cape is based on geomorphological and hydrological features it will allow coarse differentiation between wetland types within the area. Although, the classification system remains untested, it may be of use in other parts of South Africa.

- One of the goals of the classification system is to be useful for determining "ecological reserve" (South African National Water Act (No 36) of 1998), in other words the quantity and quality of water required to protect aquatic ecosystems. While the classification is limited in its ability to assist with determining water quality, the fact that the hydrological characteristics used in the classification system are based on degree and period of inundation or saturation allows us to determine, to a degree, the quantity of water required by a wetland for its sustained existence.

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Glossary

Barlkarra	An intermittently inundated flat (Semeniuk and Semeniuk, 1995).
Basin	A landform that increases in depth from the perimeter (or shoreline) to a central area of greatest depth and supports lakes and dams.
Billabong	An Australian term for a seasonally inundated, oxbow-shaped, floodplain pan or lake (Davies and Day, 1998).
Bioregion	Geographical regions distinguished from each other by differences in biotic communities.
Bog	"Bogs are permanently-wet, vegetated wetlands dominated by peat mosses" (Davies and Day, 1998).
Channel	A valley shaped landform which usually supports rivers.
Class	The highest taxonomic unit below the Subsystem level of the Cowardin system (Cowardin *et al.*, 1979).
Creek	A seasonally inundated channel (Semeniuk and Semeniuk, 1995).
Coastal lake	This term includes isolated lakes and lakes with surface connections to the marine environment but without tidal inflows.
Cowardin system	The hierarchical wetland and deepwater classification system designed for use in the United States of America by Cowardin *et al.* (1979)
Dampland	A seasonally waterlogged basin (Semeniuk and Semeniuk, 1995)
Depression	Shallow basin or landform which increases in depth from the perimeter to a central area of greatest depth, but no greater than 500 mm.

Ecological reserve	"the quantity and quality of water required to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource." (South African National Water Act (No 36) of 1998)
Emergent macrophyte	Term for aquatic plants rooted in saturated soils of inundated wetlands which protrude from the water surface (Denny, 1985).
Endorheic wetland	Also known as playa and pan. Water may be supplied to the system via streamflow, precipitation, seepage and overland flow but leaves the wetland via evaporation and seepage only; transport of water into downstream systems does not occur.
Ephemerally wet	Waterlogged soils or surface water irregularly occur for changeable time periods. Wetlands with these conditions are frequently dry for long periods in arid regions.
Estuarine system	"consists of deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land." (Cowardin *et al.*, 1979).
Exorheic	Outward draining.
Flat	Landform that supports wetlands in a landscape with a slope of less than one degree (usually support floodplains).
Floodplain	A wetland temporarily inundated as a result of river flooding; may include flooded flats and depressions (or floodplain pans); a seasonally inundated flat *sensu* Semeniuk and Semeniuk (1995).
Functional characteristic	Wetland characteristic which includes the processes that occur it (such as nutrient cycling), functional characteristics determine the service that wetlands provide in the landscape.
Highland and hill	Landform on mountains that supports wetlands such as river source sponges.

Hydricity of soils

Soil that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favour the growth and regeneration of hydrophytic vegetation." (U.S. Soil Conservation Service (1985, p1) in Mitsch and Gosselink, 1986).

Intermittent inundation

Temporarily flooded surface water, present for brief periods during the growing season but water table is otherwise well below the soil surface, also includes intermittently flooded-substratum, usually exposed but surface water is present for variable periods with no seasonal periodicity (Semeniuk and Semeniuk, 1995).

Lacustrine system

"includes wetlands and deepwater habitats with all of the following characteristics: (1) situated within a topographic depression or a dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30 % areal coverage; and (3) total area exceeds 8 ha (20 acres). Similar wetland and deepwater habitats totaling less than 8 ha are also included in the Lacustrine System if an active wave-formed or bedrock shoreline feature makes up all or part of the boundary or if the water depth in the deepest part of the basin exceeds 2 m (6.6 feet) at low water. Lacustrine waters may be tidal or nontidal, but ocean-derived salinity is always less than 0.5 ‰."(Cowardin *et al.*, 1979).

Lake

A deep permanently inundated, usually large wetland which has a shoreline zone (often vegetated) and a deepwater zone, too deep to support rooted plants; a permanently inundated basin *sensu* Semeniuk and Semeniuk (1995).

Landform

The shape of the landscape.

Marine system

"consists of the open ocean overlying the continental shelf and its associated high-energy coastline. Marine habitats are exposed to the waves and currents of the open ocean and the water regimes are determined primarily by the ebb and flow of oceanic tides. Salinities exceed 30 ‰, with little or no dilution except outside the mouths of estuaries. Shallow coastal indentations or bays without appreciable fresh-water inflow, and coasts with exposed rocky islands that provide the mainland with little or no shelter from wind and waves, are also considered part of the Marine System because they generally support typical marine biota." (Cowardin *et al.*, 1979).

Marsh Vegetated wetland with "low-growing macrophytes" and has a soft spongy substratum (Davies and Day, 1998).

Mire Soft boggy vegetated area of saturated soils that may give way under foot. Also referred to as 'morass', bog and slobland (Davies and Day, 1998).

Modifier Term used in the Cowardin system to describe wetlands and deepwater habitats classified at the Class level (Cowardin *et al.*, 1979).

Morass see mire

Pan Term used in South Africa referring to endorheic basins or depressions; includes salt pans, pans filled due to river flooding, clay bottomed pans filled by rainfall.Pans may be both temporary or permanent.

Palusmont A seasonally waterlogged highland or hill (Semeniuk and Semeniuk, 1995).

Palusplain A seasonally waterlogged flat (Semeniuk and Semeniuk, 1995).

Palusslope A seasonally waterlogged slope (Semeniuk and Semeniuk, 1995).

Palustrine system " includes all nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 ‰. It also includes wetlands lacking such vegetation, but with all of the following four characteristics: (1) area less than 8 ha (20 acres); (2) active wave-formed or bedrock shoreline features lacking; (3) water depth in the deepest part of basin less than 2 m at low water; and (4) salinity due to ocean-derived salts less than 0.5 ‰." (Cowardin *et al.*, 1979).

Permanently inundated	Surface water present throughout the year, but may occasionally dry up during periods of drought. Permanent inundation includes permanently flooded-water covering surface throughout the year in all years as well as intermittently exposed-surface water present throughout the year except in years of extreme drought (Semeniuk and Semeniuk, 1995).
Playa	Saline endorheic, usually temporarily inundated depression or basin which is episodically inundated (Davies and Day, 1998). It is also a wetland term used by Semeniuk and Semeniuk (1995) meaning intermittently inundated basin.
Poikilohaline	Term referring to variable salinity levels (Semeniuk and Semeniuk, 1995)
Pond	Small body of permanent standing water (Davies and Day, 1998).
Pool	Small body of standing water which may dry up occasionally (Davies and Day, 1998).
River	A permanently inundated channel (Semeniuk and Semeniuk, 1995).
Riverine system	"includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 ‰. A channel is "an open conduit either naturally or artificially created which periodically or continuously contains moving water, or which forms a connecting link between two bodies of standing water" (Langbein and Iseri, 1960)." (Cowardin *et al.*, 1979).
Saturated	Surface water absent but the surface soils are waterlogged which usually results in hydric soils that supports vegetation adapted to aquatic conditions.
Seasonal inundation	Surface water present at some time during a year (usually during a high rainfall event) but dries annually resulting in either complete dryness or saturated soils. Seasonal inundation includes semi-permanently flooded surface water persisting throughout the growing season in most years.

	When surface water is absent, water table is at or near the surface. It also includes seasonally flooded-surface water present for extended periods, especially in early growing season but is absent by the end of the season (Semeniuk and Semeniuk, 1995).
Seasonal waterlogging	Saturated substratum that is saturated for extended periods during the growing season but surface water is seldom present (Semeniuk and Semeniuk, 1995).
Slobland	see mire.
Slope	Landform that support wetlands on gradients higher than one degree (such as mountain side seeps) These wetlands are unlikely to be inundated.
Slough	A hollow filled with mud, a hole where water collects, or a marshy saltwater inlet (Davies and Day, 1998).
Sponge	High-altitude wetlands that occur at river sources, and may be "soft and boggy" and "may support low grasses" (Davies and Day, 1998).
Stasohaline	Term referring to constant salinity (Semeniuk and Semeniuk, 1995)
Structural characteristics	The geological, geomorphological, hydrological and biotic characteristics which give wetlands their overall appearance.
Submerged euhydrophyte	Term for plants that are rooted or anchored to the substratum but do not protrude above the water surface (Denny, 1985).
Subsystem	Subdivision of Systems level into more specific categories; it the second hierarchical level of the Cowardin system (Cowardin *et al.*, 1979).
Sumpland	A seasonally inundated basin (Semeniuk and Semeniuk, 1995).
Surface-floating macrophyte	Term for non-rooted aquatic plants which are distributed on the water surface (Denny, 1985).

Swamp — Usually a wetland with trees (Davies and Day, 1998).

System — Term referring "to a complex of wetlands and deepwater habitats that share the influence of similar hydrologic, geomorphic, chemical or biological factors." and it is the first level of wetland groups of the Cowardin system (Cowardin *et al.*, 1979).

Tarn — 'an isolated, high-altitude pool or pond in a sediment-filled basin, often supporting some submerged vegetation, and sometimes holding no water in the dry season." (Davies and Day, 1998).

Temporary inundation — Surface water present either ephemerally or seasonally, but either dries completely or leaves saturated soils at times.

Vlei — A commonly used South African term for many different wetland types, such as floodplains, pans and coastal lakes and temporary or permanent and saline or fresh.

Wadi — An intermittently inundated channel (Semeniuk and Semeniuk, 1995).

Wetland — Land "transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water." (Cowardin *et al.*, 1979) or defined as an area "of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres"(Peck, 1999).

Appendix 1. Data sheets used for data collection during the field investigation.

Desktop data sheet

Wetland code ____________________
Date ____________________
Researchers name ____________________

Identity and Location

Wetland name ____________________ Areas common name ____________________
Geographical coordinates ____________________
1: 50 000 Map: number ____________________ name of map ____________________
Bioregion (Brown *et al.*, 1996) ____________ Wetland region (Cowan, 1995) ____________
Does this wetland form part of a larger wetland system? **1** Yes **2** No
Name of larger system ____________________
Information on larger system (eg where is it) ____________________
____
____
Drainage: **1** Antarctic, **2** Atlantic, **3** Indian, **4** other ____________________
Farm, town or reserve name ____________________
Magisterial district ____________________ Province ____________________
Landowners/managers: name ____________________ Tel ____________________
Fax ____________________ e-mail ____________________
Address ____________________
Contact person ____________________ Tel ____________________
Fax ____________________ e-mail ____________________
Address ____________________
Other information ____________________
Conditions of visit ____________________
Road route to wetland/Locality description ____________________
____

Protection: 1, 2, 3, 4, 5

1 No information
2 No legal protection
3 Partly or wholly included within a forest reserve, non hunting area or similar reserve with a low level of protection
4 Partly protected within a national park, nature reserve, wildlife sanctuary or equivalent reserve
5 Wholly protected within a national park, nature reserve, wildlife sanctuary or equivalent reserve

Reserve or conservation organization ____________________

Record information from literature (e.g. species lists, chemical information and references)

Field data sheet

Researchers name ______________________ Date and time ______________________
Weather ______________________ Wetland code ______________________
Wetland name ______________________ Photograph number ______________________

Physical attributes

Size
Area when fully inundated (ha) ______________________
Wetland depth (if dry) ______________ estimated depth (if inundated) __________

Geomorphology

Landscape: 1 mountain top, **2** mountain slope, **3** foothill, **4** coastal plain, **5** coastal dunes, **6** inland plateau; **7** valley
Landform: 1 flat, **2** slope, **3** basin, **4** channel, **5** slight depression, **6** highlands or hills
Shape: **1** circular, **2** kidney, **3** oval, **4** irregular
Substratum; 1 bedrock, **2** boulders, **3** stones, **4** gravel, **5** pebbles, **6** sand, **7** mud, **8** clay, **9** detritus, **10** coral, **11** shell, logs/branches. Percentage ____________

Hydrology of the wetland

Inundation period: **1** permanent, **2** seasonal, **3** ephemeral
Degree of inundation: **1** inundated, **2** saturated, **3** dry
Area inundated (percentage estimate) ______________________
Water source: **1**streamflow, **2** stormwater, **3** seepage, **4** rain, **5** sea connection, **6** industrial discharge, **7** sewage
Water outlet: **1**streamflow, **2** seepage, **4** evaporation, **5** sea connection
Wetland current: **1** flowing, **2** still-standing, **3** dry
Modifier: **1** dredged, **2** weir, **3** bridge/road, comment ______________________
____

Sea connected wetlands

Is the water regime influenced by tides? **1** Yes **2** No
Mouth: **1** open or **2** closed,
Describe effects of tide ______________________
Water quality if wetland is inundated

Description of site ______________________
Exact location of site at wetlands on wetlands greater than 30m x 30m ______________________
Water description; **1** clear, **2** cloudy, **3** muddy, **4** other ______________________
Water colour; **1** colourless, **2** brown-tinged, **3** green, **4** yellow, **5** other ______________________
Smell: **1** H_2S, **2** algae, **3** none, **5** other ______________________
Ice extent **1** none, **2** some, **3** moderate, **4** much. Percentage ______________________

Biotic characteristics

Flora

Plant type: (Percentage plant cover: <10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 90+)

1 submerged ______________________

2 emergent ______________________

3 floating ______________________

4 riparian ______________________

Dominant species ______________________ Dominant species height ______________

Flora collected

Plant types; **1** algae, **2** aquatic moss, **3** broad-leaved deciduous, **4** broad-leaved evergreen, **5** dead wood, **6** emergent non-persistent, **7** emergent persistent, **8** floating vascular, **9** lichen, **10** needle-leaved deciduous, **11** needle-leaved evergreen, **12** rooted vascular, **13** encrusting, **14** foliose, **15** submergent, **16** floating, **17** shore forested, **18** shore bushy, **19** shore barren/grassy, **20** vegetated

Plants collected (label) ______________________________________

Fauna

Anecdotal field identifications; flying invertebrates, fish, amphibians, mammals, and birds ________

Zooplancton and invertebrate fauna collected

Sample label ______________________ Depth sampled ______________

Gear for collecting ______________________ Area/volume/time sampled ______________

Description of collection site (e.g. habitats) ______________________________

Level of threat to wetland: 1, 2, 3, 4, 5

1 No information

2 No threat known

3 Minor threat (e.g. some disturbances from hunting, fishing, recreation or overgrazing)

4 Moderate threat: some serious threats, but irreparable damage not inevitable

5 Under serious threat, from one or several sources; most, if not all of the wetland habitat is likely to be lost or major ecological changes are likely to occur unless some immediate remedial action is taken

Type of threat to wetland

Absent 1 Present 2 ,

Level of threat: + present without any obvious effects on the wetland,

++ slight effect on the wetland,

+++ moderate effect on the wetland,

++++ serious effect on the wetland.

To the catchment

Afforestation ______________ Forestation ______________

Urban development ______________ Mining ______________

Water resource/ hydroelectric development: dams, barrages, water abstraction ______________

Degradation of the catchment, soil erosion, sedimentation ______________

Alien plant infestation along water courses ______________

Ridge/furrow ______________ Erosion ______________

Keypoint disruption ______________ Flow concentration zone ______________

Grazing of veld ______________ Planted pastures ______________

Planted crops ______________ Planted timber ______________

Domestic stock ______________ Game ______________

To the wetland

Drainage ______________ Canal ______________

Dredging ______________ Groundwater abstraction ______________

Abstraction/diversion of water supply for irrigation/urban/industrial use ______________

Flood control ______________ Flood debris ______________

Flooding ______________ Dams/weirs ______________

Construction of roads, airports, waterways, rail, bridges, culverts etc. ______________

Urban/industrial development ______________ Human/informal settlement/encroachment ______________

Mining and associated development ______________

Pipelines ______________ Pylons ______________

Waste disposal ______________ Urban/industrial pollution ______________

Agricultural fertilizers ______________ Agricultural biocides ______________

Eutrophication ______________ Siltation Infilling ______________

Effluent disposal ______________ Sewage disposal ______________

Solid waste disposal ______________

Alien plants ______________ Alien animals ______________

Infestation with aquatic weeds ______________ Problem indigenous plants ______________

Agricultural development ______________ Conversion to aquaculture ponds ______________

Conversion to salt pans ______________ Overgrazing ______________

Commercial logging ______________

Tourism/recreation and associated development ______________

Boating: power, sail, paddle ______________ Swimming ______________

Food harvesting ______________ Material Harvesting ______________

Angling/Fishing and associated disturbances ______________

Hunting and associated disturbances ______________ Bait collecting ______________

Use of poisons for fishing/hunting ______________

Harvesting of aquatic plants ______________ Woodcutting for domestic use ______________

Harvesting eggs, nestling or hatchlings of birds and reptiles ______________

Burning of wetland vegetation ______________ Cutting ______________

Appendix 5a - Aquatic animals identified from each wetland - crustaceans

Class/Order	Species	A1	A2	A3	A4	A5	A7	A8	A9	A10	A11	A12	A14	B1	B2	B3	B4	B5	B6	B7	B8
Notostraca	*Triops granarius*									x		x									
Anostraca	*Streptocephalus purcelli*									x	x	x	x								
	Streptocephalus dendyi														x						
	Streptocephalus juvenile																				
	Streptocephalus new *sp*																				
	Streptocephalus female																				
	Artemia salina				x									x							
	Branchipodopsis female												x								
	unknown juvenile		x																		
Conchostraca	*Leptestheria rubidgei*									x		x	x								
Cladocera	*Daphnia (Daphnia) pulex-group*																				
	Daphnia (Ctenodaphnia) daphniopsis																				
	Daphnia (C.) magna			x			x														
	Daphnia (C.) similis-group			x	x	x	x			x	x	x	x		x	x			x		
	Daphnia (C.) carinata										x						x	x			
	Daphnia (C.) atkisoni									x		x									
	Daphnia undetermined	x	x										x		x						
	Ceriodaphnia reticulata								x												
	Ceriodaphnia dubia						x						x								
	Ceriodaphnia cf. megops																				
	Ceriodaphnia cf. laticaudata														x						
	Ceriodaphnia undetermined																				
	Simocephalus exspinosus					x	x														
	Simocephalus vetulus																				
	Scapholeberis kingi																				
	Megafenestra aurita																				
	Moina brachiata			x	x		x		x												
	Moina mongolica-group																			x	
	Bosmina (B.) longirostris																				
	Macrothrix capensis s.str					x	x		x						x		x	x		x	
	Eurycercus cf. lamellatus																				
	Leydigia macrodonta s.str																				
	Leydigia macrodonta louisi								x												
	Alona sp1																				x
	Alona sp2																				
	Karualona karua																				
	Dunhevedia crassa																				x
	Chydorus sphaericus-group																				
	Chydorus undet.																				x
	Alonella exigua																				
Copepoda	Diaptomidae (copepodite)																				
	Lovenula simplex	x				x	x	x		x	x		x		x	x	x	x	x		
	Metadiaptomus capensis	x				x	x			x	x	x	x		x	x	x	x	x		x
	Metadiaptomus purcelli								x												
	Paradiaptomus hameri							x	x												
	Paradiaptomus lamellatus									x	x	x	x								
	Pseudodiaptomus hessei																				
	Eucyclops gibsoni			x		x			x												
	Eucyclops serrulatus																				x
	Eucyclops sp1								x												
	Mesocyclops major						x														
	Microcyclops crassipes						x														
	Microcyclops inopinatus																				
	Microcyclops sp																				
	Paracyclops fimbriatus																				
	Paracyclops poppei																				x
	Thermocyclops sp																				
	Tropocyclops prasinus						x														
	Cyclopoida *sp1*																				
	Cyclopoida *sp2*																				
	Cyclopoida *spp*														x			x			
	Harpacticoida spp	x	x			x									x					x	x
Amphipoda	*Afrochiltonia capensis*					x															
	Paramelita sp																				
	Paramelita nigroculus																				
	Orchestia rectipalma																				
	Melita zeylanica																				
	Corophium triaenonyx																				
	Grandidierella lignorum																				
	Corophiidae *sp1*																				
	Corophiidae *sp2*																				
Isopoda	*Exosphaeroma hylocoetes*																				
	Pseudosphaeroma barnardi																				
	Mesamphisopus cf. penicillatus or new *sp*																				

Site codes

10	B11	B12	B13	B14	B15	B16	B17	B18	C1	C2	C3	C4	C5	C6	C8	C10	C11	D1	D2	D3	D4	D5	D6	D7	D8	D10	D11	E1	E2	E5	E6	E8	E9	E10	E11
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Appendix 5b - Aquatic animals identified from each wetland - insects (L = larvae, A = adult & P = pupae)

Order	Species	A 1	A 2	A 3	A 5	A 7	A 8	A 9	A 10	A 11	A 12	A 14	B 1	B 2	B 3	B 4	B 5
Tricoptera	*Oxyethira velocipes*																
	Hydroptilidae *sp.*																
Lepidoptera	Pyralidae *sp.*																
Odonata	*Diplocodes sp.*																X
	Anisoptera *sp.*														X		
	Crocothemis sp.																X
	Anax sparatus				X												
	Enallagma sp.																X
	Zygoptera *sp.*				X												
Ephemeroptera	*Cloeon sp.* (Baetidae)			X		X							X		X		X
	Caenis sp. (Caenidae)																
Coleoptera	*Bidessus sp* (Dytiscidae - L)			X	X									X	X	X	
	Bidessus sp a (Dytiscidae - A)																
	Bidessus sp b (Dytiscidae - A)													X		X	
	Bidessus sp c (Dytiscidae - A)																
	Bidessus sp d (Dytiscidae - A)				X					X	X			X			
	Bidessus sp e (Dytiscidae - A)																
	Hydroporus/Hygrotus sp b (Dytiscidae - L)			X	X			X			X			X			
	Laccophilinae sp d (Dytiscidae - L)				X				X					X		X	X
	Dytiscidae *sp c* (L)																
	Dytiscidae *sp e* (L)																
	Dytiscidae *sp f* (L)																
	Gyrinus sp (Gyrinidae - A)																
	Gyrinidae *sp*																
	Haliplus sp (Haliplidae - L)																
	Haliplus sp (Haliplidae)														X		
	Hydraena sp a (Hydraenidae - L)																
	Hydraena sp b (Hydraenidae - L)													X			
	Hydraena sp a (Hydraenidae - A)																
	Hydraena sp b (Hydraenidae - A)																
	Octhebius sp a (Hydraenidae - L)																
	Octhebius sp b (Hydraenidae - L)																
	Octhebius sp c (Hydraenidae - A)																
	Octhebius sp d (Hydraenidae - A)				X												
	Octhebius sp e (Hydraenidae - A)	X															
	Amphiops sp a (Hydrophilidae - L)														X		
	Amphiops sp b (Hydrophilidae - L)				X												
	Berosus sp a (Hydrophilidae - A)						X										
	Berosus sp (Hydrophilidae - L)				X												
	Berosus sp b (Hydrophilidae - A)					X											X
	Derallus sp b (Hydrophilidae - L)																
	Enochrus sp a (Hydrophilidae - A)				X												
	Enochrus sp b (Hydrophilidae - A)																
	Helochares sp (Hydrophilidae - A)																
	Hydrochus sp (Hydrophilidae - A)																
	Hydrous sp (Hydrophilidae - L)																
	Laccobius sp (Hydrophilidae - L)																
	Hydrophilidae *sp a* (L)																
	Hydrophilidae *sp b*																
	Staphylinidae *sp a* (A)																
	Staphylinidae *sp b* (A)																
	Elmidae *sp.* (A)					X											
	Ptiliidae *sp.* (A)																
	Unidentified (P)										X		X				

Site Code																																			
B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14	B 15	B 16	B 17	B 18	C 2	C 4	C 5	C 8	C 10	C 11	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 10	D 11	E 1	E 2	E 5	E 6	E 8	E 9	E 10	E 11
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Appendix 5b *cont.* Aquatic animals identified from each wetland - insects (L = larvae, A = adult & P = pupae)

Order	Species	A1	A2	A3	A5	A7	A8	A9	A10	A11	A12	A14	B1	B2	B3	B4	B5
Hemiptera	*Appasus capensis* (Belostomatidae)																
	Micronecta piccanin (Corixidae)																
	Micronecta scutellaris (Corixidae)			X				X	X	X	X	X	X				X
	Micronecta sp (Corixidae)													X			
	Sigara meridionalis (Corixidae)			X		X				X					X		X
	Sigara pectoralis (Corixidae)												X				X
	Sigara sp (Corixidae).			X	X	X		X	X						X		X
	Sigara wahlbergi (Corixidae)										X						
	Anisops amaryllis (Notonectidae)																
	Anisops debilis/balcis (Notonectidae)				X												X
	Anisops hypatia (Notonectidae)																X
	Anisops sardea (Notonectidae)			X	X			X	X								X
	Anisops sp (Notonectidae)				X	X				X					X		X
	Notonecta lactitans (Notonectidae)														X		
	Plea piccanina (Pleidae)																X
	Plea pullula (Pleidae)																X
	Plea sp (Pleidae)																
	Mesovelia vittigera (Mesovelidae)																
Diptera	*Cryptochironomus sp.* (Chironomidae)																
	Rheotanytarsus sp. (Chironomidae)							X									
	Chironomus formosipennis (Chironomini)			X	X	X		X		X							
	Chironomus sp a (Chironomini)																
	Dicrotendipes pilosimanus (Chironomini)			X	X			X	X	X							
	Einfeldia sp. Nov (Chironomini)																
	Cladotanytarsus capensis (Tanytarsini)	X			X			X									
	Tanytarsus new sp (Tanytarsini)																X
	Tanytarsus sp. (Tanytarsini)				X												
	Chaetocladius sp. Nov (Orthocladiinae)																
	Corynoneura sp. (Orthocladiinae)																
	Cricotopus scottae (Orthocladiinae)																
	Orthocladiinae *sp.*																
	Orthocladiinae (damaged)																
	Orthocladiinae (male - damaged)																
	Psectrocladius viridescens (Orthocladiinae)					X					X						
	Ablabesmyi sp. (Tanypodinae)														X		
	Paramerina nigromarmorata (Tanypodinae)														X		X
	Procladius sp. (Tanypodinae)	X										X					
	Chironomidae *sp a* (teneral - A)																
	Chironomidae *sp b*										X						
	Chironomidae *sp c*					X											
	Chironomidae *sp d* (P)																
	Chironomidae *sp e* (P)				X												
	Culex sp. (Culicidae - L & P)				X	X								X	X		X
	Mimomyia sp. (Culicidae)																
	Culiseta sp. (Culicidae)																
	Atrichopogon sp. (Ceratopogonidae)																
	Ceratopogonidae *sp. a* (P)						X		X								
	Culicoidinae *sp.* (Ceratopogonidae)							X									X
	Culicoidinae *sp.* (Ceratopogonidae - P)																
	Dixa sp. (Dixidae)																
	Dolichopodidae *sp.*				X							X					
	Ephidridae *sp a*																X
	Ephidridae *sp b*				X												
	Stratyomyidae *sp.*				X										X		

Site Code																																			
B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14	B 15	B 16	B 17	B 18	C 2	C 4	C 5	C 8	C 10	C 11	D 1	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 10	D 11	E 1	E 2	E 5	E 6	E 8	E 9	E 10	E 11
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X		X	X	X			X	X	X	X	X			X	X														X	X	X		X		X
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Appendix 5 c - Other aquatic animals identified from each wetland

Phylum/Class/ Family	Species	A 5	A 7	A 10	A 12	A 14	B 1	B 2	B 3	B 4	B 5	B 7	B 8	B 9	B 10
Gastropoda	*Arcuatula capensis* (Unionidae)														
	Tomichia spp (Pomatiopsidae)		X					X	X	X	X	X	X	X	X
	Physa acuta (Physidae)														
	Ceratophallus natalensis (Planorbidae)												X		
	Ferrissia sp (Ancylidae)														
	Bulinus tropicus (Planorbidae)														
Platyhelminthidae	*Turbellaria spp*			X		X	X							X	
Pisces	*Oreochromis mossambicus* (Cichlidae)														
	Gambusia affinis (Poeciliidae)														
	Galaxias zebratus (Galaxiidae)	X											X		
	Atherina breviceps (Atherinidae)														
Amphibia	*Xenopus laevis* (Pipidae)	X	X							X				X	
	Strongylopus grayii (Ranidiae)							X							
	Cacosternum platys (Ranidiae)							X					X	X	
Araneidae	*Pardosa sp a* (Lycosidae)	X													
	Pardosa sp b (Lycosidae)														
	Pardosa sp c (Lycosidae)		X												
	Philodromus sp (Philodromidae)		X												
	Linyphiidae *sp a*											X			
	Linyphiidae *sp b*		X												
	Linyphiidae *sp c*												X		
	Hahnia sp (Hahniidae)														
	Dictyna sp (Dictynidae)														
	Tetragnatha sp (Tetragnathidae)														
Hydracarina	*sp. a*	X	X					X	X					X	X
	sp. b	X													
	sp. c														
	sp. d		X							X	X		X		X
	sp. e												X		
	sp. f														
	sp. g							X							
	sp. h														
	sp. i														
	sp. j				X					X					
	sp. k										X				
	sp. l														
	sp. m														
	sp. n														X
	sp. o														
	sp. p														
	sp. q														
	sp. r														

Site Codes																																											
B 3	B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14	B 15	B 16	B 17	B 18	C S	C 1	C 2	C 5	C 8	C 10	C 11	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 13	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10
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Appendix 6 - Plants identified from each wetland (asterisks indicate terrestrial plants that were excluded from analysi

Family	Species	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 10	A 13	A 14	B 1
Aizoaceae	*Drosanthemum sp.* *											X	
Apiaceae	*Annesorhiza berula erecta* (Huds.) Cov. subsp. thunbergii (DC.) Burtt												
Anacardiaceae	*Rhus lucida* Thunb. *												
Aponogetonaceae	*Aponogeton distachyos*												
Asphodelaceae	*Trachyandra filiforms* (Aiton) Oberm.												
Asteraceae	*Conyza scabrida* DC.												
	Cotula coronopifolia L.					X							
	Cotula filifolia Thunb.												
	Cotula sp.	X											
	Elytropappus rhinocerotis (L.f.) Less.												
	Helichrysum patulum (L.) D.Don *												
	Plecostachys serphyllifolia (Berg.) Hilliard & Burtt												
	Senecio abruptus Thunb.			X									
	Senecio elegans L.												
	Senecio rosmarinifolius L.f. *												
Campanulaceae	*Lobelia sp.*												
Chenopodiaceae	*Atriplex sp.* *											X	
	Chenopodium sp.												
	Sarcocornia sp.	X	X	X	X	X	X	X	X				X
Colchicaceae	*Onixotis stricta* (Burm.f.) Wijnands												
Crassulaceae	*Crassula cf. glomerata* Berg. *												
	Crassula natans Thunb.												
Cyperaceae	*Bolboschoenus maritimus* (L.) Palla							X					
	Cyperus sp.			X									
	Eleocharis limosa (Schrad.) Schult.												
	Fuirena hirsuta (Berg.) P.L.Forbes *												
	Isolepis fluitans (L.) R.Br.												
	Isolepis prolifer R.Br.												
	Isolepis rubicunda Kunth												
	Isolepis sp.												
	Mariscus thunbergii (Vahl) Schrad.												
	Schoenoplectus scirpoidens (Schrad.) J.Browning												
	Schoenus nigricans L.												
	Scirpus cf. nodosus Rottb.												
	?Scirpoides sp.							X					
	sp. a										X		

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Site Codes																																									
B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14	B 15	B 16	B 17	B 18	C S	C 1	C 2	C 5	C 8	C 10	C 11	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 13	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10
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Appendix 6 *cont.* - Plants identified from each wetland (asterisks indicate terrestrial plants that were excluded from ana

Family	Species	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 10	A 13	A 14	B 1
Ericaceae	*Erica gnaphaloides* L.												
	Erica labialis (Salisb.) E.G.H.Oliver												
	Erica laeta Bartl. *												
	Erica pulchella Houtt. *												
Haemodoraceae	*Dilatris sp.*												
Hyacinthaceae	*Albuca ciliaris* (Müüller-Doblies) Müüller-Doblies *									X			
	Ornithogalum sp.												
Hypoxidaceae	*Spiloxene aquatica* (L.f.) Fourc.												
Iridaceae	*Babiana stricta* (Aiton) Ker-Gawl. *												
	Gladiolus tristis L.												
	Moraea flaccida Sweet *												
	Romulea multisulcata M.P.de Vos									X			
Juncaceae	*Juncus acutus* L.							X					
	Juncus cf. kraussii Hochst.					X							
	Juncus sp.					X							
Juncaginaceae	*Triglochin bulbosa* L.												
	Triglochin striata Ruiz & Pav.												
Oxalidaceae	*Oxalis nutans* L.												
	Oxalis sp.									X			
Plumbaginaceae	*Limonium anthericoides* (Schlechter) R.A.Dyer												
	Limonium kraussianum (Buching. ex Boiss.) Kuntze												X
Poeaceae	*Briza maxima* L. *												
	Eragrostis curvula (Schrad.) Nees												
	Merxmuellera cincta (Nees) Conert												
	Pennisetum macrourum Trin.												
	Phragmites australis (Cav.) Trin. ex Steud.												
	Polypogon monspeliensis (L.) Desf.												
	Polypogon strictus Nees												
	Sporobolus virginicus (L.) Kunth							X					
	Tribolium uniolae (L.) Renvoize												
Potamogetonaceae	*Potamogeton pectinatus* L.												

s)

Site Codes

B 4	B 5	B 6	B 7	B 8	B 9	B 10	B 11	B 12	B 13	B 14	B 15	B 16	B 17	B 18	C S	C 1	C 2	C 5	C 8	C 10	C 11	D 2	D 3	D 4	D 5	D 6	D 7	D 8	D 9	D 10	D 13	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10
																																		X							
									X																																
									X																																
X	X	X		X	X	X	X		X		X	X																				X	X			X		X		X	X
																																		X	X						
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														X	X																			X							
																X																									
																																		X							
X									X							X																	X					X		X	X
								X																																	

Appendix 6 *cont.* - Plants identified from each wetland (asterisks indicate terrestrial plants that were excluded from a

Family	Species	A 1	A 2	A 3	A 4	A 5	A 6	A 7	A 8	A 10	A 13	A 14	B 1
Proteaceae	*Diastella divaricata* (Bergius) Rourke *												
	Calopsis sp.												
	Chrondropetalum microcarpum												
	Chrondropetalum sp.												
	Elegia cuspidatus												
	Elegia filacea?												
	Elegia sp.												
Restionaceae	*Elegia stipularis*?												
	Ischyrolepis sp.												
	Restio quinqurfarius												
	Restio sp.												
	Staberoha banksii												
	Staberoha sp.												
	sp. a												
Typhaceae	*Typha sp. a*												

Site Codes																										
B 12	B 13	B 14	B 15	B 16	B 17	C 4	C 8	C 10	C 11	D 1	D 2	D 3	D 4	D 5*	D 6	D 7	D 8	D 10	D 11	E 1	E 2	E 5	E 8	E 9	E 10	E 11
												X	X	X		X	X									
	X	X	X	X													X									X
			X						X																X	
			X																					X	X	
																	X									
																										X
						X	X													X		X				X
																X										
			X												X											
	X																									
										X	X	X	X	X	X	X										
																				X						
	X		X				X	X										X			X			X		
	X																			X				X	X	
		X																								
																						X				
							X																			
											X		X			X			X							
			X						X													X	X	X		
	X						X															X				
	X																									
	X	X					X																X			
X								X		X																
																								X		
																										X
			X																							
					X																					
										X																
X																										
									X																	
					X																					
																									X	

Appendix 3. Water chemistry data collected from wetlands during winter.

Site	Water depth	Turbidity	pH	Conductivity	Temperature	Salinity	Phosphate	Ammonium	Nitrite	Nitrate	Total N	Na^+	K^+	Σmonovalent cations	Mg^{2+}	Ca^{2+}	Σdivalent cations	Cl^-	SO_4^{2-}
	mm	NTU		mS m^{-1}	°C		mg l^{-1}					mmol l^{-1}							
A1	50	21.40	9.52	1910	19.9	18	0.100	0.07	0.006	0.021	0.101	142.8	2.2	144.9	20.1	12.7	32.9	165.7	19.5
A2	100	60.60	8.59	8850.00	18.9	80	0.359	0.05	0.009	0.017	0.075	1063.2	9.1	1072.3	133.8	40.7	174.5	1173.6	57.9
A3	500	10.60	7.25	760.00	16.0	7	0.726	0.32	0.013	0.025	0.353	33.0	0.3	33.3	4.6	1.8	6.5	26.0	1.3
A4	130	8.38	8.61	765.00	17.3	65	0.808	0.08	0.006	0.034	0.123	917.1	20.3	937.4	66.3	70.6	136.8	774.7	43.5
A5	400	17.20	10.62	641.0000	17.5	5	0.003	0.05	0.004	0.033	0.084	53.6	1.1	54.7	7.1	2.19	9.31	57.7	3.3
A6																2.2	9.3		
A7	500	2.42	7.71	438.0	16.2	6	0.383	0.06	0.012	0.014	0.087	18.9	0.3	19.1	2.2	2.17	4.32	20.0	2.3
A8	150	312.00	8.63	2750	17.8	24	0.003	0.05	0.005	0.019	0.068	157.4	2.1	159.6	18.6	22.0	40.5	144.0	20.7
A9	250	52.00	8.89	387	18.7	3	0.055	0.07	0.006	0.010	0.081	9.3	0.1	9.4	1.5	0.8	2.2	11.1	0.4
A10	200	1000.00	7.66	19.63	14.9	0													
A11	500	1000.00	8.20	67.5	14.5	1													
A12	100	1000.00	7.72	15.52	21.3	4													
A14	50	1000.00	8.97	53.5	22.8	1													
B1	300	49.30	7.96	9310	14.1	87	0.016	0.11	0.003	0.017	0.134	604.2	9.7	613.9	81.6	27.3	109.0	698.7	17.5
B2	100	11.70	9.00	572	22.7	5	0.008	0.10	0.005	0.018	0.124	61.8	0.8	62.6	7.9	2.7	10.7	73.5	3.5
B3	300	4.97	9.14	1091	18.0	7	0.011	0.07	0.015	0.033	0.115	19.8	0.4	20.1	1.9	1.5	3.3	20.4	2.2
B4	300	4.73	8.66	520	19.5	4	0.008	0.08	0.016	0.016	0.109	17.3	0.4	17.7	2.3	1.3	3.6	18.3	0.9
B5	400	1.37	10.05	690	18.3	8	0.005	0.07	0.006	0.013	0.093	26.1	0.4	26.6	3.4	1.4	4.98	32.8	1.4
B6	150	16.50	8.92	739	11.6	8	0.006	0.07	0.007	0.014	0.092	74.2	2.2	76.4	6.1	2.0	8.0	78.2	2.7
B7	400	5.94	8.67	2550	16.1	20	0.026	1.30	0.019	0.023	1.341	109.9	1.5	111.4	13.6	3.3	16.9	159.8	5.1
B8	150	4.03	7.45	211	14.8	0	0.010	0.05	0.011	0.009	0.072	12.2	0.1	12.3	1.7	0.6	2.2	14.3	0.5
B9	200		7.95	194.5	20.2	0	0.005	0.08	0.010	0.009	0.093	9.7	0.9	10.6	0.9	0.5	1.4	11.0	0.5
B10	400	1.99	9.83	563	18.4	5	0.003	0.06	0.004	0.012	0.075	43.5	0.6	44.1	5.1	4.3	9.4	56.5	2.2
B11	200		11.21	810	20.4	6	0.005	0.07	0.006	0.008	0.083	41.3	0.4	41.7	5.1	1.0	6.1	49.1	2.6
B12	400	8.41	6.92	103	13.7	4	0.008	0.06	0.032	0.005	0.100	4.8	0.2	5.0	0.5	0.3	0.7	4.9	0.2
B13	400	3.20	7.45	100.2	13.5	3	0.011	0.06	0.029	0.011	0.103	7.3	0.1	7.4	0.6	0.4	1.0	7.4	0.2
B14	250	88.40	8.46	3780	18.3	30	0.050	0.08	0.007	0.011	0.094	235.4	2.6	238.0	35.4	14.7	50.1	297.4	16.3
B15	200	55.20	8.20	150	20.2	0	0.016	0.06	0.016	0.016	0.093	11.5	0.3	11.8	1.2	0.9	2.0	11.8	0.6
B16	500	6.59	9.00	1831	22.2	14	0.010	0.05	0.022	0.020	0.088	97.9	1.7	99.6	13.6	3.6	17.2	103.7	5.8
B17	400	82.10	7.10	107.4	14.6	4	0.013	0.06	0.011	0.009	0.078	9.7	0.1	9.8	1.3	0.4	1.7	12.2	0.5
B18	400	20.10	7.31	236	15.7	4	0.023	0.06	0.015	0.011	0.090	28.2	0.7	28.9	3.5	1.9	5.4	35.7	1.2

Site	Water depth	Turbidity	pH	Conductivity	Temperature	Salinity	Phosphate	Ammonium	Nitrite	Nitrate	Total N	Na^+	K^+	Σmonovalent cations	Mg^{2+}	Ca^{2+}	Σdivalent cations	Cl^-	SO_4^{2-}
	mm	NTU		mS m^{-1}	°C		mg l^{-1}					mmol l^{-1}							
CS																			
C1	50		5.08	1.64	13.9	1	0.003	0.05	0.001	0.011	0.066	0.1	0.0	0.1	0.0	0.1	0.1	0.2	0.0
C2	400	0.85	6.20	20.7	12.5	0	0.002	0.06	0.016	1.472	1.549	0.7	0.1	0.8	0.3	0.3	0.5	0.8	0.3
C3	100	1000.00	8.29	533	14.6	13													
C4	50	1000.00	7.45	9.7	16.8	3													
C5	400	16.70	7.20	19.73	14.3	2	0.008	0.06	0.005	0.013	0.076	1.0	0.2	1.1	0.3	0.2	0.5	1.7	0.1
C6	150	346.00	8.93	191.7	17.6	4	0.006	0.07	0.008	0.010	0.084	8.9	1.0	10.0	0.9	0.3	1.2	8.4	0.7
C7																			
C8	300	4.43	7.14	3.44	11.4	3	0.006	0.52	0.008	0.010	0.538	0.3	0.0	0.3	0.1	0.0	0.1	0.2	0.0
C9																			
C10	300	8.51	6.98	13.02	12.9	2	0.037	0.19	0.009	0.008	0.207	0.7	0.1	0.8	0.2	0.1	0.3	0.7	0.0
C11	200	6.26	6.11	119.5	14.0	4	0.016	0.64	0.009	0.007	0.657	7.2	0.2	7.4	1.0	0.7	1.7	8.5	0.5
D1	1000	4.09	9.10	487	20.5	3	0.005	0.05	0.019	0.020	0.090	34.3	0.7	35.0	3.5	3.0	6.5	38.1	1.4
D2	720		8.81	488	19.5	5	0.027	0.06	0.005	0.009	0.073	9.0	0.2	9.1	0.9	0.1	1.0	9.9	0.4
D3	1000	3.15	9.73	1379	20.1	10	0.011	0.04	0.005	0.013	0.055	42.7	1.2	43.9	4.7	1.0	5.6	72.3	2.9
D4	400	1.46	9.47	1668	20.7	13	0.015	0.03	0.066	0.187	0.284	64.2	1.7	65.8	8.9	0.1	8.8	70.4	3.3
D5	400	4.40	8.90	1240	21.2	9	0.100	0.10	0.025	0.043	0.166	18.4	0.5	18.9	2.0	1.6	3.6	21.4	0.7
D6	700	80.30	8.98	1207	22.1	7	0.137	0.07	0.012	0.024	0.104	17.7	0.4	18.1	2.0	1.6	3.6	18.6	2.0
D7	400	5.97	8.27	1521	21.3	9	0.011	0.10	-0.001	0.028	0.127	71.8	1.6	73.4	9.6	1.4	11.0	86.9	3.6
D8	1000	1.45	7.45	1517	18.0	12	0.010	0.11	0.005	0.020	0.135	51.1	1.2	52.4	9.2	0.2	9.4	59.8	2.7
D9																			
D10	900	24.70	7.96	309	19.7	2	0.036	0.24	0.015	0.024	0.282	4.6	0.1	4.7	0.7	0.4	1.1	4.7	0.1
D11	400	13.90	7.17	218	17.6	1	0.026	0.18	0.006	0.080	0.268	3.6	0.1	3.6	0.6	0.2	0.8	4.1	0.2
D12																			
D13																			
E1	300	2.12	5.84	559	16.0	7	0.026	0.14	0.056	0.004	0.202	13.0	0.3	13.2	2.0	0.2	2.2	16.6	0.8
E2	200	37.70	8.30	579	17.5	8	0.346	0.55	0.027	0.020	0.599	32.4	0.4	32.8	4.5	2.9	7.4	41.5	0.8
E3																			
E4																			
E5	300	2.65	8.66	429	24.4	4	0.005	0.13	0.013	0.003	0.149	24.2	0.6	24.8	3.9	1.6	5.4	27.7	1.3
E6	300	147.00	9.21	1550	25.6	9	0.108	0.17	0.026	0.020	0.215	75.0	1.5	76.5	9.8	1.7	11.4	102.5	3.2
E7																			
E8	200	2.27	8.81	905	25.0	5	0.006	0.07	0.006	0.022	0.101	33.0	0.5	33.6	5.3	2.4	7.7	31.9	4.9
E9	300	3.20	6.95	95	26.3	0	0.024	0.30	0.074	0.006	0.382	4.3	0.1	4.4	0.6	0.3	0.9	4.4	0.2
E10	200	1.62	7.76	1964	30.5	0	0.003	0.05	0.010	0.010	0.065	11.9	0.3	12.2	1.9	1.1	3.0	11.2	1.0
E11	400	2.63	7.70	257	27.8	0	0.079	0.06	0.009	0.006	0.071	6.9	0.2	7.1	1.4	2.0	3.3	7.9	0.5

Appendix 2. Abiotic characteristics of each wetland.

Site	Landform groups	Hydrology groups	Drainage categories
A1	flat	winter inundated, summer dry	Endorheic, water from flooded river
A2	basin	winter inundated, summer dry	Endorheic, water from flooded river
A3	basin	winter inundated, summer saturated	Endorheic
A4	depression	winter inundated, summer dry	Endorheic
A5	depression	permanently inundated	Exorheic
A6	flat	winter and summer dry	Endorheic, water from flooded river
A7	basin	permanently inundated	Endorheic, water from flooded river
A8	flat	winter inundated, summer dry	Endorheic, water from flooded river
A9	basin	permanently inundated	Exorheic, marine connection
A10	basin	winter inundated, summer dry	Endorheic
A11	basin	permanently inundated	Endorheic
A12	depression	winter inundated, summer dry	Endorheic
A14	depression	winter inundated, summer dry	Endorheic
B1	flat	winter inundated, summer dry	Endorheic
B2	depression	winter inundated, summer dry	Endorheic
B3	depression	winter inundated, summer dry	Endorheic
B4	depression	winter inundated, summer dry	Endorheic
B5	basin	permanently inundated	Endorheic
B6	flat	winter inundated, summer dry	Endorheic
B7	basin	permanently inundated	Endorheic
B8	flat	winter inundated, summer dry	Exorheic
B9	flat	winter inundated, summer dry	Exorheic
B10	basin	permanently inundated	Endorheic, water from flooded river
B11	flat	winter inundated, summer dry	Exorheic
B12	basin	permanently inundated	Endorheic
B13	flat	winter inundated, summer dry	Endorheic
B14	depression	winter inundated, summer dry	Endorheic
B15	depression	winter inundated, summer dry	Endorheic
B16	depression	winter inundated, summer dry	Endorheic
B17	basin	permanently inundated	Exorheic
B18	basin	permanently inundated	Exorheic
CS	slope	winter saturated, summer dry	Exorheic
C1	flat	winter saturated, summer dry	Exorheic
C2	flat	winter inundated, summer dry	Exorheic
C3	depression	winter inundated, summer dry	Endorheic
C4	depression	winter inundated, summer dry	Endorheic
C5	depression	permanently inundated	Endorheic
C6	basin	winter inundated, summer dry	Endorheic
C7	depression	winter and summer dry	Endorheic
C8	flat	winter inundated, summer dry	Exorheic
C9	flat	winter and summer dry	Exorheic
C10	flat	winter inundated, summer dry	Exorheic
C11	flat	winter saturated, summer dry	Exorheic

Site	Landform groups	Hydrology groups	Drainage categories
D1	basin	permanently inundated	Endorheic
D2	basin	permanently inundated	Endorheic
D3	basin	permanently inundated	Exorheic, marine connection
D4	basin	permanently inundated	Exorheic, marine connection
D5	basin	permanently inundated	Exorheic, marine connection
D6	basin	permanently inundated	Exorheic, marine connection
D7	basin	permanently inundated	Exorheic, marine connection
D8	basin	permanently inundated	Exorheic, marine connection
D9	flat	winter and summer dry	Exorheic
D10	depression	permanently inundated	Endorheic
D11	hole in ground	permanently inundated	Endorheic
D12	flat	winter and summer dry	Exorheic
D13	flat	winter and summer dry	Exorheic
E1	depression	winter inundated, summer dry	Endorheic
E2	depression	winter inundated, summer dry	Endorheic
E3	flat	winter and summer dry	Exorheic
E4	flat	winter saturated, summer dry	Endorheic
E5	depression	winter inundated, summer dry	Endorheic
E6	basin	winter inundated, summer saturated	Endorheic
E7	flat	winter and summer dry	Endorheic
E8	basin	winter inundated, summer dry	Endorheic
E9	depression	winter inundated, summer dry	Endorheic
E10	flat	winter inundated, summer dry	Endorheic
E11	basin	permanently inundated	Endorheic

Appendix 4. Water chemistry data collected from wetlands during summer.

Site	Water depth	Turbidity	pH	Conductivity	Temperature	Salinity	Phosphate	Ammonium	Nitrite	Nitrate	Total N	Na^+	K^+	Σmonovalent cations	Mg^{2+}	Ca^{2+}	Σdivalent cations	Cl^-	SO_4^{2-}
	mm	NTU		mS m^{-1}	°C		mg l^{-1}					mmol l^{-1}							
A1																			
A2																			
A3	100		8.24	1008.0000	30.6	0													
A4																			
A5	300	35.30	9.00	2250.0000	26.2	6	0.066	0.12	0.010	0.001	0.133	88.4	1.7	90.1	11.2	3.8	15.0	108.1	3.7
A6																			
A7	300	2.42	9.54	1202.0000	19.7	2	0.002	0.05	0.004	0.014	0.064	58.7	0.6	59.3	8.0	5.1	13.0	64.5	8.0
A8																			
A9	300	22.60	9.48	455.0000	28.2	0	0.010	0.05	0.008	0.011	0.071	11.0	0.2	11.2	1.9	0.5	2.3	14.4	0.5
A10																			
A11																			
A12																			
A14																			
B1																			
B2																			
B3																			
B4																			
B5	400	2.09	9.41	1977	22.6	15	0.003	0.05	0.009	0.005	0.061	151.1	2.2	153.3	21.3	6.9	28.1	160.9	6.0
B6																			
B7	200	6.19	8.17	3390	23.6	101	0.015	0.02	0.011	0.007	0.035	1646.0	28.6	1674.6	222.3	44.2	266.5	2180.9	48.3
B8																			
B9																			
B10	200	1.8	9.08	5540	20	42	0.008	0.05	0.005	0.007	0.066	478.3	4.3	482.6	59.4	9.6	69.0	569.0	16.5
B11																			
B12	400	120	7.2	295	25	0	0.008	0.05	0.029	0.008	0.088	18.7	0.3	19.0	2.8	1.2	4.0	23.7	0.4
B13																			
B14																			
B15																			
B16																			
B17	200	11.8	8.88	550	28.9	2	0.005	0.05	0.013	0.027	0.086	20.8	0.2	21.0	3.1	0.7	3.7	27.3	0.3
B18	400	2.71	7.49	324	26.5	3	0.002	0.04	0.009	0.007	0.059	6.9	0.1	6.9	1.3	0.7	2.0	7.7	0.2

Site	Water depth	Turbidity	pH	Conductivity	Temperature	Salinity	Phosphate	Ammonium	Nitrite	Nitrate	Total N	Na^+	K^+	Σmonovalent cations	Mg^{2+}	Ca^{2+}	Σdivalent cations	Cl^-	SO_4^{2-}
	mm	NTU		mS m^{-1}	°C		mg l^{-1}					mmol l^{-1}							
CS																			
C1																			
C2																			
C3																			
C4																			
C5	100	24.30	8.90	44.7000	32.6	0	0.013	0.05	0.006	0.014	0.074	1.5	0.4	1.9	0.5	0.5	1.0	2.2	0.3
C6																			
C7																			
C8																			
C9																			
C10																			
C11																			
D1	500	4.52	3.82	489	25.6	0	0.005	0.16	0.010	0.023	0.193	26.1	0.4	26.6	3.6	1.8	5.4	24.2	0.8
D2	1000	3.8	8.73	499	26.3	1	0.002	0.10	0.004	0.013	0.120	18.3	0.4	18.7	2.5	3.3	5.8	24.8	0.7
D3	300	1.04	9	1737	25.7	10	0.019	0.05	0.009	0.019	0.076	78.2	2.3	80.4	11.2	2.8	14.0	68.9	4.3
D4	300	4.45	8.73	1702.5	22.5	12	0.032	0.08	0.006	0.006	0.087	89.5	2.2	91.7	12.2	0.8	13.1	128.7	4.4
D5	300	2.2	8.6	1345	21.6	7	0.026	0.10	0.003	0.007	0.113	93.6	2.2	95.9	11.8	4.7	16.5	103.5	4.6
D6	1000	1.66	9.14	1219	24.1	5	0.018	0.07	0.008	0.006	0.082	47.4	1.1	48.5	6.1	0.4	6.5	60.0	2.2
D7	300	3.03	8.02	1284	24.4	8	0.018	0.14	0.004	0.018	0.157	89.6	2.0	91.5	11.8	3.7	15.5	90.0	3.7
D8	300	1.88	8.31	687	21.8	8	0.015	0.05	0.004	0.008	0.059	68.5	1.6	70.1	9.0	1.2	10.2	92.2	3.9
D9																			
D10	500	88.1	9.74	390	30.5	100	0.063	0.09	0.015	0.006	0.109	32.4	0.8	33.2	2.9	1.2	4.0	36.6	0.7
D11	1000	128		204	25.2	0													
D12																			
D13																			
E1																			
E2																			
E3																			
E4																			
E5																			
E6	50	32.6	7.89	3270	25.9	101													
E7																			
E8																			
E9																			
E10																			
E11	300	5.04	8.4	246	24.5	5	0.128	1.12	0.008	0.013	1.144	12.2	0.3	12.5	2.0	2.6	4.6	13.4	0.6