# Ephemeral Wetlands of the Nelson Mandela Bay Metropolitan Area: Classification, Biodiversity and Management Implications

Report to the
**WATER RESEARCH COMMISSION**

by

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# EXECUTIVE SUMMARY

## RATIONALE

South Africa has limited water resources in the face of a growing demand for household, rural and industrial use. Because of these pressures, it is important to manage our water resources responsibly, both in terms of those that are part of the direct supply chain and those that have a more indirect role in the provisioning of ecosystem services. Wetlands provide a variety of ecosystem services, from flood attenuation and water filtration to cultural benefits, and many more which have been well documented by other researchers (e.g. Millennium Ecosystem Assessment 2005; Kotze et al. 2009; Blackwell and Pilgrim 2011). Wetland research has gained attention and funding in recent years in response to anthropogenic pressures on these aquatic ecosystems reacting to a need to protect, conserve and manage this natural resource. In order to standardise and formalise the identification, delineation and typing of wetlands, many tools and methods have been developed to assist researchers, managers and practitioners (e.g. DWAF delineation guide (DWAF 2005), Water Research Commission series of reports, WET (Ellery *et al.* 2009) and WHI (Day and Malan 2010) programmes, SANBI's Classification System (Ollis *et al.* 2013) and National Mapping Initiative (BGIS 2011)). It is through common methods and terminology that effective communication between researchers, managers and practitioners can be achieved to reach common goals.

The advent of these tools and methods has brought about the need for more fine scale testing and use of these methods in different areas of the country, to ensure that they are generic enough for use across South Africa and yet meet the needs of unique local settings. Most have been developed in specific regions, where data are available and the immediate need to manage and protect wetlands from anthropogenic pressures has been greater. It has also been noted that there are knowledge gaps within different regions of the country. The Eastern Cape Province is one of those regions where there is a general paucity of research attention and available spatial data for wetlands. Most of the information gathered for wetlands in the Eastern Cape region has been need-driven in the context of wetland specific ecological impact assessments, in particular for proposed developments. There has been very little information available especially in terms of basic research on wetlands of this area, and in other semi-arid and arid regions of the country, such as the Northern Cape, Free State and Northwest Province.

The research presented in this report was designed to utilise the tools that have been developed nationally and apply them to wetlands in the Nelson Mandela Bay Metropolitan (NMB) area. In arid and semi-arid regions of the country, such as the NMB, the climatic conditions tend to favour a greater number of ephemeral or temporary wetlands. These ephemeral systems often include endemic species of fauna and flora that are adapted to wet and dry periods (Leibowitz 2003; Meyer et al. 2007; Day et al. 2010). Consequently, these systems potentially have a relatively high biodiversity compared to other more permanent systems (Leibowitz 2003; Keddy 2010).

Therefore, the focus of our sampling effort was placed on ephemeral wetlands in NMB, concerning those temporary systems that range from seasonal (inundation for three to six months within the wet season) to intermittent (inundation from weeks to months in times of good rains) to episodic (inundation from days to weeks during extreme rain events).

## AIMS OF THE PROJECT

There were five aims of this project as stated below:

1. Application of the National Wetland Classification System (NWCS) for South Africa (SANBI 2009) to identify wetland types within the Nelson Mandela Bay (NMB) area.
2. Delineate ephemeral wetlands in terms of their geology, hydrogeomorphology, riparian and aquatic vegetation within the NMB area.
3. Determine the biodiversity of algae, aquatic and semi-aquatic plants, and aquatic invertebrates for ephemeral wetlands in NMB.
4. Understand the interaction of geological and biological processes in the structure of biotic communities in ephemeral wetland systems within the NMB area.
5. Determine if patterns in biodiversity are more closely related to wetland classification properties or geographical location, and which factor or set of factors will be most likely to predict and describe the functioning of ephemeral wetland systems.

During the drafting of the proposal for this work the SANBI (2009) NWCS was in use and the user manual was being drafted. “*The Classification System for Wetlands and other Aquatic Ecosystems in South Africa, User Manual: Inland Systems”* (Ollis *et al*. 2013) was subsequently published and used as the basis for Aim 1 (listed above) and is referred to from this point forward as the Classification System or CS. The CS method and terminology was adopted and used throughout this report unless otherwise stated.

In summary, the main aims of this project were to locate, demarcate and classify (type) wetlands in the NMB area using the CS guidelines and to gather baseline data on abiotic variables and biotic parameters in a broad range of ephemeral wetland types. Aims 1-3 were successfully achieved within this study. Aim 4, understanding landscape processes and how they shape biotic communities has been addressed as far as the data collected will allow. This can be developed and investigated further. The first part of the fifth aim, linking biotic biodiversity patterns and classification or geography has been addressed successfully. The second part of aim 5; however, still requires more in-depth data collection and investigation. Nevertheless, great strides in adding to the knowledge base have been made and we have begun to address the issue of being able to predict and describe the functioning of ephemeral wetlands systems based on key physical and biological factors.

## METHODOLOGY

A range of desktop, field and laboratory methods were used to address each aim at multiple spatial and temporal scales. GIS techniques were used to display spatial and temporal patterns and further statistical analyses were used to explain the relationship of the different wetland types to the surrounding environment. NMB wetlands were mapped as a desktop study at a scale of 1: 2500. Wetlands were ground-truthed to confirm, modify and add information to the maps and give additional detail to the classification of selected sites. A sub-set of field sites were then chosen across the NMB area to represent the range of rainfall distribution and terrestrial vegetation areas across the metro including the spatial distribution of wetlands. A group of 46 sites were each sampled once, between 2012 and 2013, and were classified to Level 6 of the CS. A number of parameters were measured in the field, and soil and water samples were taken to the laboratory for further analysis, see Table E.1 for outline of physical and chemical data collected. Several different types of biological data were collected: vegetation, algae, aquatic invertebrates and tadpoles. Of those 46 sites, 6 sites were chosen to return to for monitoring at either weekly, monthly or quarterly intervals to investigate changes in abiotic variables and biotic communities linked to changes in inundation level.

**Table E.1 Abiotic data collection, *in situ* measurements and sample collection for laboratory processing.**

| Parameter | Measured *in situ* | Laboratory Processing |
|---|---|---|
| **Soils** | Colour<br>Texture<br>Mottles<br>Saturation<br>Profile | Organic content<br>Moisture content<br>Particle size<br>Conductivity<br>pH |
| **Surface and Sub-surface water** | Temperature<br>pH<br>Conductivity<br>Salinity<br>Dissolved oxygen<br>Total dissolved solids<br>Depth | Nutrients<br>Total Nitrogen<br>Nitrate<br>Nitrite<br>Ammonium<br>Total Phosphorus<br>Soluble Reactive Phosphorus<br>Silica<br>Total Suspended Solids (surface only) |

## KEY FINDINGS

### Assessing the use of the CS for wetlands in the NMB

- The desktop demarcation and typing results from this study had a high degree of accuracy. This approach and use of the current method and tools can be transferred to other regions of the country if there is capacity (training in GIS and basic understanding of wetland hydrogeomorphology) and local knowledge;

- The CS is easy to follow and very thorough, especially the higher levels of the classification (Levels 1-4) which are largely desktop based. It is more difficult to synthesise the lower levels as they lend themselves to site description rather than multi-site analysis;
- The use of the CS can provide a good foundation or template for use in an area or region to inventory wetlands. Other assessments, such as wetland health and ecosystem services provision can then be made on targeted systems. Having this template would also allow for more accurate and relevant management decisions to be made.

**Classified wetlands in the NMB**

- In this project we were able to identify and classify 1712 wetlands. This was a greater number than we expected to find in the NMB, especially given the semi-arid climate. The original SANBI map of wetlands for NMB numbered 596, which were dominated by larger, perennial and artificial or modified systems. This is a 65% increase in wetland numbers.
- The full range of wetland types from the CS were identified throughout the municipal area, however the majority of these systems are small, <1 ha, and range from 0.002 to 45.1 ha in size. More than likely the majority of the wetlands can be considered to be ephemeral (seasonal and intermittent) wetlands.
- The dominant wetland types, in terms of numbers are depressions (519), seeps (471) and wetland flats (387), with 70% of the wetlands in near-natural or natural areas.
- However, a significant proportion of wetlands do occur on land classified as agriculture and could be potentially threatened.

**General physical and chemical characteristics**

- Soils (e.g. mottling, organic content), a commonly used indicator of wetlands in delineation methods, were found to be good indicators of the presence of a wetland (i.e. they had properties that are deemed to be wetland soils in nature) at 60% of the sites sampled, but for the remaining sites these indicators were not present or as clear cut.
- The absence of soil indicators such as mottles and concretions was generally due to underlying geology such as aeolian sand.
- Physico-chemical properties were linked more to geographical location and underlying geology than by the type of wetland.
- With the exception of the coastal dune depressions and one salt pan, the majority of the sites were fresh to slightly brackish with predominately neutral pH.
- Nutrient levels were highly variable, ranging from below detection levels to the higher end of the range for wetland nutrient levels (Day and Malan 2005). The majority of wetlands sampled were oligotrophic at the time of sampling. It is also important to note that sites were chosen for their relative undisturbed nature,

therefore there was little differentiation amongst the sites beyond natural variance from landscape inputs such as underlying geology and surrounding vegetation.

- The primary hydrological factor influencing the morphological, physical and chemical aspects of wetland flats and seeps is rainfall. Depressions, however exhibited a wider range of hydrological influences.

**Biodiversity and distribution of the flora and fauna**

- There were >300 plant taxa identified from the 46 wetland sites, of those, 148 were considered dominant in terms of cover. All sites had at least facultative wetland species present as a dominant, even when no water was present. Overall, of the 148 dominant taxa identified, there was a mix of terrestrial (45%), obligate wetland (37%), facultative and wetland associated species (9% each). The drier sites having greater proportions of terrestrial, wetland associated and facultative wetland species. Therefore, all sites sampled had wetland indicator plant species present. As far as possible, invasive alien plants have also been identified, most being invasive weeds and grasses.
- There were no differences between wetland types in terms of overall plant diversity. Wetland plant communities tended to be unique from site to site, with no strong groupings by either wetland type or geographical position. There were loose community groups with characteristic dominant species, but at a very low level of within group similarity.
- One confirmed IUCN red data species was recorded at three wetlands, *Crinum campanulatum*, which is a regional endemic.
- Phytoplankton and microphytobenthos (MPBs) were found to be fairly numerous and diverse, with 147 and 298 taxa identified respectively. The phytoplankton were dominated by chlorophytes, cyanophytes and cryptophytes and occurred in depressions and wetland flats. Seeps do not generally support enough surface water to support phytoplankton communities.
- MPBs, however, were represented in all wetland types sampled, with 50% of the community comprised of diatoms and the other 50% a mix of other taxonomic groups dominated mainly by chlorophytes and cyanophytes, including a prevalence of pico-algae (small, 0.2-1 µm, unidentified cyanophytes and chlorophytes). MPBs in seeps and depressions appeared to be more variable and have a higher overall mean across the diversity indices; however, this was not significant.
- Diatoms were analysed both as a part of the total benthic algal (MPB) community and on their own. 180 species were identified, but with very low abundances. Of those, 76 species were also recorded as part of the overall MBP community.
- Diatom communities in freshwater ecosystems have been focussed on as water quality indicators. However, the value of the microalgal community as a whole should not be overlooked. The questions being asked by researchers and managers need to be taken into account. If the history of the wetland (or freshwater ecosystem) is of interest, in terms of various water quality variables, diatoms from the sediment

record can be used to compare with current diatom species. This is a time consuming and technical process that requires highly trained individuals. If the current state of water quality needs to be evaluated, the inclusion of other algal taxa, such as cyanophytes and filamentous chlorophytes, would be more suited to address that question. Species in these taxa respond readily to physico-chemical changes and are much easier to process and can be rapidly identified.

- There were 144 taxa of aquatic macroinvertebrate identified and unlike the floral component, there were differences in diversity between wetland types. In terms of species richness, depressions and flats were similar in their number of different taxa, with seeps having few taxa and lower overall animal densities. The Shannon-Weiner diversity index showed depressions with the greatest overall macroinvertebrate diversity of the three wetland types.
- Taxonomic composition in terms of macroinvertebrates was very different between the wetland types, with seeps being insect and "worm" dominated due to shallow or lack of surface water, and saturated soils. The community structure between depressions and wetland flats was similar, but the overall numbers of animals in the non-insect taxa were greater in wetland flats.
- Insect taxa (flies, beetles and true bugs) were the most diverse in terms of the different number of species identified, across all wetlands, whereas non-insect (i.e. branchiopods and microcrustaceans) groups that are generally specific to ephemeral or standing waters do not have a great number of different species. For instance, the order Notostraca is only represented by one family, Triopidae and two species. It is also important to note the timing of sampling with the inundation phase of an ephemeral wetland. A newly inundated wetland will have few insects and more branchiopods and microcrustaceans, whereas a "matured" wetland will be dominated by insects.
- There was one IUCN red data invertebrate recorded, an obligate ephemeral wetland species of fairy shrimp, *Streptocephalus dendyi*. This species as a broad coastal distribution in isolated populations that show local morphological characteristics.
- Several alien invasive terrestrial snails, loosely associated with surrounding wetland vegetation were also recorded, namely, *Cochilicella barbara* and *Theba pisara*.
- In the absence of water, hatching experiments of dry wetland sediments showed the presence of an array of wetland taxa, from invertebrates to algae and plants. There were differences in hatching success rates between wetland types, with seep sediments almost never showing successful hatching of branchiopods and microcrustaceans, but having plants and algae.
- There was a healthy presence of amphibians utilising the ephemeral wetlands as important breeding habitat. Ten species of tadpoles were recorded, most only utilising the wetland for breeding and early life stage development (Carruthers and Du Preez 2009). *Xenopus laevis* is predominantly aquatic in all stages of its life cycle, but uses ephemeral systems as expanded habitat and movement corridors.

## MANAGEMENT IMPLICATIONS

This study has contributed to new knowledge on the wetlands, particularly the ephemeral wetlands, of NMB and can aid in future management of them in the following ways:

- The use of a relatively new classification tool, the Classification System, outside of the regions it was developed and tested in. The project was able to demonstrate the ease of use and evaluate its effectiveness in classifying wetlands of all types with in an area. This tool can be used by municipalities, regional and provisional environmental authorities with relative ease.
- An extensive wetland database now exists for the NMBM.
  This data will be freely available on the SANBI national wetland database (http://bgis.sanbi.org/nwi/project.asp).
- The database includes information on where and what type of wetlands there are, and the associated attribute data which can be used to update landcover data, re-assess conservation and biodiversity priority areas and determine areas for potential rehabilitation projects.
- There is now site-specific data recorded, along with more detailed hydrological and ecosystem characteristics on a subset of sites as well as the species and species distribution, across a wide area of the municipality, on:
  - the aquatic and semi-aquatic vegetation with associated terrestrial vegetation;
  - phytoplankton and microphytobenthos; and,
  - aquatic invertebrates.
- Two IUCN species (*Crinum campanulatum* and *Streptocephalus dendyi*) have been recorded at their respective sites, which should be conserved.
- Along with endangered species, the presence and distribution of alien invasive invertebrate species has been documented for two snail species, *Cochilicella barabara*, and *Theba pisara*. This can aid in the documentation of spread of these species and help with control and management.
- Baseline data on wetland soils (properties and chemistry) and water chemistry has been recorded on a subset of wetlands. These data can then be used to further develop national monitoring tools for water and sediment quality, by providing more reference condition data.
- There is better understanding of systems and areas that are potentially threatened by existing and future anthropogenic activities
- The data can be used in the decision making process for developments (e.g. housing projects). Many of these wetland systems were not identified previously and are not easily identifiable during a dry climatic cycle. Any development that occurs on a wetland during this dry cycle would be at risk of flooding. This happened in many areas of PE during the floods in 2012. Subsequently, any development occurring during this time would benefit from having an extensive wetland layer.

**Ecological and anthropogenic threats to wetlands in NMB**

- Little evidence of direct use of wetland resources for harvesting, etc. with the exception of small-scale water extraction for agriculture and livestock on wetlands investigated, this may be more prevalent in urban and peri-urban wetlands;
- Litter (refuse, building rubble, etc.) was found at many sites, including at sites within conservation areas;
- Overgrazing from cattle was evident at many sites. This was visually observed in the soils (compaction), soil erosion and the destruction of vegetation. Overall land degradation had already occurred at many sites (for example, along the Swartkops River-sites RH1-4);
- Modification of wetlands for mining, storage of water, and the use of berms/barriers to build/maintain roads was evident in many areas;
- Fires (planned and accidental);
- Alien vegetation observed at several wetland sites. This includes both grass and tree species (such as *Acacia saligna*);
- The impact of flooding and droughts on the abiotic processes and the biotic community structure. Changes in catchment activities and surfaces also affect ability of wetlands to attenuate floods;

**Potential Conservation Priority Areas**

- Hopewell Conservation Estate: Site of IUCN red data species (*Crinum campanulatum*).
- Van Stadens Reserve and Parson's Vlei: Site of IUCN red data species (*Streptocephalus dendyi).*
- Theescombe: Increase protection of existing conservation site due to anthropogenic impacts.
- Grassridge: Large number of depressions situated along ridges of thicket/bonteveld associated with the underlying alluvial gravel. Vegetation is becoming increasingly degraded.
- Seaview seeps: Sites are unique due to the associated stromatolites that are situated below the systems. Seeps also within a coastal dune system and play an important role to the sediment dynamics and flow of water.
- Parson's Vlei: Many pristine wetlands that should remain conserved. Some alien vegetation removal of *A. saligna* needed.
- Redhouse: These systems need to be rehabilitated due to severe land degradation and pollution. These threats are related to overgrazing, litter and industrial activities on the edges of the floodplain.
- Bridgemead: Remove alien vegetation and prevent further ecosystem degradation (e.g. reduce number of access roads).

## CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Despite the new knowledge generated through this research, there are more questions generated than answers. This research project has provided for valuable baseline data, but more in-depth studies are necessary to fully understand ephemeral wetland ecosystem function as well as the interactions between landscape and local scale physical parameters. Interdisciplinary collaboration in wetland studies is vital to improving our understanding of such sensitive systems. Some questions for further research directions are outlined below. How these questions could link to management of wetlands and community relationships to the wetlands around them are included below:

- What are the drivers of the formation of depressions?
- What are the ecosystem services that small, ephemeral wetlands provide?
    - predominantly ecosystem functioning; or
    - direct services and goods;
    - what proportion of each?
- With an establishment of some regional specific water quality information, how does this fit with national guidelines and enhance current decision support systems?
    - There is a need for comparisons between known “reference conditions” and different gradients of anthropogenic disturbances in terms of water quality.
- In the face of global climate change, what is the effect of higher variability in rainfall periodicity and duration on the resilience and sustainability of ephemeral wetlands?
    - How would these changes modify ecosystem service provision?
    - Can the abiotic and biotic dynamics of ephemeral systems act as models for changes in both perennial and non-perennial wetlands under different climate scenarios?

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## ACRONYMS

| | |
|---|---|
| **AGIS** | Agricultural Geo-referenced Information System |
| **ANOVA** | Analysis of Variance |
| **ARC** | Agricultural Research Council |
| **ARC SCW** | Agricultural Research Council for Soil, Climate and Water |
| **CBA** | Critical Biodiversity Areas |
| **Chl *a*** | Chlorophyll *a* |
| **CS** | the Classification System by Ollis *et al.* (2013) revised from the NWCS (SANBI 2009) |
| **CSIR** | Council for Scientific and Industrial Research |
| **DAFF** | Department of Agriculture, Forestry and Fisheries |
| **dbRDA** | Distance based redundancy analysis |
| **DEA** | Department of Environmental Affairs (National Government) |
| **DEDEAT** | Department of Economic Development Environmental Affairs and Tourism (Provincial Government: Eastern Cape) |
| **DO** | Dissolved Oxygen measured in mg/L or % |
| **DWS** | Department of Water Affairs and Sanitation, also known as **DWAF** prior to 2009 and **DWA**, 2009-2014. |
| **EC** | Electrical Conductivity measured in µS/cm or mS/m |
| **ECS** | Electrical Conductivity measured in mg/L |
| **ET** | Evapotranspiration |
| **GCS** | Geographic Coordinate System |
| **GIS** | Geographic Information Systems |
| **GPS** | Global Positioning System |
| **H'** | Shannon diversity index |
| **HBH** | Hartebeesthoek (South African coordinate system) |
| **HCl** | Hydrochloric acid |
| **HGM** | Hydrogeomorphic |
| **IPCC** | International Panel on Climate Change |
| **J'** | Pielou's evenness index |
| **KZN** | KwaZulu-Natal |
| **LD** | Laser Diffraction |
| **MAP** | Mean annual precipitation |
| **MAR** | Mean annual runoff |
| **MDS** | Multi-Dimensional Scaling |

| | |
|---|---|
| **MOSS** | Metropolitan Open Space System |
| **MPB** | Microphytobenthos |
| **NFEPA** | National Freshwater Ecosystem Priority Areas |
| **$NH_4$** | Ammonium |
| **NMB** | Nelson Mandela Bay (the Study Area) |
| **NMBM** | Nelson Mandela Bay Municipality |
| **NMMU** | Nelson Mandela Metropolitan University |
| **$NO_2^-$** | Nitrite |
| **NRCS** | Natural Resources Conservation Service |
| **NWA** | National Water Act of South Africa (Act 38 of 1998) |
| **NWCS** | National Wetlands Classification System, now referred to as "The Classification System" by Ollis *et al.* (2013) |
| **OM** | Organic matter |
| **PE** | Port Elizabeth |
| **PSD** | Particle Size Distribution |
| **RH** | Relative Humidity |
| **S** | Species richness |
| **SANBI** | South African National Biodiversity Institute |
| **SA** | South Africa |
| **SANWA** | South African National Water Act |
| **SAWS** | South African Weather Service |
| **Si** | Silica |
| **SIMPER** | Similarity of Percentages |
| **SRP** | Soluble Reactive Phosphorus |
| **SSW** | Sub-surface Water |
| **SW** | Surface Water |
| **TDS** | Total Dissolved Solids measured in mg/L |
| **THU** | Total Heat Units |
| **TM** | Transverse Mercator |
| **TMG** | Table Mountain Group |
| **TN** | Total Nitrogen |
| **TOxN** | Total Oxidised Nitrogen |
| **TP** | Total Phosphorus |
| **TSS** | Total Suspended Solids measured in mg/L |
| **U.S. EPA** | United States Environmental Protection Agency |
| **USA** | United States of America |

| | |
|---|---|
| **VB** | Valley Bottom wetland |
| **VWC** | Volumetric Water Content |
| **WfWet** | Working for Wetlands Programme |
| **WGS** | World Geodetic System |
| **WHI** | Wetland Health and Importance (Research Programme) |
| **WMA** | Water Management Areas |
| **WRC** | Water Research Commission |
| **XrD** | X-ray Diffraction |

# 1 INTRODUCTION

## 1.1 Study Background

In recent years there has been a push in South Africa to better delineate, manage and conserve wetland systems within the country (Day and Malan 2009). South Africa is a semi-arid country, and as such, the sustainable use and conservation of our water resources is very important for humans, fauna, and flora (Davies and Day 1998). Perennial rivers and estuaries have received the bulk of the focus in terms of ecological, management and conservation research (Malan 2010) because of their noticeable role in the water supply chain to sustain human settlements and industry. Ephemeral (seasonally, intermittently and episodically inundated) fresh and brackish water systems have been less studied, perhaps because of their lack of perceived value for human exploitation (dams, irrigation, aesthetics and recreation) and, in many cases, their perceived cryptic nature when in a dry phase (Day *et al.* 2010). As a result these wetland systems have been disregarded, degraded and bulldozed for development (agricultural and urban) despite their protection under the South African National Water Act (Act 38 of 1998). After years of research neglect, wetland research has come to the fore since 2000 (e.g. Malan 2010).

In 2005, the Department of Water Affairs (now known as DWS) devised a wetland delineation guideline to identify outer edges of a wetland using four indicators: terrain, soil form, soil wetness and vegetation (DWAF 2005). Delineation of this nature is an intensive field process which requires trained practitioners and is more in-depth than a demarcation of where wetlands are within the landscape. DWAF (2005) illustrates the difficulties of intensive delineation and identification of wetlands in large, landscape scale detection and typing of wetlands within SA. Subsequently, this method falls outside of the scope of this study. The Given some of the limitations with wetland identification methods for coverage of broad areas, other methods have been developed relying more on landscape morphology and hydrogeomorphology (HGM) (Ewart-Smith *et al.* 2006; Dada *et al.* 2007; Ellery *et al.* 2009; SANBI 2009; Ollis *et al.* 2013). These methods allow for a desktop level of demarcation and classification/typing of wetlands on a larger scale, which is appropriate for this study.

Most of the current research effort has gone into developing tools to identify wetlands and manage them, with little funding available for fundamental research into their ecological functioning. In a presentation given to the RAMSAR Science and Technology workshop, Malan (2010) points to many challenges and knowledge gaps in South African wetland research. One of the main challenges noted was the lack of information on ephemeral wetlands, lack of funding for fundamental or “blue sky” research (Malan 2010). Of primary concern is our gap in knowledge of ecological processes in natural systems. This, in turn, effects our ability to make quantitative predictions on the effect of various impacts on wetland systems and their response to those impacts (direct anthropogenic and climate change) (Malan 2010).

## 1.2 Study Area

Nelson Mandela Bay Municipality (NMB) is approximately 1951 km$^2$ in size and is situated along the southern edge of the Eastern Cape Province of South Africa, bordering the Indian Ocean (Figure 1.1). Port Elizabeth (PE) is the major city associated with this Municipal area. PE falls in the transition zone between winter and summer maximum rainfall regions which are found on the west and east coast respectively, and experiences maximum rainfall in winter (Stone *et al.* 1998). Weather data from the South African Weather Service (SAWS) indicates that this region receives, on average, 613 mm of rainfall per annum. However, evapotranspiration rates are approximately 1 800 mm per annum, which indicates that evaporative losses far outweigh precipitation gains. This illustrates the need for appropriate water resource management (Ellery *et al.* 2009).

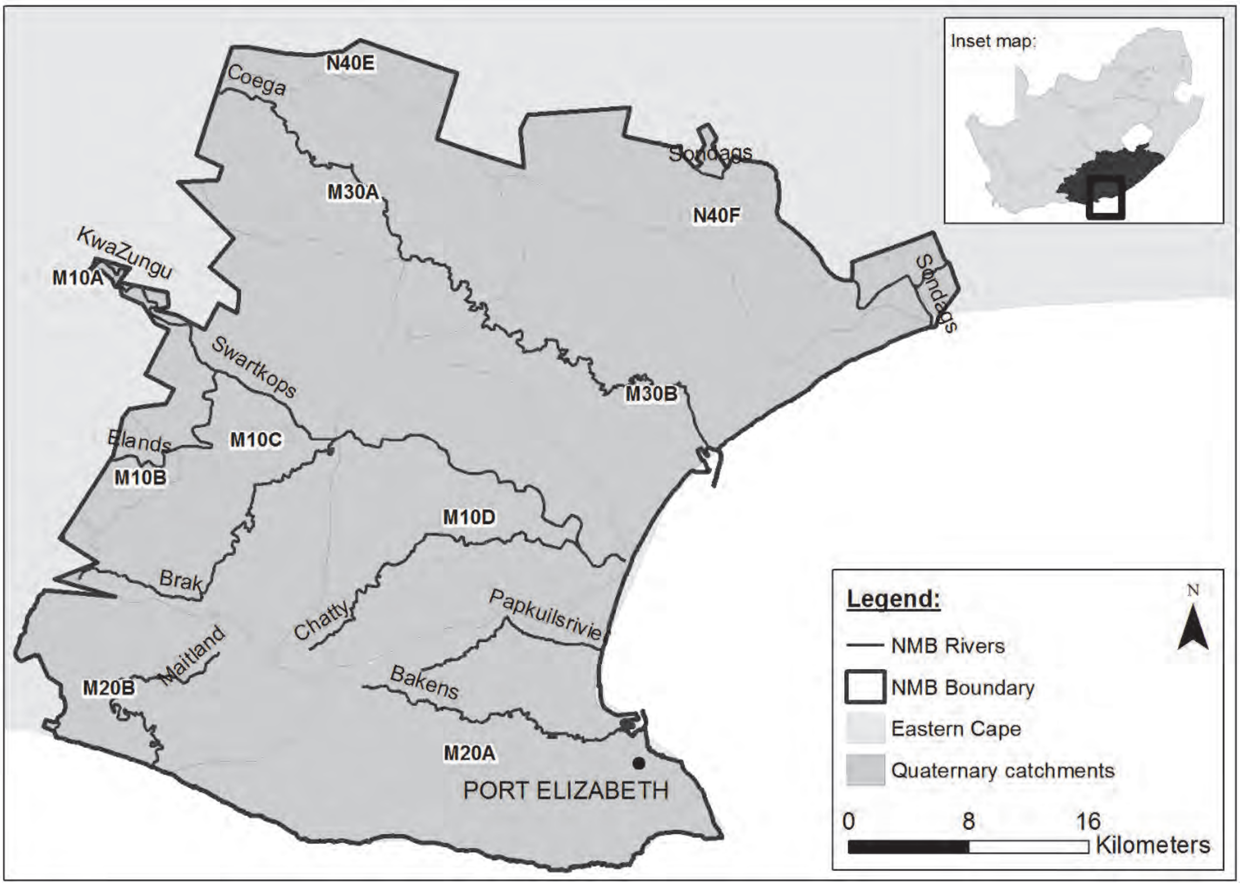


**Figure 1.1 Rivers and quaternary catchments that comprise the NMB, Eastern Cape.**

## 1.3 Project Aims

The backdrop of this aforementioned new research and management tools, as well as the paucity of data on ephemeral wetlands, was the impetus for this research. The overarching aim was to find out how many wetlands were in the Nelson Mandela Bay (NMB) Metropolitan area, what type and where they were located, and to collect basic ecological data on a subset of the dominant types of ephemeral wetlands.

The abbreviated project aims:

1. The application of the Classification System (CS) for wetlands (SANBI 2009; Ollis *et al.* 2013) to identify wetland types within the NMB area.
2. The demarcation and typing of ephemeral wetlands in terms of their geology, hydrogeomorphology, riparian and aquatic vegetation structure, in the NMB area.
3. To determine the biodiversity of algae, aquatic and semi-aquatic plants, and aquatic invertebrates for ephemeral wetlands in NMB.
4. To understand the interaction of biotic and biological processes in the structure of biotic communities in ephemeral wetland systems within the NMB area.
5. To determine if patterns in biodiversity are more closely related to wetland type or geographical location, and which factor or set of factors will be most likely to predict and describe ephemeral wetland functioning.

The original classification of National Wetland Classification System or NWCS (SANBI 2009) was updated through the SANBI publication of "*Classification System for Wetlands and other Aquatic Ecosystems in South Africa, User Manual: Inland Systems*" by Ollis *et al.* (2013). This more recent manual is also termed "the Classification System" (CS). This system of classification (typing) and nomenclature adopted for this research emanates from the CS. As this manual is one the dominant tools used to achieve the aims of this research, it should be assumed that the citation associated with the CS is Ollis *et al.* (2013), unless otherwise stated.

This research was not adopted to create new tools or redefine current terminology, but was designed to use available wetland research tools and strengthen the use and development of current terminology, all in the context of a region that has not yet had an extensive amount of research. We set out to demarcate (where), type (what kind) and enumerate (how many) the wetlands, in NMB. We then endeavoured to collect much needed baseline data on abiotic and biotic characteristics of a subset of ephemeral wetland types.

### 1.4 Problem Statement and General Approach

The bulk of the current research has been carried out in the Western Cape (WC) and KwaZulu-Natal (KZN), simply because current expertise is situated in those regions of the country. Research in other areas of the country has followed slowly, and there needs to be testing of the newly developed CS in areas outside the more predictable winter rainfall region (WC) and summer rainfall region (KZN), where in "normal" years ephemeral wetlands will be inundated during those wet seasons. In regions such as the Northern Cape, Free State and most areas of the Eastern Cape, rainfall is much less predictable on a seasonal or annual basis. The NMB municipality was selected to test the CS because of its wide range of rainfall, geological, geographic and vegetation types within a relatively small area of 1 954 $km^2$ (Stewart 2009). At the same time the region is experiencing an increase of urban and industrial growth (Stewart 2009), which threatens the existence of many ephemeral wetlands, especially those that are considered cryptic and difficult to define for non-practitioners and managers. Wetland systems are under threat, and many have already been lost to development. This loss has occurred before they can be demarcated, typed, classified or their biodiversity and ecological functioning determined. The diversity of vegetation types in the NMB area is already known and considered an ecological "hot spot" where five floristic biomes (Fynbos, Subtropical Thicket, Nama Karoo, Forest and Grassland) intersect (Stewart 2009). In order to protect, conserve and ensure sustainable use of the NMB wetlands, fundamental research is needed. The effect of aquatic and terrestrial invasive fauna and flora on these sensitive systems is unknown. As stated above, this research was designed to begin to address our knowledge gaps in NMB ephemeral wetlands in terms of where they are, the biota they contain and how they function ecologically.

The combination of broad-scale desktop analyses and fine-scale site level field and laboratory data gives new understanding of the types of wetlands in this region. This includes their vegetation and aquatic invertebrate communities, the associated biodiversity, and interactions between physical structure and chemical processes. Driving forces behind the structure and function of ephemeral wetlands in a semi-arid environment need to be established. Wetland systems are fundamentally linked to various landscape processes. Therefore, wetland research also should be conducted across different spatial and temporal scales, taking into account various wetland indicators and the different aspects of the surrounding ecosystems. This forms the foundation of this study in NMB.

Much needed data about the wetlands of this region will also aid in conservation planning, in particular that of the Nelson Mandela Bay Municipality (NMB), which would help protect vulnerable and rare wetland ecosystems and assist in the management of development within the municipal boundaries. This project will also provide spatial data which will be included in the SANBI National Wetland Inventory.

Through this research program we not only tested existing tools used in wetland research, but have also added new and critical baseline information on the functioning of these systems. With this baseline data, we will be able to assist in the prioritisation of wetlands in the NMB for conservation, protection and rehabilitation. This work will help gain insight and improve our understanding in relation to mitigating the challenges associated with climate change and important ecological drivers responsible for system alterations.

# 2 EPHEMERAL WETLAND AND CLASSIFICATION FRAMEWORK

The basis of this study is outlined in the previous chapter, with the project aims. A key component of this research is the use of the most recent classification system for wetlands by Ollis *et al.* (2013). A full description of how this classification structure was applied in this research is described in the following chapter (Chapter 3). Accordingly, the context of how and why this type of classification system was formed is firstly needed. This is outlined below (Section 2.1). As NMB is dominated by ephemeral systems, the need for a holistic approach to wetland research is also highlighted in this chapter. Ephemeral in the context of this research includes wetlands that are seasonally, intermittently or episodically inundated. This included the rare inundation periods of over a year during extremely wet climatic cycles. In contrast, other systems may be dry for extended periods of time, even years, during drought periods. It must be noted that “seasonally inundated” in the context of the NMB region is a loose term that encapsulates wetlands with a connection to the groundwater table sufficiently close enough to sustain the wetland for a period longer than 3 months after a series of good rains, such as we had in 2011 and 2012. The climatic patterns in NMB are such that there is not a true “seasonal” pattern such as occurs in the Western Cape (winter) and KwaZulu-Natal (summer), for example. The brief review of literature below forms the framework of the approach undertaken in this research.

## 2.1 Defining Wetlands in a South African Context

Attention to wetlands, particularly small, ephemeral wetlands has not been nearly as great as in fluvial systems, until recently (Day *et al.* 2010). In part, this is because wetlands have proven to be systems that are difficult to define and classify, as they tend to be a transition between terrestrial systems and more aquatic systems (such as rivers and lakes). Wetlands have been both defined and classified differently in the many regions across the globe (Mitsch and Grosselink 2000). Since the Ramsar Convention (Matthews 2013), there has been a more concerted effort to define and classify wetlands with a global standard. The Ramsar Convention defines wetlands as “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” (Ramsar Convention Secretariat 2006).

In South Africa, there have been several different definitions in use (see: National Water Act 1998; Department of Water Affairs 2005; SANBI 2009). The current accepted definition for wetlands in South Africa, and for the proposed research, is from the National Water Act (Act No. 36 of 1998) which defines wetlands as “land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil”. This definition was used in identifying wetlands in NMB.

The need for a more uniform classification (typing) system for defining different wetland types in South Africa was described by Ewart-Smith *et al.* (2006), as many of the previous classification systems were region specific and/or outdated, and not refined for the South African context. The CS takes into account these various publications (see: Ewart-Smith *et al.* 2006; Ellery *et al.* 2009; SANBI 2009). This system consists of six levels that are applied in a hierarchical manner to differentiate between the various wetland types from broad to fine scale. A full explanation of this classification system is explained in Chapter 3.

### 2.2 Characteristics of Ephemeral Wetlands

Wetlands are areas in a landscape that receive inundation or soil saturation at a duration and frequency that excludes many organisms that are not tolerant of flooding or saturation (Brinson and Malvárez 2002). Differences in inundation duration distinguish between permanent and ephemeral wetlands on a hydrological basis, and this the primary difference. Variability in inundation periodicity brings about distinctive response of abiotic and biotic features, especially on a fine or local scale level (Brinson & Malvárez 2002; Mitsch *et al.* 2009). Ephemeral wetlands illustrate varied characteristics, some of which can be seen in both permanent and ephemeral systems, but are more often seen in the latter. These systems are often more shallow (less than two metres in depth at full inundation), oval to amorphous in shape, have diameters between one metre and tens of kilometres, and have rocky or soft sediment as substrata. These biotic features give rise specialised community structures that are adapted to wet and dry periods, such as a wide variety of facultative (usually grow in wetlands but occasionally occur in terrestrial areas) and obligate (grow in wetlands, but can withstand periods of drying in the seed bank or as bulbs) wetland plants and aquatic animals (Leibowitz 2003; Leibowitz and Nadeau 2003; Meyer *et al.* 2007; Macfarlane *et al.* 2009; Day *et al.* 2010). Consequently, ephemeral systems often include endemic species, and as a result, potentially have a relatively high biodiversity compared to other systems (Leibowitz 2003; Kotze *et al.* 2009a; Keddy 2010).

Abiotic factors can provide further information on the presence and type of ephemeral wetland, including: water levels, soil characteristics (e.g. soil wetness and colour), topography, the presence of shallow clay, surface organic matter (detritus), water marks on rocks or trees, and the presence of shells or the remains of aquatic invertebrates (Machtinger 2007; Ellery *et al.* 2009; Day *et al.* 2010). A combination of these (as well as other) indicators is needed to assess, with some confidence, that wetland conditions are present, and to understand the structure and functioning of the ecosystem (Day *et al.* 2010). Consequently, the absence of a particular indicator does not mean that a wetland is not present (Day *et al.* 2010).

Some ephemeral wetlands support fauna and flora that are not observed outside periods of inundation, these wetlands are known as 'cryptic' (Day *et al.* 2010). Cryptic wetlands are wetlands that are difficult to identify reliably when they are not inundated (during dry periods) using standard wetland identification and delineation tools (Day *et al.* 2010). These systems are of particular interest to this study as these systems are vastly under-researched in the region. In these type of systems, one cannot solely rely on soils (as sometime mottles are absent) and vegetation (sometimes will be less than 50% cover as per the DWAF (2005) delineation guidelines) to classify wetlands, but require the identification of a number of abiotic and biotic characteristic features in concert with one another (Job 2009; Day *et al.* 2010), which the current classification system uses. Large scale and primary classification of a wetland usually takes into account abiotic factors, with more detailed (fieldwork based) classification also taking into account biotic factors (Ewart-Smith *et al.* 2006).

### 2.3 Holistic Approach to Wetland Studies

Wetlands are shaped by interactions between climatic, geological, biological, chemical and anthropogenic factors (Machtinger 2007). It is therefore important to examine a wetland in a holistic manner, beginning with its abiotic structure and processes to the abiotic functioning and processes. A key driving factor is the hydroperiod, i.e. the seasonal pattern of water level fluctuations in a wetland (Ellery *et al.* 2009). Wetlands from diverse geomorphic settings have different dominant sources of water (such as rainfall, surface or groundwater) and hydroperiods (Brinson and Malvárez 2002; Machtinger 2007; Tooth and McCarthy 2007), and as a result, differing flora and faunal communities that inhabit the wetland (Brinson and Malvárez 2002; Mitsch *et al.* 2009). Thus, the definition of a particular type of wetland should adequately explain these underlying factors that predominantly influence the form/shape and possibly the function of the wetland.

In a southern African context, wetlands are considered ‘temporary’ or ‘ephemeral’ when the substrate is inundated from a few days or once every few years, with subsequent dry periods (Ellery *et al.* 2009; Day *et al.* 2010). Ephemeral wetlands usually occur in areas where annual rainfall is less than annual evaporation rates, and consequently, periodically dry up (Tooth and McCarthy 2007; Ellery *et al.* 2009; Day *et al.* 2010). NMB falls within one of these climates where evaporation rates exceed rainfall on an annual basis, which has resulted in the formation of many small, ephemeral wetlands in the region.

Not all indicators maybe evident in an ephemeral wetland system. Although the presence of one indicator could suggest a wetland, observing and recording all of the indicators present is a much more robust approach to identification (DWAF 2005). Tiner (1993b) indicates that although it is accepted that hydrology is the main driving force behind wetland form and function, it has its limitations as a reliable indicator of a wetland because it is not always present. The hydrological regime influence soils and vegetation, both of which provide a much better indication of the true edge of a wetland and are more easily observed and more consistent on a longer temporal scale (Tiner 1993a; Tiner 1993b; DWAF 2005). Another indicator is to identify what part of a landscape a wetland is most likely to occur (known as ‘landscape setting’) (DWAF 2005; Day *et al.* 2010; Ollis *et al.* 2013). In accordance with these current wetland identification tools, hydrology, soils, vegetation and landscape setting will be used to demarcate and classify a wetland in this research.

Wetland indicators change according to the length of time a wetland is saturated/inundated, which is needed to further understand a wetland’s function within a particular landscape. Ephemeral wetlands, may or may not exhibit some of these indicators. For example, sandy soils tend to drain quickly, and therefore distinguishing soil colours or mottles may be absent (Day *et al.* 2010). Accordingly, during the dry season or extended periods of drought, many wetlands will dry up and may not be easily identified due to the lack of water and sometimes wetland vegetation (Day *et al.* 2010). Thus, a number of abiotic and biotic features need to be included to more accurately identify a wetland system.

Wetland systems often exhibit different vegetation, soil saturation and hydrological zones (Lewis 1995; DWAF 2005). During periods of inundation, the hydrological zonation in ephemeral systems is similar to that of permanent systems: an inner pool of open water containing aquatic plants (zone of permanent saturation), emergent vegetation zone, the temporal zone and the terrestrial zone. These zones exist along a gradient, and are strongly associated with hydroperiod where the aquatic zone is the wettest for the longest period of time. The longevity of these zones in ephemeral systems is what differentiates them from permanent systems. Essentially, the zones in ephemeral systems are in constant flux commensurate with the hydrological periodicity; the more rain or contact with groundwater the longer each zone will occur for the establishment of different floral and faunal communities. Most ephemeral systems will have intermediate and transitional zones as dominant features.

Faunal species play an important in identifying wetland and function. Faunal groups found in wetland ecosystems include: insects, amphibians, birds, and sometimes fish in the more permanent systems (Semlitsch and Bodie 1998; Cowan 1999; Bird 2010). These animals consist of both aquatic and terrestrial species which utilise wetlands as feeding, breeding and nursery grounds, inhabiting these systems on a temporary or permanent basis (Semlitsch and Bodie 1998; Cowan 1999).

Wetland fauna in ephemeral systems tend to be dominated by large brachiopod crustaceans and insects and can be diverse during periods of inundation (Day *et al.* 2010). Large branchiopods (Anostraca, Conchostraca and Notostraca) are features of ephemeral systems but are not very specious. Cladocera and other invertebrate groups can also act as indicators, albeit in a less direct manner, during dry periods (De Roeck *et al.* 2007). These taxa have evolved a life-history strategy to cope with dynamic variability of ephemeral wetlands and many are found almost exclusively in ephemeral systems (Williams 1998; Day *et al.* 2010; Bird 2010; Ferreira *et al.* 2012). They produce “resting eggs” that settle in the sediments of wetlands and wait for the next inundation (Williams 1998; Ferreira *et al.* 2012; Henri 2013). The presence of these invertebrate species can help determine whether the area sampled is a wetland during the dry season through laboratory sediment analysis and hatching experiments (Williams 1998; Rayner 2001; De Roeck *et al.* 2007; Day *et al.* 2010). These invertebrates are also indicators of ephemeral systems when inundated wetlands are sampled (Williams 1998; Bird 2010; Day *et al.* 2010; Ferreira *et al.* 2012). Other wetland faunal species (such as flying insects) will migrate to the wetland during the wet season (Day *et al.* 2010).

Like some of the invertebrate taxa, algae and wetland plants also deposit cysts and seeds, respectively, into the sediment. These cysts and seeds are resistant to most environmental pressures. To confirm a wetlands existence in the absence of most other indicators, sediment cores can be collected and returned to the lab for germination of algae and plants, and hatching of invertebrates (Brendonck & De Meester 2003; De Roeck *et al.* 2007; Day *et al.* 2010; Ferreira *et al.* 2012; Henri 2013). The nature of these taxa may lend themselves to determining wetland health, function and resilience to anthropogenic perturbations (Ferreira *et al.* 2012; Henri 2013).

## 2.4 Wetland Connectivity and Biodiversity

After classifying and demarcating wetlands in terms of their form and composition, wetlands can also be placed within a broader context in terms of their connectivity to other wetland systems. Isolated wetlands are where there appears to be a lack of surface water connection to other water bodies (Leibowitz 2003). Isolation can refer to ecological, geographical or hydrological perspectives, the latter being the most common (Leibowitz and Nadeau 2003). Although there is no one accepted scientific definition for an isolated wetland, these systems do appear to have some interactions with other water sources, whether it be temporary (during flooding) or through sub-surface/groundwater flows (Leibowitz 2003; Meyer *et al.* 2007). These connections can be biotic in nature through the movement/dispersal of plants and animals, or can happen intermittently when there are surface water connections between the water bodies (Leibowitz 2003; Leibowitz and Nadeau 2003). The degree of isolation, as well as the distance between the water bodies, affect species dispersal and therefore species richness (linked to the migration of species), as well as overall community composition (Semlitsch 2000; Leibowitz 2003; Leibowitz and Nadeau 2003).

Habitat characteristics of isolated wetlands are also affected by hydrology (Leibowitz 2003). As a result of the general lack of surface water flow, most of these wetlands are categorised as depressions (Leibowitz 2003). Spatial and temporal variation in moisture conditions associated with isolated/depression wetlands result in increased habitat variation and thus leads to an increase in species richness (Semlitsch 2000; Leibowitz 2003; Leibowitz and Nadeau 2003).

Contrastingly, it has been observed that many ephemeral wetlands occur in complexes (also known as mosaics or clusters) (Gibbs 1993; Cook and Hauer 2007; Martin *et al.* 2012). These complexes are groups of wetlands that occur in close proximity to one another (Martin *et al.* 2012), and provide biological connections within a landscape (Angeler and Alvarez-Cobelas 2005; Cook and Hauer 2007). This has been well noted in the USA and Europe (Semlitsch and Bodie 1998; Semlitsch 2000; Amezaga *et al.* 2002; Martin *et al.* 2012).

Wetlands are generally associated with high biodiversity, but this is not always the case. However, in order for existing biodiversity to be maintained, various fauna and flora species need to disperse which requires a complex of wetlands within a landscape (Semlitsch and Bodie 1998; Semlitsch 2000). This is described by Semlitsch (2000) as ‘source-sink dynamics’ where one wetland acts as a source that produces a surplus of individuals and another wetland acts as a sink when the population of a species within the wetland dies out. Thus, broad-scale mapping/demarcation is important in order to assess the spatial and temporal associations between these wetland complexes as well as to determine how they are linked to landscape processes.

## 2.5 Wetland Functioning, Health and Management

To accurately assess and manage wetlands, it is important to understand the environmental processes that occur at a larger landscape scale, the relationship between these processes, and the functions of wetlands and other aquatic resources (Semlitsch 2000; Leibowitz 2003; Leibowitz and Nadeau 2003; Granger *et al.* 2005). The landscape plays a critical role in wetland formation, maintenance and function (Leibowitz and Nadeau 2003; Cook and Hauer 2007). This includes the effect of landscape processes on wetland connectivity at both local and catchment scales. Some of the landscape processes associated with wetland functioning include: the movement of water, sediment, nutrients and energy, the dispersal of floral species, and the movement and habitat use of various faunal species (Leibowitz and Nadeau 2003; Granger *et al.* 2005).

Once wetland type, or hydromorphological structure has been defined, it is important to establish how its hydromorphology impacts the functioning of an individual wetland and/or wetland system, and how this function plays a role in the surrounding ecosystem. Wetland function can be described as the interaction/link between the various wetland structures and physical, chemical and biological processes (Smith *et al.* 1995; Barbier *et al.* 1997; Maltby and Acreman 2011). The aspects of these systems that are perceived to be of value to society are considered wetlands values (Brinson 1993; Smith *et al.* 1995; Mitsch and Gosselink 2000; Maltby and Acreman 2011; Horwitz *et al.* 2012). Better understanding on both wetland functions and values is needed.

In semi-arid climates such as South Africa, wetlands are an important source of water and nutrients (Turner *et al.* 2000; Schuijt 2002; Schuyt 2005). In general, wetlands provide a number of resources for the environment including water, land, soil, fauna and flora, all of which provide different goods and services for the surrounding ecosystem and anthropogenic activities (Mitsch and Gosselink 2000; Schuyt 2005; Kotze *et al.* 2009b; Maltby and Acreman 2011). Wetland functions can be broadly divided into biological, pedological and hydrological, which are closely related to the value of wetlands. The important role that wetlands play in an ecosystem and the ecosystem services they provide, has been discussed and reviewed by many authors (such as: Semlitsch and Bodie 1998; Keddy 2000; Leibowitz 2003; Leibowitz and Nadeau 2003; DWAF 2005; Machtinger 2007; Meyer *et al.* 2007; Kotze *et al.* 2009a; Kotze *et al.* 2009b; Mitsch *et al.* 2009; Horwitz *et al.* 2012).

Many of the world's ecosystems are under threat from anthropogenic activities and climate change, which has placed increasing pressure on ecosystems to cope with these stressors as well as continue to perform various functions and services (Hollis 1990; Rapport *et al.* 1998; Millennium Ecosystem Assessment 2005). Subsequently, many ecosystems have become degraded and have lost some, most, or all of their functioning (Millennium Ecosystem Assessment 2005; Benayas *et al.* 2009

Wetland health is intrinsically linked to wetland functioning as a wetland in good 'health' will deliver its functions (ecosystem services) well, whereas a wetland in poor health/severely modified loses its ability to perform certain functions, thereby devaluing the associated ecosystem services (Hollis 1990; Macfarlane *et al.* 2009). The assessment process detailed for South African wetland systems involves evaluating ecosystem health in terms of hydrology, geomorphology and vegetation, is outlined by Macfarlane *et al.* (2009) in WET-Health (part of the WRC Wetland Management Series).

To conserve and protect these smaller, more ephemeral systems, input and agreement is required from socio-economic, political and environmental stakeholders at various spatial scales (Turner *et al.* 2000; Schuyt 2005). Thus, wetland resources need to be sustainably used to ensure that future generations will have access to the goods and services supplied to the wetlands, before their functioning is irreversibly impacted on (van der Duim and Henkens 2007). However, in order understand and mitigate these anthropogenic impacts, wetland systems and their complexity at various spatial and temporal scales, need to be more adequately understood.

### 2.6 Climate Change

Climate change refers to statistically quantifiable changes in the climate that persist for an extended period, and refers to both naturally and human induced changes (IPCC 2007). In South Africa, climate change is predicted to result in decreasing rainfall and more extreme rainfall patterns such as prolonged droughts and intense floods (Desanker and Justice 2001; Meadows 2006; IPCC 2007; Mitchell 2013). The amount and type of rainfall affects surface hydrology, thereby affecting the amount of surface flow and groundwater flow into wetlands (Erwin 2009; Junk *et al.* 2013; Mitchell 2013). This could place strain on wetland ecosystems, especially ephemeral systems, where the timing of the hydrologic regime affects other abiotic and biotic components of the wetland system and reduces wetland connectivity (Erwin 2009; Johnson *et al.* 2010; Junk *et al.* 2013). The increase of extreme weather events can put wetland systems under increased stress and possibly reduce their tolerance for previously sustainable levels of human activity (Smit and Pilifosova 2001; Erwin 2009; Junk *et al.* 2013).

All of these changes are expected to impact smaller wetland systems to a greater extent compared to larger systems that connect to rivers or larger catchments that are thought to be less resilient (Johnson *et al.* 2010; Junk *et al.* 2013; Semlitsch 2000; Meyer *et al.* 2007; Blackwell and Pilgrim 2011). These impacts of climate change on wetland function further illustrate the need to understand and research local water resources, including ephemeral wetland systems. This enables efficient and relevant adaption and mitigation techniques to be applied where these systems have been and will be compromised in the future as the stress on these systems continues to increase.

### 2.7 Summary

In conclusion, the first step is to know where the wetlands are (identify and demarcate). The second step is to find out what they are (classify or type), and lastly understand how they function. It is from establishing this basic understanding that other more complex ecological and management questions can be addressed, such as: what are the ecosystem services each type can provide?  What would be lost in terms of that provision if the wetland is lost? And how best can we manage and mitigate wetland alteration and/or destruction?

We cannot manage what we do not know is there and what we do not understand.  This project, at its heart, has begun the process having located, identified, and classified wetlands within the NMB.  It has given baseline data of the wetland flora and fauna of the area and has begun to address fundamental ecosystem functioning and processes of these little studied and understood systems.  The following chapters describe, the processes undertaken and results obtained to meet the aims of this project.

# 3 APPROACH AND METHODS

In order to address the research aims, a multi-disciplinary and multi-scale approach was taken, from landscape to fine habitat scales. A range of desktop, field and laboratory methods were used to address each aim at a scalar level, and reported in the following sections. Ephemeral wetland types were ground-truthed to confirm, modify and add information to the maps and give added detail to the classification of selected sites. A subset of field sites were then chosen across the NMB area to represent the range of rainfall and terrestrial vegetation areas across the metro and spatial distribution of wetlands. A group of 46 sites (described in Sections 3.3-3.4 below) were sampled once each between 2012 and 2013. Of those 46 sites, 6 sites were chosen to return to for monitoring at either weekly, monthly or quarterly intervals (described in sections 3.3-3.5 below) to investigate changes in abiotic variables and biotic communities with changes in inundation level.

## 3.1 Desktop Application of the Classification System: Levels 1-4

The hierarchical CS levels, as described in Ollis *et al.* (2013), were used in the first phase of this research. The first four levels of the hierarchy are considered primary descriptors and were determined using desktop methods (Table 3.1). All wetlands considered in this project are part of the inland wetland systems, therefore estuary and marine systems were not included. We also excluded rivers, as these systems have been well demarcated. The DWAF Level 1 Ecoregions were used for Level 2 of the CS for inland systems. For NMB, the Ecoregion is the South Eastern Coastal Belt. Levels 3 and 4 were determined from available map data as described below, in Section 3.1.1. The landscape setting (Level 3) for inland systems can be described with four basic units based on topographical position (Table 3.2). Each of the landscape units determined in Level 3 can then be further classified within Level 4a of the CS by seven primary hydrogeomorphic (HGM) types or units (Table 3.2). The base of Level 4 or 4a was determined using desktop methods, but additional site level information was gathered where possible, as prescribed in the CS document. Although the degree of “naturalness” is assigned to Level 6 of the CS, a certain amount of broad-scale determination can be made on a desktop level, based on surrounding land use and morphology seen on high resolution aerial photos. This was done on a preliminary level for the wetlands delineated in NMB.

### 3.1.1 Source data

In order to locate, delineate and classify wetlands to Level 4a of the CS, a variety of data sources were used. The available maps, primary and secondary data sources for the NMB region are listed in Table 3.3, along with relevant details used in capturing the data. A complete list of all secondary data obtained and used in this project is outlined in Appendix A (Table A.1).

**Table 3.1 Basic structure of the Classification System (modified from Ollis *et al.* 2013).**

| Hierarchy Level | | Descriptor |
|---|---|---|
| Level I | System | Connectivity to open ocean |
| Level 2 | Regional setting, ecoregion | Physiographic and biogeographic features |
| Level 3 | Subsystem/Landscape Unit | Periodicity of connection to ocean (Estuarine)<br>**Landscape setting (Inland)** |
| Level 4 | Hydrogeomorphic Unit (HGM) | Landform and hydrology/hydrodynamics |
| Level 5 | Tidal/Hydrological Regime | Tidal regime (Marine/Estuarine)<br>Perennially (Inland: Channels)<br>**Inundation and saturation periodicity, inundation depth-class (Inland: non-channels)** |
| Level 6 | Wetland Characteristics | Geology, naturalness, vegetation cover (form and status), substratum type, salinity/conductivity, acidity/alkalinity (pH) |

### 3.1.2 Digitising and GIS

ArcGIS 10.2.2 for Desktop, with various extensions, was used for the spatial analysis. A simple map of the study area with the relevant quaternary catchments is illustrated Figure 3.1. Wetlands within the NMB were digitised using aerial photos obtained from the Municipality as well as existing shape files from the national SANBI wetlands database. Rivers and two metre contours were overlaid on the map as guidelines for identifying wetlands (Table 3.3). A new polygon shape file was created in order to digitise the wetlands observed when scanning through the study area (NMB). This was carried out at a scale of 1: 2500. A wetland was digitised if water was present or vegetation/contour indicators were present. Wetlands were then digitised at a scale of 1: 2000. Several attributes were also assigned to the shape files (Table 3.5) using other existing spatial datasets. Information from the attribute data was used to determine the types and numbers of each type of wetland located within NMB with the information available.

Fluvial geomorphological processes in wetlands are an important when examining how different wetland HGMs function and how they are connected to the landscape. Not all HGMs have this connection, however, but the proportions of those that possibly do were determined for this study. River datasets were used to determine the potential connectivity of wetlands to fluvial processes. This analysis was focused on seeps as they tend to form on slopes. The thought behind focusing on seeps (for this study) is that these slopes are then part of an associated catchment (at a fine scale), which potentially connect to nearby fluvial systems. To determine how well these seeps are connected to fluvial systems the following analysis was performed using GIS. Topographical river data as well as other riverine spatial data available were merged to form a single dataset. Where only linear datasets were available a buffer of 100 m was created in order to create a riverine "channel" (i.e. to include some of the connecting slopes). The "Near" function was used in the Analysis tools in

ArcGIS to determine the shortest path on a spheroid (geodesic) to a riverine feature. HGMs (particularly seeps) within 10 m were considered to have a high chance of being connected to fluvial processes.

**Table 3.2 Summary descriptions of Level 3 and Level 4a units within the Classification System as used in this research (modified from Ollis *et al.* 2013).**

| Level 3: Landscape Unit | Level 4: HGM Unit |
|---|---|
| **Bench** – an area mostly level or nearly level high ground including hilltops, saddles and shelves, considered to be those high-lying areas with a gradient of < 0.001 or 1:1000 in a higher altitude setting representing a break in slope with an up-slope on one side and down-slope on the other. Areas are generally smaller than plains ( < 50 ha) | **Channelled valley-bottom** – mostly flat valley bottom dissected by and typically elevated above a channel, characterised by bidirectional horizontal flow, with limited vertical fluctuations in depression areas. |
| **Plain** – an extensive area of low relief characterised by relatively level, gently undulating or uniformly sloping land, considered to be those relatively flat areas not located between two side-slopes that have a gradient < 0.01 or 1:100. | **Unchannelled valley-bottom** – mostly flat valley-bottom area without a major channel running through it, characterised by an absence of distinct channel banks and diffuse flows. Horizontal, unidirectional diffuse surface-flow tends to dominate. |
| **Slope** – an inclined stretch of ground that is not part of a valley floor, considered to be those areas where the gradient is ≥ 0.01, or 1:100 | **Wetland Flat** – a near-level area with little or no relief or gradient, situated on a plain or a bench in terms of landscape setting. Primary water source is precipitation, with the exception of coastal flat where groundwater may rise to surface or near surface. |
| **Valley floor** – typically gently sloping, lowest surface of a valley, gradient typically between 0.01 and 0.1, or 1:100 to 1:10 | **Floodplain** – mostly flat or gently sloping area adjacent to and formed by a lowland or upland floodplain river and subject to periodic inundation by overtopping of the channel bank. |
| | **Seep** – an area located on sloping (gentle to steep) land that is dominated by the colluvial, unidirectional movement of material down-slope. Seeps are often located on the side-slopes of a valley but they do not, typically, extend onto a valley floor. Water inputs are primarily via subsurface flows from an up-slope direction. |
| | **Depression** – an area with closed (or near-closed) elevation contours, which increases in depth from the perimeter to a central area of greatest depth, and within which water typically accumulates. Dominant water sources are precipitation, groundwater discharge, interflow and (diffuse or concentrated) overland flow. Dominant hydrodynamics are (primarily seasonal) vertical fluctuations. |

**Table 3.3 Data sources used to digitise wetlands in NMB.**

| Spatial data file name | File type | Datum/Projection | Scale | Source of data |
|---|---|---|---|---|
| Aerial photos 2009 | TIFF raster data | WGS 84 | 1 m resolution | NMB 2012 |
| Spot 5 images 2010 | JP2 raster data | WGS 84 | 2 m resolution | Fundisa CSIR 2010 |
| NMB boundary, Roads, 2 m contours | Line vector data | Hartebeesthoek 94, Transverse Mercator 25 | - | NMB 2012 |
| Rivers | Line vector data | Hartebeesthoek 94 | 1: 50 000 | NMB 2012 |
| NMB vegetation/biomes | Polygon vector data | Hartebeesthoek 94, Transverse Mercator 25 | 1: 10 000 | Stewart 2009 |
| Quaternary Catchments | Polygon vector data | Hartebeesthoek 94 | Not defined | WRC 1990 |
| Vegetation biomes | Polygon vector data | Hartebeesthoek 94 | 1:250 000 | Mucina & Rutherford 2006 (spatial data obtained from SANBI BGIS 2007) |
| SANBI NFEPA wetlands | Polygon vector data | WGS 84 | 30 m | SANBI BGIS 2011 |
| Eastern Cape Geology | Polygon vector data | GCS Cape | Not defined | Council for Geosciences |
| Gensoils | Polygon vector data | GCS WGS 1984 | 1:250 000 | Agricultural Research Institute for Soil, Climate and Water (2004) |

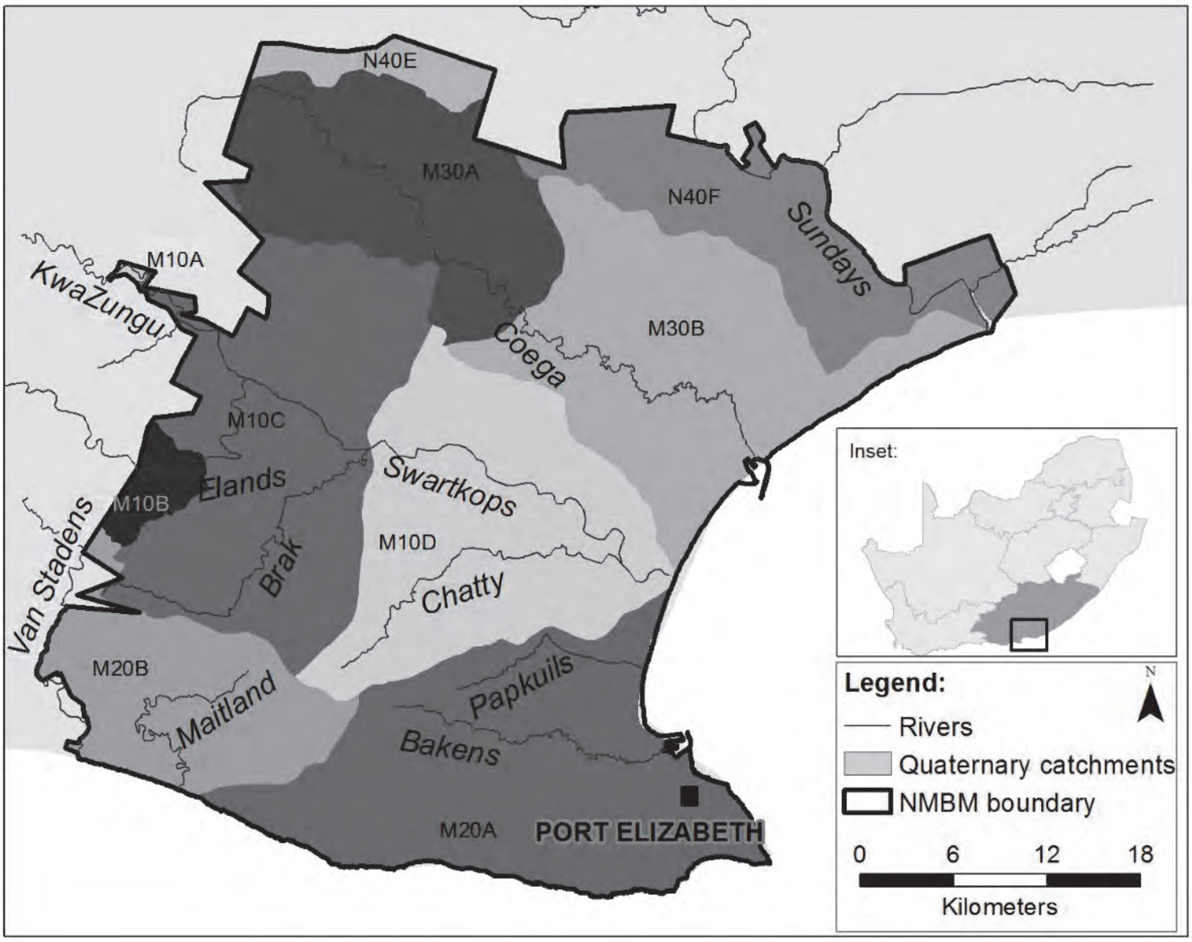


**Figure 3.1 The NMB study site with quaternary catchments and major rivers within the municipal boundary displayed.**

**Table 3.4 Attribute description for the NMB wetlands vector layer.**

| Attribute | Description |
|---|---|
| **Certainty** | A level of certainty of the presence of a wetland was assigned:<br>"1" indicated a possible wetland (contours and/or vegetation indicated the possible presence of one) CS = Low;<br>"2" if there were strong vegetation and contour indicators of a wetland, CS = Medium; or<br>"3" if there was the presence of water as well as vegetation and contour indicators, CS = High. |
| **NAT_ART** | Three levels of modification were assigned:<br>"Natural" if the wetland illustrated no signs of man-made structures<br>"Modified" if the wetland illustrated some signs of man-made structures (e.g. a berm), however, there is a high possibly that wetlands in this category were existing before; or<br>"Artificial" for wetlands that are highly modified (e.g. dams) such that it is not possible to determine whether these wetlands existed before man-made structures were implemented. |
| **NWCS L3** | Level 3 (Landscape Unit) of the CS was determined as follows:<br>"Slope";<br>"Valley floor";<br>"Plain"; or<br>"Bench" |
| **NWCS L4** | Level 4 (HGM Unit) of the CS was determined as follows:<br>"Seep";<br>"Depression";<br>"Wetland Flat";<br>"Unchannelled valley bottom wetland";<br>"Channelled valley bottom wetland"; or<br>"Floodplain wetland" |
| **SANBI_db** | This field was used to indicate whether the wetland was identified in the SANBI database. The following codes were used:<br>"Y" for an identified SANBI wetland; or<br>"N" if the wetland was not digitised previously. |
| **RIV_EST** | This field was used to indicate if the wetland is situated alongside a river or estuary. |
| **Comments** | Any further comments on the wetland |
| **Perimeter** | Perimeter of the wetland |
| **Area** | Area of the wetland in square metres |
| **Hectares** | Are of wetland in hectares |
| **X** | X coordinate of the centre of the polygon |
| **Y** | Y coordinate of the centre of the polygon |

## 3.2 Field Classification: Levels 4-6

Field verification of the classification at Levels 3 and 4a, as well as assessment of region for site selection for Levels 4b-6 was done as per methods outlined in Ollis *et al.* (2013). Site level assessments were made on the hydrological regime and surface water physico-chemical parameters (if present). Specific data collection methods are reported in Section 3.4. Based on the preliminary desktop classification, regions of the NMB were targeted for verification. Wetlands that were given a certainty level of "1" and some "2" (Table 3.5) were grouped into regions and the wetlands were visited to validate the Level 3 and 4 classification. Wetlands were visited to determine access and feasibility for inclusion in the once-off data collection for Levels 4b-6 of the classification (see Section 3.3). NMB experienced higher than average total yearly rainfall (which is approximately 618 mm per annum) in 2011 (742 mm) and 2012 (960 mm), recorded by South African Weather Service. This is described further in Chapter 5. Given the near record breaking total in 2012, we determined if an area was not inundated or soil was not saturated, or other indicators present, at the time of the site visit, it was highly unlikely that it was a wetland and was removed from the database. Likewise, areas that were not previously classified as wetlands that had surface water present, soil saturation and/or wetland vegetation, were included in the GIS database, with a Level 3 certainty. The coordinates were captured with a handheld Trimble GPS. The process of field verification and desktop demarcation and classification was an iterative one that was carried out between 2012 and 2014. Map based demarcation was over 80% successful, with almost an equal number removed and added into the NMB coverage. These results are presented in Chapter 4.

### 3.3 Site Selection Process and Parameters

Using local expert opinion and the map of delineated wetlands, the project team chose a pool of approximately 30 possible sites per quaternary catchment area. These sites were assessed to determine feasibility and suitably for selection as once-off and/or monitoring sampling.

**Table 3.5 Summary of Quaternary catchments in NMB, their area, current number of delineated wetlands, and number of wetlands per km$^2$.**

| Quaternary Catchments | Associated Main Rivers | Catchment Area (km$^2$) | Number of Wetlands | No/km$^2$ |
|---|---|---|---|---|
| M30A & N40E | Upper Coega and Upper Sundays | 262.2 | 94 | 0.36 |
| M30B & N40F | Lower Coega and Lower Sundays | 487.8 | 216 | 0.44 |
| M10C & M10B | Elands and Upper Swartkops | 360.7 | 225 | 0.62 |
| M10D | Chatty and Lower Swartkops | 306.5 | 262 | 0.85 |
| M20A | Baakens and Papkuils | 359.7 | 592 | 1.66 |
| M20B | Van Stadens and Maitland | 166.9 | 321 | 1.92 |

There were several criteria used to choose the final sites for once-off data collection. The goal was have a suite of sites that were broadly representative of the wetlands around NMB. These included, size (generally less than one ha), location (covering the different regions) and ease of access to the site. The sites chosen within each quaternary catchment were based on the broad terrestrial vegetation type, broad underlying geology and presence of the Level 3 and 4 combinations to obtain a representation of the habitat types in NMB. We chose to limit our wetland types to seasonally or intermittently inundated sites that were typed as seeps, depressions or wetland flats (these were the dominant type by number, see Chapter 4) within the various landscape forms (Level 3 of the CS). Through this iterative process we selected 70 possible sites that broadly represented ephemeral wetlands of the HGM types across NMB, considering that not all Level 3 types were present in each quaternary catchment and not all Level 4 types occur within each of the Level 3 landscape forms.

In the spring and summer of 2012 and 2013, 46 sites, in six quaternary catchments, were assessed to Level 6 of the CS (Table 3.6). Data for various abiotic and biotic parameters were collected (see Sections 3.4 and 3.6 for details). Final site distribution is illustrated in Figure 3.2, with further details provided in Table 3.7.

The monitoring sites selected were within two catchment areas, M20A and M10B&C, for logistical purposes. Two sites were monitored in the NMMU campus reserve (in Area 1, two wetland flats), Theescombe NMB protected area (in Area 2, one depression, and one wetland flat) and the Hopewell Conservation and MOSS area (in Area 4, two depressions, with different management levels) (Figure 3.2 and Table 3.7).

**Table 3.6 Total number of sites used for CS Level 6 classification and once-off data collection listed by landscape unit and HGM (Levels 3 and 4) for each quaternary catchment.**

| | | Quaternary Catchment | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Level 3** | **Level 4** | **M10B&C** | **M10D** | **M20A** | **M20B** | **M30A** | **M30B** | **Total per Type** |
| Bench | Depression | 4 | | | | | 2 | **6** |
| | Wetland Flat | 1 | | 1 | 3 | | | **5** |
| Plain | Depression | | | 3 | | | | **3** |
| | Seep | | | 1 | | | | **1** |
| | Wetland Flat | | | 3 | | | | **3** |
| Slope | Depression | | 2 | 1 | 1 | | 1 | **5** |
| | Seep | 3 | 2 | 2 | 1 | 2 | | **10** |
| | Wetland Flat | | 1 | 1 | 1 | | | **3** |
| Valley floor | Depression | 1 | 2 | 1 | 1 | | 3 | **8** |
| | Wetland Flat | | 2 | | | | | **2** |
| **Total per Catchment** | | **9** | **9** | **13** | **7** | **2** | **6** | **46** |

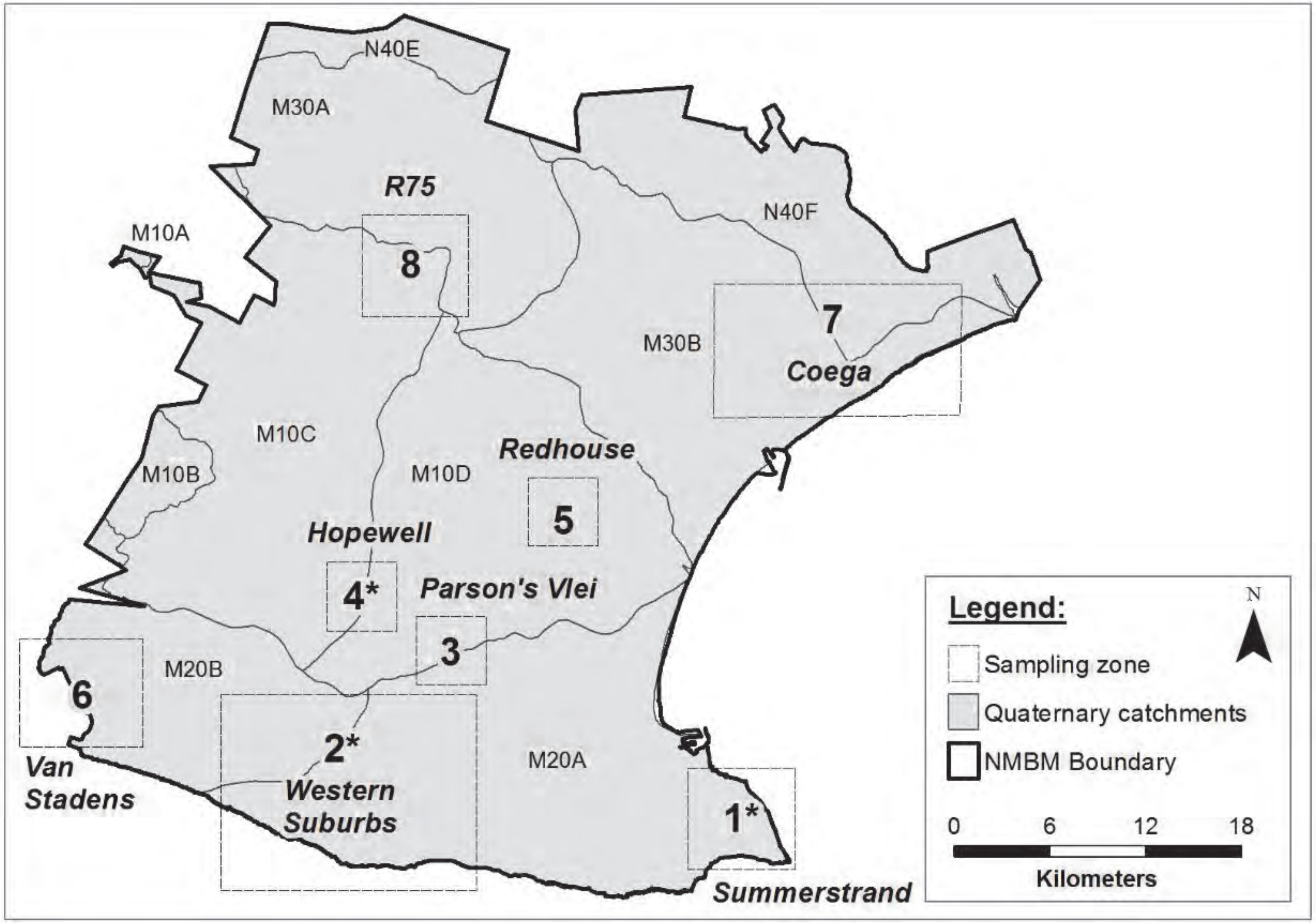


**Figure 3.2** **Map of the eight sampling zones for once-off sites. Wetland monitoring occurred at six sites in the three zones denoted by an asterisk (*).**

**Table 3.7 Reference table for all once-off and monitoring sites sampled in NMB. A more detailed table of the sites is located in Section 4 (Table 4.2).**

| Wetland ID | Field Code | Area | Level 4: HGM | Once-off/Monitoring |
|---|---|---|---|---|
| 1593 | CR1 | 1 | Wetland flat | Monitoring |
| 1595 | CR2 | 1 | Depression | Once-off |
| 1596 | CR3 | 1 | Depression | Once-off |
| 1624 | NMMU1 | 1 | Wetland flat | Once-off |
| 1626 | SBG1 | 1 | Wetland flat | Monitoring |
| 1627 | DuD1 | 1 | Depression | Once-off |
| 1641a | ResA | 1 | Seep | Once-off |
| 1641b | ResB | 1 | Depression | Once-off |
| 326 | TC2 | 2 | Wetland flat | Monitoring |
| 329 | TC1 | 2 | Depression | Monitoring |
| 1344 | CC1 | 2 | Depression | Once-off |
| 1647 | DFTN | 2 | Depression | Once-off |
| 1654 | SV2 | 2 | Seep | Once-off |
| 1655 | SV1 | 2 | Seep | Once-off |
| 683 | PV2 | 3 | Depression | Once-off |
| 1699 | PV4 | 3 | Wetland flat | Once-off |
| 789a | PV3a | 3 | Depression | Once-off |
| 789b | PV3b | 3 | Seep | Once-off |
| 790a | PV1a | 3 | Seep | Once-off |
| 790b | PV1b | 3 | Wetland flat | Once-off |
| 910 | HW3 | 4 | Depression | Once-off |
| 944 | HW1 | 4 | Depression | Monitoring |
| 947 | HW2 | 4 | Depression | Monitoring |
| 1016 | RH4 | 5 | Wetland flat | Once-off |
| 1017 | RH3 | 5 | Wetland flat | Once-off |
| 1019 | RH1 | 5 | Depression | Once-off |
| 1648 | RH2 | 5 | Wetland flat | Once-off |
| 743 | VSR1 | 6 | Depression | Once-off |
| 1668 | VSM2 | 6 | Wetland flat | Once-off |
| 1675 | YW1 | 6 | Wetland flat | Once-off |
| 1679 | VSM1 | 6 | Wetland flat | Once-off |
| 749 | VSR2 | 6 | Wetland flat | Once-off |
| 1310 | EW1 | 7 | Depression | Once-off |
| 1311 | CZ6-1 | 7 | Depression | Once-off |
| 1359 | PL1 | 7 | Depression | Once-off |
| 1649 | CDD1 | 7 | Depression | Once-off |
| 1650 | CDD2 | 7 | Depression | Once-off |
| 1651 | CDD3 | 7 | Depression | Once-off |
| 1380 | R75-2 | 8 | Depression | Once-off |
| 1381 | R75-3 | 8 | Wetland flat | Once-off |
| 1625 | R75-1 | 8 | Depression | Once-off |
| 1691 | BED1 | 8 | Seep | Once-off |
| 1692 | BED2 | 8 | Seep | Once-off |
| 1382a-c | R75-4a-c | 8 | Seep | Once-off |

## 3.4 Field Data Collection

Sampling of the once-off sites was designed to obtain an abiotic and biotic picture of the wetland as a whole. Sampling was conducted in 2012 and 2013, and for the most part restricted to the spring-early summer months (September-December), exceptions will be noted.

### 3.4.1 Abiotic variables

Data sheets were constructed with the CS model in order to complete the classification of the sites to Levels 5 and 6 and compare the ground-truthed data to Level 3 and 4 desktop classification. Sampled sites were classified up to Level 6 of the CS. The first four levels provided a confirmation of what was observed using GIS. Level 5 addressed inundation and saturation periodicity, while Level 6 looked at the habitat unit and vegetation cover of the wetland, both of which can only be measured and recorded in the field, methods of Ollis *et al.* (2013) were followed for this part of the assessment.

General site description included the observed vegetation type, the presence of disturbances (e.g. alien vegetation, grazing, etc.), a general surrounding habitat description, the position of the wetland in the landscape and a sketch map delineating any important features/hydrogeomorphic (HGM) units and sample points. The 'wetted edge' zone of the wetland was delineated using a GPS for input into ArcGIS at a later stage (Table 3.8).

Two soil samples were collected for each of the sites studied (Table 3.8). Six soil cores were dug using a one metre soil auger. Each core was evaluated at 10 cm intervals to evaluate the colour (Munsell colour), and other properties. As most soil wetland indicators were detected within the top 50 cm of the soil, the maximum depth that was augered was be between 50 and 60 cm, or to bedrock (if less than approximately 70-100 cm). Three cores were augered along each of the vegetation transects, on both sides of the wetlands and were mixed together in a labelled sample bag (one for each transect) to try create a representative sample for the site. Observations were made on the depth of soil saturation on the surface, and the water table. Indicators of a wetland soil that were recorded in the field included: high organic content in the surface soil layer, a low chroma, mottles, concretions, oxidised root channels, organic streaking, a gleyed matrix, and/or a sulfidic odour (within each 10 cm interval) (Table 3.9). The two collated samples were sealed and kept refrigerated until analyses could be conducted (Table 3.9).

Surface soil moisture at the soil cores and along the vegetation transects was also recorded in the field using a Soil Moisture Meter (Table 3.8). This meter measures the volumetric water content (VWC) in standard mode with a long probe. VWC measures the ratio of the volume of water in a given volume of soil to the total soil volume. The meter ranges from 0% (dry) to saturation (approximately 50% depending on the soil type).

**Table 3.8 Summary of abiotic field methods and references used.**

| Abiotic field methods | Parameters measured/collected | Description/tools used | References |
|---|---|---|---|
| CS classification | Levels 1 to 6 | Confirm first 4 levels of CS and describe Levels 5 & 6 | Ewart-Smith *et al.* 2006; Ollis *et al.* 2013 |
| Site description | None | General data on the site and surrounding land use | DWAF 2005; Ewart-Smith *et al.* 2006; Kotze *et al.* 2009; Ollis *et al.* 2013 |
| Wetland demarcation | XY coordinates | Trimble Juno SB GPS was used to measure wetted edge of the wetland | Job 2009 |
| Soil core | Soil texture, colour, presence of mottles/concretions, etc. | 3 soil cores to a depth of 50 cm along each of the 2 vegetation transects | Environmental Laboratory, 1987; DWAF 2005; Ewart-Smith *et al.* 2006; Job 2009 |
| Soil moisture | Soil moisture (%) | Field Scout TDR 300 Soil Moisture Meter | Job 2009; Day and Malan 2010 |
| Physico-chemical properties | Temperature ($^{o}$C), pH, EC, Salinity (ppt), DO (mg/L), TDS (mg/L) | YSI hand-held multi-probe (556 MPS) and Crison Conductivity Meter 524 | Ewart-Smith *et al.* 2006 Ollis *et al.* 2013 |
| Water quality | Water colour, smell, total suspended solids (TSS) | Visual inspection and 2 x water samples for lab processing of TSS | Ewart-Smith *et al.* 2006 |
| Surface and sub-surface nutrients | Chlorophyll (from surface water & MPBs), nutrients | Collected and filtered in field and kept cool until further processing in lab | Ewart-Smith *et al.* 2006; Day and Malan 2010 |

Several hydrological parameters were recorded in the field (Table 3.8 and Table 3.9). Observations were done on the water sources and outlets (e.g. groundwater, surface water, channelled, etc.), as well as connectivity to other wetlands. When surface water was present, water depth measurements were made every 3 m along each transect in conjunction with the vegetation data collection. Estimates of the annual depth of inundation were also recorded.

Water colour (brown, red, etc.), transparency and smell (algae, sulfur, etc.) were evaluated and recorded on site. Physico-chemical properties were also measured and recorded *in situ* using a YSI including: water temperature, pH, conductivity, total dissolved solids (TDS), dissolved oxygen (DO) (mg/L) and salinity at three points within the wetland, one at the deepest point, one within the marginal vegetation (if present) and a third point randomly selected. Several water samples were also collected at random representative points within the wetland for further laboratory analysis.

**Table 3.9 Abiotic data collection, *in situ* measurements and sample collection for laboratory processing.**

| Parameter | Measured *in situ* | Laboratory Processing |
|---|---|---|
| **Soils** | Colour<br>Texture<br>Mottles<br>Saturation<br>Profile | Organic content<br>Moisture content<br>Particle size<br>Conductivity<br>pH |
| **Surface and Sub-surface water** | Temperature<br>pH<br>Conductivity<br>Salinity<br>Dissolved oxygen<br>Total dissolved solids<br>Depth | Nutrients<br>Total Nitrogen<br>Nitrate<br>Nitrite<br>Ammonium<br>Total Phosphorus<br>Soluble Reactive Phosphorus<br>Silica<br>Total Suspended Solids (surface only) |

Two surface water samples and two sub-surface water samples were collected for nutrient analysis and two samples for total suspended solids (TSS), where present (Table 3.8 and Table 3.9). Sub-surface samples were collected from two random points next to the wetland, one of which was 'upstream' of the surface water. Holes were dug in the ground and left to fill up with water before measuring physico-chemical properties and collecting water samples. All field samples were stored in an ice box until filtering could be conducted. Samples were filtered and frozen on the same day of collection, to preserve the sample until laboratory processing could be done. Samples were processed within six months of collection.

### 3.4.2 Biotic variables

Several different types of biological data were collected: vegetation, algae, aquatic invertebrates and tadpoles. Auxiliary data on birds and other fauna present on site were noted.

Vegetation collection/identification and cover determination was carried out using quadrat sampling (Macfarlane *et al.* 2009). Two vegetation transects were placed perpendicular to each other along the longest and shortest axis of the wetland, and extended to the edge of the terrestrial zone on either side of the wetland. The species and relative cover of each species was recorded in 1 $m^2$ quadrats every 3 m along each transect. All species with greater than 1% coverage in the quadrat were recorded and their coverage estimated using the Braun-Blanquet cover-abundance scale. The dominant plant species, as well as their height was recorded. A number of guides were used to identify plants in the laboratory if they could not be identified in the field, these references include: Vanderplank (1998), Vanderplank (1999), Manning (2001), Cook (2004), Manning (2009), Van Outshoorn (1999), Bromilow (2010), Vlok and Schutter-Vlok (2010), Van Ginkel *et al*. (2011), Dorrat-Haaksma and Linder (2012).

Filamentous and macro algae were also recorded along each vegetation transect, where present, as well as overall emergent and submerged vegetation cover. Sub-samples were collected for further identification in the lab.

At wetland sites that were inundated sufficiently to support a phytoplankton community (maximum water depth greater than 25 cm) three replicate 1 L water samples were collected for biomass assessment in terms of Chlorophyll *a*, filtered either in the field or in the lab. Two replicate 1 L samples were also collected and preserved with Lugol's for phytoplankton community analysis. Where there was suitable habitat of bare sediment substrata, five replicate samples of benthic cores were collected at the top 1 cm of the sediment, for microphytobenthic algae (MPB) biomass assessment. A further five cores were collected, and their top 1 cm pooled into one representative sample, and preserved in Lugol's for community analysis. These MPB cores were collected in shallow water, less than 10 cm in depth, or saturated soils, with no overlying vascular vegetation.

Aquatic invertebrate samples were collected in both shallow (less than 20 cm and/or emergent vegetation zone) and deeper inundated sections (greater than 25 cm and/or open water zone) of inundated wetland sites. A kick-net with 900 µm mesh was dragged through all layers of the water column at different points within each inundated wetland. Two sweeps were done for each sample type for 1 min and 1.5 min respectively, and pooled. Samples were preserved in 98% Ethanol in the field.

## 3.5 Monitoring Sites

The monitoring sites were initially sampled in the same way as the once-off sites to garner a set of data that could be used as a base-line to add to the once-off assessments. Thereafter monitoring was done at the site at specific intervals.

Sampling for surface and sub-surface water and biological parameters was done on a more regular basis with periods between samples governed by rainfall and drying events (days, weeks and months post-inundation or major rainfall event until drying commenced) as per standard field and laboratory methods. Soils and vegetation were not collected on as fine of a temporal scale, but at strategic shifts within the dynamics of the wetlands' transition from wet to dry were monitored (or at minimum, quarterly).

Several soil samples were collected at monitoring sites for finer resolution data. Nine soil cores were augered at various points around the wetland and put into separate sample bags for more in-depth analyses. Two samples were taken from each core (subsurface to 30 cm depth and 40 to 60 cm depth) and the GPS position of each core was recorded. The cores were analysed for particle size composition, EC and pH. This provided a more extensive overview of the variability of soil characteristics within a wetland.

### 3.5.1 Periodicity

At all sites, vegetation was monitored on a quarterly basis, with the first site visit being the first of the sampling events, for at least one year post inundation. The other abiotic variables and biotic parameters were collected at different temporal scales, dependant on rate of drying and accessibility of the sites. Two sites on the NMMU campus were sampled/monitored on a finer temporal scale post-inundation until drying, on a weekly to monthly basis. The Theescombe sites were sampled monthly and the Hopewell sites, quarterly, due to logistical reasons (Table 3.10).

**Table 3.10 Sampling timeline for monitoring sites from base-line (first sampling) to last. Standard monitoring in grey, vegetation data collection points in black.**

| (a) | Sep-12 | Oct-12 | Nov-12 | Dec-12 | Jan-13 | Feb-13 | Mar-13 | Apr-13 | May-13 |
|---|---|---|---|---|---|---|---|---|---|
| CR1 | | | | | | | | | |
| SBG1 | | | | | | | | | |
| TC1 | | | | | | | | | |
| TC2 | | | | | | | | | |
| HW1 | | | | | | | | | |
| HW2 | | | | | | | | | |

| (b) | Jun-13 | Jul-13 | Aug-13 | Sep-13 | Oct-13 | Nov-13 | Dec-13 | Jan-14 | Feb-14 |
|---|---|---|---|---|---|---|---|---|---|
| CR1 | | | | | | | | | |
| SBG1 | | | | | | | | | |
| TC1 | | | | | | | | | |
| TC2 | | | | | | | | | |
| HW1 | | | | | | | | | |
| HW2 | | | | | | | | | |

## 3.6 Laboratory Processing

Although some parameters were collected *in situ*, many abiotic and biotic samples were brought back to the laboratory for processing. The following sections outline the methods used to record data collected at each wetland site. All water and soil samples were analysed at NMMU by members of the project team, unless otherwise specified. Water samples collected for nutrients were not sent to nationally accredited laboratories for analysis due to the generally low nutrient levels in the samples that were mostly below the detection limits of external laboratories.

### 3.6.1 Sediment samples

The soil samples for both once-off and monitoring sites were brought to the lab for analysis of standard soil chemistry and composition, moisture content, organic content and electrical conductivity (EC) (Strickland and Parsons 1972; Sparks *et al.* 1996).

*Soil moisture content*

Three replicates of approximately 10 to 15 g of sediment per field sample were used to determine the soil moisture content (Black 1965). The samples were weighed and placed in an oven at 40$^{o}$C to dry for 48 hours. The samples were then re-weighed to determine the percentage moisture content using the following equation:

$$\left(\frac{Mw - Md}{Mw}\right) * 100$$

Where *Mw* is the initial mass of the soil (wet) and *Md* is the mass after drying.

*Soil organic matter content*

The dried samples used to determine sediment moisture were then used for the percentage organic matter, which was calculated using the loss on ignition method (ashing) (Smith and Atkinson 1975; Briggs 1977). The soil samples were ashed in a muffle furnace at 550$^{o}$C for 6 hours. The percentage organic matter was then calculated using the following equation:

$$\left(\frac{Md - Ma}{Md}\right) * 100$$

Where *Md* is the initial dry mass and *Ma* is the mass after ashing.

*Soil texture*

Determining the particle size distribution (PSD) of sediments provides important information on the physical properties of the soil. There are various methods for determining particle size fractions. Mechanical sieving and sedimentation are well known methods that produce comparable data (Foth 1990; The Non-Affiliated Soil Analysis Work Committee, 1990; Eshel *et al.* 2004). However, laser diffraction (LD) can produce accurate results in less time and with a smaller sample (Konert and Vandenberghe 1997; Eshel *et al.* 2004). LD also provides data on a wide range of size fractions which can be divided up into particle size groups compared to the sieving and sedimentation methods that are limited to sieve mesh sizes and proportions of sand, silt and clay respectively. Eshel *et al.* (2004) and Konert and Vandenberghe (1997) both discuss the advantages and disadvantages of these different PSD methods in detail. LD was used for particles smaller than one millimetre in size, and sieving was used for more coarse particles, the process of which is outlined below. Numerous sources provide a full explanation on how LD works (For example: Stojanovic and Markovic 2012).

Two sediment samples were collected at each site. Approximately 50 g of soil was dried at room temperature for PSD analysis. A pestle and mortar was used to grind the sample to separate the particles and clumps. Any material greater than 4 mm in diameter (coarse gravel and cobbles) was removed and measured separately. Particle size was then measured using dry sieving method (Foth 1990; The Non-Affiliated Soil Analysis Work Committee 1990). The size of the sieves used is outlined in Table 3.11 with the particle size class given according to the Wentworth Scale. Sieves were stacked according to the mesh size and a mechanical shaker was used to sort particle size class fractions (Table 3.11). Size fractions smaller than one millimetre were collected in the sieve tray for further sampling using LD. The total sediment weight in each of the sieves was weighed separately and recorded. The remainder of the sample was then weighed and used for LD analysis.

The Malvern Instrument Marstersizer (Malvern Instruments Ltd, Worcestershire, England) with Mastersizer-S v2.18 software was used to determine particle sizes ranging from 0.02 µm to 1000 µm. The average density was set before each analysis for each respective site using the following equation:

$$D_p = \text{oven-dry weight (g)/–volume of soil solids (cm}^3\text{)}$$

Where $D_p$ is the particle density of soil, a value approximately 2.65 g.cm$^{-3}$ (the density of silica) (Foth 1990; Brady and Weil 1999; Blake 2008).

The following parameters were set for sediment analyses:

| | |
|---|---|
| Pump speed: | 2000 rpm |
| Ultrasound: | 60% (on during analysis) |
| Sensitivity: | Normal |
| Measurement time: | 20 sec |
| Obscuration: | 20-30% |

Each of the sediment samples were dispersed using Sodium hexametaphosphate with 3 drops of Triton X165 solution. The ultrasonic bath was filled with water and the lasers initialised before the sample was slowly added to the bath. Three measurements (replicates) were performed for each sample once the obscurity had settled.

The data were extracted from the Mastersizer software and stored in an excel file, to group according to the respective particle size classes (Table 3.11). The total proportion in each class was then calculated and corrected for the sample that was measured in the sieves.

**Table 3.11 Particle size class and methods used for particle size analysis.**

| Particle diameter (mm) | Particle size class | Method of analysis |
|---|---|---|
| > 2 | Fine gravels (and larger) | Sieve |
| 1-2 | Very coarse sand | Sieve |
| 0.5-1 | Coarse sand | Sieve tray & Laser diffraction |
| 0.25-0.5 | Medium sand | Sieve tray & Laser diffraction |
| 0.125-0.25 | Fine sand | Sieve tray & Laser diffraction |
| 0.063-0.125 | Very fine sand | Sieve tray & Laser diffraction |
| 0.031-0.063 | Coarse silt | Sieve tray & Laser diffraction |
| 0.016-0.031 | Medium silt | Sieve tray & Laser diffraction |
| 0.008-0.016 | Fine silt | Sieve tray & Laser diffraction |
| 0.002-0.008 | Very fine silt | Sieve tray & Laser diffraction |
| 0.001-0.002 | Clay | Sieve tray & Laser diffraction |

*Soil electrical conductivity (EC) and pH*

Electrical Conductivity (EC) was measured as an indicator of salinity as EC increases proportionally with salt concentration. EC was calculated using the methods described in The Non-Affiliated Soil Analysis Work Committee (1990). Soil samples were air dried and de-ionised water was added to 250 g of soil until a saturated paste was formed. The amount of de-ionised water added was noted and the paste was left to stand for at least one hour before filtering. The soil paste was then filtered through a Whatman no. 1 filter paper through a Buchner funnel, using suction. The filtrate was collected in a test tube and measured using a hand held Crison Conductivity Meter 524. The solution was also used to measure the pH of the extracted solution using a RE 357 Microprocessor pH meter calibrated to 4.7, 7 and 10.

### 3.6.2 Surface and subsurface water samples

The MPB and surface water chlorophyll *a* were measured by extracting the chlorophyll *a* with Ethanol, filtering and absorbance read at 665 nm using a spectrophotometer. Processing of water samples for nutrient contents and total suspended solids (TSS) is outlined in the following sections.

*Total suspended solids (TSS)*

A 250 ml water sample was filtered on to a pre-dried and weighed 0.45 µm filter paper. The filter paper was then re-dried for 48 hrs and weighed. The total amount of TSS (mg/L) was then calculated by determining the amount of solids left on the filter paper after filtration. The following equation is used:

$$\left(\frac{Ma - Mb}{Fa}\right) * 1000$$

Where *Ma* is the mass (g) of the filter paper after filtering, *Mb* is the mass of the filter paper before filtering and *Fa* is the amount of sample filtered in ml.

*Nutrients*

Surface and sub-surface water samples were filtered through a 0.45µm filters and frozen until analysis could be conducted. Total Nitrogen, Nitrates, Nitrites, Ammonium, Soluble Reactive Phosphorous, Total Phosphorous and Silica were analysed according to the methods laid out by Strickland and Parsons (1972), and Bate and Heelas (1975).

Nitrite and nitrate were analysed using the methods outlined in Bate and Heelas (1975). Nitrate was reduced to nitrite using the copper cadmium reduction method and analysed as per the nitrite method. One ml of each sample was read on a spectrophotometer at a wavelength of 540 nm. Seven standards of nitrite and nitrate were used in order to measure absorbance against a known concentration.

Total nitrogen was measured using a similar method to nitrate analysis. Firstly, an oxidising reagent was created. Five ml of the field sample was added to one ml of the oxidising solution which was then autoclaved for 30 min. The nitrate method outlined above was used after autoclaving to determine TN concentrations.

Ammonium concentration was measured using methods outlined by Solorzano (1969) and Strickland and Parsons (1972). Absorbances were read at a wavelength of 640 nm using a spectrophotometer and compared to a series of standards of known concentrations.

Standard methods for TP and SRP were used as outlined in Strickland and Parsons (1972). TP was first oxidised with persulfate solution and then autoclaved before processing using the same method as SRP. Absorbance of each sample was read on a spectrophotometer at a wavelength of 885 nm. Seven standard solutions of TP and SRP of known concentrations were processed as per methods for calculations.

Silica was determined using methods of Wetzel and Likens (1991). Absorbances were read on a spectrophotometer at a wavelength of 700 nm against a control sample and a series of silica standards of known concentration.

#### 3.6.3 Plant specimens

Specimens of plants not identified in the field were tagged and coded per quadrat and transect and returned to the laboratory for further identification. Once in the laboratory a picture was taken of each specimen and then was pressed for further processing and identification using relevant keys and herbarium resources. Species list of those identified to at least genus is in Appendix C.

#### 3.6.4 Algal samples

Phytoplankton biomass was assessed using Chlorophyll *a* analysis, by filtering replicate samples either in the field or in the lab using 1.6 µm glass fibre filters (GF/C). Filters were either frozen in foil until extraction within 3-4 days from day of sampling, or immediately placed in Ethanol for extraction and processing within 24 hrs. MPB biomass was also assessed for Chlorophyll *a* by extracting each 1 cm benthic core in 30 ml of Ethanol for 24-36 hrs. All extractions were read on a spectrophotometer at 665 nm, before and after acid addition and resultant absorbance converted to Chl *a* in µg/L for phytoplankton and $mg/m^2$ for MPBs. Sediment from the MPB samples was dried and a dry weight was used to calculate the amount of Chl *a* per gram of sediment.

Algal species from both the phytoplankton and MPB samples were identified to the lowest practical level and cells enumerated using a haemocytometer (Perez 2006). The entire community of taxa were identified to the lowest practical level and cells enumerated (Swanepoel *et al.* 2008; Taylor *et al.* 2007). A subsample of the cores was also used specifically for diatom species assemblage identification (Taylor *et al.* 2007). Several references were used for the identification of algal species and are listed along with taxa identified in Appendix C.

#### 3.6.5 Aquatic Invertebrate samples

Open water and marginal vegetation aquatic invertebrate samples were sorted from debris and preserved in 70% Ethanol. Taxa were initially identified to family level in the lab during the sorting process and later identified to the lowest practical level and enumerated (WRC 2000). Any tadpoles/froglets collected were removed immediately and placed in 70% Ethanol and identified, measured and enumerated. Several references were used for the identification of aquatic invertebrate and tadpole species and are listed along with taxa identified in Appendix C.

Due to the extremely low rainfall experienced in 2013 as compared to previous two years (see Chapter 5 for detail), many of the sites visited were dry. Some invertebrates are associated with ephemeral wetlands and survive these systems through the deposition of resting eggs. To collect partial data on invertebrates (those associated with these systems), sediment hatching experiments were conducted in the lab using dry sediment samples collected from the field. Sediment was collected at 19 sites during the dry phase. Three replicates of the sediment of each site were used in the experiments.

The invertebrate experiments were conducted for 28 days in February and again in June 2013. Hatchlings that had grown to a stage of maturity were identified to the lowest practical taxonomic level. The goal of these experiments was to optimise conditions for a diverse array taxa to hatch, not necessarily optimising conditions for a particular taxa. Using methods similar to those of Brendonck (1996), Vandekerkhove *et al.* (2005), Keltey (2005) and Day *et al.* (2009), experiments were conducted using 2 L containers, 50 g of dried sediment, and distilled water. Experiments were conducted in a temperature and light controlled growth chamber, with temperature kept at 17$^{o}$C in February and 24$^{o}$C in June with a 24 hr light cycle. Abiotic parameters such as temperature, dissolved oxygen, pH and conductivity were measured every 4 days using a Crison Conductivity Meter 524, along with a check for hatchlings. As per similar studies (Day *et al.* 2010; Ferreira *et al.* 2012), hatchlings were placed in growth medium/food to help them reach maturity. At the end of the 30 days all invertebrates were fixed with 70% Ethanol.

## 3.7 Data Analyses

All field and laboratory data were captured in MS Excel spreadsheets for ease of access and manipulation. A combination of data analysis techniques were used to analyse the collected data. Both non-parametric and parametric statistical analyses were used using the following different statistical computer packages: Statistica 10.0, R- open source statistical coding, Primer 6.0, and CANOCO, ARC GIS 10.2.2.

### 3.7.1 Climate

Raw weather data were collected from the South African Weather Service (SAWS). The monthly average was calculated for the historical data (1950-2013), and monthly totals for 2012 and 2013. This was used as a basis for determining the hydrological characteristics of the once-off and monitoring wetland sites.

### 3.7.2 Wetlands and the surrounding environment

The environmental variables that were spatially joined to the wetland dataset were compared across wetland HGM types. Histograms were created for the HGM wetland groups for landcover, modification of wetland systems (natural, modified and artificial systems), quaternary catchments, morphology of landscape, potential groundwater occurrence, underlying geology, annual rainfall zone, soil depth zones, calcareous areas, and vegetation biomes (and broad habitat units). Only some of this data are displayed, and some of the data are only illustrated for the three prominent HGM types (depressions, seeps, and wetland flats).

### 3.7.3 Statistical data analysis

Boxplots were created in R and SigmaPlot to compare the HGM types with the associated environmental variables. Further statistical analysis was conducted using a one-way ANOVA, to establish whether there was a significant difference in means of these variables among the different HGM types. If a significant difference was found, a post-hoc Tukey HSD test was conducted to indicate the level of significance between to HGM types.

### 3.7.4 Non-parametric statistical data analysis

A Bray-Curtis similarity resemblance analysis was conducted in Primer. All relevant environmental data was added into the matrix. The wetland HGM unit was used as a factor, with depressions being sub-divided into: inter-dune, pan and bowl. The output was displayed as a horizontal cluster dendogram. The results were also placed on a non-metric Multi-Dimensional Scaling (MDS) plot in order to display the two-dimensional distribution of the sites.

A distance based redundancy analysis (dbRDA) was conducted on the vegetation community structure within each sampling zone in NMB. This method determines which set of variables best explain the dissimilarity between the different groups (which was sampling zone in this case). This analysis is a combination of several step-wise statistical techniques and is run using the dbRDA function in PERMANOVA+. Combinations of the input variables were used to establish which variables were more prominent with different sample data. This included: water and nutrient variables, sediment and position in landscape characteristics, and a combination of all these variables. Only key variables were displayed graphically.

SIMPER (similarity of percentages) analyses identifies which variables (such as particle size classes) contribute to the observed pattern of similarity in each group (CS Level 4) This analysis was conducted in Primer 6 using the Bray-Curtis measure of similarity for vegetation and Euclidean distance for environmental variables.

BIOENV in Primer was used to determine which environmental variables best explain the vegetation community pattern. This analysis runs all permutation of the trial variables that are selected.

# 4 OUTCOMES OF THE CLASSIFICATION OF WETLANDS IN NMB

The first aim of this research was to evaluate and use the CS of Ollis *et al.* (2013) in the NMB. This was done to firstly, to see how applicable the system was outside the winter and summer rainfall regions, beyond isolated test cases. Secondly, to provide NMB with much needed baseline of information of the numbers and types of wetlands that were located within its borders. Other than the national SANBI (SANBI 2011) initiative, there had been no systematic attempt to demarcate and type wetlands (outside of rivers and estuaries) within the metropolitan area.

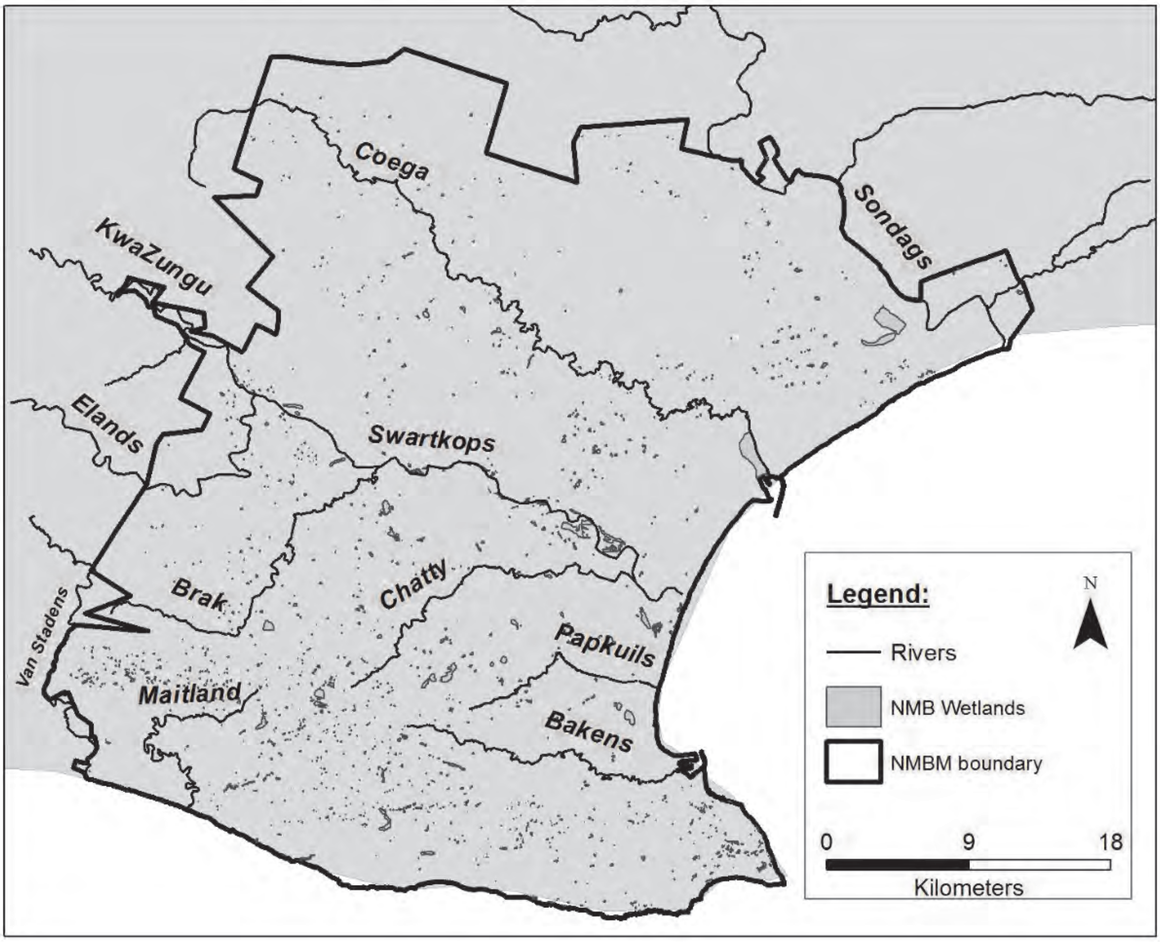


**Figure 4.1 Map of delineated wetlands in the NMB, with major rivers shown.**

## 4.1 Desktop Analysis: Level 1-4a

As the NMB is a very specific area, Levels 1 and 2 of the CS are determined and static as previously stated and are **Inland** and the regional setting is the **South Eastern Coastal Belt** respectively (Table 3.1). The landscape level unit types, Level 3 descriptions were assigned to each wetland as per definition (Table 3.2). The desktop exercise outlined in Section 3.1, produced 1712 digitised wetlands within NMB, excluding rivers, estuaries and floodplains with direct connectivity to a river or estuary (Table 4.1 and Figure 4.1). A detailed metadata report is supplied in Appendix D (Table D.1). A summary of the numbers of wetlands in each

HGM Unit by the Landscape Level Unit is given in Table 4.1. The valley floor landscape unit was the most diverse, with all HGM types present, but overall numbers of wetlands were lower than in slope and bench units (Table 4.1). Slope and bench landscape units had the highest number of wetlands, 661 and 487 respectively, but only had 4 of the 6 HGM unit types. Valley floor wetlands tended to be larger than wetlands in other areas of the landscape, with an average of 2.37 ha (± 0.66 SE). The average wetland size on a plain was small, 0.35 ha (± 0.06 SE). Although 38.5% of the wetlands were located in slope landscape units, those wetlands were on average smaller than those defined as a valley floor wetland (Figure 4.2).

When examining proportions of HGMs, depressions were dominant both by total number (518) and area (568.2 ha) (Table 4.1). By contrast, floodplains had fewer individual wetlands (Table 4.1) but a relatively large total area covered, 401.9 ha (Figure 4.3). Unchannelled valley bottom wetlands also had a high aerial coverage (390.1 ha) relative to their fewer overall numbers (Table 4.1). Seeps, wetland flats and channelled valley bottoms followed a similar pattern for both total numbers and area (Figure 4.3). Depressions, seeps and wetland flats were the dominant HGM types by numbers of individual wetlands, 80% of all wetlands delineated (Table 4.1) and 50% of the total wetland area (Figure 4.3).

The majority (86%) of wetlands in NMB were less than 1 ha in size (Figure 4.4). A large portion of these smaller systems were natural (average area of 0.92 ha), with artificial systems having significantly larger areas, with an average of 4.57 ha (t-test (1242) = 4.27, p = 0.0001).

Of the wetland areas delineated by this project, 66% wetlands were considered near natural, with 28% thought to have some modification and the remaining 6% artificial (Figure 4.5). It is important to note that "near natural" does not denote the present state of the health or provisioning of ecosystems services of wetlands, rather, that within the landscape it was not created or modified in terms of its hydrogeomorphology. These have been determined through desktop assessment and through an iterative process of site visits and updated source material. Further work could adjust these numbers to some extent. With shifts in the surrounding land use there will most likely be shifts to fewer natural wetland systems and more modified and artificial systems in the future.

**Table 4.1 Numbers of wetlands typed at Level 3 and 4 (landscape and HGM respectively) of the CS. CVB – channelled valley bottom, UCVB – unchannelled valley bottom, FP – floodplain.**

| | HGM | | | | | | |
|---|---|---|---|---|---|---|---|
| **Landscape Unit** | **Depression** | **Seep** | **Wetland flat** | **CVB** | **UCVB** | **FP** | **Total** |
| **Bench** | 207 | | 275 | 1 | 4 | | **487** |
| **Plain** | 22 | 1 | 89 | | | | **112** |
| **Slope** | 183 | 444 | 14 | 19 | | | **660** |
| **Valley floor** | 106 | 26 | 10 | 103 | 130 | 78 | **453** |
| **Total** | **518** | **471** | **388** | **123** | **134** | **78** | **1712** |

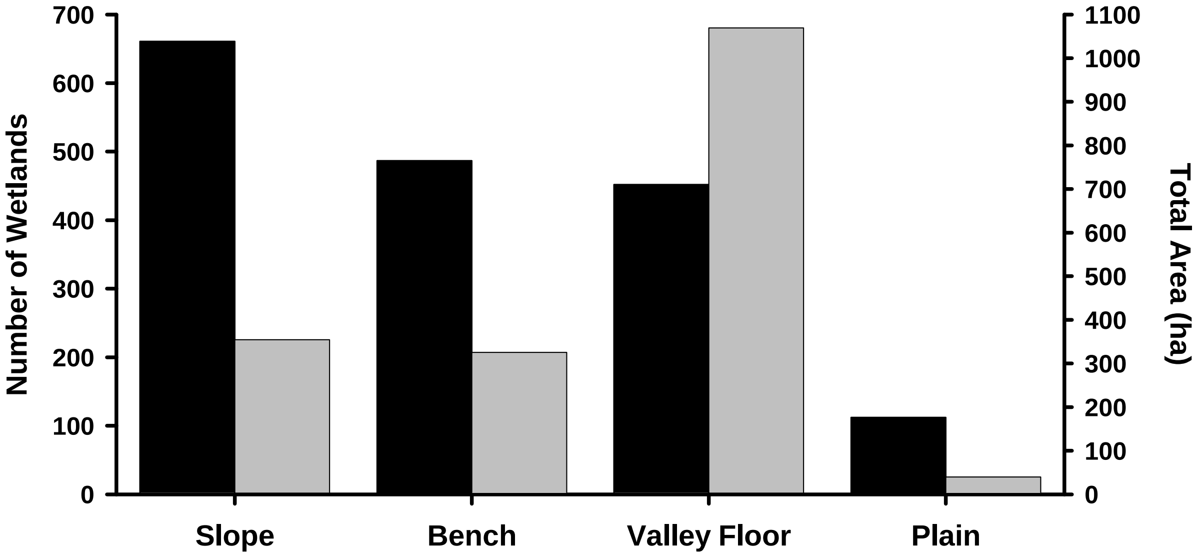


**Figure 4.2** Number (black bars) and total area coverage (grey bars) of wetlands per Level 3 landscape unit delineated in the NMB.

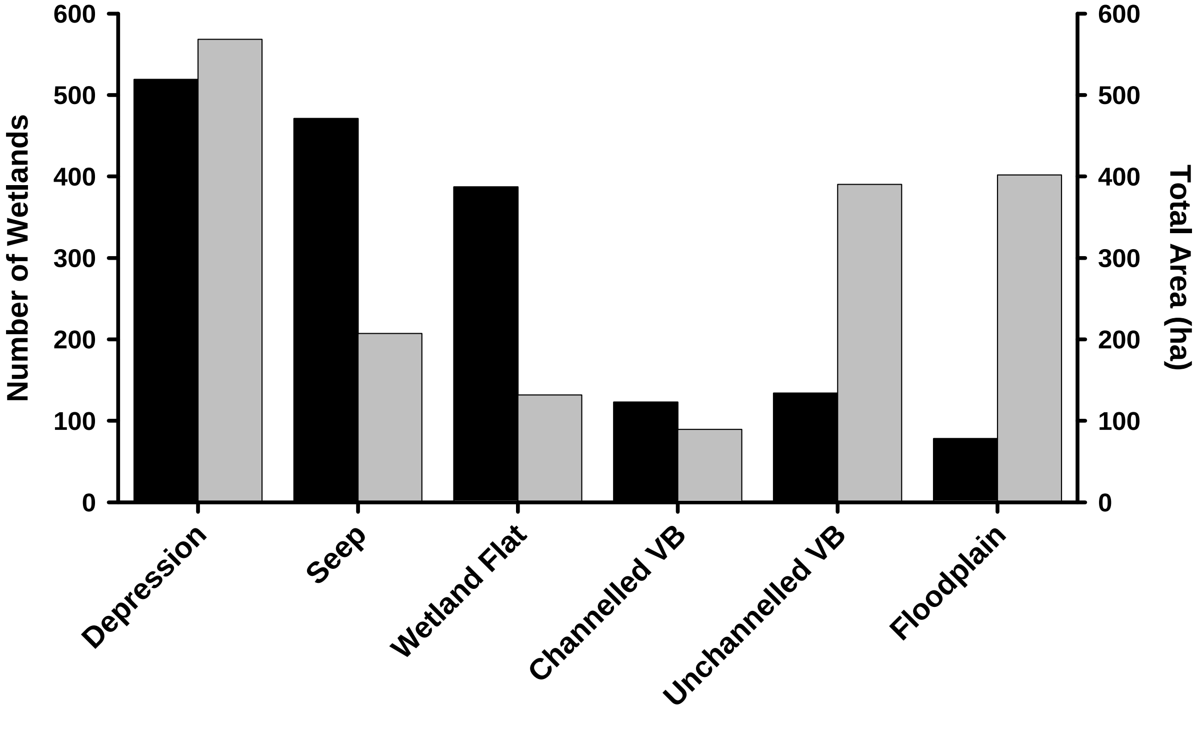


**Figure 4.3** Number (black bars) and total areal coverage (grey bars) of wetlands per Level 4 hydrogeomorphic unit (HGM) delineated in the NMB.

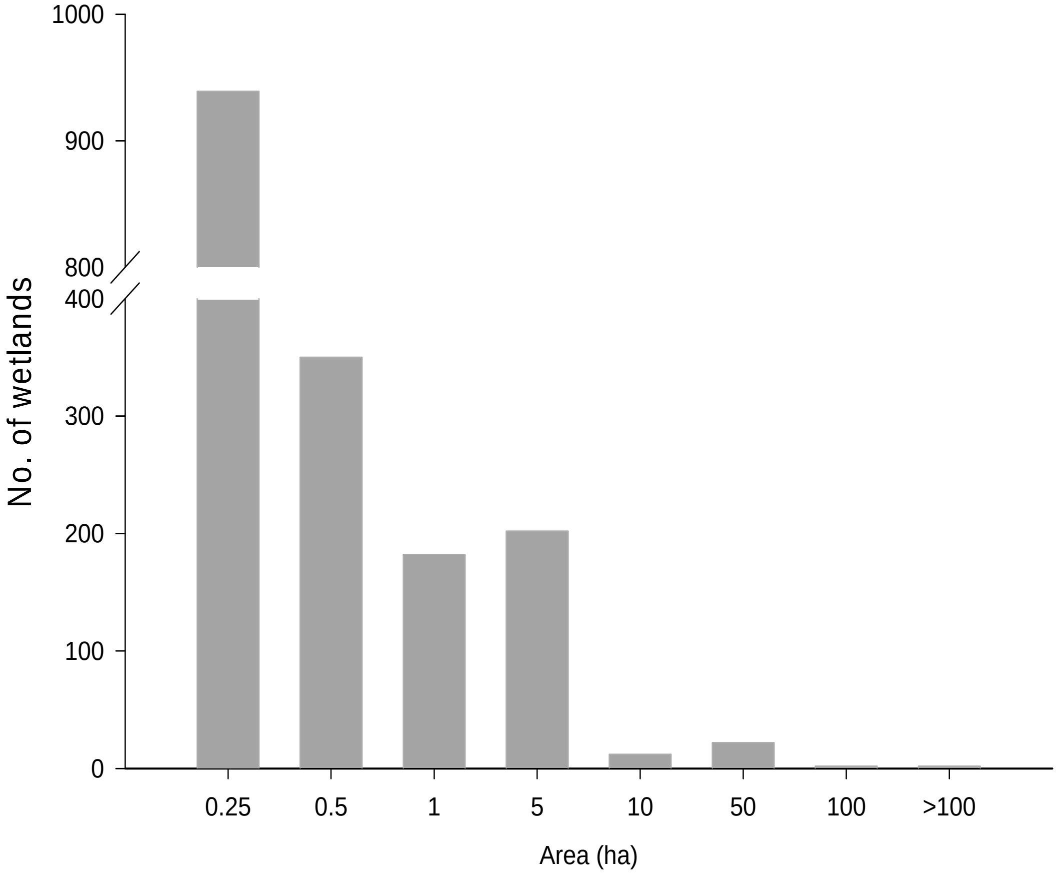


**Figure 4.4** **Number of wetlands observed in the associated area class. Note: horizontal scale is not uniform as numbers were highly irregular.**

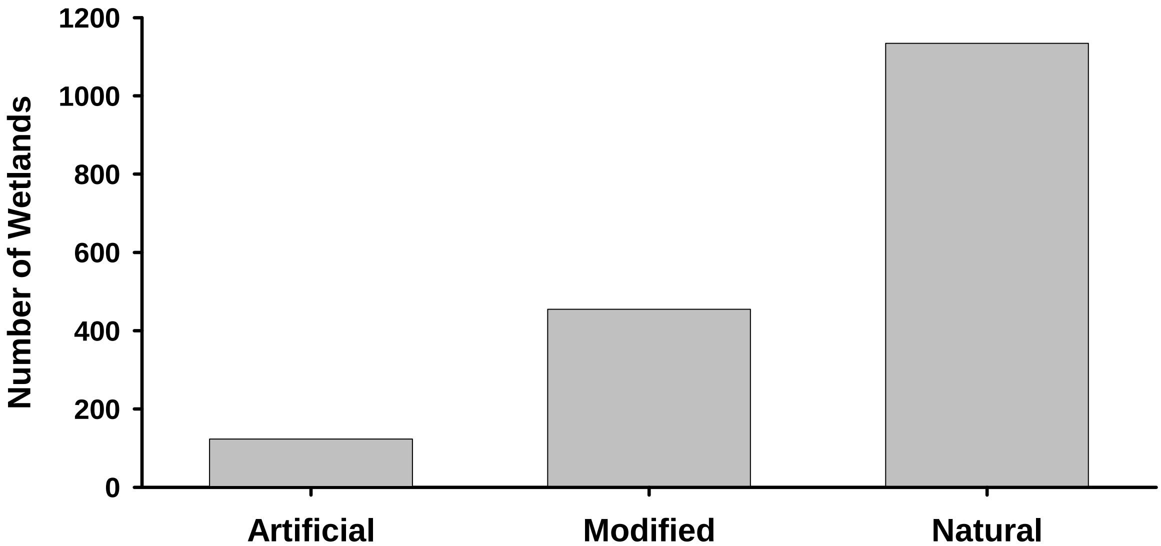


**Figure 4.5** **Total number of delineated wetlands by modification extent.**

## 4.2 Comparisons with Previously Available Data

Previous wetland demarcation of the NMB completed by SANBI as a part of their national initiative (SANBI BGIS 2011) indicated 596 wetlands within the NMB borders (Figure 4.6), a little over a third of the number located in this project. Of those delineated by SANBI, approximately 50% were modified or artificial wetlands with areas ranging from 0.01-45.1 ha. SANBI wetlands were larger on average, 1.42 ha, than the wetlands digitised for the full delineated coverage in this project, which was 0.87 ha, but had a wider range of sizes 0.002-214.8 ha. Combined, the two coverages produced the 1712 wetlands (Figure 4.1) and wetlands ranging in size from as small as a 0.002 ha freshwater seep to a large 214.8 salt pan depression (Figure 4.7).

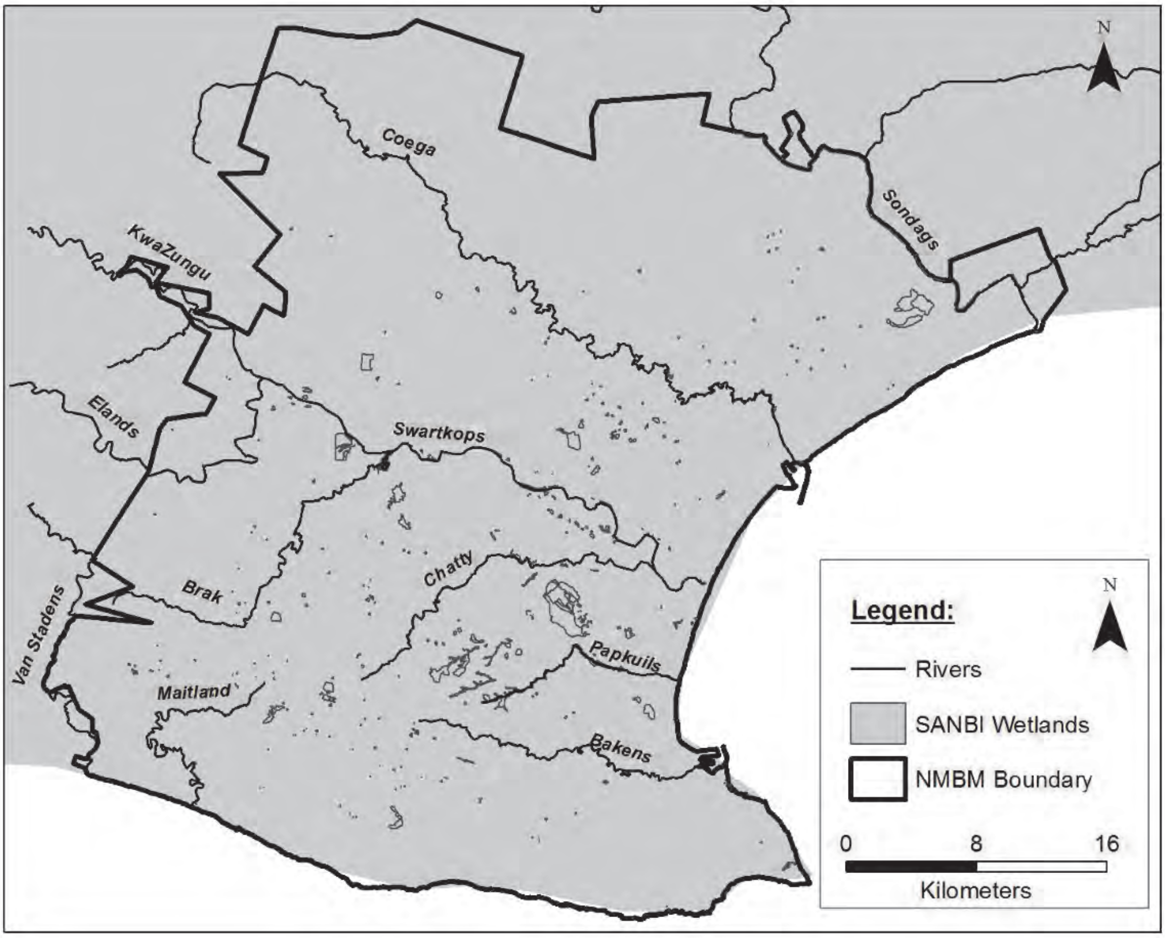


**Figure 4.6 Map of SANBI (2011) delineated wetlands in NMB.**

The underestimation in the NFEPA coverage had an effect on numbers of landscape units represented as well as total numbers wetlands (Figure 4.7). Valley floor wetlands and to a slightly lesser extent, slope sites, were recognised and delineated at a greater proportion to that of wetlands on benches, and there were no recognised wetlands on the plain landscape unit (Figure 4.7). The general pattern of wetland landscape units was the same between data sets, with the main difference being the degree of magnitude between the data sets (Figure 4.8). The biggest differences were in the numbers of the main HGMs: depressions, seeps and wetland flats. The other HGMs were more similar to the original SANBI numbers (Figure 4.9).

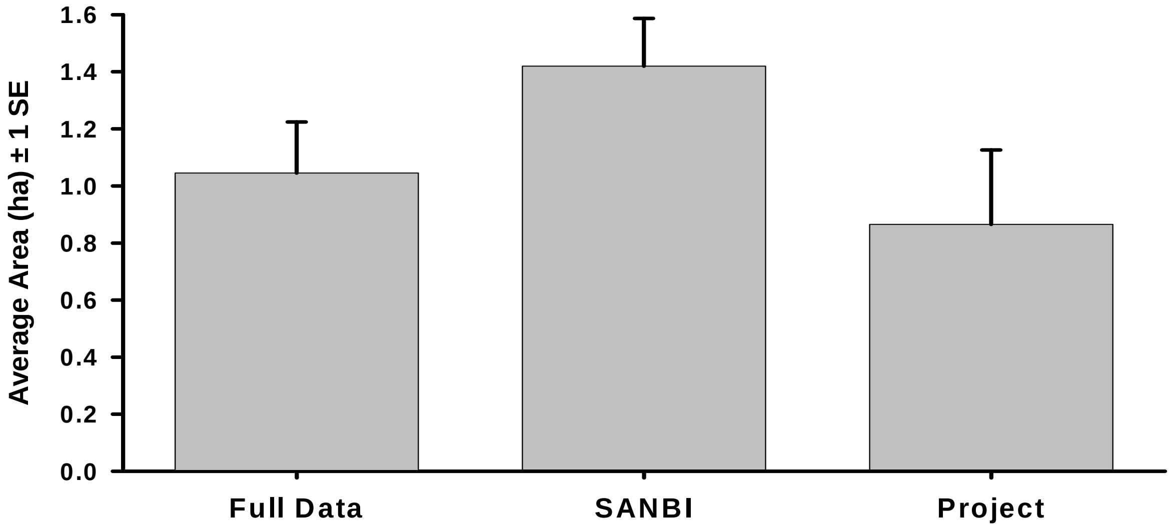


**Figure 4.7 Average size of wetlands delineated in this project compared to the SANBI (2011) coverage and the overall average (± 1 SE) for both data sets.**

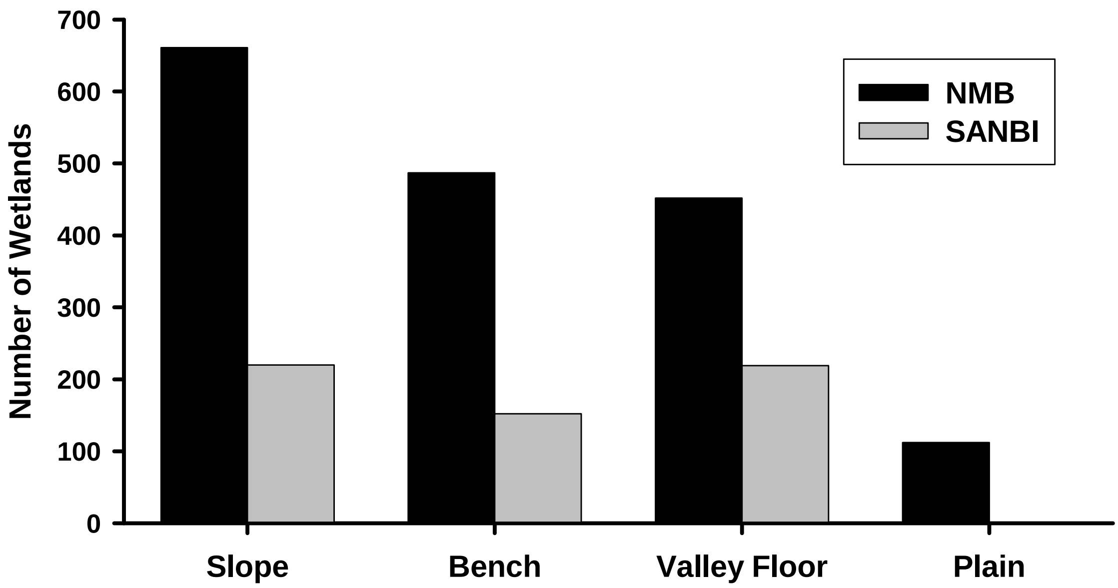


**Figure 4.8 Number of wetlands by landscape unit (Level 3 in the CS) comparing overall NMB and SANBI data.**

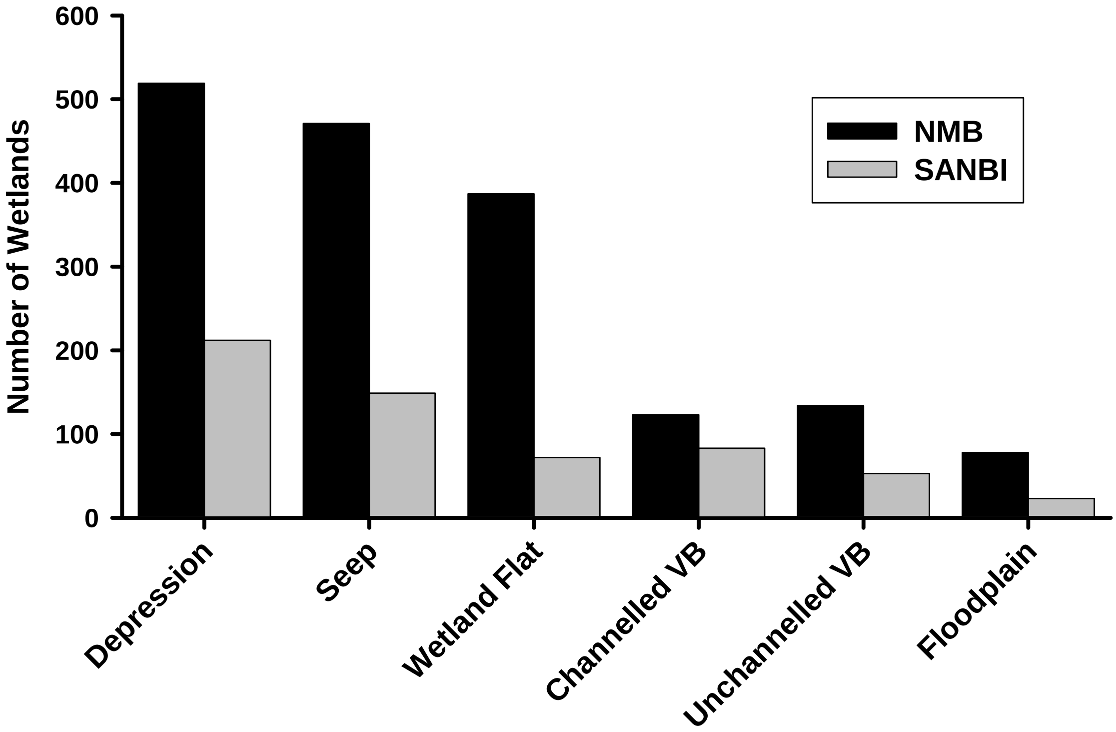


**Figure 4.9 Comparison between wetland numbers delineated per HGM for the full NMB data set and the SANBI data set. VB = valley bottom.**

### 4.3 Level 3-6 Classification of Selected Sites

Thus far, the data presented were for the desktop classification of the recognised wetlands within NMB. In order to use the CS in its entirety, 46 HGMs at 41 locations were chosen between 2012-13 for classification to Level 6, and more in-depth once-off sampling as described in Sections 3.4-3.5 (Table 4.2). The Level 3 assessment was refined for the bench landscape unit and divided into one of three types: saddle, shelf and hilltop. The latter two of the three types were present for the once-off sites. Three sites had two different HGMs connected, either a seep to a depression or to a wetland flat. One site had three seeps in sequence with clear visually defined vegetation communities, therefore they were split into three HGMs (site 1382, Table 4.2). The desktop component of Level 4 was described in Chapter 3. Levels 4a-c describe the hydrological characteristics and hydrodynamics (nature of the water movement in and out of the wetland, and the direction and strength of the flow respectively). Although Level 4 can be described at a desktop level, the confidence level of the assessment is increased when it is field verified. Water sources for the different HGMs are described in detail in the CS. Subsequently, Levels 4b-c are not applicable to wetland flats, and Level 4c for seeps. Depressions have the most diverse hydrological characteristics and hydrodynamics, thus all modes were assessed for this HGM.

**Table 4.2** **List of field sites by GIS database code, field code, geographic coordinates (Coord) and classification to Level 4 of the CS. Sites are arranged by area in NMB (See Figure 3.2), and the year in which they were sampled. Sites were sampled between September and December of each year, with the exception of *, which was sampled in March and ** in May of 2013. Depression HGMs were further classified into three sub-types at Level 4a. W/O Ch = without channel; W/Ch = with channel, n/a = not applicable for this HGM type.**

| | | | | | | Level 3 | Level 4: HGM Unit | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wetland ID | Field Code | X-Coord | Y-Coord | Area | Year | Landscape Unit | 4A | | 4B | 4C |
| 1593 | CR1 | 25.65959 | -34.00777 | 1 | 2012 | Plain | Wetland flat | | n/a | n/a |
| 1595 | CR2 | 25.65826 | -34.00753 | 1 | 2012 | Plain | Depression | Inter-dune | Endorheic | W/O Ch Inflow |
| 1596 | CR3 | 25.68600 | -34.00584 | 1 | 2012 | Plain | Depression | Pan | Dammed | W/O Ch Inflow |
| 1624 | NMMU1 | 25.68444 | -34.00694 | 1 | 2012 | Plain | Wetland flat | | n/a | n/a |
| 1626 | SBG1 | 25.66291 | -34.01336 | 1 | 2012 | Plain | Wetland flat | | n/a | n/a |
| 1627 | DuD1 | 25.64535 | -34.00046 | 1 | 2012 | Valley floor | Depression | Inter-dune | Endorheic | W/O Ch Inflow |
| 1641a** | ResA | 25.65568 | -34.01411 | 1 | 2013 | Plain | Seep | | W/Ch Outflow | n/a |
| 1641b** | ResB | 25.65671 | -34.01363 | 1 | 2013 | Plain | Depression | Pan | Endorheic | W/O Ch Inflow |
| 326 | TC2 | 25.48374 | -33.98322 | 2 | 2012 | Slope | Wetland flat | | n/a | n/a |
| 329 | TC1 | 25.48184 | -33.98550 | 2 | 2012 | Slope | Depression | Pan | Exorheic | W/O Ch Inflow |
| 1344 | CC1 | 25.38273 | -33.97307 | 2 | 2013 | Valley floor | Depression | Pan | Dammed | W/O Ch Inflow |
| 1647 | DFTN | 25.32904 | -33.94909 | 2 | 2013 | Slope | Depression | Pan | Dammed | W/O Ch Inflow |
| 1654 | SV2 | 25.36622 | -34.01732 | 2 | 2013 | Slope | Seep | | W/O Ch Outflow | n/a |
| 1655 | SV1 | 25.36819 | -34.01784 | 2 | 2013 | Slope | Seep | | W/O Ch Outflow | n/a |
| 683 | PV2 | 25.47138 | -33.91230 | 3 | 2012 | Slope | Depression | Pan | Exorheic | W/O Ch Inflow |
| 1699 | PV4 | 25.47032 | -33.92215 | 3 | 2013 | Bench hilltop | Wetland flat | | n/a | n/a |
| 789a | PV3a | 25.48831 | -33.90878 | 3 | 2013 | Bench hilltop | Depression | Pan | Exorheic | W/O Ch Inflow |
| 789b | PV3b | 25.48801 | -33.90770 | 3 | 2013 | Slope | Seep | | W/O Ch Outflow | n/a |
| 790a | PV1a | 25.48551 | -33.90562 | 3 | 2013 | Bench hilltop | Seep | | W/O Ch Outflow | n/a |
| 790b | PV1b | 25.48581 | -33.90509 | 3 | 2012 | Slope | Wetland flat | | n/a | n/a |
| 910* | HW3 | 25.40828 | -33.88168 | 4 | 2013 | Bench hilltop | Depression | Pan | Endorheic | W/O Ch Inflow |
| 944 | HW1 | 25.40724 | -33.87354 | 4 | 2012 | Bench hilltop | Depression | Bowl | Endorheic | W/O Ch Inflow |
| 947 | HW2 | 25.41190 | -33.87525 | 4 | 2012 | Bench hilltop | Depression | Pan | Endorheic | W/O Ch Inflow |
| 1016 | RH4 | 25.54663 | -33.83190 | 5 | 2013 | Valley floor | Wetland flat | | n/a | n/a |

| | | | | | | Level 3 | Level 4: HGM Unit | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wetland ID | Field Code | X-Coord | Y-Coord | Area | Year | Landscape Unit | 4A | | 4B | 4C |
| 1017 | RH3 | 25.54470 | -33.82998 | 5 | 2013 | Valley floor | Wetland flat | | n/a | n/a |
| 1019 | RH1 | 25.54057 | -33.82971 | 5 | 2013 | Valley floor | Depression | Pan | Endorheic | W/O Ch Inflow |
| 1648 | RH2 | 25.54439 | -33.82872 | 5 | 2013 | Valley floor | Wetland flat | | n/a | n/a |
| 743 | VSR1 | 25.21528 | -33.91320 | 6 | 2013 | Slope | Depression | Pan | Dammed | W/O Ch Inflow |
| 1668 | VSM2 | 25.22572 | -33.91622 | 6 | 2013 | Bench shelf | Wetland flat | | n/a | n/a |
| 1675 | YW1 | 25.22877 | -33.91290 | 6 | 2013 | Bench shelf | Wetland flat | | n/a | n/a |
| 1679 | VSM1 | 25.23575 | -33.95090 | 6 | 2013 | Slope | Wetland flat | | n/a | n/a |
| 749 | VSR2 | 25.22253 | -33.91369 | 6 | 2013 | Slope | Wetland flat | | n/a | n/a |
| 1310 | EW1 | 25.68759 | -33.73170 | 7 | 2013 | Slope | Depression | Pan | Endorheic | W/O Ch Inflow |
| 1311 | CZ6-1 | 25.39075 | -33.73305 | 7 | 2013 | Bench hilltop | Depression | Bowl | Endorheic | W/O Ch Inflow |
| 1359 | PL1 | 25.66212 | -33.71678 | 7 | 2013 | Bench hilltop | Depression | Pan | Endorheic | W/O Ch Inflow |
| 1649 | CDD1 | 25.79942 | -33.73520 | 7 | 2013 | Plain | Depression | Inter-dune | Endorheic | W/O Ch Inflow |
| 1650 | CDD2 | 25.79981 | -33.73540 | 7 | 2013 | Plain | Depression | Inter-dune | Endorheic | W/O Ch Inflow |
| 1651 | CDD3 | 25.79658 | -33.73422 | 7 | 2013 | Plain | Depression | Inter-dune | Endorheic | W/O Ch Inflow |
| 1380 | R75-2 | 25.45338 | -33.70309 | 8 | 2012 | Valley floor | Depression | Pan | Dammed | W/O Ch Inflow |
| 1381 | R75-3 | 25.45341 | -33.70228 | 8 | 2012 | Valley floor | Wetland flat | | n/a | n/a |
| 1625 | R75-1 | 25.45845 | -33.69553 | 8 | 2012 | Valley floor | Depression | Bowl | Endorheic | W/O Ch Inflow |
| 1691 | BED1 | 25.42619 | -33.67663 | 8 | 2013 | Slope | Seep | | W/O Ch Outflow | n/a |
| 1692 | BED2 | 25.42592 | -33.67612 | 8 | 2013 | Slope | Seep | | W/O Ch Outflow | n/a |
| 1382a | R75-4a | 25.44693 | -33.70510 | 8 | 2013 | Slope | Seep | | W/Ch Outflow | n/a |
| 1382b | R75-4b | 25.44693 | -33.70510 | 8 | 2013 | Slope | Seep | | W/Ch Outflow | n/a |
| 1382c | R75-4c | 25.44693 | -33.70510 | 8 | 2013 | Slope | Seep | | W/Ch Outflow | n/a |

### 4.3.1 Summary of general site characteristics

Sites in all four landscape units were evaluated. HGMs (Level 4) were present in four of the five landscape units (Table 4.3). There was an uneven distribution of HGMs, with 46% of sites being depressions (Table 4.3). This "skewness" was partly due to the diversity of hydrological characteristics and hydrodynamics. To get a representation of these different depression types, more depression HGM sites were chosen (Table 4.4). The dammed sites in this case refer to sites that have been slightly modified by a road that resulted in back-flooding. Most would probably have been endorheic without the influence of the road-cut.

**Table 4.3 Distribution of HGM types by landscape unit.**

| | | HGM | | |
|---|---|---|---|---|
| **Landscape Unit** | **Depression** | **Wetland Flat** | **Seep** | **Total** |
| **Bench hilltop** | 6 | 1 | 1 | **8** |
| **Bench shelf** | | 2 | | **2** |
| **Plain** | 6 | 3 | 1 | **10** |
| **Slope** | 5 | 4 | 8 | **17** |
| **Valley floor** | 5 | 4 | | **9** |
| **Total** | **22** | **14** | **10** | **46** |

**Table 4.4 The number and type of different HGMs by Levels 4a-c. W/O Ch = without channel; W/Ch = with channel.**

| 4A | 4B | 4C | Total |
|---|---|---|---|
| **Depression** | Dammed | W/O Ch Inflow | **5** |
| | Endorheic | W/O Ch Inflow | **14** |
| | Exorheic | W/O Ch Inflow | **3** |
| **Wetland Flat** | **-** | - | **14** |
| **Seep** | W/Ch Outflow | | **4** |
| | W/O Ch Outflow | | **6** |
| **Total** | | | **46** |

The Level 5 assessment concentrates on the hydrological regime. As depressions, seeps and wetland flats are examined here, there is no flow assessed, but the inundation and saturation levels and periods are evaluated. Permanent systems can be evaluated for depth class; however, none of the sites observed were permanently inundated (Table 4.5). One seep site was permanently saturated, with the inundation dominance being mixed (seasonal/intermittent) (Table 4.5). By HGM, wetland flats and seeps were dominated by intermittent inundation and saturation periods. Depressions, however, were a mix of seasonal and mixed (seasonal/intermittent) saturation and inundation (Table 4.5). Overall, the sites used for this assessment were predominantly intermittently to seasonally saturated and inundated (Figure 4.10), with a few sites that were rarely saturated.

**Table 4.5 Sites evaluated for Levels 5a-b (hydroperiod): dominant inundation, and saturation periodicity. Sites with co-dominant periods of inundation and saturation are considered "Mixed", with the co-dominants listed in parenthesis. P/S = permanent and seasonal; S/I = seasonal and intermittent; I/R = intermittent and rarely.**

| Inundation | Saturation | Depression | Wetland Flat | Seep | Total |
|---|---|---|---|---|---|
| Seasonal | Permanent | | | 2 | **2** |
| | Seasonal | 5 | | | **5** |
| | Mixed (S/I) | 2 | 2 | | **4** |
| Mixed (S/I) | Permanent | | | 1 | **1** |
| | Seasonal | 2 | 1 | | **3** |
| | Intermittent | 1 | | | **1** |
| | Mixed (S/I) | 2 | | | **2** |
| Intermittent | Seasonal | 1 | 2 | 1 | **4** |
| | Intermittent | 3 | 7 | 3 | **13** |
| | Mixed (S/I) | 4 | 2 | 1 | **7** |
| Mixed (I/R) | Mixed (I/R) | 1 | | | **1** |
| Rarely | Intermittent | | | 1 | **1** |
| | Mixed (S/I) | 1 | | 1 | **2** |
| **Total** | | **22** | **14** | **10** | **46** |

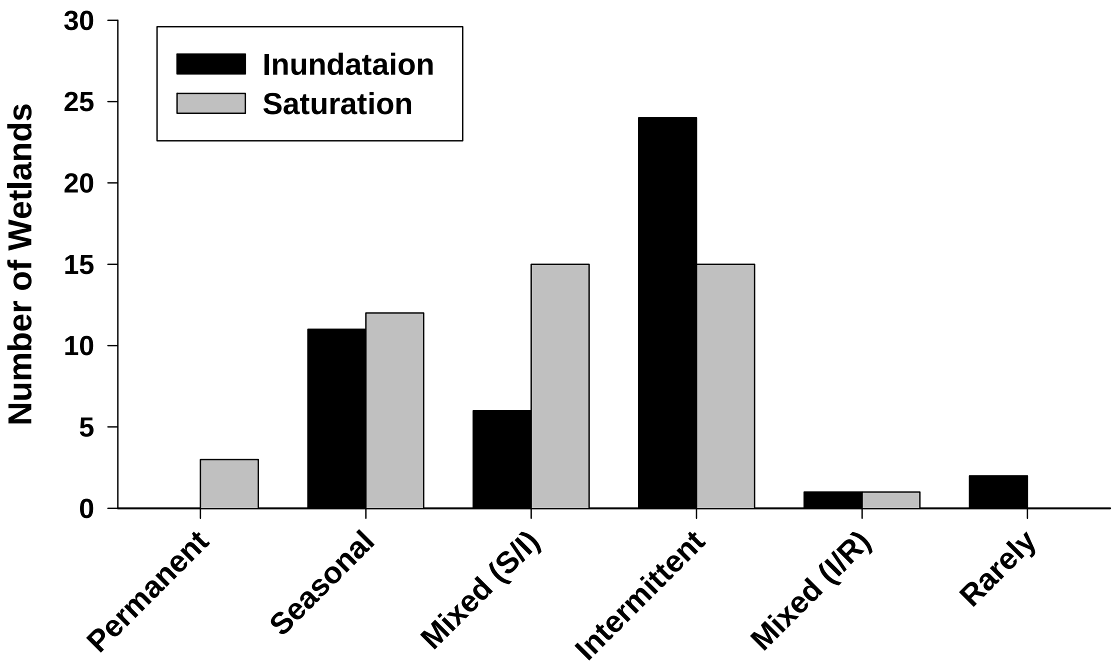


**Figure 4.10 Numbers of wetlands with different dominant inundation and saturation periods. S = seasonal, I = Intermittent and R = rarely.**

Level 6 of the CS characterises the site in terms of general water chemistry, underlying geology, substrate vegetation cover and broad types. It is the most descriptive part of the CS and therefore the most difficult to distil down and summarise across sites. All sites can be considered natural. However, a few have a degree of modification and not all could be considered pristine or un-impacted. Data used for the Level 6 assessment are observed on-site and more detailed data for some sections of this level will be presented in subsequent chapters.

In terms of pH and electrical conductivity for the Level 6a classification, the majority of the sites were circum-neutral (6 slightly alkaline and 2 slightly acidic) and considered fresh, with one each brackish and saline, and three hypersaline sites. The dominant substratum type was sand in 63% of the sites (Table 4.6). The sites were on a wide range of underlying geological types, but most were dominated by quarzitic sandstone and aeolian sand (Table 4.7). A full list of the geological types and sequence in NMB is outlined in Appendix B. Vegetation is shown in Table 4.8.

Most of the dominant vegetation status for the sites evaluated would be considered indigenous. Given the nature of ephemeral wetlands, there is an influence of alien vegetation, especially pioneer weed species. These, however, were not the dominant vegetation features at any of the sites. Most sites were grass and/or sedge dominant, with 65% of the sites having one or the other as dominant vegetation form (Table 4.8). Aquatic vegetation was predominantly found in depressions, with only one other site (a wetland flat), having aquatic vegetation.

**Table 4.6 Summary of substratum types by HGM.**

| **6a: Substratum types** | | **HGM** | | |
|---|---|---|---|---|
| **Primary** | **Secondary** | **Depression** | **Wetland Flat** | **Seep** |
| **Clay** | Sandy clay | 4 | 1 | 4 |
| **Gravel/Clay** | Gravel | 1 | | |
| **Pebbles/Gravel/Sand** | Gravel | 1 | | |
| **Sandy** | Sand | 10 | 8 | 6 |
| **Sandy/Clay** | Sand | | 3 | |
| **Sand/Silt** | Sand | 1 | 1 | |
| **Silty** | Silt | 4 | 1 | |
| **Silt/Clay** | Silty clay | 1 | | |

**Table 4.7 Underlying geological types associated with sampled sites (by HGM type).**

| Formation | Level 6a: Geology | Depression | Wetland Flat | Seep |
|---|---|---|---|---|
| Recent deposits | Aeolian sand; Intermediate & low-level fluvial terrace gravel | 8 | 6 | 1 |
| Bluewater Bay | Alluvial gravel, sand, silt | 3 | | |
| Nanaga | Semi-consolidated to consolidated calcareous sandstone and sandy limestone with large-scale cross-bedding | 2 | 2 | |
| Kirkwood | Variegated (reddish-brown and greenish) silty mudstone and sandstone, subordinate grey shale and sandstone | 2 | 1 | |
| Skurweberg | Medium to coarse grained quarzitic sandstone | 2 | | |
| Goudini | Brownish-weathering, quartzitic sandstone, subordinate shale & siltstone | 1 | | |
| Van Stadens | Quartzite, arkose, phyllite, conglomerate | | 1 | |
| Peninsula | Quarzitic sandstone, minor conglomerate and shale | 4 | 4 | 7 |
| Kleinrivier | Phyllite, quartzite, conglomerate, arkose, greywacke | | | 2 |

**Table 4.8 Level 6 vegetation parameters by HGM.**

| Vegetation Cover | Vegetation Form | | HGM | | |
|---|---|---|---|---|---|
| **A** | **B** | **C-D** | **Depression** | **Seep** | **Wetland Flat** |
| Unvegetated | | | 3 | | |
| Unvegetated/Vegetated | Herbaceous | Herbs & Forbs | 1 | | |
| | Aquatic | Submerged | 1 | | |
| Vegetated | Aquatic/Herbaceous | Submerged/Sedges | 3 | | |
| | | Free-floating/Sedges/Restios | | | 1 |
| | | Floating-attached/Rushes | 1 | | |
| | Herbaceous | Grasses | 4 | 1 | 4 |
| | | Grasses/Herbs & Forbs | 1 | 1 | |
| | | Grasses/Sedges | 1 | 1 | 1 |
| | | Reeds | 1 | 2 | 1 |
| | | Restios | | 2 | 1 |
| | | Rushes | | | 1 |
| | | Sedges | 6 | 2 | 3 |
| | | Sedges & Rushes | | 1 | 1 |
| | Shrubs & Thicket/Herbaceous | Grasses/Rushes/Shrubs | | | 1 |

### 4.3.2 Examples of complete sites as per CS

To demonstrate Level 1-6 summaries for individual sites, a sub-sample of 8 sites is presented. As depressions were present in all sampled areas and are the dominant HGM type, one site from each area of NMB was randomly selected (see Figure 3.2). The examples of sites are shown in Figures 4.11 and 4.12, and site codes correspond to Table 4.2.

Tables 4.9 to 4.11 are examples of data output tables produced when assessing sites in the field from Level 1 to Level 6 of the CS. All the data collected were analysed as per the User Manual "rules" for the various sections in Ollis *et al.* (2013). Each component of Levels 5 and 6 have cover ratings and this detailed information can be distilled down into their dominant (or co-dominant) characteristics as shown in Tables 4.10 and 4.11.

As all sites were assessed in the field, the assessment confidence was high for all components (Table 4.9). In this example, all sites were depressions, but some have different hydrological characteristics defining their connectivity to surface water inputs and outputs. None of the sites had channelled inflow, but all three outflow characteristic have been demonstrated here: endorheic (inward draining), exorheic (outward draining) and dammed (artificially regulated). In these cases, the exorheic flow was diffuse surface and/or sub-surface flow based and the dammed sites were due to anthropogenic disturbance. Site number 743 (VSR1) was an abandoned gravel pit with a shored up berm wall on two sides. VSR1 now resides inside a protected area, the Van Stadens Flower Reserve. VSR1 has since "naturalised" and probably would have originally been a smaller endorheic depression. Site number 1380 (R75-2) was disturbed by the R75 road. This site is a large salt pan, whose extent goes beyond and under the road (Figure 4.13c) via a berm and culvert, to prevent the road from being flooded during high rainfall periods or events. This site would also been endorheic had it been left undisturbed. The majority of these sample sites were intermittently inundated and were a mix of seasonal and intermittently saturated (Table 4.10).

The underlying geology was as varied in these eight sites as in the whole database. The substratum was sandy to silt/clay. Site 743 was gravel dominated, which demonstrates why at some point in its history it was exploited for its gravel. All of these sites were vegetated, although each site showed different dominance in terms of dominant aquatic and marginal vegetation. These eight sites all had vegetation and soils indicative of wetlands, supporting the desktop assessment (Table 4.11).

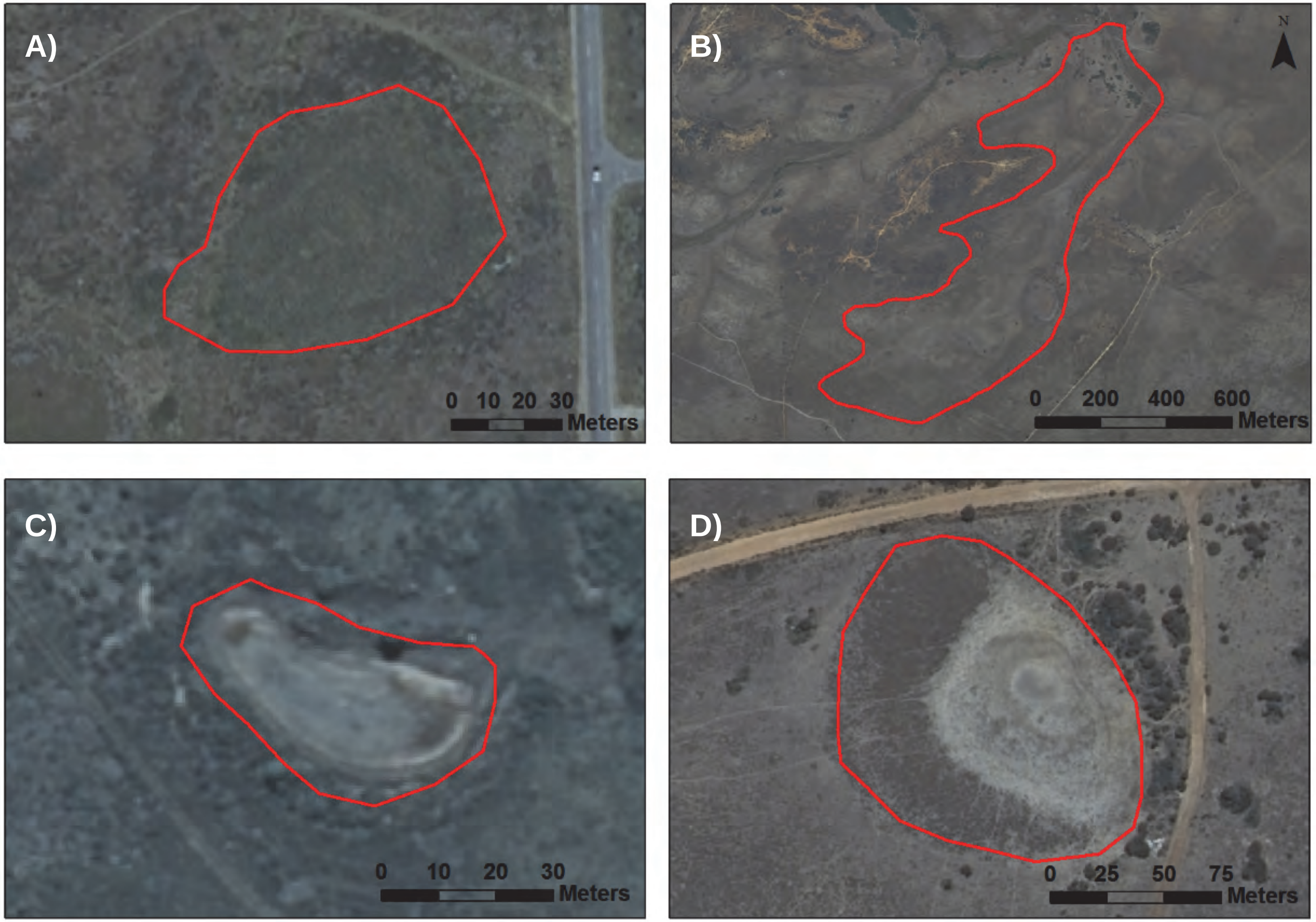


**Figure 4.11** **Aerial photos with four of the eight sites demarcated for the application of CS Levels 1 to 6: A) 329; B) 683; C) 743 and D) 910, see Table 4.2 for site codes, coordinates and information.**

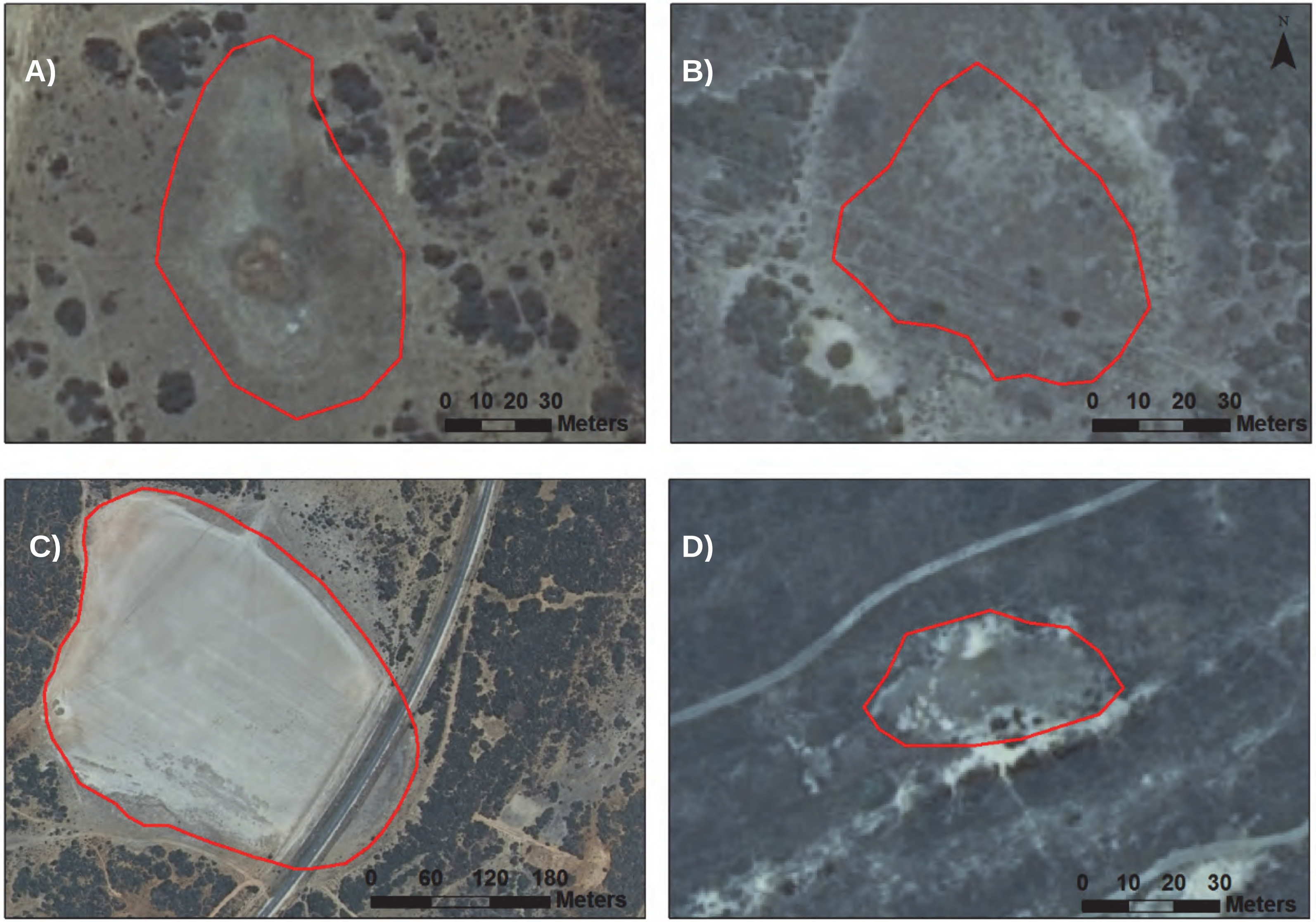


**Figure 4.12** Aerial photos with four of the eight sites demarcated for the application of CS Levels 1 to 6: A) 1019; B) 1359; C) 1380; D) 1595, see Table 4.2 for site codes, coordinates and information

**Table 4.9** Results of the application of Levels 1 to 4 of the CS to the 8 depression wetlands.

| | | Level 1 | Level 2: Regional Setting | Level 3 | Level 4: HGM | | |
|---|---|---|---|---|---|---|---|
| Wetland ID | Field Code | System | DWA Ecoregion | Landscape Unit | 4A | 4B | 4C |
| 1595 | CR2 | Inland | Southern Coastal Belt | Plain | Depression | Endorheic | Without Channel Inflow |
| 329 | TC1 | | | Slope | | Exorheic | |
| 683 | PV2 | | | | | Exorheic | |
| 743 | VSR1 | | | | | Dammed | |
| 910 | HW3 | | | Bench hilltop | | Endorheic | |
| 1359 | PL1 | | | | | Endorheic | |
| 1019 | RH1 | | | Valley floor | | Endorheic | |
| 1380 | R75-2 | | | | | Dammed | |

**Table 4.10 Dominant hydroperiod for the 8 depression wetlands at Level 5.**

| | | Level 5: Dominant hydroperiod (and inundation depth-class) | | |
|---|---|---|---|---|
| Wetland ID | Field Code | 5A: Inundation period | 5B: Saturation period | 5C: Inundation depth-class |
| 1595 | CR2 | Intermittent | Intermittent | n/a |
| 329 | TC1 | Seasonal | Mixed (Seasonal/Intermittent) | |
| 683 | PV2 | | | |
| 743 | VSR1 | | Seasonal | |
| 910 | HW3 | | | |
| 1359 | PL1 | | | |
| 1019 | RH1 | Intermittent | Intermittent | |
| 1380 | R75-2 | Seasonal | Seasonal | |

**Table 4.11 The dominant characteristics of the 8 depression wetlands according to descriptors at Level 6.**

**Level 6: Dominant descriptor categories**

| | | Natural vs. Artificial | | Broad Chemistry | | | Substratum type | | Vegetation cover, form, status | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wetland ID** | **Field Code** | **6A** | **6B: Artificial sub-categories** | **Salinity** | **pH** | **6a: Geology (lithology)** | **6a: Primary Soil** | **6b: Secondary** | **6A: Veg Cover** | **6B: Veg Form** | **6C: Aquatic Veg** |
| 1595 | CR2 | | | Fresh | Alkaline | Aeolian sand | Sandy | Sand | | Herbaceous | n/a |
| 329 | TC1 | | | Fresh | Circum-neutral | Semi-consolidated to consolidated calcareous sandstone and sandy limestone with large-scale cross-bedding | Silt | Silt | | Aquatic/Herbaceous | Submerged |
| 683 | PV2 | | | Fresh | Circum-neutral | Quartzitic sandstone, minor conglomerate and shale | Sandy/Silt | Sand | | Herbaceous | n/a |
| 743 | VSR1 | Natural | n/a | Fresh | Circum-neutral | Quartzitic sandstone, minor conglomerate and shale | Pebbles/Gravel/Sandy | Gravel | Vegetated | Aquatic/Herbaceous | Floating attached/Submerge |
| 910 | HW3 | | | Fresh | Circum-neutral | Goudini – Brownish-weathering, quartzitic sandstone, subordinate shale & siltstone | Clayey | Clay | | Herbaceous | n/a |
| 1359 | PL1 | | | Fresh | Alkaline | Alluvial gravel, sand, silt | Silt | Silt | | Herbaceous | n/a |
| 1019 | RH1 | | | Brackish | Circum-neutral | Intermediate & low-level fluvial terrace gravel | Sandy | Sand | | Herbaceous | n/a |
| 1380 | R75-2 | | | Saline | Alkaline | Variegated silty mudstone and sandstone, subordinate grey shale and sandstone | Clayey | Clay | | Aquatic | Submerged |

## 4.4 Summary

The primary aim of this chapter was to use the CS in NMB. We started with the simple question: how many wetlands were in NMB? We used the SANBI coverage, available resources (Appendix A, Table A.1), and the CS user manual to determine where and how many wetlands currently exist in NMB. It was a laborious process, but one that was well worth the effort. Through the structure of the CS, the classification of the wetlands of the area was possible in a systematic and reproducible way. On a desktop level, with available resources, it was possible to type demarcated wetlands to Level 4 of the CS with high confidence. This may not be possible in all regions of the province, let alone the country. We were fortunate to have resources at our disposal, such as high resolution aerial photos, that are not necessarily widely available or accessible. The study area was relatively small, which helped focus our resources, and accessibility to most areas was good. With expert knowledge and support, ground-truthing the desktop data was feasible. Over one-thousand more wetlands were added to the national database through this process.

Whilst the CS is relatively user friendly on a desktop level, completing the entire classification to Level 6 on a multi-site scale is not as simple. The manual is clear and does guide the user through each level, but there is a learning curve and some aspects are dependent on the knowledge and background of the person doing the assessment. The system of ratings can be difficult to follow especially when there are several factors that are similar or co-dominant in the various categories. It also takes a bit of experience to gage the different levels of inundation and saturation along with its periodicity, if the assessor is not familiar with the area. The best case scenario for detailed assessments would be to visit the site or sites of interest at different times/levels of inundation (for ephemeral systems this would be in a dry and wet period). This is rarely possible, however. The reporting of the data is also cumbersome for more than a few sites. For instance, in this chapter we only selected 8 of our 46 HGMs to report, because of the sheer volume of information that is produced and difficult to condense or analyse statistically/quantitatively.

The CS was general enough to allow for different types of systems to be classified in a standard manner, and adaptive enough to allow for “atypical” situations. We were fortunate to have a wet sampling year to learn our way forward and gain experience. It is more difficult to define and assess ephemeral systems during dry times (Day *et al.* 2010).

The information generated through this process is invaluable for the NMBM. The municipality now has a thorough database of wetlands to integrate into both their conservation and urban planning sections. This allows the NMBM to operate from a point of knowledge, gives more power to the decision makers and managers, and aids in rational future development.

In addition, the data gathered here can be taken further with other wetland assessment tools to assess ecosystem health and ecosystem service provision of target sites.

# 5 ABIOTIC CHARACTERISATION OF EPHEMERAL WETLANDS IN NMB

Wetlands are true multidisciplinary, multi-scalar and multifaceted systems. It is important to get an understanding of the abiotic template that the biotic parameters interact with to understand the system as a whole. The first levels of the CS, as reported in Chapter 4, set the landscape context, underlying geology, geomorphology, and general hydrology. These are large scale features that have an effect on local scale features and processes. This chapter reports on the abiotic characteristics of NMB wetlands on a local scale. As most of the wetlands in NMB are precipitation driven, rainfall and positon in landscape are very important as a base to understand the dynamics of wetland systems and other abiotic drivers.

## 5.1 The Influence of Landscape and Rainfall Patterns

The NMB region experiences approximately 618 mm (± 160 mm) of rainfall per annum (Figure 5.1). Table 5.1 below illustrates the environmental conditions during field sampling. The rainfall had an influence on the data collected and this was accounted for as far as possible. The first year of the study (2012) had flood conditions with a total of 962 mm of rainfall. The second year had much drier conditions with 575 mm of rainfall.

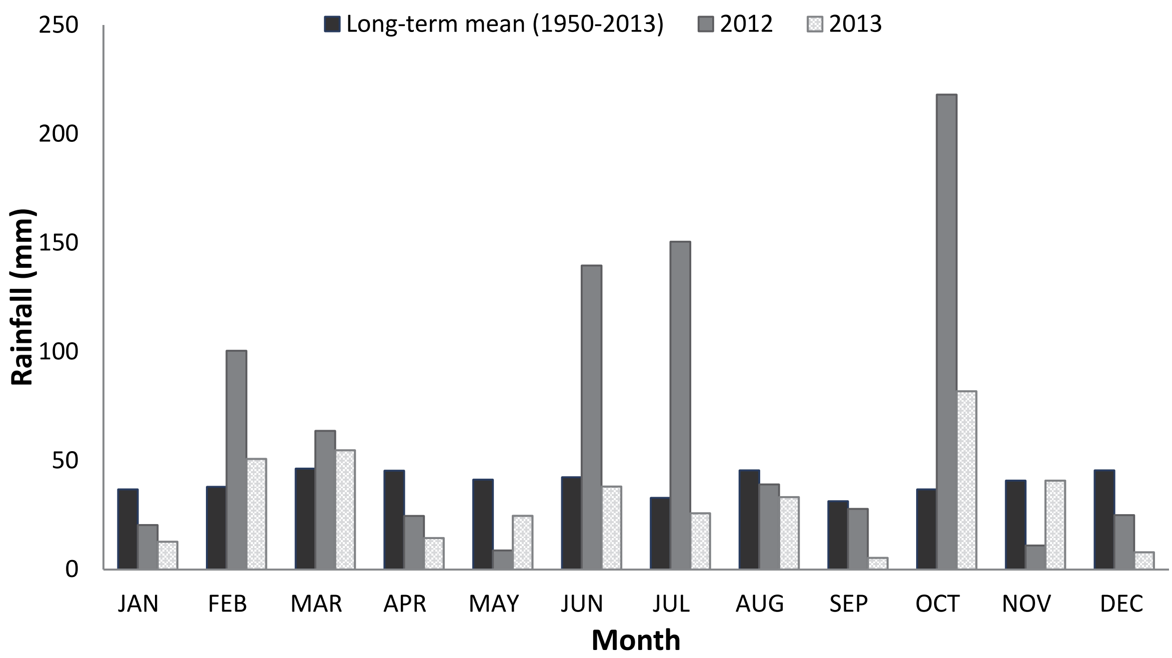


**Figure 5.1 Monthly rainfall measured (mm) in NMB during the fieldwork season (2012-2013) compared to the long-term mean. Raw data obtained from SAWS (2013).**

**Table 5.1 Environmental conditions during 2012 and 2013 field work periods.**

| | 2012 | 2013 |
|---|---|---|
| **Rainfall in preceding months** | High with several flood events | Very low |
| **General climate condition** | Flood | Drought |
| **Inundation levels observed** | ¾ full to flood (over-full) | Dry – ½ full |
| **Types of wetlands inundated** | All (temporary & permanent) | Permanent & seasonal; wetlands in contact groundwater |

Annual rainfall increases from the northern section of the Municipality (catchments M30A & B, N40E & F) towards the south (M20A and B), which coincides with an increase in the total number of wetlands found within a catchment (Figure 5.2 and Table 3.6). Almost all wetland types were found within these nine quaternary catchments, with the exception of floodplain wetlands which were limited to the coastal areas and along permanent river/estuarine systems (Figure 5.2). Seeps and wetland flats were more prominent in the southern parts of the municipality, with higher rainfall, while depressions were more common in the drier, northern parts of the Municipality (Figure 5.2).

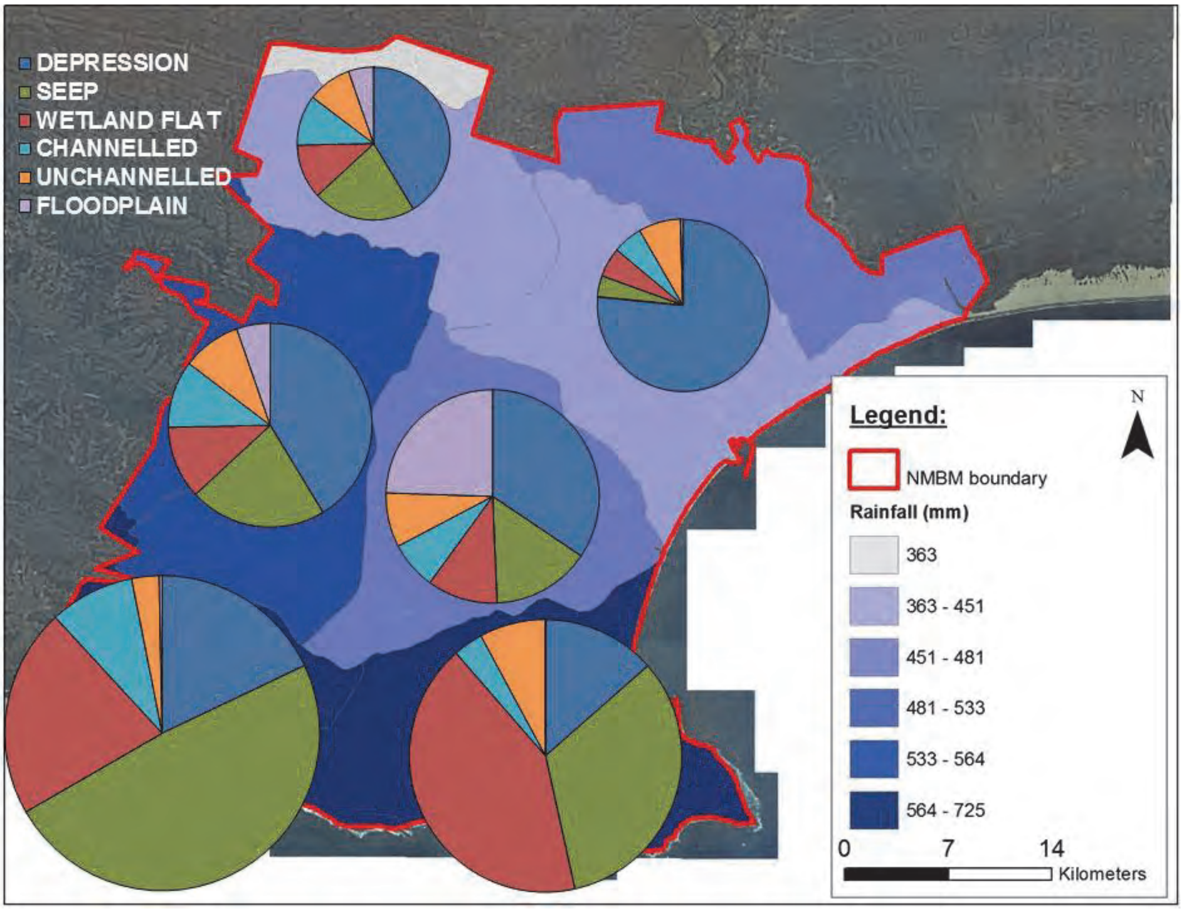


**Figure 5.2 HGM types found in each quaternary catchment in NMB with pie chart sizes indicating the relative number of wetlands compared to other catchments. Associated annual rainfall per catchment is illustrated.**

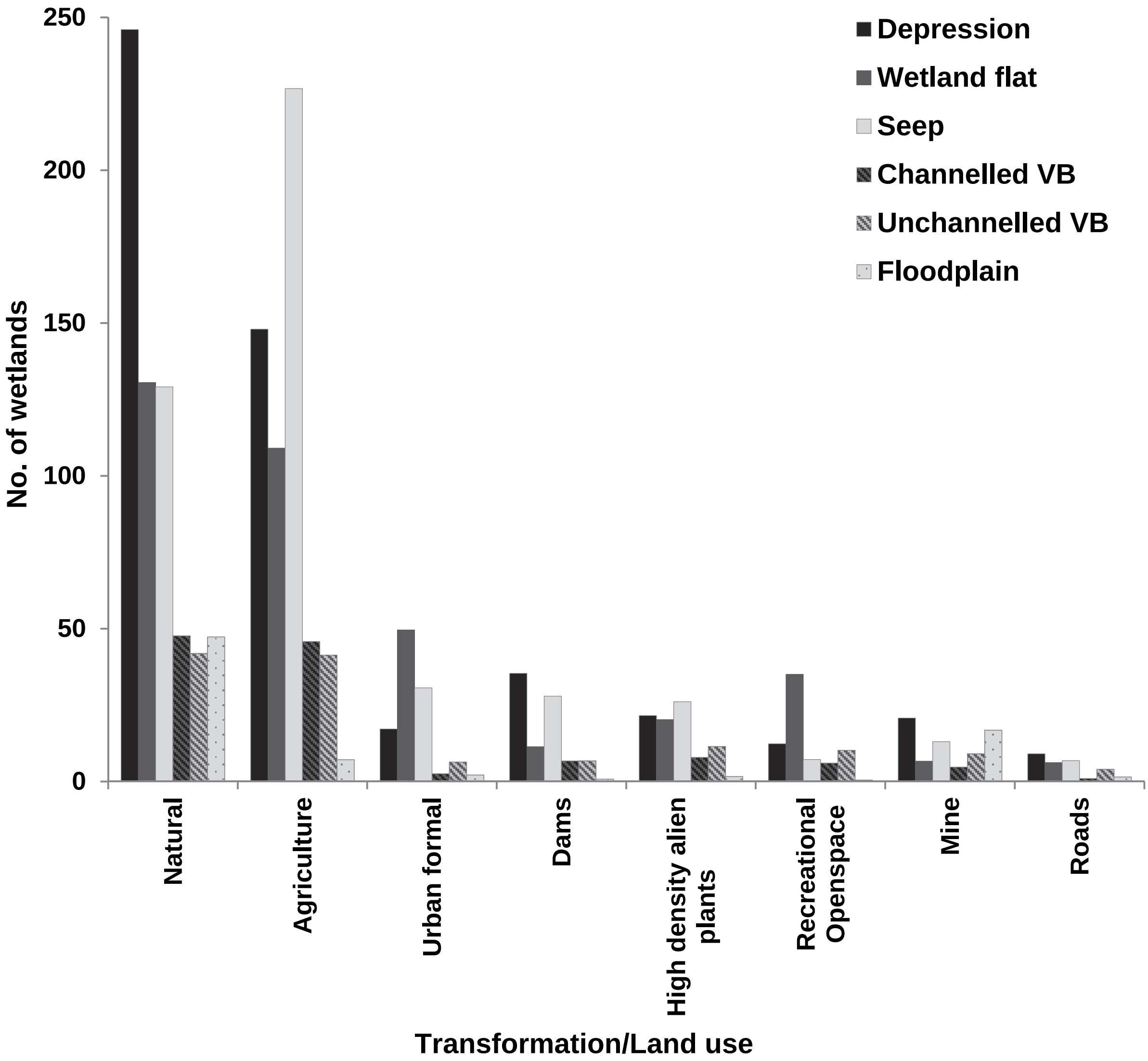


**Figure 5.3 HGM types associated with the most common transformation. "Natural" indicates areas of the Municipality that have not been developed.**

Most wetlands were found within agricultural areas and in the Nelson Mandela Open Space System ("natural areas") (Figure 5.3). However, wetlands were also found in transformed and degraded areas, such as urban areas and land dominated by alien vegetation (Figure 5.3). These results explain the degree of modification seen in wetlands in NMB (Figure 4.6).

A large portion of the wetlands were found in areas with more recent geology, such as aeolian sand (recent deposits), and the Algoa and Grahamstown Groups (Figure 5.4). Recent deposits as well as formations within the Algoa group are predominantly comprised on easily erodible aeolian sand, with a relatively coarse particle size (dominated by coarse sands and gravel) (Appendix B, Table B.1). The Grahamstown group is comprised of silcrete material and is associated with depressions and wetland flats. A large number of wetlands, especially wetland flats were also associated with the Gamtoos group (Figure 5.4).

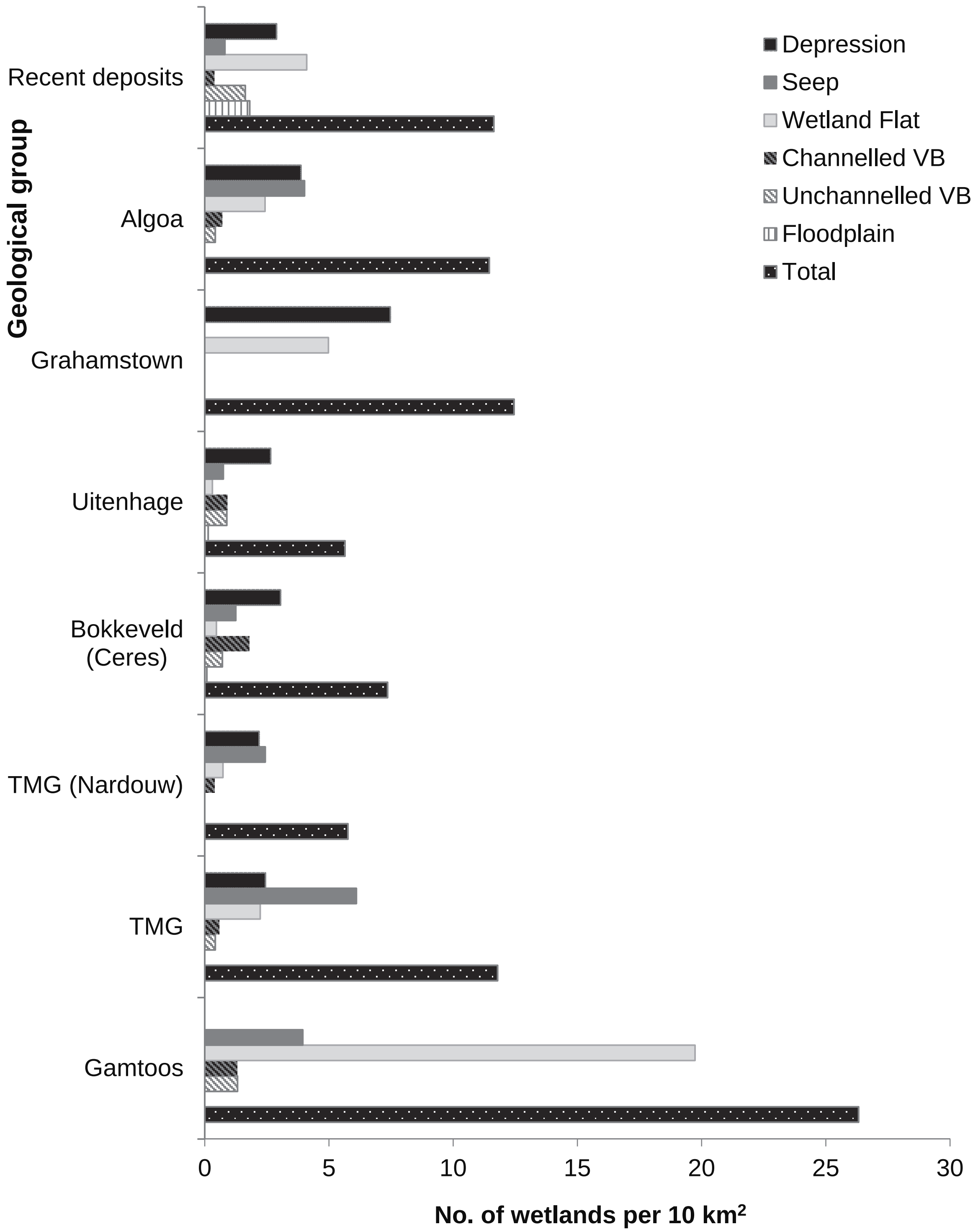


**Figure 5.4** **Underlying geological groups associated with the HGM types. See appendix for full group/subgroup description.**

Depressions were situated in all soil depths, especially dominating in shallow soils of 301-450 mm (Figure 5.5). Seeps and wetland flats were found in medium to deep soils of greater than 450 mm in depth, especially wetland flats which were predominately situated in deep soils (greater than 750 mm) (Figure 5.5). Channelled and unchannelled valley bottom wetlands and floodplain wetlands were also associated with deep soils (Figure 5.5).

A few wetlands from each HGM type were found on classified wetland soils (Figure 5.6). However, the majority of wetlands in NMB were situated on soils that have been classified as freely drained, structureless or sandy soils by ARC, supporting the aforementioned geological data (Figure 5.6).

A third of the wetlands in NMB were associated with intergranular rock (Figure 5.7). Wetlands were also associated with fractured rock, with greater densities linked to a higher potential groundwater occurrence (Figure 5.7). Depressions were more evenly spread throughout the different groundwater regions, while all other HGM units were primarily associated with one or two areas (Figure 5.7). Seeps and wetland flats were predominantly located in fractured rocks with a potential discharge of 0.5-2.0 $L.s^{-1}$, while the other three HGM units were primarily associated with high yielding fractured rocks and the intergranular rock (Figure 5.7).

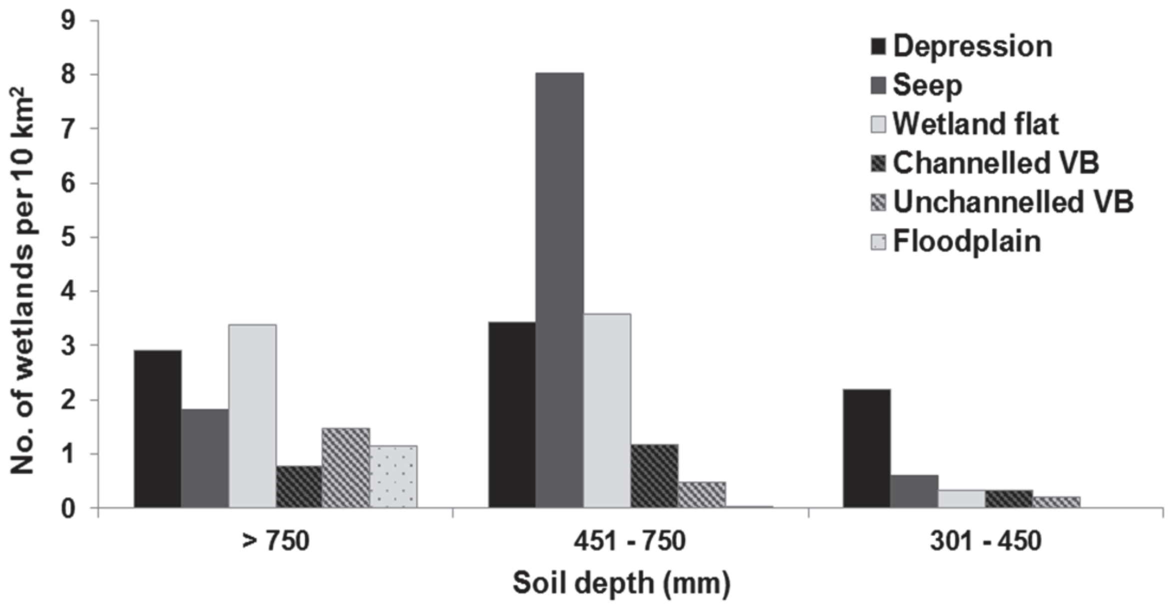


**Figure 5.5** **The number of wetlands found within each soil depth zone. VB = valley bottom wetland.**

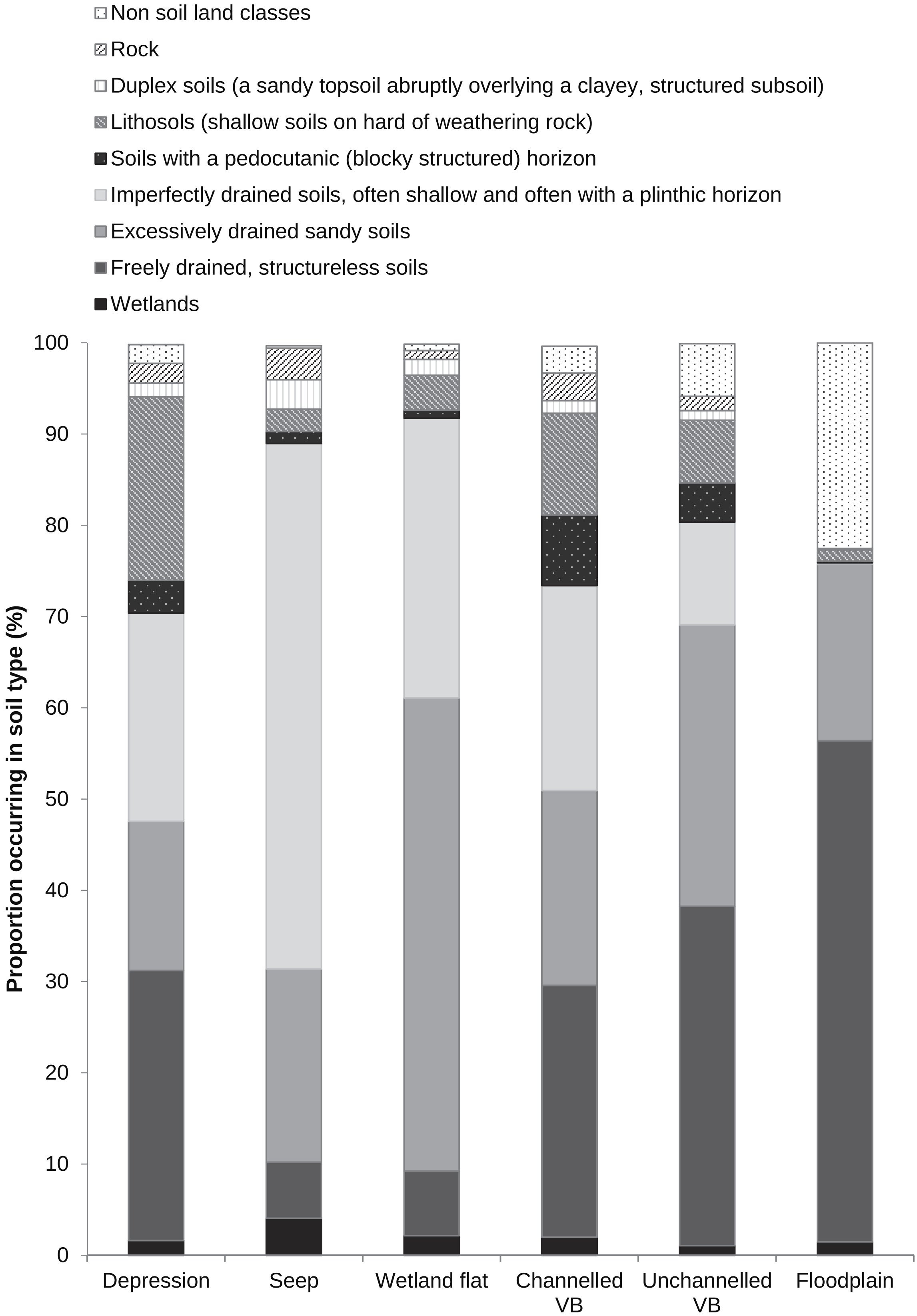


**Figure 5.6 Proportion of wetlands found within different soil types per HGM unit.**

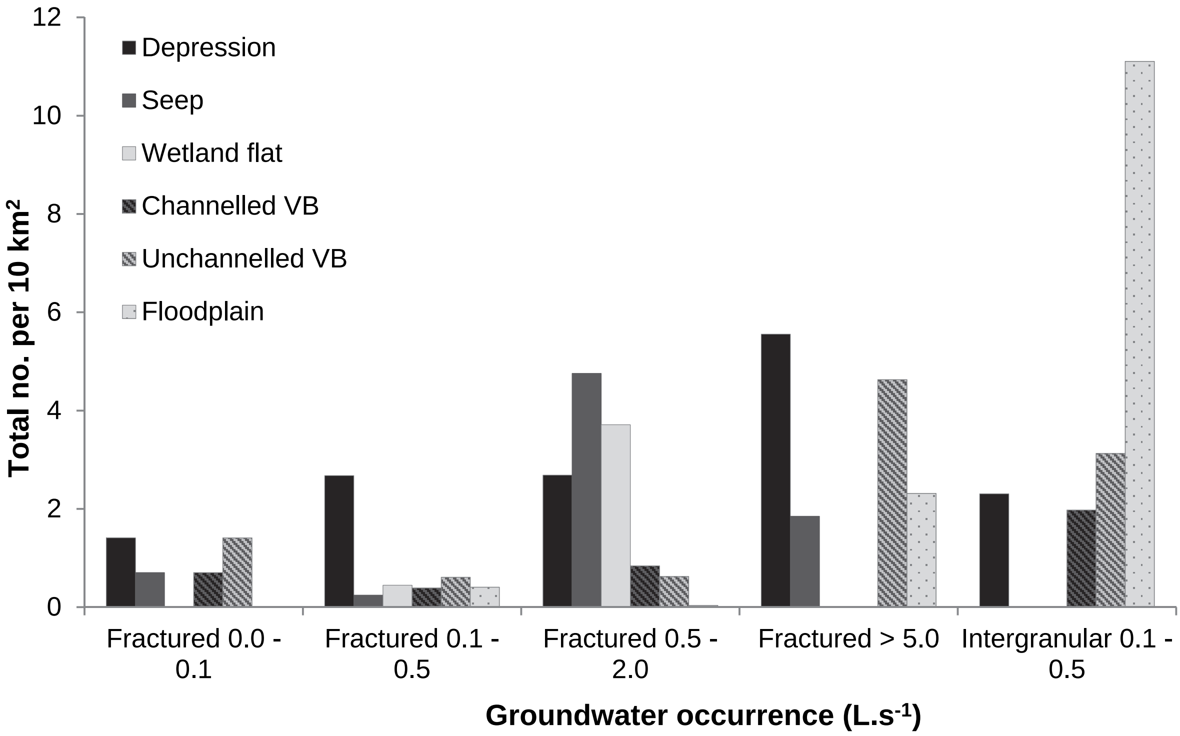


**Figure 5.7 The number of wetlands associated with the regional groundwater occurrence (in fractured and intergranular rock).**

## 5.2 Soils

Various soil wetland indicators were found in the soil samples analysed at the once-off sites. The most prominent indicator was high organic matter in the surface layer of the sediment which was found at 78% of the sites (Figure 5.8). Mottles and concretions were found in cores at 61% of the sites while 57% of the sites had soils with a low chroma (Figure 5.8). Sulfidic odours and organic soils, that are more prevalent in permanent wetland systems, were not found in most of the sites, as predicted (Figure 5.8). Wetlands situated on aeolian sand generally did not have soil indicators present. When looking at the same data in terms of HGM units, the top three indicators were highest for the three HGM units (Figure 5.8).

Approximately 96% of soils in South Africa have less than 2% organic matter (OM) (Du Preez *et al.* 2011). The mean for the wetland sites in NMB was almost double with an average 3.36% (Figure 5.9). There was variation in the average percentage OM among the different regions and across HGM units; however, a large portion of this is directly related to the surrounding land use and is not a result of the system itself.

Table 5.2 summarises the physico-chemical parameters that were correlated with each other. As expected, there was a strong relationship between surface water electrical conductivity (ECS) and salinity ($r^2$ = 0.52) (Table 5.2). There were also similar relationships among ECS, salinity and pH, in surface water, sub-surface and in the soils (Table 5.2). A positive correlation was found between the percentage organic matter and the soil moisture ($r^2$ = 0.55). However, the climatic conditions also played a role in the soil moisture, with samples in 2013 being drier than the samples collected in 2012 (after the flooding) (Figure 5.10 and Table 5.1). A weaker correlation existed between organic matter and the soil percentage clay content ($r^2 = 0.34$). The clay content of the soil was also correlated with the sub-surface physico-chemical parameters (Table 5.2).

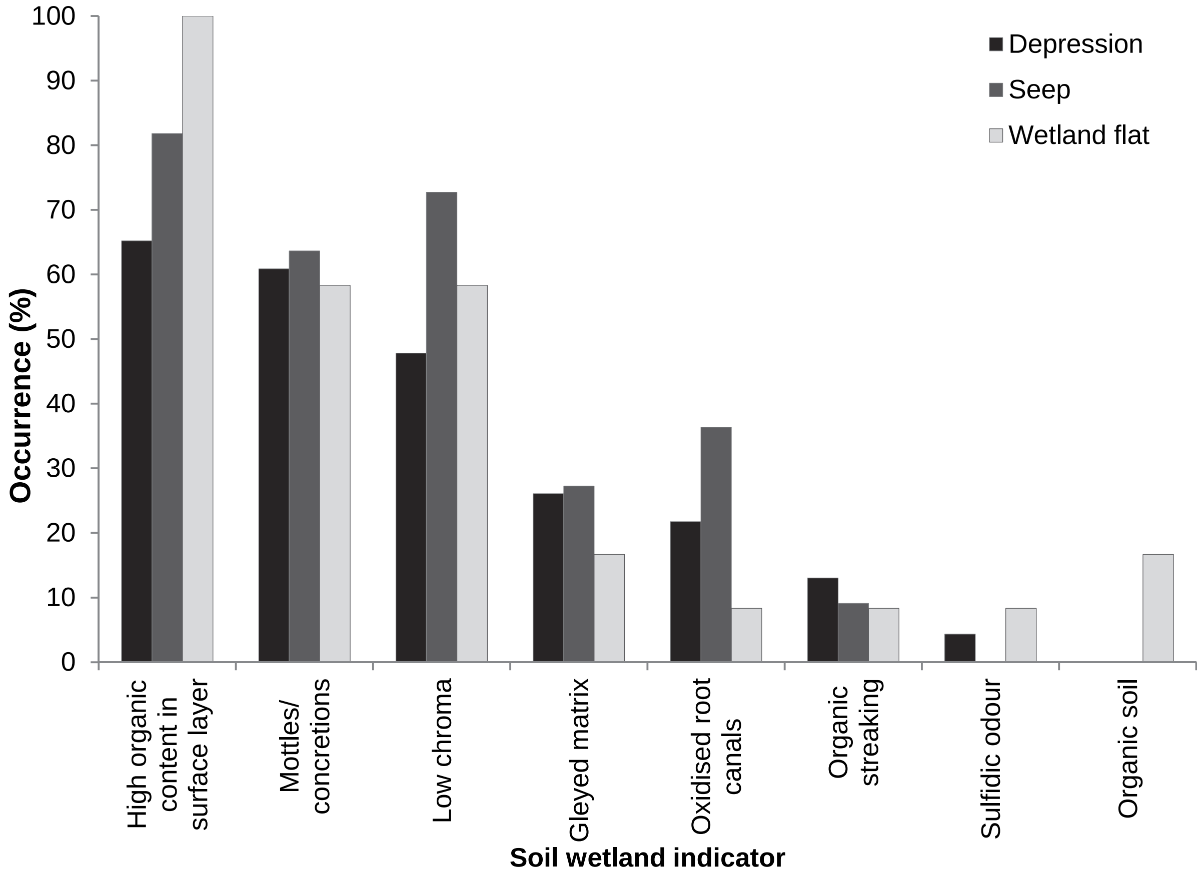


**Figure 5.8 Occurrence of wetland soil indicators at each of the once-off sites, per HGM. Indicator is present if three or more cores at a site had the indicator.**

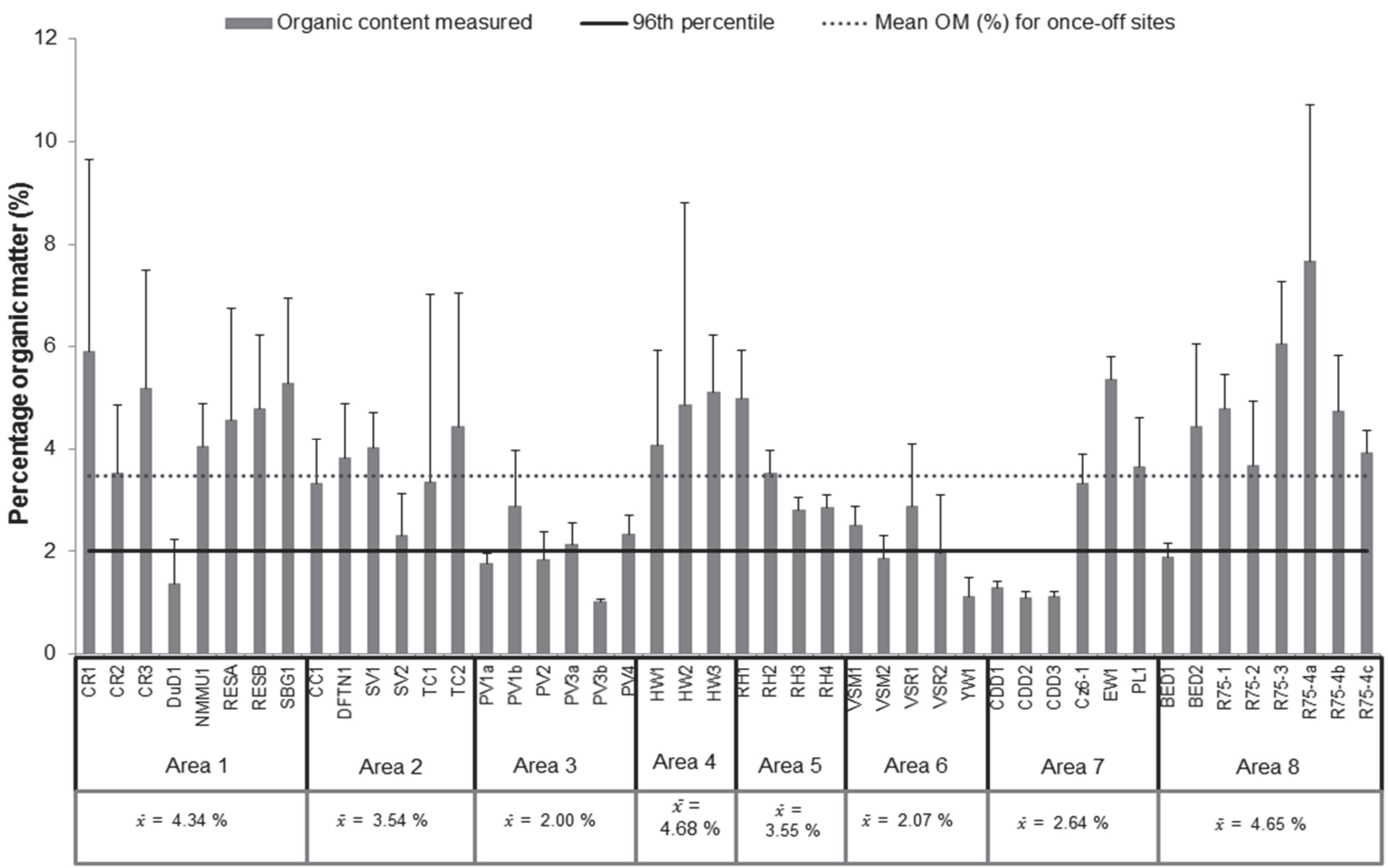


**Figure 5.9** **Organic matter (OM) (%) and standard deviations (SD) for once-off sites grouped in geographic areas (Figure 3.2). Means for each area are indicated at the base of the graph; overall mean is indicated as a dotted line on the graph. The solid line represents the 96th percentile.**

**Table 5.2** **Correlation matrix showing the relationship between physico-chemical variables in the surface water (SW), sub-surface water (SSW) and soils. Only moderate to strong relationships are illustrated (Pearson's $r^2$ values of greater than ± 0.35). Asterisks indicate very strong relationships.**

| | SW pH | SW EC | SW DO (mg/L) | SW DO (%) | SW Salinity | SSW pH | SSW EC | SSW TDS | SSW Salinity | Soil moisture | Soil OM | Soil EC | Soil pH | Clay content |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SW pH** | | | | | | | | | | | | | | |
| **SW EC** | | | | | | | | | | | | | | |
| **SW DO (mg/L)** | 0.78** | | | | | | | | | | | | | |
| **SW DO (%)** | | 0.99*** | | | | | | | | | | | | |
| **SW Salinity** | | 0.52 | | 0.48 | | | | | | | | | | |
| **SSW pH** | 0.61* | 0.48 | 0.43 | 0.48 | 0.43 | | | | | | | | | |
| **SSW EC** | | 0.48 | | 0.44 | 0.87*** | 0.41 | | | | | | | | |
| **SSW TDS** | | 0.42 | | 0.38 | 0.86*** | 0.39 | 0.99*** | | | | | | | |
| **SSW Salinity** | | 0.69* | | 0.65 | 0.88*** | 0.48 | 0.96*** | 0.94*** | | | | | | |
| **Soil moisture** | | | | | | | | | | | | | | |
| **Soil OM** | | | | | | | | | | 0.55 | | | | |
| **Soil EC** | | 0.74** | | 0.74** | | | | | | | | | | |
| **Soil pH** | 0.47 | | 0.41 | | | 0.43 | | | | | | | | |
| **Clay content** | | | | | 0.36 | | 0.66* | 0.69* | 0.51 | | 0.34 | | | |

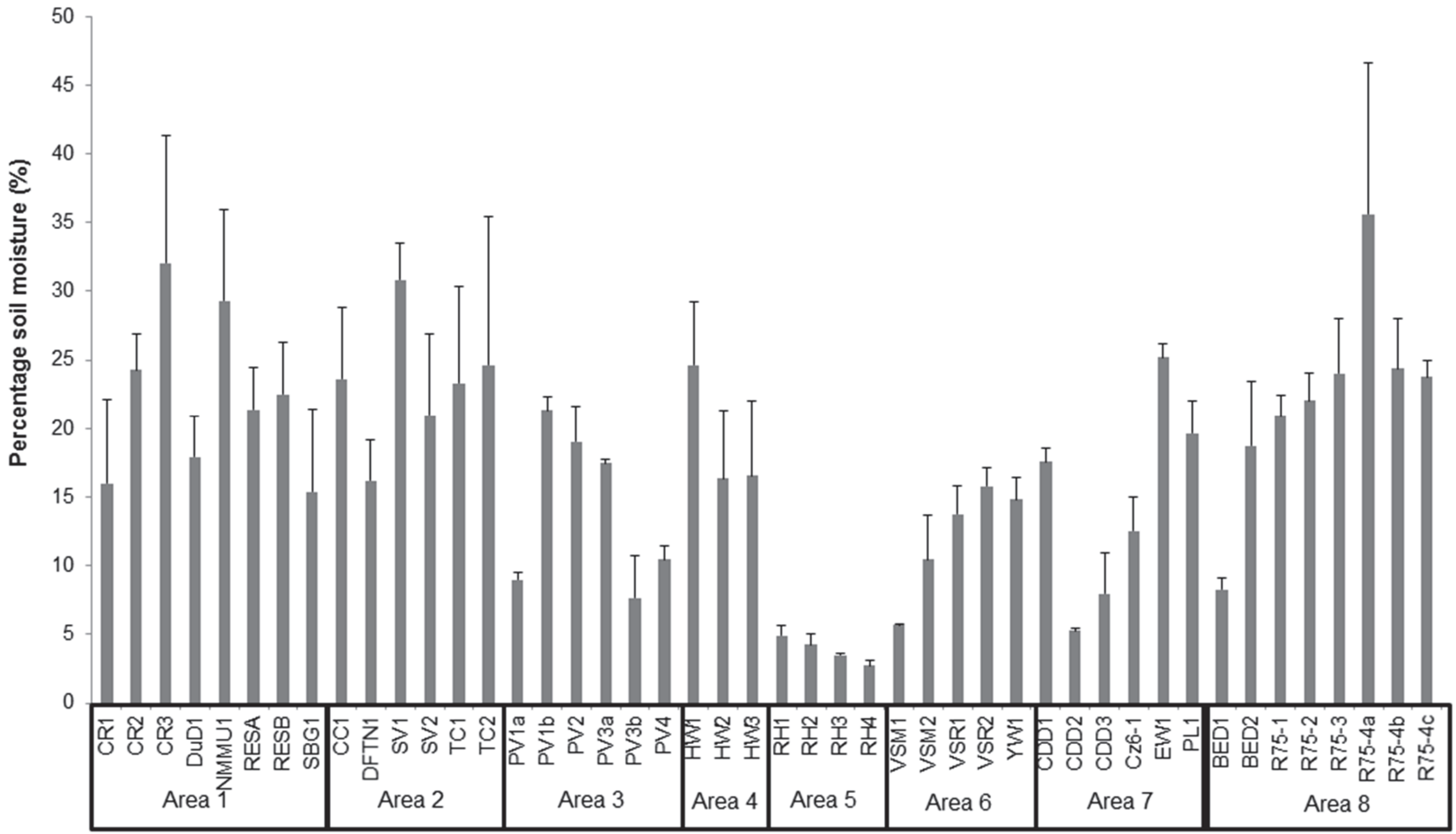


**Figure 5.10** **Percentage soil moisture (%) and SDs for the once-off sites grouped in the eight geographic areas.**

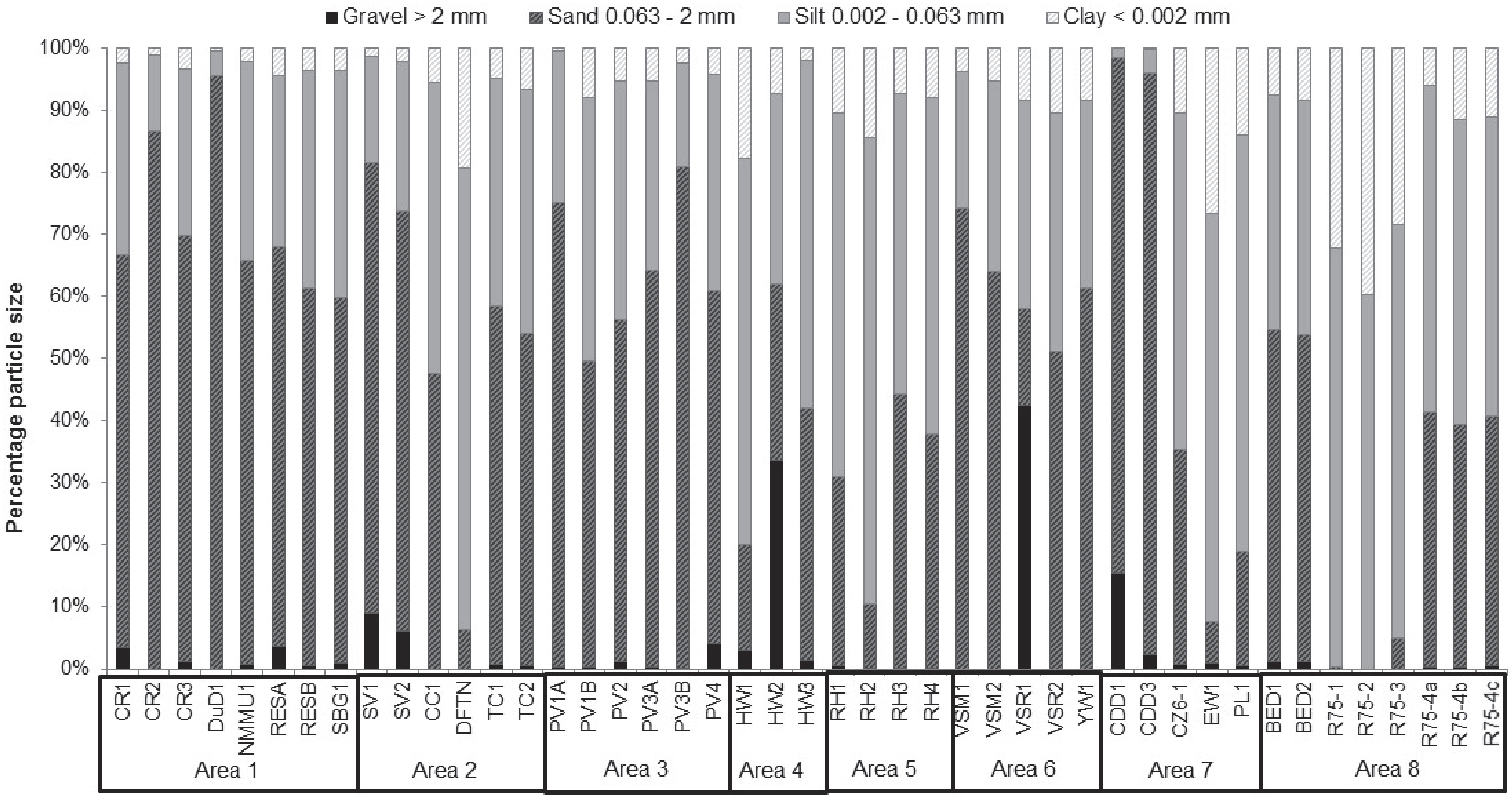


**Figure 5.11** **Particle size distribution (PSD) for all once off wetland sites (average percentages illustrated).**

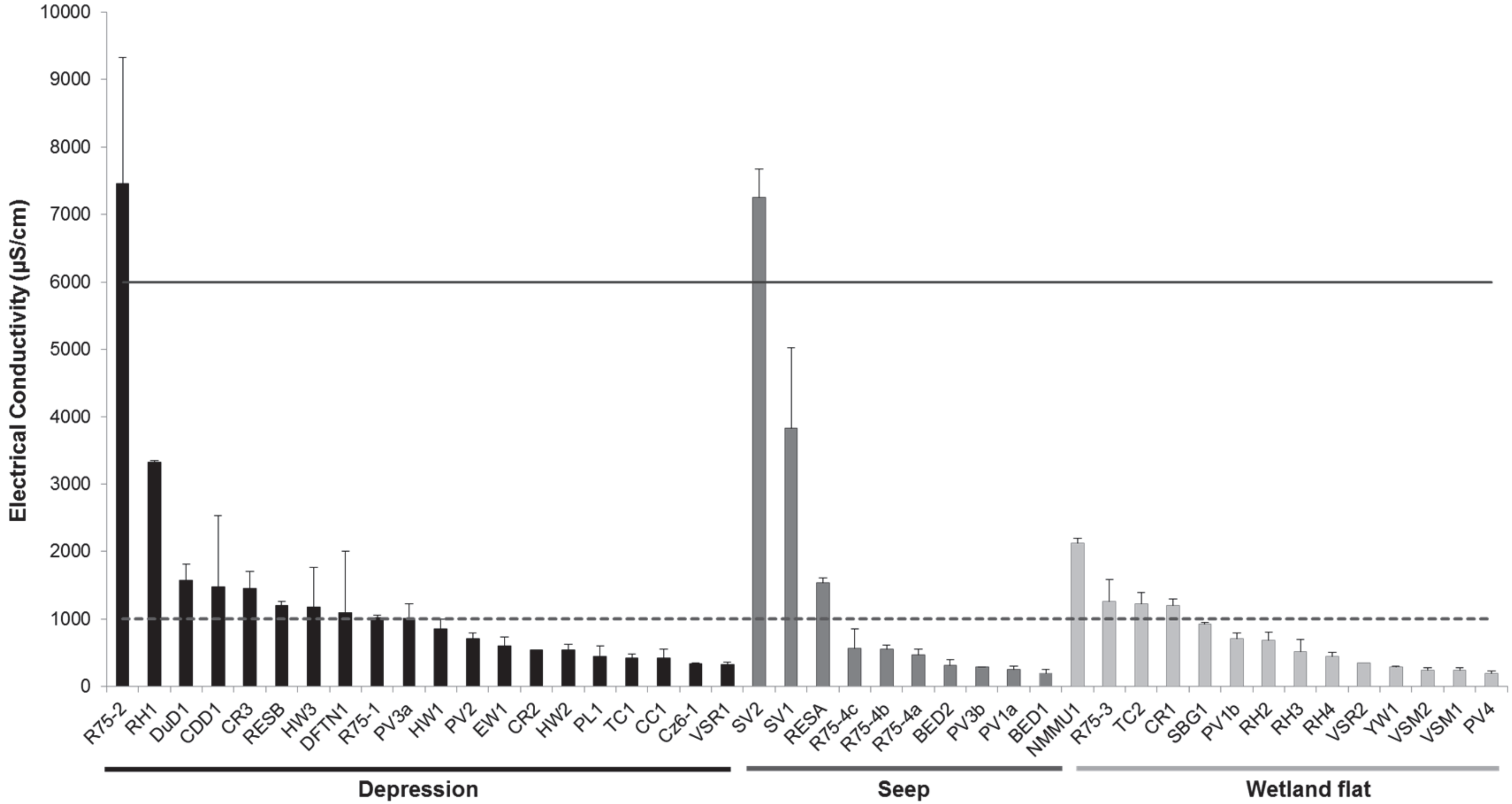


**Figure 5.12** **Sediment electrical conductivity for all once-off sites. Horizontal grey line indicates the freshwater/brackish boundary (dashed line) and the brackish/saline boundary (solid line) (values based on Taylor *et al.* 2007).**

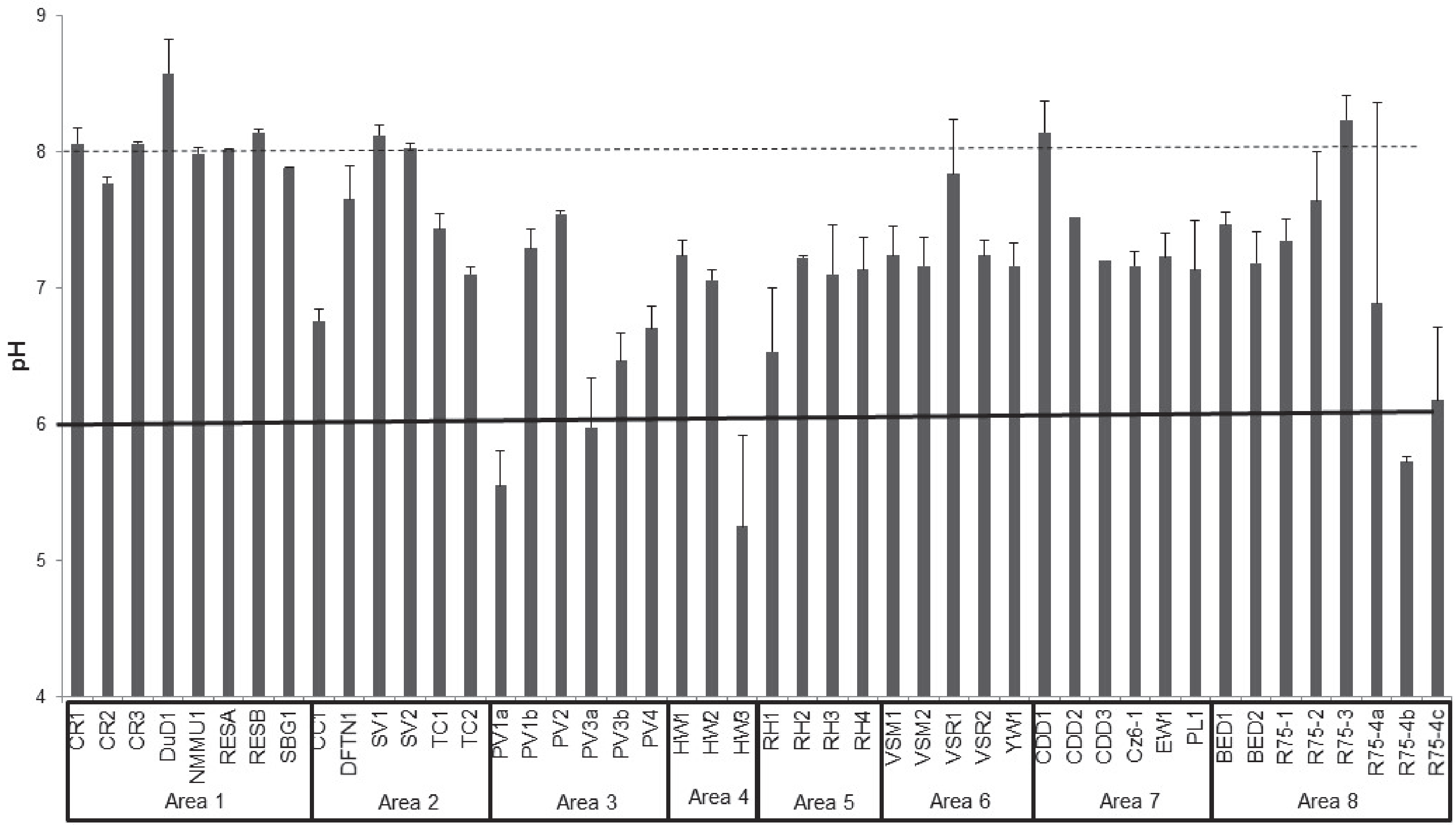


**Figure 5.13 Soil pH for all once-off sites. Values below the solid line indicate acidic soils (pH < 6.0) and values above the dotted line indicate alkaline soils (pH > 8.0). pH values between 6.0 and 8.0 indicate circum- neutral soils.**

There were some similarities in the particle size distributions (PSD) of the sediments within each region (Figure 5.11). Areas that have a sandy underlying geology (e.g. aeolian sand in Area 1) had a smaller percentage of silt and clay (Figure 5.11). As expected, dune depressions and coastal seeps were dominated by sand sized particles, such as sites: DuD 1, SV 1&2, and CDD 1&3 (Figure 5.11).

None of the wetlands that were studied had a poor or low electrolyte content (Figure 5.12). Most wetlands in NMB were electrolyte rich, with an average electrical conductivity of 1176 µS/cm, indicating brackish conditions with a high electrical conductivity (Figure 5.12). Two wetlands found in a coastal dunefield had hypersaline conditions (27 400 and 30 400 µS/cm) and were removed from the analyses as they were extreme outliers. Another two wetlands were saline, a coastal seep and inland salt pan (Figure 5.12). With the exception of these saline systems, there was no significant difference in the salinity/electrolyte content among depressions, seeps and wetland flats (ANOVA, df = 2, F = 0.52).

Most wetland soils measured in NMB were circum-neutral (pH 6.0-8.0) (Figure 5.13). The acidity and slight alkalinity of soils measured at some of the sites could not be attributed to geographical location or HGM unit (Figure 5.13). In general, there was no distinction between soil pH and geographical location (Figure 5.13). Seeps had a slightly lower average pH (6.99) than wetland flats (7.42) and depressions (7.32), although this was not significant (ANOVA, df = 2, F = 1.171).

## 5.3 Water Chemistry

The majority of wetlands in NMB had circum-neutral waters (Figure 5.14), with no significant difference among the HGM types for sub-surface waters (ANOVA, F = 1.439, p = 0.2441). In the surface water, seeps were slightly more acidic ($\bar{x}$ = 6.47), compared to wetland flats and depressions (ANOVA, F = 4.221, p = 0.0246).

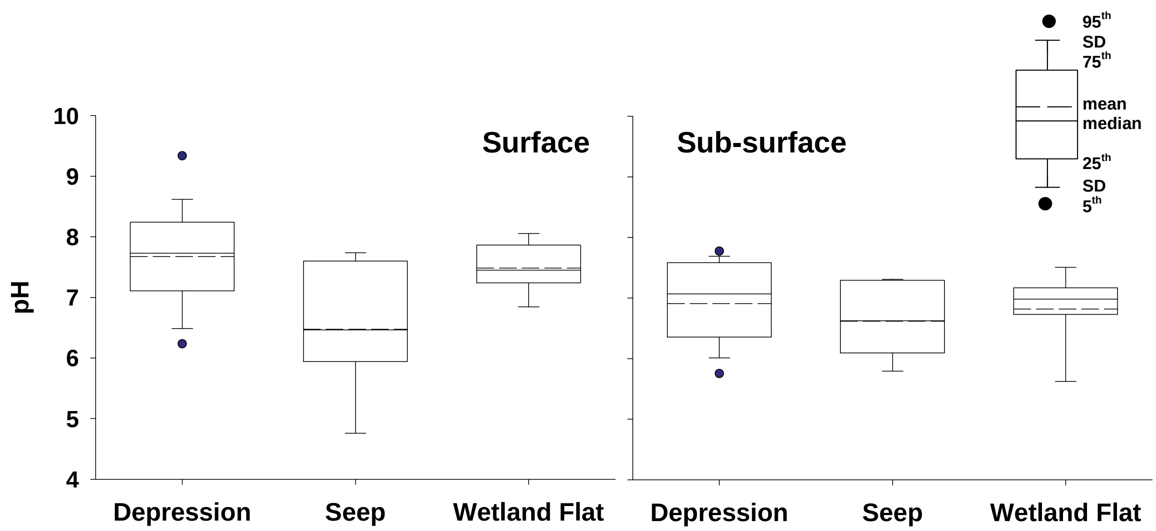


**Figure 5.14 Surface and sub-surface water pH and standard deviation for the three HGM types. Sample sizes as follows for each HGM: depression (18, 17), seep (6, 6) and Flat (8, 6), (surface, sub-surface).**

There was a significant difference in the EC (ANOVA, F = 3.224, p = 0.045) of the sub-surface waters; however, there was no significant difference in the salinity measurements (SSW ANOVA, F = 1.315, p = 0.278; SW ANOVA, F = 0.656, p = 0.527). All three HGM types had freshwater to saline EC levels, with overall averages indicating brackish waters (Figure 5.15). The lowest mean EC of 920.0 µS/cm occurred in wetland flats. Similar trends were observed in the EC of the soils (Figure 5.12) and in the surface water with a mean of 702.2 µS/cm in wetland flats. Depressions (mean = 803.5 µS/cm) and seeps (mean = 871.7 µS/cm) were also mainly comprised of freshwater to brackish waters, with a few systems that had an extremely high EC, which were removed for the analysis (as outliers) (Figure 5.15). These differences in the surface water EC were not significantly different among the HGM types (ANOVA, F = 0.942, p = 0.401). Further details of means and ranges are in Appendix Table A.2.

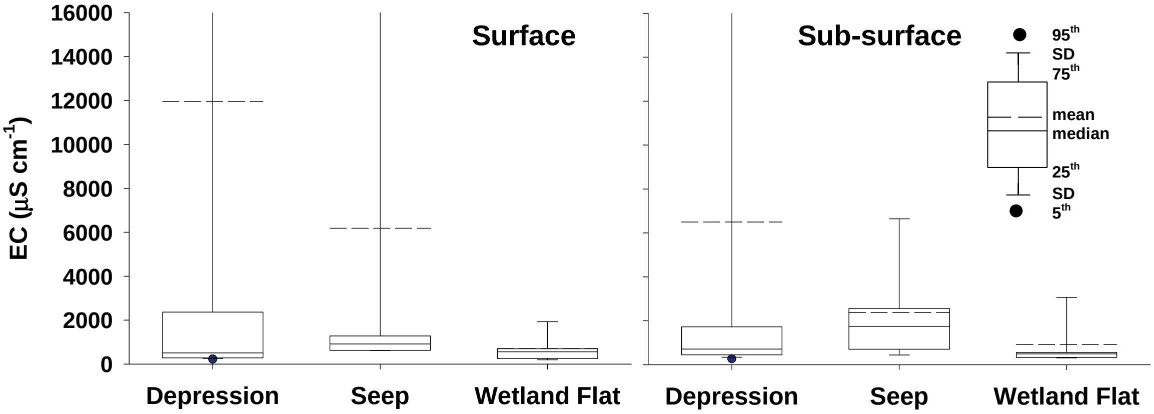


**Figure 5.15 Surface and sub-surface water electrical conductivity (EC) and standard deviation for the three HGM types. Axes truncated to illustrate the dominant range, full data range in Appendix A.2. Sample sizes: depression (18, 17), seep (6, 6) and Flat (8, 6), (surface, sub-surface).**

Similar trends were seen in total dissolved solids (TDS) for both sub-surface water and surface water where seeps had a slightly higher average TDS (Figure 5.16). However, this difference was not significant for both sub-surface water (ANOVA, F = 0.930, p = 0.400) and surface water (ANOVA, F = 0.773, p = 0.715). The TDS mean and range indicated that most of these systems are fresh to slightly brackish, which is consistent with natural systems in this region.

Depressions tended to have higher levels of dissolved oxygen in the surface water (Figure 5.17). However, there was no significant difference between the three HGM types (ANOVA, F = 0.339, p = 0.715).

In summary, the results indicate that the majority of wetlands in NMB are fresh, with a neutral pH. This was illustrated in both sub-surface and surface waters as well as in the soil. Therefore, the more natural wetland systems in NMB appear to be relatively healthy/normal, with physico-chemical parameters within the natural bounds of freshwater systems in this region.

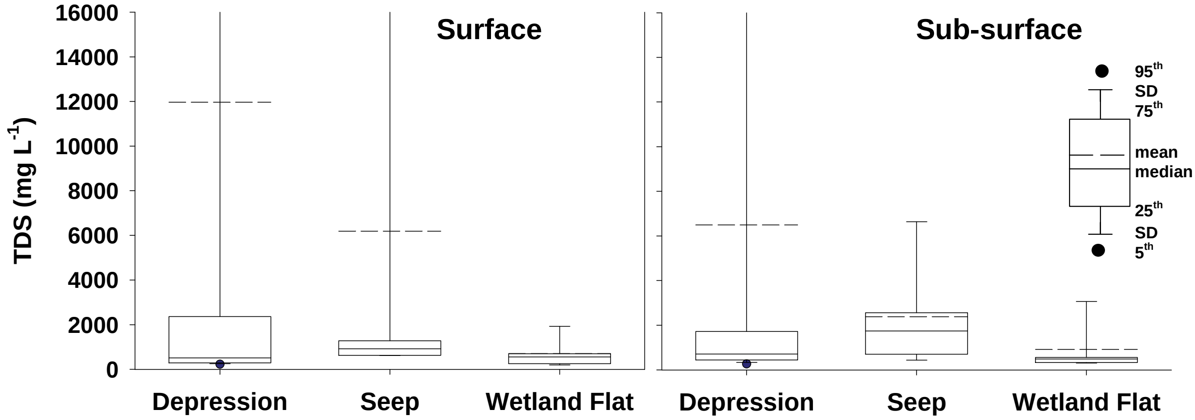


**Figure 5.16 Surface and sub-surface water total dissolved solids (TDS) box plots for three HGM types. Axes truncated due to the wide TDS range, full data range in Appendix A.2. Sample sizes: depression (18, 17), seep (6, 6) and Flat (8, 6), (surface, sub-surface).**

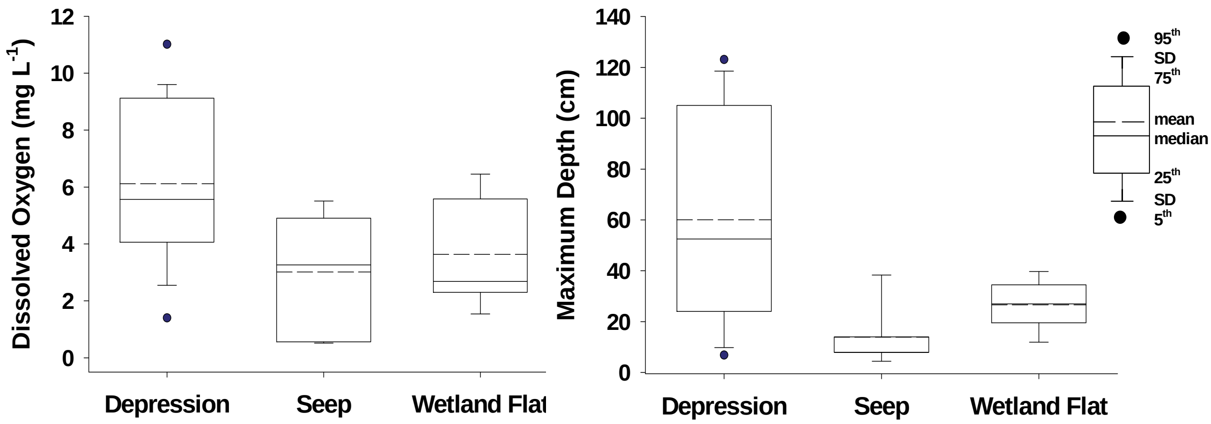


**Figure 5.17 Surface water total dissolved oxygen (mg/L) and maximum depth (cm) box plots for the three HGM types. Sample sizes: depression (18), seep (6) and Flat (8).**

## 5.4 Summary

The prevalence of ephemeral wetlands in NMB is influenced by climatic factors. Results indicate that rainfall is important for the occurrence of seeps and wetland flats, and to a lesser extent, depressions. The majority of wetlands in NMB are found on natural or agricultural land, with much fewer systems located within the formal urban boundary.

The underlying geology and sediment also influenced the presence of wetlands. A large portion of wetlands were associated with various types of sandstone deposits as well as Aeolian and fluvial deposits. Seeps and wetland flats were also primarily associated with deeper soils (greater than 450 mm).

Soil indicators were present at most temporary wetland sites, with the exception of sites situated on aeolian sand. The most prevalent indicators across the landscape were high organic content, mottles and concretions, and low chroma. The relatively high organic content was also reflected in lab analysis with a mean of 3.36%, much higher than the national average for soils.

Particle size was largely driven by the underlying geology, with wetlands located on aeolian or alluvial sands being comprised of coarse sand sized particles. Wetlands found on quarzitic sandstones, mudstones and shales tended to have a greater portion of finer particles (silt and clay).

Various physico-chemical properties were measured *in-situ* at each of the once-off sites. Physico-chemical properties tended to be more influenced by geographical location (the combination of geology and geographical features) rather than the HGM type. Salinity, TDS, and EC measurements all indicated that the majority of systems are fresh to brackish, with the exception of coastal dune depressions and inland natural salt pans which were saline. The pH measured in the wetlands was primarily neutral in both the soil and the water (sub-surface and surface); however, there were sites that were more acidic. Overall the more natural wetland systems in NMB appeared to have good water quality parameters.

The underlying geology (and the associated sediment particle size) and climatic influences, have played a role in the current distribution of wetlands in NMB. These factors combined with physico-chemical parameters affect the establishment of biotic communities (for example, vegetation and invertebrates), which will be discussed in the next chapter.

# 6 BIODIVERSITY OF AQUATIC AND SEMI-AQUATIC FLORA AND FAUNA ACROSS NMB

The flora, algae to vegetation, and fauna, aquatic invertebrates to tadpoles, were assessed at each site where the habitat was available at the once-off sites (see Figure 3.2 for map and Table 4.2 for list of sites and classification). As stated in the Methods section, vegetation transects were done at all sites. The diversity of these different phylogenetic groups is presented in this chapter with an emphasis on comparing the different HGM units and evaluating if there are distinguishing biological features with hydrogeomorphological features. Relationships between the different areas of the NMB and other abiotic features will be addressed in Chapter 7.

## 6.1 Wetland Vegetation

Vegetation associated with wetlands, especially ephemeral systems, is a complex mix of terrestrial, wetland associated plants, facultative (positive and negative) and obligate plants, as defined by various sources such as DWAF (2005) Macfarlane *et al.* (2009), and Van Ginkel *et al*. (2010). During times of transition, either newly inundated or under drying conditions, terrestrial plants (especially weedy pioneering species) and opportunistic invasives can dominate a wetland site leaving a smaller proportion of obligate and facultative wetland species. From the surveys of the 46 wetland HGMs, thus far a total of 307 taxa have been identified to genus and/or species level (Appendix C, Table C.1 and C.2). Of those, 148 taxa could be considered dominant within the sites they were found (i.e. occurred at a greater than 25% coverage for more than one quadrat per transect). There were 39 alien plant species identified to date (including invasive tree species such as *Acacia saligna*) and approximately 90% of this list is plants that are considered terrestrial plants. There were 197 indigenous plant taxa identified, 42% of which are considered to be South African endemics. Fourteen of these endemics are wetland plants. The dominant taxa identified at all sites were a mix of wetland and terrestrial vegetation: 45% were terrestrial species, 9% wetland associated, 9% facultative wetland species and 37% obligate wetland species. When these dominant taxa were examined by their wetland functionality per site and HGM they gave varied results (Figure 6.1). For example, obligate wetland plants were still present and were part of the dominant vegetation even though 15 of the wetland sites were not inundated at the time of sampling.

The diversity indices by HGM type showed no significant differences between HGMs (Table 6.1). However, there is a pattern of differing variances, where depressions tended to have greater variability across all indices and seeps showed least variability (Table 6.1). In part, this increased variance in the depressions can be attributed to the unvegetated or sparsely vegetated dune depressions (i.e. CDD1, CDD2 and DuD1). When considering all the HGMs they all had similar medians and means to that of the overall values (Table 6.1).

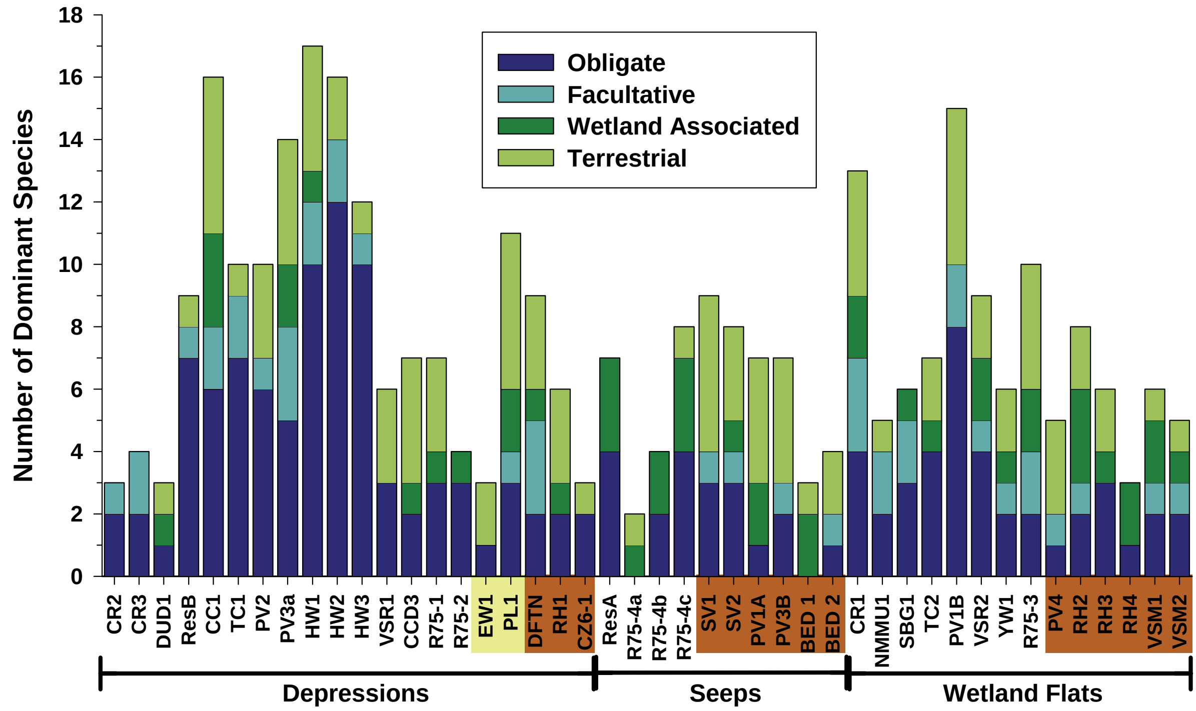


**Figure 6.1** **Proportion of the dominant plant species wetland attributes within each site. Sites are grouped by HGM and broad inundation level. Depressions = blue bar, seeps = green bar and wetland flats = red bar. The tan shading indicates sites that were nearly dry at the time of sampling and the brown shading indicates sites that were dry, all others were inundated at time of sampling. See Table 4.2 for site codes.**

**Table 6.1** **Diversity indices for vegetation by HGM as compared to all sites combined.**

| | **Species Richness (S)** | | | **Shannon-Wiener (H')** | | | **Pielou's Evenness (J')** | | |
|---|---|---|---|---|---|---|---|---|---|
| **HGM** | **Median** | **Mean** | **SD** | **Median** | **Mean** | **SD** | **Median** | **Mean** | **SD** |
| **Depression** | 18 | 17.5 | 10.6 | 2.54 | 2.18 | 0.94 | 0.87 | 0.78 | 0.26 |
| **Seep** | 17 | 15.2 | 6.2 | 2.39 | 2.28 | 0.54 | 0.85 | 0.88 | 0.06 |
| **Wetland Flat** | 17 | 16.7 | 7.2 | 2.43 | 2.31 | 0.50 | 0.90 | 0.85 | 0.04 |
| **All Sites** | **17.5** | **16.8** | **8.7** | **2.43** | **2.24** | **0.74** | **0.86** | **0.82** | **0.19** |

The total number of taxa recorded showed a wide range and diversity of plant species, with some sites recording more than 35 taxa, and approximately 60% wetland species commensurate with ephemeral wetlands. The obligate ephemeral wetland species, *Crinum campanulatum*, is an IUCN red data listed species (Dold *et al.* 2010), and was found in the three Hopewell sites (HW1, HW2 and HW3, see Plate 1 and Table 4.2 for locations). This vlei lily (Plate 1) is a South African and Eastern Cape endemic species, and may even be a local population subspecies – it is listed as Vulnerable. The main threats to this species are deteriorating water quality from pollution due to agriculture and residential development. Populations are very fragmented throughout the southern part of the Eastern Cape.

**Plate 1** ***Crinum campanulatum* flowering in November 2012 at HW1.**

A multivariate analysis of the dominant taxa for each site showed that there were no strong similarities between sites; each wetland has a fairly unique set of plant species that define the site (Figure 6.2). There were four groups which separated from one another at less than 5% similarity level, as shown by the groups in Figure 6.2. Within group similarity was low, ranging from 7% (group 2) to 15% (group 1). However, the SIMPER (similarity percentage) analysis identified that each group had a unique species or group of species which defined it, independent of geographical location and, to some extent, HGM (Table 6.2). Groups 1 and 4 were defined by the presence of one dominant taxon, *Chara* sp. and *Cynodon dactylon* respectively (Table 6.2). *Chara* sp. is a macroalgal species that was common in many of the inundated depressions and one wetland flat in group 1 (Figure 6.2). Groups 2 and 3 were defined by a mix of several taxa, with *Phragmites australis* indicative of group 2 (Table 6.2). Each group has a decreasing number of obligate wetland species, 100% in group 1 to 25% in group 4, indicative of the inundation level or soil moisture levels at the time of sampling. Groups 2-4 had a combination of grasses and sedges present from a mix of dry, saturated and inundated sites. Group 3 can be considered a grass/sedge wetland, and had a mixture of grasses, sedges and restios (Table 6.2). The wetland sites within group 3 were also the most diverse in terms of moisture levels. The opportunistic grass, *C. dactylon* that characterises group 4 is a terrestrial species, but as it is commonly found in a number of ephemeral wetlands it has been characterised as wetland associated.

As has been reported in other work, such as Corry (2012) and Sieben (2011), wetland vegetation community structure is probably more closely tied to hydroperiod and soil moisture. Further analysis, comparing the vegetation community structure with hydroperiod and soil moisture, needs to be conducted before any conclusions are drawn.

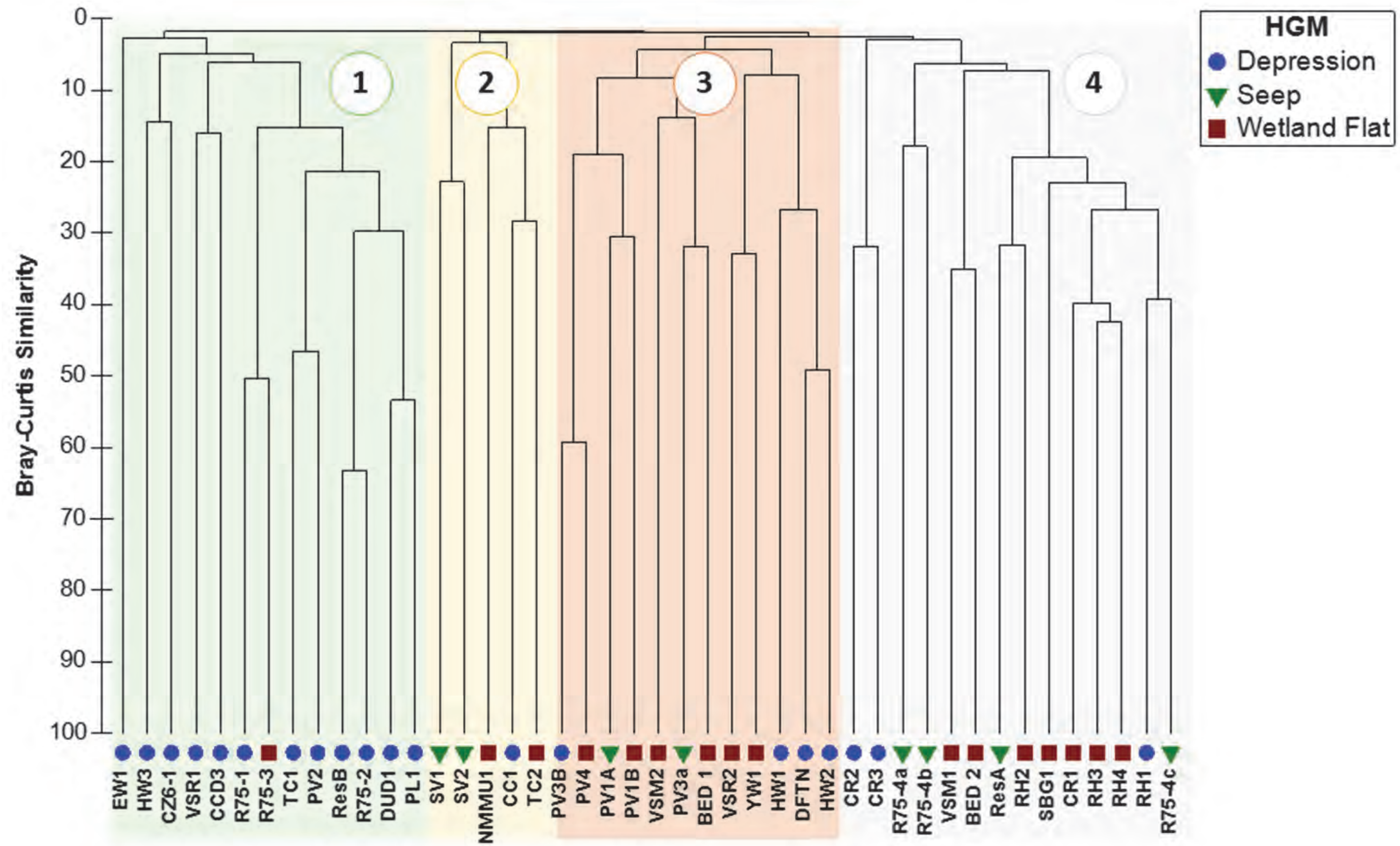


**Figure 6.2** Bray-Curtis similarity dendogram of dominant vegetation taxa per site. Shading indicates each separate group at a > 95% dissimilarity. See Table 4.2 for site codes.

**Table 6.2** **Taxa/species contributing to similarities within groups (as per Figure 6.2). The designated functional role defined by this project, obligate (OW), facultative (FW), wetlands associated (WA) and terrestrial (T) is given with each taxon.**

| Group 1 | | Group 2 | | Group 3 | | Group 4 | |
|---|---|---|---|---|---|---|---|
| **Species** | **%** | **Species** | **%** | **Species** | **%** | **Species** | **%** |
| *Chara* sp. (OW) | 45 | *Phragmites australis* (OW) | 28 | *Themeda triandra* (T) | 19 | *Cynodon dactylon* (WA) | 76 |
| *Schoenoplectus decipiens* (OW) | 28 | *Chrysanthemoides monilifera* (T) | 22 | *Eleocharis limosa* (OW) | 15 | *Imperata cylindrica* (FW) | 10 |
| Filamentous green algae (OW) | 20 | *Lemna gibba* (OW) | 18 | *Pennisetum thunbergii* (WA) | 12 | Pteridophyta sp. (WA) | 3 |
| | | *Eleocharis dregeana* (OW) | 16 | *Paspalum distichum* (OW) | 12 | *Cyperus congestus* (OW) | 3 |
| | | *Schoenoplectus juncii* (OW) | 6 | *Elegia ebracteata* (T) | 9 | | |
| | | *Erica* sp. (T) | 3 | *Andropogon appendiculatus* (FW) | 7 | | |
| | | | | *Thamnochortus* sp. (T) | 5 | | |
| | | | | *Isolepis fluitans* (OW) | 4 | | |
| | | | | *Epischoenus gracilis* (OW) | 4 | | |
| | | | | *S. decipiens* (OW) | 3 | | |

## 6.2 Algal Species Assemblages

Algae can split into several groups based on their habitat, growth forms and/or sizes. Algae that inhabit the water column are phytoplankton and are predominantly microscopic, but can also be seen as organised colonies or appear as filamentous mats. Those microalgae inhabiting the substratum or benthos are referred to as the microphytobenthos (MBP). There are also larger forms of macroalgae, such as *Chara* sp., that will not be included in this section but were included in the vegetation surveys. The pattern of algal biomass, both phytoplankton and MPB by HGM is shown in the box plots in Figure 6.2.

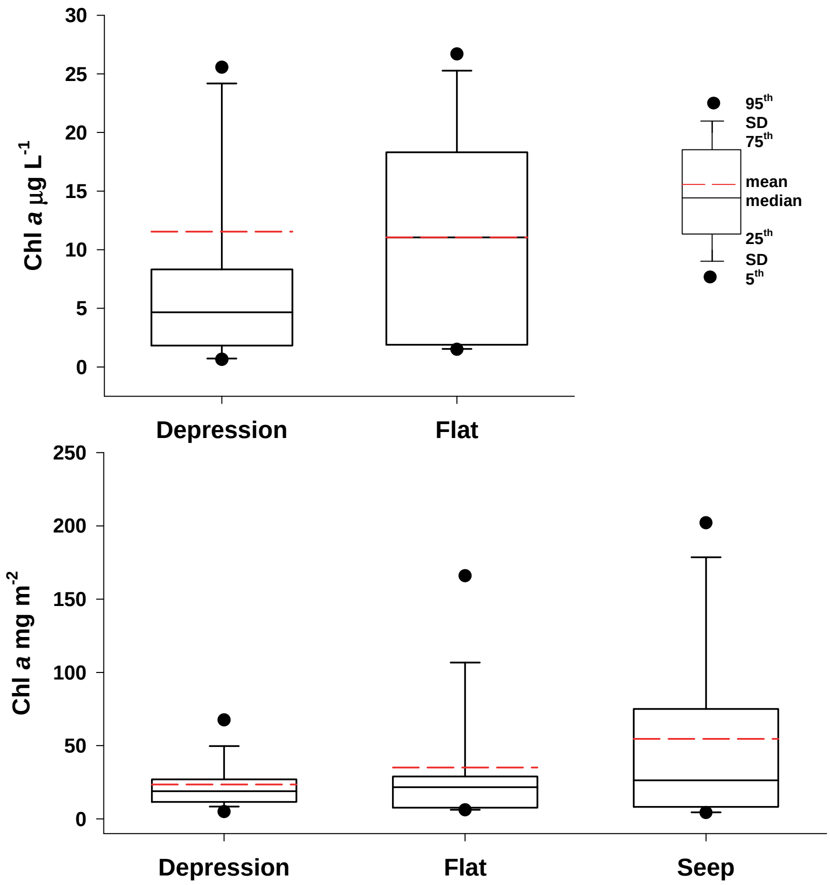


**Figure 6.3 Chlorophyll *a* biomass of phytoplankton (top) and MPB (bottom) by HGM.**

### 6.2.1 Phytoplankton

The presence of a stable water column is critical to the development of phytoplankton populations in natural waters, particularly in permanent standing waters Ephemeral wetlands provide similar conditions as permanent systems, when inundated (where depth is greater than 25 cm). This creates a habitat for a variety of phytoplankton to develop, supporting higher trophic levels.

A total of 147 phytoplankton taxa from 8 divisions were identified from 14 wetlands, with a wide variation in physical and chemical variables across the different wetland types (Appendix C, Table C.3). Of the 14 wetland sites, six were wetland flats. Of the five wetland flats, three (sites PV1b, R75-3, and CR1) had cyanophytes, contributing to 50% or more to the total number of the taxa. Sites TC2 and PV1b had chlorophytes and cryptophytes which contributed as much as 64 and 90% respectively, of the taxa enumerated (Figure 6.3).

Phytoplankton taxa in depressions displayed more variation in species composition compared to wetland flats. Of the nine depressions, two had cyanophytes contributing to over 50% of the total composition, while three sites had chlorophytes that contributed about 48% or more to the number of taxa enumerated. The rest of the wetland sites had a larger contribution of other taxonomic groups, resulting in a varied representation of phytoplankton (Figure 6.3). Sites PV2, HW1, HW2, R75-1 and ResB (all depressions) displayed a broader representation of phytoplankton taxa, with more than six groups included. These depressions had a high degree of taxonomic group variation and they also occurred at different geographical locations within the NMB. In contrast, only the Hopewell sites (HW1 and HW2) occurred in close proximity (approx. 450 m) from each other, compared to the other depressions (PV2, R75-1 and ResB) that occurred as much as 45 km away. A Bray-Curtis similarity matrix was calculated and further demonstrated that the series of once-off samples at wetlands sites showed no community pattern with either geographical location or HGM unit, with local factors being a more important influence on species composition within a site.

The composition of phytoplankton groups at the Hopewell sites included: chlorophytes, chrysophytes, cryptophytes, cyanophytes, euglenophytes, and prasinophytes. However, HW2 differed in that it had the dinoflagellates as an additional group. In terms of species diversity, four depressions had similar levels of phytoplankton species diversity with a Shannon-Wiener diversity score of greater than two. Among the wetland flats, two sites (PV1b and CR1) exhibited highest species diversity (greater than two), whereas sites R75-3 and SBG1 showed the lowest level of phytoplankton species diversity of all the wetland sites.

Comparing the two HGM types in terms of species richness (S), diversity (H') and evenness (*J'*), depressions were consistently greater than wetlands flats (Figure 6.4). Depressions also displayed more variance in species richness. Both HGMs did not have high evenness scores, indicating that there were a few dominant taxa, and many taxa with low numbers.

### 6.2.2 Microphytobenthos

Unlike phytoplankton, MPBs do not need a stable water column; MPBs need a saturated substratum on which to colonise. The MPBs referred to in this report represent those that live on top of or within the top 1 cm of the sediment, at the sediment-water interface. Many studies have demonstrated that this algal community can be useful in determining water quality in rivers and estuaries (Taylor *et al.* 2007). These studies focus on one phylogenetic group, the diatoms (Bacillariophyceae). In this case, we have looked at the community as a whole, as well as the diatoms. Within the total community, there were 298 identified taxa

(Appendix C, Table C.4). Diatoms comprised over 50% of the taxonomic composition in some sites (Figure 6.5). Other microphytobenthic groups (OMG) also play a significant role which should not be overlooked. The OMGs consist of taxa from Chrysophyceae, Coccolithophoraceae, Prasinophyta, Pyrrhophyta, Raphidophyta, and Xanthophyta divisions or classes. In general, after diatoms, chlorophytes and cyanophytes were the most abundant taxonomic groups in NMB wetlands.

Picoalgae are small in terms of cell size (classified here as those approximately 0.2-1.0 µm in diameter), contribute less to the overall biomass than other groups and are very difficult to identify due to their size. However, these picoalgae are numerically abundant, and subsequently, should not be overlooked. For example, the genus *Synechococcus,* which is part of the cyanophytes that made up the picoalgae, were present in all samples collected. Based solely on abundance, this group eclipsed all of the other taxa, including diatoms, with an average of 79% of the total composition picoalgae (range across sites between 24-99%). Their role in nutrient cycling, nitrogen fixation and the food web requires further research particularly given that this group of microalgae has been shown to have high turnover rates in the water column (Chamberlain *et al.* 2014).

Diversity (H') of taxa was ranged from 1.5 to 3 across sites (Figure 6.6). Looking at species richness (S), H' and evenness (*J'*), seeps, and to some extent depressions, appear to be more variable than wetland flats (Figure 6.6). However, statistically the HGMs are not significantly different from one another ($p > 0.05$). There was a large variance around *J'* for seeps, suggesting that there were a few dominant species and a large number of taxa with low abundances. Wetland flats tended to be least variable across all indices, suggesting a more consistent diversity and abundance pattern. Multivariate analyses on species composition, with and without the picoalgae, did not show distinctive patterns, either by HGM or geographical location. Community composition of the sites was influenced by parameters other than geography and geomorphology.

The diatom portion of the community was analysed on its own and 180 taxa were identified to at least genus. A further 23 taxa need to be identified further (Appendix C, Table C.5). The diversity pattern was similar to that of the entire MPB community (Figure 6.6). Depressions had the widest range of taxon numbers (1 to 64) with an average of 17 taxa (± 4 SE). This average is much greater than that of seeps and wetland flats which were 11 and 19, respectively. The evenness index was high for all sites, showing a lack of a dominant species.

Of note is the R75-4 connected seep system. This system comprised three connected, yet identifiably discrete seeps, where water flowed from R75-4a through R75-4b, to R75-4c (characterised by different slope gradients). The R75-4c was the most degraded and modified component of the system: heavily grazed by cattle, probably organically polluted, and most proximal to the dirt road running through the farm. This seep was dominated by filamentous cyanophytes, possibly indicating the effects of degradation on the MPB community. The increase in H' away from R75-4c (H' = 1.5) upslope toward the less disturbed site of R75-4a (H' = 3.0) reflects a trend towards greater species richness and equitability with improving system health and pristine character. This has implications for management and understanding the effects of agricultural and anthropogenic influences on the integrity of wetlands.

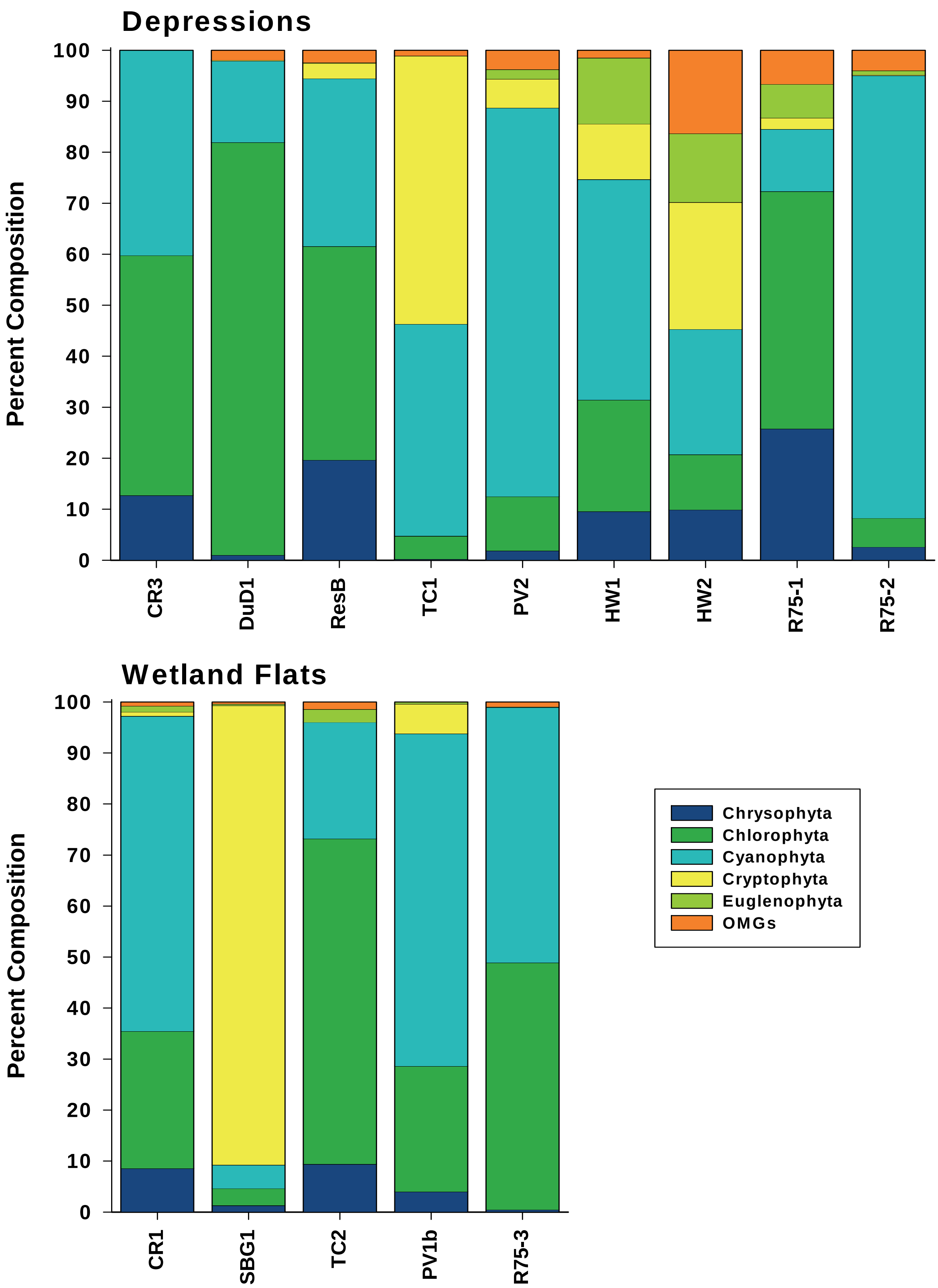


**Figure 6.3** **Percent contribution by phytoplankton divisions in depressions and wetland flats. OMGs = other microalgal groups consisting of Prasinophyta, Pyrrhophyta and Xanthophyta. See Table 4.2 for site codes.**

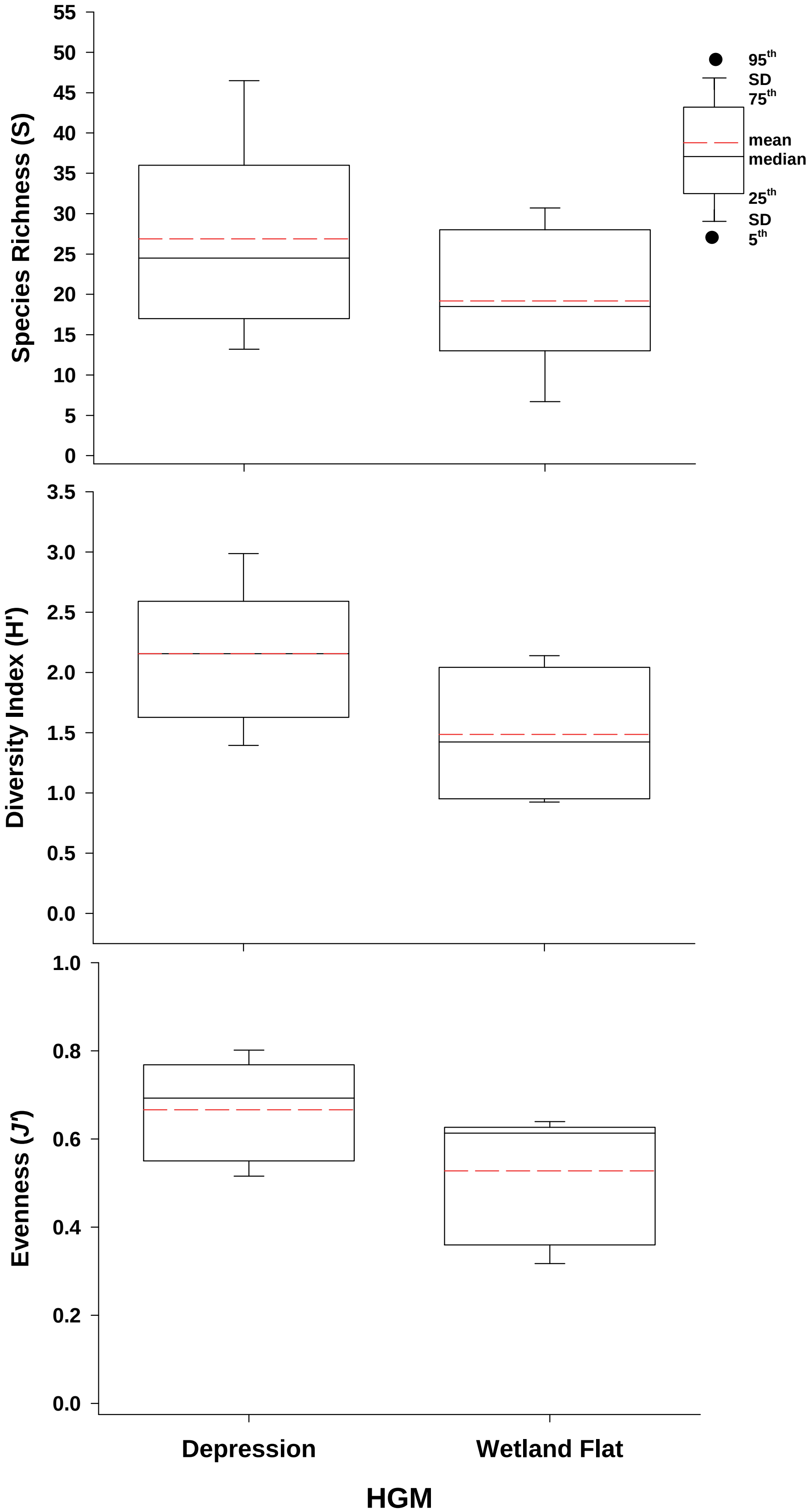


**Figure 6.4** **Diversity indices of phytoplankton species assemblages by HGM unit.**

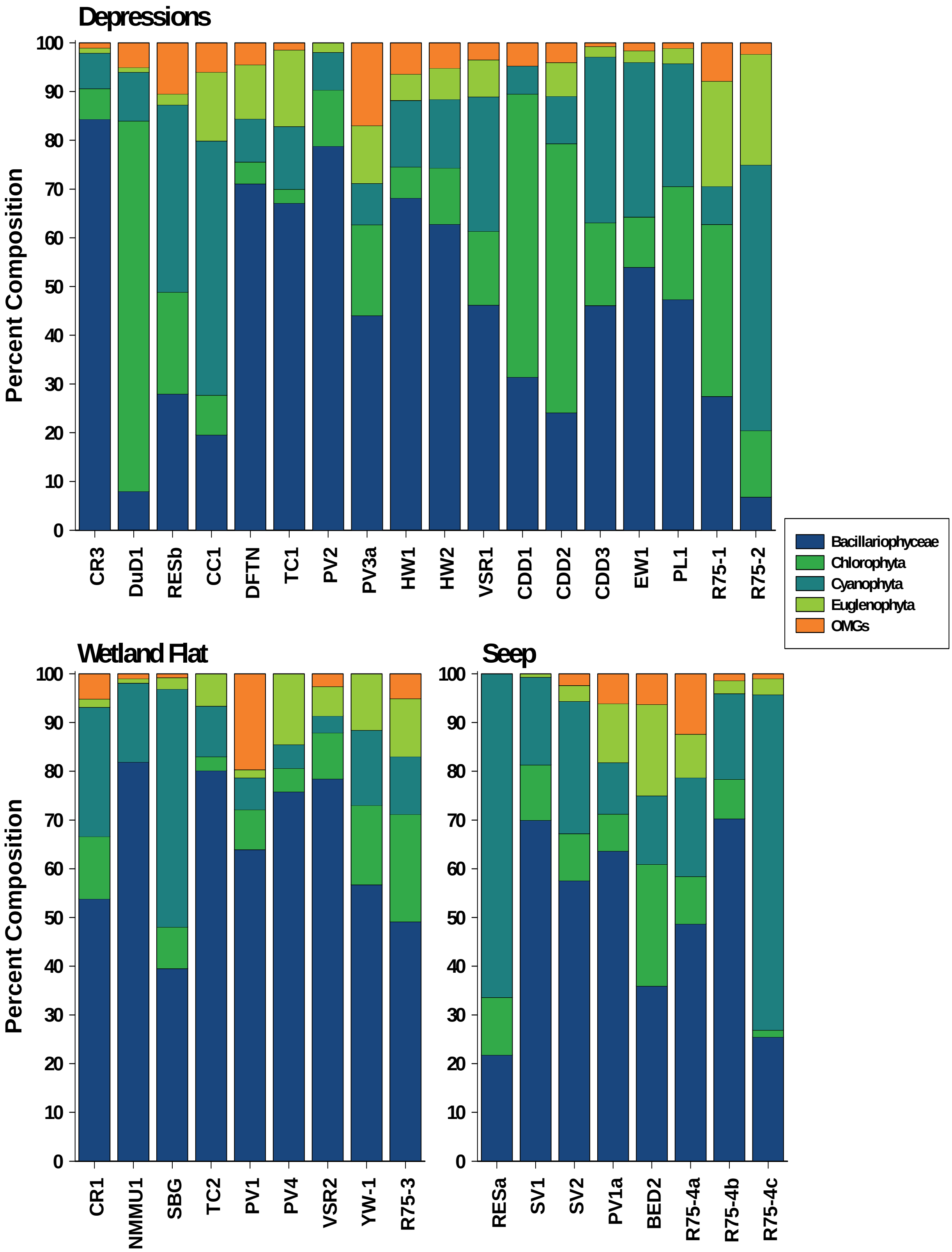


**Figure 6.5** **Proportion of each division of MPBs per HGM. OMGs = other microalgal groups consisting of seven other divisions each contributing to less than 10% of the total composition.**

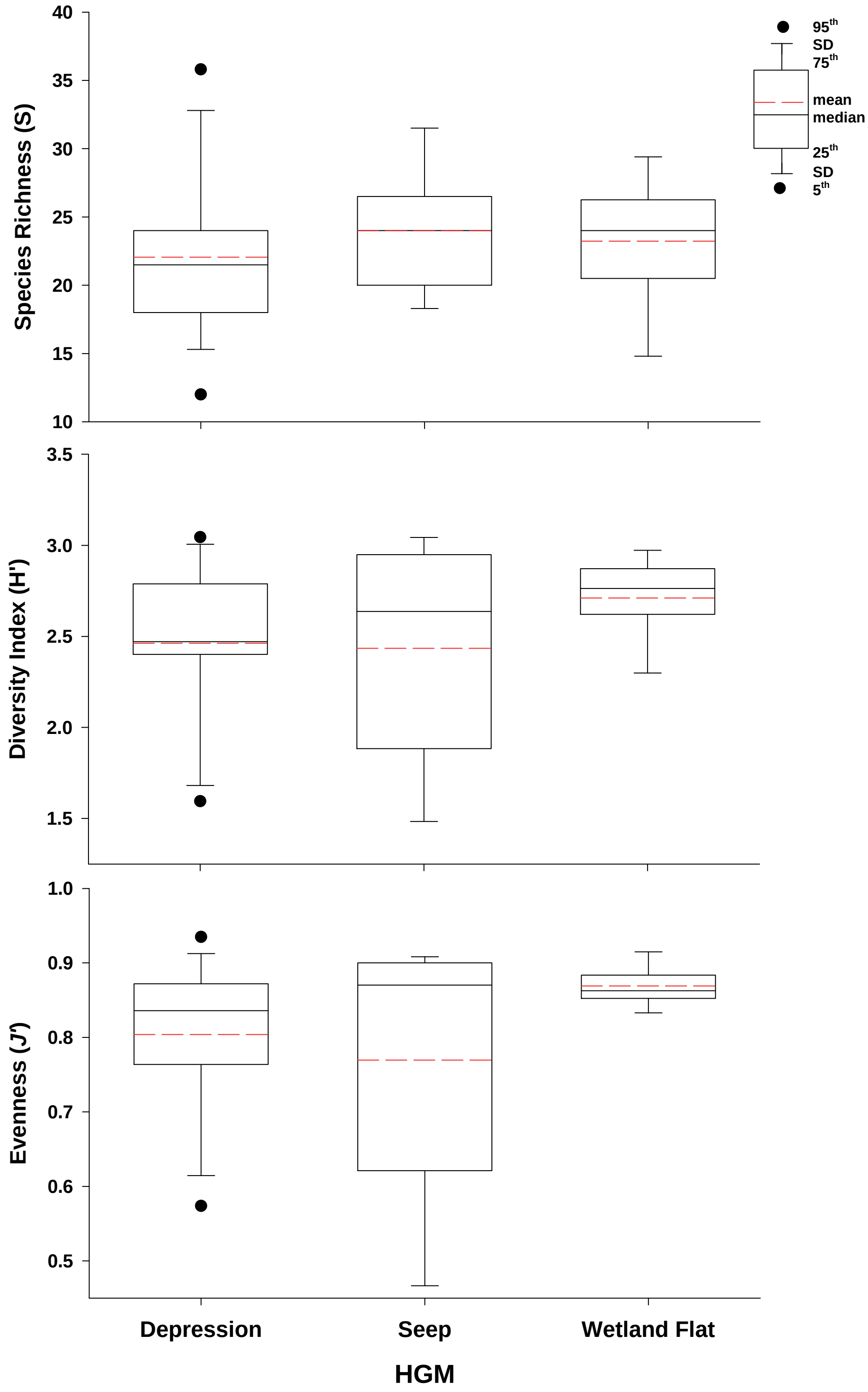


**Figure 6.6** Diversity indices of MPB species assemblages by HGM unit.

## 6.3 Macroinvertebrate Species Assemblages

Aquatic macroinvertebrates are an important component of the food web. In ephemeral wetlands, such as those in NMB, the community has some unique features, as mentioned in Chapter 2. On inundation, there is a release of nutrients from the sediments, stimulates the production of primary producers, such as algae (discussed in Section 6.2). Soon thereafter, the non-insect taxa hatch from the sediments to form a community of large branchiopods, Cladocera, ostracods and copepods. Once the inundation period has established, there is a transition to colonising insects, and a new community develops. This transition will be reported on in Chapter 7. However, it is important to note this dynamic, as the community and species diversity identified at a site is, in part, determined by the timing of sampling. As these were once-off sites, some of the difference may be attributed to "age" (how long it has been inundated for) of the wetland as well as other factors, such as HGM type.

Combining both sample habitats (from the open water and marginal vegetation), there were a total of 144 taxa identified (some groups only to order or family, see Appendix C, Tables C.6 and C.7). Different stages of the same species were combined for analysis if more than one stage (adult/larvae/pupae) was present. Not all taxa collected were aquatic, several terrestrial snails were also identified, *Physella acuta*, *Cochilicella barabara*, and *Theba pisara,* the latter two, of which, are alien invasive species (N. Miranda *pers. comm*.). These were most likely collected from the marginal vegetation and knocked into the water. Several terrestrial spiders along with semi-aquatic spiders were also observed.

One IUCN red data species was identified, the Anostraca (fairy shrimp), *Streptocephalus dendyi,* which is considered endangered. Their isolated populations are under threat from anthropogenic activities and the associated destruction of their habitat. This species is a South African endemic that is an obligate ephemeral wetland species. These were identified from one Parson's Vlei (PV1b) and Van Stadens (VSR2) site.

The ranges of S, J' and H' among the HGMs is shown in the box plots in Figure 6.7. There were no statistical differences in diversity between geographical areas, with the exception of S (ANOVA, $F = 3.1$, $p = 0.023$), because of the differences between Area 4 (Hopewell) sites and Areas 7 and 8 (Tukey's, $p < 0.05$). There were significant differences between HGMs ($p < 0.05$) for each of the indices with the exception of H' ($p = 0.1$). Using multiple comparison test statistics wetland flats and depressions were always significantly different from seeps (Tukey's, $p < 0.05$), but they did not differ significantly from each other.

The general taxonomic composition was examined to determine why there were these differences between HGMs. The mean and standard error of the abundances of each species, per taxonomic order, was plotted by HGM (Figure 6.8). The orders were organised as follows: "worms" (nematodes, leeches, oligochaetes), "spiders", "scuds", "snails" (gastropods, bivalves), large branchiopods (Notostraca, Conchostraca, Anostraca), zooplankton (cladocerans, ostracods, copepods), and insects. This series of plots illustrate that seeps are predominately made up of "worms" and insect taxa, with little to no crustacean taxa (branchipods and zooplankton). The abundances of the taxa present were also lower than that of the wetland flats and depressions.

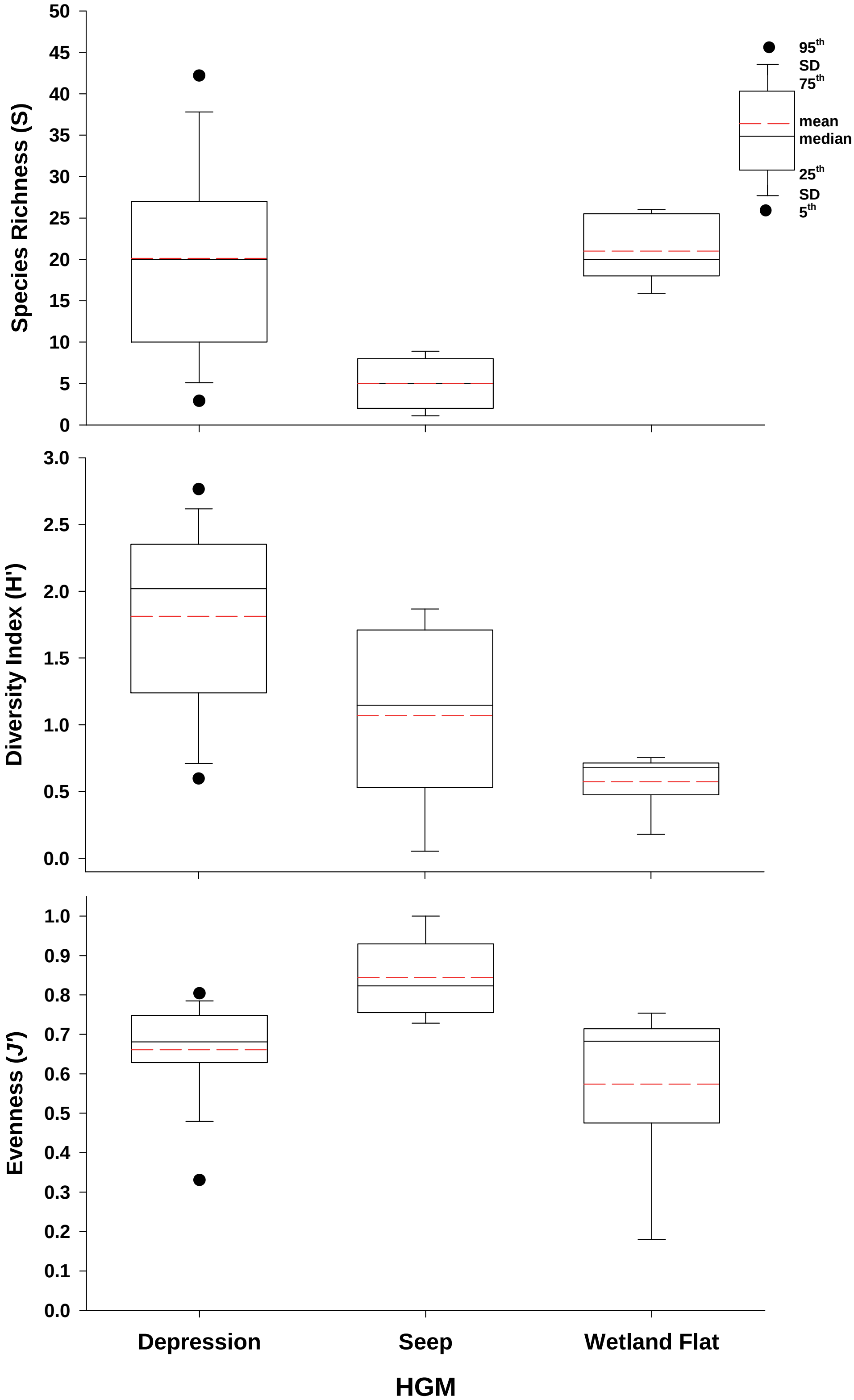


**Figure 6.7 Box plot of diversity indices of macroinvertebrate species assemblages by HGM unit.**

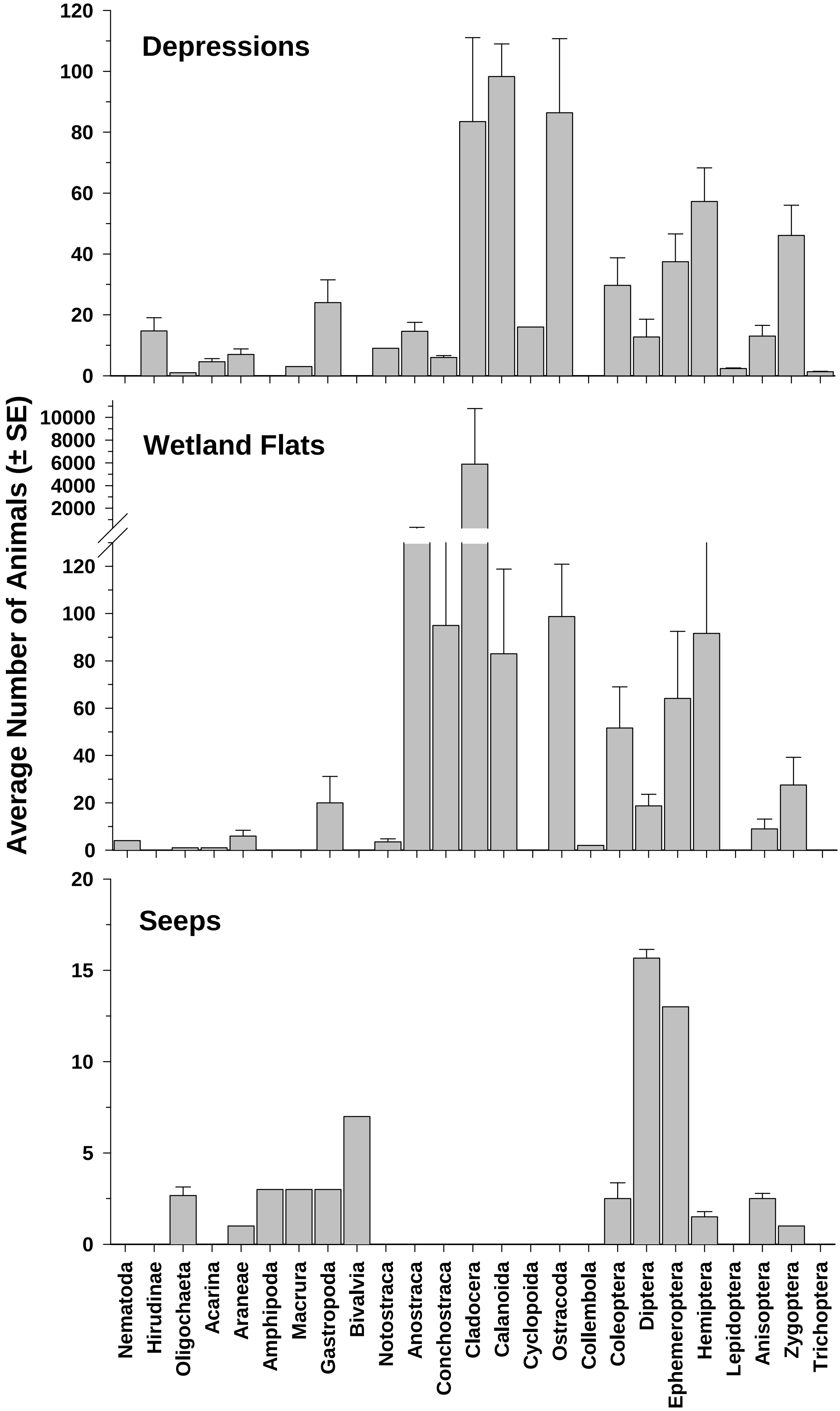


**Figure 6.8** **Mean number of taxa per macroinvertebrate order by HGM.**

The community structure of depressions and wetland flats was similar with zooplankton and insects, but overall abundances were greater in wetland flats. There was also a subtle shift between the two HGM types from the large branchiopods being abundant in wetland flats, and the depressions having more of the smaller zooplankton taxa and insects (Figure 6.8).

Even with confounding influence of inundation timing and periodicity there seems to be some differences between HGMs in terms aquatic macroinvertebrate taxonomic structure and diversity.

## 6.4 Tadpole Assemblages

Although the sampling programme was not designed to assess frog distributions, tadpoles were collected as part of the macroinvertebrate sampling. With the assistance of Dr John Measy (currently University of Stellenbosch, Centre for Biodiversity), tadpoles were identified and enumerated. A total of ten different species were identified across the NMB area (Table 6.3). There were two different species of toads and eight species of frogs. Only one frog identified is aquatic for its entire life cycle, *Xenopus laevis*. The rest of the species will metamorphose as the wetlands dry and migrate to the terrestrial zone (Carruthers and Du Preez 2009).

## 6.5 Summary

Landscape, or geographic position, and wetland type were not dominant factors influencing floral and faunal communities. Vegetation associated with wetlands in NMB was a mix of terrestrial, wetland associated plants, facultative (positive and negative) and obligate plants. The total number of taxa recorded show a wide range and diversity of plant species, with some sites recording more than 35 taxa. Overall, wetland plant communities tended to be unique from site to site, with no strong groupings by either wetland type or geographical position.

Phytoplankton taxa in depressions displayed more variation in species composition and diversity compared to wetland flats. The phytoplankton were dominated by chlorophytes, cyanophytes and cryptophytes and occurred mainly in depressions and wetland flats. Seeps do not generally have enough surface water to support phytoplankton communities. Phytoplankton species distribution did not follow a geographic line, but is more than likely influenced by local or site level processes. Phytoplankton taxa data indicates that depressions tend to have higher S, H' and *J'* scores compared to wetland flats. However, both depressions and wetland flats had relatively low evenness scores overall.

MPBs were represented in all wetland types sampled, with 50% of the community comprised of diatoms and the other 50% a combination of other taxonomic groups dominated mainly by chlorophytes and cyanophytes, including a prevalence of picoalgae. MPBs in seeps and depressions appeared to be more variable and have a higher overall mean across the diversity indices; however, this was not significant.

One system, comprised of three connected seeps, possibly illustrated the impact of land degradation on algal species assemblages. At this site, the increase in H’ was associated with more pristine components of the system.

**Table 6.3** **Species list of amphibian tadpoles collected within the NMB area. The species names with "?" indicate an identification based on distribution and breeding timing rather than morphological characteristics.**

| Family | Taxon | CR1 | CR2 | CR3 | NMMU1 | SBG1 | DuD1 | TC2 | TC1 | PV 1 | PV 2 | HW1 | HW 2 | HW3 | R75-1 | R75-3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bufonidae** | *Amietophrynus ?rangeri* | | | | | 2 | 10 | | | | 1 | | | | | |
| | *Amietophrynus pardalis* | | | | | | 109 | | | | | | | | | |
| **Hyperoliidae** | *Hyperolius marmoratus* | | | | | | | 4 | 12 | | | 2 | 6 | 25 | | |
| | *Semnodactylus wealii* | | | | | | | | | | | 2 | 5 | | | |
| **Pipidae** | *Xenopus laevis* | | | 34 | | 236 | | | 171 | 13 | 6 | 121 | 53 | 18 | 55 | 101 |
| **Pyxicephalidae** | *Cacosternum ?nanum* | | 70 | 4 | | 36 | 2 | | 6 | 110 | 28 | | | | | |
| | *Cacosternum boettgeri* | | | | | | | 4 | 2 | | 1 | 2 | 15 | | 3 | 3 |
| | *Strongylopus fasciatus* | | | | | | | 1 | 2 | | | | | | | |
| | *Strongylopus grayii* | | | | | 6 | | | | 118 | | | | | | |
| | *Tomopterna delalandii* | 31 | 30 | | 26 | 1 | 5 | | | | 3 | | 11 | | | |

Invertebrates differed more by HGM type than by geographical region, with depressions having the greatest overall diversity. Diversity indices indicated that seeps were predominately comprised of worms and insect taxa, while wetland flats and depressions were mainly comprised of zooplankton and insects. This supersedes the influence of inundation timing on a wetland system. However, it was observed that a newly inundated wetland will have few insects and more branchiopods and microcrustaceans, whereas a “matured” wetland will be dominated by insects.

Tadpoles were collected as ancillary data. Most species only utilise the wetland for breeding and early life stage development. *Xenopus laevis* was the only species found that is predominantly aquatic for in all stages of its life cycle, and will use ephemeral systems as expanded habitat and movement corridors

Two IUCN red data species were recorded in this study. *Crinum campanulatum*, the vlei lily, is an aquatic plant found in Hopewell and is listed as Vulnerable on the red data list (Dold *et al.* 2009). This lily is endemic to the Eastern Cape. The invertebrate species, *Streptocephalus dendyi*, is an obligate ephemeral wetland species that was also identified during this study. This invertebrate is endemic to South Africa and is classified as Endangered on the red data list (Hamer 1996).

# 7 THE INFLUENCE OF ABIOTIC FACTORS ON BIOTIC COMMUNITY STRUCTURE: SPATIAL PATTERNS

A wide range of sites across the NMB were sampled in order to obtain as much baseline data as possible, in a short time, over as wide a range of geological types and rainfall zones. The 46 once-off sites also produced the first look at the role of landscape and broad scale spatial patterns on wetlands, which was partly discussed in Chapter 6. The lack of pattern observed in Chapter 6 in the different biotic communities illustrates the need for a more holistic approach; the purpose of this chapter.

Various spatial patterns were noted among the wetlands sampled in NMB when examining the abiotic factors that could potentially affect biotic community structure. Spatial patterns were more prominent in the vegetation and phytoplankton samples compared to the MPBs and macroinvertebrates. Only key trends and or patterns are discussed.

## 7.1 Vegetation

When looking at vegetation and soil properties, sites showed greater similarity within a region in comparison to sites within the same HGM type; however, this was not significant. Even when taking into account the hydrological parameters that were measured (for the subset of wet sites), this pattern of similarity was observable on a catchment scale rather than an HGM type. Subsequently, further analysis was done on the similarity of vegetation across the different sampling zones (see Figure 3.2), using SIMPER analysis. To simplify the outcomes, Table 7.1 illustrates key factors influencing the plant communities in the different zones.

**Table 7.1 Factors influencing plant community structure. Results are from various SIMPER analyses using three combinations of variables to account for both wet and dry sites sampled.**

| Variables | Factors influencing plant community |
|---|---|
| Site characteristics that can be measured in both wet and dry seasons. This includes: Sediment characteristics (soil particle size and soil chemistry) and position in landscape (GPS position, elevation, slope aspect, slope gradient and wetland area) | Predominantly influenced by soil ECS. No other factors significantly contributing except in Zone 6 (Van Stadens) where gravel, fine sand and very fine sand sized particles contributed to 23% of the similarity of plants in the zone. |
| Only water chemistry and nutrient variables | Surface water ECS, surface and sub-surface water TN. |
| Sediment characteristics and position in landscape, water chemistry and nutrient variables | In general, surface water and sub-surface TN were significant factors. In Zone 2 and 8, ECS contributed the most, followed by TN. These trends are illustrated graphically in a dbRDA in Figure 7.1. In Hopewell (Zone 4), sediment characteristics also had an influence (more than any other sample zone); however, the overall contribution was minor (2.39%). |

As nutrient content was generally low, with many values below detectable limits, the significance of these results needs to be examined further. Nonetheless, it appears that site specific plant community structure is driven more by local hydrology (specifically the TN of the water), ECS and to a lesser extent, soil properties (primarily soil ECS). Particle size also played a minor role in influencing the community structure (Table 7.1).

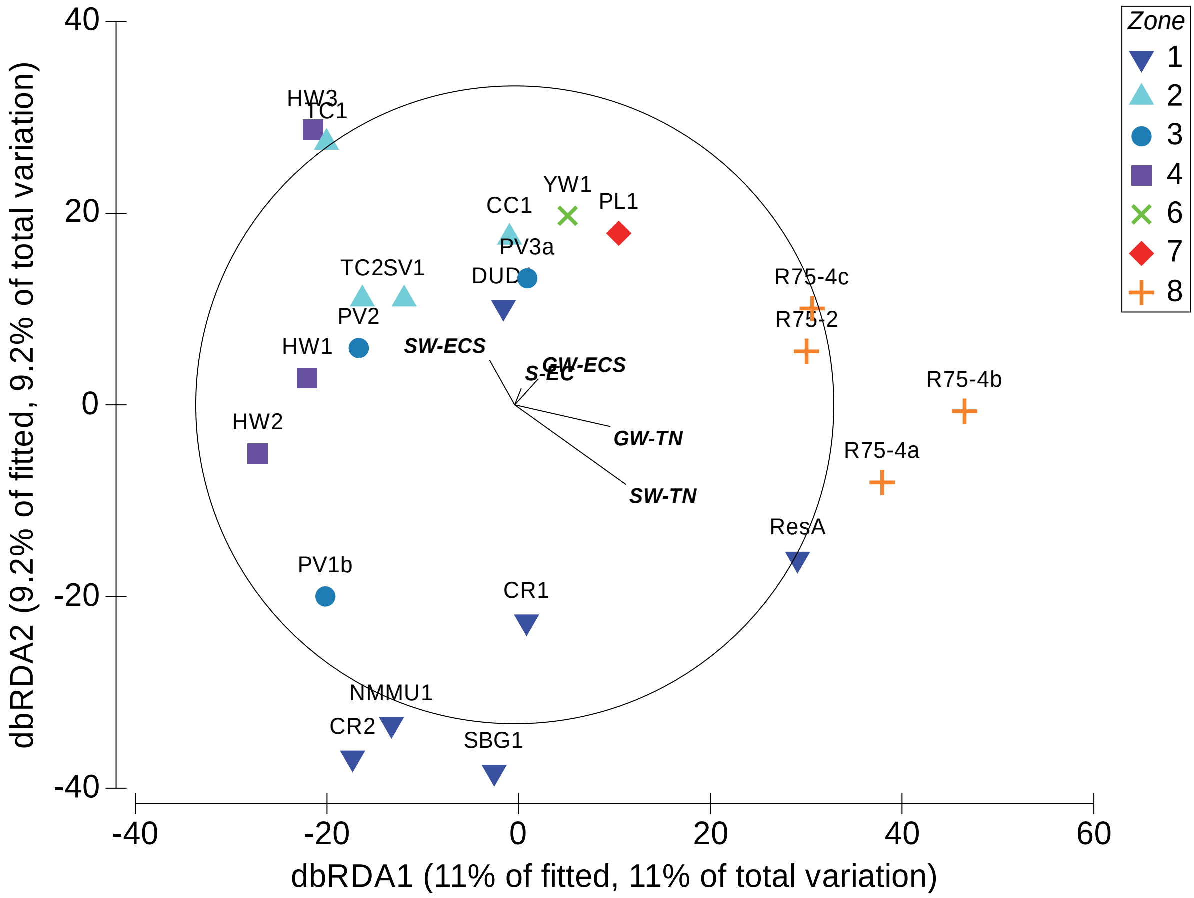


**Figure 7.1** **Distance based redundancy analysis (dbRDA) indicating key variables influencing plant community structure. This analysis included all available environmental variables.**

## 7.2 Algal Biomass and Community Structure

There was a significant difference between algal biomass, both water column and MPB, among geographical areas (ANOVA, F = 3.9 and 3.87 respectively, $p < 0.001$). Box plots illustrating the biomass distribution are shown in Figure 7.3. Zones 1 and 2 had the greatest variability of site MPB biomass and highest mean, which also corresponds to the areas of highest rainfall in the NMB. A similar pattern is shown with phytoplankton biomass, with zone 7 having the greatest variability. This may be due more to the water chemistry of the areas than the geographic position and will require more investigation. There were weak positive correlation of phytoplankton biomass with TP (r = 0.33), and TN (r = 0.21) and negative correlation with pH (r = -0.38). The correlation between MPB biomass and pH, TDS and TN were much stronger, with correlation coefficients of 0.54, 0.56 and 0.58 respectively.

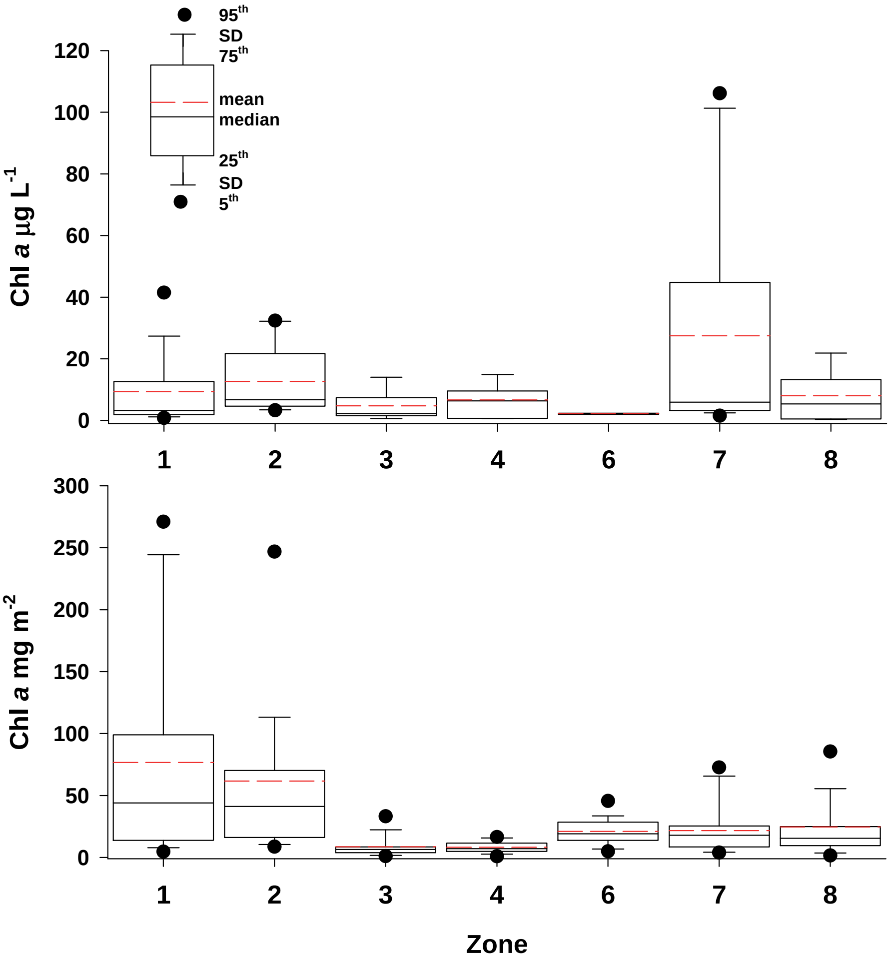


**Figure 7.2** **Chlorophyll *a* biomass of phytoplankton (top) and MPB (bottom) by geographic zone (see Figure 4.2).**

Phytoplankton species composition failed to detect any strong relationships among different wetland types, at the broad HGM level, particularly those from different geographic locations (Figure 7.3). Although certain HGMs, from similar geographic locations, appeared to group together, there are possibly other stronger environmental drivers at finer spatial or even temporal scale that are responsible for the patterns observed. Processes that may be taking place at landscape level are not easily defined by events or biological changes at a local or microscopic level (Weilhoefer and Pan 2007).

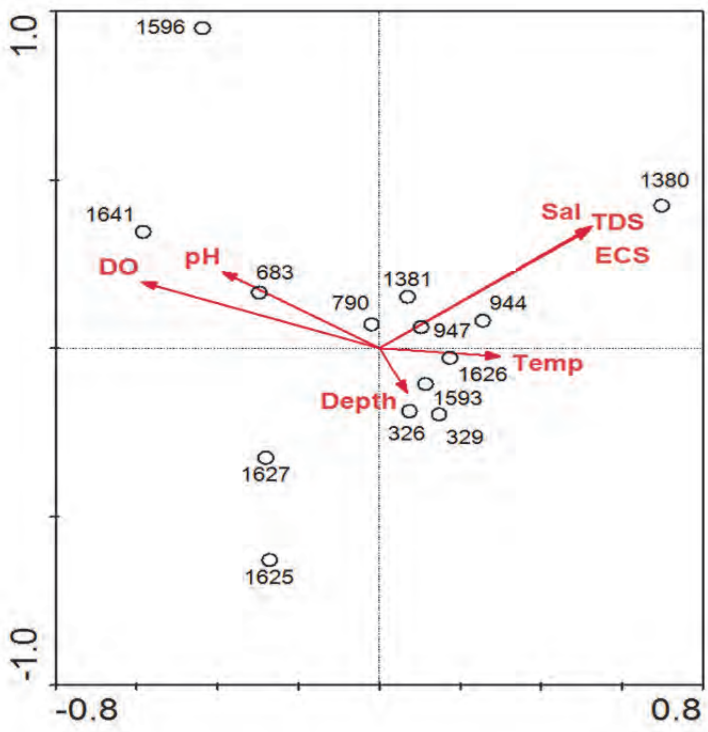


**Figure 7.3** **Ordination plot of wetland sites in the NMB based on phytoplankton taxa with environmental variables superimposed. Length of arrow indicates variables with strong response.**

BIOENV was used to investigate which variables influence the phytoplankton community. A range of environmental variables were included, from geographic data (position, slope, elevation, etc.) to site specific physical (depth, area) and chemical (ECS, temperature, nutrients). Landscape related variables had no correlation with the phytoplankton community structure. Similar to the ordination plot in Figure 7.3, the main influence was ECS (Salinity and TDS cross-correlate) and SRP, with a correlation coefficient ratio of 0.354.

MPB species composition did not show any clear patterns with landscape variables. However, ECS is a strong influence on species composition, similar to phytoplankton.

### 7.3 Macroinvertebrates

Similar to algal species assemblages, the macroinvertebrates did not demonstrate any patterns in community structure by geographical zone. As demonstrated in Chapter 6, they are tied more closely to HGM. This can most likely be linked to the easy broad dispersal of most of the insect taxa identified within the general area. There is more of a chance of the branchiopod crustaceans being linked with specific sites or areas, but as timing of sampling from first inundation is important (as discussed in Chapter 6 and Day *et al.* 2010), it is difficult to make these links with the data collected here.

## 7.4 Summary

Wetlands are complex systems that function as a result of multiple influences occurring at both site and landscape level. Wetlands in NMB were no different, with various faunal and floral indicators linked with both physico-chemical factors measured on site and landscape/catchment influences (such as underlying geology), There is no definitive way to successfully merge these variables and analyse them on one platform, and subsequently, a variety of analyses need to be conducted to reach any ecologically sound conclusions.

Similarities in vegetation, algal and invertebrate community structure did not appear to be related to geographic location. An exception was the algal biomass, with both phytoplankton and MPB chlorophyll *a* showing a trend of increasing biomass with increasing rainfall region. There were, however, hydrological and environmental variables that were associated with various biotic community structures. This includes the ECS of the water (and sometimes soil), TN and TP, which all play an important role in identifying these community structures. Indicating that local hydrological variables are important factors to consider when analysing biotic communities.

# 8 TEMPORAL SCALE PATTERNS

Whilst it is important to collect data for general reference conditions, it is also important to establish temporal patterns on a local or fine scale to feed into a landscape/catchment level spatial and temporal patterns. Ephemeral wetlands illustrate various trends in their abiotic and biotic character depending on the wetland type. However, the predominant factor driving temporal patterns will be rainfall. As the fieldwork component of this study took place over two years, only trends that were apparent within this time frame are expounded on. To this end, a subset of six sites were sampled at different intervals commensurate with their inundation periodicity, as was outlined in Chapter 3.

## 8.1 Drying Patterns of Surface Water in the Monitoring Sites

Understanding the inundation and drying patterns of wetlands is useful in establishing accurate wetland boundaries. The wetted edge of the six monitoring sites was recorded at each site visit. One-way ANOVAs were carried out on each of the monitoring sites for both surface water and sub-surface water variables to compare the maximum water depth of the site to physico-chemical parameters and nutrient content. The results indicated that there were no significant changes; therefore depth (associated with recent rainfall events or drying of the wetland) does not significantly influence the nutrient content and physico-chemical properties of a wetland over a relatively short time frame (Table 8.1).

**Table 8.1 Summary of the one-way ANOVAs for each of the monitoring sites, for both surface and sub-surface water. P-values, degrees of freedom (df) and F-values are denoted.**

| Site | SW† | SSW‡ |
|---|---|---|
| **1593** | p = 0.525, df = 5, F = 0.841 | p = 0.687, df = 5, F = 0.618 |
| **1626** | p = 0.746, df = 5, F = 0.539 | p = 0.934, df = 5, F = 0.256 |
| **326** | p = 0.753, df = 10, F = 0.667 | p = 0.896, df = 10, F = 0.485 |
| **329** | p = 0.544, df = 11, F = 0.898 | p = 0.637, df = 11, F = 0.791 |
| **944** | p = 0.569, df = 5, F = 0.777 | p = 0.566, df = 5, F = 0.746 |
| **947** | p = 0.370, df = 2, F = 1.024 | p = 0.358, df = 2, F = 1.067 |

†SW variables include: Temp, pH, ECS, TDS, DO, TP, SRP, Si, TOxN, Ni, TN, NH4

‡SSW variables include: pH, ECS, TDS, TP, SRP, Si, TOxN, Ni, TN, NH4

Both wetland flats on the NMMU reserve in Summerstrand illustrate an unconfined system with an uneven drying pattern due to the flat topography (Figure 8.1 and Figure 8.2). Once the wetland dried there was little evidence remaining of where the water was distributed at these sites (on aerial photos). When full, these systems were still relatively shallow with a maximum depth of 25 cm in 1593 and 39 cm in 1626. Subsequently, these systems dried up relatively quickly over three months, from the last significant rainfall event (Figure 8.3).

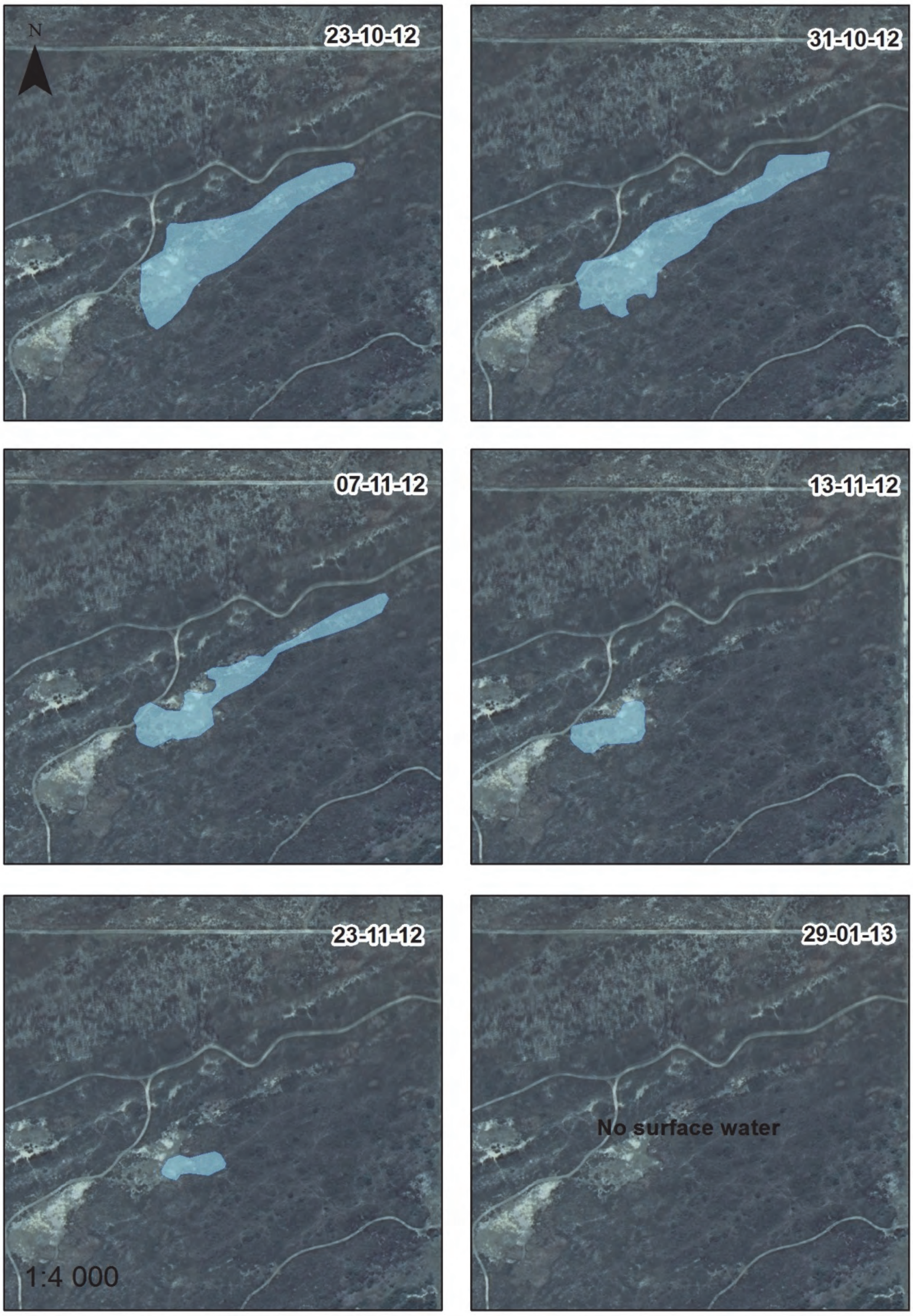


**Figure 8.1 The drying pattern of a wetland flat (1593) on NMMU, South Campus, Summerstrand (Catchment M20A).**

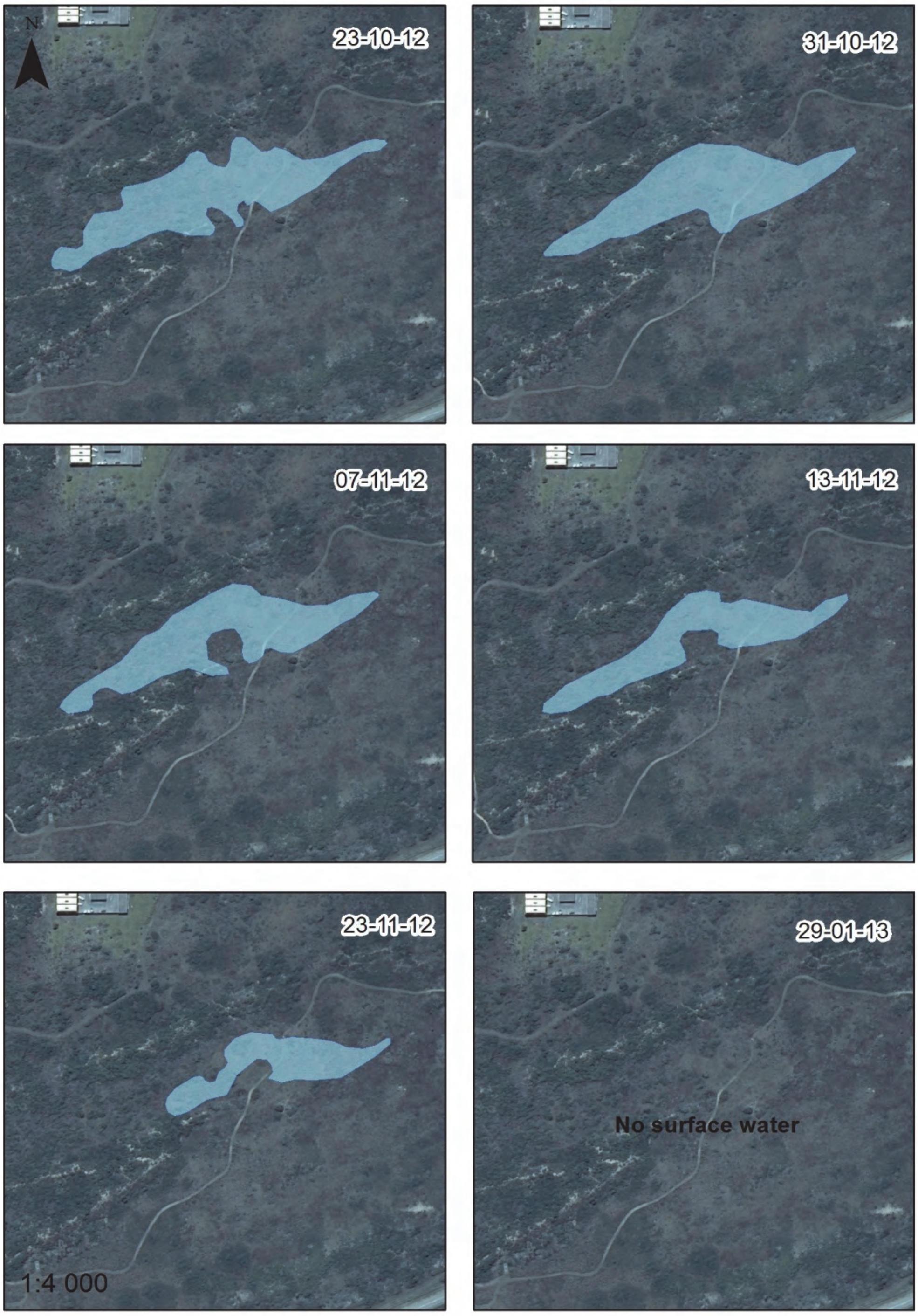


**Figure 8.2 The drying pattern of a wetland flat (1626) on NMMU, South Campus, Summerstrand (Catchment M20A).**

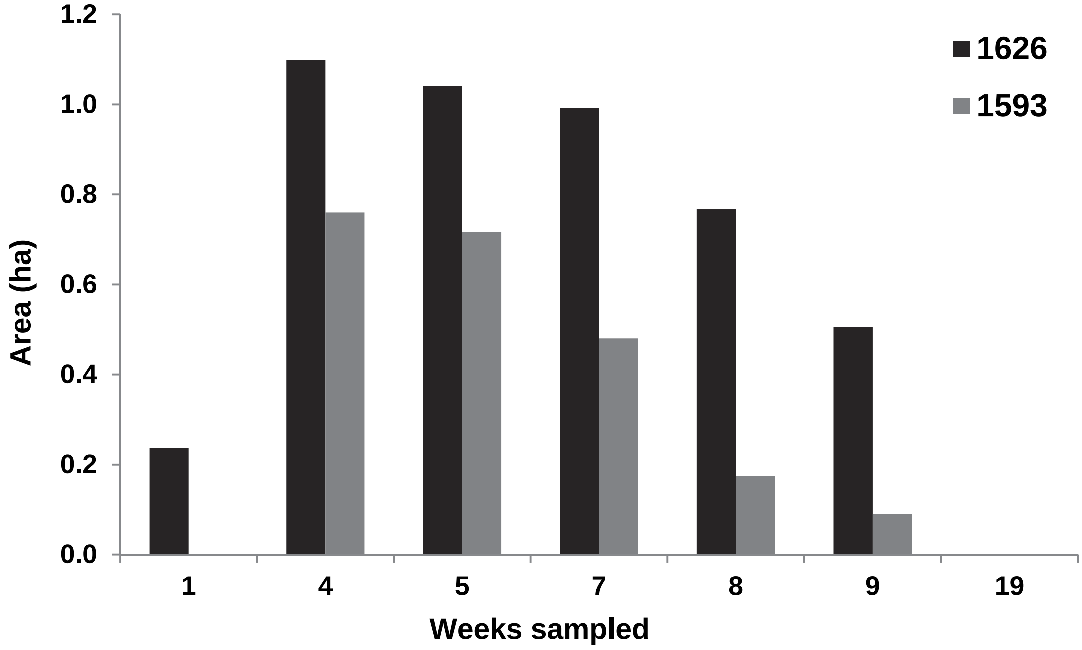


**Figure 8.3** **Changes in the wetted area of the two wetland flats on NMMU illustrated in Figure 8.1 and Figure 8.2. Monitoring commenced in September 2012 (Week 1). The wetlands were both dry by January 2013 (Week 19) and did not inundate again during the study.**

The drying pattern of the two wetlands in Theescombe (Figure 8.4) was different compared to the Summerstrand sites. The depression (site 329) had steep banks and a flat base. Maximum water depth could only be measured from February 2013, at 120 cm. During 2012, maximum depth was slightly deeper; however, sampling equipment was not available to measure greater depths. The shape of the wetland influenced the drying pattern as can be seen by the sudden increase in the wetland area after it breached the top of the depression (Figure 8.4 and Figure 8.5). Subsequently, water depth provided a better indication of drying (from 120 cm to 100 cm), rather than the area.

The other Theescombe site (326) was a *Phragmites* dominated wetland flat. Due to difficulty is measuring the exact wetted edge, Figure 8.4 illustrates the spread of the *Phragmites* and the area of soil saturation. Due to the large amount of vegetation in the wetland, a portion of the system remained inundated with a large area of saturation coinciding with the *Phragmites* distribution. Subsequently, there was a small change in the area of this wetland (Figure 8.5).

Two depressions were also monitored quarterly in Hopewell (sites 944 and 947) (Figure 8.6). These systems were both full when initial sampling took place in 2012, with significantly larger wetland areas and maximum depths of 125 cm and 120 cm respectively (Figure 8.7). There was a rapid decline in the wetland area after the rains in 2012, with site 947 drying up by May 2013 (Figure 8.7). Subsequently, a small amount of rain during winter in 2013 resulted in both wetlands receiving more water, but this was not sufficient to keep 947 inundated for more than two months (Figure 8.7).

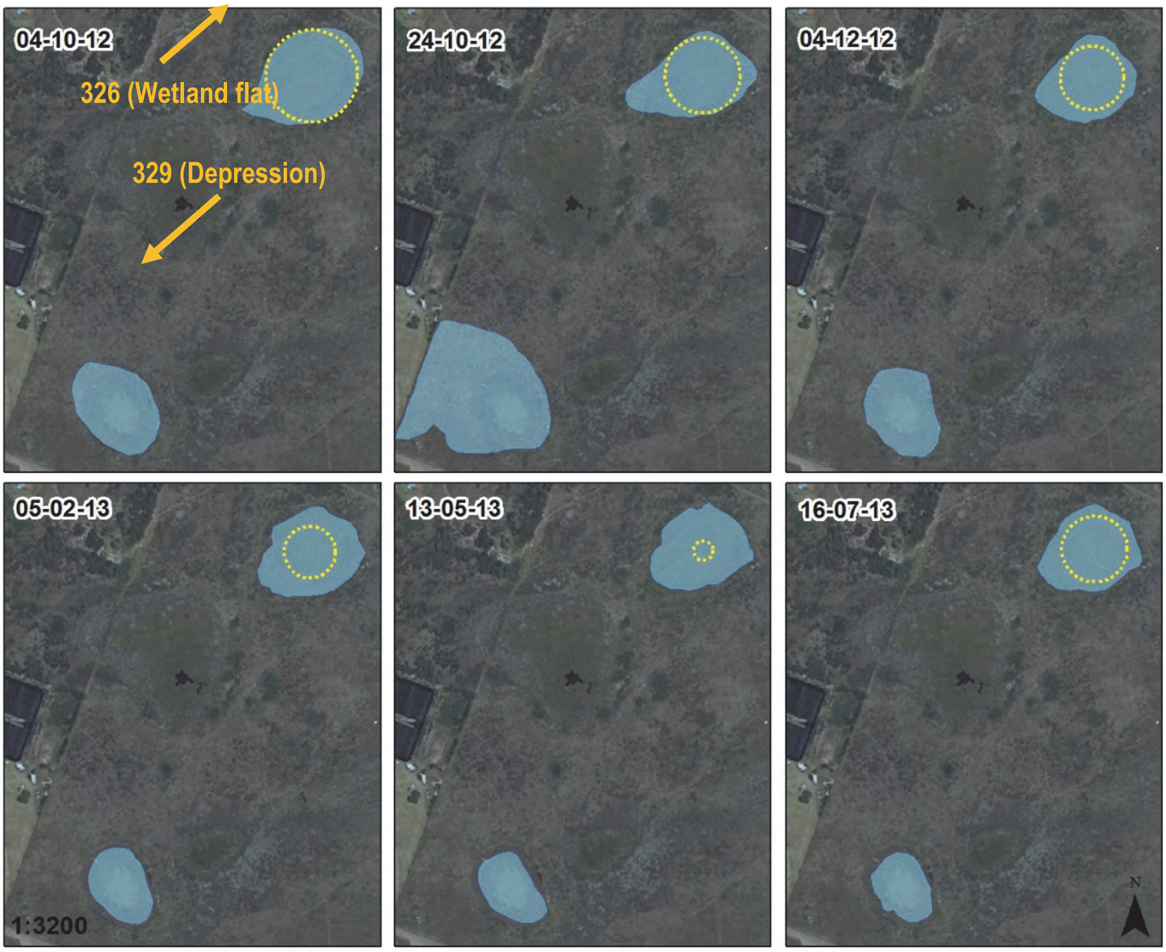


**Figure 8.4** **An example of the drying pattern of two sites monitored in Theescombe (catchment M20A). Site 326 is dominated by *Phragmites australis*, it is therefore the *P. australis* edge was mapped. The yellow dotted line represents the estimated wetted area using measurements taken along the vegetation transects.**

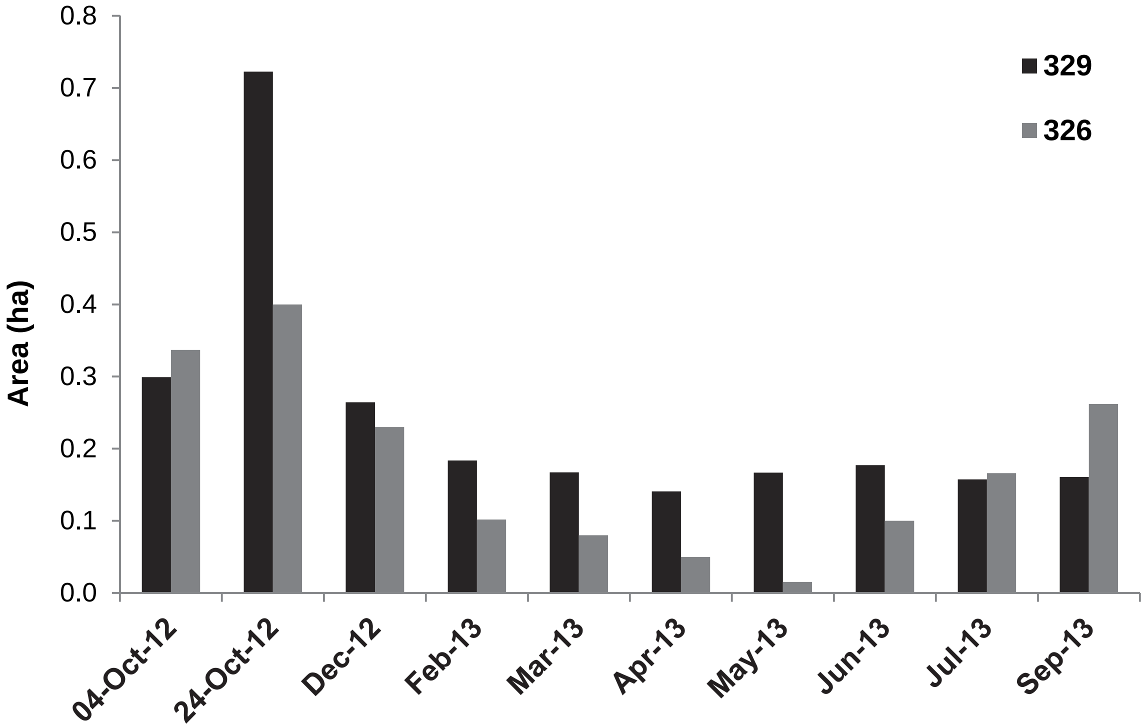


**Figure 8.5** **Changes in the wetted area of the two sites monitored in Theescombe (see Figure 8.4). Monitoring was conducted between October 2012 and August 2013. Area for site 326 is estimated based on vegetation transects.**

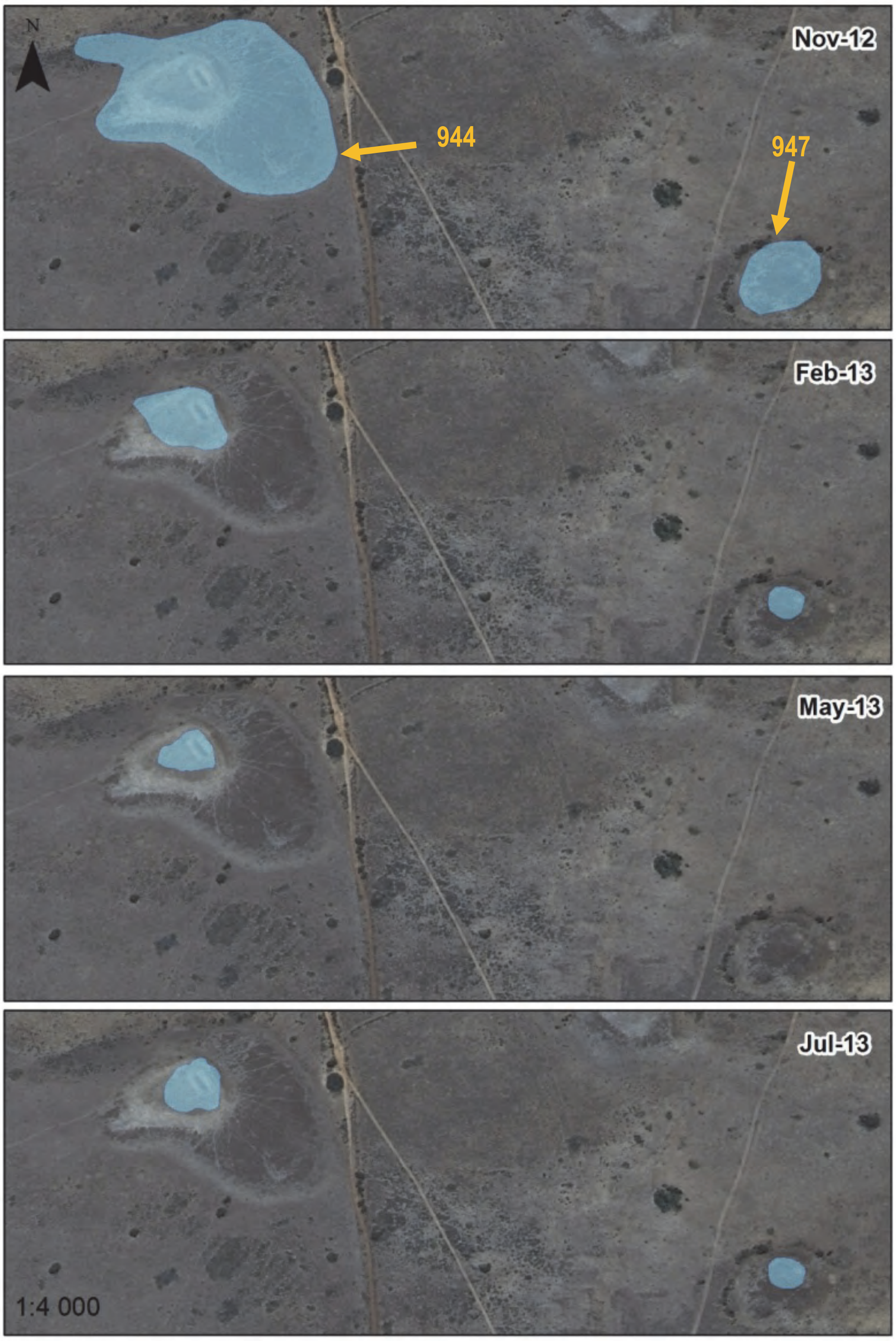


**Figure 8.6** **An example of the drying pattern of two depressions monitored in Hopewell (catchment M10A).**

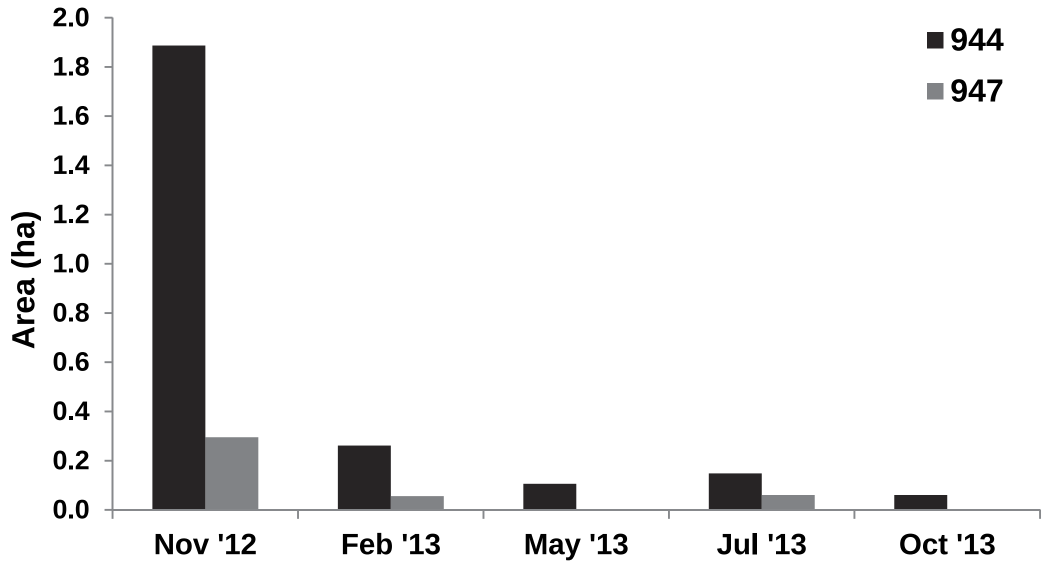


**Figure 8.7 Changes in the wetted area of the two sites monitored in Hopewell (see Figure 7.9). Monitoring was conducted between November 2012 and October 2013.**

### 8.2 Intermittent wetland sites: patterns with rapid inundation and drying

Wetland flats and seeps studied in NMB were generally intermittent in nature (see Table 4.5). This partially relates to two factors, their geomorphology (inability to "catch"/hold water) as well as their dependency on rainfall as the main hydrological input (Figure 5.2), compared to depressions that were also found in regions with lower rainfall and were associated with higher levels of groundwater (Figures 5.2 and 5.7).

Sites that undergo a more rapid cycle of inundation to drying would also be associated with higher decomposition rates of the submersed, emergent and surrounding vegetation. The bare ground would then be covered by pioneer terrestrial species that would subsequently become flooded and consequently die off. This would allow hydrophilic vegetation to establish and grow in its place. This is illustrated by the pattern of vegetation types recorded on a quarterly basis. The two sites that exhibited rapid drying had a high proportion of terrestrial and pioneering plant species over time (Figure 8.8). This pattern was somewhat reflected in the organic content in the surface soil, with depressions having lower OM content compared to the other two HGMs; however, this was not significant (ANOVA, $F = 0.345$, $p = 0.7$). This could perhaps be attributed to a loss of accumulated organic matter in depressions rendered loose by drying of the wetland at the surface due to removal by strong winds.

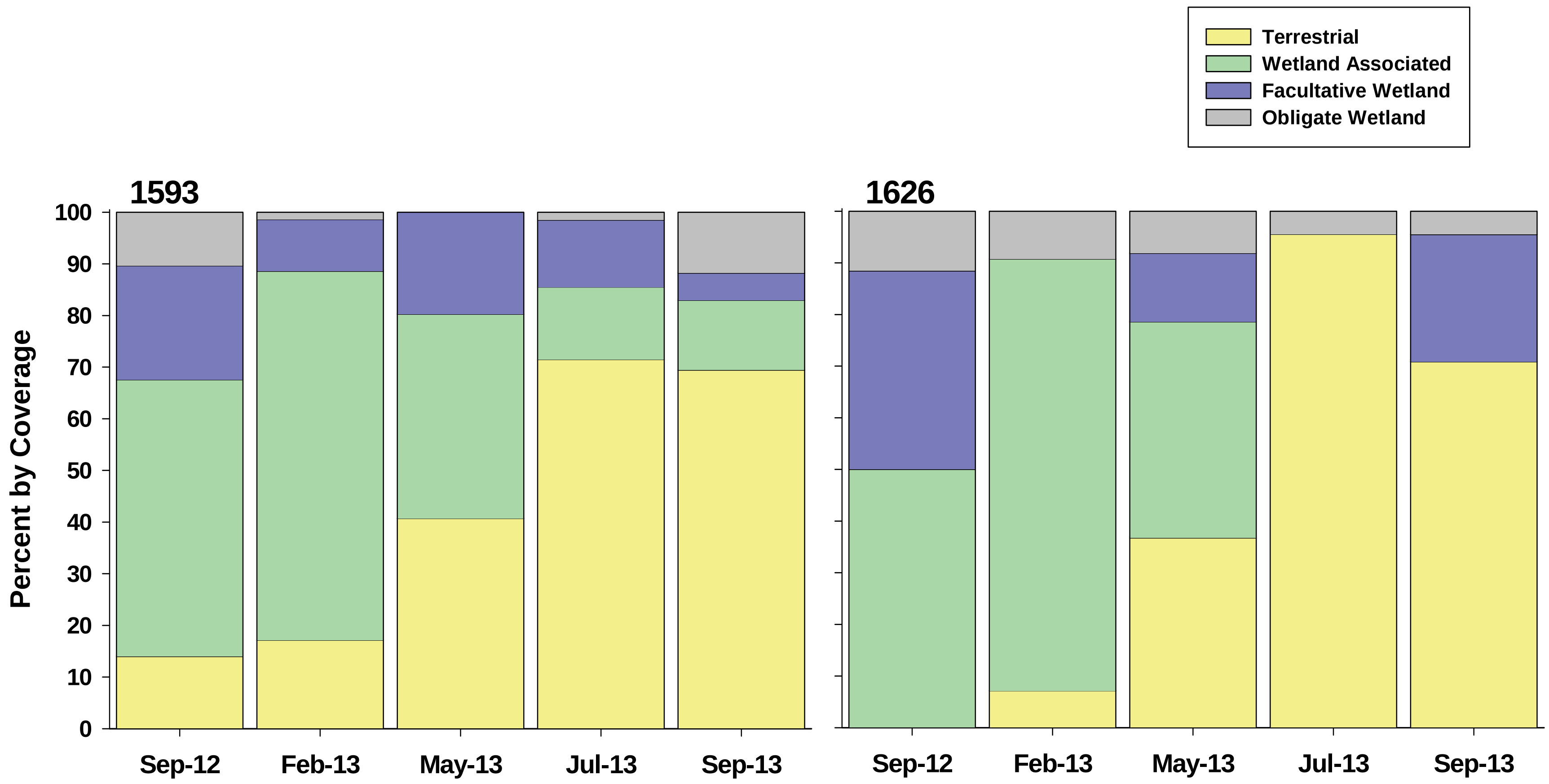


**Figure 8.8** **Shifts in composition of obligate, facultative, wetland associated and terrestrial vegetation from quarterly vegetation surveys at the NMMU campus monitoring sites.**

Given the short duration of full inundation, the algal biomass was monitored weekly until the habitat was no longer present. Levels of both benthic (when habitat present, Figure 8.9) and water column biomass (Figure 8.10) varied from week to week. The timing and levels of both benthic and water column biomass has important implication on higher trophic levels, such as micro and macroinvertebrate production. Although there was not a direct link to algal biomass and invertebrates in community structure or numbers over this period, they are dependent on primary productivity. Number of animals for sites 1593 (CR1) and 1626 (SBG1) ranged from 212 to 331 in this period. There was not a pattern in community structure with sampling week in the two wetland flats as shown in the MDS analysis (Figure 8.11). There were distinct differences between the two sites, however (Figure 8.11).

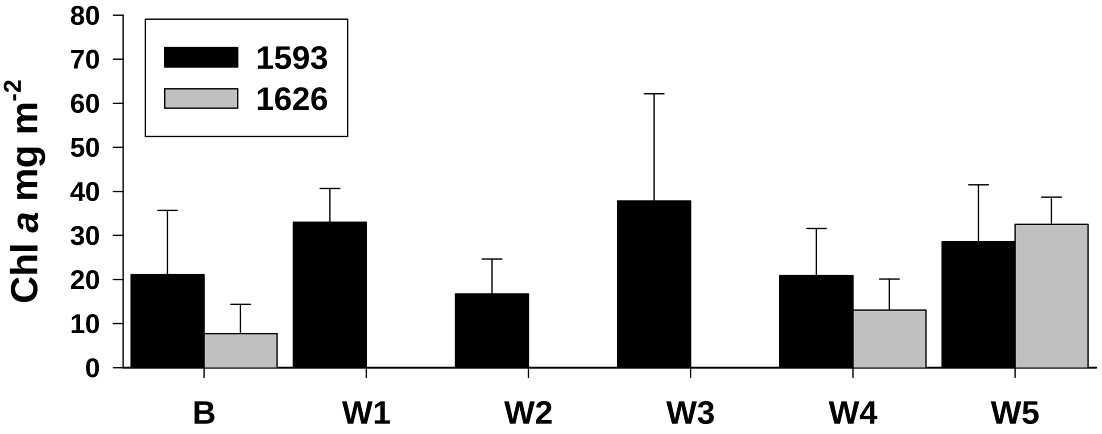


**Figure 8.9 MPB biomass in the NMMU campus sites sampled over five weeks as compared to the baseline (B) after inundation. Weeks 1-3 did not have substrata for MPB collection in the 1626 site.**

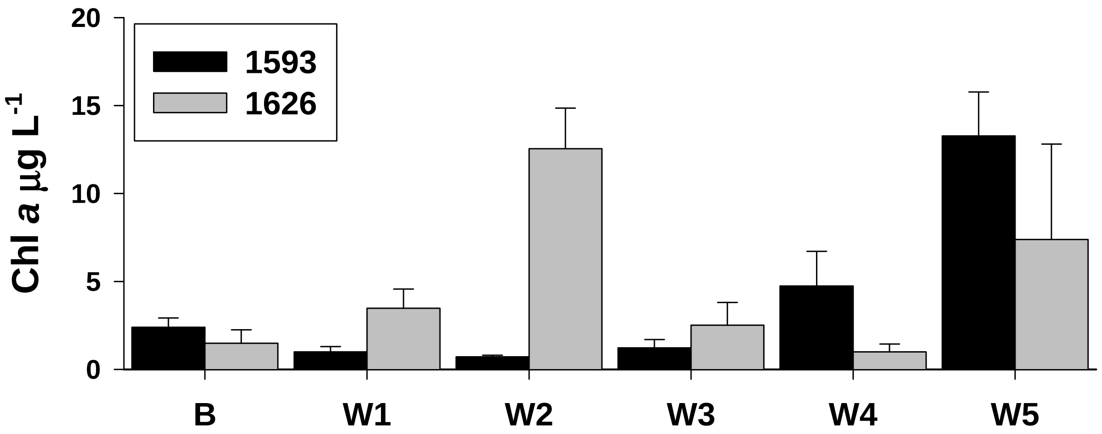


**Figure 8.10 Phytoplankton biomass in the NMMU campus sites sampled over five weeks as compared to the baseline (B) after inundation.**

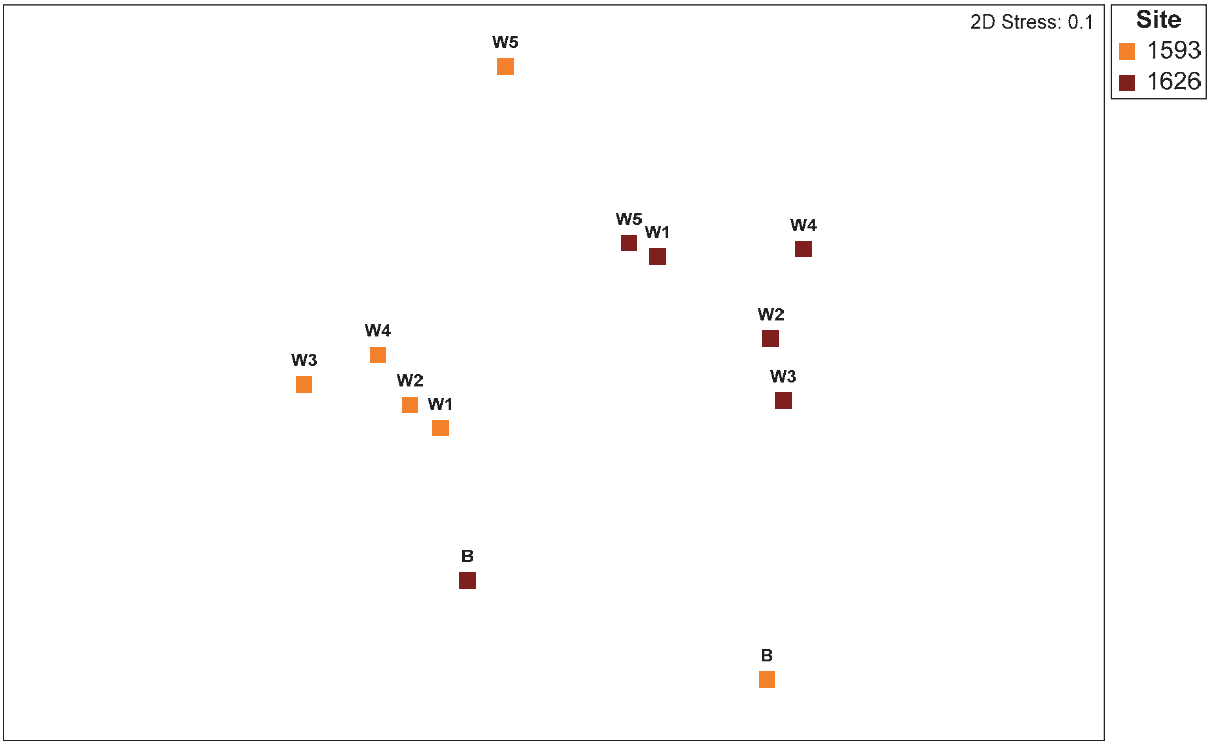


**Figure 8.11 MDS plot of baseline (B) and weekly (W1-5) family level macroinvertebrate community similarities for NMMU campus wetland flat sites 1593 and 1626.**

## 8.3 Seasonal wetland sites: patterns within an annual cycle

The seasonal wetland sites were monitored on a monthly (Theescombe, 326 and 329) basis for water quality parameters and aquatic biota, with the exception of vegetation which was carried out quarterly. The two Hopewell sites were monitored on a quarterly basis for all parameters (Table 3.10). In these sites, the pattern of vegetation did not demonstrate as dramatic of a shift compared to the intermittent NMMU campus sites. There was a greater proportion of obligate and facultative aquatic vegetation throughout the annual cycle, despite the decreasing surface area of water (Figures 8.12 and 8.13). Despite the fact that site 947 dried twice during the sampling period, the vegetation did not show a large shift towards terrestrial and opportunistic plant species (Figure 8.13).

Algal biomass varied through the monitoring period (Table 8.2). Community structure patterns of MPBs and phytoplankton showed differences between sites; however, there were no strong temporal patterns. Community patterns of macroinvertebrates at family level (Figures 8.14 and 8.15) were similar to that of the algal communities for both sites, so only the macroinvertebrate MDS plots are displayed as an example.

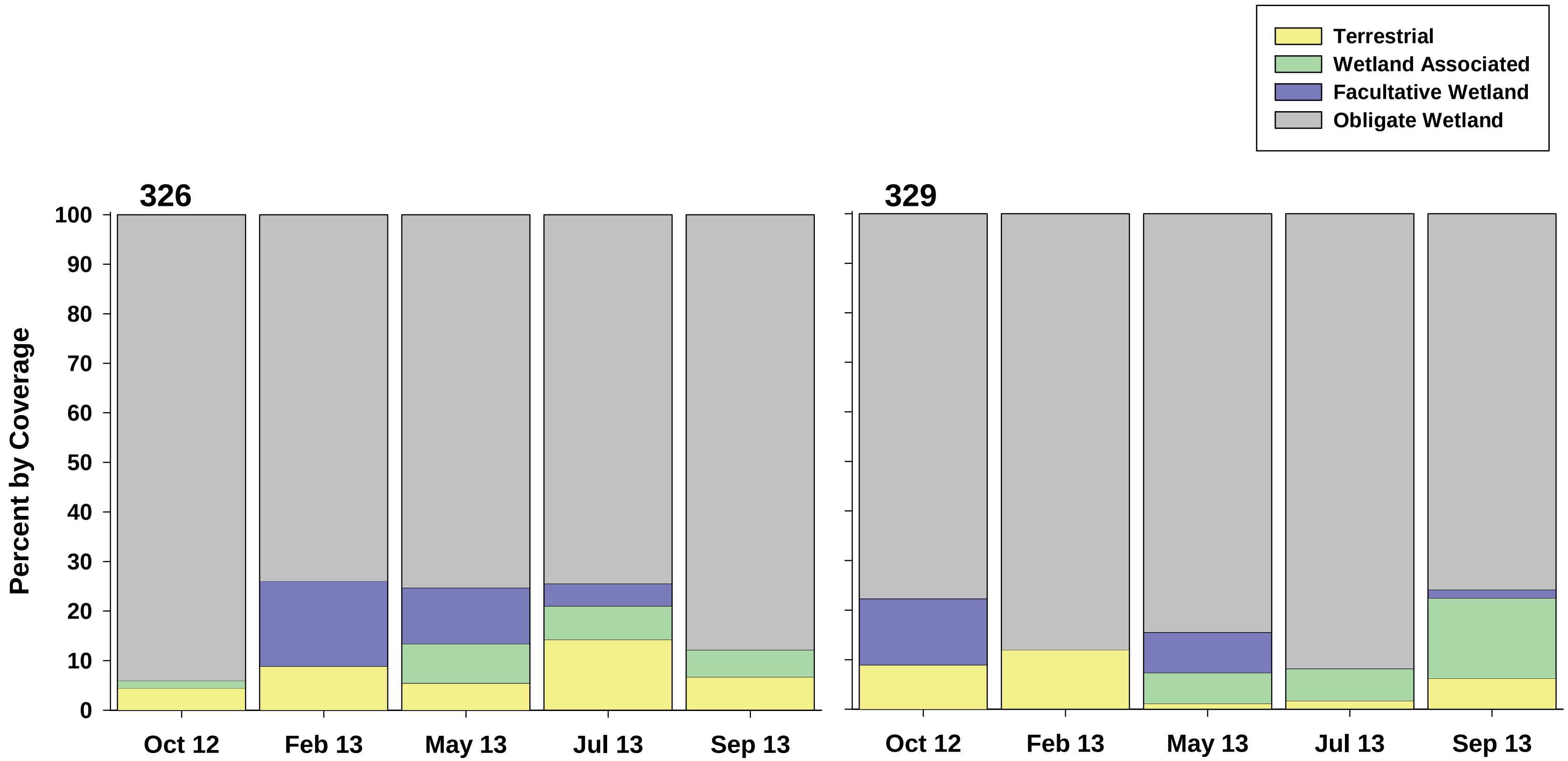


**Figure 8.12** **Shifts in composition of obligate, facultative, wetland associated and terrestrial vegetation from quarterly vegetation surveys at the Theescombe monitoring sites.**

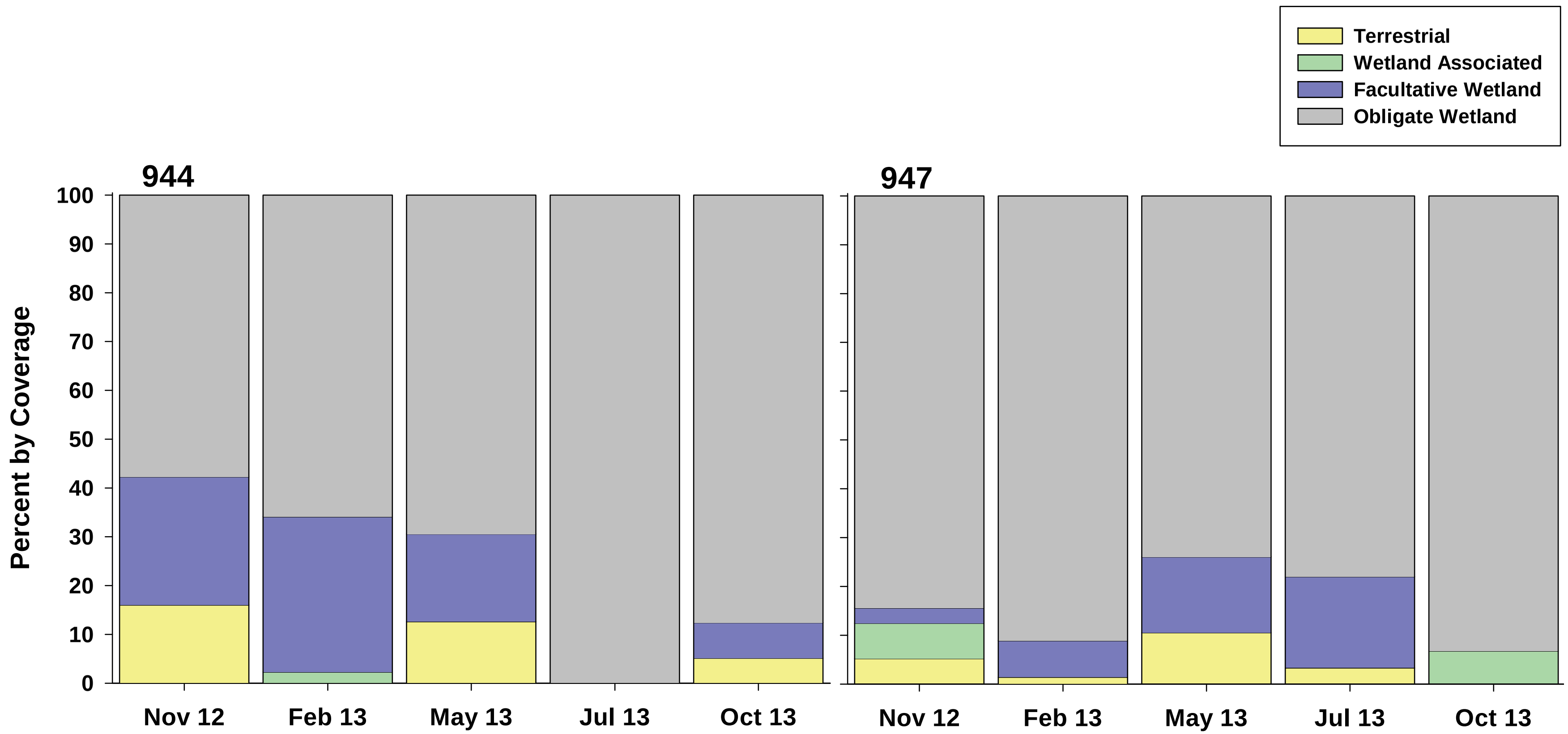


**Figure 8.13** **Shifts in composition of obligate, facultative, wetland associated and terrestrial vegetation from quarterly vegetation surveys at the Hopewell monitoring sites.**

**Table 8.2 Biomass, Chlorophyll *a*, ranges for monitoring period at Theescombe and Hopewell sites.**

| | Phytoplankton (µg $L^{-1}$) | | | | | MPB (mg $m^{-2}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **N** | **Min** | **Max** | **Mean** | **SD** | **N** | **Min** | **Max** | **Mean** | **SD** |
| **329** | 11 | 0.36 | 79.92 | 20.21 | 16.01 | 11 | 6.75 | 19.45 | 9.97 | 4.37 |
| **326** | 6 | 0.46 | 72.45 | 17.51 | 27.83 | 4 | 6.33 | 47.50 | 29.03 | 20.98 |
| **944** | 6 | 1.21 | 49.81 | 16.60 | 18.65 | 6 | 9.29 | 23.62 | 15.11 | 5.84 |
| **947** | 3 | 7.36 | 11.68 | 9.07 | 2.30 | 3 | 4.78 | 19.63 | 9.78 | 8.54 |

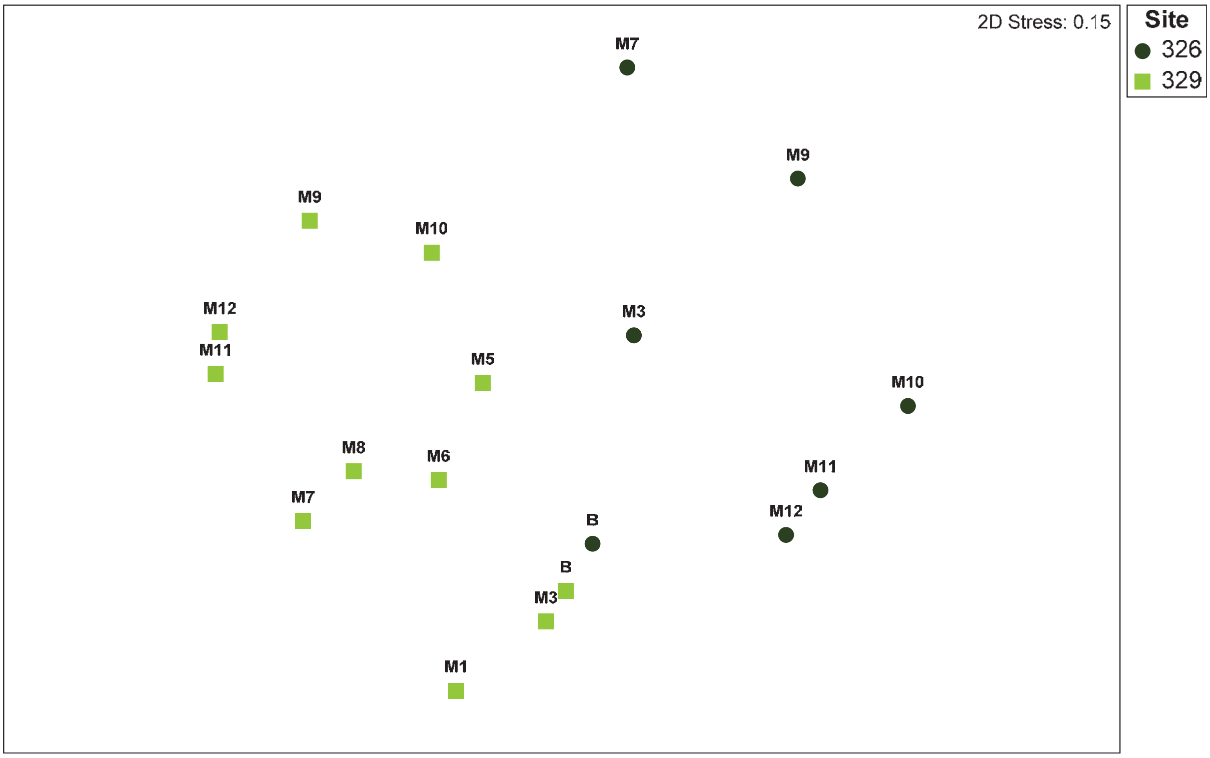


**Figure 8.14 MDS plot of monthly family level macroinvertebrate community structure for Theescombe sites for the baseline (B) and monthly samples (M1-12).**

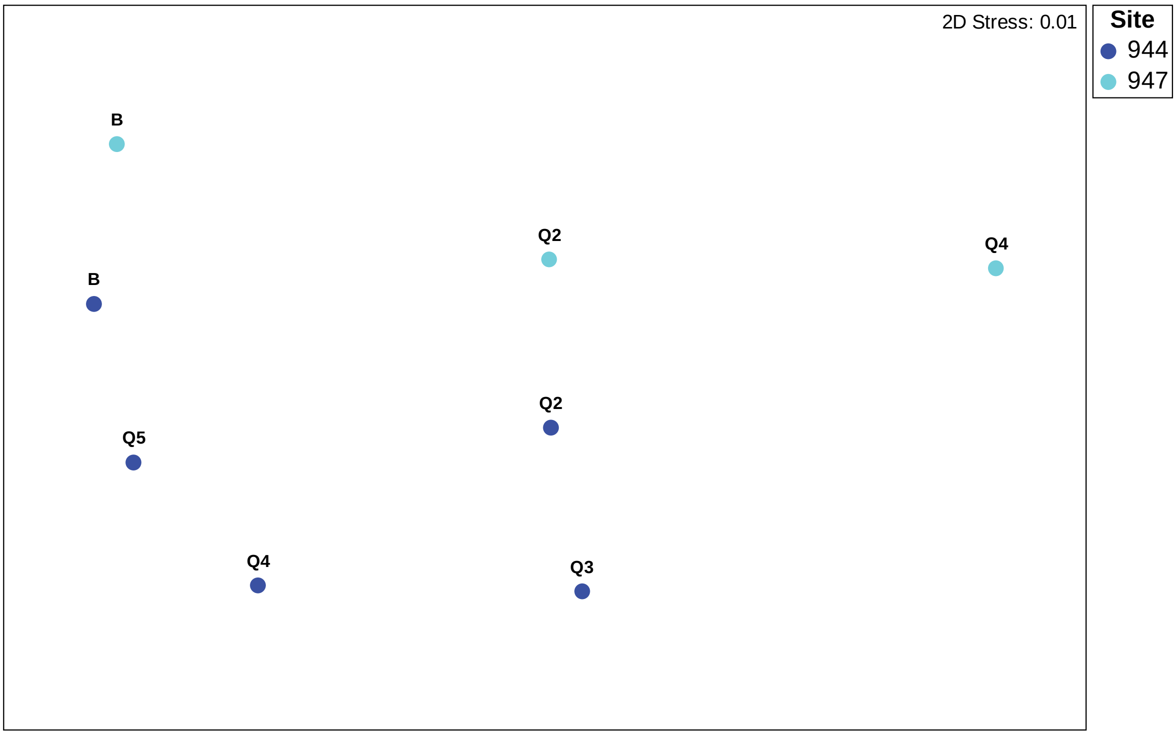


**Figure 8.15 MDS plot of quarterly family level macroinvertebrate community structure for Hopewell sites for the baseline (B) and quarterly samples (Q1-5).**

## 8.4 Summary

Topography played a role in the drying pattern of the monitoring sites. Wetland flats were wetter for shorter periods of time compared to depressions. Overall there were no significant changes in the water quality and nutrients with these changes in depth. Thus, these values are being affected by processes happening on a broader scale or across a longer period of time.

Wetland flats and seeps in NMB were generally intermittent in nature. This is most probably a result of the site-level geomorphology and the greater dependency on rainfall as the main hydrological input. In contrast, depressions were wetter for longer periods of time, and were present in the drier areas of NMB, indicating that their 'wet' status is maintained by both surface and sub-surface hydrological inputs.

On a short temporal scale (week to week), the patterns of response of aquatic biotic communities to the abiotic conditions was not clear with sampling on a weekly interval, interactions would need to be monitored in shorter intervals over a longer period. There was a clear pattern with vegetation coverage, which showed that sites that were more intermittent in nature tended to have a higher proportion of pioneering terrestrial plant species over time.

In seasonal wetlands, vegetation did not demonstrate as much of shift in community structure compared to more intermittent systems. There was a greater proportion of obligate and facultative aquatic vegetation throughout the annual cycle, despite the decreasing surface area of water. Phytoplankton and MPB community structure also did not show any shifts during the monitoring period, but there were differences in community structure among the different sites, even when they were in close proximity to each other.

To understand the general interaction of wetland systems with their associated catchment, broad scale research needs to be conducted. This poses logistical problems as it requires highly intensive fieldwork. However, this would possibly be easier in locations with simpler geological and geomorphological features as one can draw conclusions pertaining to these interactions that occur at a larger scale. But, when dealing with complex interactions in a diverse setting such as NMB, the problem becomes more difficult. This complexity was foreseen, and this project attempted to, at least, begin to address this (see Aims 4 and 5). An example is: the plant community structure was more closely related to the geographical setting. This indicates the need for sampling of diverse systems within a catchment, rather than focusing on one particular HGM type. However, more sampling and further integration of environmental variables is needed to fully address these type of research questions.

# 9 CONCLUSIONS AND RECOMMENDATIONS

Ephemeral wetland systems are, by nature, not always wet. The problems associated with this have been discussed in Chapters 1 and 2. The large number of new wetlands that were identified in NMB during this study illustrates the value of extensive research in a semi-arid region. The flood events that occurred throughout 2012 (the onset of this study), also provided us with a good start but also exposed and revealed certain short comings in the methodology on how to tackle wetland ecosystems prone to variable wetting and drying cycles which had not been attempted previously in semi-arid environments. Having "wet" wetlands helped the project team quickly learn what features could be used (i.e. were relevant) to identify ephemeral wetland systems in this region. This proved to be extremely useful when further mapping was conducted as well as when identifying monitoring site. In essence, it allows one to develop an eye for determining possible wetland sites, even after extensive dry periods. Contrastingly, there were also sampling problems during the flood cycle, with wetlands "breaching" their natural boundaries, and subsequently, becoming uncharacteristically larger and more difficult to delineate. This brings in a further temporal issue. Research on ephemeral wetlands needs to occur over extensive periods of time to fully understand their nature and function within a landscape. This requires consistency in sampling over a period of several years, and is costly. The monitoring also needs to occur over both drought and flood cycles in order to fully understand the complete spectrum of fluctuations of biotic community structure in these systems.

## 9.1 Overview of the project

Fieldwork and laboratory work began in July 2012 and was completed in February 2014. During this time, over 1712 wetlands were identified in NMB, all of which were classified to Level 4 of the CS (HGM unit). Many sites were also visited to validate the presence of a wetland (from the desktop study) and to choose sites for fieldwork. Once-off site visits were conducted at 46 sites, 6 of which were monitoring sites. These sites were classified to Level 6 of the CS. Samples and data collected in the field and processed further in the laboratory have been analysed to address the aims of this project. A summary of the aims of the project with their associated outcomes/results is outlined below. Note: many results address more than one aim but have only been noted once.

*Aim 1: Application of the CS for South Africa to identify wetland types within the NMB area*

- A desktop study and site validation resulted in a total of 1712 wetlands being mapped within NMB; this was much higher than originally expected (65% increase in the previous estimate).
- Wetlands ranged from 0.002-45.1 ha in size.
- The dominant wetland types, in terms of numbers are: depressions (519), seeps (471) and wetland flats (387), with 70% of the wetlands in near-natural or natural areas.
- The application of the CS was thorough and easy to follow:

- All 1712 sites were classified to Level 4 of the CS
- 46 Sites were visited to collect data once-off. These sites were classified to Level 6 of the CS.
- There was some difficulty in analysing Levels 5 and 6 across different sights due to the high level of detail.

*Aim 2: Delineate ephemeral wetlands in terms of their geology, hydrogeomorphology, riparian and aquatic vegetation in NMB*

- A large portion of the wetlands were found in areas with more recent geology, such as aeolian sand (recent deposits), and the Algoa and Grahamstown Groups. Recent deposits as well as formations within the Algoa group are predominantly comprised on easily erodible aeolian sand, with a relatively coarse particle size (dominated by coarse sands and gravel) which possibly influences wetland formation.
- Many wetlands were associated with agricultural and natural land within NMB
- Soils were found to be good indicators of a wetland at 60% of the sites; but for the remaining sites these indicators were not present or as clear cut.
- With the exception of the coastal dune depressions and one salt pan, the majority of the sites were fresh to slightly brackish with predominately neutral pH.
- Nutrient levels were highly variable, ranging from below detection levels to eutrophic. The majority of wetlands sampled were oligotrophic at the time of sampling. It is also important to note that sites were chosen for their relative undisturbed nature, therefore, there was little differentiation amongst the sites beyond natural variance.
- The primary hydrological factor influencing wetland flats and seeps is rainfall. Depressions, however, exhibited a wider range of hydrological influences.
- During times of transition, either newly inundated or under drying conditions, terrestrial plants (especially weedy pioneering species) and opportunistic invasive species can dominate a wetland site leaving a smaller proportion of obligate and facultative wetland species.
- The dominant taxa identified at all sites were a mix of wetland and terrestrial vegetation: 45% were terrestrial species, 9% wetland associated, 9% facultative wetland species and 37% obligate wetland species.

*Aim 3: Determine the biodiversity of algae, aquatic and semi-aquatic plants, and aquatic invertebrates for ephemeral wetlands in NMB*

- **Vegetation:**
  - There were > 300 plant taxa identified from the 46 wetland sites, of those, 148 were considered dominant in terms of cover. All sites sampled had wetland indicator plant species present.
  - One confirmed IUCN red data species was recorded at three wetlands, *Crinum campanulatum*, which is a regional endemic.
  - There were no differences between wetland types in terms of overall plant diversity.
- **Algae:**
  - Phytoplankton and microphytobenthos (MPBs) were found to be fairly numerous and diverse, with 147 and 298 taxa identified respectively. Seeps do not generally support enough surface water to support phytoplankton communities. MPBs, however, were represented in all wetland types sampled.
  - The phytoplankton were dominated by chlorophytes, cyanophytes and cryptophytes and these occurred in depressions and wetland flats.
  - Phytoplankton taxa in depressions displayed more variation in species composition and diversity compared to wetland flats.
  - In MPBs, 50% of the community was comprised of diatoms and the other 50% a mix of other taxonomic groups dominated mainly by chlorophytes and cyanophytes, including a prevalence of pico-algae (small, 0.2-1 µm, unidentified cyanophytes and chlorophytes).
  - MPBs in seeps and depressions appeared to be more variable and have a higher overall mean across the diversity indices, however, this was not significant.
  - Diatoms were analysed both as a part of the total MPB community and on their own. 180 species were identified, but with very low abundances. Of those, 76 species were also recorded as part of the overall MBP community.
- **Invertebrates:**
  - There were 144 taxa of aquatic macroinvertebrate identified. Overall, depressions had the greatest diversity of invertebrates.
  - There was one IUCN red data invertebrate recorded, an obligate ephemeral wetland species of fairy shrimp, *Streptocephalus dendyi*.
  - Several alien invasive terrestrial snails, loosely associated with surrounding wetland vegetation were also recorded, namely, *Cochilicella barabara* and *Theba pisara*.
  - The Shannon-Weiner diversity index showed depressions as having the greatest overall diversity in macroinvertebrates. In terms of species

richness, depressions and flats were similar in macroinvertebrate numbers, with seeps being much lower in numbers.

- Insect taxa were most diverse across all wetlands, non-insect (i.e. branchiopods and microcrustaceans) groups generally being specific to ephemeral or standing waters and not as specious. A newly inundated wetland will have few insects and more branchiopods and microcrustaceans, whereas a "matured" wetland will be dominated by insects.
- Taxonomic composition was very different between the wetland types, with seeps being insect and "worm" dominated due to shallow or lack of surface water, and saturated soils. The community structure between depressions and wetland flats was similar, but the overall numbers of animals in the non-insect taxa were greater in wetland flats.
- In the absence of water, hatching experiments of dry wetland sediments showed the presence of an array of wetland taxa, from invertebrates to algae and plants.
- Ten species of tadpoles were recorded, most only utilising the wetland for breeding and early life stage development. *Xenopus laevis* is a predominantly aquatic species that was identified in these systems.

*Aim 4: Understand the interaction of geological and biological processes in the structure of biotic communities in ephemeral wetland systems within the NMB*

- Topography played a role in the drying pattern of the monitoring sites. Wetland flats and seeps were wetter for shorter periods (more intermittent) of time compared to depressions (more seasonal in nature). Overall there were no significant changes in the water quality and nutrients with these changes in depth. Thus, these values are being affected by processes happening on a broader scale or across a longer period of time.
- On a short temporal scale (week to week), the patterns of response of aquatic biotic communities to the abiotic conditions was not clear with sampling on a weekly interval, interactions would need to be monitored in shorter intervals over a longer period. There was a clear pattern with vegetation coverage, which showed that sites that were more intermittent in nature tended to have a higher proportion of pioneering terrestrial plant species over time.
- In seasonal wetlands, vegetation did not demonstrate as much of shift in community structure compared to more intermittent systems. There was a greater proportion of obligate and facultative aquatic vegetation throughout the annual cycle, despite the decreasing surface area of water. Phytoplankton and MPB community structure also did not shift much during the sample period, but there were differences in community structures among the different sites, even when they were in close proximity to each other

*Aim 5: Determine if patterns in biodiversity are more closely related to wetland classification properties or geographical location, and which factor or set of factors will be most likely to predict and describe the functioning of ephemeral wetland systems*

- Physico-chemical properties were influenced more by geographical location and underlying geology than by the type of wetland.
- Depth and rainfall do not directly influence nutrient content or physico-chemical properties of a wetland over a short time frame.
- Landscape, or geographic position, and wetland type were not dominant factors influencing floral and faunal communities.
- An exception was the algal biomass, with both phytoplankton and MPB chlorophylls showing a trend of increasing biomass with increasing rainfall.
- The macroinvertebrates did not demonstrate any patterns in community structure by geographical location, but did indicate patterns according to HGM type.
- MPB species composition did not show any clear patterns with landscape variables. However, ECS is a strong influence on species composition, similar to phytoplankton.
- There were hydrological and environmental variables that were associated with various biotic community structures. This includes the ECS of the water (and sometimes soil), TN and SRP, which all played an important role in identifying these community structures. Indicating that local hydrological variables are important factors to consider when analysing biotic communities.

Ephemeral wetland systems are, by nature, not always wet. The problems associated with this have been discussed in Chapters 1 and 2. The large number of new wetlands that were identified in NMB during this study illustrates the value of extensive research in a semi-arid region. The flood events that occurred throughout 2012 (the onset of this study), also provided us with a good start but also exposed and revealed certain short comings in the methodology on how to tackle wetland ecosystems prone to variable wetting and drying cycles which had not been attempted previously in semiarid environments. Having “wet” wetlands helped the project team quickly learn what features could be used (i.e. were relevant) to identify ephemeral wetland systems in this region. This proved to be extremely useful when further mapping was conducted as well as when identifying monitoring site. In essence, it allows one to develop an eye for determining possible wetland sites, even after extensive dry periods. Contrastingly, there were also sampling problems during the flood cycle, with wetlands “breaching” their natural boundaries, and subsequently, becoming uncharacteristically larger and more difficult to delineate. This brings in a further temporal issue. Research on ephemeral wetlands needs to occur over extensive periods of time to fully understand their nature and function within a landscape. This requires consistency in sampling over a period of several years, and can be costly. The monitoring also needs to occur over both drought and flood cycles in order to fully understand the complete spectrum of fluctuations of biotic community structure in these systems.

## 9.2 Recommendations

There are many tools available for evaluating wetland condition, assessing important wetlands and determining which systems should be rehabilitated. Thus, this section will not address the application of these tools such as those found in the DWAF guidelines (2005), the WET series and the wetland Health and Importance Series (the latter two being WRC projects).

### 9.2.1 Management implications

This study has contributed to new knowledge on the wetlands, particularly the ephemeral wetlands, of NMB and can aid in future management of them in the following ways:

- The use of a relatively new classification tool, the Classification System, outside of the regions it was developed and tested in. The project was able to demonstrate the ease of use and evaluate its effectiveness in classifying wetlands of all types with in an area. This tool can be used by municipalities, regional and provisional environmental authorities with relative ease.
- An extensive wetland database now exists for the NMBM. This data will be freely available on the SANBI national wetland database.
- The database includes information on where and what type of wetlands there are, and the associated attribute data which can be used to update landcover data, re-assess conservation and biodiversity priority areas and determine areas for potential rehabilitation projects.
- There is now site-specific data recorded, along with more detailed hydrological and ecosystem characteristics on a subset of sites as well as the species and species distribution, across a wide area of the municipality, on:
    - the aquatic and semi-aquatic vegetation with associated terrestrial vegetation;
    - phytoplankton and microphytobenthos; and,
    - aquatic invertebrates.
- Two IUCN species (*Crinum campanulatum* and *Streptocephalus dendyi*) have been recorded at their respective sights, which should be conserved.
- Along with endangered species, the presence and distribution of alien invasive invertebrate species has been documented for two snail species, *Cochilicella barabara*, and *Theba pisara*. This can aid in the documentation of spread of these species and help with control and management.
- Baseline data on wetland soils (properties and chemistry) and water chemistry has been recorded on a subset of wetlands. These data can then be used to further develop national monitoring tools for water and sediment quality, by providing more reference condition data.

- There is better understanding of systems and areas that are potentially threatened by existing and future anthropogenic activities, which is discussed in more detail below.
- The data can be used in the decision making process for developments (e.g. housing projects). Many of these wetland systems were not identified previously and are not easily identifiable during a dry cycle. Any development that occurs on a wetland during this dry cycle would be at risk of flooding. This happened in many areas of PE during the floods in 2012. Subsequently, any development occurring during this time would benefit from having an extensive wetland layer to more accurately predict/manage flood risk.

### 9.2.2 Ecological and anthropogenic threats to wetlands in NMB

There was little evidence of direct use of wetland resources in NMB (in terms of ecosystem services). This excludes wetlands that were used to supply water for surrounding agriculture and livestock. The one exception was a depression wetland in the Theescombe conservation area (one of the monitoring sites) (Plate 2). Litter was observed both in and around the wetland, mainly plastic items (including garden furniture). Landowners bordering the conservation area also reported that people would use the wetland for swimming. However, this did not appear to reduce water quality (both visual, physico-chemical and nutrient values), although it did negatively influence the aesthetic value. At the end of the sampling season (in 2014), it appeared that the wetland had been stocked with juvenile fish. There are possible future impacts to the system if these fish survive.

Over a third of the wetlands in NMB are situated on land that is classified as agricultural (Figure 5.3). This land use is possibly the largest threat to wetland degradation and loss of biodiversity or wetland function in NMB. Grazing activities on agricultural and rural land result in trampling and grazing of the vegetation, potentially altering vegetation community structure. Livestock trampling on a system also increases sediment compaction and soil erosion, which could potentially alter the hydrological dynamics of the system, as well as any surrounding systems that are connected hydrologically. An example of the impact of these activities was observed along the R75, where a series of three connected seeps (R75-4a-c) were modified, to differing degrees, by grazing. This was reflected in the MPBs and plant community structure, and is discussed in Section 6.2 and illustrated in Plate 3.

Another threat to the biodiversity and hydrology of wetland systems is the encroachment of alien vegetation both in the wetland and in the upper reaches of the catchment (affecting water input). Port Jackson (*Acacia saligna*) was a common invasive tree observed within and around wetlands in NMB (Plate 4).

Some wetlands, classified as “Modified” in this study, retained a measure of ecosystem functioning. The wetland illustrated in Plate 5 is a relic mine and was previously used to mine gravel, effectively scouring the site. Scouring, draining or shoring up one side of a wetland were found mostly on agricultural lands, next to roads, or were associated with mining activities (such as gravel, clay or salt). Over time, if little further disturbance occurs in these systems, they begin to recover and restore some of their previous functioning, or they can shift to a new ecological state with new functions, as can be seen in this picture

The effect of fires on wetland systems in NMB should also be determined, as both planned and unplanned fire occurs in many of the biomes associated with NMB. Fynbos vegetation needs fire to maintain the community structure (for reproduction and for preventing the intrusion of vegetation typical of other biomes). Thus, wetlands located in the fynbos biome may potentially be exposed to planned fires every few years. This would have an effect on the vegetation cover, the physico-chemical properties of both the sediment and water, as well as releasing carbon and nitrogen into the soil directly surrounding the wetland (Wetzel 2001). An example of the visual effect of an unplanned fire at Hopewell Estate is illustrated in Plate 6 and 7.

The flooding that occurred during 2012 had major implications around the municipality. Many wetlands extended beyond their natural boundaries and, as a result, flooded roads and lands bordering these wetlands. The picture in Plate 6 illustrates the “normal” vegetation limit of the boundary. This whole section of property remained under water for over a month after extensive rainfall, resulting in a loss of grazing land and the access route to the farm was blocked. A main road in Port Elizabeth, linking Walmer and Seaview was also impacted. The road closed for approximately five months as the road and neighbouring properties (including a restaurant) were severely flooded. The flooding of the road had happened many times in previous years. The local geomorphology and hydrology create a bottleneck and prevents water from draining away long after the rains stop.


**Plate 2** **Depression in Theescombe (TC1).**

**Plate 3** **Degradation of a wetland (R75-4b) as a result of livestock grazing and agriculture. Arrow indicates location of seep.**

**Plate 4** **Depression wetland in Parson's Vlei (PV2) with Port Jackson. The trees can be seen in the wetland and around the periphery.**

**Plate 5** **Wetland (VSR 1) that was previously scoured (for gravel mining) and bermed up. Subsequently, it has "naturalised" and provides many functions/ecosystem services associated with wetlands.**

**Plate 6** **Depression at Hopewell Conservation Estate. This was one of the monitoring sites (HW 1) during the study. This is a picture from before the fire that occurred in October 2013.**

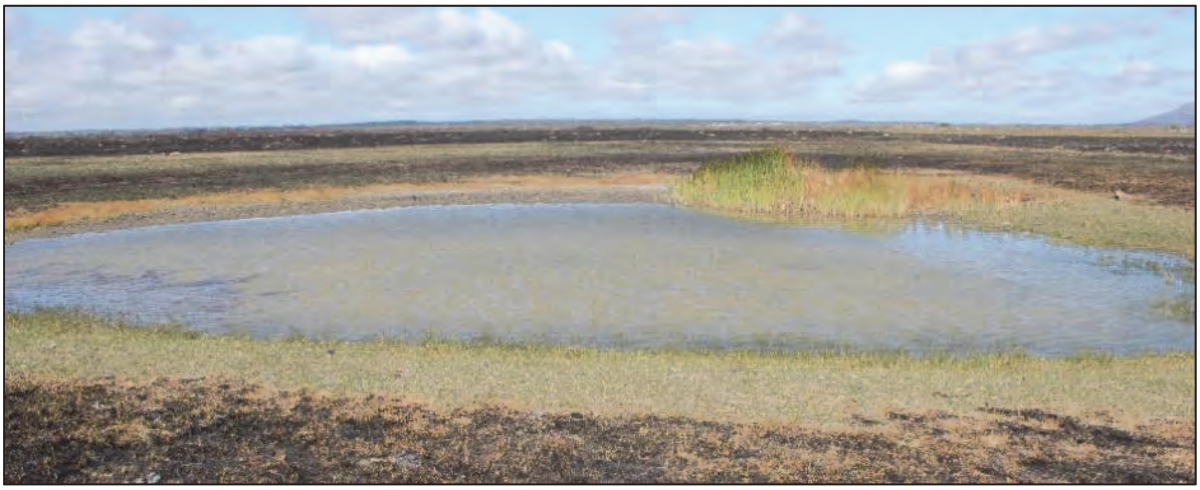

**Plate 7** **Depression wetland (HW 1). This picture depicts what remained after an accidental fire that occurred in October 2013.**

**Plate 8 Site R75-1 before the floods in October 2012.**

**Plate 9 Site R75-1 after the floods in October 2012.**

### 9.2.3 Potential conservation priority areas

Prioritisation procedures were not conducted according to the WET-Prioritise method described by Rountree *et al.* (2009), as this was beyond the scope of this study. However, the broad-scope of this project has helped us to estimate which areas are of key concern and which areas should potentially be conserved.

Stewart et al. 2009 suggests that the existing network of protected areas in NMB is not adequately conserving biodiversity sustainably. Currently 21% of wetlands in NMB are within existing CBAs

Some recommendations for key conservation and rehabilitated areas in NMB are suggested below (Figure 8.1).

**Figure 9.1 Recommendations for key conservation and rehabilitation areas in NMB**

| Location | Conservation/Rehabilitation | Reason/Comments |
|---|---|---|
| Hopewell Conservation Estate and the neighbouring MOSS | Conservation and increased protection | Site of IUCN red data species (*Crinum campanulatum*). Area within and outside reserve are under increasing measures of grazing. This should be managed and possibly reduced to prevent degradation of the wetland vegetation and surrounding fynbos. |
| Van Stadens Reserve, Parson's Vlei | Conservation of existing Reserve and the privately owned land in Parson's Vlei | Site of IUCN red data species (*Streptocephalus dendyi)* unique to ephemeral systems. Currently there is minimal impact by anthropogenic activities. |
| Theescombe | Conservation and rehabilitation | Continue to protect with increased awareness and more signage indicating conservation area. Prevent swimming, stocking of fish and pedestrian activity.<br>Removal of alien vegetation upslope is also recommended. However, further studies should be conducted first as there are settlements downslope. |
| Grassridge | Part of the Coega IDZ. Some areas are zoned for conservation | A large number of depressions are situated on a stretch of thicket/bonteveld associated with alluvial gravel (Bluewater Bay Formation). Vegetation is becoming increasingly degraded from overgrazing and anthropogenic activities (increased access routes, illegal dumping and settlements. |
| Seaview seeps | Conservation of system to maintain connectivity of seeps and to control hydrological dynamics | Coastal seeps dominated by P*hragmites australis*. These seeps are unique due to the associated stromatolites that are situated below the systems. These types of stromatolites are only found between PE and St Francis Bay and thus should be conserved.<br>The seeps are also within a coastal dune system and thus the destruction of systems might lead to changes in sediment dynamics and flow of water towards the coast. This could possibly result in flooding of the coastal road (a |

| Location | Conservation/Rehabilitation | Reason/Comments |
|---|---|---|
| | | main access route to residential areas). |
| Parson's Vlei | Conservation and rehabilitation | Area should remain non-developed (besides few access roads) as there are many pristine wetland systems. Alien vegetation (*Acacia saligna)* clearing needed around the wetland systems. |
| Redhouse | Conservation and rehabilitation | Several wetlands are situated on an alluvium associated with a relic floodplain. These systems are below an industrial area. The surrounding land is severely degraded thicket due to overgrazing, litter and dumping (industrial and building rubble).<br>These systems need to be rehabilitated due to their unique setting and potential for ecosystem service provision. The wetlands can act as a buffer between the industrial area and the Swartkops River, reducing the influx of water into the system (flood attenuation) and absorb pollution from industrial area (reducing nutrient inputs into the river). |
| Bridgemead | Rehabilitation | Removal of alien vegetation. Reduce number of access roads which are increasing run-off across the landscape. |

Key conservation areas were highlighted in the 2009 conservation assessment and plan for the NMB by Stewart (2009). A summary of the number of wetlands that fall within key conservation areas is outlined below. The definitions of what is considered a priority area and how the different categories are defined is described in the report.

- Figure 8.2 below illustrates the number of wetlands per HGM type associated with the various critical biodiversity area categories.
    - 358 of the wetlands digitised are associated with CBAs in the Municipality. All of these should be conserved (according to regulations)
    - The 41 wetlands that fall within ESA2 should all be visited to determine the status of these systems
    - 100 wetlands currently lie within protected areas, with a further 11 systems in areas that will possibly be protected in the future

- 132 wetlands are situated on existing Nature Reserves, 62 of which are situated on the NMMU Campus Reserve, and are mostly depressions and wetland flats.
- 438 wetlands are associated with critical ecological processes. This is mostly comprised of wetlands of all HGM types that are located along riverine corridors (a total of 419 systems). 19 wetlands also fall within sand movement corridors, most of which are depressions.

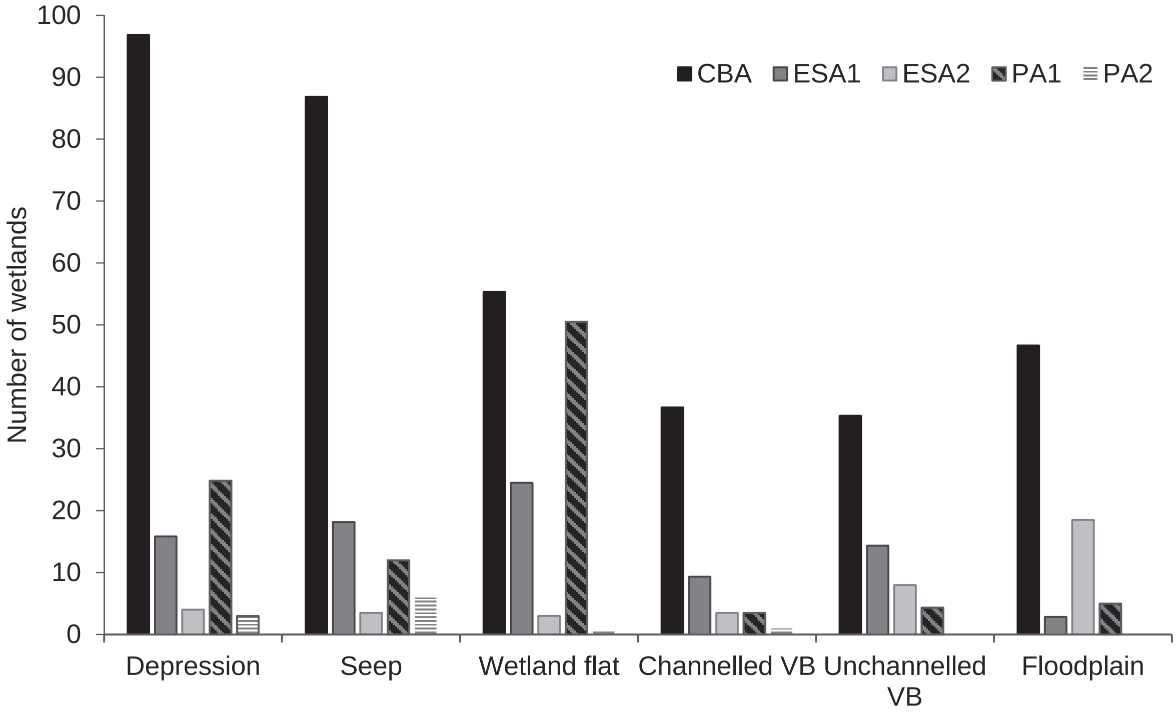


**Figure 9.2 Critical biodiversity areas (as defined by Stewart (2009)) associated with the different HGM units. CBA = Critically endangered habitats, ESA1 = Agricultural land that has an important role in ecosystem functioning, ESA2 = Severely disturbed/destroyed areas by human activities that need to be restored, PA1 = Declared protected areas, PA2 = Protected areas pending declaration.**

### 9.2.4 Recommendations for future research

Despite the new knowledge generated through this research, there are more questions generated than answers. This has provided for valuable baseline data, but more in-depth studies are necessary to fully understand wetland ecosystem function as well as the interactions between landscape and local scale physical parameters. Interdisciplinary collaboration in wetland studies is important. Existing tools should be used to assist future research, such as the WET series and the WHI publications. Some questions for further research direction are outlined below. How these questions could link to management of wetlands and community relationships to the wetlands around them are included below:

- What are the drivers of the formation of depressions?

- What are the ecosystem services that small, ephemeral wetlands provide?
    - predominantly ecosystem functioning; or
    - direct services and goods;
    - what proportion of each?
- With an establishment of some regional specific water quality information, how does this fit with national guidelines and enhance current decision support systems?
    - There is a need for comparisons between known “reference conditions” and different gradients of anthropogenic disturbances in terms of water quality.
- In the face of global climate change, what is the effect of higher variability in rainfall periodicity and duration on the resilience and sustainability of ephemeral wetlands?
    - How would these changes change ecosystem service position?
    - Can the abiotic and biotic dynamics of ephemeral systems act as models for changes in both perennial and non-perennial wetlands under different climate scenarios?

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# 11 APPENDICES

## Appendix A

This appendix has the physical and chemical data either used or collected in the field. A detailed list of data sources for the desktop and landscape level data analyses conducted in the report are found in Table A.1. A summary of the physico-chemical data collected for each site is in Table A.2

**Table A.1 List of data resources used listed by theme (purpose for its use), types of data files, scales and resolution along with the source of the data.**

| Data theme | Spatial data file name | File type | Datum | Scale/Resolution | Area | Source of data |
|---|---|---|---|---|---|---|
| | Landcover | Polygon vector data | HBH 1994, TM 25 | 1: 10 000 | NMB | SRK Consulting (2007) |
| **Anthropogenic** | NMBM Boundary, Roads | Line vector data | HBH 1994, TM 25 | Unknown | NMB | NMBM (2012) |
| | Provinces | Polygon vector data | HBH 1994 | Unknown | SA | Municipal Demarcation Board (2012) |
| **Background** | Aerial Photos 2009 | TIFF raster data | WGS 1984 | 1 $m^2$ | NMB | NMBM (2012) |
| | Spot 5 Images 2010 | JP2 raster data | WGS 1984 | 2 m | NMB | CSIR (2011) |
| | 1 m and 2 m Contours | Line vector data | HBH 1994, TM 25 | Unknown | NMB | NMBM (2012) |
| | Annual Rainfall | Raster data | WGS 1984 | 1 $km^2$ | National | DAFF (n.d.) |
| | Annual Rainfall | Polygon vector data | D North American 1927 | 1 $km^2$ | National | AGIS (2007) |
| | Annual Rainfall 33rd Percentile | Raster data | WGS 1984 | 1 $km^2$ | National | DAFF (n.d.) |
| | Annual Rainfall 67th Percentile | Raster data | WGS 1984 | 1 $km^2$ | National | DAFF (n.d.) |
| | Average Relative Humidity | Excel with GPS coordinates | WGS 1984 | N/A | National | AGIS (2007) |
| | Average Total Heat Units | Excel with GPS coordinates | WGS 1984 | N/A | National | AGIS (2007) |
| | Average Total Radiation | Excel with GPS coordinates | WGS 1984 | N/A | National | AGIS (2007) |
| | Average Total Relative Evapotranspiration | Excel with GPS coordinates | WGS 1984 | N/A | National | AGIS (2007) |
| | Average Wind Speed | Excel with GPS coordinates | WGS 1984 | N/A | National | AGIS (2007) |
| | Boreholes | Point vector data | GCS WGS 1984 | - | NMB | DWA (2010) |
| **Environmental** | Dams | Polygon vector data | GCS WGS 1984 | | National | DAFF (n.d.) |
| | EC CBA Reserves | Polygon vector data | GCS WGS 1984 | | EC | NFEPA (2008) |
| | EC CBA Terrestrial | Polygon vector data | GCS WGS 1984 | Unknown | EC | NFEPA (2008) |
| | EC Geology | Polygon vector data | GCS Cape | 1: 500 000 | EC | Council for Geosciences (N.D.) |
| | Elevation (Extract from 20 x 20 m DEM) | DEM | WGS 1984, TM 25 | 400 $m^2$ | NMB | NMBM (2012) |
| | Evaporation (Pan) | Polygon vector data | D North American 1927 | 1 $km^2$ | National | AGIS (2007) |
| | FEPA Sub-WMA | Polygon vector data | GCS WGS 1984 | Unknown | National | NFEPA (2011) |
| | FEPA WMA | Polygon vector data | GCS WGS 1984 | Unknown | National | NFEPA (2011) |
| | Generalised Soil Patterns | Polygon vector data | GCS WGS 1984 | | National | DAFF (n.d.) |
| | Geology (simplified) | Polygon vector data | GCS WGS 1984 | | National | DAFF (n.d.) |
| | Land capability | Polygon vector data | GCS WGS 1984 | | National | DAFF (n.d.) |
| | Landcover | Polygon vector data | GCS WGS 1984 | ? | National | DWAF 2000 |
| | Moisture Availability | Raster data | WGS 1984, Albers | 1 $km^2$ | National | DAFF (n.d.) |
| **Environmental** | Moisture Availability | Polygon vector data | D North American 1927 | 1 $km^2$ | National | AGIS (2007) |

| Data theme | Spatial data file name | File type | Datum | Scale/Resolution | Area | Source of data |
|---|---|---|---|---|---|---|
| | Morphology, Rainfall (per Quaternary Catchment), Soils | Polygon vector data | GCS Cape | ? | National | Schulze (2007) |
| | NFEPA Rivers | Polygon & Line vector data | WGS 1984, Albers | Unknown | National | NFEPA (2011) |
| | NFEPA Wetland Vegetation | Polygon vector data | GCS WGS 1984 | Unknown | National | NFEPA (2011) |
| | NFEPA Wetlands | Polygon vector data | WGS 1984, Albers | Unknown | National | NFEPA (2011) |
| | NFEPA Wetlands | Polygon vector data | WGS 1984 | 30 m | National | Biodiversity GIS (2011) |
| | NMB land types | Polygon vector data and associated attribute data in PDF files | | | NMB | ARC |
| | PE Hydrogeology (Lithology, Groundwater Yield and Rain) | Polygon vector data | GCS Cape, Clark 1880 | 1: 500 000 | NMB | DWA (1998) |
| | Quaternary Catchments | Polygon vector data | HBH 1994 | Unknown | National | DWA (2012) |
| | Rainfall | Excel with GPS coordinates | WGS 1984 | N/A | National | AGIS (2007) |
| | Rivers | Line vector data | HBH 1994 | 1: 50 000 | NMB | NMBM (2012) |
| | Rivers | Line vector data | GCS Cape | 1: 500 000 | National | DWAF (2006) |
| | Rivers | Line vector data | HBH 1994 | 1: 50 000 | South Africa | Digital topographical maps |
| | SA Soils | Polygon vector data | GCS Cape, Clark 1880 | ? | National | AGIS (2007) |
| | Saline & Sodic Soils | Polygon vector data | D North American 1927 | 1 $km^2$ | National | AGIS (2007) |
| | Slope Aspect (Extract from 20 x 20 m DEM) | DEM | WGS 1984, TM 25 | 400 $m^2$ | NMB | NMBM (2012) |
| | Slope Form, Morphology, etc. | Polygon vector data & Raster data | GCS Cape, Clark 1880 | ? | National | Schulze (2007) |
| | Soils | Polygon vector data | GCS WGS 1984 | 1: 250 000 | National | Agricultural Research Institute for Soil, Climate and Water (2004) |
| | SOTER Soil Association Map | Polygon vector data | D North American 1927 | 1 $km^2$ | National | AGIS (2007) |
| | Strategic Water Supply Areas | Polygon vector data | GCS WGS 1984 | Unknown | National | NFEPA (2011) |
| | Sub-Quaternary Catchments | Polygon vector data | GCS WGS 1984, Albers | 1: 500 000 | EC | CSIR (2009) |
| | Temperature | Excel with GPS coordinates | WGS 1984 | N/A | National | AGIS (2007) |
| | Various – vegetation | Polygon vector data | HBH 1994, TM 25 | 1: 10 000 | NMB | SRK Consulting (2007) |
| | Vegetation biomes | Polygon vector data | HBH 1994 | 1: 250 000 | National | Mucina and Rutherford (2006). Spatial data obtained from SANBI BGIS (2007) |
| | Critical Biodiversity Areas | Polygon vector data | HBH 1994, TM 25 | 1: 10 000 | NMB | Stewart (2009) |
| | Critical Ecological Processes | Polygon vector data | HBH 1994, TM 25 | 1: 10 000 | NMB | Stewart (2009) |
| | Protected Areas | Polygon vector data | HBH 1994, TM 25 | 1: 10 000 | NMB | Stewart (2009) |

**Table A.2** **Summary of the water chemistry and physico-chemical properties of the once-off sites. SW = surface water, SSW = sub-surface water, PC = physico-chemical properties, EC = electrical conductivity, TDS = total dissolved solids, TSS = total suspended solids, SR = soluble reactive, TOxN = total oxidised nitrogen.**

| | | All | | Depression | | Wetland flat | | Seep | |
|---|---|---|---|---|---|---|---|---|---|
| **Water chemistry** | **Unit** | **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** | **Mean** | **Range** |
| **SW PC** | | | | | | | | | |
| Maximum depth | cm | 43 | 4-125 | 60 | 6-125 | 27 | 11-40 | 14 | 4-41 |
| Water temperature | °C | 20.5 | 13.3-29.9 | 60.1 | 13.3-27.3 | 18.7 | 14.7-29.9 | 24.5 | 18.1-29.4 |
| EC | µS/cm | 8063.5 | 179.3-89510.0 | 11961.0 | 212-89510 | 702.2 | 179.3-2423.3 | 6183.4 | 614.8-32741.7 |
| pH | | 7.4 | 4.6-9.8 | 7.7 | 6.1-9.8 | 7.5 | 6.7-8.1 | 6.5 | 4.6-7.8 |
| TDS | mg/L | 1471.8 | 12.4-19346.7 | 2288.8 | 19.1-19346.7 | 437.8 | 94.2-1525.7 | 399.8 | 12.4-797.5 |
| Dissolved oxygen | mg/L | 8.3 | 0.5-57.9 | 6.7 | 0.8-16.6 | 10.4 | 1.4-57.9 | 10.4 | 0.5-49.1 |
| Salinity | PSU | 5.7 | 0.1-63.71 | 8.1 | 0.1-63.7 | 0.4 | 0.1-1.5 | 5.3 | 0.3-29.3 |
| TSS | % | 0.85 | 0.02-3.82 | 0.55 | 0.02-2.95 | 0.37 | 0.07-1.50 | 2.13 | 0.16-3.80 |
| **SW nutrients** | | | | | | | | | |
| Total phosphorus | µg/L | 154.2 | 1.9-1665.9 | 53.6 | 3.8-314.2 | 28.3 | 8.3-62.1 | 624.1 | 1.9-1666.0 |
| SR phosphorus | µg/L | 121.7 | 0.2-1405.4 | 20.2 | 0.58-70.2 | 45.1 | 9.2-158.4 | 528.6 | 0.2-1405.5 |
| Total nitrogen | µg/L | 7236.8 | 0-12478.8 | 7778.4 | 0.0-59566.2 | 5744.2 | 30.4-20865.9 | 7941.0 | 355.6-12478.8 |
| Nitrite | µg/L | 26.3 | 0-161.6 | 27.3 | 0-161.6 | 35.6 | 0-122.7 | 11.1 | 0-52.7 |
| TOxN | µg/L | 38.8 | 0-975.7 | 9.1 | 0-59.2 | 119.9 | 0-975.7 | 1.4 | 0-7.5 |
| Ammonium | µg/L | 14.4 | 0-54.6 | 13.2 | 0-34.01 | 16.7 | 0.2-54.6 | 14.6 | 0-32.4 |
| Silica | µg/L | 7.3 | 0-50.6 | 5.5 | 0-26.2 | 16.1 | 0.2-50.6 | 1.4 | 0.4-2.7 |
| **SSW PC** | | | | | | | | | |
| EC | µS/cm | 4711.5 | 96.2-66100.0 | 6647.1 | 96.2-66100.0 | 8822.2 | 133-3450 | 2761.5 | 183.7-14910 |
| pH | | 6.9 | 5.0-9.0 | 7.0 | 5.31-9.0 | 6.7 | 5.0-7.6 | 6.7 | 5.6-8.2 |
| TDS | mg/L | 2179.1 | 60.2-41000.0 | 2984.6 | 60.2-41000.0 | 610.3 | 83.8-2170 | 1449.9 | 332-3418.8 |
| Salinity | PSU | 3.8 | 0.1-43.2 | 5.3 | 0.1-43.2 | 0.3 | 0.1-0.6 | 2.3 | 0.2-10.8 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SSW nutrients** | | | | | | | | | |
| Total phosphorus | | 43.3 | 0-185.5 | 43.0 | 0-185.5 | 25.5 | 0-55.8 | 72.4 | 35.0-125.5 |
| SR phosphorus | | 49.9 | 1.16-488.6 | 57.1 | 1.4-350.6 | 44.8 | 13.8-115.8 | 36.0 | 17.28-64.8 |
| Total nitrogen | | 15940.3 | 0-179854.7 | 21643.4 | 0-179854.7 | 6481.9 | 31.5-25768.0 | 9239.9 | 5156.8-14461.5 |
| Nitrite | | 44.4 | 0-412.6 | 63.2 | 0-412.6 | 37.5 | 0.0-172.6 | 1.3 | 0-7.1 |
| TOxN | | 495.4 | 0-12903.1 | 834.7 | 0-12903.1 | 25.9 | 4.5-55.7 | 3.5 | 0-20.1 |
| Ammonium | | 34.7 | 0-348.0 | 38.3 | 0-348.0 | 19.0 | 8.2-44.4 | 40.7 | 4.9-171.2 |
| Silica | | 10.8 | 0.1-43.9 | 10.2 | 0.1-43.9 | 17.1 | 4.9-34.4 | 6.0 | 2.2-9.7 |
| **Soil PC** | | | | | | | | | |
| Soil moisture | % | 17.5 | 2.7-35.6 | 18.4 | 4.93-32.04 | 14.2 | 2.72-29.28 | 20.2 | 7.64-35.59 |
| Soil organic matter | % | 3.5 | 1.0-7.7 | 3.4 | 1.13-5.37 | 3.4 | 1.12-6.05 | 3.7 | 1.02-7.66 |
| EC | µS/cm | 8329.0 | 196-304000 | 16246.6 | 331-304000 | 746.2 | 201.5-4.04 | 1526.2 | 1.88-2.3 |
| pH | | 7.2 | 4.3-8.6 | 7.3 | 4.25-8.58 | 7.4 | 6.7-8.24 | 7.0 | 5.55-8.12 |
| **Other** | | | | | | | | | |
| Elevation | m | 117.3 | 1-298 | 111.7 | 1-228 | 106.9 | 8-225 | 144.2 | 1-298 |
| Gradient | $^{o}$ | 1.9 | 0.1-10.1 | 1.3 | 0.1-4.573 | 0.9 | 0.1-3.3 | 4.6 | 0.5-10.1 |
| Wetland area | $m^2$ | 15396.5 | 75.2-450700.3 | 28655.7 | 387.6-450700.3 | 2871.2 | 75.2-7151.6 | 3761.7 | 460.4-11148.2 |

**Appendix B**

This appendix describes the details of each of the geological formation associated with NMB.

**Table B.1 Geological sequence associated with wetlands in the NMB. Formations are listed youngest to oldest.**

| Group (sub-group) | Formation | Lithology |
|---|---|---|
| Quaternary Recent deposits | Recent deposits | Aeolian sand, Alluvium, Intermediate and low-level fluvial terrace gravel |
| Algoa | Salnova | Marine terrace deposit |
| Algoa | Bluewater Bay | Alluvial gravel, sand, silt |
| Algoa | Nanaga | Semi-consolidated to consolidated calcareous sandstone and sandy limestone with large-scale cross-bedding |
| Algoa | Kinkelbos | Silt, sand, calc-tufa, minor gravel |
| Algoa | Alexandria | Calcareous sandstone, conglomerate, coquinite |
| Grahamstown | Grahamstown | Silcrete |
| Uitenhage | Kirkwood | Variegated (reddish-brown and greenish) silty mudstone and sandstone, subordinate grey shale and sandstone |
| Bokkeveld (Ceres) | Ceres | Three sandstone and three shale units |
| Bokkeveld (Ceres) | Tra-Tra | Mudstone, siltstone, subordinate sandstone |
| Bokkeveld (Ceres) | Hex River | Feldspathic arenite, wacke, mudrock |
| Bokkeveld (Ceres) | Voorstehoek | Grey shale, siltstone and fine-grained sandstone |
| Bokkeveld (Ceres) | Gamka | Fine-grained, feldspathic sandstone, subordinate mudrock |
| Bokkeveld (Ceres) | Gydo | Mudrock, siltstone |
| TMG (Nardouw) | Baviaanskloof | Fine- to medium-grained, dark to light grey, feldspathic sandstone, shale |
| TMG (Nardouw) | Skurweberg | Thick-bedded, medium- to coarse-grained, cross-bedded, white-weathering, quartzitic sandstone |
| TMG (Nardouw) | Goudini | Brownish-weathering, quartzitic sandstone, subordinate shale and siltstone |
| TMG | Peninsula | Quartzitic sandstone, minor conglomerate and shale |
| TMG | Sardinia Bay | Quartzitic sandstone, phyllitic shale, subordinate small-pebble conglomerate |
| Gamtoos | Van Stadens | Quartzite, arkose, phyllite, conglomerate |
| Gamtoos | Kleinrivier | Phyllite, quartzite, conglomerate, arkose, greywacke |

## Appendix C

Detailed taxonomic lists for the biological data collected and identified to the lowest practical level. There is a table for each phylogenetic group, beginning with the vegetation data and ending with the macroinvertebrates.

**Table C.1 Vegetation species list, presence/absence by site. Sites from areas 1, 2, 3 and 4 are represented here, see Table 4.2 in text for codes.**

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acanthaceae | *Hypoestes aristata* | | | | | | | | | | | | | | + | | | | | | | | | |
| Agavaceae | *Agave sisalana* | | | | | | | | | | | | | | | | | | | | | | | |
| Aizoaceae | *Aizoon rigidum* | | | | | | | + | | | | | | | | | | | | | | | | |
| | *Tetragonia* sp. | | | | | | | | | | | | | + | | | | | | | | | | |
| Amaranthaceae | *Atriplex* sp. | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Guilleminea densa* | | | | | | | + | | | | | | | | | | | | | | | | |
| | *Salicornia quinqueflora* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Salicornia* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| Amaryllidaceae | *Crinum campanulatum* | | | | | | | | | | | | | | | | | | | | | + | + | + |
| Anacardiaceae | *Searsia glauca* | | | | | | | + | | | + | + | | | | | | | + | | | | | |
| | *Searsia longispina* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Searsia lucida* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Searsia undulata* | | | | | | | | | | | | | | | | + | | | | | | | |
| Apiaceae | *Centella asiatica* | | | | | | | | + | | + | + | + | | | | | + | | | + | + | + | + |
| | *Ciclospermum leptophyllum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Dasispermum suffruticosum* | | | | | | | | | | | | | | | | | | | | | | | |
| Apocynaceae | *Carissa bispinosa* | | | | | | | | | | | | | | | | | | | | | | | |
| Aponogetonaceae | *Aponogeton junceus* | | | + | | | | | | | | | | | | + | | + | | | + | + | + | + |
| Araceae | *Zantedeschia aethiopica* | | | | | | | | | + | | + | | | + | | | | | | | | | |
| Arecaceae | *Phoenix reclinata* | | | | + | | | | | | | | | | | | | | | | | | | |
| Asparagaceae | *Albuca* sp. | | | | | | | | | | | | | | | | | | | | | | + | |
| Asteraceae | *Anthemis cotula* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Arctotheca calendula* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Arctotis stoechadifolia* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Chrysanthemoides monilifera* | | | | | | | | | | | | | + | + | | | | | | | | | |
| | *Chrysanthemoides* sp. | | | | | | + | + | | | | | | | | | | | | | | | | |
| | *Cineraria lobata* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Cirsium vulgare* | | | | | | | | | | | | | | | | | + | | | | + | | |
| | *Conyza bonariensis* | | | | | | | + | + | | | | + | | | | | | | | | | | |
| | *Conyza canadensis* | | | | | | | + | | | | | | | | | | | | | | | | |
| | *Conyza* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Cotula coronopifolia* | | | | | | | | | | | | | | + | | | | | | | | | |
| Asteraceae | *Cotula zeyheri* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Eclipta prostrata* | | | | | | | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Felicia fascicularis* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Gazania krebsiana* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Gazania pectinata* | | | | | | | | | | | | | | | | | | + | + | | | | |
| | *Gazania* sp. | | | | | | | | | | | | | | | | | | | + | | | | |
| | *Helichrysum arenarium* | | | | | | | | | | | | | | | | | | | | | + | + | + |
| | *Helichrysum foetidum* | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Helichrysum oxyphyllum* | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Helichrysum* sp. | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Helichrysum subglomeratum* | | | | | | | + | | | | + | | | | | | | | | + | | + | |
| | *Picris echioides* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Printzia polifolia* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Pseudognaphalium* sp. | | | + | | | | | | | | | | | | | | | | | | | | |
| | *Relhania pungens* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio angulatus* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio bonariensis* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio ceneraria* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio erubescens* | | | | | | | | | + | | + | | | | | | | | | | | | |
| | *Senecio glutinosus* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio ilicifolius* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio inaequidens* | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Senecio lanceus* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio latifolius* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio linifolius* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio litorosus* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio madagascariensis* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio oederiifolius* | + | | | | | | | | + | + | | + | | | | | | | | | | | |
| | *Senecio* sp. | | | | | | | | | | | + | | | | | | + | | + | | | + | |
| | *Seriphium plumosa* | | | | | | | | | | | | | | | | + | | | | | | | |
| | *Seriphium* sp. | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Sonchus asper* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Sonchus dregeanus* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Sonchus* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Syncarpha loganiana* | | | | | | | | | | | | | | | | + | + | | | | | | |
| Asteraceae | *Taraxacum* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Vellereophyton velleum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Xanthium strumarium* | | | | | | | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brassicaceae | *Canola* sp. | | | + | | | | | | | | | | | | | | | | | | | | |
| Campanulaceae | *Wahlenbergia procumbens* | | | | | | | | | | | | | | | | | | | | | | | + |
| | *Wahlenbergia stellarioides* | | | | | | | | | | | | | | | | | | | | | | | |
| Caryophyllaceae | *Polycarpon tetraphyllum* | | | | | | | | | | | | | | | | | | | | | | | |
| Celestraceae | *Gymnosporia buxifolia* | | | | | | | | | | | | | | | | | | | | | | + | |
| Characeae | *Chara* sp. | + | | + | | | | + | + | | + | | | | | | | | | | | + | + | + |
| Chenopodiaceae | *Chenopodium album* | | | | | | | | | | | | + | | | | | | | | | | | |
| Chlorophyceae | *Oedogonium* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| Colchicaceae | *Wurmbea stricta* | | | | | | | | | | | | | | | | | | | | + | | | |
| Compositae | *Hertia kraussii* | | | | | | | | | | | | | | | | | | | | | | | |
| Convolvulaceae | *Convolvulus arvensis* | | | | | | | | | | | | | + | | | | | | | | | | |
| | *Falkia repens* | | | | | | | + | | | + | | | | | | | + | | | | + | | |
| Crassulaceae | *Crassula expansa* | + | | | | | | | | | | | | | | | | | | | | | | |
| | *Crassula rubricaulis* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Crassula* sp. | + | | | | | | | | | | | | | | | | | | | | | + | + |
| | *Crassula tetragona* | | | | | | | | | | | | + | | | | | | | | | | | |
| Cyperaceae | *Bolboschoenus maritimus* | | | + | | | | | | | + | | | | | | | | | | + | | | |
| | *Bulboschoenus* sp. | | | | | | | | | | | | | + | | | | | | | | | | |
| | *Carex glomerabilis* | + | | | | | | | | | | | | | | | | | | | | | | |
| | *Carex* sp. | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Carpha glomerata* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Cyperaceae* sp. | | | | | | | | | | | | | | | | | | | + | | | + | |
| | *Cyperus congestus* | | | | | | | | + | | | + | | | | | | | | | | | | |
| | *Cyperus denudatus* | | | + | | | | | | | + | | | | | | | + | | | + | + | | |
| | *Cyperus marginatus* | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Cyperus nataliensis* | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Cyperus* spp. | | | | | | | | | | | | | | | | | + | | + | | + | | |
| | *Cyperus thunbergii* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Eleocharis dregeana* | | | | | + | | | | | + | + | | | | | | | | | | | + | |
| | *Eleocharis limosa* | | | | | | | | | + | | | | | | | | | | | | | + | |
| | *Eleocharis* spp. | + | + | | | + | | + | | | | + | + | | | | | | | | + | | + | + |
| | *Epischoenus gracilis* | | | | | | | | | | | | | | | | + | + | + | | | | | |
| Cyperaceae | *Epischoenus* sp. | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Ficinia capillifolia* | | | | | | | + | + | | | + | | | | | | | | | | | | |
| | *Ficinia nodosa* | | | | | | | | | | | | | | | | | + | + | | + | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Ficinia* spp. | | + | | | + | | | | | | | | | | + | | | | + | + | + | + | |
| | *Fimbristylis complanata* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Fimbristylis dichotoma* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Fuirena hirsuta* | + | | | | | | | | | | | | | | | | | | | | | + | + |
| | *Fuirena* spp. | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Isolepis cernua* | | | | | + | | | | | | | | | | | | + | | | + | | | + |
| | *Isolepis fluitans* | | | | | | | + | + | | | | | | + | | | | | | + | | + | + |
| | *Isolepis levynsiana* | | | | | | | | | | | | | | | | | | | | | | + | |
| | *Isolepis marginata* | + | | | | | | | | | | | | | | | | | | | | | | |
| | *Isolepis setacea* | | | | | | | | | | | | | | | | | | | | | | + | + |
| | *Isolepis* sp. | + | + | | | + | | | | | + | | + | | | + | | + | + | + | | + | | |
| | *Isolepis striata* | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Pycreus nitidus* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Pycreus* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Schoenoplectus brachyceras* | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Schoenoplectus decipiens* | | + | | | + | | + | + | | | | | | | + | | + | | | | + | + | + |
| | *Schoenoplectus juncii* | | | | | | | | | | | | | + | + | | | | | | | | | |
| | *Schoenoplectus* spp. | + | | | | + | | | + | | + | | | | | + | | + | | + | + | | + | + |
| | *Schoenoplectus triqueter* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Schoenus nigricans* | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Scleria nigra* | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Scleria* sp. | | | | | | | | | | | | | | | | | | | | + | | | |
| | Sedge sp. 1 | | | | | | | | | | | | | | | | | + | | | | | | |
| Dracaenaceae | *Dracaena hookeriana* | | | | | | | | | | | | | | + | | | | | | | | | |
| Ebenaceae | *Euclea undulata* | | | | | | | | | | | | | | | | | | | | | | | |
| Ericaceae | *Erica chamissonis* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Erica copiosa* | | + | | | | | | | | | | + | | | | | | | | | | | |
| | *Erica* sp. | + | | | | | | | | + | | | | | | | | | + | | | | | |
| Euphorbiaceae | *Euphorb* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Euphorbia bothae* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Euphorbia mauritanica* | | | | | | | | | | | | | | | | | | | | | | | |
| Fabaceae | *Acacia karoo* | | | | | | | | | | | | | | | | | | | | | | | |
| Fabaceae | *Acacia longifolia* | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Acacia saligna* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Acacia* sp. | | | | | + | | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Argyrolobium sericeum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Aspalathus* sp. | | | | | | | | | | | | | | | + | | | + | | | | | |
| | *Aspalathus vulpina* | | | | | | | | | | | | | | | | | + | + | | | | | |
| | *Calpurnia aurea* | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Crotalaria obscura* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Lessertia brachystachya* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Lotus* sp. | | | + | | | | | | | | | | | | | | + | | | | | | + |
| | *Medicago* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Psoralea repens* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Trifolium* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Vicia cracca* | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Vicia* sp. | | | | | | | | | | | | | | | | | | + | | | | | |
| Frankeniaceae | *Frankenia repens2* | | | | | | | + | | | | | | | | | | | | | | | | |
| Gentianaceae | *Chironia* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| Geraniaceae | *Erodium moschatum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Pelargonium pulverulentum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Pelargonium* spp. | + | | | | | | | | | | | | | | | | | | | | | | |
| Haemodoraceae | *Wachendorfia paniculata* | | | | | | | | | | | | | | | | | | | | + | | | |
| Hydrocharitaceae | *Elodea nuttalii* | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Elodea* sp. | | | | | | | | | | | | | | | | | | | | | | + | + |
| Hypoxidaceae | *Hypoxis* sp. | | | | | | | | | | | | | | | | | + | + | | | | | |
| | *Hypoxis vilosa* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Spiloxene aquatica* | | | | | | | | | | | | | | | | | | | | + | | + | |
| Iridaceae | *Watsonia angusta* | | | | | | | | | | | | | | | | | | | | | | | |
| Juncaceae | *Juncus dregeanus* | | | | | | | | | | | + | | | | | | | | | | + | + | |
| | *Juncus effuses* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Juncus krausii* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Juncus rigidus* | | | | | | | | | + | | | | | | | | | | | | | | |
| Juncaceae | *Juncus* spp. | | | | | | | | | | | | | | | | | | | | | + | | |
| Lamiaceae | *Salvia africana-lutea* | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Stachys byzantina* | | | | | | | + | | | | | | | | | | | | | | | | |
| | *Teucrium africanum* | | | | | | | | | | | | | | | | | | | | | | | |
| Lamiaceae | *Lemna gibba* | | | + | | | | | + | + | | | | | | | | | | | | | | |
| Lobeliaceae | *Lobelia* sp. | | | | | | | | | | | | | | | | | | | | | | + | |
| | *Lobelia tomentosa* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Monopsis scabra* | | | | | | | | | | | | | | | | | + | | | | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Malvaceae | *Abutilon sonneratianum* | | | | | | | | | | | | | | | | | | | | | | | |
| Malvaceae | *Hibiscus grandifolia* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Malva parviflora* | | | | | | | + | + | | | | + | | | | | | | | | | | |
| | *Malva* sp. | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Sida rhombifolia* | | | | | | | | | | | | | | | | | | | | | + | | |
| Marsileaceae | *Marsilea macrocarpa* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Marsilea* spp. | + | + | | | | | | | | | | | | | + | | | | | | | | |
| Mesembryanthemaceae | *Carpobrotus deliciosus* | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Carpobrotus mellei* | | | | | | | | | + | + | | | | | | | | | | | | | |
| | *Carpobrotus* sp. | | | | | | | | | | | | | + | | | | | | | | | | |
| | *Drosanthemum hispidum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Mesembryanthemum aitonis* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Mesembryanthemum parviflorum* | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Ruschia cymbifolia* | | | | | | | | | | | | | | | | | | | | | | | |
| Myricaceae | *Morella quercifolia* | + | | | | | | | | | | | | | | | | + | | | | | | |
| Myrsinaceae | *Rapanea* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| Nymphaeaceae | *Nymphea* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| Ochnaceae | *Ochna serrulata* | | | | | | | | | | | + | | | | | | | | | | | | |
| Orchidaceae | *Cyrtorchis arcuata* | + | | | | | | | | | | | | | | | | | | | | | | |
| Oxalidaceae | *Oxalis incarnata* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Oxalis latifolia* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Oxalis* sp. | | | | | | | | | | | + | | | | | | | | | | | | |
| Plantaginaceae | *Plantago* sp. | | | | | | | | + | | | | + | | | | | + | | | | | | |
| Plumbaginaceae | *Limonium linifolium* | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Plumbago* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| Poaceae | *Ammophila arenaria* | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Andropogon* sp. | | | | | + | | | | | | | | | | | + | + | + | + | + | | | + |
| | *Bromus catharticus* | | | | | | | | | | | | | | | | | | | | | | + | |
| | *Cynodon dactylon* | + | | + | + | + | | + | + | | | + | + | + | | | | + | | | | + | + | |
| | *Dactyloctenium sp.* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Digitaria argyrograpta* | | | | | | | | | | | | | | | | | | | | | | | |
| Poaceae | *Digitaria* sp. | | | | | | | | | | | | + | | | | | | | | | + | | |
| | *Digitaria ternata* | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Echinochloa* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Ehrharta* spp. | | | | | | + | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Eragrostis* spp. | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Eragrostis planiculmis* | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Eragrostis tef* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Hemarthria altissima* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Hordeum murinum* | | | | | + | | | | | | | | | | | | | | | | | | |
| | *Imperata cylindrica* | + | + | + | + | + | | | + | | | | | | | | | | | | | | + | + |
| | *Imperata* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Leersia hexandra* | | | | | | | | | | | | + | | | | | | | | | + | | + |
| | *Lolium* sp. | | | | | | | | | | | | | | | | | | | | | | | |
| | *Merxmuellera disticha* | | | | | | | | | | + | | | | | | | | | | | | | |
| | *Panicum coloratum* | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Panicum deustum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Panicum ecklonii* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Panicum* sp. | | | | | | | | | | | | | | + | | | | + | | | | | |
| | *Paspalum distichum* | | | + | | + | | + | | | | | | | | + | | | | | | | | |
| | *Paspalum* sp. | | + | | | | | | | | + | | | | | | | | | | | + | | + |
| | *Paspalum vaginatum* | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Pennisetum clandestinum* | | + | + | | | | | | | | | | + | + | | | | | | + | | | |
| | *Pennisetum* sp. | | | | | | | | | | | | + | | | | + | + | + | + | | | | |
| | *Pennisetum thunbergii* | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Pentaschistis heptamera* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Phalaris minor* | + | | | | | | | | | | | | | | | | | | | | | | |
| | *Phragmites australis* | | | | | | | | | + | | | | + | + | | | | | | | | | |
| | *Setaria incrassata* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Setaria lindenbergiana* | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Setaria* sp. | | | | | | | | | | | | | | | | + | + | + | | | | | |
| | *Setaria sphacelata* | | | | | | | | | | | | | | | | | | | | | | + | |
| | *Sporobolus africanus* | + | | | | | | | | | | | | | | + | | | | | | | | |
| | *Sporobolus centrifugus* | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Sporobolus fimbriatus* | | | | | | | | | | | | | | | | | | | | | | + | |
| | *Sporobolus* sp. | | + | | | | | | + | | + | | | | | + | | | | | | + | | |
| Poaceae | *Stenotaphrum secundatum* | | | | + | | | | | | + | + | + | | | | | | | | + | | | |
| | *Stipagrostis* sp. | | | | | | | | | | | | | | | | | | | + | | | | |
| | *Stipagrostis zeyheri* | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Tenaxia disticha* | | | | | | | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Themeda* sp. | | | | | | | | | | | | | | | | + | + | + | + | | | + | |
| | *Themeda triandra* | | | | | + | | | | | | | | | | + | | | | | + | | + | |
| | *Trachypogon spicatus* | | | | | | | | | | | | | | | | | | | | | | + | |
| Polygalaceae | *Muraltia ericaefolia* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Emex australis* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Perscaria* sp. | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Persicaria orientalis* | | | | | | | | + | | + | | | | | | | | | | | | | |
| | *Persicaria serrulata* | | | | | | | | | | | + | | | | | | | | | | | | |
| Potamogetonaceae | *Potamogeton* sp. | + | | | | + | | | | | | | | | | | | | | | | | + | + |
| Primulaceae | *Anagallis arvensis* | | | | | | | | | | | | | | | | | + | | | | | | |
| Proteaceae | *Leucadendron* sp. | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Leucospermum* sp. | | | | | | | | | | | | | | | | | | + | + | | | | |
| Pteridophyceae | *Pteridium aquilinum* | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Pteridophyta* sp. | | | | | | | + | | | | | | | | | | | | | | | | |
| Restionaceae | *Chondropetalum nudum* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Elegia ebracteata* | | | | | | | | | | | | | | | | + | + | + | | | | | |
| | *Elegia filacea* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Elegia* sp. | | | | | | | | | | | | | | | + | | | | | + | | | |
| | *Elegia stipularis* | | | | | | | | | | | | | | | | | | | + | + | | | |
| | *Elegia tectorum* | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Eligia microcarpa* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Eligia* sp. | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Ischyrolepis* sp. | | | | | + | | | | | | | | | | | | + | | | | | | |
| | *Restio capensis* | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Restio dispar* | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Restio* spp. | | | | | + | | | | | | | | + | | | | | + | + | | | + | |
| | *Restio* subgen. *Ischyrolepis* | + | + | | | | | | | | | | | | | | | | | | | | | |
| | *Restio tetragonus* | | | | | | | | | | | | | | | | | | | | + | | | |
| | Restio-like | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Thamnochortus insignis* | | | | | | | | | | | | | | | + | | | | + | | | | |
| | *Thamnochortus lucens* | | | | | | | | | | | | | | + | | | | | | | | | |
| Restionaceae | *Thamnochortus* sp. | | | | | | | | | | | | | | | + | + | + | + | + | | | | + |
| | *Willdenowia* sp. | | + | | | | | | | | | | | | | | | | | | | | | |
| Rhamnaceae | *Phylica ericoides* | + | | | | | | | | | | | | | | | | | | | | | | + |
| | *Phylica lanata* | + | | | | | | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 789b | 790a | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Phylica* sp. | | | | | | | | | | | | | | | | | | | + | | | | |
| | *Scutia myrtina* | | | | | | | | | | | | | | | | | | | | | | | |
| Rivulariaceae | *Gloeotrichia* sp. | + | | | | | | | | | | | | | | | | | | | | + | | |
| Rosaceae | *Rubus* sp. | | | | | | | | | | | | | | + | | | | | | | | | |
| Rubiaceae | *Anthospermum* sp. | | | | | | | | | | + | | | | | | | | | | | | | |
| | *Rubia* sp. | | | | | | | | | | | + | | | | | | | | | | | | |
| Ruppiaceae | *Ruppia* sp. | | | + | | | | | | | | | | | | | | | | | | + | | + |
| Rutaceae | *Agathosma* sp. | | | | | | | | | | | | | | | | | + | + | | | | | |
| | *Coleonema* sp. | + | | | | | | | | | | | | | | | | | | | | | | |
| Salviniaceae | *Azolla* sp. | | | | | | | | | | + | + | | | | | | | | | | | | |
| Scrophulariaceae | *Halleria lucida* | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Ilysanthes dubia* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Limosella grandiflora* | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Phyllopodium cuneifolium* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Sutera campanulata* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Sutera pauciflora* | | | | | | | | | | | | | | | | | | + | | | | | |
| Solanaceae | *Nicandra physalodes* | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Solanum africanum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Solanum americanum* | | | | | | | | | | | | | | | | | | | | | | | |
| | *Solanum chrysotrichum* | | | | | | | + | | | | | | | | | | | | | | | | |
| Thymelaeaceae | *Struthiola argentea* | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Struthiola hirsuta* | | | | | | | | | | | | | | | | + | | | | | | | |
| | *Struthiola* sp. | | | | | | | | | | | | | | | + | | | | | | | | |
| Typhaceae | *Typha capensis* | | | + | | | | | + | | | + | | | | | | | | | | | | |
| Ulvaceae | *Ulva* sp. | | | | | | | | | | | | | + | + | | | | | | | | | |
| Vitaceae | *Cyphostemma cirrhosum* | | | | | | | | | | | | | | + | | | | | | | | | |
| Xanthorrhoaeceae | *Trachyandra* sp. | | | | | | | | | | | | | | | | | + | | + | | | | |
| Zygophyllaceae | *Zygophyllum* sp. | | | | | | | | | | | | | | + | | | | | | | | | |
| Graphidaceae | Lichen sp. | | | | | | | | | | | | | | | | | | | | | | | |
| Bryophytaceae | Moss sp. | + | | | | | | + | + | | | | + | | | | | | | | | | | + |

**Table C.2 Vegetation species list, presence/absence by site. Sites from areas 5, 6, 7 and 8 are represented here, see Table 4.2 in text for codes.**

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Acanthaceae | *Hypoestes aristata* | | | | | | | | | | | | | | | | | | | | | |
| Agavaceae | *Agave sisalana* | + | | | | | | | | | | | | | | | | | | | | |
| Aizoaceae | *Aizoon rigidum* | | | + | | | | | | | + | | | | | | | | | | | |
| | *Tetragonia sp.* | | | | | | | | | | | | | | | | | | | | | |
| Amaranthaceae | *Atriplex sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Guilleminea densa* | | | | | | | | | | | | | | | | | | | | | |
| | *Salicornia quinqueflora* | | | | | | | | | | | | | | + | | | | | | | |
| | *Salicornia sp.* | | | | | | | | | | | | | | | | | | | | | + |
| Amaryllidaceae | *Crinum campanulatum* | | | | | | | | | | | | | | | | | | | | | |
| Anacardiaceae | *Searsia glauca* | | | | | | | | | | | + | | | | | | | + | | | |
| | *Searsia longispina* | | | | | | | | | | | | + | | | | | | | | | |
| | *Searsia lucida* | + | | | | | | | | | | | | | | | | | | | | |
| | *Searsia undulata* | | | | | | | | | | | | | | | | | | | | | |
| Apiaceae | *Centella asiatica* | | + | | + | + | + | | | + | | | | | | | | | | | + | |
| | *Ciclospermum leptophyllum* | | | | | | | | | | | | | | | | | | | | + | |
| | *Dasispermum suffruticosum* | | | | | | | | | | | | | + | | | | | | | | |
| Apocynaceae | *Carissa bispinosa* | | + | | | | | | | | | | | | | | | | | | | |
| Aponogetonaceae | *Aponogeton junceus* | | | | | | | | | + | + | | | | | | | | | | | |
| Araceae | *Zantedeschia aethiopica* | | | | | | | | | | | | | | | | | | | | | |
| Arecaceae | *Phoenix reclinata* | | | | | | | | | | | | | | | | | | | | | |
| Asparagaceae | *Albuca sp.* | | | | | | | | | | | | | | | | | | | | | |
| Asteraceae | *Anthemis cotula* | | + | | | | | | | | | | | | | | | | | | | |
| | *Arctotheca calendula* | | | | | | + | | | | | | | | | | | | | | | |
| | *Arctotis stoechadifolia* | | | | | | | | | + | | | | | | | | | | | | |
| | *Chrysanthemoides monilifera* | | | | | + | | | | | | | | + | | | | | | | | |
| | *Chrysanthemoides sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Cineraria lobata* | | | + | | | | | | | | | | | | | | | | | | |
| | *Cirsium vulgare* | | | | | | + | | | | | | + | | | | | | | | + | |
| | *Conyza bonariensis* | | | | | | | | | | | | + | | | | | | | | | |
| | *Conyza canadensis* | | | | | | | | | | | | | | | | | | | | | |
| | *Conyza sp.* | | | | | | | | | | | + | | | | | | | | | | |
| | *Cotula coronopifolia* | | | | | | | | | | | | | | | | | | | | | |
| | *Cotula zeyheri* | | + | | | | | | | | | | | | | | | | | + | | |
| Asteraceae | *Eclipta prostrata* | | | | | | | | | | | | | | | + | | | | | | |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Felicia fascicularis* | | | | | | | | | | | | | | | | | | + | | | |
| | *Gazania krebsiana* | | | | | | | | | | | | | + | | | | | | | | |
| | *Gazania pectinata* | | | | | | | | | | | | | | | | | | | | | |
| | *Gazania sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Helichrysum arenarium* | | | | | + | | | | | | | | | | + | | | | | | |
| | *Helichrysum foetidum* | | | | | | | | | | | | | | | | | | | | | |
| | *Helichrysum oxyphyllum* | | | | | | | | | | | | | | | | | | | | | |
| | *Helichrysum sp.* | | | | | | | | | | + | | + | | | | | | | | | |
| | *Helichrysum subglomeratum* | | | | | | | | | | | + | | | | | | | | | | |
| | *Picris echioides* | | | | | + | | | | | | | | | | | | | | | | |
| | *Printzia polifolia* | | | + | | | | | | | | | | | | | | | | | | |
| | *Pseudognaphalium sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Relhania pungens* | | | | + | | | | | | | | | | | | | | | | | |
| | *Senecio angulatus* | | | | | | + | | | | | | | | | | | | | | | |
| | *Senecio bonariensis* | | | | | | | | | | | | + | | | | | | | | | |
| | *Senecio ceneraria* | | | + | | | | | | | | | | | | | | | | | | |
| | *Senecio erubescens* | | | | | | | | | | | | | | | | | | | | | |
| | *Senecio glutinosus* | | | | | | + | | + | | + | | + | | | | | | | | | |
| | *Senecio ilicifolius* | | | | | | | | | | | | + | | | | | | | | | |
| | *Senecio inaequidens* | + | | + | | | | | | | + | | + | | | | | | | | | |
| | *Senecio lanceus* | | | | | | + | | | | | | | | | | | | | | | |
| | *Senecio latifolius* | | | | | | | | | | | | | | | | + | | | | | |
| | *Senecio linifolius* | | | | | | | | | | | | + | | | | | | | | | |
| | *Senecio litorosus* | | | | | | | | | | | | | + | | | | | | | | |
| | *Senecio madagascariensis* | | | | | | | | | | | | | | | + | | | | | | |
| | *Senecio oederiifolius* | | | + | | + | | | | + | | | | | | | | | | | | |
| | *Senecio sp.* | | | | | | | | | | | | | | | | | | | + | + | + |
| | *Seriphium plumosa* | | | | | | | | | | | | | | | | | | | | | |
| | *Seriphium sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Sonchus asper* | | + | + | | | | | | | | | | | | | | | | | | |
| | *Sonchus dregeanus* | | | | | | | | | | | | | | | | | | | | | + |
| | *Sonchus sp.* | | | | | | | | | | | | | | | | | | | + | + | |
| | *Syncarpha loganiana* | | | | | | | | | | | | | | | | | | | | | |
| | *Taraxacum sp.* | | | | | | | | | | | | | | | | | | | | + | |
| Asteraceae | *Vellereophyton velleum* | | | | | | | | | | | | | + | | | | | | | | |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Xanthium strumarium* | | | + | | | | | | | | | | | | | | | | | | |
| Brassicaceae | *Canola sp.* | | | | | | | | | | | | | | | | | | | | | |
| Campanulaceae | *Wahlenbergia procumbens* | | | | | | | | | | | | | | | | | | | | | |
| | *Wahlenbergia stellarioides* | | | | | | | | + | | | | | | | | | | | | | |
| Caryophyllaceae | *Polycarpon tetraphyllum* | | | + | | | | | | | | | | | | | | | | | | |
| Celestraceae | *Gymnosporia buxifolia* | | | | | | | | | | | | | | | | | | | | | |
| Characeae | *Char asp.* | | | | | + | | | | | | | + | | + | + | + | | | | | |
| Chenopodiaceae | *Chenopodium album* | | | + | | | | | | | + | | | | | | | | | | | |
| Chlorophyceae | *Oedogonium sp.* | | | | | | | | | | | | | | | | | | | | | + |
| Colchicaceae | *Wurmbea stricta* | | | | | | | | | | | | | | | | | | | | | |
| Compositae | *Hertia krausii* | | | | | | | | | | | | + | | | | | | | | | |
| Convolvulaceae | *Convolvulus arvensis* | | | | | | | | | | + | | | | | | | | | | | |
| | *Falkia repens* | | | | + | | | | | | | | + | | | + | + | | | | | + |
| Crassulaceae | *Crassula expansa* | | | | | | | + | | | | | | | | | | | | | | |
| | *Crassula rubricaulis* | | | | | | | | | | | | | | + | + | | | | | | |
| | *Crassula sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Crassula tetragona* | | | | | | | | | | | | | | | | | | | | | |
| Cyperaceae | *Bolboschoenus maritimus* | | | | | | | | | | | | | | | | | | | | | |
| | *Bulboschoenus sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Carex glomerabilis* | | | | | | | | | | | | | | | | | | | | | |
| | *Carex sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Carpha glomerata* | | | | | | | | | | | | | | | | | | + | | | |
| | *Cyperaceae sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Cyperus congestus* | | | | | | + | | + | + | | + | | | | | | | + | | | |
| | *Cyperus denudatus* | | | | | | | | | | | | | | | | | | | | | |
| | *Cyperus marginatus* | | | | | | | | | | | | | | | | | | | | | |
| | *Cyperus nataliensis* | | | | | | | | | | | | | | | | | | | | | |
| | *Cyperus spp.* | | | | | + | | + | | + | | | | | | | | | | | | |
| | *Cyperus thunbergii* | | | | | | | | | | | + | | | | | | | | + | + | |
| | *Eleocharis dregeana* | | | | | | | | | | | | | | | | | | + | | | |
| | *Eleocharis limosa* | | | | | | | | | + | | | | | | | | | | | | |
| | *Eleocharis spp.* | | | | | + | | + | | | | | | + | | | | | | + | + | + |
| | *Epischoenus gracilis* | | | | | | | | | | | | | | | | | | | | | |
| | *Epischoenus sp.* | | | | | | | | | | | | | | | | | | | | | |
| Cyperaceae | *Ficinia capillifolia* | | | | | | | | | | | | | | | | | | | | | |
| | *Ficinia nodosa* | | | | | | + | | | | | | | + | | | | | | | | |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Ficinia spp.* | | | | | | | | | | | | | | | + | | | | | | |
| | *Fimbristylis complanata* | | | | | | | | | | | | | | | | | | | | | |
| | *Fimbristylis dichotoma* | | | | | | | | | | | | | | | | | | | | | |
| | *Fuirena hirsuta* | | | | | | | | | | | | | | | | | | | | | |
| | *Fuirena spp.* | | + | + | | | | | | | | | | | | | | | | | | |
| | *Isolepis cernua* | | | | | | | | + | | | | | | | + | | | | + | + | |
| | *Isolepis fluitans* | | | | | | | | | | | | | | | | | | | | | |
| | *Isolepis levynsiana* | | | | | | | | | | | | | | | | | | | | | |
| | *Isolepis marginata* | | | + | | | | | | | | | | | | | | | | | | |
| | *Isolepis setacea* | | | | + | | | | | | | | | | | | | | | | | |
| | *Isolepis sp.* | | | | | + | + | | | + | | + | | + | | + | | | | | + | + |
| | *Isolepis striata* | | | | | | | | | | | | | | | + | | | | | | |
| | *Pycreus nitidus* | | | | | | | | | | | | | | | | | | | | + | + |
| | *Pycreus sp.* | | | | | | + | | | | | | | | | | | | | | | |
| | *Schoenoplectus brachyceras* | | | | | | | | | | | | | | | | | | | | | |
| | *Schoenoplectus decipiens* | | | | | | | | | | + | | + | | | | | | | | | |
| | *Schoenoplectus juncii* | | | | | | | | | | | | | | | | | | | | | |
| | *Schoenoplectus spp.* | | | + | + | | | + | | | | | | | | + | + | | | | + | |
| | *Schoenoplectus triqueter* | | | | | | | | | | | | | | | | | | | | | |
| | *Schoenus nigricans* | | | | | | | | | | | | | | | | | | | | | |
| | *Scleria nigra* | | | | | | | | | | | | | | | | | | | | | |
| | *Scleria sp.* | | | | | | | | | | | | | | | | | | | | | |
| | Sedge sp. 1 | | | | | | | | | | | | | | | | | | | | | |
| Dracaenaceae | *Dracaena hookeriana* | | | | | | | | | | | | | | | | | | | | | |
| Ebenaceae | *Euclea undulata* | | + | | + | | | | | | | | | | | | | | | | | |
| Ericaceae | *Erica chamissonis* | | | | | + | | | | | | | | | | | | | | | | |
| | *Erica copiosa* | | | | | | | | | + | | | | | | | | | | | | |
| | *Erica sp.* | | | | | + | | | | + | | | | | | | | | | | | |
| Euphorbiaceae | *Euphorb sp.* | | + | | | | | | | | | | | | | | | | | | | |
| | *Euphorbia bothae* | + | | | | | | | | | | | | | | | | | | | | |
| | *Euphorbia mauritanica* | | + | | | | | | | | | | | | | | | | | | | |
| Fabaceae | *Acacia karoo* | | | | | | | | | | | | | | | | | + | | + | | |
| | *Acacia longifolia* | + | | | | | | | | | | | | | | | | | | | | |
| Fabaceae | *Acacia saligna* | | | | | | | | | | | | | | | | | | | | | |
| | *Acacia sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Argyrolobium sericeum* | | | | | | + | | | | | | | | | | | | | | | |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Aspalathus sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Aspalathus vulpina* | | | | | | | | | | | | | | | | | | | | | |
| | *Calpurnia aurea* | | | | | | | | | | | | | | | | | | | | | |
| | *Crotalaria obscura* | | | | | | | + | | | | | | | | | | | | | | |
| | *Lessertia brachystachya* | | | + | | | | | | | | | | | | | | | | | | |
| | *Lotus sp.* | + | + | | + | | | | | | | + | | | + | | | | | | | |
| | *Medicago sp.* | | | + | | | | | | | | | | | | | | | | | | |
| | *Psoralea repens* | | | | | | | | | | | | | + | | | | | | | | |
| | *Trifolium sp.* | | | | | | | + | | | | | | | | | | | | | | |
| | *Vicia cracca* | | | | | | + | | | | | | | | | | | | | | | |
| | *Vicia sp.* | | | | | | | | | | | | | | | | | | | | | |
| Frankeniaceae | *Frankenia repens* | | | | | | | | | | | | | | | | | | | | | |
| Gentianaceae | *Chironia sp.* | | | | | | | | | | + | | | | | | | | | | | |
| Geraniaceae | *Erodium moschatum* | | | + | | | | | | | | | | | | | | | | | | |
| | *Pelargonium pulverulentum* | | | | | | | | | | | | + | | | | | | | | | |
| | *Pelargonium spp.* | | | | | | | | | | | | | | | | | | | | | + |
| Haemodoraceae | *Wachendorfia paniculata* | | | | | | | | | | | | | | | | | | | | | |
| Hydrocharitaceae | *Elodea nuttalii* | | | | | | | | | | | | | | | | | | | | | |
| | *Elodea sp.* | | | | | | | | | | | | | | | | | | | | | |
| Hypoxidaceae | *Hypoxis sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Hypoxis vilosa* | + | + | + | + | | | | | | | | | | | | | | | | | |
| | *Spiloxene aquatica* | | | | | | | | | | | | | | | | | | | | | |
| Iridaceae | *Watsonia angusta* | | | | | | | | | + | | | | | | | | | | | | |
| Juncaceae | *Juncus dregeanus* | + | + | | | | | | | | | | | | | | | | | | | |
| | *Juncus effuses* | + | + | | | | | | | | | | | | | | | | | | | |
| | *Juncus krausii* | | + | + | + | | | | | | | | | | | | | | | | | |
| | *Juncus rigidus* | | | | | | | | | | | | | | | | | | | | | |
| | *Juncus spp.* | | | | | | | + | | + | | + | | | | | | | | | | |
| Lamiaceae | *Salvia africana-lutea* | | | | | | | | | | | | | | | | | | | | | |
| | *Stachys byzantina* | | | | | | | | | | | | | | | | | | | | | |
| | *Teucrium africanum* | | | | | | | | | | | | + | | | | | | | | | |
| | *Lemna gibba* | | | | | | | | | | | | | | | + | | | | | | |
| Lobeliaceae | *Lobelia sp.* | | | | | | | | | | | | | | | | | | | + | | |
| | *Lobelia tomentosa* | | | | | | | | | | | | | | | | | | | | | + |
| | *Monopsis scabra* | | | | | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Malvaceae | *Abutilon sonneratianum* | | | | | | | | + | | | | | | | | | | | | | |
| Malvaceae | *Hibiscus grandifolia* | | | | | | | | | + | | | | | | | | | | | | |
| | *Malva parviflora* | | | | | | | | | | | | | | | | | | | | | |
| | *Malva sp.* | | | | | | | | | | | | + | | | | | | | + | + | |
| | *Sida rhombifolia* | | | | | | | | | | | | | | | | | | | | | |
| Marsileaceae | *Marsilea macrocarpa* | | | | + | | | | | | | + | | | | | | | | | | |
| | *Marsilea spp.* | | | | | | | | | | | | | | | | + | | | | | + |
| Mesembryanthemaceae | *Carpobrotus deliciosus* | | | | | | | | | | | | | | | | | | | | | |
| | *Carpobrotus mellei* | | + | | | | | | | | | | | | | | | | | | | |
| | *Carpobrotus sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Drosanthemum hispidum* | | | + | + | | | | | | | | | | | | | | | | | |
| | *Mesembryanthemum aitonis* | | | | | | + | | | | | | | | | | | | | | | |
| | *Mesembryanthemum parviflorum* | | | | | | | | | | | | | | | | | | | | | |
| | *Ruschia cymbifolia* | | + | | | | | | | | | | | | | | | | | | | |
| Myricaceae | *Morella quercifolia* | | | | | | | | | | | | | | | | | | | | | |
| Myrsinaceae | *Rapanea sp.* | | | | | | | | | | | | | | | | | + | | | | |
| Nymphaeaceae | *Nymphea sp.* | | | | | + | | | | | | | | | | | | | | | | |
| Ochnaceae | *Ochna serrulata* | | | | | | | | | | | | | | | | | | | | | |
| Orchidaceae | *Cyrtorchis arcuata* | | | | | | | | | | | | | | | | | | | | | |
| Oxalidaceae | *Oxalis incarnata* | | | | | | | | | | | | | | | + | + | | | | | |
| | *Oxalis latifolia* | | | | + | | | | | | | | | | | | | | | | | |
| | *Oxalis sp.* | + | + | | | | | | | | | | | | | | | | | | | |
| Plantaginaceae | *Plantago sp.* | | | + | | | | + | | | | | | | | + | + | | | | | |
| Plumbaginaceae | *Limonium linifolium* | | | | | | | | | | | | | | | | | | | | | |
| | *Plumbago sp.* | | | | | | | | | | | | | | | | | | | + | | |
| Poaceae | *Ammophila arenaria* | | | | | | | | | | | | | | | | | | | | | |
| | *Andropogon sp.* | | | | + | | | | + | + | | | | | | + | | | | + | | |
| | *Bromus catharticus* | | | | | | | | | | | | | | | | | | | | | |
| | *Cynodon dactylon* | + | + | + | + | + | + | + | + | + | + | + | + | | + | + | + | | | + | + | + |
| | *Dactyloctenium sp.* | | | + | | | | | | | | | | | | | | | | | | |
| | *Digitaria argyrograpta* | | | | | | | | | | | | | | | | + | | | | | |
| | *Digitaria sp.* | | | | + | | | | | | | + | | | | | | | | | | |
| Poaceae | *Digitaria ternata* | | | | | | | | | | | | | | | | | | | | | |
| | *Echinochloa sp.* | | | | | | + | | | | | | | | | | | | + | | | |
| | *Ehrharta spp.* | | | | | | | | | | | | | | | | | | | | + | + |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Eragrostis spp.* | | + | | | | | | | | | | + | | | | | | | | | + |
| | *Eragrostis planiculmis* | | | | | | | | | | | | | | | | | | | | | |
| | *Eragrostis tef* | | | | | | | | | | | | | | | | + | | | | | |
| | *Hemarthria altissima* | | | | | | | | | | | | | | + | + | | | | | | |
| | *Hordeum murinum* | | | | | | | | | | | | | | | | | | | | | |
| | *Imperata cylindrica* | | | | | | | | | + | | | | | | | | | | | | |
| | *Imperata sp.* | | | | | + | | | | | | | | | | | | | | | | |
| | *Leersia hexandra* | | | | | | | | | | | + | | | | | | | | | | |
| | *Lolium sp.* | | | | | | | | | | | | | | | | | | | | + | |
| | *Merxmuellera disticha* | | | | | | | | | | | | | | | | | | | | | |
| | *Panicum coloratum* | | | | | | | | | | | | | | | | | | | | | |
| | *Panicum deustum* | | | | | | | | | | | + | | | | | | | | | | |
| | *Panicum ecklonii* | | | | | | | | | | | | + | | | | | | | | | |
| | *Panicum sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Paspalum distichum* | | | | | | | | | | | | | | | | | | | | | |
| | *Paspalum sp.* | | | + | + | + | | + | | + | | | | + | | | | | | | | + |
| | *Paspalum vaginatum* | | | | | | | | | | | | | | | | | | | | | |
| | *Pennisetum clandestinum* | | | | | | | + | | | | | | | | | | | | | | |
| | *Pennisetum sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Pennisetum thunbergii* | + | + | | + | | + | | + | | | | | | | | | + | | | | |
| | *Pentaschistis heptamera* | | | | | | | | | | | | | + | | | | | | | | |
| | *Phalaris minor* | | | | | | | | | | | | | | | | | | | | | |
| | *Phragmites australis* | | | | | | | | | | | | | | | | | | | | | |
| | *Setaria incrassata* | | | | | | | | | | | + | | | | | | | | | | |
| | *Setaria lindenbergiana* | | | | | | | | | + | | | | | | | + | | | | | |
| | *Setaria sp.* | | | | | | | | | | | | | | | + | | | | | | |
| | *Setaria sphacelata* | | | | | | | | | | | | | | | | | | | | | |
| | *Sporobolus africanus* | | | | | | + | | | | | | | | | | | | | | | |
| | *Sporobolus centrifugus* | | | | | | | | | | | | | | | | | | | | | |
| | *Sporobolus fimbriatus* | | | | | | | | | | | | | | | | | | | | | |
| | *Sporobolus sp.* | | | | | | | + | | | | | + | | | | | | | | | |
| Poaceae | *Stenotaphrum secundatum* | + | + | | | + | + | | | + | | | | | | | | | | | | |
| Poaceae | *Stipagrostis sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Stipagrostis zeyheri* | | | | | | | | | | | | | | | | | | | | | |
| | *Tenaxia disticha* | | | | | | + | | | | | | | | | | | | | | | |
| | *Themeda sp.* | | | | | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Themeda triandra* | | | | | + | | | | | | | | | | | | | + | | | |
| | *Trachypogon spicatus* | | | | | | | | | | | | | | | | | | | | | |
| Polygalaceae | *Muraltia ericaefolia* | | | | | | | | | | | | | | | | | | | | | |
| | *Emex australis* | | | | | | | | | | | | + | | | | | | | | | |
| | *Perscaria sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Persicaria orientalis* | | | | | | | | | | | | | | | | | | | | | |
| | *Persicaria serrulata* | | | | | | | | | | | | | | | | | | | + | + | |
| Potamogetonaceae | *Potamogeton sp.* | | | | | | | | | | | | | | | | + | | | | | |
| Primulaceae | *Anagallis arvensis* | | | | | | | | + | | | | | | | | | | | | | |
| Proteaceae | *Leucadendron sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Leucospermum sp.* | | | | | | | | | | | | | | | | | | | | | |
| Pteridophyceae | *Pteridium aquilinum* | | | | | | | | | | | | | | | | | | | | | |
| | *Pteridophyta sp.* | | | | | | | | | | | | | | | | | | | + | + | |
| Restionaceae | *Chondropetalum nudum* | | | | | | | | | | | | | | | | | | | | | |
| | *Elegia ebracteata* | | | | | | | | | | | | | | | | | | | | | |
| | *Elegia filacea* | | | | | | | | | | | | | | | | | | | | | |
| | *Elegia sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Elegia stipularis* | | | | | | | | | | | | | | | | | | | | | |
| | *Elegia tectorum* | | | | | | | | | | | | | | | | | | | | | |
| | *Eligia microcarpa* | | | | | | | | | | | | | | | | | | | | | |
| | *Eligia sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Ischyrolepis sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Restio capensis* | | | | | | | | | | | | | | | | | | | | | |
| | *Restio dispar* | | | | | | | | | | | | | | | | | | | | | |
| | *Restio spp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Restio subgen. Ischyrolepis* | | | | | | | | | | | | | | | | | | | | | |
| | *Restio tetragonus* | | | | | | | | | | | | | | | | | | | | | |
| | *Restio-like* | | | | | | | | | | | | | | | | | | | | | |
| | *Thamnochortus insignis* | | | | | | | | | | | | | | | | | | | | | |
| | *Thamnochortus lucens* | | | | | | | | | | | | | | | | | | | | | |
| | *Thamnochortus sp.* | | | | | | | | | | | | | | | | | | | | | |
| Restionaceae | *Willdenowia sp.* | | | | | | | | | + | | | | | | | | | | | | |
| Rhamnaceae | *Phylica ericoides* | | | | | | | | | | | | | | | | | | | | | |
| | *Phylica lanata* | | | | | | | | | | | | | | | | | | | | | |
| | *Phylica sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Scutia myrtina* | | | | | | | | | | | | | | | | | | | | | |
| Rivulariaceae | *Gloeotrichia sp.* | | | | + | | | | | | | | | | | | | | | | | |

| Family | Taxon | 1016 | 1017 | 1019 | 1648 | 743 | 1668 | 1675 | 1679 | 749b | 1310 | 1311 | 1359 | 1651 | 1380 | 1381 | 1625 | 1691 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rosaceae | *Rubus sp.* | | | | | | | | | | | | | | | | | | | | | |
| Rubiaceae | *Anthospermum sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Rubia sp.* | | | | | | | | | | | | | | | | | | | | | |
| Ruppiaceae | *Ruppia sp.* | | | | | | | | | | | | | | | | | | | | | |
| Rutaceae | *Agathosma sp.* | | | | | | | | | | | | | | | | | | | | | |
| | *Coleonema sp.* | | | | | | | | | | | | | | | | | | | | | |
| Salviniaceae | *Azolla sp.* | | | | | | | | | | | | | | | | | | | | | |
| Scrophulariaceae | *Halleria lucida* | | | | | | | | | | | | | | | | | | | | | |
| Scrophulariaceae | *Ilysanthes dubia* | | | | | | | | | | | | | | | | | | | | | |
| | *Limosella grandiflora* | | | | | + | | | | + | | | | | | | | | | | | |
| | *Phyllopodium cuneifolium* | | | | | | | | | | | | | | | | | | | | | |
| | *Sutera campanulata* | | | | | | + | | | | | | | | | | | | | | | |
| | *Sutera pauciflora* | | | | | | | | | | | | | | | | | | + | | | |
| Solanaceae | *Nicandra physalodes* | | | | | | | | | | | | | | | | | | | | | |
| | *Solanum africanum* | | | | | | | | | | | | | | | | | | | | | |
| | *Solanum americanum* | | | | | | | | | | | | + | | | | | | | | | |
| | *Solanum chrysotrichum* | | | | | | + | | | | | | | | | | | | | | | |
| Thymelaeaceae | *Struthiola argentea* | | | | | | | | | | | | | | | | | | | | | |
| | *Struthiola hirsuta* | | | | | | | | | | | | | | | | | | | | | |
| | *Struthiola sp.* | | | | | | | | | | | | | | | | | | | | | |
| Typhaceae | *Typha capensis* | | | | | | | | | | | | | | | | | | | | | |
| Ulvaceae | *Ulva sp.* | | | | | | | | | | | | | | | | | | | | | |
| Vitaceae | *Cyphostemma cirrhosum* | | | | | | | | | | | | | | | | | | | | | |
| Xanthorrhoaeceae | *Trachyandra sp.* | | | | | | | | | | | | | | | | | | | | | |
| Zygophyllaceae | *Zygophyllum sp.* | | | | | | | | | | | | | | | | | | | | | |
| Graphidaceae | *Lichen sp.* | | | | | | | | | | | | | | | | | | | | | |
| Bryophytaceae | *Moss sp.* | | | + | | + | | | | + | | + | + | | | | | | | | | |

**Table C.3** **Phytoplankton species list, presence/absence by site. Site codes as per Table 4.2 in text.**

| Division | Taxon | 1593 | 1596 | 1626 | 1627 | 1641 | 326 | 329 | 683 | 790 | 944 | 947 | 1380 | 1381 | 1625 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chlorophyta** | *Actinochloris terrestris* | | | | | + | | | | + | | | | | |
| | *Ankistrodesmus falcatus* | + | | | | + | | | | | + | | | + | |
| | *Ankistrodesmus sp.* | | | + | | | | | | + | | | | | |

| Division | Taxon | 1593 | 1596 | 1626 | 1627 | 1641 | 326 | 329 | 683 | 790 | 944 | 947 | 1380 | 1381 | 1625 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Botryococcus sp.* | + | | | | | + | | | | | | | | |
| | *Botryosphaerella sp.* | | | | | + | | | | | | + | | + | |
| | *Chlamydomonas sp.1* | | | | | + | | | + | + | + | + | | | |
| | *Chlamydomonas sp.2* | | | | | | | | | | | + | | | |
| | *Chlorella sp.* | + | + | | | + | | + | | | + | | + | | |
| | *Chlorochytrium sp.* | | | | | | | | | | | | + | | |
| | *Chlorococcum sp.* | | | | + | + | + | | | + | + | + | | | + |
| | *Chlorococcus sp.* | | | + | | + | | + | + | + | | + | | | |
| | *Chlorogonium sp.* | | | | | | | | | | | + | | | |
| | *Closterium dianae var. minus* | | | | | + | | | | | | + | | | |
| | *Closterium kuetzingii* | | | | | | | | | | | + | | | |
| | *Closterium parvulum* | | | | | + | | | | | | | | | |
| | *Closterium sp.* | | | | | | + | | | + | + | | | | + |
| | *Coenochloris sp.* | + | | + | + | | + | | | | | + | | | + |
| | *Cosmarium crenulatum* | | | | | | | | | + | | | | | |
| | *Cosmarium moniliforme* | | | | | | | | | + | | | | | |
| | *Cosmarium sp.* | + | | | | | | | | | | | | | |
| | *Cosmarium subcrenatum* | | | | | | | | | + | | + | | | |
| | *Cosmarium tinctum* | | | + | | | | | | | | | | | |
| | *Eremosphaera sp.* | | | | | + | | | | | | | | | |
| | *Euastrum binale* | | | | + | | | | | + | | | | | |
| | *Gloeocystis sp.* | | | | | | | | + | + | | + | | | |
| | *Kirchneriella lunaris* | + | | | + | + | | | | | | | | + | |
| | *Moegeotia sp.* | + | | | | + | | | | | | + | | | |
| | *Monoraphidium contortum* | | | | + | + | | + | | | | + | | | |
| | *Nanochloris sp.* | | | | | | | | | | | | + | | |
| | *Nautococcus sp.* | | | | | | | | | | | | | | + |
| | *Nephrocytium sp.* | | | | | | | + | | | + | + | | | |
| **Chlorophyta** | *Oedogonium sp.* | | | | | | | | | + | | | | | |
| | *Oocystis apiculata* | | | | + | | | | | | | | | | |
| | *Oocystis borgei* | | | | | | | + | | | | | | | + |
| | *Oocystis lacustris* | | | | | + | | | | | | | | | |
| | *Oocystis obesa* | | | | + | | | | | | | | | | |

| Division | Taxon | 1593 | 1596 | 1626 | 1627 | 1641 | 326 | 329 | 683 | 790 | 944 | 947 | 1380 | 1381 | 1625 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Oocystis sp.* | | | | | + | | + | | | | | | + | |
| | *Pascherina sp.* | | | | | | | | | | | | | | + |
| | *Pediastrum tetras* | + | | | | | | + | | + | | | | | + |
| | *Quadrigula sp.* | | | | | + | | | | | | | | | |
| | *Scenedesmus arcuatus* | | | | | + | | | | | | | | | |
| | *Scenedesmus hystrix* | | | + | | + | | | | | | | | | |
| | *Scenedesmus planctonicus* | + | | | | + | | + | | + | | | | | |
| | *Scenedesmus sp.* | | | | | | | | | + | | | | | |
| | *Scenedesmus verrucosus* | | | | | | | | | | + | | | | |
| | *Selenestrum sp.* | | | | | + | | | | | | | | | |
| | *Sphaerocystis sp.* | | | | + | + | | | | | + | + | + | + | |
| | *Staurastrum sp.* | | | | | + | | | | | | | | | |
| | *Tetraedron sp.* | | | | | + | | | | + | | | | | + |
| | *Trebonema sp.* | | | | | + | | | | | | | | | |
| | *Trebouxia sp.* | | | | | + | | | | | | + | + | | |
| | *Trochiscia sp.* | | | | | + | | + | | | | | | | |
| | *Volvox sp.* | | | | | | | + | | | | | | | |
| **Chrysophyta** | *Achnanthidium minutissimum* | | | | + | + | | + | | | | + | | | |
| | *Amphora inariensis* | | | + | | | + | | | | | | | | + |
| | *Chrysochromulina sp.* | | | + | | | | | | | | | | | |
| | *Chrysococcus sp.* | | | | | | | | | | + | | | | |
| | *Cocconeis placentula* | | | | | | + | | | | | | + | | |
| | *Cyclotella sp.* | | | | | | | | | | | | | | + |
| | *Cymbella sp.* | | | | | | + | | | | | | | | |
| | *Dinobryon sp.* | + | | | | | | | | | + | | | | |
| | *Eolimna sp.* | | | | | | | | | | | | | | + |
| | *Epithemia aduata* | | | | | + | | | | | | | | | |
| | *Epithemia sp.* | | | | + | + | | | | | | | | | |
| **Chrysophyta** | *Eppithemia sp.* | | | | | | | | | | | | | | + |
| | *Eunotia bilunaris* | | | | | | | | | + | | + | | | |
| | *Eunotia formica* | | | | | | | | | | | + | | | |
| | *Eunotia incisa* | | | | | | | | | | + | | | | |
| | *Eunotia minor* | | | | | | + | + | | + | + | + | | | |

| Division | Taxon | 1593 | 1596 | 1626 | 1627 | 1641 | 326 | 329 | 683 | 790 | 944 | 947 | 1380 | 1381 | 1625 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Eunotia rhomboidea* | | | | | | | + | + | | | | | | |
| | *Fallacia sp.* | | | | | + | | | | | | | | | |
| | *Fragilaria tenera* | | | | | + | | | | | + | | | | |
| | *Fragilaria ulna* | + | + | | | | | | | | | | | | + |
| | *Gomphonema sp.* | | | | | | | | | | | + | | | |
| | *Gomphonema gracile* | | | + | | | | | | | | | | | |
| | *Gomphonema parvulum* | | | | | + | | | | + | + | | | + | |
| | *Gomphonema sp.* | | + | | | | | | | | | | | | |
| | *Gyrosigma sp.* | | | | | | | | | | | | + | | |
| | *Licmophora sp.* | | | | | | | | | | | + | | | |
| | *Mallomonas sp.* | | | | | + | | | | | | | | | |
| | *Navicula angusta* | | | | | | | | | | | + | | | |
| | *Navicula cryptocephala* | | | + | | + | | | | + | | | | | |
| | *Navicula cryptonella* | | | | | | | | | + | | | + | | |
| | *Navicula cryptotenella* | + | | | | + | + | | | | + | + | | | |
| | *Navicula sp.* | | | | | | | | | | | + | | | |
| | *Neidium sp.* | | | | | | | | + | | | | | | |
| | *Nitzschia linearis* | | | + | | + | | | | | | | | | |
| | *Nitzschia palea* | | | | | | | | | | + | | + | | |
| | *Nitzschia sp.* | | | | | | | | | + | | | | | |
| | *Nitzschia umbonata* | | | | | | + | | | | | | | | |
| | *Oocystis sp.* | | | | | | + | | | | | | | | |
| | *Pinnularia borealis* | | | | | | | | | + | | + | | | |
| | *Pinnularia subcapitata* | | | | | | | | | + | | + | | + | |
| | *Pinnularia viridis* | | | | | | | + | + | | + | | | | |
| | *Planothidium sp.* | | | + | | | | | | + | | | | | |
| | *Rhapolodia sp.* | | | | | | | | | | | | | | + |
| | *Stauroneis producta* | | | | | | | | | | | | + | | |
| **Chrysophyta** | *Tryblionema sp.* | + | | | | | | | | | | | | | |
| **Cryptophyta** | *Chroomonas rosenbergii* | | | + | | | | + | | | + | + | + | | |
| | *Cryptomonas erosa* | | | | | | | + | | | | | | | |
| | *Cryptomonas marssonii* | + | | | | | | + | | | | | | | |
| | *Cryptomonas ovata* | | | + | + | + | | + | + | + | + | + | | | + |

| Division | Taxon | 1593 | 1596 | 1626 | 1627 | 1641 | 326 | 329 | 683 | 790 | 944 | 947 | 1380 | 1381 | 1625 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Cryptomonas rosenbergii* | | | | | + | | | | | | | | | |
| | *Rhodomonas sp.* | | | | | | | + | | | | + | | | |
| **Cyanophyta** | *Anabaena sp.* | + | | | + | + | + | | | | | + | | + | + |
| | *Aphanocapsa sp.* | | | + | | | | | | | + | | | | |
| | *Aphanothece sp.* | + | | | | | | | | | | | | | |
| | *Chroococcus minutus* | + | | + | + | + | + | | + | | | + | | + | + |
| | *Chroococcus sp.* | | | | | | | + | | + | + | | + | + | |
| | *Microcystis sp.* | + | | + | + | + | | + | + | + | + | + | + | | |
| | *Oscillatoria sp.* | + | | + | | + | | + | + | + | + | + | | | |
| | *Oscillatoria sp.1* | + | + | + | | + | | | | | | | | | + |
| | *Oscillatoria sp.2* | + | | | | + | | | | | | | | | |
| | *Phormidium sp.* | + | | | | | | + | | | + | | | | |
| | *Planktolyngbya limnetica* | | | | | | | | | | | | + | | |
| | *Spirulina sp.* | | + | | | | | | | | | | | | |
| | *Synechococcus sp.* | | + | | | | | | | | | | | | |
| **Euglenophyta** | *Euglena caudata* | | | + | | | | | | | | | | | |
| | *Euglena longicauda* | | | | | + | | | | | | | | | + |
| | *Euglena oblonga* | | | | | | | + | + | | | | | | |
| | *Euglena polymorpha* | | | | | | | | | | + | + | | | |
| | *Euglena sp.* | + | | | | | | | | | | | | + | |
| | *Lepocinclis sp.* | | | | | | | | | | + | | | | |
| | *Phacus caudatus* | | | | | | | | | | | + | | | |
| | *Phacus elegans* | | | | | | | + | | | | | | | |
| | *Phacus hamelii* | | | | | | + | | | | | | | | |
| | *Phacus longicauda* | | | | | | | | | | | + | | | |
| | *Strombomonas eurystoma* | | | | | | | | | | | | + | | |
| | *Strombomonas sp.* | | | | | | | | | | + | | | | |
| | *Trachelomonas cylindrica* | | | | | | | | | | | | | | + |
| **Euglenophyta** | *Trachelomonas hispida* | + | | | | | | | | | | | | | |
| | *Trachelomonas intermedia* | | | | | | | | | | | | | | + |
| | *Trachelomonas sp.* | | | | | | | | | | | + | | | |
| | *Trachelomonas volvocina* | + | | + | | | + | | | + | + | + | + | | |
| **Prasinophyta** | *Pedimomonas sp.* | + | | | + | + | | | + | | | + | | | |

| Division | Taxon | 1593 | 1596 | 1626 | 1627 | 1641 | 326 | 329 | 683 | 790 | 944 | 947 | 1380 | 1381 | 1625 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Pyramimonas sp.* | | | | + | + | | | | | | | | | |
| | *Scourfieldia sp.* | | | | | | | + | | | + | + | | | |
| **Pyrrhophyta** | *Gymnodinium sp.* | + | | + | | | | | | | | + | | + | |
| | *Katodinium sp.* | + | | + | | | | | | | | + | | | |
| | *Peridinium anglicum* | | | | | | | | | | | | | | + |
| | *Peridinium sp.* | | | | | + | | | | | | | | + | |
| | *Woloszynskia sp.* | | | | | | | + | | | | | | | |
| **Xanthophyta** | *Goniochloris sp.* | | | | | | | + | | | | | | | |
| | *Ophiocytium sp.* | | | | | | + | | | | | | | | |
| | *Pleurogaster llunaris* | | | | | | | | | | | | + | | |
| | *Pleurogaster lunaris* | | | | | | | | | | | | + | | |

**Table C.4 Microphytobenthos species list, presence/absence by site. Site codes as per Table 4.2 in text.**

| Division/Class | Taxon | 1593 | 1596 | 1624 | 1627 | 1641 | 326 | 329 | 1647 | 1655 | 683 | 1699 | 790b | 790a | 947 | 743 | 749b | 1310 | 1359 | 1651 | 1381 | 1625 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cyanophyta | *Aphanothece* sp. | + | | | | | | | | | | | | | | | | | | | | | | | |
| | *Asterocapsa* sp. | | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Chroococcidiopsis* sp. | | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Chroococcopsis* sp. | | | | | | | | | | | | | | | | | | | | + | | | | |
| | *Chroococcus* spp. | + | | | | | + | | | + | | + | | + | | | | | | | + | | + | | |
| | *Chroococcus varius* | | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Coelosphaerium* sp. | | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Cyanosarcina* sp. | | + | + | | | | | | | | | | | | | | | | | | | | | |
| | *Cyanothece* sp. | + | | | | | | | | | | | | | | | | | | | | | | | |
| | *Cylindrospermum* sp.1 | + | | | | | | | | | | | | | | | | | | | | | | | |
| | *Eucapsis* sp. | | | | | | | | | | | | | | | | | | + | | + | | + | + | |
| | *Gloeocapsa sanguinea* | | | | | | | | | | | | | | | | | + | | | | | | | |
| | *Gloeocapsa* sp. | | | | | | | | | | + | | | | | | | | | | | | | | |
| | *Gloeocapsopsis* sp. | | | | | | | | | + | | | | | | | | | | | | | + | + | |
| | *Gloeothece* sp. | + | | | | | | | | | | | | | | | | | | | | | | | |
| | *Homoeothrix* sp. | | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Hydrococcus* sp. | | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Jaaginema* sp? | | | | | | | | | | | | | | | + | | | | | | | + | | + |
| | *Komvophoron* sp. | | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Lyngbya* spp. | | | | | | | | | | | | | | | + | | | + | | | | | | |
| | *Merismopedia* spp. | | | | | | | | | + | | | | | | | | + | + | + | | | | | |
| | *Oscillatoria* spp. | | | | | | | + | | + | | | | | | + | | + | | + | | + | + | + | + |
| | *Pannus spumosus* | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Phormidium* spp. | + | | + | | + | + | + | | + | | | | + | | | + | | + | | + | | + | | + |
| | *Schizothrix* spp. | | | | + | | + | | | | | | | | | + | | | | | | | + | + | |
| | *Spirulina maior* | | | | | | | | | + | | | | | | | | + | | | | | | | + |
| | *Spirulina* sp. | | | + | | | | | | | + | | | | | | | | | | | | | | |
| | *Syctonema sp.* | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Synechocystis* spp. | | | | | | | | | | | | | + | | + | | | | | | | + | | + |
| Cryptophyta | *Cryptomonas* spp. | | | + | | | | | | | | | | | | + | | | | | | | | | |
| Bacillariophyceae | *Achnanthes* spp | | | | | + | | | | | | | | | | | | | | | | | + | | + |
| | *Achnanthes standeri* | | | | | + | | | | | | | | | | | | | | | | | | | |

| Division/Class | Taxon | 1593 | 1596 | 1624 | 1627 | 1641 | 326 | 329 | 1647 | 1655 | 683 | 1699 | 790b | 790a | 947 | 743 | 749b | 1310 | 1359 | 1651 | 1381 | 1625 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bacillariophyceae | *Achnanthidium minutissimum* (Kützing) Czarnecki | + | | | | | | + | | | + | | | | | + | | | + | + | | | | | |
| | *Achnanthidium* spp. | | + | | | + | + | | | | | + | | | | | + | | | | | + | | | |
| | *Amphora coffeaeformis* | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Amphora* spp. | | | | | + | | + | | + | + | | | | | | + | | | + | | | + | | + |
| | *Amphora veneta* Kützing | + | | | | | | | | | | | | | | | | | | | | | | | |
| | *Aulacoseira* spp. | | | | | | + | | + | | | | | | | | | | | | | + | | | |
| | *Caloneis bacillum* (Grunow) Cleve | | | | | | | | | | | + | | | | | | | | | | | | | |
| | *Caloneis* sp.? | | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Chroococcus* spp. | | | | | | | | | | | | | | | | | | | | | | | | + |
| | *Cocconeis* sp. (placentula?) | | | + | | | + | | | | | | | | | | | | | | | | | | |
| | *Cocconeis* spp. | | | | + | | | | | + | | | | | | + | | | | | | | | | |
| | *Craticula halophila* (Grunow) DG Mann | | | + | | | | | | | | | | | | | | + | | | | | | | |
| | *Craticula molestiformis* (Hustedt) Lange-Bertalot | | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Craticula* sp. | | + | | | | | | | | | | | | | | | | | | | | | | |
| | *Cyclotella* spp. | | | | | | + | | | | | | | + | | + | | + | | | | | | | |
| | *Cylindrotheca closterium* | | | | | | | | | + | | | | | | | | | | + | | | | | |
| | *Cymbopleura sublanceolata* | | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Cymbopleura* spp. | | | | | | | | | | | | | | | + | + | | | | | | | | |
| | *Diadesmis confervacea* | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Diadesmis contenta* | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Diadesmis contenta* (Grunow in Van Heurk) DG Mann | | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Diploneis caffra* | | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Diploneis incurvata* | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Diploneis* spp. | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Discotella Woltereckii* (Hustedt) Houk and Klee | | | | | | + | | | | | | | | | | | | | | | | | | |
| | *Encyonema* spp. | | + | | | | | + | | | | | | | | + | + | | | | | | | | |
| | *Entomoneis amphiprora* | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Eolimna subminuscula* | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Epithemia adnata* (Kützing) Brebisson | | | | + | | | | | | | | | | | | | | | | | | | | |
| | *Epithemia* sp. | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Eucapsis* sp. | | | | | | | | | | | | | | | | | | | | | | | | + |
| | *Eunotia bilunaris* (Ehrenberg) Mills | | | | | | | + | | | | | | | | | | | | | | | | | |

| Division/Class | Taxon | 1593 | 1596 | 1624 | 1627 | 1641 | 326 | 329 | 1647 | 1655 | 683 | 1699 | 790b | 790a | 947 | 743 | 749b | 1310 | 1359 | 1651 | 1381 | 1625 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bacillariophyceae | *Eunotia bilunaris/flexuosa* | | | | | | | | + | | | | | | + | + | | | | | | | | | |
| | *Eunotia minor* | | | | | | | | + | | + | | + | | | | | | | | | | | | |
| | *Eunotia rhomboidea* | | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Eunotia* sp. (kociolekii?) | | | | | | | | + | | | | | | | + | | | | | | | | | |
| | *Eunotia* spp. | | | | | | + | + | + | | | | | + | + | + | + | | | + | | | | | |
| | *Fallacia pigmaea* (Kützing) Sickle and Mann | | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Fallacia* sp. | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Fragilaria* spp. | | | | | | | | | | | | | | | | | + | | | | + | | | |
| | *Fragilaria ulna* var. *acus* Kützing (Lange-Bertalot) | | | | | | + | | | | | | | | | | | | + | | | | | | |
| | *Frustulia* spp. | | | | | | | | | | | | | | | | | | | | + | | | | |
| | *Frustulia vulgaris* (Thwaites) De Toni | | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Gomphonema aff. gracile* | | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Gomphonema angustatum* | | | | | | | | | | + | | | | | | | | | | | | | | |
| | *Gomphonema gracile* Ehrenberg | | | | | + | + | + | | | | | | | | | | | | | | | | | |
| | *Gomphonema insigne* Gregory | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Gomphonema minutum* (Agardh) Agardh | | | | | + | | | | | | | | | + | | | | | | | | | | |
| | *Gomphonema parvulum* (Kützing) Kützing | + | | | | | + | | | | | | | | | | | | + | | | | | | |
| | *Gomphonema* spp. | | + | | | | | | | | | | + | | + | | + | + | | | + | | | | |
| | *Hantzschia amphioxys* (Ehrenberg) Grunow | | | | | | | + | | | | | | | | | | | | | + | | | | |
| | *Hantzschia distinctepunctata* | | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Lemnicola hungarica* (Grunow) Round & Basson | | | | | | + | | | | | | | | | | | | | | | | | | |
| | *Luticola cohnii* (Hilse) DG Mann | | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Luticola* spp. | | | | | | | | | | | | | | + | | | | | | + | | + | | |
| | *Navicula antonii?* | | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Navicula cryptocephala* Kützing | | | | | | | | | | | | | | | | | | + | | | | | + | |
| | *Navicula cryptotenella* (Lange- Bertalot) | | | | | | + | | | | | | + | | | | | | + | | | | | | |
| | *Navicula microcari?* | | | | | | | | | | | | | | | | | | | | | | | | + |
| | *Navicula microrhombus* (Cholnoky) Schoeman and Archibald | + | | | | | | | | | | | | | | | | | | | | | | | |
| | *Navicula riediana/libonensis* | | | | | | | | | | | | | | | | | | | | | | | | + |
| | *Navicula rostellata* (Kützing) | | | | + | | | | | | | | | | | | | | | | | | | | |

| Division/Class | Taxon | 1593 | 1596 | 1624 | 1627 | 1641 | 326 | 329 | 1647 | 1655 | 683 | 1699 | 790b | 790a | 947 | 743 | 749b | 1310 | 1359 | 1651 | 1381 | 1625 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Navicula* spp. | | + | + | | | | + | | + | + | + | | + | + | | + | | | + | + | + | + | + | + |
| Bacillariophyceae | *Navicula vandamii* Schoeman and Archibald | + | | | | | + | | | | | | | | | | | + | | | | | | | |
| | *Navicula veneta* Kützing | | | | | | | | | + | | | | | | | | | | | | | + | | |
| | *Nitzschia amphibia* Grunow | | | | | | | | | | + | | | | | | | | | | | | | | |
| | *Nitzschia clausii* Hantzsch | | | | | | | | | | | | + | | + | | | | | | | | | | |
| | *Nitzschia fonticola* | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Nitzschia frustulum* (Kützing) Grunow | + | + | + | | | + | | | + | | | | | + | | | | + | | | + | + | | |
| | *Nitzschia gracilis* Hantzsch | | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Nitzschia liebertruthii* Rabenhorst? | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Nitzschia palea* (Kützing) W Smith | | | | | | + | | + | | | | | | | | | + | | | | | + | + | + |
| | *Nitzschia sigma* (Kützing) W Smith | | | | | | + | | | | | | | | | | | | | | | | | | |
| | *Nitzschia* spp. | | + | + | | + | + | + | + | + | | + | | + | + | + | + | | | + | + | + | | | |
| | *Nitzschia supralitorea* Lange-Bertalot | + | | | | | | | | | + | | | | | | | | | | | | | | |
| | *Oedogonium* spp. | | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Opephora* sp. | | | | | | | | + | | | | | | | | | | | | | | | | |
| | *Phormidium* spp. | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Pinnularia acrosphaeria* W Smith | | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Pinnularia borealis* | | | | | | | + | + | | + | + | + | + | + | | | | | | | | | | |
| | *Pinnularia langerstedtii* (Cleve) Cleve-Euler | | | | | | | | + | | | | | | | | | | | | | | | | |
| | *Pinnularia* spp. | | | | | | + | | | | | + | + | + | | + | + | | | | | | + | | |
| | *Pinnularia subbrevistriata* Krammer | | | | | | + | | | | | | | | | | | | | | + | | | + | + |
| | *Pinnularia subcapitata* Gregory | | | | | | | + | + | | | | | + | | + | + | | | | | | | + | |
| | *Pinnularia viridiformis* Krammer | | | | | | | | + | | | + | | | | | + | | | | | | | | + |
| | *Pinnularia viridis* (Nitzsch) Ehrenberg | | | | | | | | | | | | | | | | | | | | | | + | + | |
| | *Placoneis dicephala* (W Smith) Mereschkowsky | | | | | | | | | | | | | | | | | | | | | | | | + |
| | *Placoneis* spp. | | | | | + | | | | | | + | | | | | | | | | | | | | |
| | *Planothidium engelbrechtii* (cholnoky) Round and Bukhityarova | | | | | | | + | | | + | + | | | + | | | | | | | | + | | |
| | *Planothidium frequentissimum* (Lange-Bertalot) Round & Bukhityarova | | | + | | | | | + | + | | | + | | | | | | | | | | | + | |
| | *Planothidium rostratum* (Oestrup) Round and Bukhityarova | | | | | | | | | + | | | + | | | | | | | | | | | | |
| | *Planothidium* spp. | | | | | + | | | | | | | | | | | | | | | | | + | | + |

| Division/Class | Taxon | 1593 | 1596 | 1624 | 1627 | 1641 | 326 | 329 | 1647 | 1655 | 683 | 1699 | 790b | 790a | 947 | 743 | 749b | 1310 | 1359 | 1651 | 1381 | 1625 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Pleurosigma salinarum* Grunow | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Pseudostaurosira brevistriata* | | | | | | + | | | | | | | | | | | | | | | | | | |
| Bacillariophyceae | *Rhoicosphenia abbreviata* (Agardh) Lange-Bertalot | | | + | | | | | | | | | | | | | | + | | | | | | | |
| | *Rhopalodia gibba* (Ehrenberg) O Müller | | | | + | | | | | | | | | | | | | | | | | | | | |
| | *Rhopalodia musculus* | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Rhopalodia operculata* | | | + | | | + | | | | | | | | | | | | | | | | | | |
| | *Sellaphora pupula* (Kützing) Mereschkowsky sensu lato | | | + | | | | | | | + | | | | | | | | | | | | | | |
| | *Sellaphora stroemii* (Hustedt) DG Mann | | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Stauroneis phoenicenteron* | | | | | | | | | | | | | | | | | | | | | | + | | + |
| | *Stauroneis producta* Grunow | | | | | | | | | | | | | | | | | | | | + | | | | |
| | *Stauroneis* spp. | | | | | | | | | | | | | | | + | + | | | | | | + | + | |
| | *Staurosira elliptica* (Schumann) Williams and Round | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Surirella ovalis* | | + | + | | | | | | | | | | | | | | | | | | | | | |
| | *Surirella* sp.? | | | | | | | | | | | | | | | | | + | | | | | | | |
| | *Tabularia fasciculata* (Agardh) Williams & Round | | + | | | | | | | | | | | | | | | | | | | | | | |
| Chrysophyceae | *Tryblionella hungarica* (Grunow) DG Mann | | | + | | | | | | | | | | | | | | | | | | | | | |
| | *Tryblionella* spp. | | | | | | | | | | | + | | | | | | | | | | | | + | |
| | *Chromophyton cyst* | | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Uroglena* spp. (stomatocyst) | + | | | | | | | + | | | | + | | | | + | | | | + | | | | + |
| | *Chrysococcus* spp. | | | | | | | | + | | | | | | | + | | | | | | + | | | |
| Pyrrophyta | Dinoflagellate | | | | | | | | | | | | | | | | + | | | + | + | + | + | | |
| | *Gymnodinium* sp. | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Katodinium* sp. | | | | | | | | | | | | | | | | | | | | | | + | | |
| Euglenophyta | *Euglena* spp. | + | | + | | | | + | | | | + | | | | | | | | | | | | + | + |
| | *Mesotaenium* spp. | | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Phacus* (corculeum?) | | | | | | | | | | | | | | | | | | + | | | | | | |
| | *Phacus* spp. | | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Strombomonas eurystoma* | | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Strombomonas* sp.? | | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Trachelomonas abrupta?* | | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Trachelomonas hispida* | | | | | | | | | | | | | | + | | | | | | | | | | |

| Division/Class | Taxon | 1593 | 1596 | 1624 | 1627 | 1641 | 326 | 329 | 1647 | 1655 | 683 | 1699 | 790b | 790a | 947 | 743 | 749b | 1310 | 1359 | 1651 | 1381 | 1625 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Trachelomonas lacustris?* | | | | | | | | | | | | | | | | | | | | + | + | | | |
| | *Trachelomonas* spp. | + | + | | + | | + | + | + | + | + | + | + | + | | + | + | + | + | | + | + | + | + | + |
| | *Trachelomonas zuberi* | | | | | | | | + | | | | | | | | | | | | | | | | |
| Chlorophyta | *Actinotaenium* spp. | | | | | | + | | | | | | | | + | | | | + | | + | + | | | |
| | *Ankistrodesmus* sp. | | | | | | | + | | | | | | | | | | | + | | | | | | |
| | *Apatococcus* sp. | | | | | | | | | | | | | | | | | | | | | | | + | |
| | *Asterococcus* sp. | | | | | | | | | | | | | + | | | | | | | | | | | |
| | *Chlamydomonas* spp. | | | | | | | | | + | + | | + | + | + | | + | + | + | + | | | + | | |
| | *Chlamydopodium* sp. | | | | | | + | | | | | | | | | | | | | | | | | | |
| | *Chlorochytrium* sp. | | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Chlorococcum* spp. | + | | | + | | | | | | + | | | + | | | | | | | | | | + | |
| | *Chroococcus* spp. | | | | | | | + | | | | | | | | | | | + | + | | | | | + |
| | *Chroomonas* sp. | | | | | | | | | | | | | | | | | | | | | | | | |
| | *Closteriopsis* sp.? | | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Closterium gracile* | | | | | | | | | | | | | | | + | + | | | | | | | | |
| | *Coenococcus* sp. | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Cosmarium* spp. | + | | | + | | | | | | | | | | | + | + | | | | + | + | | | |
| | *Cylindrocapsa* sp. | | | | + | | | | | | | | | | | | | | | | | | + | | |
| | *Euastrum binale* | | | | + | | | | | | | | | | | | | | | | | | | | |
| | *Euastrum* sp. | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Fallacia* sp. AJ Stickle & DG Mann | | | | | | | | | + | | | | | | | | | | | | | | | |
| | *Geminella* spp. | | | | | | | | | | | | | | | | | | | | + | + | | | |
| | *Gloeocystis* spp. | | | | + | + | | | | + | | | | | | + | | | | + | | + | | | |
| | *Kirchneriella* sp. | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Klebsormidium* sp. | | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Lobomonas francei* | | | | | | | | | | | | | | | | | | | + | | | | | |
| | *Lobomonas* sp. | | | | | | + | | | | | | | | | | | | | | | | | | |
| | *Mesotaenium* spp. | | | | | | | | | | | | | | | | | | | | + | | + | | |
| | *Microspora* sp. | | | | | | | | | | | | | | | | | + | | | | | | | |
| | *Monoraphidium* sp. | | | | | + | | | | | | | | | | | | | | | | | | | + |
| | *Netrium* sp. | | | | | | | | | | | | | | | | | | | | + | | | | |
| | *Oedogonium* spp. | | + | | + | | | | | | | | | | | | + | | | | | | | | |
| | *Oedogonium/Spirogyra Cyst* | | | | + | | | | | | | | + | | + | | | | | | + | + | | | |
| | *Oocardium stratum* | | | | | | | | | + | | | | | | | | | | | | | | | |

| Division/Class | Taxon | 1593 | 1596 | 1624 | 1627 | 1641 | 326 | 329 | 1647 | 1655 | 683 | 1699 | 790b | 790a | 947 | 743 | 749b | 1310 | 1359 | 1651 | 1381 | 1625 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Oocystis parva* | | | | + | | | | | | | | | | | | | | | | | | | | + |
| | *Oocystis* spp. | | | | + | | + | | | | | | | | | + | | | | | | | | | |
| | *Pediastrum boryanum* | + | | | | | | | | | | | | | | | | | | | | | | | |
| Chlorophyta | *Phacotus* spp. | | | | | | + | | | | | | | | | | | | | + | | | | | |
| | *Pteromonas* sp. | | | | | | | | | | | | | | | | | | | + | | | | | + |
| | *Scenedesmus ellipticus* | | | | | | | | | | | | | | | + | | | | | | | | | |
| | *Scenedesmus obtusus* | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Scenedesmus* spp. | | | | | | | | | | | | | | | + | | | + | | + | | | | |
| | *Scotiella* sp. | | | | | | | | | | | | + | | | | | | | | | | | | |
| | *Sphaerobotrys* sp. | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Sphaerocystis* spp. | | | | | + | | | | | | | | | | | | | | + | + | + | | | |
| | *Spirogyra* sp. | | + | | | | | | | | | | | | | | | | | | | | | | |
| | *Spondylosium* sp? | | | | | | | | | | | | | | | + | | | | | | | + | | |
| | *Staurastrum* sp. | | | | | | | | | | | | | | | | + | | | | | | | | |
| | *Trebouxia* sp. | | | | | | | | | | | | | | | | | | | | | + | | | |
| | *Trochiscia aspera* | | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Trochiscia* spp. | | | | | | | | | | | | | | | | | | | + | | | + | | |
| Prasinophyta | *Prasinochloris sessilis* | | | | + | | | | | | | | | | | | | | | | | | | | |
| | *Scourfieldia* sp. | | | | | | | | | | | | | | | | | | + | | | | | | |
| Raphidophyta | *Gonyostomum* sp. | | | | | | | | | | | | | | + | | | | | | | | | | |
| Xanthophyta | *Botrydiopsis arrhiza* | | | | | | | + | | | | | | + | | | | | | | | | | + | |
| | *Goniochloris* sp. | | | | | + | | | | | | | | | | | | | | | | | | | |
| | *Rhomboidella oblique* | | | | | | | | | | | | | | | | | | | | | | + | | |
| | *Tribonema* sp. | | + | | | | | | | | | | | | | | | | | | | | | | |
| | *Chlorobotrys* sp. | | | | | | | | + | | | | | | | | | | | | | | | | |

## Table C.5 Diatom species list, presence/absence by site. Site codes as per Table 4.2 in text.

| Taxon | 1593 | 1596 | 1624 | 1626 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 790 | 790a | 944 | 947 | 743 | 1675 | 749 | 1310 | 1359 | 1649 | 1650 | 1651 | 1380 | 1381 | 1625 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Achnanthes* sp. | + | | | | | | + | | | | + | | | + | | | | | | | | | + | | | | | | | | | | | |
| *Achnanthes brevipes* var. *intermedia* (Kutzing) Cleve | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Achnanthes delicatula* (Kutzing) Grunow | | | | | | | | | | | + | + | | | | | | | | | | | | | | | | | | | | | | |
| *Achnanthes oblongella* Oestrup | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | |
| *Achnanthidium affine* (Grunow) Czarnecki | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | |
| *Achnanthidium exiguum* (Grunow) Czarnecki | | | | | | | + | | | | | | | | | | | | | | | | + | | | | | | | | | | | |
| *Achnanthidium minutissimum* (Kutzing) Czarnecki | + | + | | + | | | + | + | | | | | + | | + | | | + | + | + | + | | | + | | | | | | | | + | | |
| *Amphora* sp. | | | | | | | | | | | + | + | | + | | | | | | | | | + | | | | | | | + | | | | |
| *Amphora coffeaeformis* (Agardh) Kutzing | | | | | | | | | | | + | + | | | | | | | | | | | | | | | + | | | | | | | |
| *Amphora commutata* Grunow | | | | | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | |
| *Amphora veneta* Kutzing | + | + | | + | | | + | | | | | | | | | | | | + | | | | | | | | + | | | | | | | |
| *Brachysira* sp. | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Brachysira brabissonii* Ross | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | |
| *Brachysira neoexilis* (Grunow) DG Mann | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | |
| *Caloneis bacillum* (Grun.) Cleve | | | | | | | | | | | | | | | + | | + | + | | | | | | | | | | | | | | | | |
| *Caloneis hyalina* Hustedt | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | |
| *Caloneis* sp. | + | | | | | | | | | | | | | + | + | | | | | | | | | | | | | | | | | | | |
| *Cocconeis capensis* (Cholnoky) Witkowski | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | |
| *Cocconeis* sp. | | | | | | | | + | | + | + | | | | | + | | | | | | | + | | | | | | | | | | | |
| *Cocconeis engelbrechtii* Cholnoky | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Cocconeis placentula* Ehrenberg | | | + | | | | + | + | | | | + | | | | | | | | | | | + | | | | | | | | | | | |
| *Cocconeis placentula* var. *euglypta* (Ehr) Grunow | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | |
| *Craticula* sp. | | | | + | | | + | | | | | | | | | | | | | | | + | | | | | | | | | | | + | |
| *Craticula accomodiformis* Lange-Bertalot | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Craticula acidoclinata* Lange-Bertalot & Metzeltin | | | | | | | + | | | | | | | | | | | | | + | | | | + | | | | | | | | | | |
| *Cyclotella* sp. | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Cyclotella meneghiniana* Kutzing | | | | | | | + | + | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Taxon | 1593 | 1596 | 1624 | 1626 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 790 | 790a | 944 | 947 | 743 | 1675 | 749 | 1310 | 1359 | 1649 | 1650 | 1651 | 1380 | 1381 | 1625 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Cymbella pusilla* Grunow ex. A. Schmidt | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Cymbella turgidula* Grunow | | | | | | | | | | | | | | | | | | | | + | | + | | | | | | | | | | | | |
| *Cymbopleura naviculiformis* (Auerswald) Krammer | | | | | | | | | | | | | | | | | + | | | + | | | | | | | | | | | | | | |
| *Cymbopleura* sp. | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Delphineis* sp. | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Denticula* sp. | | | + | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Diadesmis confervacea* (Kutzing) DG Mann | | | | | | | + | + | | | | | | | | + | | | | | | | | | | | | | | | | | | |
| *Diploneis* sp. | | | | | | | + | + | | | + | | | | | | | | | | + | | + | | | + | | | | | | | | |
| *Diploneis elliptica* (Kutzing) Cleve | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | |
| *Diploneis oblongella* (Naegeli) Cleve-Euler | | | | | | | | | | | | + | | | | | | | | | | | | | | | + | | | | | | | |
| *Diploneis smithii* (?) var. *recta* | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | |
| *Discotella Woltereckii* (Hustedt) Houk & Klee | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Encyonema mesianum* (Cholnoky) DG Mann | | | | | | | | | | | | | | | | | | | | + | | + | | | | | | | | | | | | |
| *Encyonema silesiacum* (Bleisch) DG Mann | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | |
| *Eolimna* sp. | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | |
| *Epithemia adnata* (Kutzing) Brebisson | | | | | + | + | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Epithemia* sp. | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Eunotia* sp. | | | | | | | + | + | | | | | | | | | | + | + | + | | + | + | | | | + | | | | | | | |
| *Eunotia* [abnormal form of *E curvata*] (Kutzing) Langerstedt | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Eunotia arcus* Ehrenberg | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | |
| *Eunotia bilunaris* (Ehrenberg) Mills | | | | | | | + | + | | + | | | + | | + | | | + | + | | | | | | | | | | | | | | | |
| *Eunotia diodon* Ehrenberg | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Eunotia formica* Ehrenberg | | | | | | | + | + | | + | | | + | | | | | | + | + | | | | | | | | | | | | | | |
| *Eunotia incisa* Gregory | | | | | | | | + | | | | | | | | | | + | + | | | | | | | | | | | | | | | |
| *Eunotia minor* (Kutzing) Grunow | | | | | | | + | + | | | | | | + | | | + | | | | | | | | | | + | | | | | | | |
| *Eunotia pectinalis* var. *undulata* (Ralfs) Rabenhorst | | | | | | | | + | | + | | | | | | | | | | | | | | | | | | | | | | | | |
| *Eunotia rhomboidea* Hustedt | | | | | | | | | | | | | | | + | | | | | + | | + | | | | | | | | | | | | |
| *Eunotia* sp. (Girdle view) | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | |
| *Fallacia* sp. | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | |
| *Fallacia pigmaea* (Kutzing) Sickle & Mann | | | | | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | |

| Taxon | 1593 | 1596 | 1624 | 1626 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 790 | 790a | 944 | 947 | 743 | 1675 | 749 | 1310 | 1359 | 1649 | 1650 | 1651 | 1380 | 1381 | 1625 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Fallacia* sp. AJ Stickle and DG Mann | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Flagilaria ulna* var. *acus* (Kutzing) Lange-Bertalot | | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | |
| *Fragilaria* sp. | + | | + | | | | + | + | | | | | | | | | | | | | | | + | | | | | | | | | | | |
| *Fragilaria biceps* (Kutzing) Lange-Bartalot | | + | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Fragilaria capucina* Desmazieres | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Fragilaria tenera* (Wm Smith) Lange-Bertalot | | | | | | | | + | | | | | | | | | | + | + | | | | | | | | | | | | | | | |
| *Frustulia* sp. | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | |
| *Frustilia carssinervia* (Kutzing) Cleve | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | |
| *Frustulia rostrata* Hustedt | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | + | |
| *Frustulia saxonica* Rabenhorst | | | | | | | | | | | | | | | | | | | + | + | | | | | | | | | | | | | | |
| *Gomphonema* sp. | + | | | | | | + | + | | + | | + | + | | | | | + | + | + | + | | + | + | | | + | | + | | | | | |
| *Gomphonema aff. gracile* | | | | | + | | | + | | | | | + | | | | | + | | | | + | + | | | | | | | | | | | |
| *Gomphonema affine* Kutzing | | | | | | + | + | | | | | | | | | | | + | | | | | | | | | | | | | | | | |
| *Gomphonema angustatum* (Kutz) Rabe | | | | | | | | | | | | | | | + | | | | + | | | | | + | | | | | | | | | | |
| *Gomphonema exilissimum* Lange-Bertalot and Reichar | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | + |
| *Gomphonema gracile* Ehrenberg sensu stricto | + | | | + | | | + | + | + | + | | | | | + | | | + | + | | | | | + | | | | | | | | | | |
| *Gomphonema insigne* Gregory | + | + | + | + | + | | + | + | | | | | + | | | | | | + | + | | | | | | | | | | | | | | |
| *Gomphonema minutum* (Agardh) Agardh | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | |
| *Gomphonema parvulius* Lange-Bertalot and Reichardt | | | | | | | | + | | | | | + | | | | | | + | | | | | | | | | | | | | | | |
| *Gomphonema parvulum* (Kutzing) Kutzing | + | | | | | | | + | | | | | | + | | | | + | | | | | | + | | | | | | + | | | + | |
| *Gomphonema parvulum cf. saprophilum* Lange-Bertalot & Riechard | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Gomphonema pseudoaugur* Krammer | + | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | |
| *Hantzschia amphioxys* (Ehrenberg) Grunow | + | | | | | | | + | | | | | | | + | | | | | | | | | + | | | | | | | | | | |
| *Kobayasiella subtillissima* (Cleve) Lange-Bertalot | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | + | |
| *Lemnicola* sp. | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | |
| *Lemnicola hungarica* (Grunow) Round & Basson | | | | | | | + | + | + | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Luticola* sp. | + | | | | | | + | + | | | | | | | + | | | | | | | | + | | | | | | | | | | | |
| *Luticola acidoclinata* Lange-Bertalot | | | | | | | | + | | | | | + | | | | | | | | | | | | | | | | | | | | | |

| Taxon | 1593 | 1596 | 1624 | 1626 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 790 | 790a | 944 | 947 | 743 | 1675 | 749 | 1310 | 1359 | 1649 | 1650 | 1651 | 1380 | 1381 | 1625 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Luticola cohnii* (Hilse) DG Mann | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | |
| *Luticola mutica* (Kutzing) DG Mann | + | | | | | | | | | | | | | | + | | | + | | | + | | | | | | | | | | | | + | |
| *Luticola obligata* (Hustedt) DG Mann | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | |
| *Martyana martyi* (Heribaud) FE Round | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | |
| *Mastogloia* sp. | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | |
| *Mastogloia elliptica* (Agardh) Cleve | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | |
| *Mastogloia exigua* Lewis | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | |
| *Navicula* sp. | + | + | | + | | | + | + | | | | + | + | + | + | + | + | + | | | | + | + | | | | | | | | | + | + | + |
| *Navicula antonii* Lange-Bertalot | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | |
| *Navicula capitatoradiata* Germain | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Navicula cincta* (Ehrenberg) Ralfs | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Navicula cryptocephala* Kutzing | + | + | | | | | + | + | | | | | | | | | | | | | | | | + | | | | | | | | | + | |
| *Navicula cryptotenella* Lange-Bertalot | | | | | | | + | + | | | | | | | | | | | | | | | | + | | | | | | | | | | |
| *Navicula cryptotenelloides* Lange-Bertalot | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Navicula erifuga* (OF Muller) Bory | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | |
| *Navicula gregaria* Donkin | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | |
| *Navicula libonensis* Schoeman | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | |
| *Navicula longicephala* Hustedt | | | | | | | | + | | | | | | + | | | | | | | | | | | | | | | | | | | | |
| *Navicula reinhardtii* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | + | |
| *Navicula riediana* Lange-Bertalot & Rumrich | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | + | |
| *Navicula rostellata* Kutzing | | | | | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | |
| *Navicula tenelloides* Hustedt | | + | + | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Navicula vandamii* Schoeman & Archibald | + | | + | + | + | + | + | | | | | + | | | | | | + | + | | | | + | + | | | | | | | | | | + |
| *Navicymbula pusilla* (Grunow) Krammer | | + | | | | | + | | | | + | + | | + | | + | | | | | | | | | | | + | | | | | | | |
| *Neidium* sp. | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Nitzschia* sp. | + | + | | | | | + | + | | + | | | + | + | + | | + | + | + | + | + | + | + | + | | | + | | | | | + | + | |
| *Nitzschia* sp. 1 | | | | | | | | + | | | | | | | + | | | + | | | | | | | | | | | | | | | | |
| *Nitzschia acicularis* (Kutzing) W Smith | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia agnita* Hustedt | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia amphibia* Grunow | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia archibaldii* Lange-Bertalot | | | | | | | | + | | | | | | | | | | + | | | | | | | | | | | | | | | | |
| *Nitzschia capitellata* Hustedt | | | | | | | | + | | | | | | | | | | + | | | | + | | | | | | | | | | | | |
| *Nitzschia cf. subcapitata* Hustedt | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | |

| Taxon | 1593 | 1596 | 1624 | 1626 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 790 | 790a | 944 | 947 | 743 | 1675 | 749 | 1310 | 1359 | 1649 | 1650 | 1651 | 1380 | 1381 | 1625 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Nitzschia clausii* Hantzsch | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia desertorun* Hustedt | | + | | | | | + | + | | | | | | | | | | + | + | | | | | | | | | | | | | | | |
| *Nitzschia dissipata* (Kutzing) Grunow | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia fonticola* Grunow | + | | | + | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia frustulum* (kutzing) Grunow | + | + | + | + | | | + | + | | | | + | | | + | | | | + | | | | + | | | | + | | | + | | | + | |
| *Nitzschia frustulum* group | + | + | | | | | | | | | | + | | | | | | | | | | | + | | | | | | | | | | | |
| *Nitzschia gracilis* Hantzschia | | | | | | | | + | | | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Nitzschia heufleriana* Grunow | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | + | |
| *Nitzschia hybrida* Grunow | | | | | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | |
| *Nitzschia iremissa* Cholnoky | | | | | | | + | + | | | | | | | | | | + | + | | | | | | | | | | | | | | | |
| *Nitzschia libertruthii* Rabenhorst | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia littorea* Grunow | | | + | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia microcephala* Grunow | | | | | | | | | | | | | | | | + | | + | | | | | | | | | | | | | | | | |
| *Nitzschia nana* Grunow | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Nitzschia palea* (kutzing) W Smith | + | | + | + | + | + | + | + | | + | | + | + | | + | | | + | + | | | | + | + | | | + | | + | | + | + | + | |
| *Nitzschia pura* Hustedt | | | | | | | | + | | | | | | | | | | + | | | | + | | | | | | | | | | | | |
| *Nitzschia pusilla* Grunow | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Nitzschia scalpelliformis* (Grunow in Cleve and Moller) Grunow | | | | | | | | + | | | | | | + | | | | | | | + | | | | | | | | | | | | | |
| *Nitzschia sigma* (Kutzing) W Smith | | | + | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Nitzschia supralitorea* Lange-Bertalot | + | + | | | | | | + | | | | + | + | | | + | + | + | | | | | | | | | | | | | | | | |
| *Nitzschia umbonata* (Ehrenberg) Lange-Bertalot | + | | | | | | | + | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Opephora* sp. | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Pinnularia* sp. | | | | | | | + | + | | | | | + | + | + | | + | + | | | + | + | + | | | | + | | | | | + | + | |
| *Pinnularia abaujensis* (Pantocsek) R Ross | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | |
| *Pinnularia appendiculata* (Agardh) Cleve | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | |
| *Pinnularia borealis* sensu lato Ehrenberg | | | | | | | | | | + | | | | + | + | | + | + | + | | + | | | | | | | | | | | | | |
| *Pinnularia divergens* var. *undulata* (Peragallo & Heribaud) | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Pinnularia divergens* W Smith | | | | | | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | |
| *Pinnularia langerstedtii* (Cleve) Cleve-Euler | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | |
| *Pinnularia subbrevistriata* Krammer | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | |
| *Pinnularia subcapitata* Gregory | | | | | | | | + | | + | | | | | | | | | | + | | + | | | | | | | + | | + | | + | |

| Taxon | 1593 | 1596 | 1624 | 1626 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 790 | 790a | 944 | 947 | 743 | 1675 | 749 | 1310 | 1359 | 1649 | 1650 | 1651 | 1380 | 1381 | 1625 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pinnularia viridiformis* Krammer | | | | | | | | + | | + | | | | + | | | | | | | | | | | | | | | | | | | | |
| *Placoneis dicephala* (W Smith) Mereschkowsky | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | + |
| *Placoneis placentula* (Ehrenberg) Heinzerling | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | |
| *Planothidium* sp. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | + | |
| *Planothidium delicatulum* (Kutzing) Round & Buktyarova | | | | | | | + | + | | | | | + | | | | | | | | | | | | | | | | | | | | | |
| *Planothidium engelbrechtii* (Cholnoky) Round & bukhityarova | | + | | | | | + | + | | | | | + | + | + | + | | + | + | | | | + | | | | | | | | | | | + |
| *Planothidium frequentissimum* (Lange-Bertalot) Round & Bukhityarova | | | + | | | | + | | | | | + | + | | | + | | + | | | + | | | | | | | | | | | | | |
| *Planothidium rostratum* (Oestrup) Round & Bukhityarova | + | + | + | + | | | | + | | + | | + | | | | | | + | + | | | | | | | | | | + | | | + | | + |
| *Pleurosigma salinarum* Grunow | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Rhopalodia* sp. | | | | | | | | | | | + | | | | | | | | | | | | + | | | | | | | | | | | |
| *Rhopalodia brebissonii* Krammer | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Rhopalodia gibba* (Ehrenberg) O Muller | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Rhopalodia operculata* (Agardh) Hakansson | | | + | | | | + | | | | | | | | | + | | | | | | | + | | | | | | | | | + | | |
| *Sellaphora* sp. | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | |
| *Sellaphora pupula* (Kutzing) Mereschkowsky | | | + | | | | | + | | | | | | | | | + | | | + | | | | | | | | | | | | | | |
| *Sellaphora seminulum* (Grunow) DG Mann | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | | |
| *Sellaphora stroemii* (Hustedt) DG Mann | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | |
| *Stauroneis* sp. | | | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | |
| *Stauroneis anceps* Ehrenberg | | | | | | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Stauroneis gracilior* Reichart | | | | | | | | | | | | | | | | | | + | | | | + | | | | | | | | | | | | |
| *Stauroneis producta* Grunow | | | | | | | | | | | | | | | | | | | | | | | | | | | | | + | | | | | |
| *Staurosira elliptica* (Schumann) Williams & Round | | | + | | | | | + | | | | | | | | + | | | | + | | | | | | | | | | | | | + | |
| *Surirella angusta* Kutzing | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | + | | |
| *Surirella ovalis* Brebisson | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Tabularia* sp. | | | | | | | | + | | | | | | | | | + | | | | | | | | | | | | | | | | | |
| *Tabularia fasciculata* (Agardh) Williams & Round | | + | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Tryblionella* sp. | | | | | | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Tryblionella apiculata* Gregory | + | + | | + | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Taxon | 1593 | 1596 | 1624 | 1626 | 1641a | 1641b | 326 | 329 | 1344 | 1647 | 1654 | 1655 | 683 | 1699 | 789a | 790 | 790a | 944 | 947 | 743 | 1675 | 749 | 1310 | 1359 | 1649 | 1650 | 1651 | 1380 | 1381 | 1625 | 1692 | 1382a | 1382b | 1382c |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Tryblionella debilis* Arnott | | | | | | | + | | | | | | | + | | | + | | | | | | | | | | | | | | | | | |
| *Tryblionella hungarica* (Grunow) DG Mann | | | + | | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | |
| *Tryblionella littoralis* (Grunow) DG Mann | | | | | | | | | | | | | | + | | | | | | | | | | | | | | | | | | | | |

**Table C.6 Macroinvertebrate species list, presence/absence by site. Sites from areas 1, 2, 3 and 4 are represented here, see Table 4.2 in text for codes. Sites in italics were used in sediment hatching experiments only, as there was no habitat to sample in the field.**

| Group/Order | Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1625 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | *1647* | 1655 | 683 | *1699* | *789a* | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nematoda | Unspecified | Nematoda spp. | | | | | | | | | | + | | | | | | | | | | | |
| Oligochaeta | Lumbriculidae | *Lumbriculus variegatus* | | | | + | | | | | | | | | | | | | | | + | | |
| Oligochaeta | Naididae | *Nais* sp. | | | | | | | | | | | + | | | | | | | | | | |
| Hirudinae | Glossiphoniidae | *Alboglossiphonia conjugata* | | | | | | | | | | | | | | | | | | | | | + |
| | | *Alboglossiphonia macrorhyncha* | | | | | | | | | | | | | | | | | | | + | | + |
| | | *Helobdella conifera* | | | | | + | | | | | | | | | | | | | | + | + | |
| | | *Helobdella stagnalis* | | | | | | | | | + | | | | | | | | | | | | |
| Anostraca | Branchiopodidae | Branchiopodidae sp. | | | | | | | | | | | | | | | | | | | | | + |
| | | *Branchipodopsis hodgsoni* | + | + | + | | | | + | | | | | | | | | | | | | | |
| | Streptocephalidae | *Streptocephalus dendyi* | | | | | | | | | | | | | | | | | | + | | | |
| | | *Streptocephalus* sp. | | | | | | | | | | | | | + | | | | | | | | |
| | Unspecified | Anostraca sp. | | | | | | | | | | | | | | | | | | | | | |
| Conchostraca | Leptestheriidae | *Leptestheria rubidgei* | + | | + | | | | | | | | | | | | | | | + | | | |
| | | *Leptestheria* sp. | | | | | | | | | | | | | + | | | | | | | | + |
| | | *Leptestheriidae brevirostis* | | | | | | | | | | | | | | | | | | | | | |
| | Unspecified | Conchostraca sp. | | | | | | | | | | | | | + | | | | | | | | |
| Notostraca | Triopsidae | *Triops granarius* | + | | | | | | | | | | | | | | | | | + | | | + |
| Cladocera | Chydoridae | Chydoridae sp. | | | | | | | | | | | | | | | | | | | | | |
| | | *Eurycercus gr. lamellatus* | | | | | + | | | | | | | | | | | | | | | | |
| | Daphniidae | *Daphnia (Ctenodaphnia) barbata* | + | | | | | | | | | | | | | | | | | | | | |
| | | *Daphnia (Ctenodaphnia) dolichocephala* | + | | | | | | | | | | | | | | + | | | + | | | + |
| | | *Daphnia laevis* | | | | | | | | | | | | | | | | | | | + | | |
| | | *Daphnia obtusa* | | | + | | | | | | | | | | | | | | | | | | |
| | | *Daphnia pulex* | + | + | + | | | | + | | | | | | | | | | | | | | |
| | | *Daphnia* sp. | | | | | | | | | | | | | | | | | + | | | | |
| | | *Simocephalus exspinosus* | + | + | + | | | + | | | | + | + | | | | + | | | | | + | + |
| | | *Simocephalus vetulus* | | | | | | | | | | | + | | | | | | | | | | |
| | Unspecified | Cladocera sp. | | | | | | | | | | | | | + | | | | | | | | |
| Copopoda | Unspecified | Copepodite sp. | | | | | + | | | | | | | | | | | | | | | | |
| Calanoida | Diaptomidae | Diaptomidae spp. | | | | | | | | | | | | | | | | | | | | | |
| Calanoida | Diaptomidae: Paradiaptominae | *Lovenula falcifera* | + | | | | | | | | | | + | | | | + | | | | + | + | + |
| | | *Lovenula simplex* | | | | | | | | | | | | | | | | | | | + | | |
| | | *Paradiaptomus lamellatus?* | | | | | | | | | | | + | | | | | | | | | + | + |
| | | *Paradiaptomus natalensis* | | | | | | | | | | | | | | | | | | | | | |

| Group/Order | Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1625 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | *1647* | 1655 | 683 | *1699* | *789a* | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calanoida | Diaptomidae: Paradiaptominae | Paradiaptominae sp. | | | | | | | | | | | | | | | | | | | | | |
| Cyclopoida | Cyclopidae | *Ectocyclops phaleratus/Paracyclops poppei* | | | | | | | | | | | | | | | | | | | | | |
| | | Cyclopidae sp. | | | | | | | | | | | | | | | | | | | | | |
| Ostracoda | Cyprididae | Cyprididae sp. | | | | | | | | | | | | | + | | | | | | | | |
| | | Cyprididae sp. 1 | | | | | | | | | | + | + | | | | + | | | | + | + | + |
| | | *Megalocypris princeps/durbani* | | | | | | | | | | + | | | | | + | | | + | | | + |
| | | *Parastenocypris?* sp. | | | | | | | | | | | | | | | | | | | | | |
| | | *Physocypria?* sp. | | | | | + | + | | | | | | | | | + | | | | | | + |
| | | *Potamocypris* sp. | | | | | | | | | | + | | | | | | | | | | + | |
| | | *Zonocypris?* sp. 1 | | | + | | | | | | | | | | | | | | | | | | |
| | | Ostracoda sp. | | | | | | | | | | | | | + | | | + | + | | | | |
| Amphipoda | Unspecified | Amphipoda (marine) sp. | | | | | | | | | | | | | | + | | | | | | | |
| Decapoda: Macrura | Palaemonidae | *Palaemon?* sp. | | | | | | | | | | | | | | + | | | | | | | |
| | Upogebiidae | *Upogenia* sp. | | | | | | | | | | | | | | | | | | | | | |
| Bivalvia | Sphaeriidae | *Sphaerium capense* | | | | | | | | | | | | | | | | | | | | | |
| Gastropoda | Ancylidae | *Ferrissia* sp. | | | | | | | | | | | + | | | | | | | | | + | |
| | Cochlicellidae | *Cochlicella barbara* | | | | + | | | | | | | | | | | | | | | | | |
| | Helicidae | *Eobania vermiculata* | | | | | | + | | | | | | | | | | | | | | | |
| | | *Theba pisana* | | | | + | | | | | | | | | | | | | | | | | |
| | Lymnaeidae | *Lymnaea columella* | | | | | | | | | | | + | | | | | | | | + | | |
| | Physidae: Physinae: Physellini | *Physella acuta* | | | + | + | | | | | | | | | | | | | | | | + | |
| | Planorbidae: Bulininae | *Bulinus tropicus* | | | | | + | | | + | | + | | | | | | | | | + | + | + |
| | Unspecified | Gastropoda | | | | | | | | | | | | | | | | | | | | | + |
| | | terretrial snail | | | | | + | | | | | | | | | | | | | | | | |
| Acarina | Unspecified | Acarina sp. | | | | | + | + | | | | | + | | | | + | | | | | + | + |
| Araneae | Araneidae: Araneinae | Araneinae sp. | | | | | + | + | | | | | | | | | | | | | | + | |
| | Eresidae | Eresidae sp. | | | | | + | + | | | | | | | | | | | | | | + | |
| | Lycosidae | Lycosidae sp. | | | | | | | | | | | | | | | | | | | + | | |
| | | *Wadicosa?* sp. | | | | | | + | | | | | | | | | | | | | | | |
| | Pisauridae: Thalassinae | *Thalassius ?massajae* | | | | + | + | | | | | + | | | | | | | | + | | + | |
| | Segestriidae | *Ariadna?* sp. | | | | | | + | | | | | | | | | | | | | | | |
| | Tetragnathidae | *Tetragnatha vermiformis* | | | + | + | | | | | | | + | | | | | | | | | + | |
| | | *Tetrathemis ?polleni* | | | | | | | | | | | | | | | + | | | + | | | |
| | Unspecified | Araneae spp. | + | | | + | + | | | | | | | | | | | | | | | | |
| Collembola | Poduridae | *Podura* sp. | | | | | | + | | | | | | | | | | | | | | | |
| Coleoptera | Curculionidae: Bagoini | *Bagoini* sp. larvae | | | | | + | | | | | | | | | | | | | | | | |

| Group/Order | Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1625 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | *1647* | 1655 | 683 | *1699* | *789a* | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coleoptera | Curculionidae: Bagoini | *Bagous ?humeralis* adults | | | | | + | | | | | | | | | | | | | + | | + | |
| | Dytiscidae: Colymbetinae: Colymbetini | *Rhantus* sp. adults | + | | | | + | | | | + | | | | | | | | | | | | |
| | | *Rhantus* sp. larvae | + | + | + | | | + | + | | + | | | | | | | | | + | | | |
| | Dytiscidae: Copelatinae: Copelatini | *Copelatus* sp. larvae | | | | | | + | | | | | | | | | | | | | | | |
| | Dytiscidae: Dytiscinae: Cybistrini | *Cybister* sp. adults | | | | | | | | | | | | | | | | | | | | + | |
| | | *Cybister* sp. larvae | | | | | + | | | | | | | | | | | | | + | + | + | + |
| | Dytiscidae: Dytiscinae: Hydaticini | *Hydaticus* (Guignotites) sp. 1 larvae | | | | | | | | | | | | | | | | | | + | | | |
| | | *Hydaticus* (Guignotites) sp. 2 larvae | | | | | | | | | | + | | | | | | | | | | | |
| | | *Hydaticus* (Guignotites) sp. adults | | | | | | | | | + | | | | | | + | | | | + | | |
| | Dytiscidae: Hydroporinae: Bidessini | *Hydroglyphus* sp. adults | | | | | | | + | | | | | | | | | | | | | | + |
| | | *Leiodytes* sp. 1 adults | | | | | | | | + | + | | | | | | | | | | | | |
| | | *Leiodytes* sp. 2 adults | | | | | | | | | + | | | | | | | | | | | | |
| | | *Uvarus/Hydroglyphus?* sp. larvae | | | | | | + | + | | + | | | | | | | | | | | | |
| | Dytiscidae: Hydroporinae: Hydroporini | *Canthyporus* sp. adults | | + | | | + | + | | | | | | | | | | | | | | | |
| | Dytiscidae: Hydroporinae: Hydrovatini | *Hydrovatus* sp. adults | | | | | | | | | | | | | | | | | | | + | | |
| | | *Hydrovatus* sp. larvae | | | | | + | | | | | | | | | | | | | + | | | |
| | Dytiscidae: Hydroporinae: Hygrotini | *Herophydrus* sp. adults | | | | | + | | | | | | + | | | | | | | + | | + | + |
| | | *Herophydrus* sp. larvae | | | | | + | | | | | | | | | | | | | | | | + |
| | Dytiscidae: Hydroporinae: Hyphydrini | *?Hydropeplus trimaculatus* larvae | + | + | + | | | | | | | | | | | | | | | | | | |
| | | *Coelhydrus brevicollis* adults | | | | | | + | | | + | | | | | | | | | | | | |
| | | *Hydropeplus trimaculatus* adults | + | | | | | + | + | | + | | | | | | | | | + | | | |
| | | Hyphydrini sp. larvae | | | | | + | | | | | + | + | | | | | | | | + | + | + |
| | | *Hyphydrus* sp. adults | | | | | | | | | + | | | | | | + | | | | + | | |
| | Dytiscidae: Laccophilinae: Laccophilini | *Laccophilus* sp. adults | | | | | | + | | | + | | | | | | | | | | | + | + |
| | | *Laccophilus* sp. larvae | | | | | | | | | | | | | | | | | | | + | + | + |
| | Gyrinidae: Gyrininae: Gyrinini | *Aulonogyrus* sp. adults | | | | | | | | | | | + | | | | | | | | | + | |
| | | *Gyrinus* (s.str.) *vcinus* adults | | | | | | | | | | | | | | | + | | | | | | |
| | | *Gyrinus* (s.str.) *vcinus* larvae | | | | | | | | | | | | | | | | | | | | | |
| | Gyrinidae: Gyrininae: Orectochilini | *Orectogyrus* sp. larvae | | + | | | | | | | | | | | | | | | | | | | |
| | Halipidae | *Haliplus* sp. larvae | | | | | + | | | | | | | | | | | | | | | | |
| | Helophoridae | *Helophorus (Rhopalohelophorus) aethiops* adults | | | | | | | | | | | | | | | | | | | | | |
| | Hydraenidae: Ochthebiinae: Ochthebiini | *Ochthebius* sp. adults | | | | | | | | | | | | | | | | | | | | | |

| Group/Order | Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1625 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | *1647* | 1655 | 683 | *1699* | *789a* | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydrochidae | *Hydrochus* sp. adults | | | | | | | | | | | | | | | | | | + | + | | |
| Coleoptera | Hydrophilidae: Hydrophilinae: Anacaenini | *Anacaena* sp. adults | | | | | | | | | | | | | | | | | | + | + | | |
| | Hydrophilidae: Hydrophilinae: Berosini | *Berosus* sp. 1 adults | | | | | | | | | | | | | | | | | | | | | |
| | | *Berosus* sp. 2 adults | | | | | | | | | | | | | | | | | | | | | |
| | | *Berosus?* sp. larvae | | | | | | | | | | | | | | | | | | + | | | |
| | | *Regimbartia condicta?* sp. adults | | | | | | | | | | | | | | | | | | + | + | | |
| | Hydrophilidae: Hydrophilinae: Chaetarthriini | *Amphiops globus* adults | | | | | + | | | | | | | | | | | | | | + | | |
| | | *Amphiops* sp. 1 larvae | | | | | + | | | | | | | | | | | | | | | | |
| | | *Amphiops* sp. 2 larvae | | | | | | | | | | | | | | | | | | | | + | |
| | Hydrophilidae: Hydrophilinae: Hydrophilini | *Enochrus* sp. adults | | | | | | + | | | + | | | | | | | | | | + | | |
| | | *Enochrus* sp. larvae | | | | | + | + | | | | | | | | | | | | | | | |
| | | *Helochares* sp. adults | | | | | | | | | | | | + | | | | | | | + | | |
| | | *Hydrochara* sp. larvae | | | | | | | | | | | | | | | + | | | | | | |
| | | *Hydrophilini* sp. larvae | | | | | | | | | | | + | | | | | | | + | + | | |
| | Hydrophilidae: Hydrophilinae: Laccobiini | *Laccobius* sp. adults | | | | | | | | | | | | | | | | | | | | | |
| | | *Laccobius* sp. larvae | | | + | | + | + | | | | | | | | | | | | | + | | |
| | Scarabaeidae? | *Scarabaeidae?* sp. adults | | + | | | | | | | | | | | | | | | | | | | |
| | Spercheidae | *Spercheus ?cerisyi* adults | | | + | | | + | | | | | + | | | | | | | | | | |
| | | *Spercheus ?cerisyi* larvae | | | | | | | | | | | | | | | | | | | | | |
| | Staphylinidae | Staphylinidae sp. adults | | | | + | | | | | | | | | | | | | | | + | + | |
| | Scirtidae | Scirtidae sp. larvae | | | | | | | | | | + | | | | | | | | | | | |
| | Haliplidae | *Haliplus* sp. adults | | | | | + | | | | | | | | | | | | | | | | + |
| | | *Haliplus* sp. larvae | | | | | | | | | | | | | | | | | | | | | + |
| | Noteridae | *Hydrocanthus (Sternocanthus)* sp. | | | | | | | | | | | | | | | | | | | + | | |
| | Unspecified | Coleoptera spp. | + | | | | + | + | | | | | + | | | | | | | + | + | | |
| Diptera | Chironomidae | Chironomidae spp. adults | | | + | | | | | | | | | | | | + | | | | | | |
| | Chironomidae: Chironominae: Chironomini | *Chironomus* sp. larvae | | | + | + | | + | + | + | + | + | | | | | | | | | | | |
| | | *Chironomus* sp. pupae | + | + | | | | | | | | | | | | | | | | | | | |
| | | *Polypedilum* sp. larvae | + | + | + | | + | + | + | | | + | | | | | | | | | + | + | + |
| | | *Polypedilum?* sp. pupae | + | | | | | | | | | | | | | | | | | | | | |
| | Chironomidae: Chironominae: Tanytarsini | *Cladotanytarsus* sp. larvae | | | | | | | + | | | | | | | | | | | | | | |
| | | *Tanytarsus* sp. 1 larvae | | | + | | | | | | | + | | | | | | | | | + | | |

| Group/Order | Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1625 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | *1647* | 1655 | 683 | *1699* | *789a* | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Tanytarsus* sp. 2 larvae | | | | | | | | + | + | | | | | | | | | | | | |
| Diptera | Chironomidae: Orthocladinae | *Cricotopus* sp. larvae | | | | + | | | | | | | | | | | + | | | | | | |
| | | *Nanocladius* sp. larvae | | | | | + | | | | + | | | | | | | | | | | | |
| | | *Nanocladius* sp. pupae | | | | | + | | | | | | | | | | | | | | | | |
| | | *Parakiefferiella?* sp. larvae | | | + | | | | | | | | | | | | | | | | | | |
| | Chironomidae: Tanypodinae | *Ablabesmyia* sp. larvae | | | | | | | | | | | | | | | | | | | | | |
| | | *Ablabesmyia* sp. pupae | | | | | | | | | | | | | | | | | | | | | |
| | | *Macropelopia* sp. larvae | | | | | | | | | | | | | | | | | | | | | |
| | | *Paramerina* sp. larvae | | | | | | | | | | | | | | | | | | | | | |
| | | *Paramerina* sp. pupae | | | | | | | | | | | | | | | | | | | + | | |
| | | *Tanypus?* sp. pupae | | | | | | | | | | | | | | | | | | | | | |
| | Culicidae: Anophelinae | *Anopheles* sp. larvae | | | | | + | | | | | | | | | | | | | | | | |
| | | *Anopheles* sp. pupae | | | | | + | | | | | | | | | | | | | | | | |
| | Culicidae: Culicinae | *Aedes* sp. larvae | | | | | | + | | | | + | | | | | | | | | | | |
| | | *Culex* sp. larvae | | | | | | + | | | | + | | | | | | | | | | | |
| | | *Culex* sp. pupae | | | | | | + | | | | | | | | | | | | | | | |
| | | *Culicinae* spp. adults | | + | + | | | | | | | | + | | | | | | | + | | | |
| | Dixidae | *Dixella ?harrisoni* pupae | | | + | + | | | | | | | | | | | | | | | | | |
| | | *Dixella harrisoni* larvae | | | + | + | + | | | | | | + | | | | | | | | | + | |
| | Stratiomyidae: Stratiomyinae | *Odontomyia?* sp. | | | | + | + | | | | | + | | | | | | | | | | | |
| | Tipulidae: Limoniinae | *c. f. Gonomyia* sp. larvae | | | + | | | | | | | | | | | | | | | | | | |
| | | *Erioptera* sp. larvae | | | | | + | | | | | | | | | | | | | | | | |
| | | *Limnophila* sp. pupae | | | | + | | | | | | | | | | | | | | | | | |
| | | *Limonia* sp. larvae | | | | | | | | | | + | | | | | | | | | | | |
| | Chaoboridae | *Chaoborus (Sayomyia) microstictus* larvae | | | | | | | | | | + | | | | | | | | | + | + | + |
| | | *Chaoborus (Sayomyia) microstictus* pupae | | | | | | | | | | + | | | | | | | | | | | |
| | Unspecified | Diptera spp. adults | | | | + | | | | | | | | | | | | | | + | | | |
| Ephemeroptera | Baetidae | *Cloeon* spp. | + | + | + | | + | + | + | | + | + | + | | | | + | | | + | + | + | + |
| Hemiptera | Belastomatidae: Belastomatinae | *Appasus* sp. | | | | | + | | | | + | | + | | | | | | | + | + | + | + |
| | | Belastomatinae sp. | | | | | + | + | | | | | | | | | | | | | | | |
| | Circopidae | Circopidae sp. | + | | | | | | | | | | | | | | | | | | | | |
| | Corixidae: Corixinae | Corixinae spp. | | | | | | | + | | | | + | | | | | | | + | | | |
| | | *Sigara* sp. | + | + | + | | + | + | | + | + | | | | | | + | | | + | + | + | + |
| | Corixidae: Micronectinae | *Micronecta* sp. | | | | | | | | | | | | | | | | | | | + | + | + |
| | Gerridae: Gerrinae | *Gerris swakopensis* | | | + | | + | | | | | | + | | | | + | | | | | + | |
| | | *Neogerris severeni* | | | | | | | | | | | | | | | | | | + | | | |

| Group/Order | Family | Taxon | 1593 | 1595 | 1596 | 1624 | 1625 | 1626 | 1627 | 1641a | 1641b | 326 | 329 | 1344 | *1647* | 1655 | 683 | *1699* | *789a* | 790b | 910 | 944 | 947 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hydrometridae | *Hydrometra* sp. | | | | | + | | | | | | | | | | | | | | | | |
| | Nepidae: Ranatrinae | *Ranatra* sp. | | | | | | | | | | | | | | | | | | | | | |
| | Notonectidae: Anisopinae | *Anisops* sp. | + | + | + | | + | + | + | | + | | + | | | | | | | + | | + | |
| | Notonectidae: Notonectinae: Notonectini | *Enithares* sp. | | | | | | | | | | | | | | | + | | | | + | + | + |
| | | Notonectini sp. | | | | | | | | | | | | | | | | | | | + | | |
| | Pleidae | *Plea* sp. | | | | | | | | | | | | | | | | | | | + | + | + |
| | Veliidae: Veliinae | *Angilia* sp. | | | | | | | | | | | | | | | | | | + | | | |
| | Notonectidae | *Notonectidae* sp. | | | | | | | | | | | + | | | | | | | | | | |
| | Mesoveliidae | *Mesovelia vittigera* | | | | | | | | | | | | | | | | | | | + | | |
| | Unspecified | Hemiptera spp. adults | | | | + | | + | + | | | | + | | | | | | | | + | | |
| Lepidoptera | Crambridae: Nymphulinae | *Nymphula* sp. | | | | | | | | | | | | | | | | | | | | + | |
| | Unspecified | Lepidoptera sp. | | | | | | | | | | | + | | | | | | | | | | |
| Odonata: Anisoptera | Aeshnidae | *Aeshna minuscula/subpupillata* | | | + | + | | | | | | | | | | | | | | | | | |
| | | *Anax* sp. | | | | | | | | | | + | | | | | | | | | + | + | + |
| | Libellulidae | *Crocothemis* sp. | | | | + | | | | | | | | | | | | | | | | | |
| | | *Diplacodes ?lefebvrii* | + | + | + | | + | + | + | + | + | | | | | | + | | | | | + | |
| | | Libellulidae sp. | | | | | + | | | | | | | | | | | | | | | | |
| | | *Orthetrum* sp. | | | | | | | | | | | | | | | | | | | | | |
| | | *Pantala* sp. | | | | | | | | | | | | | | | | | | | + | | |
| | | *Tetrathemis ?polleni* | | | + | | | | | + | | | | | | | | | | | | | |
| Odonata: Zygoptera | Coenagrionidae | Coenagrionidae sp. | + | | | | | | | | | | | | | | | | | | | | |
| | | *Enallagma* sp. | | | + | | | | | | | | + | | | | | | | | + | + | |
| | | *Ischnura senegalensis?* | + | + | + | + | + | + | | + | + | + | + | | | | + | | | | + | + | + |
| | Lestidae | *Lestes plagiatus/virgatus* | | | | | | | | | | | | | | | | | | | + | | |
| Trichoptera | Hydroptilidae | *Oxyethira velocipes* | | | | | | | | | | | + | | | | + | | | | + | | |

**Table C.7 Macroinvertebrate species list, presence/absence by site. Sites from areas 5, 6, 7 and 8 are represented here, see Table 4.2 in text for codes. Sites in italics were used in sediment hatching experiments only, as there was no habitat to sample in the field.**

| Group/Order | Family | Taxon | *1016* | *1017* | *1019* | *1648* | 743 | 1675 | *1679* | 749 | 1310 | *1311* | 1359 | 1650 | *1651* | 1380 | 1381 | 1692 | 1382a | 1382b | 1382c | 689a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nematoda | Unspecified | Nematoda spp. | | | | | | | | | | | | | | | | | | | | |
| Oligochaeta | Lumbriculidae | *Lumbriculus variegatus* | | | | | + | | | + | | | | | | | | | + | + | + | |
| Oligochaeta | Naididae | *Nais* sp. | | | | | | | | | | | | | | | | | | | | |
| Hirudinae | Glossiphoniidae | *Alboglossiphonia conjugata* | | | | | | | | | | | | | | | | | | | | |
| | | *Alboglossiphonia macrorhyncha* | | | | | | | | | | | | | | | | | | | | |
| | | *Helobdella conifera* | | | | | | | | | + | | | | | | | | | | | |
| | | *Helobdella stagnalis* | | | | | + | | | | + | | + | | | | | | | | | |
| Anostraca | Branchiopodidae | Branchiopodidae sp. | + | | | + | | | | | | + | + | | + | | | | | | | |
| | | *Branchipodopsis hodgsoni* | | | | | | | | | | | | | | | | | | | | |
| | Streptocephalidae | *Streptocephalus dendyi* | | | | | | | | + | | | | | | | | | | | | |
| | | *Streptocephalus* sp. | | | + | | | | | | + | | | | | | | | | | | + |
| | Unspecified | Anostraca sp. | | | | | | | | | | + | | | | | | | | | | |
| Conchostraca | Leptestheriidae | *Leptestheria rubidgei* | | + | + | | | | | | | | | | | | | | | | | + |
| | | *Leptestheria* sp. | + | + | + | | | | | | + | + | | | | | | | | | | |
| | | *Leptestheriidae brevirostis* | | | + | | | | | | | | | | | | | | | | | |
| | Unspecified | Conchostraca sp. | | | | | | | | | | | | | | | | | | | | |
| Notostraca | Triopsidae | *Triops granarius* | + | + | + | + | | | | | + | + | | | | | | | | | | + |
| Cladocera | Chydoridae | Chydoridae sp. | | | + | | | | | | | | | | | | | | | | | |
| | | *Eurycercus gr. lamellatus* | | | | | | | | | | | | | | | | | | | | |
| | Daphniidae | *Daphnia (Ctenodaphnia) barbata* | | | | | | | | | | | | | | | | | | | | |
| | | *Daphnia (Ctenodaphnia) dolichocephala* | | | | | | | | | | | | | | | | | | | | |
| | | *Daphnia laevis* | | | | | + | | | | | | | | | | | | | | | |
| | | *Daphnia obtusa* | | | | | | | | | | | | | | | | | | | | |
| | | *Daphnia pulex* | | | | | | | | | | | | | | | | | | | | |
| | | *Daphnia* sp. | | | + | + | | | | | | | | | | | | | | | | |
| | | *Simocephalus exspinosus* | | | | | | | | | | | | | | | + | | | | | |
| | | *Simocephalus vetulus* | | | | | + | | | + | | | | | | | | | | | | |
| | Unspecified | Cladocera sp. | | | | | | | | | | | | | | | | | | | | |
| Copopoda | Unspecified | Copepodite sp. | | | | | | | | | | | | | | | | | | | | |
| Calanoida | Diaptomidae | Diaptomidae spp. | | | | | | | + | | + | | | | | | | | | | | |
| Calanoida | Diaptomidae: Paradiaptominae | *Lovenula falcifera* | | | | | | | | + | | | | | | | + | | | | | |
| | | *Lovenula simplex* | | | | | | | | | | | | | | | | | | | | |
| | | *Paradiaptomus lamellatus?* | | | | | | | | + | | | | | | | | | | | | |
| | | *Paradiaptomus natalensis* | | | | | | + | | | | | | | | | | | | | | |

| Group/Order | Family | Taxon | *1016* | *1017* | *1019* | *1648* | 743 | 1675 | *1679* | 749 | 1310 | *1311* | 1359 | 1650 | *1651* | 1380 | 1381 | 1692 | 1382a | 1382b | 1382c | 689a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Calanoida | Diaptomidae: Paradiaptominae | Paradiaptominae sp. | | | | | | | | | | | | | | | | | | | | |
| Cyclopoida | Cyclopidae | *Ectocyclops phaleratus/Paracyclops poppei* | | | | | | | | | + | | | | | | | | | | | |
| | | Cyclopidae sp. | | + | + | | | | | | | | | | | | | | | | | |
| Ostracoda | Cyprididae | Cyprididae sp. | + | | + | | | | | | + | + | | | | | | | | | | |
| | | Cyprididae sp. 1 | | | | | | + | | | | | | | | | | | | | | |
| | | *Megalocypris princeps/durbani* | | | | | | | | | | | | | | | | | | | | |
| | | *Parastenocypris?* sp. | | | | | | | | + | | | | | | + | + | | | | | |
| | | *Physocypria?* sp. | | | | | | + | | + | | | | | | | + | | | | | |
| | | *Potamocypris* sp. | | | | | | | | | | | | | | | | | | | | |
| | | *Zonocypris?* sp. 1 | | | | | | | | | | | | | | | | | | | | |
| | | Ostracoda sp. | + | + | + | + | | | + | | | | + | | | | | | | | | |
| Amphipoda | Unspecified | Amphipoda (marine) sp. | | | | | | | | | | | | | | | | | | | | |
| Decapoda | Palaemonidae | *Palaemon?* sp. | | | | | | | | | | | | | | | | | | | | |
| | Upogebiidae | *Upogenia* sp. | | | | | | | | | | | | + | | | | | | | | |
| Bivalvia | Sphaeriidae | *Sphaerium capense* | | | | | | | | | | | | | | | | | | + | | |
| Gastropoda | Ancylidae | *Ferrissia* sp. | | | | | | | | | | | | | | | | | | | | |
| | Cochlicellidae | *Cochlicella barbara* | | | | | | | | | | | | | | | | | | | | |
| | Helicidae | *Eobania vermiculata* | | | | | | | | | | | | | | | | | | | | |
| | | *Theba pisana* | | | | | | | | | | | | | | | | | | | | |
| | Lymnaeidae | *Lymnaea columella* | | | | | + | | | + | | | | | | | | | | | | |
| | Physidae: Physinae: Physellini | *Physella acuta* | | | | | | | | | | | + | | | | | | | | | |
| | Planorbidae: Bulininae | *Bulinus tropicus* | | | | | | | | | | | | | | | + | | | | | |
| | Unspecified | Gastropoda | | | | | | | | | | | | | | | | | | | | |
| | | terretrial snail | | | | | | | | | | | | | | | | | | | | |
| Acarina | Unspecified | Acarina sp. | | | | | | | | + | | | | | | | + | | | | | |
| Araneae | Araneidae: Araneinae | Araneinae sp. | | | | | | | | | | | | | | | + | | | | | |
| | Eresidae | Eresidae sp. | | | | | | | | | | | | | | | | | | | | |
| | Lycosidae | Lycosidae sp. | | | | | | | | | | | | | | | | | | | | |
| | | *Wadicosa?* sp. | | | | | | | | | | | | | | | | | | | | |
| | Pisauridae: Thalassinae | *Thalassius ?massajae* | | | | | | + | | | | | | | | | | + | | | | |
| | Segestriidae | *Ariadna?* sp. | | | | | | | | | | | | | | | | | | | | |
| | Tetragnathidae | *Tetragnatha vermiformis* | | | | | | | | | | | | | | | | | | | | |
| | | *Tetrathemis ?polleni* | | | | | | | | | | | | | | | | | | | | |
| | Unspecified | Araneae spp. | | | | | | + | | | | | | | | | | | | | | |
| Collembola | Poduridae | *Podura* sp. | | | | | | | | | | | | | | | | | | | | |
| Coleoptera | Curculionidae: Bagoini | *Bagoini* sp. larvae | | | | | | | | | | | | | | | | | | | | |

| Group/Order | Family | Taxon | *1016* | *1017* | *1019* | *1648* | 743 | 1675 | *1679* | 749 | 1310 | *1311* | 1359 | 1650 | *1651* | 1380 | 1381 | 1692 | 1382a | 1382b | 1382c | 689a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coleoptera | Curculionidae: Bagoini | *Bagous ?humeralis* adults | | | | | | | | | | | | | | | + | | | | | |
| | Dytiscidae: Colymbetinae: Colymbetini | *Rhantus* sp. adults | | | | | | + | | | | | | | | | | | | | | |
| | | *Rhantus* sp. larvae | | | | | | + | | | | | | | | | + | | | | | |
| | Dytiscidae: Copelatinae: Copelatini | *Copelatus* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Dytiscidae: Dytiscinae: Cybistrini | *Cybister* sp. adults | | | | | | | | | | | | | | | | | | | | |
| | | *Cybister* sp. larvae | | | | | | | | | | | | | | | + | | | | | |
| | Dytiscidae: Dytiscinae: Hydaticini | *Hydaticus* (Guignotites) sp. 1 larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Hydaticus* (Guignotites) sp. 2 larvae | | | | | | + | | | | | | | | | | | | | | |
| | | *Hydaticus* (Guignotites) sp. adults | | | | | | | | | | | | | | | | | | | | |
| | Dytiscidae: Hydroporinae: Bidessini | *Hydroglyphus* sp. adults | | | | | | + | | | | | | | | | | | | | | |
| | | *Leiodytes* sp. 1 adults | | | | | | | | | | | | | | | | | | | | |
| | | *Leiodytes* sp. 2 adults | | | | | | | | | | | | | | | | | | | | |
| | | *Uvarus/Hydroglyphus?* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Dytiscidae: Hydroporinae: Hydroporini | *Canthyporus* sp. adults | | | | | | | | | | | | | | | | | | | | |
| | Dytiscidae: Hydroporinae: Hydrovatini | *Hydrovatus* sp. adults | | | | | | | | | | | | | | | | | | | | |
| | | *Hydrovatus* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Dytiscidae: Hydroporinae: Hygrotini | *Herophydrus* sp. adults | | | | | | + | | | | | | | | | + | | | | | |
| | | *Herophydrus* sp. larvae | | | | | | + | | | | | | | | | + | | | | | |
| | Dytiscidae: Hydroporinae: Hyphydrini | *?Hydropeplus trimaculatus* larvae | | | | | | + | | | | | | | | | | | | | | |
| | | *Coelhydrus brevicollis* adults | | | | | | | | | | | | | | | | | | | | |
| | | *Hydropeplus trimaculatus* adults | | | | | | + | | | | | | | | | | | | | | |
| | | Hyphydrini sp. larvae | | | | | | | | + | | | | | | | + | | | | | |
| | | *Hyphydrus* sp. adults | | | | | + | | | | | | | | | | | | | | | |
| | Dytiscidae: Laccophilinae: Laccophilini | *Laccophilus* sp. adults | | | | | + | + | | | | | | | | | + | | | | | |
| | | *Laccophilus* sp. larvae | | | | | | | | | | | | | | | + | | | | | |
| | Gyrinidae: Gyrininae: Gyrinini | *Aulonogyrus* sp. adults | | | | | + | | | | | | | | | | | | | | | |
| | | *Gyrinus* (s.str.) *vcinus* adults | | | | | | | | | | | | | | | | | | | | |
| | | *Gyrinus* (s.str.) *vcinus* larvae | | | | | | | | | | | | | | | + | | | | | |
| | Gyrinidae: Gyrininae: Orectochilini | *Orectogyrus* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Halipidae | *Haliplus* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Helophoridae | *Helophorus (Rhopalohelophorus) aethiops* adults | | | | | | + | | | | | | | | | | | | | | |
| | Hydraenidae: Ochthebiinae: Ochthebiini | *Ochthebius* sp. adults | | | | | | | | | + | | | | | | | | | | | |
| | Hydrochidae | *Hydrochus* sp. adults | | | | | + | | | | | | | | | | | | | | | + |
| | Hydrophilidae: Hydrophilinae: Anacaenini | *Anacaena* sp. adults | | | | | | | | | | | | | | | | | | | | |
| Coleoptera | Hydrophilidae: Hydrophilinae: Berosini | *Berosus* sp. 1 adults | | | | | | | | | | | | | | + | | | | | | |

| Group/Order | Family | Taxon | *1016* | *1017* | *1019* | *1648* | 743 | 1675 | *1679* | 749 | 1310 | *1311* | 1359 | 1650 | *1651* | 1380 | 1381 | 1692 | 1382a | 1382b | 1382c | 689a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Berosus* sp. 2 adults | | | | | | | | | | | | + | | | | | | | | |
| | Hydrophilidae: Hydrophilinae: Berosini | *Berosus?* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Regimbartia condicta?* sp. adults | | | | | | | | | | | | | | | + | | | | | |
| | Hydrophilidae: Hydrophilinae: Chaetarthriini | *Amphiops globus* adults | | | | | + | | | + | | | | | | | | | | | | |
| | | *Amphiops* sp. 1 larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Amphiops* sp. 2 larvae | | | | | | | | + | | | | | | | | | | | | |
| | Hydrophilidae: Hydrophilinae: Hydrophilini | *Enochrus* sp. adults | | | | | | | | | | | | | | | | | | | | |
| | | *Enochrus* sp. larvae | | | | | | | | | | | | | | | | + | | | | |
| | | *Helochares* sp. adults | | | | | | | | | | | | | | | | | | | | |
| | | *Hydrochara* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Hydrophilini* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Hydrophilidae: Hydrophilinae: Laccobiini | *Laccobius* sp. adults | | | | | | | | | + | | | | | | | | | | | |
| | | *Laccobius* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Scarabaeidae? | Scarabaeidae? sp. adults | | | | | | | | | | | | | | | | | | | | |
| | Spercheidae | *Spercheus ?cerisyi* adults | | | | | + | + | | + | | | | | | | + | | | | | |
| | Spercheidae | *Spercheus ?cerisyi* larvae | | | | | | | | + | | | | | | | | + | | | | |
| | Staphylinidae | Staphylinidae sp. adults | | | | | | | | | | | | | | | | | | | | |
| | Scirtidae | Scirtidae sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Haliplidae | *Haliplus* sp. adults | | | | | + | | | | | | | | | | | | | | | |
| | | *Haliplus* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Noteridae | *Hydrocanthus (Sternocanthus)* sp. | | | | | | | | | | | | | | | | | | | | |
| | Unspecified | Coleoptera spp. | | | | | | + | | + | | | | | | | | | | | | |
| Diptera | Chironomidae | Chironomidae spp. adults | | | | | | | | | | | | | | | | | | | | |
| | Chironomidae: Chironominae: Chironomini | *Chironomus* sp. larvae | | | | | | | | | | | | | | | | + | + | | | |
| | | *Chironomus* sp. pupae | | | | | | | | | | | | | | | | | | | | |
| | | *Polypedilum* sp. larvae | | | | | + | | | + | | | + | | | | + | + | | | | |
| | | *Polypedilum?* sp. pupae | | | | | | | | | | | | | | | | | | | | |
| | Chironomidae: Chironominae: Tanytarsini | *Cladotanytarsus* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Tanytarsus* sp. 1 larvae | | | | | + | | | | | | | | | | | | | | | |
| | | *Tanytarsus* sp. 2 larvae | | | | | | | | | | | | | | | | | + | | | |
| | Chironomidae: Orthocladinae | *Cricotopus* sp. larvae | | | | | + | + | | | | | | | | | + | | | | | |
| Diptera | Chironomidae: Orthocladinae | *Nanocladius* sp. larvae | | | | | | + | | | | | | | | | | | | | | |
| | | *Nanocladius* sp. pupae | | | | | | | | | | | | | | | | | | | | |
| | | *Parakiefferiella?* sp. larvae | | | | | | | | | | | | | | | | | | | | |

| Group/Order | Family | Taxon | *1016* | *1017* | *1019* | *1648* | 743 | 1675 | *1679* | 749 | 1310 | *1311* | 1359 | 1650 | *1651* | 1380 | 1381 | 1692 | 1382a | 1382b | 1382c | 689a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Chironomidae: Tanypodinae | *Ablabesmyia* sp. larvae | | | | | | | | | | | | | | | | | + | | | |
| | | *Ablabesmyia* sp. pupae | | | | | | | | | | | | | | | | | + | | | |
| | | *Macropelopia* sp. larvae | | | | | + | | | | | | | | | | | | + | | | |
| | | *Paramerina* sp. larvae | | | | | | | | | | | + | | | | | | | | | |
| | | *Paramerina* sp. pupae | | | | | | | | | | | | | | | | | | | | |
| | | *Tanypus?* sp. pupae | | | | | | | | | | | | | | | | | + | | | |
| | Culicidae: Anophelinae | *Anopheles* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Anopheles* sp. pupae | | | | | | | | | | | | | | | | | | | | |
| | Culicidae: Culicinae | *Aedes* sp. larvae | | | | | | | | | | | | | | | | | | | | + |
| | | *Culex* sp. larvae | | | | | | + | | | | | + | | | | | + | | | | |
| | | *Culex* sp. pupae | | | | | | | | | | | | | | | | | + | | | |
| | | *Culicinae* spp. adults | | | | | | | | | | | | | | | | | | | | |
| | Dixidae | *Dixella ?harrisoni* pupae | | | | | | | | | | | | | | | | | | | | |
| | | *Dixella harrisoni* larvae | | | | | | | | | | | | | | | | | | | | |
| | Stratiomyidae: Stratiomyinae | *Odontomyia?* sp. | | | | | | | | | | | | | | | | | | | | |
| | Tipulidae: Limoniinae | *c. f. Gonomyia* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Erioptera* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Limnophila* sp. pupae | | | | | | | | | | | | | | | | | | | | |
| | | *Limonia* sp. larvae | | | | | | | | | | | | | | | | | | | | |
| | Chaoboridae | *Chaoborus (Sayomyia) microstictus* larvae | | | | | | | | | | | | | | | | | | | | |
| | | *Chaoborus (Sayomyia) microstictus* pupae | | | | | | | | | | | | | | | | | | | | |
| Diptera | Unspecified | Diptera spp. adults | | | | | | | | | | | | | | | | | | | | |
| Ephemeroptera | Baetidae | *Cloeon* spp. | | | | | + | + | | + | + | | + | | | + | | + | | | | |
| Hemiptera | Belastomatidae: Belastomatinae | *Appasus* sp. | | | | | + | | | | | | | | | | | | | | | |
| | | Belastomatinae sp. | | | | | | | | | | | | | | | + | | | | | |
| | Circopidae | Circopidae sp. | | | | | | | | | | | | | | | | | | | | |
| | Corixidae: Corixinae | Corixinae spp. | | | | | | | | | | | + | | | | | | | | | |
| | | *Sigara* sp. | | | | | + | + | | + | + | | + | | | + | + | + | | | | |
| | Corixidae: Micronectinae | *Micronecta* sp. | | | | | | | | | + | | | | | | | | | | | |
| | Gerridae: Gerrinae | *Gerris swakopensis* | | | | | | | | | | | | | | | + | | | | | |
| | | *Neogerris severeni* | | | | | | | | | | | | | | | | | | | | |
| | Hydrometridae | *Hydrometra* sp. | | | | | | | | | | | | | | | | | | | | |
| | Nepidae: Ranatrinae | *Ranatra* sp. | | | | | | | | | | | | | | | + | | | | | |
| | Notonectidae: Anisopinae | *Anisops* sp. | | | | | + | | | + | + | | + | | | + | + | | | | | |
| Hemiptera | Notonectidae: Notonectinae: Notonectini | *Enithares* sp. | | | | | | | | | | | | | | | | | | | | |
| | | Notonectini sp. | | | | | | | | | | | | | | | | | | | | |

| Group/Order | Family | Taxon | *1016* | *1017* | *1019* | *1648* | 743 | 1675 | *1679* | 749 | 1310 | *1311* | 1359 | 1650 | *1651* | 1380 | 1381 | 1692 | 1382a | 1382b | 1382c | 689a |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pleidae | *Plea* sp. | | | | | | + | | | | | | | | | | | | | | |
| | Veliidae: Veliinae | *Angilia* sp. | | | | | | | | | | | | | | | | | | | | |
| | Notonectidae | Notonectidae sp. | | | | | | | | | | | | | | | | | | | | |
| | Mesoveliidae | *Mesovelia vittigera* | | | | | | | | | | | | | | | | | | | | |
| | Unspecified | Hemiptera spp. adults | | | | | | | | | | | | | | | | | | | | |
| Lepidoptera | Crambridae: Nymphulinae | *Nymphula* sp. | | | | | + | | | | | | | | | | | | | | | |
| | Unspecified | Lepidoptera sp. | | | | | | | | | | | | | | | | | | | | |
| Odonata: Anisoptera | Aeshnidae | *Aeshna minuscula/subpupillata* | | | | | + | | | | | | | | | | | | | | | |
| | | *Anax* sp. | | | | | + | | | | | | | | | | | | | | | |
| | Libellulidae | *Crocothemis* sp. | | | | | | | | | | | | | | | | | | | | |
| | | *Diplacodes ?lefebvrii* | | | | | | | | | | | + | | | | + | | | | | |
| | | Libellulidae sp. | | | | | | | | | | | | | | | | | | | | |
| | | *Orthetrum* sp. | | | | | + | | | | + | | | | | | | | + | | | |
| | | *Pantala* sp. | | | | | | | | | | | | | | | | | | | | |
| | | *Tetrathemis ?polleni* | | | | | | | | | | | | | | | | | | | | |
| Odonata: Zygoptera | Coenagrionidae | *Coenagrionidae* sp. | | | | | | | | | | | | | | | | + | | | | |
| | | *Enallagma* sp. | | | | | | | | | | | | | | | | | | | | |
| | | *Ischnura senegalensis?* | | | | | + | | | + | | | + | | | + | | | | | | |
| | Lestidae | *Lestes plagiatus/virgatus* | | | | | + | | | + | | | | | | | + | | | | | |
| Trichoptera | Hydroptilidae | *Oxyethira velocipes* | | | | | | | | | | | | | | | | | | | | |

**Appendix D**

Metadata report that applies to the NMB wetland database created by this project. This report has been done according to SANBI guidelines and the data will be available on the SANBI BGIS website.

**Table D.1 Metadata report for the NMB wetland database.**

# South African National Biodiversity Institute

## GIS METADATA: DETAILED REPORT

| **FILE NAME: NMBM_wetlands_WGS84TM25_Nov2014.shp** | |
|---|---|
| **Full Path** | |
| **Description (detailed)** | ArcGIS 10 was used to delineate the ephemeral/temporary wetland types in NMB up to Level 4 of the NWCS (Ollis *et al.* 2013). Wetlands were digitized for NMB in a vector format as discrete polygon units with associated attribute data. Aerial photos obtained from the Municipality, as well as existing shape files of the national SANBI wetlands database, rivers and 2 m contours, were overlaid onto the map as guidelines for identifying wetlands. The study area (NMB) was scanned from east to west at a 1: 2500 scale. Mapping occurred at a 1:2000 m scale. |
| **Copyright** | None |
| **Data Origin** | |
| **Capture Source** | Nelson Mandela Metropolitan University |
| **Scale Digitised** | 1:2000 |
| **Date Captured** | 2012-2014 |
| **Data Copyright** | No |
| **To be** | Yes, available on BGIS |

| DATA INFORMATION AND METADATA INFORMATION | |
|---|---|
| **Owner Organisation** | NMMU |
| **Contact Person** | Brigitte Melly, Denise Schael |
| **Position of Contact Person** | PhD student, Project leader |
| **Contact Address** | Botany Department, South Campus NMMU, Admiralty Way |
| **Contact Number** | |
| **Contact Email** | brigittemelly@gmail.com; denise.schael@nmmu.ac.za |

| LEGEND PROPERTIES | |
|---|---|
| **Legend Title** | **Wetland** |
| **Feature Type** | Polygon |
| **Scale Parameters** | |

| PROJECTION | |
|---|---|
| Transverse_Mercator<br>False_Easting: 0.00000000<br>False_Northing: 0.00000000<br>Central_Meridian: 25.00000000<br>Scale_Factor: 1.00000000<br>Latitude_Of_Origin: 0.00000000<br>Linear Unit: Meter | |
| **Projection Name** | Transverse Mercator |
| **Central Meridian** | 25 |
| **Upper Parallel** | |
| **Lower Parallel** | |

| DATUM | |
|---|---|
| Geographic Coordinate System: GCS_WGS_1984<br>Datum: D_WGS_1984<br>Prime Meridian: Greenwich<br>Angular Unit: Degree | |
| **Name** | WGS 84 |
| **Semi Major Axis** | 0 |
| **Semi Minor Axis** | 0 |
| **Inverse Flattening** | 0 |

| DETAILED NOTES |
|---|
| **Purpose:**<br>No extensive research has been conducted on wetlands in NMB. This study aimed to digitize and classify wetlands in NMB. This forms part of a Water Research Commission project (K5-2181) to be published in 2015.<br><br>**Methods:**<br>In order to locate, delineate and classify wetlands to Level 4a of the Classification System a variety of data sources were used. The available maps, primary and secondary data sources for the NMB region used were: aerial photos, NMB boundary, NMB roads, 2 m contours, rivers, SANBI NFEPA wetlands.<br><br>A simple map of the study area with the relevant quaternary catchments is illustrated Figure 3.1. Wetlands within the NMB were digitised using aerial photos obtained from the Municipality as well as existing shape files of the national SANBI wetlands database. Rivers and 2 m contours were overlaid on the map as guidelines for identifying wetlands (Table 3.3). A new polygon shape file was created in order to digitise the wetlands observed. A 500 m by 500 m grid was also created to ensure scanning over the aerial photos was done in a methodical manner. The study area (NMB) was scanned from east to west at a 1: 2500 scale, overlapping at the top and bottom of the screen to confirm all areas were covered. A wetland was digitised if water was present or vegetation/contour indicators were present. Wetlands were then digitised at a scale of 1: 2000.<br><br>Field verification of the classification at Levels 3 and 4a was done as per methods outlined in Ollis *et al.* (2013). Based on the preliminary desktop classification, regions of the NMBM were targeted for verification. Wetlands that were given a certainty level of "1" and some "2" (Table 3.5) were |

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|---|
| grouped into regions and the wetlands were visited to validate the Level 3 and 4 classification.<br><br>**Available documentation:**<br><br>Full report regarding wetlands in NMB will be published by the Water Research Commission project (K5-2181) in 2015. Title of report: Ephemeral Wetlands of the Nelson Mandela Bay Metropolitan Area: Classification, Biodiversity and Management implications by Schael, Gama and Melly. |

| **ATTRIBUTE FIELDS** | | |
|---|---|---|
| **Field Name** | **Description** | **Alias** |
| ID | Wetland ID for Nelson Mandela Bay Municipality (NMBM) | Wetland ID |
| Certainty | A level of certainty of the presence of a wetland was assigned:<br><br>"1" indicated a possible wetland (contours and/or vegetation indicated the possible presence of one) CS = Low;<br><br>"2" if there were strong vegetation and contour indicators of a wetland, CS = Medium; or<br><br>"3" if there was the presence of water as well as vegetation and contour indicators, CS = High. | |
| NAT_ART | Three levels of modification were assigned:<br><br>"Natural" if the wetland illustrated no signs of man-made structures<br><br>"Modified" if the wetland illustrated some signs of man-made structures (e.g. a berm), however, there is a high possibly that wetlands in this category were existing before; or<br><br>"Artificial" for wetlands that are highly modified (e.g. dams) such that it is not possible to determine whether these wetlands existed before man-made structures were implemented. | |
| NWCS_L3 | The updated the Classification System (CS) from Ollis *et al.* (2013) was used. Level three of the classification system was added to this field which are as follows:<br><br>"Slope";<br><br>"Valley floor";<br><br>"Plain"; or<br><br>"Bench" | |
| NWCS_L4 | The updated CS from Ollis *et al.* (2013) was used. Level four of the | |

| | | |
|---|---|---|
| | classification system was added to this field which are as follows:<br>"Channel";<br>"Seep";<br>"Depression";<br>"Unchannelled valley bottom wetland";<br>"Floodplain wetland"; or<br>"Wetland Flat" | |
| SANBI_db | This field was used to indicate whether the wetland was identified in the SANBI database. The following codes were used:<br>"Y" for an identified SANBI wetland; or<br>"N" if the wetland was not digitised previously. | |
| RIV_EST | This field was used to indicate if the wetland is situated alongside a river or estuary. | |
| Comments | Any further comments on the wetland | |
| Perimeter | Perimeter of polygon | |
| AREA | Area of polygon in square metres | |
| Areakm2 | Area of polygon in square kilometres | |
| Hectares | Area of polygon in hectares | |
| X2 | X coordinate of centre of polygon | |
| Y2 | Y coordinate of centre of polygon | |

## Appendix E

Capacity building and knowledge/technology transfer for this WRC project (Project No: K5/2181).

### Capacity building

There were several opportunities for the development and training of university students and interested volunteers throughout the project. Involvement ranged from a few field trips or laboratory assistance, to data collection, management and analysis toward a university qualification or degree. Table E.1 provides a breakdown, by involvement. The duration of the involvement ranged between a few field trips to several years of full involvement. Honours projects were generally six months in duration and 3rd projects were two to three months.

In addition there was capacity building within the NMBM Environmental Section personnel, in terms of collaboration both with the Metro Open Space System coordinators, conservation planning and reserve managers.

### Knowledge dissemination and technology transfer

Direct knowledge dissemination and technology transfer of the project was done in two ways. The first was in the form of a workshop for NMB Municipality Interns and their mentors. 20 interns from the Groen Sebenza programme participated in the workshop held in August 2013, which was an introduction to wetland classification and field identification as well as an opportunity to develop awareness of the project and its outcomes. The workshop was a combination of lecture and field interaction.

The second was in the form of a public presentation to the local bird club to raise awareness of the research in April 2013, which was well received and feedback and interaction with the participants was particularly helpful in gaining more local knowledge of where different wetlands were and how best to access them, and any background history available.

In collaboration with NMBM and an UN Local Action for Biodiversity (LAB) initiative representatives of the project team participated in a workshop to make other divisions of the NMBM government structures aware of the project. Research outcomes, particularly the demarcation and typing of wetlands, fed directly into the Local Government Action Plan for the protection of wetlands drafted by the municipality with the support of LAB. This workshop also involved community groups, who were then made aware of the research being conducted and were sufficiently impressed with the number of wetlands within the municipal borders.

Results of the wetland classification and GIS cover and associated metadata were made available to both the NMBM, for their use in conservation and urban planning, and SANBI BGIS for integration into the South African National Wetland database.

Several members of the project team have presented results at national conferences between 2012 and 2014.

Further communication of the finding of this research are in the form of, this Water Research Commission report, one PhD and two MSc theses and several peer-reviewed publications based on the different aims.

**Table E.1 Student and volunteers involved in the project. The degree they were registered for at the time of involvement, the role in the project and the year/s they were involved.**

| Name | Degree/Other | Role | Year(s) |
|---|---|---|---|
| Ms Brigitte Melly | PhD – Botany | Student, data collected toward degree. | 2012-14 |
| Mr Mandla Dlamini | MSc – Geography | Student, data collected toward degree. Completed. | 2012-14 |
| Ms Jodi Lategan | MSc – Botany | Student, data collected toward degree. | 2013-14 |
| Mr Wynand Calitz | BSc Honours – Botany<br><br>BSc – Botany | Student, data collected toward degree.<br><br>3rd year laboratory and field assistance, glassware and nutrients. | 2013<br><br>2012 |
| Mr Riaan Weitz | BSc – Biological Science | Field and laboratory assistance | 2012-14 |
| Ms Nozuko Ngqiyaza | NRF Internship | Field and laboratory assistance | 2013-14 |
| Ms Sixolile Mazwane | NRF Internship | Field and laboratory assistance | 2014-15 |
| Ms Kelly Rautenbach | BSc Honours – Botany | Student, data collected toward degree. | 2012 |
| Ms Khwezi Ndaba | BSc Honours – Botany | Student, data collected toward degree. | 2013 |
| Ms Kelly Wren | BSc Honours – Botany | Student, data collected toward degree. | 2013 |
| Ms Leigh-Ann Adams | BSc – Botany | Student, data collected toward degree. | 2012 |
| Mr Gareth Greenwood | BSc – Botany | 3rd year project | 2012 |
| Mr Kevin Rous | BSc – Botany | 3rd year project | 2013 |
| Ms Lunesheri Odayar | BSc – Botany | 3rd year, laboratory assistance | 2012 |
| Ms Tracy Kooepile | BSc – Botany | 3rd year, laboratory assistance, | 2013-14 |
| Ms Erin Hillmer | BSc – Botany | 1st year, laboratory assistance | 2013 |
| Ms Lungelwa Maneli | BSc-Microbiology | 3rd year, laboratory assistance | 2012 |
| Mr M Mdutyana | | MSc student in Botany helped on several field trips. | 2012 |
| Ms Carla Hazel | | Private volunteer, member of Dendrological Society, interested in wetlands and vegetation, assisted in field work at specific sites | 2012-13 |

**Appendix F**

Summary of the MSc Thesis by Mandla Dlamini submitted through the Geosciences Department. Thesis was examined and received a passing mark for Mr Dlamini to graduate April 2015 from Nelson Mandela Metropolitan University.

## An assessment of vegetation condition of small, ephemeral wetland ecosystems in conserved and non-conserved areas of the Nelson Mandela Metropole

**Mr Mandla E Dlamini**

**ABSTRACT**

Wetlands in South Africa are increasingly under threat from agriculture and urban development, and subsequently, they are rapidly disappearing, especially smaller, more ephemeral wetlands. In response to the many threats to wetlands, South Africa has seen an increased interest in wetland research which has introduced many methods to help standardize the approach to research, management and conservation of these systems. Remote sensing can be a powerful tool to monitor changes in wetland vegetation and degradation potentially leading to a loss of wetland habitats. However, research into wetland ecosystems has focused on large systems (> 8 ha). Small wetlands (< 5 ha), by contrast, are often over looked and unprotected due to the lack of detailed inventories at a scale that is appropriate for their inclusion. The main aim of this study was to determine if Remote Sensing (RS) and Geographical Information System (GIS) techniques could detect changes in small, ephemeral wetlands within areas under different management regimes in the Nelson Mandela Bay Metropole (NMBM), across different time intervals. Furthermore, this study explores the potential of hyperspectral remote sensing for the discrimination between different plant species and to see if these differences could be detected in the same species within the areas of different levels of management.

Four SPOT satellite images, taken within a 6-year period (2006-2012), were analysed to detect land cover land changes. A post-classification change detection technique was used and land cover classes were classified using supervised classification. Proportions of dense vegetation were higher in the conservation area, and bare surfaces were higher outside the conservation area, in the surrounding Metropolitan Open Space area (MOSS).

Statistical tests were performed to compare the spectral responses of the four individual wetland sites using Normalized Difference Vegetation Index (NDVI) and Red Edge Position (REP). REP results showed significant differences between conserved and non-conserved sites ($p < 0.05$). This implies that wetland vegetation that is in less degraded condition can be spectrally discriminated from those in more degraded wetlands. Field spectroscopy and multi-temporal imagery can be

useful in studying small wetlands; however, new methods and tools need to be considered for better monitoring and evaluation of these ecosystems.

**OBJECTIVES**

Three objectives of the thesis were:

1. The comparison of wetland condition within conserved and non-conserved was achieved by using multi-temporary imagery and field hyperspectral remotely sensed data.
2. The assessment of temporal and spatial changes in wetland vegetation was achieved by analysing a series of multi-temporary images using post-classification and cross-tabulation.
3. In order to determine the spectral characteristics of the dominant wetland vegetation, statistical analyses were performed for NDVI and REP results using field spectroscopy data.

**STUDY AREA**

The study was conducted in the Hopewell Nature Conservancy, which was initially a series of farms (Goodman Matsha *pers. comm*; Stewart 2008). It was owned by the Dakian Trust and Judith Issroff Trust, which was then bought by the Issroff family during 1940's. From the mid 1960's onwards the poor quality of the soils, the lack of water for irrigation, problems of personal security, and stock theft made the land untenable for farming. Therefore, all farming operations were terminated and the area was fenced in 2009. Dr Issroff made a number of attempts through personal research and the appointment of consultants to find a productive ways to utilise the land holdings. A conservation-based development (Hopewell Conservation project) was then proposed that hoped to have environmental benefits including the removal of alien species, eradication of illegal activities (e.g. mining and dumping), rehabilitation of degraded areas that were illegally mined, and the implementation of management practices such as fire management. Just outside the boundaries of the Hopewell Conservancy is the Nelson Mandela Municipal Open Space System (NM MOSS), which is managed by the local municipality. The Hopewell Conservation area ($25^0$ 27' E and $34^0$ 27' S) is approximately 3000 ha in size and is located within the NMBM, approximately 22 km northwest from the city of Port Elizabeth in the Eastern Cape Province (Figure F.1). The Hopewell Conservation management area encompasses the Hopewell Planning domain (green shaded area, Figure F.1) and the properties immediately adjacent to it on either side of Stanford Road until the NM MOSS boundary where there are fence lines. To the north and northeast are two townships, KwaNobuhle and Booysen's Park, and to the south is the suburb of Greenbushes. Both sides of the Hopewell Conservation area experience grazing, with different levels of management. The NM MOSS is generally unregulated and consists predominately of cattle grazing from the local communities. The Hopewell conservation area is stocked with game (ungulates) and some cattle, which has some management and regulation structure.

**METHODS**

Changes in wetland land cover classes were assessed using SPOT imagery. Fieldwork was conducted to select and delineate wetland sites and to determine dominant wetland plant species.

Field spectroscopy for spectral reflectance of dominant wetland vegetation species was also done. The types of data, data sources and equipment used is summarised in Table F.1.

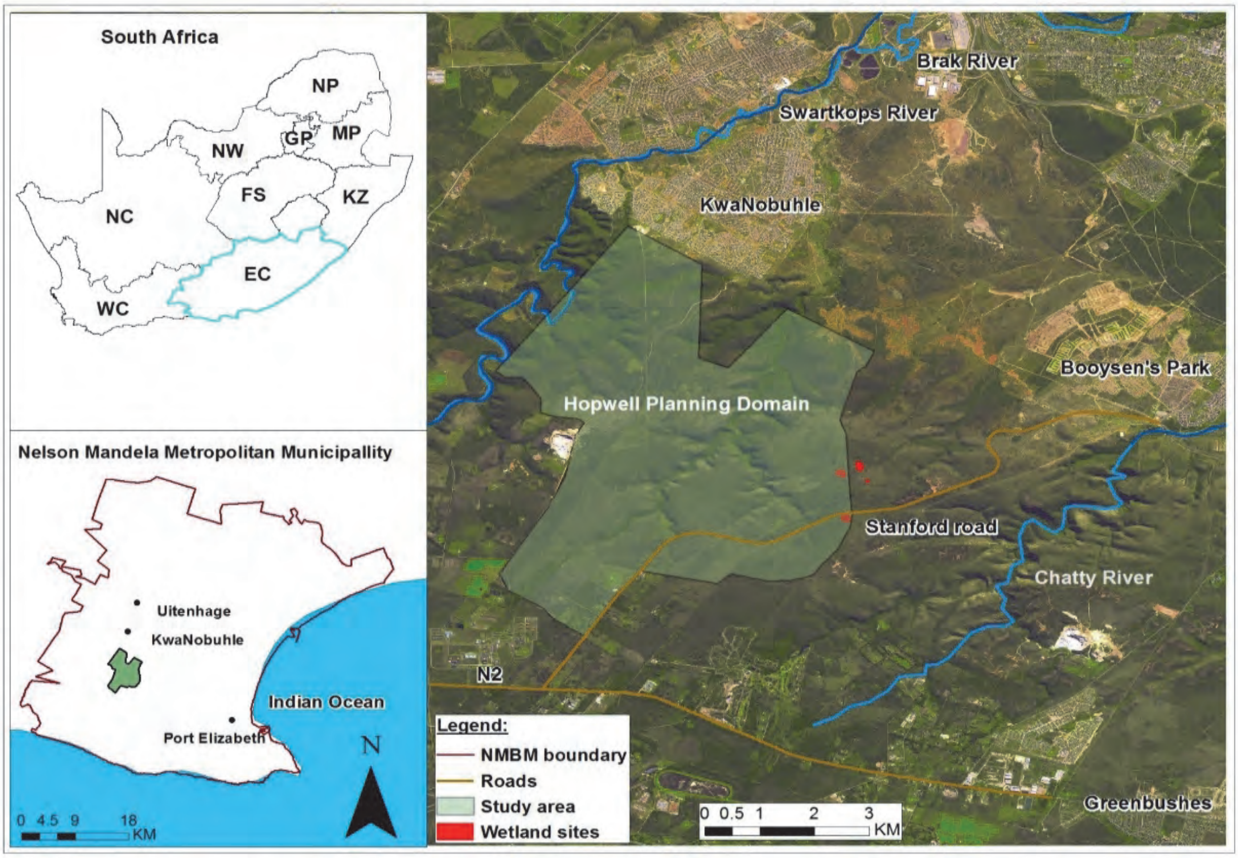
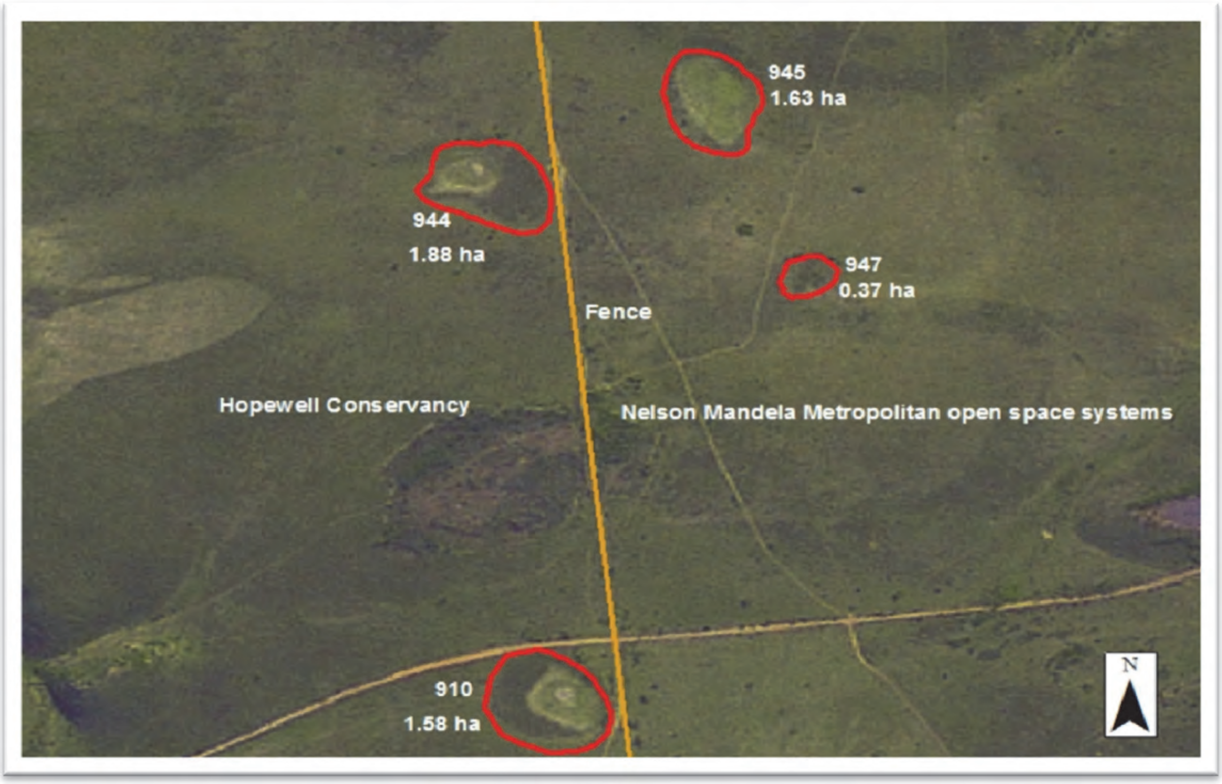



**Figure F.1 The location of the study area, Hopewell Conservancy in Port Elizabeth, Eastern Cape, South Africa. Green shading denotes the Conservancy.**

**Table F.1 Data and equipment used in this study**

| Data and equipment | Source |
|---|---|
| SPOT 5images for 2006, 2008, 2010 and 2012 | South African National Space Agency |
| Port Elizabeth rainfall data | South African Weather Services |
| SANBI shapefiles | SANBI |
| Hand held Trimble Global Positioning System (GPS) navigation device | |
| Spectral Evolution Portable Spectroradiometer (PSR) 3500 | |
| Image processing software: GIS (ArcGIS 10.2), remote sensing (IDRISI Kilimanjaro) | |
| Statistical package (STATISTICA 12) | |

Hopewell Conservancy wetlands were selected to compare with wetlands in the NM MOSS, each with different protection and management levels. These wetlands were selected because of their close proximity of one another. In this way differences between would be because of management and land use of the wetlands as opposed to natural difference due to climate, geology or vegetation. This was to establish effects of land use activities on the wetland ecosystems in the NM MOSS since they are more susceptible to human induced such as overgrazing, relative to conserved area (Hopewell Conservancy). Four wetland sites, two within the recently conserved area (910 and 944)




and two in non-conserved area (945 and 947) were selected (Figure F.2).

**Figure F.2 SPOT 5 imagery (2010) and wetland polygons for conserved and non-conserved area showing wetlands within conserved and non- conserved area (SANSA). The Seville orange line shows the fence separating the conserved and non-conserved area.**

## SUMMARY OF RESULTS

### Temporal changes in vegetation cover

Images from 2006, 2008, 2010 and 2012 were classified into four land cover classes: water, dense vegetation, sparse vegetation and bare surface. Figures F.3 and F.4 illustrate the land cover classification for the conservation area sites, 910 and 944. The classified sites from the NM MOSS, 945 and 947 are illustrated in Figures F.5 and F.6. Using long term rainfall records, the average monthly rainfall peaked in March and April; therefore, SPOT images used were captured between March and April for the years 2006, 2008, 2010 and 2012. In year 2008, April had a higher average monthly rainfall of 49 mm than all other years, whereas year 2012 had the lowest average of 13 mm. A visual inspection of the images showed 2008 to appear to have a higher proportion of dense vegetation cover in the Hopewell Conservancy sites than in the NM MOSS sites (Figures F.3 and F.4). Overall, the ANOVA showed no significant differences in vegetation cover between all sites ($p = 0.132$). The Tukey's multiple comparison test showed that the two Hopewell Conservation sites were not significantly different from each other ($p = 0.897$) and the two NM MOSS sites were not significantly different from one another ($p = 0.089$). However, the vegetation cover was significantly different between conservancy sites and NM MOSS sites ($p < 0.05$, all comparisons). In terms of visual interpretations, it can be also noted that bare surface covered a greater area in the NM MOSS sites.

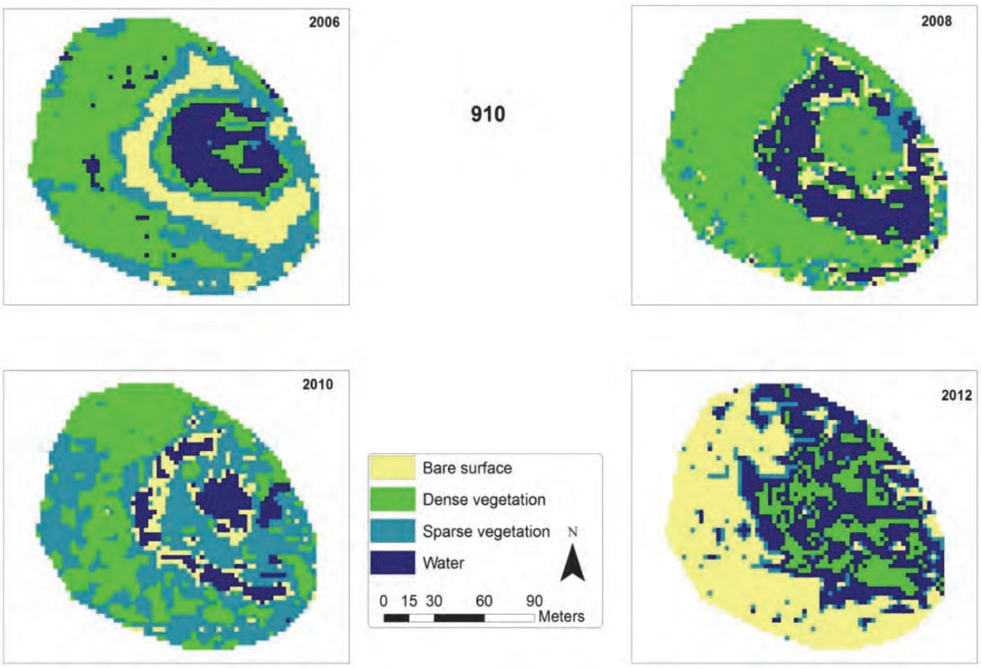



**Figure F.3 Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 910.**

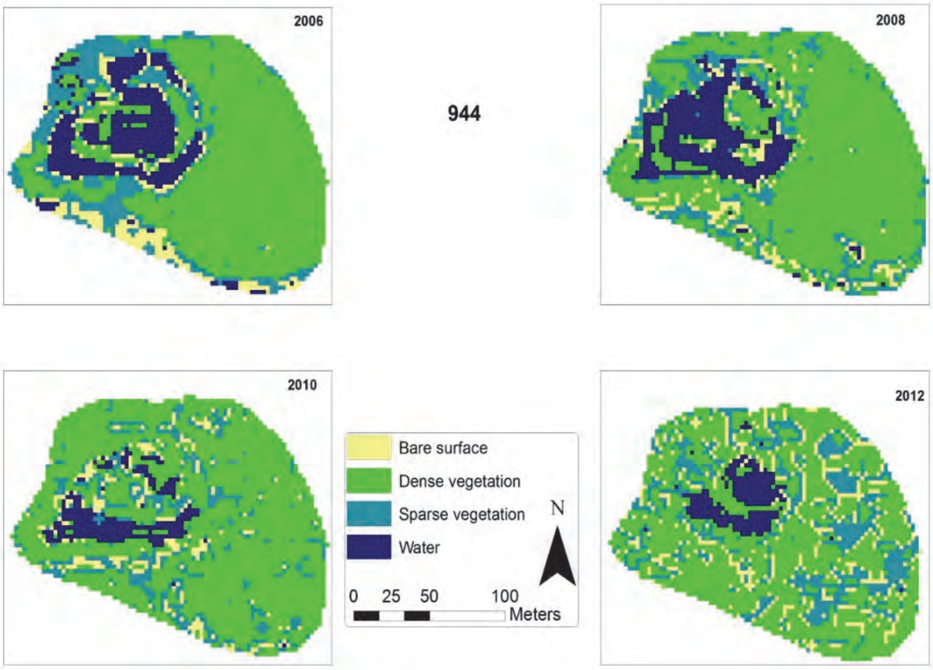



**Figure F.4** Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 944.

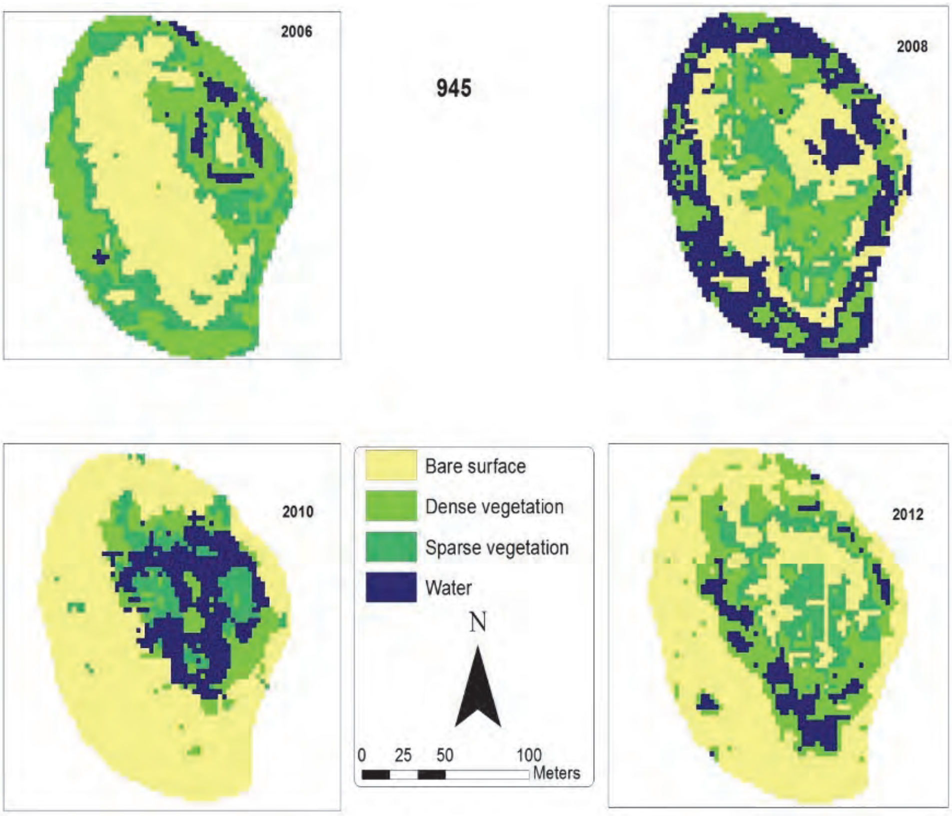



**Figure F.5** Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 945

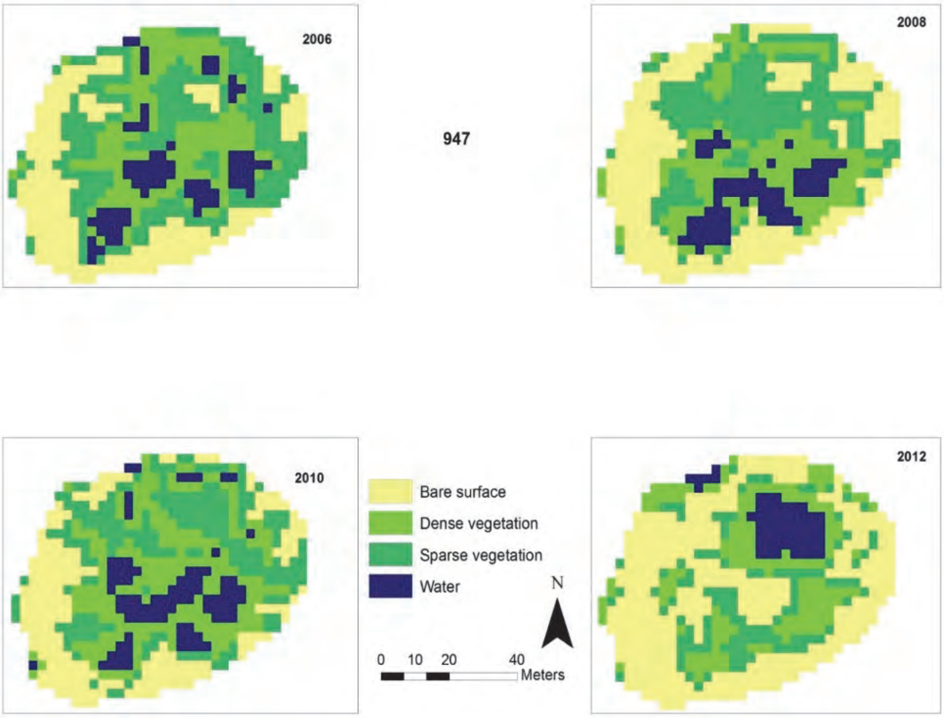



**Figure F.6 Supervised classification for 2006, 2008, 2010 and 2012 illustrating land cover classes for wetland site 947.**

**Discriminating wetland vegetation using NDVI and the REP**

REP and NDVI are indicators of chlorophyll concentration, hence, they were used to assess health in dominant vegetation species of the conserved and under-managed areas. These results correspond to the collected spectral reflectance curves. The higher the reflectance curve especially in the NIR region of the electromagnetic spectrum, the higher the NDVI, or REP value.

Ten plant species were selected based on their percentage cover. These plant species were representatives of two major plant taxa of grasses and reeds (Poaceae) and sedges (Cyperaceae). *Sporobolus africana,* a grass, was common in all four sites. *Schoenoplectus decipiens* and *Cyperus* sp., common sedges were dominant in sites 910, 945 and 947. Plant species common to all or most sites were tested using one-way ANOVA or Student's T-test, to determine if the spectral reflectance of each plant species was the same between sites. Both NDVI and REP did not show any significant differences for *S. decipiens*. *Cyperus* sp. showed a significant difference for both NDVI and REP ($p = 0.000$). *S. africana* showed a significant difference only on the REP ($p = 0.000$).

The REP and NDVI of the different plant species were compared for the two conservation areas (910 and 944) and the open space (945 and 947). One-way ANOVA for both REP and NDVI have shown that the reflectance spectra of most plant species were statistically different from one another ($p < 0.05$). Using Tukey's multiple comparison showed *Cyperus* spp. and *T. lucens* were statistically different in site 910 ($p < 0.05$); however, the other species did not differ significantly. In site 944, *M.disticha, E.limosa and T.capense* were statistically different ($p < 0.05$); however, the other plant species did not differ. In site 947, *I. sepulcralis* was significantly different from the other plant species ($p < 0.05$). However, there was no significant difference between *S. africana* and

*Cyperus* sp. In terms of the common plant species, only NDVI showed a significant different between sites 945 and 947 for *S. africana,* sites 910 and 944 did not differ significantly. Both NDVI and REP for *Cyperus* sp. showed a significant difference between sites (p=0.000).

## GENERAL CONCLUSIONS

The present study has provided an insight of the condition, spatial and temporal changes in vegetation in small scale wetlands between 2006, 2008, 2010 and 2012. This was achieved by analysing land cover between wetland sites within different management levels. From this study, it can be concluded that SPOT imagery can be used to assess and compare small, ephemeral wetland condition and land cover changes between the areas of different management regimes. It can also be concluded that REP and NDVI can discriminate spectral reflectance of wetland vegetation at canopy level; therefore, it is possible to discriminate wetland vegetation at species level using field spectroscopy.

The present study has demonstrated the vegetation changes in small, ephemeral wetlands between conservancy area and under-managed area through multispectral and hyperspectral remote sensing techniques. These techniques proved to be useful and suitable in studying small wetlands. Depending on the spatial resolution of a satellite sensor and availability of image data, multispectral remote sensing is fast and can be used to study small wetlands. Field spectroscopy on the other hand can also be useful in discriminating wetland vegetation at the species level; however, it is expensive and time consuming. Therefore, new approaches and innovative methods such as airborne and satellite hyperspectral remote sensing need to be considered for better, quick identification and evaluation of wetland vegetation species. Based on the results, it can be concluded that NMB MOSS was more degraded than the conservancy area whereby the area of bare surface was larger. This is also qualified by the plant species from the conserved area which were healthier compared to NMB MOSS. NDVI was low (average of 0.26) for plant species in wetland site 947; Site 947 was observed to be more heavily grazed. NDVI values for plant species in the conservancy area were higher, between 0.53 and 0.55, respectively, than the in NM MOSS. By implication, wetland vegetation in its less degraded condition can be spectrally discriminated, unlike the most degraded species in under-managed wetlands.