Limnoecology of the freshwater algal genera (excluding diatoms) on Marion Island (sub-Antarctic)

Wilma van Staden

B.Sc. (Botany and Microbiology) – UNISA,

B.Sc. Hons. – North-West University

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Supervisor: Dr. Sanet Janse van Vuuren (North-West University)

Co-supervisor: Prof. Valdon Smith (Stellenbosch University)

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ABSTRACT

The aim of this study was to identify the algal genera found in the different freshwater bodies on Marion Island, to relate the presence or absence of the genera to the chemistry of the water bodies and to group the genera according to their limno-chemical preferences. The Island's freshwater algal genera were also compared with genera found on other Southern Ocean islands.

The major factors influencing the chemical composition of the freshwaters of the island are the surrounding ocean and the manuring of seals and seabirds. The Western and Southern lakelets and wallows had higher mean conductivity values than most of the other water bodies. Eastern Inland lakelets, crater lakes and glacial lakes had low ion and nutrient concentrations, since they are mainly situated inland, away from bird or seal colonies. The chemical composition of wallows was influenced by manuring of seals and seabirds. The freshwaters are acidic and lakelets tend to be more acidic than glacial lakes. The lentic waters were more acidic than the stream.

In total, 106 genera, mainly belonging to Chlorophyta (60 genera; 56% of total) and Cyanophyta (29 genera; 27% of total), were found in the freshwaters on the island. Other algal divisions found were Chrysophyta (7 genera), Euglenophyta (4 genera), Pyrrophyta (2 genera) and Xanthophyta (4 genera). Mean number of genera per sample ranged from 8 (in wallows) to 16 (in Eastern Inland lakelets). Filamentous algae were present in all the samples. Abundant green algae were *Cosmarium, Klebsormidium, Mougeotia* and *Oedogonium.* The most common cyanobacteria were *Lyngbya* and *Chroococcus.* The filamentous yellow-green alga, *Tribonema,* was also common.

There were distinct differences in the algal composition between the southern, western and northern lakelets and the lakelets on the eastern side of the island. Sixty percent of the algal genera were present in waters with low conductivity values. *Trichodesmium, Sphaerocystis* and *Tolypothrix* occurred in freshwater bodies with higher conductivity values.

Variance analysis showed that 87 of the 106 genera were less likely to occur in nitrogen and phosphate containing waters. *Chlamydomonas, Prasiola, Spirogyra Trachelomonas, Tribonema, Ulothrix* and *Xanthidium* were among the genera commonly found in nitrogen and phosphate containing waters. Diversity (number of genera per sample) was negatively correlated with conductivity, PO_4-P, NH_4-N and NO_3-N. Diversity declined significantly with increasing salinity and eutrophication. Genera likely to occur in acidic waters include *Binuclearia, Chlamydomonas, Chroococcus, Cosmarium, Klebsormidium, Microspora, Oedogonium, Oocystis, Prasiola, Scenedesmus, Staurastrum, Stigeoclonium, Tetrastrum, Ulothrix, Lyngbya*, *Synura* and *Tribonema.*

Marion Island's algal flora shows a high affinity with that of Îles Kerguelen and Crozet, both located in the same biogeographical province (South Indian Ocean Province) of the sub-Antarctic than Marion Island, and a lesser affinity with islands in other sub-Antarctic provinces. Algal genera were grouped according to their limno-chemistry preferences.

KEY WORDS: ALGAE, MARION ISLAND, SOUTH INDIAN OCEAN PROVINCE, LIMNOLOGY, FRESHWATER, WATER CHEMISTRY

Die limnologie en ekologie van die varswateralge (uitsluitend diatome) van Marion-eiland (sub-Antarktika)

OPSOMMING

Die doel van hierdie studie was om die alge wat voorkom in die varswaters op Marion eiland, te identifiseer en die teenwoordigheid of afwesigheid van hierdie alge met die chemiese omgewingsveranderlikes van die varswaterbronne te vergelyk. Die inligting is gebruik om die varswaterbronne, volgens hulle algsamestelling en die alge se chemiese voorkeure, te klassifiseer. Marion-eiland se alge is ook vergelyk met alge wat gevind is op ander eilande in die Suidelike Oseaan.

Die belangrikste faktore wat die chemiese samestelling van die varswater op die eiland beïnvloed, is die omringende oseaan en die afvalprodukte van robbe en seevoëls. Die westelike-, suidelike- en voedingstofryke kusmere het hoër sout- en ioonkonsentrasies gehad as die ander waterbronne. Die oostelike binnelandse mere, kratermere en gletsermere is geneig tot laer ioon- en voedingstofkonsentrasies omdat hierdie waterbronne verder weg van die kus, seevoëls en robbekolonies geleë is. Die voedingstofryke mere by die kus se chemiese samestelling word deur robbe en seevoëls beïnvloed. Die varswaterbronne het oor die algemeen ‘n lae pH en die gletsermere is meer alkalies as die ander mere. Die stroom was meer alkalies as die stilstaande varswaterbronne.

Honderd-en-ses alggenusse, insluitende 60 Chlorophyta en 29 Cyanophyta is in die varswaterbronne op die eiland geïdentifiseer. Ander alggroepe sluit Chrysophyta (7 genusse), Euglenophyta (4 genusse), Pyrrophyta (2 genusse) en Xantophyta (4 genusse) in. Die gemiddelde aantal genusse per water eksemplaar was tussen 8 (in voedingstofryke kusmere) en 16 (in oostelike binnelandse mere). Filamentvormige alge was in al die eksemplare teenwoordig. Groenalge soos *Cosmarium, Klebsormidium, Mougeotia* en *Oedogonium* het algemeen voorgekom. Die volopste sianobakterieë was *Lyngbya* en *Chroococcus.* Die filamentvormige geelgroenalg, *Tribonema,* was ook algemeen.

Daar was ‘n duidelike verskil in die algbevolkings van die suidelike-, westelike- en noordelike mere en dié van die mere aan die oostelike kant van die eiland. Sestig persent van die alggenusse was in waters met lae ioon- en soutkonsentrasies teenwoordig. *Trichodesmium, Sphaerocystis* en *Tolypothrix* het in varswater met hoë soutkonsentrasies voorgekom. ANOVA het aangedui dat 82% van die alge geneig was om in water met lae nitraat- en fosfaatkonsentrasies voor te kom. *Chlamydomonas, Oedogonium, Prasiola, Spirogyra, Tetmemorus, Trachelomonas, Ulothrix* en *Xanthidium* was van die algemeenste alge in waters wat nitraat en fosfaat bevat. Diversiteit (aantal genusse per eksemplaar) het ‘n negatiewe korrelasie met soutkonsentrasie, en voedingstowwe soos PO_4-P, NH_4-N en NO_3-N gehad. Dit verklaar die verlaging van diversiteit tydens die verhoging van ioniese soute en voedingstofkonsentrasies in die water. *Binuclearia, Chlamydomonas, Chroococcus, Cosmarium, Klebsormidium, Microspora, Oedogonium, Oocystis, Prasiola, Scenedesmus, Staurastrum, Stigeoclonium, Tetrastrum, Ulothrix, Lyngbya, Synura* en *Tribonema* was algemeen in suur water.

Marion-eiland se algbevolking het ‘n hoë affiniteit met die alge van Île Kerguelen en Île Crozet, beide geleë in dieselfde gebied (Suid Indiese Oseaan Provinsie) as Marion-eiland, en ‘n laer affiniteit met ander eilande, geleë in ander sub-Antarktiese provinsies.

SLEUTELWOORDE: ALGE, SUID INDIESE OSEAAN PROVINSIE, LIMNOLOGIE, VARSWATER, CHEMIESE OMGEWINGSVERANDERLIKES.

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CHAPTER 1: INTRODUCTION

1.1 *The Prince Edward Islands*

The Prince Edward Islands comprise of Marion Island and Prince Edward Island and they are situated in the Southern Indian Ocean Province (SIOP) of the sub-Antarctic region. These islands are situated about 2 000 km from Africa, which is the nearest continent. Marion Island (46° 54' S, 37° 45' E; 290 km^2) is the larger of the two and has a permanent meteorological and biological research station. Prince Edward Island (46° 38' S, 37° 57' E; 70 km^2) is about 20 km to the north of Marion Island and is unoccupied. Other islands in the SIOP include Îles Crozet, Îles Kerguelen, Heard Island and McDonald Island (Figure 1.1). Other sub-Antarctic islands are Macquarie Island, which lies within in the South Pacific Ocean Province and South Georgia Island, which is situated in South Atlantic Ocean Province (Figure 1.1).

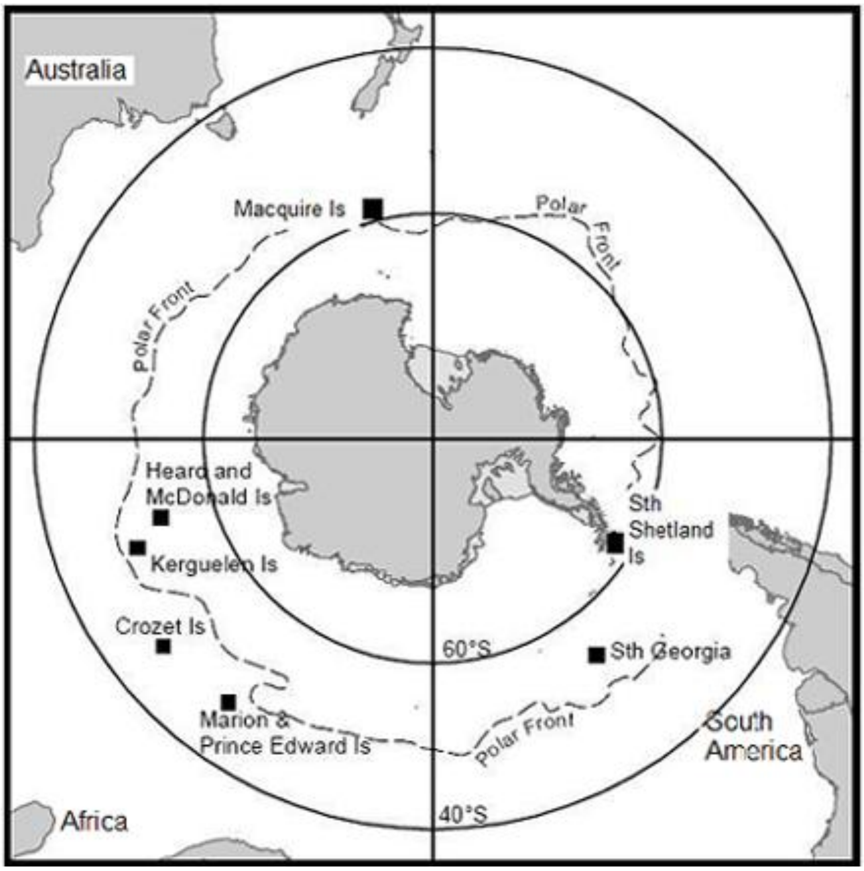

Figure 1.1 Southern hemisphere view of the earth showing the positions of the sub-Antarctic and Maritime Antarctic islands mentioned in text. Compiled by Australian Antarctic Division, Kingston, Tasmania. (ANON, 2011; http://www.doc.govt.nz.)

The sub-Antarctic climate is cold, windy and wet. Precipitation includes snow, hail and mists, but rainfall is the dominant form at low altitude regions (Schultze, 1971). The annual precipitation in the 1990s averaged 1 975 mm (Le Roux, 2008). On average ca 162 days per year receive 5 mm or more of rainfall (Le Roux & McGeoch, 2008). Relative humidity averages 80% on most days, although short periods of low humidity can occur due to Föhn winds (Schultze, 1971; Smith & Steenkamp, 1990; Le Roux, 2008). Annual mean temperature on Marion Island is 6.6 °C and there is only a 3.6 °C difference between the mean temperatures of the warmest and coldest months (Smith, 2002).

1.2 *Classification of Marion Island's freshwater bodies*

The combination of high rainfall (mean 1 975 mm; Le Roux, 2008), high humidity (mean 80%; Le Roux, 2008), low evaporation (c. 430 mm y^{-1}; Smith, personal communication) and impeded drainage due to peat accumulation, leads to the formation of many freshwater bodies on the island, ranging from smaller than 10 m^2 pools to lakelets of several thousand square meters. The island is volcanic and in his account of its limnology, Grobbelaar (1975) termed most of the island's lentic freshwater bodies *lava lakelets*.

Two main volcanic events formed the island. The first, about half a million years ago, resulted in grey basalts that were subjected to glaciations during the Pleistocene, and the second in black basalts that have been intermittently laid down during the Holocene and have never been glaciated. Lava lakelets occur mainly on these Holocene lavas, in sheltered, well-vegetated areas (mostly grassy mires) and they have bottoms and sides of peat, generally with a thick layer of benthic algae and mosses. On the grey lavas the water bodies occur mainly in exposed areas of sparsely-vegetated fellfield vegetation and have bottoms and sides of lava rock or grit-like volcanic ash, sometimes mixed with peat. Some grey lava water bodies originated through periglacial processes and they are commonly referred to as *glacial lakes* (Huntley, 1971; Smith, 2008). Grobbelaar (1975) showed that the water chemistry of lava lakelets and glacial lakes is sufficiently different to warrant distinguishing between the two types.

Grobbelaar (1975) also classified some of the island's water bodies as *lakes*. None of the water bodies is large enough to be considered a true lake and he used the term simply to distinguish a few larger water bodies from smaller ones, which he termed "lava lakelets". In fact, there is a large overlap in size between what he considered to be lakes and lakelets and, except for the glacial lakes described above, they do not differ in their type of substrate or chemical composition. In this study, lakes and lava lakelets *sensu* Grobbelaar (1975) are collectively called *lakelets* and are distinguished from *glacial lakes*.

A third type of lentic water body are the *crater lakes* found at the top of some cinder cones. Crater lakes are situated at medium to high altitudes and they are therefore exposed to very strong wind and wave action. The wave action moves the loose scoria occupying their bottom and sides, so they seldom have a well-developed littoral or bottom vegetation. This, and the fact that they do not have peaty bottoms, are the main characteristics distinguishing them from lava lakelets.

Seals or penguins cause depressions in the peat that fill with water, which are consequently enriched by manure. These animal-influenced water bodies are termed *wallows* and they range in area from a few to several hundred square meters. Wallows, occupied by seals and seabirds, have no rooted vegetation, but when they are abandoned they are quickly colonised by nitrophilous vascular plants that encroach from the sides and may eventually cover the wallow. Wallows may persist for many years and may coalesce and take on the nature of small, highly eutrophic ponds. In this study, "wallow" refers to all manured water bodies, including muddy pools at the entrance to petrel burrows.

There are no rivers on the island, only streams that are rarely more than a few meters wide and seldom more than a meter deep. Most are intermittent but seldom dry up for more than a day or so, and even when stagnant, many pools remain along its course. They generally have a rocky bottom, or a bottom covered with pebble-sized scoria. Filamentous algae and mosses are sometimes present on the rocks. One of the larger *streams* on the island is Van den Boogaard Stream (see Figure 2.9), a perennial stream situated on young black basaltic lava(Grobbelaar, 1974).

1.3 *Chemistry and productivity of Marion Island's freshwater bodies*

The island's freshwaters comprise of very dilute solutions of seawater, with an ionic concentration order $Cl^- > Na^+ > SO_4^{2-} > Mg^{2+} > Ca^{2+} > K^+ > HCO_3^-$, which is the same composition as that of seawater (Grobbelaar, 1978b). The oceanic origin factor (O.O.F.), which is a measure of the extent to which the major anions are of marine origin (Anderson, 1941) is also close to one, the value for seawater (Grobbelaar, 1978b). This does not mean the freshwaters are salty, on the contrary, except for some coastal pools they are extremely fresh, with low conductivity values (0 to 200 µS/cm; Wetzel, 1983). Since calcareous rocks do not occur on the island, the freshwaters contain low Ca^{2+}, CO_3^{2-} and HCO_3^- concentrations. They are, therefore, extremely soft and have a low alkalinity and buffering capacity (Grobbelaar, 1978b). They rarely contain detectable levels of nitrogen and phosphate, unless they are influenced by seabirds or seals.

Pelagic phytoplankton productivity in non-manured water bodies is low (1 to 102 mg C m^{-2} d^{-1}; Grobbelaar, 1974) and is similar to productivity values found in oligotrophic waters of cold temperate and sub-polar areas (Kalff, 1970; Alexander *et al.,* 1980). Benthic (epipelic) algal productivity in Marion Island's waters (44 to 258 mg C m^{-2} d^{-1}) is also low, similar to benthic productivities in tundra ponds (53 to 131 mg C m^{-2} d^{-1}; Smith, 2008). In contrast, phytoplankton productivity in the island's freshwaters that are influenced by seal or seabird manuring is high (up to 6 000 mg C m^{-2} d^{-1}; Grobbelaar, 1974; Smith, 2008). Grobbelaar (1978b) showed that nitrogen and phosphate synergistically stimulate algal production, but neither has any effect if added alone. In addition to this nutrient limitation, freshwater productivity on the island is restricted by low temperatures and light availability (Grobbelaar *et al.,* 1987).

Zooplankton (particularly *Pseudoboeckella volucris* and *Daphniopsis studeri*) dominates the trophic levels in the island's freshwater food chain (Grobbelaar *et al.,* 1987). High rates of zooplankton grazing, but low instantaneous values of phytoplankton and bacterial biomass, result in a rapid carbon turnover in the pelagic zone. No studies of the carbon flow in the benthos of the island's freshwater bodies have been done.

1.4 *The existing knowledge on the biota of Marion Island*

Marion Island is of recent volcanic origin and it originated less than 1 million years ago (Boelhouwers *et al*., 2008). The combination of youth and isolation has resulted in an impoverished biota. Only 41 vascular species (Gremmen & Smith, 2008b) and 33 insect species (Chown *et al.,* 2008) occur on the island, and in both cases about 40% of the species are exotic aliens introduced through human activity. Bryophytes are more diverse, with 137 moss and liverwort species present on the island (Gremmen, 2008; Ochyra, 2008). The taxonomy and ecology of all these biota have been studied thoroughly (Chown & Marshall, 2008; Chown *et al.,* 2008; Gremmen & Smith, 2008a; b; Ochyra, 2008).

Intensive limnological studies, which included primary production of the island's freshwaters, were conducted during the early 1970s and mid 1980s (Grobbelaar, 1974; 1975; Grobbelaar *et al*., 1987). The only reference to the identity of non-diatom freshwater algae from the Prince Edward Islands, is in an account of nutrient limitation to primary production in the freshwaters of Marion Island (Grobbelaar, 1978a), in which it is mentioned that *Chlorella* and *Scenedesmus* were used as test organisms.

Five diatom species were collected on Marion Island by Moseley in 1873 (Kellogg & Kellogg, 2002). Subsequent collections (Van de Vijver & Gremmen, 2006; Van de Vijver *et al.,* 2008) have resulted in a total of 214 moss-, soil- and freshwater-inhabiting diatom species being recorded for the Prince Edward Islands, three not found anywhere else. Species richness in the samples varied from 8 to 40 species per sample (Van de Vijver *et al.,* 2008). Considering all habitats (freshwater and terrestrial) the dominant diatom genera were *Pinnularia* (42 species), *Nitzschia* (15 species), *Psammothidium* (13 species), *Diadesmis* (11 species) and *Navicula* (10 species). The lentic water bodies were mostly dominated by *Aulacoseira cf. distans*, *Psammothidium abundans* and *Eunotia paludosa*. Streams were mostly dominated by *Fragilaria capucina*, *Fragilaria germainii* and *Psammothidium confusum*, with *Planothidium lanceolatum* and *Eolimnia minima* often subdominant. *Achnanthidium minutissimum* may be dominant in both lentic and lotic water bodies. The diatom flora of the Prince Edward Islands has very strong affinities with the diatom floras of other SIOP Islands, but poor affinities with those of non-SIOP sub-Antarctic islands (Van de Vijver *et al.*, 2008).

It is clear from the above paragraphs that the geology and physiography of the freshwater bodies on Marion Island are well known. The animal and plant life were also studied in detail but, except for diatoms, little is known about the island's freshwater algae. Prior to this study almost nothing was known about the taxonomy or ecology of the non-diatom freshwater algae on the island. Therefore, the aim of this study was to identify the algal genera found in the different freshwater bodies on Marion Island, to relate their presence or absence to the chemistry of the water bodies and to group the algal genera according to their limno-chemical preferences. The island's freshwater algal flora is also compared, at genus level, with those of other sub-Antarctic and maritime Antarctic islands.

CHAPTER 2: SAMPLING SITES, MATERIALS AND METHODS

2.1 *Sampling sites*

During April and May 2007 and 2010 a total of 148 freshwater bodies were sampled at the localities shown in Figure 2.1.

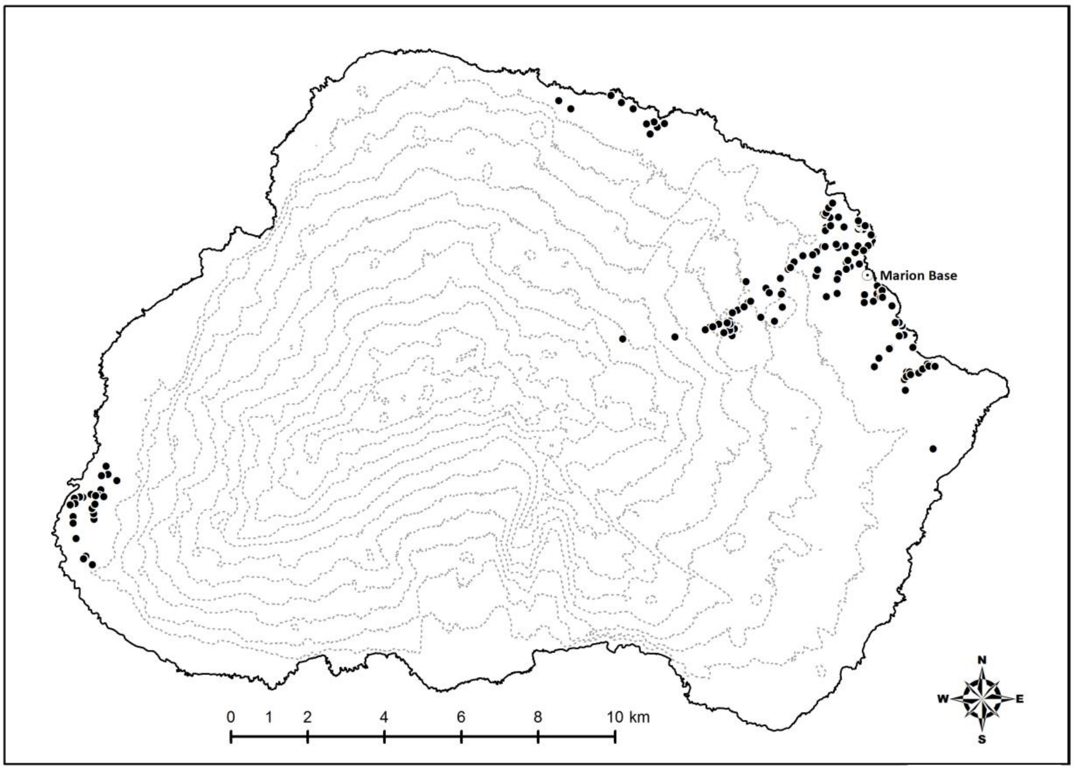

Figure 2.1 Map of the freshwater sites sampled during 2007 & 2010.

Smith (personal communication) classified the island's water bodies as described in Chapter 1, but subdivided lakelets based on differences in limno-chemistry related to their location. Different types of water bodies, and their classification, are as follows:

- Lakelets
    - *Nellie Humps lakelets* are situated on the eastern side of the island, in and around the Nellie Humps area (the locality of the meteorological station). The 39 Nellie Humps lakelets sampled all lie within one kilometre from the coast and are situated on well-vegetated, black lava (Figure 2.2).
    - *Eastern Inland lakelets* are also situated on black lava on the island's eastern side. They are situated further inland and at a higher elevation than the Nellie Humps lakelets. Figure 2.3 is a photograph of one of the 15 Eastern Inland lakelets sampled. The lakelet in the photograph is situated near Hendrik Fister and surrounded by an *Agrostis magellanica* mire.

- *Western* and *Southern lakelets* are situated on the western and southern sides of the island. The 28 lakelets sampled are physiognomically similar to the Nellie Humps lakelets but, since wind at the island is predominant westerly, they are subjected to much more intense seaspray. Figure 2.4 is a photograph of a Western lakelet located at Swartkop Point.

- *Northern lakelets* lie on the island's northern coastal plain and they are physiognomically very similar to the Nellie Humps lakelets. In total six of these lakelets were sampled and the largest, Prinsloo lake, is shown in Figure 2.5.

Figure 2.2 A Nellie Humps lakelet (site 302).


Figure 2.3 An Eastern Inland lakelet (site 317).


Figure 2.4 A Western lakelet situated at Swartkop Point (site 324).

Figure 2.5 A Northern lakelet, Prinsloo lake (site 54).

- Glacial lakes are situated on grey lava on the island's eastern side - as described in the introduction. A total of 39 glacial lakes were sampled and Figure 2.6 is a photograph of such a lake located on Skua Ridge.

- Crater lakes are found in the scoria cones of many craters on the island. Only three crater lake samples were analysed in this study. One sample was taken at the top of a cinder cone approximately 300 m above sea level and the other two samples between 2.5 km and 3.8 km inland of the meteorological station. Figured 2.7 is a typical crater lake situated on top of Hendrik Fister crater.

- All 17 wallows (Figure 2.8) sampled during this study were situated at the coast in the Nellie Humps area or the northern part of the island.

- Streams are sparsely found on the island. Only one stream (Van den Boogaard stream) was sampled at 28 locations over its *c.* 7 km course. Figure 2.9 shows Van den Boogaard stream with steep sided banks.

Figure 2.6 A glacial lake situated on Skua Ridge (site 311).

Figure 2.7 A crater lake in the Hendrik Fister scoria cone (site 315).

Figure 2.8 A wallow situated on the coast near Nellie Humps (Site 370)

Figure 2.9 Van den Boogaard stream.

The water bodies sampled for algal analyses were classified into the same groups as described above. Appendix 1 lists the water bodies, their coordinates, size, altitude, nearest distance from sea, chemical composition and number of algal genera found in the samples.

2.2 *Sampling and chemical analyses*

During April and May 2007 & 2010 147 lentic water bodies and one lotic water body were sampled (shown in Figure 2.1). The geographical position of each site was established by a Garmin Global Positioning System (GPS). The latitudes and longitudes are given in decimal degrees (See Appendix 1). The altitude of each site was also established with the aid of a Garmin GPS.

The dimensions, in metre, were determined by estimating each water body's basic geometrical shape, such as a circle, rectangle or triangle and then the area of each water body was calculated. For a circle-shaped water body the diameter was measured. For rectangle shaped water bodies the length and width were measured.

Logistic constraints and unpredictable weather prevented even distribution of sampling sites over the island and made achieving the ideal sampling program impossible. Most of the sample sites were located on the western, northern and eastern coast. Inland samples were mostly collected on the eastern side of the island as this area is easily accessible via the route from Marion base to Cathedral Peak Hut. Samples were taken in such a way that all water body types were represented. However, there were difficulties in achieving an equal amount of samples per water body type due to spatial distribution of the water bodies. Also, an equal amount of samples per water body type could not be achieved as crater lakes are not as common as lakelets while wallows are only located on the coastal areas colonised by seals.

Conductivity and pH of the top 20 cm water layer were measured *in situ* using a Hanna HI-9828 Multi-probe or an YSI 556 MPS multi-parameter probe, calibrated against standard solutions. No other parameters were measured due to equipment constraints. Samples of the same water layer were collected in clean plastic bottles from the banks of the water bodies. Within 12 hours of collection sub-samples were analysed for NH_4-N (phenol-hypochlorite reaction; Solórzano, 1969), NO_3-N (nitrospectral reaction using the reagents from a Spectroquant 14773 NO_3^- analysis kit; Merck KGaA, Darmstadt) and PO_4-P (phosphomolybdate-blue method; Murphy & Riley, 1962) and thereafter the sample absorbencies at 515 nm were compared against the absorbencies of known concentration standards. Nutrient concentration values are reported here as mg L^{-1}. The detection limit for PO_4-P, NO_3-N and NH_4-N was 0.001 mg L^{-1}.

The remaining sub-samples were stored at 1-4 ºC for up to 4 weeks before analysing for Ca^{2+}, Mg^{2+}, Na^+, K^+, SO_4^{2-} (inductively coupled plasma optical emission spectrometry; Clesceri *et al.,* 1998) and Cl^- (silver nitrate titration; Clesceri *et al.*, 1998) upon return in South-Africa. The detection limit for all anions and cations measured was 0.001 mg L^{-1}. The oceanic origin factor (O.O.F.) was calculated as 1.107 (mEq Cl / Σ mEq anions; Anderson, 1941). Carbonate and bicarbonate concentrations were not measured during this study, due to unforeseen equipment constraints during 2010's sampling. Also, in the absence of limestone or any other calcareous rock, the freshwaters are not enriched by carbonate or bicarbonate and concentrations were expected to be low (Smith, 2008). Therefore, data compiled by Grobbelaar (1978b) were used when calculating the O.O.F. The mean alkalinity values reported for the different water body types by Grobbelaar (1978b) were taken as the CO_3^{2-} plus HCO_3^- concentrations when calculating the O.O.F (Manahan, 1994).

2.3 *Algal collection and identification*

Plankton nets (35 µm mesh, one throw net and the other a hand net) were used to sample algae and cyanobacteria. The throw net was casted into deep water and allowed to sink before being slowly retrieved. The hand net, on the end of a long pole, was moved through the water along the banks of the water bodies and in the open areas of those water bodies that were too shallow to use the throw nets. The hand net was also scraped through the vegetation along the sides and bottom of the water bodies. Benthic algae were also collected by scraping rocks and vegetation with a knife or spoon. The samples, collected with the two nets and by scraping, were combined.

The 2007 samples were immediately fixed with Lugol's solution and later examined in the phycology laboratory at the Potchefstroom Campus of the North-West University, Potchefstroom, South Africa. All algae, excluding diatoms, were identified to genus level using light microscopy (Zeiss Photomicroscope III and a Nikon 80i microscope equipped with differential interference contrast optics D and linked to a JVC video camera with frame grabber). Some of the algal samples were also examined using scanning electron microscopy (FEI Quanta 200 E-SEM). All the 2010 samples were examined shortly after collection (<36 hours) in the island's laboratory using a Nikon Optiphoto microscope fitted with a Canon digital camera. Thereafter the samples were fixed with Lugol's solution for further examination at the North-West University using a Zeiss Photomicroscope III and a Nikon 80i microscope as described in the above paragraph.

The main texts used to identify the algae were Anand (1989), Entwisle *et al.* (2007), Gauthier-Lievre (1960), Geitler (1932), Hindák (1996), Huber-Pestalozzi (1950, 1955, 1961, 1962a & 1962b), John *et al.* (2008), Komárek & Anagnostidis (1986, 1999), Kondratyeva (1968), Prescott (1951, 1970), Prescott *et al.* (1981,1982), Therezine & Coute (1977), Uherkovich (1995) and Wehr & Sheath (2003).

2.4 *Relationships between algal assemblages and water chemistry*

Statistica™ software was used to analyse algal presence or absence and water chemistry data using ANOVA one-way statistics (StatSoft Inc., 2009). Analyses using variance comparison between the chemical composition of the samples containing a particular genus and samples in which the genus was absent were conducted. Analysis of variance for all genera present in the lentic samples were calculated, however some genera were found in 4 or less samples and therefore not subjected to the ANOVA.

Conductivity values were log-transformed to prevent skewed distribution of the data as there was a considerable difference in the lowest and highest conductivity values. Analysis of variance of the log-transformed conductivity data was preformed for each genus. Log conductivity was chosen as the *dependent variable* and the genus as the *predictor variable*. The aim of this analysis was to determine the significant (*P*-value will be < 0.05) difference in conductivity values between samples in which the genus (*predictor variable*) were absent and the samples containing the genus. This analysis determined the means and standard deviation errors of log conductivity for the samples containing the genus (the chosen *predictor variable*) and the samples in which the genus was absent. The aim of this analysis was to determine what conductivity range each genus occurred in and if there were some genera which occurred more frequently in water with specific conductivity values.

Analysis of variance between the pH data and each genus was also conducted. pH was the *dependent variable* and the genus the *predictor variable*. Analysis aimed to determine the significant (*P*-value will be < 0.05) difference in pH between samples in which the genus (*predictor variable*) were absent and the samples containing the genus. The means and standard deviation errors of pH for the samples containing the genus (the chosen *predictor variable*) and the samples in which the genus was absent were determined. This analysis provided the pH range for each genus. Analysis of the pH data included examination of the pH ranges that encompassed ≥ 75% of the occurrences of each genus. Only genera which occurred in more than 10 samples were included in the calculation of the pH ranges for each genus. Data were graphically represented in Statistica™ as scatterplots.

Canonical ordination techniques analyse numerous samples and many environmental variables simultaneously, with the primary aim to detect the relationship patterns between the specimens and environmental variables (Kent, 2011). Canonical Correspondence Analysis (CCA) was used to relate the presence and absence patterns of the algal genera to water chemistry using CANOCO because it is best suited for analysis if biological (genera) and environmental data are available (Ter Braak & Smilauer, 1998). Only chemical parameters were used as explanatory variables.

The statistical significance of the linear combination of measured environmental and chemical variables' influence on genera community composition was tested using Monte Carlo permutation procedures (999 permutations, $P \leq 0.05$). Forward selection was used to select the minimal number of parameters that could explain the largest amount of variation in the species data. Before relating environmental variables to algal abundance, it was important to detect (and eliminate) any colinearity between environmental variables, because multi-collinear data cause problems for multiple regression analysis (Chatterjee & Price, 1977). Since there was a high degree of colinearity between conductivity, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, and also between PO_4-P, NH_4-N and NO_3-N, the CCA was carried out on only three of the water chemistry variables, namely conductivity, PO_4-P and pH in an attempt to avoid colinearity. Other parameters that were under consideration, but not included were d*istance from coast*, *animal influence* and *altitude*. The statistical significance of the linear combination of the above mentioned parameters' influence on genera community composition was tested using Monte Carlo permutation procedures (999 permutations, $P \leq 0.05$) and these parameters' influence on the genera community composition was deemed insignificant ($P \geq 0.05$). This was expected because of colinearity between many of the variables that could influence the genera composition. For example the water bodies situated on the coast line are subjected to sea spray and therefore have predominantly high conductivity values (Broady, 1989; Vinocur & Unrein, 2000). Consequently, *distance from coast* was excluded from the analysis because it correlated with conductivity. *Animal influence* was difficult to determine and the most practical way to detect animal influence is by measuring the phosphate and nitrate concentrations of the water. For this reason *animal influence* was not included as a variable. Due to logistic constraints and spatial distribution of the sampling sites *altitude* was also not considered relevant. No stream sample was included for the CCA.

The frequency distribution of conductivity values across the 175 samples was significantly positively skewed, the log of the conductivity values was used in the CCA. Only genera that occurred in 10 or more of the samples were included in the CCA. Results obtained from the CCA were represented in genera-environmental and sample-environmental biplots created with CANODRAW (Ter Braak & Smilauer, 1998).

Sample scores that are linear constraints of the environmental variables of the three axes were given in the CANOCO *.sol file. The algal genera found in the lentic samples were clustered according to these scores on the first three CCA axes with Statistica™ software (StatSoft Inc., 2009) using a weighted pair-group average linkage procedure for the clustering and a city-block (Manhattan) distance as the dissimilarity measure. Cluster analysis was chosen because it can be added on ordination plots, it gives a good overview of data and also outlines many groups in data (Romesburg, 1984). The sample scores were also used as an indication of which genera scored high or low on the different axis. From the CCA "archetype" algal assemblages were defined for the different limno-chemical regimes of the lentic waters on the island by means of the sample scores and other results (*P*-values, means and standard deviation data) of the variance analysis.

2.5 *Comparison of Marion Island's freshwater algae with the algae of other Southern Ocean islands*

The Sørensen-Dice similarity coefficient was used to estimate the affinities of Marion Island freshwater algae with that of other sub-Antarctic and maritime Antarctic islands. The coefficient was calculated as 2a/(2a+b+c), where a is the number of genera common to both islands, b is the number of genera only present on Marion Island and c is the number of genera present only on the other island (Murguía & Villaseñor, 2003).

CHAPTER 3: RESULTS

3.1 *Algal assemblages in the lentic freshwater bodies*

Table 3.2 lists the algal genera found in the different water bodies. In total, 106 genera, mainly belonging to Chlorophyta (60 genera; 56% of total) and Cyanophyta (29 genera; 27% of total), were recorded in the freshwater communities on the island. Other algal divisions found were Chrysophyta (7 genera), Euglenophyta (4 genera), Pyrrophyta (2 genera) and Xanthophyta (4 genera). Mean number of genera per sample ranged from 8 (in wallows) to 16 (in Eastern Inland lakelets). During this study the number of non-diatom freshwater algal genera found on Marion Island has increased from 2 known genera (Grobbelaar, 1978a) to 106 genera. *Ichtyocercys* and *Ceratium* are new additions to the algal flora of the sub-Antarctic and have not been recorded previously on any sub-Antarctic or maritime Antarctic island. The data from the present study will form an important baseline against which to measure future environmental changes on the island.

3.1.1 *Chlorophyta*

Cosmarium, *Klebsormidium*, *Mougeotia* and *Oedogonium* were present in more than 50% of the water samples investigated. *Botryococcus* and *Scenedesmus* were present in 33% to 50% of the samples. *Asterococcus, Elakatothrix, Ulothrix* and *Zygnema* were also frequently found, in about a quarter of the samples. At the other end of the scale, *Crucigenia, Desmidium, Groenbladia* and *Schroederia* were only found in a single water body. All genera recorded were present in the lakelets, except for *Ichtyocercys*. There were differences in the algal composition between lakelets on the southern, western and northern side of the island on the one hand and those on the eastern side (the Nellie Humps and Eastern Inland lakelets) on the other hand. *Actinotaenium* was absent in the southern, western and northern side lakelets, but was found in one fifth of the samples taken from the eastern lakelets. Other genera not found in the western, southern or northern lakelets, but present in at least one eastern lakelet, were *Chlorococcum, Crucigenia, Crucigeniella, Desmidium, Groenbladia, Hormotila, Netrium, Penium* and *Prasiola.* *Ankyra, Coenochloris, Mesotaenium, Pediastrum* and *Schroederia* were absent from all eastern lakelets, but present in at least one southern, western or northern side lakelet.

Monoraphidium, Pediastrum, Spondylosium and *Staurastrum* were present in the Northern lakelets, but were not found in any Western or Southern lakelet samples. In addition, *Asterococcus, Bulbochaete* and *Sphaerocystis* were absent in the Northern lakelets, but present in at least one quarter of the Western and Southern lakelets. Despite the differences in bottom substrate, surrounding vegetation and water chemistry of glacial lakes and lakelets, the two types of water bodies were dominated (based on frequency of occurrence) by similar genera. *Cosmarium, Klebsormidium, Mougeotia* and *Oedogonium* were the most common in both types. In total 49 genera were found in the glacial lakes. Some genera were more frequently found in glacial lakes than lakelets. For instance *Asterococcus* and *Elakatothrix* were present in approximately 40% of the glacial lakes, but in less than 20% of the lakelets. In addition, *Treubaria, Roya, Closterium* and *Chaetosphaeridium* were present in more than 25% of glacial lakes but in 10% or less of the lakelets. *Ulothrix* was the only genus found more frequently in lakelets (40% occurrence) than in glacial lakes (8% occurrence). *Ichtyocercys* was found in glacial lakes, but not in any of the lakelets.

Of the 48 genera found in both lakelets and glacial lakes, 16 genera did not occur in any of the wallows. The most common genus in the wallows was *Zygnema* (occurred in 41% of the wallows). Other genera commonly found in wallows (in about 33% of the samples) were *Cosmarium, Klebsormidium, Oedogonium* and *Ulothrix*. All these genera were also common in lakelets and glacial lakes. In fact, no genus was restricted only to wallows.

Of the different lakelets, the Western and Southern lakelets showed an algal assemblage most similar to that of wallows. *Zygnema* was also frequently found in Western and Southern lakelets (occurred in 46% of the Western and Southern lakelets), but was uncommon in the other lakelets. *Golenkinia, Monoraphidium* and *Spondylosium* were frequently found in Nellie Humps, Eastern Inland and Northern lakelets, but were not found in any of the Western, Southern lakelets or wallows. *Binuclearia, Bulbochaete* and *Carteria* were present in the Nellie Humps, Eastern Inland, Western and Southern lakelets, but were absent from the Northern lakelets and wallows.

A total of 17 genera were found in the three crater lake samples. The most common genus was *Mougeotia,* which was present in all three samples. No genus was restricted to crater lakes. Crater lakes' algal assemblage differed from the assemblages in other freshwater bodies. *Ankistrodesmus, Botryococcus, Hyalotheca, Rhizoclonium* and *Ulothrix* were present in all freshwater bodies on the island, except in crater lakes. However, with only 3 crater lake samples, no reliable comparison to other water body groups can be made.

3.1.2 *Cyanophyta*

Across all the water bodies, a total of 30 genera were identified. *Chroococcus* and *Lyngbya* were the most common and were present in more than 33% of the samples. *Anabaena* was present in more than 10% of the samples. *Microcystis* and *Synechocystis* were present in only 1 sample. All 30 genera were present in the lakelets. Overall, Northern lakelets possessed an assemblage (based on frequency of occurrence) that is more similar to that of the Eastern Inland lakelets than that of the Western and Southern lakelets. For instance, *Cylindrospermopsis, Gloeotheca, Hapalosiphon, Scytonema* and *Scytonematopsis* were present in the Western and Southern lakelets, but not in any of the Northern or Eastern Inland lakelets. Furthermore, *Homoeothrix, Leptolyngbya, Microchaeta, Nodularia, Schizothrix, Synechocystis* and *Tolypothrix* occurred in the Western and Southern lakelets, but not in any of the Northern, Eastern Inland or Nellie Humps lakelets.

The most commonly found genus in the glacial lakes was *Anabaena*, which was found in 46% of the glacial lakes. Genera common in lakelets were also quite common in the glacial lakes, these include *Calothrix, Chroococcus, Lyngbya, Oscillatoria* and *Scytonema.* On the other hand, *Aphanothece, Homoeothrix, Microchaeta, Microcystis, Scytonematopsis* and *Synechocystis* were present in at least one lakelet, but were not found in any glacial lake. Fifteen genera were found in the wallows, the most common being *Anabaena, Oscillatoria* and *Trichodesmium.* *Calothrix* was not found in any wallow, but were common in the lakelets. The cyanophyte assemblage of the wallows most closely resembles that of the Western and Southern lakelets (also regarding the Chlorophyta; section 3.1.1). *Homoeothrix, Microchaeta, Scytonema* and *Nodularia* were only found in wallows and in the Western and Southern lakelets, but were absent in all other lakelets. Wallows, Western and Southern lakelets are the most saline of the freshwater bodies, which might account for these similarities in the composition of the algal assemblages (see Appendix 1).

3.1.3 *Chrysophyta*

Seven genera were present, the most common being *Lagynion* and *Epipyxis*, present in 15 and 13 samples, respectively. *Dinobryon, Epipyxis, Mallomonas, Salpingoeca* and *Synura* were present in the Nellie Humps lakelets. Only two genera, *Mallomonas* and *Synura,* were identified in the Northern lakelets. All genera were present in the glacial lakes. *Dinobryon* was the only chrysophyte genus found in the wallows and *Lagynion* in the crater lakes. The chrysophyte composition in the Northern lakelets, wallows and crater lakes was different from that in the other water bodies.

3.1.4 *Euglenophyta*

Only four genera were found. *Euglena* (found in 24% of the lakelets and in 44% of the glacial lakes) and *Trachelomonas* (found in 30% of the lakelets and 41% of the glacial lakes) were the most common genera. *Chrysosphaera* was present in the Nellie Humps lakelets, Western lakelets, Southern lakelets and glacial lakes, while *Lepocinclis* was only recorded in the Nellie Humps lakelets.

3.1.5 *Pyrrophyta*

Representatives of the Pyrrophyta were present in only 15 samples. Pyrrophyta occurred more frequently in glacial lakes than lakelets. *Peridinium* occurred in 13% of the glacial lakes (5 of the 39 samples) and only in 3% of the lakelets (3 of the 88 samples). Pyrrophyta were not found in any wallows or crater lakes.

3.1.6 *Xanthophyta*

Four genera were identified. *Tribonema*, the most common genus, was present in lakelets (55% of samples), wallows (41% of samples) and glacial lakes (28% of samples). *Tribonema* was found in one crater lake. *Characiopsis, Hemisphaerella* and *Heterothrix* were not found in wallows and crater lakes.

3.2 ***Algal assemblages in the stream***

Table 3.1 provides presence and absence data for Van den Boogaard stream, based on 28 locations sampled along its course. In total, 67 genera (35 Chlorophyta, 4 Chrysophyta, 23 Cyanophyta, 3 Euglenophyta, 1 Pyrrophyta and 1 Xanthophyta) were found, with an average of 10 genera per sample.

3.2.1 *Chlorophyta*

Actinotaenium, Carteria, Chaetosphaeridium, Klebsormidium, Mougeotia and *Oedogonium* were the most common genera and occurred in 33% to 49% of the samples. All the genera found in the stream were present in the lakelets. *Characium, Oocystis* and *Teilingia* were common in the lakelets and glacial lakes, but absent in the stream. The chlorophyte assemblages of the wallows were different from that of the stream, this could be ascribed to the difference in limno-chemistry of wallows and the stream (Table 3.1).

3.2.2 *Cyanophyta*

Calothrix and *Scytonema* were present in approximately 33% of the samples. All 23 genera present in the stream were also found in the lakelets. *Homoeothrix, Microchaeta, Microcystis* and *Phormidium* were present in the stream, but absent in the glacial lakes. *Cylindrospermopsis, Gloeotheca, Hapalosiphon, Leptolynbya, Microcystis, Schizothrix, Scytonema* and *Tolypothrix* were present in the stream, but absent in glacial lakes or wallows.

3.2.3 *Chrysophyta*

Dinobryon was the most commonly found genus (present in 25% of the samples). *Epipyxis, Lagynion* and *Pseudokephyrion* were present in 2 or more samples.

3.2.4 *Euglenophyta*

Trachelomonas was the most common genus and was present in 18% of the samples. *Euglena* and *Chrysosphaera* were also found in 2 or more samples.

3.2.5 *Pyrrophyta*

Peridinium occurred in 29% of the samples and *Ceratium* was absent from the stream.

3.2.6 *Xanthophyta*

Only one genus, *Tribonema*, was recorded. *Tribonema* was also found in a stream sample taken about 1 km inland and 60 m above sea level (a.s.l.).

3.3 ***Freshwater chemical composition***

The limno-chemistry of the water bodies is given in Table 3.2. The chemical composition of the island's freshwater is strongly influenced by the surrounding ocean, through sea spray and aerosols of seawater. Consequently, Na^+ is always the most abundant cation, and Cl^- is the most abundant anion. The mean Na:Cl ratio for all 175 samples listed in Table 3.2 was 0.52 and this is similar to that of the seawater surrounding the island (0.54). The mean Na:Cl ratio in the Western and Southern lakelets, as well as the wallows, was 0.54, which is exactly the same as the ratio in sea water. Eastern Inland lakelets had the lowest mean Na:Cl ratio of 0.42.

The mean oceanic origin factor (O.O.F.; a measure of the extent to which the major anions are of marine origin; Anderson, 1941) of all 175 samples was 0.94, which is very close to the value for seawater (1.00). The Western and Southern lakelet's O.O.F. was the closest to that of seawater at 0.99 and the wallows had the lowest O.O.F of 0.88.

The highest mean conductivity was measured in the Western and Southern lakelets (386 $\mu S\ cm^{-1}$; Table 3.2). This high conductivity value is still only 3% of that measured in seawater (Millero, 1974). Seventy six percent of the water samples had conductivities values less than 124 $\mu S\ cm^{-1}$ (0.25% that of seawater). Only three samples can be considered to be oligohaline (conductivity values 0.03 to 0.3% of that in seawater), the rest of the samples are ultra-oligohaline or fresh, with conductivity values less than 0.03% of that found in seawater.

Table 3.1 List of algal genera found in the various types of freshwater bodies. Only one stream was sampled, at 28 localities. If a genus was present in any of the 28 samples it is indicated as + in the stream column, with the number of samples it in which it occurred in square brackets.

			Lakelets					Glacial lakes	Wallows	Crater lakes	Stream
		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern				
Number of samples taken:		147	88	39	15	28	6	39	17	3	[28]
Total number of genera present:		106	106	82	64	75	39	87	53	30	[67]
Mean genera per sample:		13	12	13	16	11	11	15	8	12	[10]
			Lakelets Lakelets								
		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
	Chlorophyta	Number of samples containing the genus									
ACT	*Actinotaenium* (Nägeli) Teiling	22	12	7	5	0	0	8	1	1	+ [11]
ANK	*Ankistrodesmus* Corda	17	9	2	1	5	1	7	1	0	+ [3]
ANKY	*Ankyra* Fott	2	1	0	0	1	0	0	1	0	-
AST	*Asterococcus* Scherffel	35	17	6	3	8	0	15	2	1	+ [3]
BIN	*Binuclearia* Wittrock	15	10	5	2	3	0	4	0	1	+ [1]
BOT	*Botryococcus* Kützing	51	29	17	6	3	3	19	3	0	+ [5]

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
BUL	*Bulbochaete* Agardh	27	15	6	2	7	0	11	0	0	+ [4]
CHL	*Chlorococcum* Meneghini	4	3	2	1	0	0	1	0	0	-
CAR	*Carteria* Diesing	9	4	1	1	2	0	5	0	0	+ [9]
CHA	*Chaetosphaeridium* Klebahn	19	5	0	1	3	1	10	4	0	+ [11]
CHAR	C*haracium* Braun in Kützing	16	11	4	4	3	0	4	1	0	-
CHLA	C*hlamydomonas* Ehrenberg	33	22	13	4	5	0	7	4	0	+ [2]
CHL	C*hlorella* Beijerinck	23	15	6	4	4	1	5	2	1	+ [7]
CLO	*Closterium* Nitzsch *ex* Ralfs	21	8	3	4	0	1	11	1	1	+ [1]
COE	*Coelastrum* Nägeli	23	9	4	2	3	0	12	2	0	+ [2]
COCH	*Coenochloris* Korshikov	3	1	0	0	1	0	2	0	0	-
COCO	*Coenococcus* Korshikov	3	5	2	2	1	0	4	1	0	-
COS	*Cosmarium* Ralfs	79	47	25	13	5	4	25	5	2	+ [5]
CRU	*Crucigenia* Morren	1	1	1	0	0	0	0	0	0	-
CRUC	*Crucigeniella* Lemmermann	5	1	1	0	0	0	4	0	0	-

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
CYL	*Cylindrocystis* Meneghini *ex* De Bary	31	16	4	6	5	1	13	1	1	+ [5]
DES	*Desmidium* Agardh *ex* Ralfs	1	1	1	0	0	0	0	0	0	-
DIC	*Dictyosphaerium* Nägeli	11	2	0	1	1	0	6	3	0	+ [5]
EL	*Elakatothrix* Wille	35	17	3	9	4	1	15	2	1	+ [3]
EUA	*Euastrum* Ehrenberg *ex* Ralfs	22	15	7	6	2	0	4	2	1	+ [3]
GEM	*Geminella* Turpin	2	2	1	0	1	0	0	0	0	+ [2]
GO	*Golenkinia* Chodat	3	3	1	1	0	1	0	0	0	+ [2]
GRO	*Groenbladia* Teiling	1	1	1	0	0	0	0	0	0	-
HOR	*Hormotila* Borzi	5	5	3	2	0	0	0	0	0	-
HY	*Hyalotheca* Ehrenberg *ex* Ralfs	17	8	1	4	1	2	8	1	0	-
ICH	*Ichtyocercys* West & West	2	0	0	0	0	0	2	0	0	-
KL	*Klebsormidium* Silva, Mattox & Blackwell	85	48	25	8	13	2	31	5	1	+ [9]
MES	*Mesotaenium* Nägeli	2	1	0	0	1	0	1	0	0	-
MICR	*Microspora* Thuret	31	21	12	2	5	2	9	0	1	+ [3]

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
MON	*Monoraphidium* Komárková-Legnerová	14	10	6	2	0	2	3	0	1	-
MOU	*Mougeotia* Agardh	74	45	17	13	11	4	21	4	3	+ [15]
NE	*Netrium* (Nägeli) Itzigsohn & Rothe in Rabenhorst	6	1	0	1	0	0	5	0	0	-
OE	*Oedogonium* Link *ex* Hirn	89	54	28	12	13	1	27	5	2	+ [10]
OO	*Oocystis* Braun	24	18	11	2	4	1	6	0	0	-
PE	*Pediastrum* Meyen	4	2	0	0	0	2	2	0	0	-
PEN	*Penium* Brébisson *ex* Ralfs in Ralfs	3	1	0	1	0	0	2	0	0	+ [3]
PRA	*Prasiola* Meneghini	4	2	2	0	0	0	1	1	0	-
RH	*Rhizoclonium* Kützing	15	8	3	3	1	1	5	2	0	+ [1]
RO	*Roya* West & West	16	4	0	2	1	1	10	1	1	-
SCE	*Scenedesmus* Meyen	63	41	22	10	7	2	15	5	2	+ [2]
SCH	*Schroederia* Lemmermann	1	1	0	0	0	1	0	0	0	+ [1]
SPH	*Sphaerocystis* Chodat	12	9	1	0	8	0	2	1	0	+ [4]
SPI	*Spirogyra* Link	17	9	5	2	2	0	6	2	0	+ [4]

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
SPO	*Spondylosium* Brébisson *ex* Kützing	9	7	2	3	0	2	2	0	0	+ [1]
STA	*Staurastrum* (Meyen) Ralfs	10	8	6	0	0	2	2	0	0	-
STAU	*Staurodesmus* Teiling	6	5	0	1	3	1	1	0	0	+ [8]
STI	*Stigeoclonium* Kützing	2	2	1	0	1	0	0	0	0	+ [1]
TEI	*Teilingia* Bourrelly	24	16	3	7	6	0	5	2	1	-
TE	*Tetmemorus* Ralfs *ex* Ralfs	14	5	2	7	0	0	7	2	0	-
TET	*Tetrastrum* Chodat	3	3	2	0	1	0	0	0	0	-
TRE	*Treubaria* Bernard	18	4	1	0	3	0	11	3	0	+ [3]
UL	*Ulothrix* Kützing	42	34	17	5	8	4	3	5	0	+ [4]
XA	*Xanthidium* Ehrenberg *ex* Ralfs	5	3	2	0	1	0	1	1	0	-
ZY	*Zygnema* Agardh	41	20	4	2	13	1	13	7	1	+ [6]

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
	Cyanophyta										
AN	*Anabaena* Bory de Saint-Vincent *ex* Bornet & Flahault	38	16	8	4	4	0	18	3	1	+ [1]
ANA	*Anabaenopsis* Miller	4	1	0	1	0	0	2	1	0	-
AP	*Aphanocapsa* Nägeli	18	9	2	3	4	0	6	1	2	+ [2]
APH	*Aphanothece* Nägeli	2	2	2	0	0	0	0	0	0	-
CAL	*Calothrix* Agardh *ex* Bornet & Flahault	25	16	6	3	6	1	8	0	1	+ [10]
CHR	*Chroococcus* Nägeli	50	37	18	8	9	2	10	2	1	+ [6]
CYLM	*Cylindrospermum* (Kützing) Bornet *et* Flahault	7	5	1	4	0	0	1	1	0	+ [2]
CYLS	*Cylindrospermopsis* Seenayya *et* Subba Raju in Desikachary	6	3	1	0	2	0	3	0	0	+ [2]
GLO	*Gloeocapsa* Kützing	27	20	11	6	2	1	5	1	1	+ [2]
GLOE	*Gloeothece* Nägeli	5	4	1	0	3	0	1	0	0	+ [2]
HA	*Hapalosiphon* Nägeli *ex* Bornet *et* Flahault	4	3	2	0	1	0	1	0	0	+ [3]
HO	*Homoeothrix* (Thuret *ex* Bornet & Flahault) Kirchner	3	2	0	0	2	0	0	1	0	+ [1]
KO	*Komvophoron* Anagnostidis & Komárek	5	3	3	0	0	0	2	0	0	-

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
LEP	*Leptolyngbya* Anagnostidis & Komárek	3	1	0	0	1	0	2	0	0	+ [1]
LY	*Lyngbya* Agardh *ex* Gomont	48	37	22	6	5	4	8	2	1	+ [3]
ME	*Merismopedia* Meyen	3	2	2	0	0	0	1	0	0	-
MI	*Microchaete* Thuret *ex* Bornet *et* Flahault	2	1	0	0	1	0	0	1	0	+ [2]
MIC	*Microcystis* Kützing *ex* Lemmermann	1	1	0	0	1	0	0	0	0	+ [1]
NOD	*Nodularia* Mertens *ex* Bornet *et* Flahault	6	1	0	0	1	0	3	2	0	+ [2]
NOS	*Nostoc* Vaucher *ex* Bornet *et* Flahault	19	14	7	4	1	2	2	2	1	+ [7]
OS	*Oscillatoria* Vaucher *ex* Gomont	27	15	7	5	2	1	8	3	1	+ [1]
PH	*Phormidium* Kützing *ex* Gomont	19	8	2	1	5	0	9	2	0	+ [2]
SCHIZ	*Schizothrix* (Kützing) Gomont	4	3	0	0	3	0	1	0	0	+ [6]
SC	*Scytonema* Agardh *ex* Bornet & Flahault	24	16	10	0	6	0	8	0	0	+ [9]
SCY	*Scytonematopsis* Kiseleva	2	2	1	0	1	0	0	0	0	-
SP	*Spirulina* Turpin *ex* Gomont	2	1	1	0	0	0	1	0	0	-
ST	*Stigonema* Agardh *ex* Bornet *et* Flahault	18	15	8	3	4	0	1	1	1	+ [1]

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
SY	*Synechocystis* Sauvageau	1	1	0	0	1	0	0	0	0	-
TO	*Tolypothrix* Kützing *ex* Bornet & Flahault	6	4	0	0	4	0	2	0	0	+ [1]
TRIC	*Trichodesmium* Ehrenberg	15	6	0	1	4	1	6	3	0	+ [2]
	Chrysophyta										
DIN	*Dinobryon* Ehrenberg	12	4	2	1	1	0	6	2	0	+ [7]
EPIX	*Epipyxis* Ehrenberg	13	7	2	1	4	0	6	0	0	+ [2]
LAG	*Lagynion* Pascher	15	7	0	2	5	0	7	0	1	+ [3]
MA	*Mallomonas* Perty	7	5	1	2	1	1	2	0	0	-
PS	*Pseudokephyrion* Pascher	2	0	0	0	0	0	2	0	0	+ [2]
SA	*Salpingoeca* Clark	6	2	2	0	0	0	4	0	0	-
SYN	*Synura* Ehrenberg	9	8	5	1	0	2	1	0	0	-

		All lentics	All	Nellie Humps	Eastern Inland	Western & Southern	Northern	Glacial lakes	Wallows	Crater lake	Stream
	Euglenophyta										
CHRY	*Chrysosphaera* Pascher *emend*. Bourrelly	13	8	5	0	3	0	5	0	0	+ [3]
EUG	*Euglena* Ehrenberg	43	21	7	4	9	1	17	5	0	+ [2]
LE	*Lepocinclis* Perty	1	1	1	0	0	0	0	0	0	-
TRA	*Trachelomonas* Ehrenberg	49	26	11	4	9	2	16	5	2	+ [5]
	Pyrrophyta										
CER	*Ceratium* Schrank	6	4	2	1	0	1	2	0	0	-
PER	*Peridinium* Ehrenberg	9	3	2	0	1	0	5	1	0	+ [8]
	Xanthophyta										
CHAP	*Characiopsis* Borzí	4	4	2	0	2	0	0	0	0	-
HEM	*Hemisphaerella* Pascher in Rabenhorst	6	4	1	2	1	0	2	0	0	-
HET	*Heterothrix* Pascher	1	1	1	0	0	0	0	0	0	-
TRIB	*Tribonema* Derbès & Solier	67	48	27	4	14	3	11	7	1	+ [5]

There are no limestones or other calcareous rocks on the island, resulting in low Ca^{2+} concentrations in the freshwaters. Mean Ca^{2+} concentrations of all the water bodies sampled varied between 0.6 mg L^{-1} (Eastern Inland lakelets and crater lakes) and 3.6 mg L^{-1} (Western and Southern lakelets). Bicarbonate and carbonate concentrations were not measured, but it is known from previous studies that these concentrations are extremely low, so that total alkalinity of the lentic waters is low (mostly <0.02 mEq L^{-1}) compared to streams that may have values up to 0.2 mEq L^{-1} (Grobbelaar, 1978b). Consequently, the island's freshwaters are acidic and only 17 of the 175 water samples had a pH higher than 7.0. Most of these higher pH samples were collected from the stream. Lakelets tend to be more acidic than glacial lakes (Table 3.2). The mean SO_4^{2-} concentrations in the lakelets were usually higher than in glacial lakes.

Inorganic nitrogen (NH_4-N and NO_3-N) and phosphate (PO_4-P) were present in low concentrations in most of the samples. The presence of nitrogen and phosphate could be ascribed to the influence of seabirds or seals. Wallows were therefore the only water bodies in which moderate concentrations of nitrogen and phosphate were found. Wallows also showed higher mean ion concentrations (Na^+, Cl^-, Mg^{2+}, Ca^{2+}, K^+ and SO_4^{2-}) and thus higher mean conductivity values, than most of the other water body groups, except for the Western and Southern lakelets (Table 3.2).

Table 3.2 The limnochemistry of the different groups of freshwater bodies on Marion Island. The mean, standard deviation, minimum and maximum values are included for pH, conductivity (Cond, µS cm^{-1}), NH_4–N (mg L^{-1}), NO_3–N (mg L^{-1}), PO_4–P (mg L^{-1}), Ca^{2+} (mg L^{-1}), Mg^{2+} (mg L^{-1}), K^+ (mg L^{-1}), Na^+ (mg L^{-1}), Cl^- (mg L^{-1}), SO_4^{2-} (mg L^{-1}) and the Oceanic Origin Factor (O.O.F) .

	Nellie Humps lakelets (N=39)	**Eastern Inland lakelets (N=15)**	**Western and Southern lakelets (N=28)**	**Northern lakelets (N=6)**
pH	5.2 ± 0.56 (4.4 - 7.1)	5.8 ± 0.36 (5.2 - 6.6)	6.0 ± 0.74 (4.7 - 8.5)	5.7 ± 0.62 (4.9 - 6.5)
Cond	133 ± 248 (34 - 1562)	39 ± 20 (13 - 79)	386 ± 401 (115 - 1814)	97 ± 15 (77 - 122)
NH_4-N	0.05 ± 0.145 (0.0 - 0.6)	0	0.01 ± 0.045 (0.0 – 0.2)	0
NO_3-N	0.26 ± 0.543 (0.0 - 2.8)	0	0.03 ± 0.108 (0.0 - 0.5)	0.11 ± 0.281 (0.0 - 0.7)
PO_4-P	0.04 ± 0.090 (0.0 - 0.5)	0	0.01 ± 0.051 (0.0 - 0.27)	0.03 ± 0.061 (0.0 - 0.15)
Ca^{2+}	1.2 ± 1.47 (0.4 - 9.3)	0.6 ± 0.27 (0.4 - 1.3)	3.6 ± 3.53 (0.9 – 16.8)	1.0 ± 0.37 (0.6 - 1.6)
Mg^{2+}	2.8 ± 4.64 (0.7 - 28.5)	0.8 ± 0.38 (0.3 - 1.6)	9.3 ± 11.13 (2.0 – 52.9)	1.8 ± 0.23 (1.5 - 2.2)
K^+	0.9 ± 1.57 (0.0 - 9.5)	0.2 ± 0.29 (0.0 - 0.9)	2.8 ± 3.35 (0.4 – 14.9)	0.8 ± 0.15 (0.5 - 0.9)
Na^+	23.4 ± 37.34 (7.2 - 230.5)	5.7 ± 1.93 (3.5 - 9.8)	80.2 ± 96.11 (18.5 – 442.4)	14.5 ± 2.35 (10.7 - 18.1)
Cl^-	44.6 ± 71.57 (15.0 - 443.2)	13.5 ± 4.43 (7.1 - 22.1)	148.6 ± 179.61 (31.8 – 817.7)	29.1 ± 4.81 (21.2 - 35.3)
SO_4^{2-}	6.5 ± 9.01 (2.4 - 56.7)	2.5 ± 0.58 (1.8 - 3.6)	21.3 ± 26.33 (4.8 – 123.9)	4.5 ± 0.57 (3.5 - 5.2)
O.O.F	0.96 ± 0.035 (0.80 - 1.00)	0.92 ± 0.033 (0.85 - 0.97)	0.99 ± 0.011 (0.97 - 1.02)	0.96 ± 0.021 (0.92 - 0.98)
	Glacial lakes (N=39)	**Crater lakes (N=3)**	**Wallows (N=17)**	**Stream (N=28)***
pH	6.1 ± 0.41 (5.4 - 7.1)	5.4 ± 0.93 (4.4 – 6.3)	5.6 ± 0.75 (4.6 - 7.3)	6.9 ± 0.50 (6.1 - 7.9)
Cond	73 ± 16 (43 - 122)	47 ± 17 (30 - 64)	162 ± 124 (53 - 476)	53 ± 14 (36 - 80)
NH_4-N	0	0	1.24 ± 0.964 (0.0 - 2.9)	0
NO_3-N	0.02 ± 0.105 (0.0 - 0.5)	0	1.44 ± 0.882 (0.3 - 3.2)	0
PO_4-P	0.01 ± 0.019 (0-0.08)	0	0.29 ± 0.289 (0.0 - 0.9)	0
Ca^{2+}	0.9 ± 0.21 (0.5 - 1.5)	0.6 ± 0.11 (0.5 – 0.7)	1.1 ± 0.64 (0.4 – 2.9)	2.0 ± 0.38 (1.0 - 2.6)
Mg^{2+}	1.9 ± 0.64 (0.9 – 4.9)	1.0 ± 0.24 (0.7 – 1.2)	2.6 ± 1.88 (0.6 – 7.7)	1.5 ± 0.23 (1.1 - 2.2)
K^+	0.3 ± 0.34 (0.0 – 1.3)	0.1 ± 0.18 (0.0 – 0.3)	1.3 ± 1.75 (0.0 – 6.1)	0.5 ± 0.44 (0.0 - 1.3)
Na^+	13.0 ± 2.2 (6.5 - 18.3)	8.0 ± 1.47 (6.5 – 9.4)	23.7 ± 14.10 (11.3 – 63.4)	8.5 ± 0.78 (6.4 - 9.9)
Cl^-	26.5 ± 4.5 (16.8 - 38.9)	15.6 ± 4.36 (10.6 – 18.5)	43.6 ± 27.74 (17.6 – 121.9)	15.6 ± 3.60 (8.8 - 22.1)
SO_4^{2-}	4.2 ± 0.53 (3.22 - 5.8)	3.1 ± 0.79 (2.2 – 3.7)	6.8 ± 4.15 (2.6 – 18.8)	2.6 ± 0.42 (1.8 - 3.8)
O.O.F	0.96 ± 0.021 (0.9 - 1.0)	0.92 ± 0.017 (0.91 – 0.94)	0.88 ± 0.080 (0.7 - 0.97)	0.94 ± 0.032 (0.87 - 0.99)

** Only one stream was sampled 28 times.*

3.4 *Algal genera and water chemistry*

Table 3.3 gives the mean, minimum and maximum values for conductivity, pH, NH_4-N, NO_3-N and PO_4-P of the water samples in which each genus was found. Differences in conductivity mirrored the differences in Na^+, Cl^-, Mg^{2+}, K^+, Ca^{2+} and SO_4^{2-} concentrations, therefore conductivity is used as a substitute for these above mentioned ions in Table 3.3.

It was pointed out earlier that the island's water bodies are fresh. However, salinity, or its proxy, conductivity, was an important determinant of the probability that a particular genus would be present. The mean conductivity of samples in which the chlorophytes *Crucigenia, Geminella* and *Xanthidium*'s and the cyanophytes *Microchaeta, Tolypothrix* and *Trichodesmium* were present, were all above 250 µS cm^{-1}. Chrysophyta, Euglenophyta, Pyrrophyta and Xanthophyta were absent from samples with mean conductivity values above 250 µS cm^{-1}.

Analysis of variance (one-way ANOVAS of log conductivity with each genus as the categorical predictor) showed that 62% of the genera occurred in samples with lower conductivity, than the conductivity of the samples in which these genera were not found. Therefore, more than 60% of the genera preferred habitats with low conductivity. The analysis of variance of the (log-transformed) conductivity values showed that the difference was significant ($P \leq 0.05$) in only 18 cases (*Actinotaenium, Botryococcus, Chroococcus, Closterium, Cosmarium, Cylindrospermum, Hormotila, Hyalotheca, Klebsormidium, Microchaeta, Mougeotia, Nostoc, Oedogonium, Sphaerocystis, Teilingia, Tetmemorus, Tolypothrix* and *Trichodesmium*). Conversely, the probability of occurrence of *Sphaerocystis*, *Tolypothrix* and *Trichodesmium* increased significantly with increasing conductivity. The mean conductivities of samples in which these three genera were found were 250 µS cm^{-1} or more, representing the upper 12.5% of conductivity values found in the study. *Microcystis* and *Microchaete* were present in only 2 samples, which are too few to reveal their limno-chemistry preferences by ANOVA, but they possibly also favour more saline waters. The mean conductivity values of the samples in which *Microcystis* and *Microchaete* occurred were 251 and 314 µS cm^{-1}, respectively (Table 3.3).

In 124 of the 147 lentic water samples, NH_4-N could not be detected. NH_4-N and NO_3-N concentrations were extremely low (zero mg/L^{-1}). Twenty-two chlorophyte genera, 16 cyanophytes, 5 chrysophytes, 1 euglenophyte, 1 pyrrophyte and 1 xanthophyte were only present in waters with no detectable NH_4-N concentrations, while 13 chlorophytes and 12 cyanophytes were only present in water with no detectable NO_3-N concentrations. *Lagynion, Pseudokephyrion* and *Characiopsis* were also only present in water with no detectable NO_3-N concentrations.

PO_4-P could not be detected in 112 of the 147 lentic water bodies sampled or any of the stream samples. Many of the 106 genera were only found in samples with no detectable PO_4-P concentrations. Fourteen chlorophytes, 11 cyanophytes 3 chrysophytes, 1 pyrrophyte and 1 xanthophyte were only found in oligotrophic waters with no detectable PO_4-P concentrations.

Analysis of variance showed that 87 of the 106 genera were less likely to be present with increasing nitrogen and phosphate concentrations. This difference was however only significant ($P \leq 0.05$) for *Klebsormidium* and *Mougeotia*. But this pattern is somewhat confounded by the effect of salinity, because most water bodies containing nitrogen and phosphate are those situated at the coast, where the intensity of seal and seabird manuring is greatest but where the influence of salt spray is also very high.

Genera frequently present in waters containing nitrogen and phosphate were *Chlamydomonas*, *Prasiola, Tetmemorus, Trachelomonas, Tribonema, Ulothrix,* and *Xanthidium*. *Prasiola* was found in only 4 samples and therefore not subjected to the ANOVA but the mean PO_4-P concentration and mean NO_3-N concentration of those 4 samples were the 4th and 5th highest at 0.07 mg L^{-1} and 0.33 mg L^{-1}, respectively.

Table 3.3 Mean, minimum and maximum chemistry values for each algal genus. N is the number of samples in which genus occurred.

		N	pH	Conductivity (µS cm^{-1})	NH_4-N (mg L^{-1})	NO_3-N (mg L^{-1})	PO_4-P (mg L^{-1})
Chlorophyta							
Actinotaenium	ACT	33	6.2 (4.7 - 7.9)	61 (23 - 116)	0.00 (0.00 - 0.05)	0.04 (0.00 - 0.54)	0.00 (0.00 - 0.09)
Ankistrodesmus	ANK	20	6.4 (5.4 - 7.5)	150 (28 - 459)	0.09 (0.00 - 1.81)	0.14 (0.00 - 1.75)	0.02 (0.00 - 0.47)
Ankyra	ANKY	2	5.5 (5.5 - 5.6)	181 (124 - 237)	0.73 (0.00 - 1.45)	1.32 (0.00 - 2.64)	0.19 (0.00 - 0.38)
Asterococcus	AST	38	5.8 (4.7 - 7.3)	98 (13 - 362)	0.08 (0.00 - 1.45)	0.16 (0.00 - 2.64)	0.02 (0.00 - 0.38)
Binuclearia	BIN	17	5.5 (4.7 - 7.0)	87 (13 - 348)	0.01 (0.00 - 0.20)	0.03 (0.00 - 0.50)	0.01 (0.00 - 0.08)
Botryococcus	BOT	56	5.8 (4.8 - 7.5)	86 (34 - 319)	0.05 (0.00 - 1.45)	0.10 (0.00 - 2.64)	0.02 (0.00 - 0.38)
Bulbochaete	BUL	31	6.0 (4.8 - 7.2)	115 (42 - 948)	0.00 (0.00 - 0.14)	0.06 (0.00 - 0.54)	0.00 (0.00 - 0.08)
Chlorococcum	CHLOR	4	5.8 (5.5 - 6.2)	84 (62 - 116)	0	0	0
Carteria	CAR	18	6.6 (5.5 - 7.9)	77 (49 - 138)	0	0.05 (0.00 - 0.54)	0
Chaetosphaeridium	CHA	30	6.4 (4.8 - 7.9)	94 (46 - 459)	0.02 (0.00 - 0.28)	0.08 (0.00 - 0.61)	0.02 (0.00 - 0.26)
Characium	CHAR	16	5.9 (4.8 - 7.1)	99 (19 - 237)	0.19 (0.00 - 2.60)	0.22 (0.00 - 1.80)	0.00 (0.00 - 0.04)
Chlamydomonas	CHLA	35	5.6 (4.7 - 6.8	98 (23 - 362)	0.18 (0.00 - 2.60)	0.26 (0.00 - 2.64)	0.03 (0.00 - 0.38)
Chlorella	CHL	30	5.9 (4.4 - 7.6)	92 (28 - 319)	0.21 (0.00 - 2.90)	0.24 (0.00 - 2.10)	0.05 (0.00 - 0.92)
Closterium	CLO	23	5.9 (4.8 - 7.1)	66 (13 - 124)	0.06 (0.00 - 1.45)	0.11 (0.00 - 2.64)	0.02 (0.00 - 0.38)
Coelastrum	COE	25	5.7 (4.7 - 7.1)	80 (28 - 199)	0.10 (0.00 - 1.45)	0.22 (0.00 - 2.64)	0.02 (0.00 - 0.38)
Coenochloris	COCH	3	6.1 (5.9 - 6.3)	90 (71 - 121)	0	0.13 (0.00 - 0.39)	0
Coenococcus	COCO	10	5.7 (4.9 - 6.2)	96 (19 - 244)	0.20 (0.00 - 1.45)	0.35 (0.00 - 2.64)	0.04 (0.00 - 0.38)
Cosmarium	COS	84	5.7 (4.4 - 7.1)	125 (13 - 1562)	0.11 (0.00 - 2.42)	0.22 (0.00 - 3.23)	0.04 (0.00 - 0.74)
Crucigenia	CRU	1	5.1	319	0	0.26	0.04
		N	**pH**	**Conductivity (µS cm^{-1})**	**NH_4-N (mg L^{-1})**	**NO_3-N (mg L^{-1})**	**PO_4-P (mg L^{-1})**

Crucigeniella	CRUC	5	5.6 (5.1 - 6.0)	127 (77 - 319)	0	0.13 (0.00 - 0.39)	0.01 (0.00 - 0.04)
Cylindrocystis	CYL	37	6.0 (4.7 - 7.9)	104 (13 - 896)	0.00 (0.00 - 0.05)	0.05 (0.00 - 0.69)	0.00 (0.00 - 0.09)
Desmidium	DES	1	4.8	91	0	0	0
Dictyosphaerium	DIC	16	6.3 (4.8 - 7.9)	103 (49 - 459)	0.03 (0.00 - 0.21)	0.12 (0.00 - 0.61)	0.02 (0.00 - 0.15)
Elakatothrix	EL	38	6.0 (5.1 - 7.6)	105 (13 - 459)	0.01 (0.00 - 0.28)	0.06 (0.00 - 0.61)	0.01 (0.00 - 0.26)
Euastrum	EUA	25	5.9 (4.8 - 7.5)	97 (13 - 348)	0.13 (0.00 - 1.45)	0.25 (0.00 - 2.64)	0.03 (0.00 - 0.38)
Geminella	GEM	4	5.8 (4.9 - 6.3)	337 (36 - 1205)	0	0	0
Golenkinia	GO	5	6.2 (4.9 - 7.6)	75 (50 - 96)	0	0.14 (0.00 - 0.69)	0
Groenbladia	GRO	1	5.1	121	0.35	0.62	0.17
Hemisphaerella	HEM	6	5.9 (5.2 - 7.0)	96 (13 - 348)	0	0	0
Hormotila	HOR	5	5.4 (5.0 - 5.9)	48 (19 - 82)	0	0	0.00 (0.00 - 0.00
Hyalotheca	HY	17	5.9 (4.6 - 6.8)	74 (13 - 180)	0.03 (0.00 - 0.49)	0.10 (0.00 - 0.79)	0.00 (0.00 - 0.02)
Ichtyocercys	ICH	2	6.1 (6.1 - 6.1)	51 (43 - 59)	0	0	0
Klebsormidium	KL	94	5.8 (4.7 - 7.6)	113 (18 - 1205)	0.04 (0.00 - 1.45)	0.12 (0.00 - 2.64)	0.02 (0.00 - 0.47)
Mesotaenium	MES	2	5.5 (4.8 - 6.2)	114 (59 - 169)	0	0	0
Microspora	MICR	34	5.7 (4.7 - 6.6)	136 (23 - 1205)	0.01 (0.00 - 0.35)	0.03 (0.00 - 0.62)	0.01 (0.00 - 0.17)
Monoraphidium	MON	14	5.9 (5.1 - 7.1)	113 (50 - 416)	0	0.12 (0.00 - 0.61)	0.03 (0.00 - 0.47)
Mougeotia	MOU	89	5.9 (4.4 - 7.5)	109 (13 - 948)	0.03 (0.00 - 0.78)	0.07 (0.00 - 0.97)	0.02 (0.00 - 0.47)
Netrium	NE	6	6.1 (5.6 - 6.5)	74 (46 - 116)	0	0	0
Oedogonium	OE	98	5.8 (4.4 - 7.2)	106 (13 - 948)	0.12 (0.00 - 2.90)	0.17 (0.00 - 3.23)	0.04 (0.00 - 0.92)
Oocystis	OO	24	5.4 (4.4 - 6.8)	176 (13 - 1562)	0.02 (0.00 - 0.54)	0.19 (0.00 - 2.81)	0.04 (0.00 - 0.47)
Pediastrum	PE	4	6.1 (5.9 - 6.5)	84 (59 - 122)	0	0	0.04 (0.00 - 0.15)
		N	**pH**	**Conductivity (µS cm^{-1})**	**NH_4-N (mg L^{-1})**	**NO_3-N (mg L^{-1})**	**PO_4-P (mg L^{-1})**

Penium	PEN	6	6.8 (6.1 - 7.5)	61 (43 - 79)	0	0	0
Prasiola	PRA	4	5.1 (4.4 - 5.9)	109 (79 - 161)	0.05 (0.00 - 0.22)	0.33 (0.00 - 0.61)	0.07 (0.00 - 0.15)
Rhizoclonium	RH	16	6.1 (4.8 - 7.9)	189 (39 - 1549)	0.06 (0.00 - 0.67)	0.15 (0.00 - 0.76)	0.01 (0.00 - 0.15)
Roya	RO	16	6.0 (4.8 - 7.1)	83 (53 - 177)	0.00 (0.00 - 0.05)	0.05 (0.00 - 0.40)	0.01 (0.00 - 0.09)
Scenedesmus	SCE	65	5.7 (4.4 - 7.3)	139 (13 - 1562)	0.11 (0.00 - 1.81)	0.25 (0.00 - 2.81)	0.04 (0.00 - 0.47)
Schroederia	SCH	2	6.1 (4.9 - 7.2)	84 (80 - 87)	0	0	0
Sphaerocystis	SPH	16	6.4 (5.3 - 7.6)	246 (62 - 896)	0.01 (0.00 - 0.21)	0.06 (0.00 - 0.61)	0.01 (0.00 - 0.15)
Spirogyra	SPI	21	6.0 (4.6 - 7.6)	190 (39 - 1814)	0.14 (0.00 - 1.51)	0.22 (0.00 - 1.55)	0.04 (0.00 - 0.42)
Spondylosium	SPO	10	5.9 (4.9 - 7.6)	76 (44 - 122)	0	0	0.02 (0.00 - 0.15)
Staurastrum	STA	10	5.4 (4.4 - 6.3)	117 (50 - 416)	0	0.20 (0.00 - 0.69)	0.01 (0.00 - 0.14)
Staurodesmus	STAU	14	7.0 (5.5 - 7.9)	132 (22 - 459)	0	0	0
Stigeoclonium	STI	3	6.5 (6.2 - 7.1)	195 (36 - 459)	0	0.16 (0.00 - 0.47)	0
Teilingia	TEI	24	5.7 (4.8 - 6.5)	119 (13 - 948)	0.08 (0.00 - 1.45)	0.15 (0.00 - 2.64)	0.02 (0.00 - 0.38)
Tetmemorus	TE	14	5.8 (4.7 - 6.5)	76 (13 - 177)	0.23 (0.00 - 1.81)	0.36 (0.00 - 2.64)	0.09 (0.00 - 0.47)
Tetrastrum	TET	3	5.0 (4.4 - 5.5)	206 (138 - 319)	0	0.20 (0.00 - 0.33)	0.06 (0.00 - 0.14)
Treubaria	TRE	21	6.3 (5.5 - 7.9)	163 (49 - 1549)	0.11 (0.00 - 1.45)	0.21 (0.00 - 2.64)	0.03 (0.00 - 0.38)
Ulothrix	UL	46	5.6 (4.4 - 6.8)	166 (13 - 1205)	0.14 (0.00 - 1.81)	0.29 (0.00 - 2.64)	0.05 (0.00 - 0.47)
Xanthidium	XA	5	5.7 (4.9 - 6.7)	299 (64 - 896)	0.29 (0.00 - 1.45)	0.58 (0.00 - 2.64)	0.08 (0.00 - 0.38)
Zygnema	ZY	48	5.9 (4.6 - 8.5)	170 (23 - 1549)	0.12 (0.00 - 2.60)	0.19 (0.00 - 1.80)	0.02 (0.00 - 0.27)

		N	pH	Conductivity (µS cm^{-1})	NH_4-N (mg L^{-1})	NO_3-N (mg L^{-1})	PO_4-P (mg L^{-1})
Cyanophyta							
Anabaena	AN	39	5.9 (4.4 - 7.2)	150 (30 - 1549)	0.02 (0.00 - 0.67)	0.11 (0.00 - 0.76)	0.01 (0.00 - 0.15)
Anabaenopsis	ANA	4	5.8 (4.8 - 6.3)	72 (44 - 93)	0.01 (0.00 - 0.05)	0.20 (0.00 - 0.40)	0.02 (0.00 - 0.09)
Aphanocapsa	AP	20	6.0 (4.7 - 7.0)	157 (30 - 1549)	0.03 (0.00 - 0.67)	0.04 (0.00 - 0.76)	0.00 (0.00 - 0.04)
Aphanothece	APH	2	5.6 (5.5 - 5.7)	55 (54 - 56)	0	0	0
Calothrix	CAL	35	5.9 (4.6 - 7.6)	112 (23 - 1205)	0.01 (0.00 - 0.35)	0.04 (0.00 - 0.62)	0.01 (0.00 - 0.17)
Chroococcus	CHR	56	5.7 (4.4 - 7.0)	118 (13 - 1814)	0.05 (0.00 - 1.45)	0.11 (0.00 - 2.64)	0.02 (0.00 - 0.47)
Cylindrospermum	CYLM	9	6.0 (5.5 - 6.6)	70 (22 - 244)	0.22 (0.00 - 1.45)	0.39 (0.00 - 2.64)	0.05 (0.00 - 0.38)
Cylindrospermopsis	CYLS	8	5.9 (4.8 - 6.7)	108 (42 - 348)	0	0	0
Gloeocapsa	GLO	29	5.8 (4.7 - 7.5)	114 (36 - 810)	0.01 (0.00 - 0.15)	0.04 (0.00 - 0.56)	0.01 (0.00 - 0.14)
Gloeotheca	GLOE	7	6.4 (5.5 - 7.6)	202 (62 - 810)	0	0	0
Hapalosiphon	HA	7	6.3 (4.7 - 7.2)	172 (50 - 810)	0	0	0
Homoeothrix	HO	4	6.0 (5.2 - 7.6)	136 (76 - 214)	0	0.08 (0.00 - 0.33)	0.02 (0.00 - 0.09)
Komvophoron	KO	5	5.6 (4.4 - 6.7)	157 (77 - 319)	0	0.21 (0.00 - 0.47)	0.04 (0.00 - 0.14)
Leptolyngbya	LEP	4	6.2 (5.5 - 7.6)	84 (66 - 115)	0	0	0
Lyngbya	LY	51	5.6 (4.4 - 7.1)	147 (19 - 1562)	0.09 (0.00 - 2.90)	0.19 (0.00 - 2.81)	0.03 (0.00 - 0.92)
Merismopedia	ME	3	5.1 (4.4 - 5.9)	186 (79 - 319)	0	0.33 (0.26 - 0.39)	0.06 (0.000.14)
Microchaeta	MI	4	6.5 (5.2 - 7.5)	315 (70 - 896)	0	0.08 (0.00 - 0.33)	0.02 (0.00 - 0.09)
Microcystis	MIC	2	6.3 (6.2 - 6.4)	251 (43 - 459)	0	0	0
Nodularia	NOD	8	6.4 (5.2 - 7.5)	156 (65 - 459)	0.19 (0.00 - 1.51)	0.28 (0.00 - 0.97)	0.06 (0.00 - 0.42)
Nostoc	NOS	26	5.7 (4.4 - 6.8)	66 (19 - 161)	0.13 (0.00 - 1.81)	0.21 (0.00 - 2.64)	0.04 (0.00 - 0.47)
		N	**pH**	**Conductivity (µS cm^{-1})**	**NH_4-N (mg L^{-1})**	**NO_3-N (mg L^{-1})**	**PO_4-P (mg L^{-1})**

Oscillatoria	OS	28	5.7 (4.4 - 7.1)	83 (19 - 237)	0.16 (0.00 - 2.60)	0.23 (0.00 - 2.64)	0.02 (0.00 - 0.38)
Phormidium	PH	21	6.0 (4.8 - 7.4)	183 (13 - 1549)	0.11 (0.00 - 1.45)	0.22 (0.00 - 2.64)	0.03 (0.00 - 0.38)
Schizothrix	SCHIZ	10	6.3 (4.7 - 7.5)	107 (36 - 348)	0	0	0
Scytonema	SC	33	6.0 (4.7 - 7.9)	131 (42 - 1205)	0	0	0.01 (0.00 - 0.07)
Scytonematopsis	SCY	2	5.5 (4.8 - 6.2)	261 (63 - 459)	0	0	0
Spirulina	SP	2	5.3 (4.9 - 5.6)	82 (74 - 89)	0	0	0
Stigonema	ST	19	5.4 (4.4 - 6.7)	132 (13 - 896)	0.09 (0.00 - 1.45)	0.17 (0.00 - 2.64)	0.02 (0.00 - 0.38)
Synechocystis	SY	1	5.5	138	0	0	0
Tolypothrix	TO	7	6.5 (6.2 - 7.2)	369 (73 - 896)	0	0	0
Trichodesmium	TRIC	17	6.2 (4.8 - 7.6)	274 (53 - 1549)	0.06 (0.00 - 0.67)	0.15 (0.00 - 0.76)	0.02 (0.00 - 0.26)
Chrysophyta							
Dinobryon	DINO	19	6.5 (4.8 - 7.9)	136 (49 - 1205)	0.00 (0.00 - 0.05)	0.05 (0.00 - 0.54)	0.00 (0.00 - 0.09)
Epipyxis	EPIX	15	5.8 (4.7 - 7.0)	161 (13 - 1205)	0.02 (0.00 - 0.35)	0.04 (0.00 - 0.62)	0.01 (0.00 - 0.17)
Lagynion	LAG	18	6.0 (4.8 - 6.7)	89 (19 - 362)	0	0	0.01 (0.00 - 0.07)
Mallomonas	MA	7	6.0 (5.1 - 6.5)	175 (46 - 459)	0	0.04 (0.00 - 0.26)	0.01 (0.00 - 0.04)
Pseudokephyrion	PS	4	6.5 (5.5 - 7.6)	77 (74 - 81)	0	0	0
Salpingoeca	SA	6	5.9 (5.5 - 6.5)	70 (62 - 81)	0	0.09 (0.00 - 0.54)	0
Synura	SYN	9	5.2 (4.4 - 5.9)	110 (50 - 319)	0	0.14 (0.00 - 0.69)	0.02 (0.00 - 0.14)
Euglenophyta							
Chrysosphaera	CHRY	16	5.9 (4.8 - 7.0)	161 (36 - 1205)	0.02 (0.00 - 0.35)	0.09 (0.00 - 0.62)	0.01 (0.00 - 0.17)
Euglena	EUG	45	6.0 (4.8 - 7.2)	183 (43 - 1549)	0.10 (0.00 - 2.90)	0.18 (0.00 - 2.10)	0.03 (0.00 - 0.92)
Lepocinclis	LE	1	4.7	50	0	0	0
		N	**pH**	**Conductivity (µS cm^{-1})**	**NH_4-N (mg L^{-1})**	**NO_3-N (mg L^{-1})**	**PO_4-P (mg L^{-1})**

Trachelomonas	TRA	54	5.8 (4.5 - 7.6)	140 (13 - 1562)	0.23 (0.00 - 2.90)	0.32 (0.00 - 3.23)	0.06 (0.00 - 0.92)
Pyrrophyta							
Ceratium	CER	6	6.0 (5.5 - 6.5)	78 (46 - 140)	0	0.14 (0.00 - 0.47)	0
Peridinium	PER	18	6.5 (4.8 - 7.9)	114 (49 - 810)	0.06 (0.00 - 0.70)	0.18 (0.00 – 1.55)	0.02 (0.00 - 0.20)
Xanthophyta							
Characiopsis	CHAP	4	5.7 (4.8 - 6.3)	149 (55 - 348)	0	0	0
Heterothrix	HET	1	5.1	121	0.35	0.62	0.17
Tribonema	TRIB	72	5.7 (4.4 - 7.3)	180 (13 - 1814)	0.15 (0.00 - 2.42)	0.29 (0.00 - 3.23)	0.05 (0.00 - 0.74)

3.5 *Canonical Correspondence Analysis of the algal genera and environmental data*

A correlation in which the mean number of genera was compared with the mean conductivity, of each water-type, showed that the mean diversity (number of genera per sample) of all the lentic samples negatively correlates with conductivity (*P*=0.043), PO_4-P (*P*=0.017), NH_4-N (*P*=0.015) and NO_3-N (*P*=0.048). Hence, genus diversity declined with increasing salinity and eutrophication.

Mean (log) conductivity explained 56% (*P*=0.053; Figure 3.1) of the variation in algal diversity between the lentic water body groups and PO_4-P explains 59% (*P*=0.043; Figure 3.2) of the variation in algal diversity between the lentic water body groups. As the only regularly nitrogen and phosphate containing water body group wallows, are very much an outlier group. (Note that “eutrophic” is used here in a relative sense; by world water body standards the mean concentrations of 0.29 mg L^{-1} PO_4-P, 1.24 mg L^{-1} NH_4-N and 1.44 mg L^{-1} NO_3-N in the wallows would certainly not be considered indicative of eutrophication; Table 3.3). The PO_4-P value of the wallows has a higher leverage which prevents correct assessment of the relative importance of both factors.

Therefore, further analysis of the lentic waters, excluding wallows, were conducted. Conductivity of the lentic waters, excluding wallows, still explained 50% (*P*=0.114) of the variation in algal diversity. However, the influence that PO_4-P concentrations have on the algal diversity of the lentic waters was much lower. PO_4-P explained only 21% (*P*=0.352) of the variation in algal diversity between the lentic water body groups, excluding wallows. These results suggest that conductivity plays an important role in the determination of algal diversity. Furthermore, a comparison of the lentic water, excluding Figures 3.2 and 3.3 suggests that conductivity (proxy for salinity), rather than PO_4-P, is the important determinant of algal diversity. Wallows and the Western and Southern lakelets were by far the most saline of the water body types and possessed the lowest diversity, despite an order of magnitude difference in their mean PO_4-P concentrations (Figures 3.2 & 3.3).

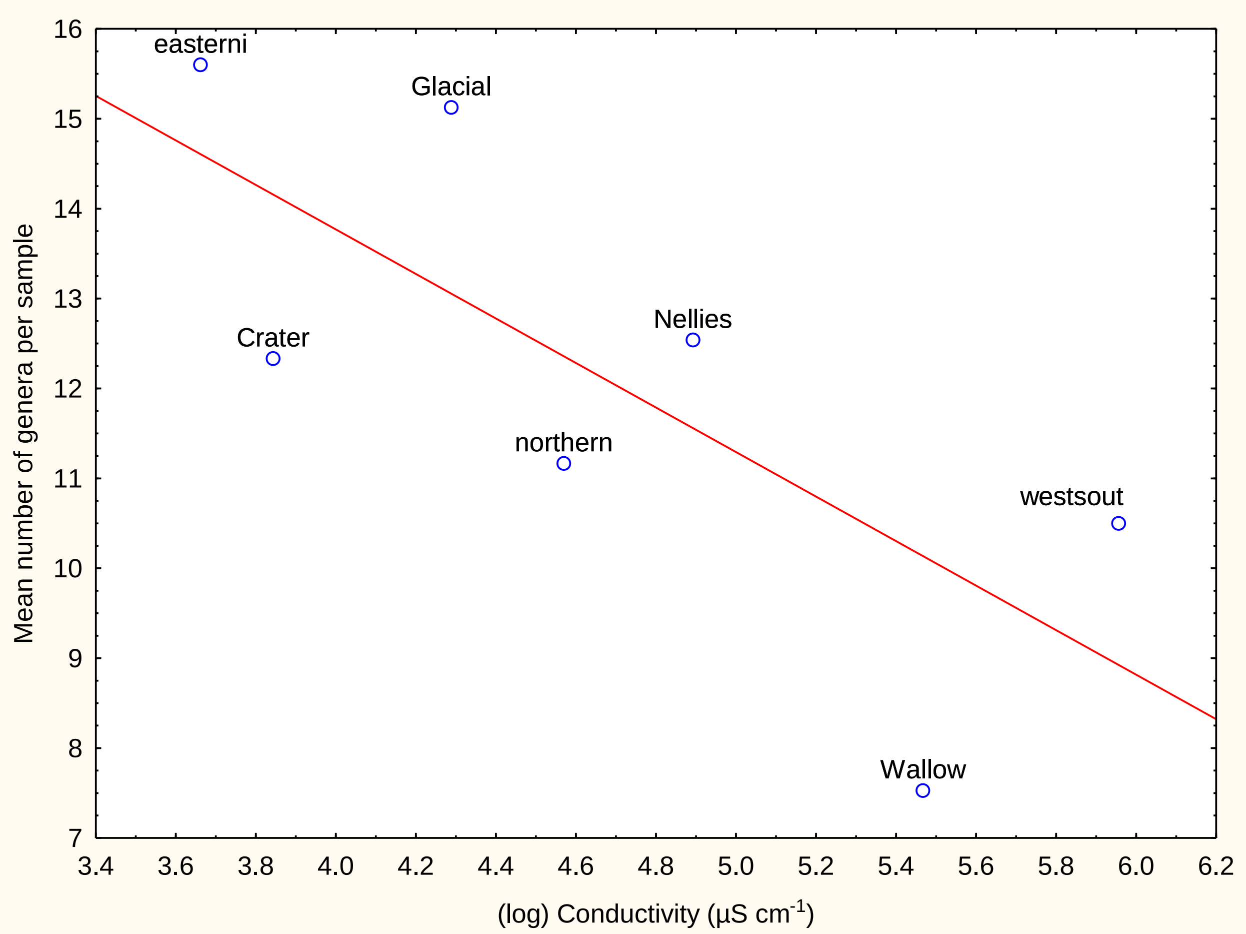

Figure 3.1 Algal diversity (mean number of genera) of the different water body groups compared to mean(log) conductivity of the different water body groups. (Mean (log) conductivity :Mean diversity; r = -0.7478, p = 0.0533; r^2 = 0.5591).

The mean (log) conductivity explained 56% (*P*=0.053; Figure 3.1) of the variation in algal diversity between the lentic water body groups and PO_4-P explains 59% (*P*=0.043; Figure 3.2) of the variation in algal diversity between the lentic water body groups.

To investigate the pH preference of each genus, one-way ANOVAS of pH were conducted with each genus a categorical predictor. This analysis calculated the mean pH for samples where each genus occurred and the mean pH where each genus did not occur. The univariate results determined if the presence or absence of each genus was significant. This analysis showed that 58% of the genera occurred in samples with lower pH than the pH of the samples in which these genera were not found. This implies that 63 genera preferred habitats with low pH. However, the pH difference was only significant (*P* ≤ 0.05) for 29 genera. Genera that preferred more circum-neutral environments (higher pH) included *Actinotaenium, Ankistrodesmus, Carteria, Chaetosphaeridium, Dictyosphaeridium, Dinobryon, Penium, Sphaerocystis, Staurodesmus, Treubaria*, *Tolypothrix* and *Peridinium.* Genera more likely to occur as pH lowers, include *Binuclearia, Chlamydomonas, Chroococcus, Cosmarium, Klebsormidium, Microspora, Oedogonium, Oocystis, Prasiola, Scenedesmus, Staurastrum, Stigeoclonium, Tetrastrum, Ulothrix, Lyngbya*, *Synura* and *Tribonema.*

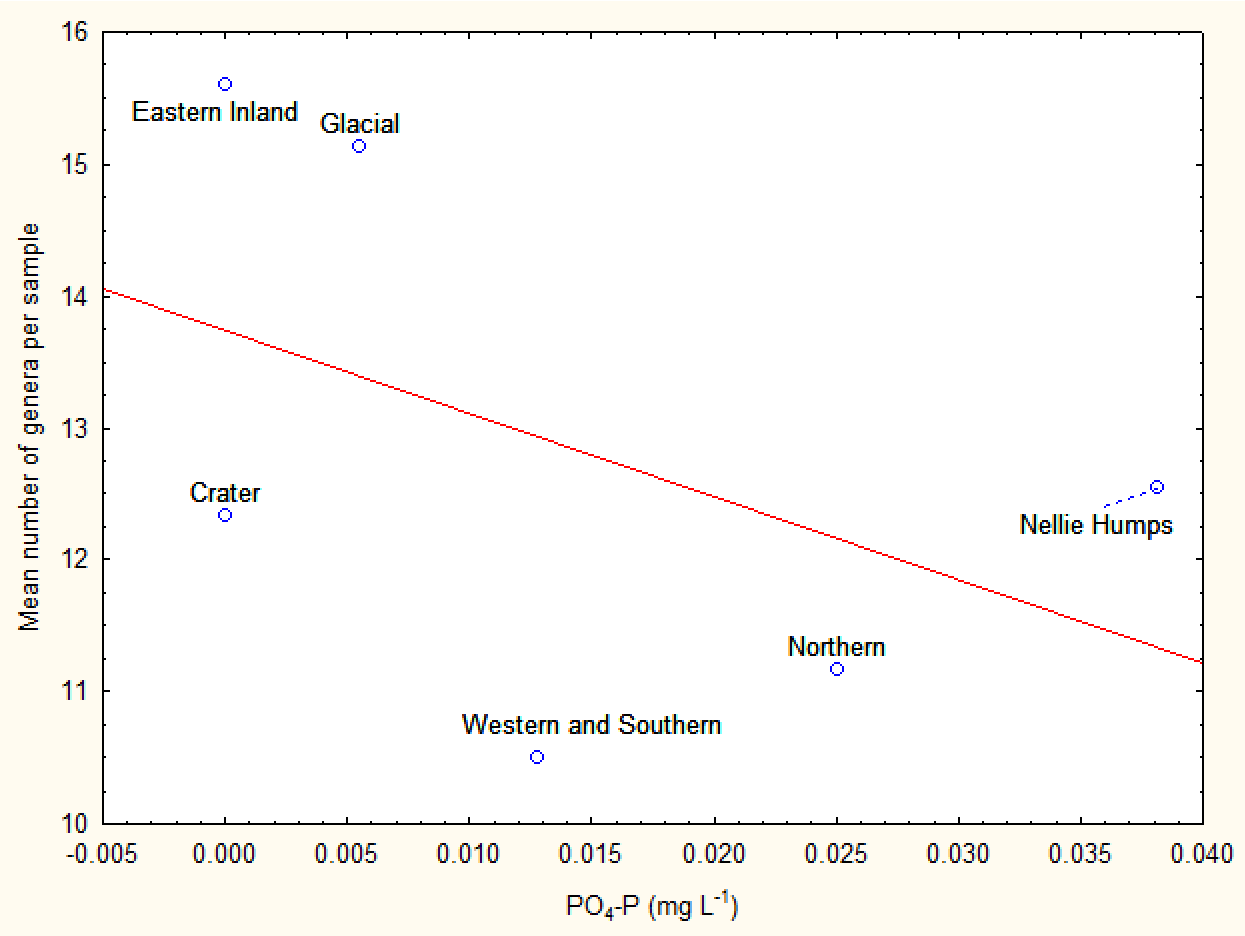

Figure 3.2 The mean algal diversity compared with the mean PO_4–P concentrations of the different water body groups. (Mean PO_4-P:Mean diversity: $r = -0.7710$, $p = 0.0424$; $r^2 = 0.5944$).

Table 3.4 shows the pH ranges for each genus found in 10 or more lentic samples. All 53 genera were found predominantly below mean pH 7. This was determined by the use of one-way ANOVAS of pH with each genus a categorical predictor. The results showed the mean pH for samples where each algal genus occurred and the mean pH where it did not occur. *Microspora, Nostoc, Oocystis* and *Scytonema* were only infrequently found at a pH more than 6.0. Most of the rare genera (in less than 10 samples, therefore not included in Table 3.4) occurred in acidic waters encountered in this study. For example, the mean pH values of samples containing *Crucigenia, Desmidium, Groenbladia, Hormotila, Prasiola,* *Tetrastrum, Merismopedia, Spirulina, Synura, Lepocinclis* and *Heterothrix* were all less than 5.5 (Table 3.3).

Table 3.4 shows the pH ranges for each genus found in 10 or more lentic samples. All 53 genera were found predominantly below pH 7. *Microspora, Nostoc, Oocystis* and *Scytonema* were only infrequently found at pH more than 6.0. Most of the rare genera (in less than 10 samples, therefore not included in Table 3.4) occurred mostly in the acidic waters encountered in this study. For example, the mean pH values of samples containing *Crucigenia, Desmidium, Groenbladia, Hormotila, Prasiola, Tetrastrum, Merismopedia, Spirulina, Synura, Lepocinclis* and *Heterothrix* were all less than 5.5 (Table 3.3).

Algae found in more circum-neutral environments (although still mostly at pH<7.0) were *Carteria, Chaetosphaeridium, Peridinium, Phormidium, Schizothrix, Staurodesmus, Stigeoclonium* and *Zygnema* (Table 3.4). *Staurodesmus* occurred in only 6 samples, but the mean pH of 7.0 (Table 3.3) was the highest for all the genera, so possibly this genus also prefers the more basic waters.

Canonical Correspondence Analysis (CCA) shows that the genus composition is significantly related to (log-transformed) conductivity, PO_4-P concentration and pH. The genus-environment biplot (Figure 4.1) on CCA axes 1 and 2 explains 88.4% of the variance in genus presence or absence with respect to the three water chemistry variables (Table 3.5). The intraset correlation between axis 1 and pH is 0.958 and the correlations between axis 2 and conductivity and PO_4-P are 0.976 and 0.368, respectively. The correlation between axis 3 and PO_4-P is 0.901. Axis 1 thus relates genus presence and absence to pH whereas axis 2 relates it to conductivity and to a lesser extent to PO_4-P, i.e. the influence of sea spray and animal manuring. The two types of influences are distinguished on axis 3 (not shown in graph), where the intraset correlations for conductivity and PO_4-P have opposite signs (-0.135 and 0.901, respectively).

It should also be noted that although axes 1 and 2 explain a lot of the variance in the fitted values of the presence/absence of the genera, together they explain only 4.2% of all variation in the presence/absence of the genera in the data. This is quite low, but not exceptional for ecological data, especially since only the chemical data were used here, and not other water body characteristics, such as lentic or lotic, geographical position, etc.

3.6 *Summary*

In total, 106 genera, mainly belonging to Chlorophyta (60 genera; 56% of total) and Cyanophyta (29 genera; 27% of total), were found in the freshwaters on the island. Other algal divisions found were Chrysophyta (7 genera), Euglenophyta (4 genera), Pyrrophyta (2 genera) and Xanthophyta (4 genera). New additions to the algal flora list of sub-Antarctic and maritime Antarctic islands were contributed and the number of non-diatom freshwater algal genera found on Marion Island has increased from 2 to 106 genera (Grobbelaar, 1978a).

The major factors influencing the chemical composition of the freshwaters on the island are the surrounding ocean and the manuring of seals and seabirds. There were distinct differences in the algal composition between the southern, western and northern lakelets and the lakelets on the eastern side of the island. Algal diversity (number of genera per sample) was negatively correlated with conductivity, PO_4-P, NH_4-N and NO_3-N. Diversity declined significantly with increasing salinity and eutrophication.

Table 3.4 The mean pH ranges for each genus present in 10 or more samples of the lentic freshwaters of Marion Island. These pH ranges were determined by using ANOVAS of pH choosing each genus as the categorical predictor.

4.5-6.0	**4.5-6.5**	**5.0-6.0**	**5.0-6.5**	**5.5-6.5**	**5.0-7.0**	**5.5-7.0**	**6.0-7.0**	**5.5-7.5**
Microspora	*Chlamydomonas*	*Chroococcus*	*Binuclearia*	*Asterococcus*	*Anabaena*	*Actinotaenium*	*Phormidium*	*Carteria*
Nostoc	*Chrysosphaera*	*Teilingia*	*Coelastrum*	*Botryococcus*	*Bulbochaete*	*Ankistrodesmus*	*Schizothrix*	*Chaetosphaeridium*
Oocystis	*Cosmarium*		*Cylindrocystis*	*Closterium*	*Calothrix*	*Aphanocapsa*	*Stigeoclonium*	*Staurodesmus*
Staurastrum	*Gloeocapsa*		*Elakatothrix*	*Coenococcus*	*Chlorella*	*Characium*		*Peridinium*
	Klebsormidium		*Epiphysis*	*Dinobryon*	*Euastrum*	*Dictyosphaerium*		*Zygnema*
	Lyngbya		*Hyalotheca*	*Lagynion*	*Euglena*	*Mougeotia*		
	Oscillatoria		*Monoraphidium*	*Nodularia*	*Rhizoclonium*	*Scytonema*		
	Scenedesmus		*Oedogonium*	*Roya*	*Sphaerocystis*	*Treubaria*		
	Stigonema		*Tetmemorus*	*Spondylosium*	*Spirogyra*			
	Tribonema		*Trachelomonas*		*Trichodesmium*			
	Ulothrix							

Table 3.5 Canonical Correspondence analysis results of the algal genera and environmental data

Axes	1	2	3	4	Total inertia
Eigenvalues	0.136	0.045	0.024	0.370	4.327

Taxon-environment correlations	0.612	0.592	0.481	0.000	
Cumulative percentage variance					
Of taxon-data	3.1	4.2	4.7	13.3	
of taxon-environment relation	66.6	88.4	100.0	0.0	
Sum of all eigenvalues					4.327
Sum of all canonical eigenvalues					0.205

CHAPTER 4: DISCUSSION

4.1 *Freshwater chemical composition*

The island's freshwaters are mostly acidic - the stream being less acidic than the lentic water bodies. Lakelets tend to be more acidic than glacial lakes, probably due to more biological H^+ production in the peaty sediments of the lakelets than in the gravel bottoms of the glacial lakes. In addition, the amount of humic substances is expected to be similarly higher in the lakelets as a result of their peaty sediments than in the glacial lakes leading to lower pH values. Oxidation of H_2S produced in the peaty sediment can also contribute to acidity in the lakelets and can account for the higher observed SO_4^{2-} concentrations in the Nellie Humps, Western and Southern lakelets than in glacial lakes.

The wallows, Western and Southern lakelets showed higher mean conductivity values than most of the other water bodies, which is likely related to their location. Wallows are situated close to the sea and thus highly subjected to sea spray. The wind at the island is predominant westerly. Therefore, the Western and Southern lakelets are subjected to much more intense sea spray than the lakelets located on the northern and eastern side of the island. Hence, Eastern Inland lakelets, crater lakes, and glacial lakes tend to have low ion and nutrient concentrations, since they are mainly situated inland, away from bird or seal colonies. The chemical composition of wallows is similarly to a large extent influenced by manuring of seals and seabirds.

In summary, the major factors influencing the chemical composition of the island's freshwaters are geographic location, the distance to the surrounding ocean and the biotic influence (Chapter 3). This is also the case on other Antarctic and Maritime Antarctic Islands. For example, on King George Island, the freshwater lakes were strongly affected by a combination of substrate type, presence of animals and vegetation, exposure to prevailing wind and the proximity to the sea (Vinocur & Urein, 2000). Broady (1989) also concluded that sea-spray influenced the chemical characteristics of the freshwater lakes on Ross Island.

The mean conductivity (370 µS cm^{-1}; range 0 µS cm^{-1} to 1 571 µS cm^{-1}) reported by Saunders *et al.* (2008) for the freshwaters of Macquarie Island is higher than the mean conductivity of the lakes on Marion Island (123.74 µS cm^{-1}; range 39 µS cm^{-1} to 1 814 µS cm^{-1}). On Île de la Possession the overall PO_4-P concentration is similar to that of Marion Island, ranging between 0.00 mg L^{-1} and 0.32 mg L^{-1}, except for a single sample which had a PO_4–P concentration of 2 500.00 mg L^{-1} (Van den Vijver & Beyens, 1999). Marion Island's waters are generally more acidic than those of Macquarie Island where the pH ranges from 5.50 to 9.95 (Saunders *et al.,* 2008). On average, the freshwater bodies on Île de la Possession (pH range 4.9 to 10.0) are more alkaline than that of Marion and Macquarie Islands. These differences in chemical limnology are expected to have a profound effect in the diversity and community composition of the water bodies on the different sub-Antarctic islands (see below).

4.2 *Algal assemblage*

Filamentous algae (green, blue-green or yellow-green) were present in all the samples. The most common green algae were *Cosmarium, Klebsormidium, Mougeotia* and *Oedogonium.* The most common cyanobacteria were *Lyngbya* and *Chroococcus.* The filamentous yellow-green alga, *Tribonema,* was also abundant.

Cosmarium occurred in more than half of the samples and is one of the most diverse genera of the order Desmidiales, containing more than 1 000 species (Wehr & Sheath, 2003). It is not surprising that *Cosmarium* is one of the most commonly found genera on Marion Island as the island's freshwaters are oligotrophic, acidic and characterised by low calcium concentrations; conditions regarded as optimal for this genus (John *et al*., 2008).

Klebsormidium also occurred in more than half of the freshwater bodies. *Klebsormidium* usually grows intermingled with other filamentous forms and was accompanied by *Oedogonium* 67% of the time and by *Mougeotia* 59% of the time. *Mougeotia* is a cosmopolitan genus that generally occurs in oligotrophic and acidic aquatic lentic and lotic environments (Wehr & Sheath, 2003; John *et al.,* 2008). *Oedogonium* is a widespread cosmopolitan genus that is common in less calcareous conditions (John *et al*., 2008). In samples where *Oedogonium* was present, epiphytes were also present. This is likely related to the fact that *Oedogonium* has very hard walls, which are frequently covered by many minute filamentous epiphytes (Wehr & Sheath, 2003). Among these, *Lagynion* and *Epipyxis* were the most frequently found chrysophytes. Although *Lagynion* is one of the genera which is often overlooked in algal collections, because it is slightly transparent and relatively small (Prescott, 1951), it was identified in 15 of the water bodies sampled, and it was only found in samples in which *Oedogonium* was also present. The epiphytes *Epipyxis, Hemisphaerella, Characium* and *Ankyra* occurred in 80% and *Characiopsis* in 75% of the samples in which *Oedogonium* was present. These findings underline the importance of *Mougeotia* and *Oedogonium* as ecosystem engineers in providing a habitat for epiphytes in these water bodies.

Of the 30 cyanophyte genera identified in the freshwater of Marion Island, unicellular *Chroococcus* and species belonging to the filamentous genus *Lyngbya* were the most abundant. Many of the Cyanophyta present in the water samples form heterocysts, which are likely related to the oligotrophic nature of these water bodies. Heterocysts enable cyanobacteria to fixate atmospheric N_2 and make nitrogen biologically available.

Euglenoids, such as *Trachelomonas* and *Euglena,* were found in water bodies with relatively high PO_4-P concentrations (mean value of 0.92 mg L^{-1}). These algae indicate organic water pollution and high nutrient levels (Wehr & Sheath, 2003). *Euglena* can tolerate a wide pH range, from extremely acidic to alkaline conditions (Wehr & Sheath, 2003). In this study *Euglena* was found in water bodies with a pH between 5 and 7 and *Trachelomonas* between 5 and 6.5 (Table 3.3).

The algal flora of Marion Island closely resembles that of other sub-Antarctic islands, such as Îles Kerguelen, Îles Crozet and Macquarie Island, where Chlorophyta and Cyanophyta also dominate (Therezien & Coute, 1977; Selkirk *et al.,* 1990). The same six algal divisions present on Marion Island were also recorded on Îles Kerguelen, and representatives of the Rhodophyta also occurred on Îles Kerguelen (Therezien & Coute, 1977). However, in-depth studies of the algal floras of most Sub-Antarctic Islands are largely lacking, preventing an in-depth comparison.

Considering that the island is quite small (290 km^2) and relatively young (c. 0.45 million years), the freshwater algal flora of Marion Island is very diverse, with 109 genera found so far. This is more than the 97 genera found on Îles Kerguelen, the largest (6 500 km^2), and the oldest (40 million years) of the sub-Antarctic islands, and also the best studied regarding freshwater algae (Therezien & Coute 1977; Van de Vijver, 2001). The total number of genera found on Marion Island is more than twice that found in South Georgia, Signy, Livingston or King George Islands (Hirano, 1965; Therezien & Coute, 1977, Priddle & Belcher, 1982; Selkirk *et al.*, 1990; Vinocur & Unrein, 2000; Mrozińska *et al.,* 2007; Zidarova, 2008). Nineteen freshwater and terrestrial algae, belonging to Cyanophyta and Chlorophyta, have been recorded from Macquarie Island. This number of genera from Macquarie Island is surprisingly low, but Selkirk *et al*. (1990) suggested that sampling has been incomplete, thereby giving a possible explanation.

A similarity analysis was performed on the island's algal flora and that of other sub-Antarctic and Maritime Antarctic islands (Table 4.1). Marion Island had the lowest affinity with Macquarie Island, situated in the South Pacific Ocean Province and South Georgia Island, situated in the South Atlantic Ocean Province (Table 4.1). The algal flora of Marion Island shows the highest affinity with the flora of Îles Kerguelen, and to a lesser extent with the flora of Îles Crozet. This likely reflects the fact that both Îles Kerguelen and Crozet belong to the South Indian Ocean Province (SIOP), as does Marion Island. Similar results were found for diatoms (Van de Vijver & Beyens, 1999) and vascular plants (Van den Putten *et al*., 2010). Hence, the degree of island endemism is relatively low, but the incidence of endemism within each of the provinces is relatively high (Van de Vijver & Beyens, 1999). There is no significant relation between the distance of the islands and the similarity of their algal floras (r= -0.619; *P*= 0.138; Table 4.1). This is similar to freshwater diatom floras, in which the similarity coefficients between sub-Antarctic islands and Maritime Antarctic islands were lower than the coefficients between islands within each group, irrespective of how far the islands were situated apart from each other (van de Vijver & Beyens, 1999).

Table 4.1 Affinities of algal genera between some Southern Ocean islands

	Sub-Antarctic				Maritime Antarctic		
	South Indian Ocean Province		South Pacific Ocean Province	South Atlantic Ocean Province	South Orkney Islands	South Shetland Islands	
	Îles Kerguelen[1]	Îles Crozet[1]	Macquarie Island[2]	South Georgia Island[3]	Signy Island[4]	Livingston Island[5]	King George Island[6,7]
Sørensen-Dice coefficient	0.55	0.42	0.27	0.20	0.35	0.36	0.41

No. of genera	97	37	19	16	31	47	53
Km away from Marion Island	2313	1068	8631	5070	5284	5905	5820

[1]Therezien & Coute (1977), [2]Selkirk *et al.* (1990), [3]Hirano (1965), [4]Priddle & Belcher (1982), [5]Zidarova (2009), [6]Vinocur & Unrein (2000), [7]Mrozińska *et al.* (2007).

However, despite similar observations in different taxonomic groups, the comparison between the different algal floras needs to be cautiously interpreted, because the inventories of most regions were based on a very small amount of samples. This might for example explain why the Marion Island algal flora shows a higher affinity with the flora of two Maritime Antarctic islands close to, but south of, South Georgia than with that island itself. A more in depth analysis of the algal diversity is therefore needed (see Chapter 5 – perspectives).

4.3 *Algal genera and water chemistry*

Distinct differences were observed in the algal composition between the southern, western and northern lakelets, and the lakelets on the eastern side of the island, which are likely related to limnological variability. Most of the island's algae occur more frequently in oligosaline (low conductivity) and ultra-oligotrophic (low NH_4-N, NO_3-N and PO_4-P) waters. The majority of the algal studies on sub-Antarctic and maritime-Antarctic are taxonomical studies, where ecological questions were secondary and therefore little information on algal ecology is available for the sub-Antarctic region (Hirano, 1965; Therezien & Coute, 1977; Priddle & Belcher, 1982; Selkirk *et al*., 1990; Mrozińska *et al*., 2007; Zidarova, 2009). Many algal genera have particular environmental tolerances or requirements and are constricted to specific environmental conditions (Wehr & Sheath, 2003). The difference in salinity and eutrophication (nitrogen and phosphate concentrations) accounts for much of the differences in algal diversity between the different groups of lentic water bodies. The glacial lakes, crater lakes and the Eastern Inland lakelets are the freshest of the water bodies and exhibit a high algal diversity, while the wallows, Western and Southern lakelets are the most saline with detectable nitrogen and phosphate concentrations, but the lowest algal diversity.

The influence of sea spray, nitrogen and phosphate enrichment by marine animals on algal diversity has also been shown in studies from other Antarctic regions. For example, ponds on King George Island enriched with penguin guano showed the highest phytoplankton densities (in terms of numbers), but the lowest diversity (Vinocur & Unrein, 2008). This was also found to be true on Signy Island, where nutrient-poor lakes, with low nitrogen and phosphate concentrations, had a much higher algal diversity, than the enriched lakes (Heywood, 1978).

The wallows (17 samples) had the highest phosphate concentrations (mean PO_4-P = 0.29 mgL^{-1}) and the lowest mean number of genera per sample (8 genera; Table 3.1 & 3.2). The Eastern Inland lakelets (15 samples) contained no detectable nitrogen or phosphate concentrations and had the highest mean number of genera per sample (16 genera; Table 3.1 & 3.2). The decrease in algal richness with increasing nitrogen and phosphate concentrations is surprising because in most field-based and experimental studies, the algal diversity increases along a gradient from low to moderate nutrient concentrations and primary production (Cardinale *et al*., 2009). The higher diversity of the nitrogen and phosphate poor lakes is probably related to the fact that these types of lakes are more abundant on the island and other Antarctic regions leading to a higher regional diversity of taxa adapted to low nitrogen and phosphate concentrations, which in turn results in a higher diversity.

4.4 *The relation between community composition and limno-chemistry*

The biplots of the canonical correspondence analysis (CCA) of the genera found in ten or more samples indicated that there are differences in algal assemblages between the various types of freshwater bodies (Figure 4.1 & 4.2). This is in accordance with the results of their limno-chemical preferences based on analyses of variance comparing the samples in which the genera occurred with those in which the genera were absent (Chapter 3).

The genera on the lower left part of biplot (e.g. *Binuclearia, Nostoc, Oscillatoria, Teilingia* and *Tetmemorus;* Figure 3.1) occur in more acidic waters with low conductivity values. Genera occurring at the lower part centre along the negative side of the second axis (e.g. *Closterium* and *Hyalotheca*) occurred in oligosaline waters.

Staurodesmus and *Carteria* are both strongly positively correlated with pH and occur in more circum-neutral waters. Genera (e.g. *Carteria, Chaetosphaeridium, Dictyosphaerium, Dinobryon, Staurodesmus, Schizothrix* and *Peridinium*) on the lower right part of the environmental biplot (Figure 3.1) occur in more alkaline waters with low phosphate concentrations and low conductivity values. This is in accordance with ANOVA results, as all these genera occur at high pH values (Table 3.4) in oligotrophic waters (with very low concentrations of nitrogen and phosphate).

Genera (i.e. *Actinotaenium, Bulbochaete, Calothrix, Chlorella, Cylindrocystis, Elakatothrix, Lagynion, Roya, Scytonema* and *Spondylosium)* situated on the negative side of the second and first axis occur in more neutral waters with low phosphate concentrations and low conductivity values.

Genera occurring in the upper right quadrant of the plot (i.e. *Anabaena, Ankistrodesmus, Aphanocapsa, Chrysosphaera, Euglena, Monoraphidium, Phormidium, Rhizoclonium, Sphaerocystis, Spirogyra, Treubaria, Trichodesmium* and *Zygnema*) are characterised by slightly alkaline (high pH) and more brackish (high conductivity) waters. Genera which are found at the upper left part of the plot (e.g. *Ulothrix, Tribonema, Oocystis* and *Staurastrum*) occurred in slightly eutrophic and acidic waters.

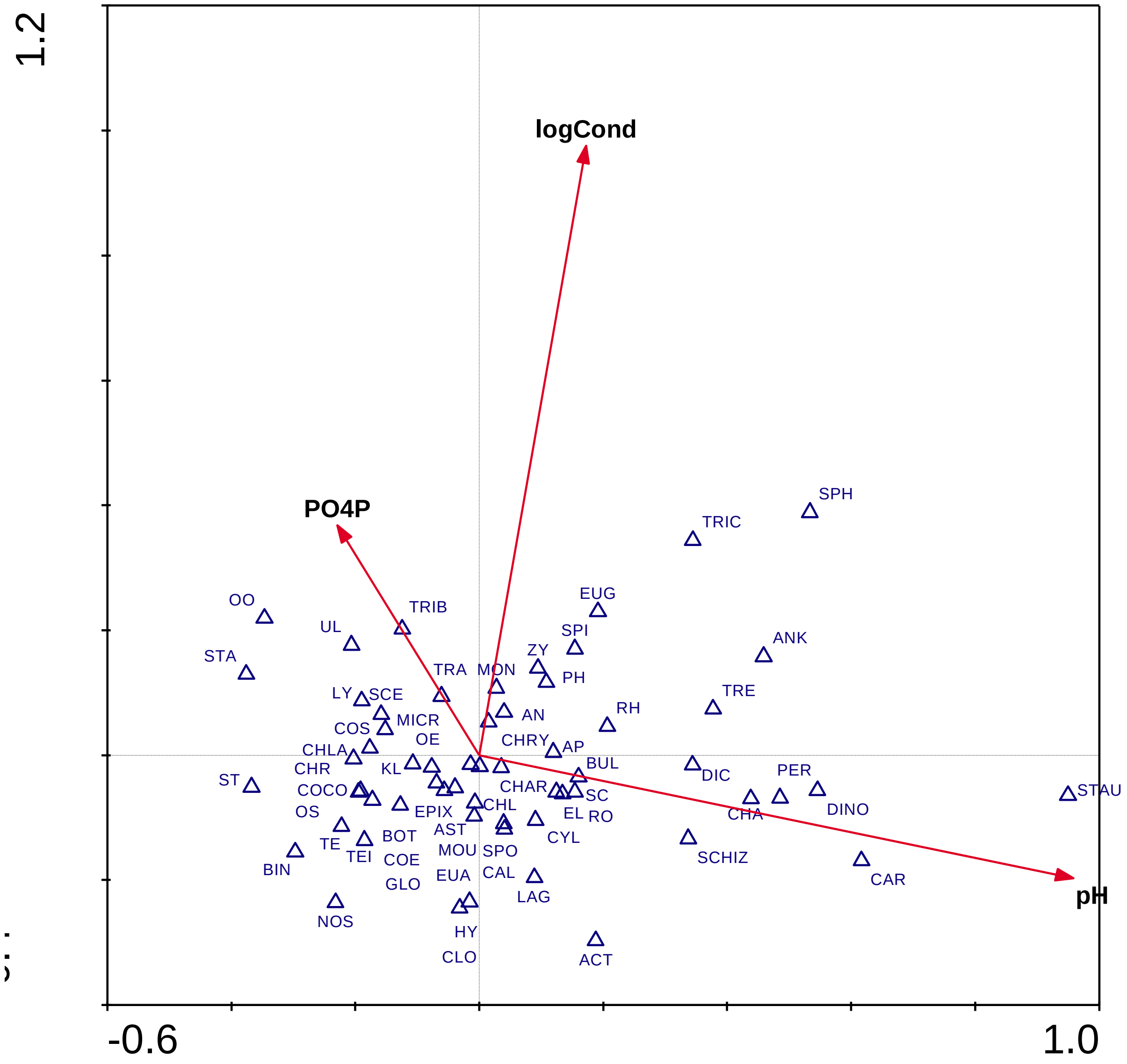

Figure 4.1 Canonical Correspondence Analysis genera and environment biplot.

In general, stream samples are different from samples from the lentic environments and characterised by *Staurodesmus* and *Carteria* (Figure 4.2). The Western and Southern lakelets and some wallows are situated along the positive side of the second axis and characterised by the presence of *Sphaerocystis, Trichodesmium* and *Ankistrodesmus.* Eastern Inland lakelets are clustered along the negative side of the second axis. The Nellie Humps, most of the wallows, and some Western and Southern lakelets are situated along the positive side of the second axis, but the negative side of the first axes. Figure 3.2 shows that they are characterised by the presence of genera such *as Ulothrix, Tribonema* and *Scenedesmus.*

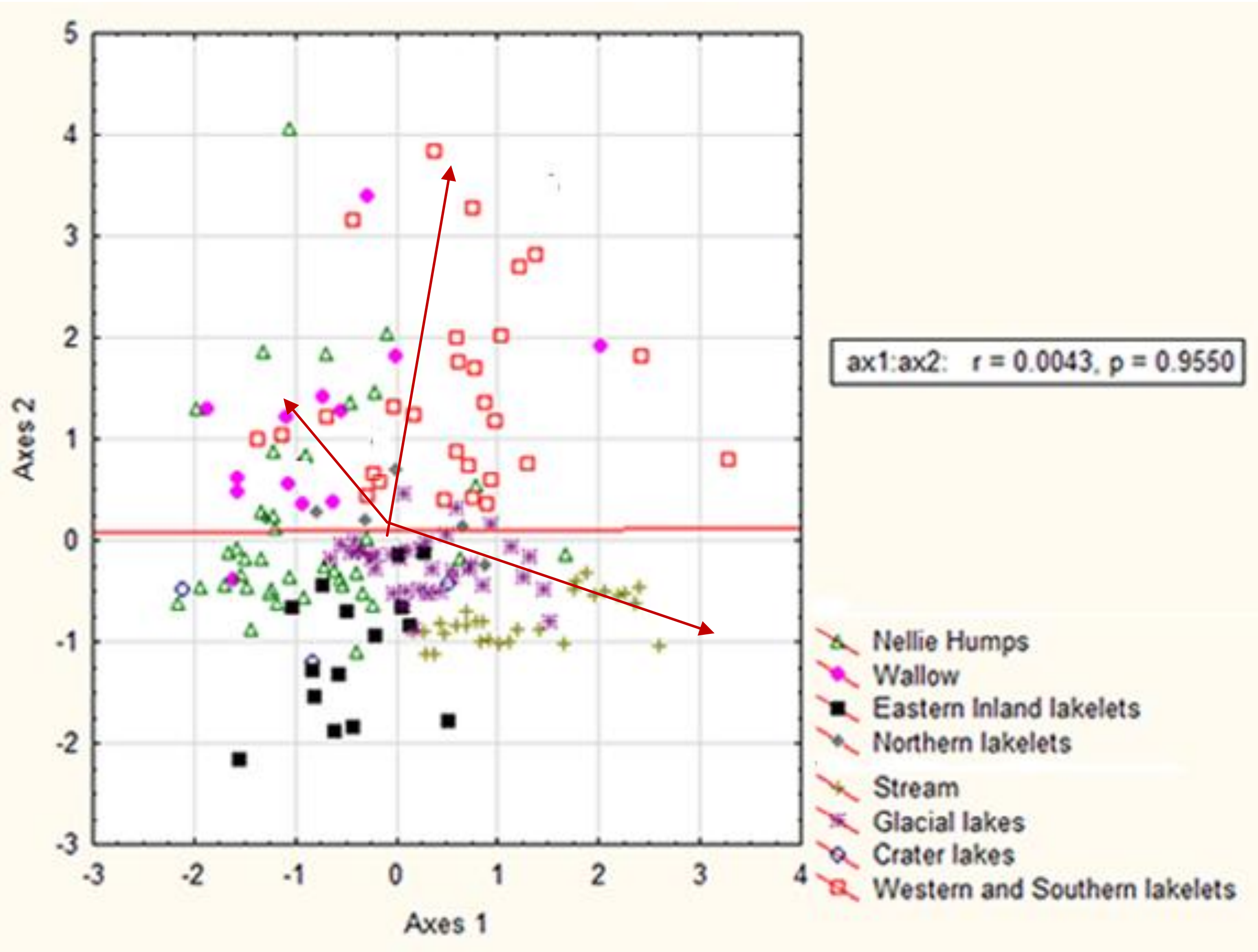

Figure 4.2 Canonical Correspondence Analysis showing the samples and environmental variables. In this sample-environment biplot, sampling positions are the original sampling sites and none of the sites have been fitted.

The ordination analysis revealed a close coupling between limnological conditions and the presence of particular algal communities (Figures 4.1 & 4.2). The first group is characteristic of the island's most oligohaline and acidic waters. Since oligohaline and acidic water is the most prevalent limnochemistry type, this group may be considered as the most abundant freshwater algal assemblage on Marion Island (Table 4.2). The oligohaline and acidic algal genera occured in many of the Nellie Humps and Eastern Inland lakelets. The genera which preferred oligohaline and acidic waters according to the CCA results include *Asterococcus, Binuclearia, Botryococcus Closterium, Coelastrum, Coenococcus, Epiphysis, Euastrum, Gloeocapsa, Hyalotheca, Mougeotia, Nostoc, Oscillatoria* and *Teilingia* (Table 4.2, column 1).

The genus-environmental biplot (Figure 4.1) indicates *Sphaerocystis* and *Trichodesmium* as the characteristic genera of the islands more saline waters, especially the Western and Southern lakelets. Water samples containing these genera had a mean conductivity nearly 4 times higher than that of samples in which *Sphaerocystis* and *Trichodesmium* did not occur (difference significant at P=0.002 and P=0.03, respectively). These two genera are not indicative of substantial nitrogen or phosphate enrichment. *Tolypothrix, Microchaeta* and *Microcystis* occurred in too few samples to be included in the CCA, but the mean conductivities of the samples in which they were found were higher than for any of the other genera. Therefore, they also preferred euhaline conditions (Table 4.2, column 2). The CCA results indicated that other genera also found in euhaline conditions include *Anabaena, Ankistrodesmus, Aphanocapsa, Chrysosphaera, Euglena, Monoraphidium, Phormidium, Rhizoclonium, Spirogyra, Treubaria* and *Zygnema* (Table 4.2, column 6). These genera occurred in euhaline conditions, but also waters with low conductivity values, therefore these genera are more generalists and occurred under high and low conductivity conditions.

The genus-environment and samples-environment biplots (Figures 4.1 and 4.2) distinguish genera associated with (relatively) eutrophic water bodies, such as wallows and the more phosphate enriched lakelets close to the sea. These genera include *Chlamydomonas, Trachelomonas, Tribonema, Ulothrix* and *Xanthidium. Cosmarium*, *Lyngbya*, *Oocystis* and *Staurastrum* occurred in the same region of the genus-environmental biplot mainly because of their low location on the pH arrow; they prefer acidic, oligotrophic (low nitrogen and phosphate concentrations) waters and are therefore separated from the relatively eutrophic group on the biplot, not shown, with CCA axes 2 and 3). *Prasiola* was not included in the CCA but is considered to belong to the relatively eutrophic algal group on the basis that mean PO_4-P and NO_3-N concentrations for the four samples in which it occurred (0.074 and 0.334 mg L^{-1}, respectively) are both in the upper part 5% of the concentrations found for the water samples overall.

The genus-environment biplot (Figure 4.1) on axes 1 and 2 identify *Carteria, Chaetosphaeridium, Dictyosphaerium, Dinobryon, Staurodesmus, Schizothrix* and *Peridinium* to occur in more basic freshwaters. These 7 genera, scored highest on CCA axis 1, prefer the island's basic, or more correctly, less acid, waters. The mean pH of the samples in which each of these genera occurred ranged between 6 and 6.5 (Table 3.3; 75% of those samples had a pH more than 6.0). The genera which preferred more basic conditions occurred in the glacial and crater lakes. (Table 4.2, column 4).

Most of the algal genera preferred pH values < 6.5 and it is difficult to distinguish the most acidophilic genera in the genus-environmental biplot. Analyses of variance of the raw data and also their positions on axis 3 of the CCA (not shown) suggest the genera *Chroococcus, Cosmarium, Lyngbya, Microspora, Oocystis, Scenedesmus, Stigonema,* and *Stuarastrum* as being some of the algae that prefer the island's most acid waters. These genera all occurred in water with a mean pH lower than 6. Genera occurred in acidic waters were often found in the Nellie Humps, Northern, Western and Southern lakelets and also the wallows (Table 4.2, column 5).

Some algal genera (such as *Anabaena* and *Monoraphidium*) had low intraset correlations with all three axes. They show no discernible affinities to particular water chemistry regimes, although they were less frequently found in the most haline or nitrogen and phosphate containing samples. Hence, they are considered as the island's generalist algae regarding their water chemistry preferences (Table 4.2, column 6).

Table 4.2 The algal genera occurring in the different limno-chemical environments according to their water chemistry preferences and based on the CCA results and one-way ANOVA analysis (Figures 4.1 & 4.2). Note, as explained in the text, the terms basic, euhaline and eutrophic are relative; all the waters sampled in this study were acidic or neutral and would be considered very fresh and oligotrophic by world standards.

Oligohaline/ Acidic waters	**Euhaline**	**Eutrophic**	**Basic**	**Acid**	**Generalist**
Asterococcus	*Microchaeta*	*Chlamydomonas*	*Carteria*	*Oocystis*	*Anabaena*
Binuclearia	*Microcystis*	*Trachelomonas*	*Chaetosphaeridium*	*Staurastrum*	*Ankistrodesmus*
Botryococcus	*Sphaerocystis*	*Tribonema*	*Dictyosphaerium*	*Lyngbya*	*Aphanocapsa*
Closterium	*Tolypothrix*	*Ulothrix*	*Dinobryon*	*Scenedesmus*	*Chrysosphaera*
Coelastrum	*Trichodesmium*	*Xanthidium*	*Staurodesmus*	*Cosmarium*	*Euglena*
Coenococcus			*Schizothrix*	*Stigonema*	*Microspora*
Epiphysis			*Peridinium*	*Chroococcus*	*Monoraphidium*
Euastrum					*Phormidium*
Gloeocapsa					*Rhizoclonium*
Hyalotheca					*Spirogyra*
Mougeotia					*Treubaria*
Nostoc					*Zygnema*
Oscillatoria					
Teilingia					

5.5 *Conclusions*

Here we report the results of the first taxonomic inventory of the algal (excluding diatom) flora in 175 freshwater bodies on the volcanic Marion Island. Our data captured the limnological diversity of the island. Nitrogen and phosphate concentrations were low (below detection limits) in most water bodies. The most slightly eutrophic water bodies (as a result of seabird and seal manuring) were located near the coast. Generally, the water bodies were oligosaline, with the most brackish lakes situated along the western and eastern coast.

Hundred and nine algal genera (belonging to 6 phyla) were identified, showing a diversity significantly exceeding any other guild of living organisms on the island. Chlorophyta (green algae) and cyanobacteria were the most common, and dominated over all other phyla. The most common chlorophytes included *Cosmarium*, *Klebsormidium*, *Mougeotia* and *Oedogonium*, while *Anabaena, Chroococcus* and *Lyngbya* were the most common cyanophytes. The filamentous yellow-green alga, *Tribonema,* also occurred frequently. Other algal groups present on the island (in lower concentrations and diversity) included members of the Chrysophyta, Euglenophyta, Pyrrophyta and Xanthophyta.

There were distinct differences in the algal composition between the streams, the southern, western and northern lakelets, and the lakelets on the eastern side of the island. Sixty seven genera were identified in the stream. The most frequently occurring chlorophytes found in the stream were *Actinotaenium, Carteria, Chaetosphaeridium, Klebsormidium, Mougeotia* and *Oedogonium*. The cyanophytes *Calothrix* and *Scytonema* were also frequently found in the stream.

We observed a clear relation between the occurrence of particular genera and environmental conditions, of which conductivity, PO_4-P and pH significantly explained variation in community structure. Diversity declined with increasing salinity and eutrophication. The chlorophytes *Crucigenia, Geminella* and *Xanthidium* and the cyanophytes, *Microchaeta, Tolypothrix* and *Trichodesmium* were present in the more brackish waters. Chrysophyta, Euglenophyta, Pyrrophyta and Xanthophyta did not occur in any sample with conductivity above 250 µS cm^{-1}.

Genera found in nitrogen and phosphate containing waters were *Chlamydomonas, Oedogonium, Prasiola, Spirogyra, Tetmemorus, Trachelomonas, Tribonema, Ulothrix* and *Xanthidium*. Most genera preferred low pH (<6.5) water and some rare genera were restricted to the acidic waters. Genera likely to occur in acidic waters include *Binuclearia, Chlamydomonas, Chroococcus, Cosmarium, Klebsormidium, Microspora, Oedogonium, Oocystis, Prasiola, Scenedesmus, Staurastrum, Stigeoclonium, Tetrastrum, Ulothrix, Lyngbya*, *Synura* and *Tribonema.*

The algal flora of Marion Island showed the highest similarity with algal assemblages on Îles Kerguelen and Crozet, which are located in the same biogeographic province (Van der Putten *et al*., 2010). A similarity was found with the islands from the other 2 Sub-Antarctic provinces and Maritime Antarctica.

CHAPTER 5: FUTURE RESEARCH

5.1 *Future research*

Although we obtained interesting results, we encountered some limitations, which are discussed below.

5.1.1 *Sampling*

The sampling on Marion Island is strongly affected by severe logistical limitations. Never the less, it would be important to extend sampling to the large empty spaces on the map (Fig. 2.1), by e.g. sampling water bodies in the Cape Davis and Mixed Pickle Cove area, as well as in the region around Kildalkey. In addition, more high altitude water bodies, as well as streams, should be included to obtain a clear picture of all aquatic systems on the island. For the stream only a few, widely spaced samples should be taken, extending from high altitude to the coast line.

Sampling during different seasons would also allow investigation of seasonal variation of algae on the island.

5.1.2 *Limitations of the results and identification constraints*

Accurate algal species determination is a prerequisite to infer the relation between taxa and environmental conditions (Rossaro & Mietto, 1998). Identification to genus level only allows scientists to reveal broadscale patterns (Resh & MecElravy, 1993). During this study algae were identified to genus level, because (i) floras specific for the sub-Antarctic region are largely lacking, (ii) some algae do not show morphological characteristics which enable us to identify them to species level. Moreover, separation of cyanophyte species are difficult, because many characters used to distinguish species belonging to *Oscillatoria, Lyngbya* and *Phormidium* are often markedly influenced by environmental conditions (John *et al.,* 2008). In addition, in order to accurately identify the majority of filamentous green and yellow green algae, characteristics pertaining their life cycles are required. For example, Zygnemataceae including *Mougeotia, Oedogonium, Spirogyra* and *Zygnema* undergo sexual reproduction and species delineation is largely based on the characteristics of the conjugation cells and the resulting zygospores (John *et al.,* 2008;

Wehr & Sheath, 2003). Observation of algal reproduction within a sample is very rare. Hence, for these taxa a culturing approach including observations of their life cycle characteristics, is necessary for species delineation. Moreover, during a study on the freshwater algae of Livingston Island, 47 algal species were only discovered after extensive culturing (Zidaravo, 2008). This shows that there are reasons to believe that many sub-Antarctic algal species remain unidentified, because culturing techniques are not always used during phycological studies. Other taxa such as chrysophytes, pyrrophytes and desmids require the use of the Scanning Electron Microscope (SEM) to investigate the morphology necessary for identification in detail (Wehr & Sheath, 2003). Finally, for most groups, current species boundaries are defined using molecular phylogenies based on multiple genes (De Wever *et al.*, 2009).

Therefore, it is recommended that a follow-up study must be done that aims to identify all the taxa to species level, using detailed morphological and molecular analyses of the algae living in the various habitats of Marion and Prince Edwards Islands. Culturing algal samples will also be valuable. The advent of next generation pyrosequencing techniques (Petrosino *et al*., 2009) is in this respect promising and will allow scientists to accurately analyse a large amount of samples.

5.1.3 *Comparison between Southern Ocean Islands.*

It is becoming increasingly clear that regional endemism among microorganisms in the sub-Antarctic and Antarctic regions does exist and that allopatric speciation is predicted among Antarctic microorganisms (Sabbe *et al.,* 2003, Vyverman *et al.,* 2010). The present study showed that there are likely to be regional endemic species among the algal genera of SIOP, because a large amount of taxa did not fit in floras from elsewhere. Again, the use of SEM, life cycle studies for a selection of taxa, in combination with molecular markers have the potential to study biogeography of microalgae in the Southern Ocean and compare the patterns found with those present in plants and animals. These studies will also lead to a more correct assessment of the true diversity, because the number of recognised algal species found in the Antarctic, sub-Antarctic and maritime Antarctic is probably greatly underestimated. In part, this is due to the under sampling of many habitats, in combination with the difficulties encountered for studying their diversity (see above, Stevenson *et al.,* 1996; Vanormelingen *et al.,* 2008). Molecular markers can also be used to develop phylogenies and molecular clocks, which will allow scientists to assess the importance of past climate and tectonic events for the evolution of microalgae in the Antarctic region. This approach was for example used to study mites and revealed a complex biogeographic pattern with colonisation events between the different regions in response to past geological events (Mortimer *et al*., 2011).

In future research, aimed at assessing the difference between the different provinces, one should also ensure that all lacustrine habitats in each region are included. This will involve the analysis of physical and chemical limnological data, in combination with a multivariate analysis of the limnological diversity. Ideally, sufficient samples from each habitat type should be included.

In addition to the lacustrine algae, the study of terrestrial algae in soil also holds a great potential. These communities include soil and aerophytic algae but also aquatic algae inhabiting the littoral zone of mires. These types of environment remain poorly studied. These taxonomic inventories can then be used to study the difference and potential species turnover between terrestrial and aquatic habitats. This is important, because it is becoming clear that the Antarctic microbial flora is dominated by terrestrial species, as for example observed in diatoms (Van de Vijver *et al*., 2011). Moreover, the different habitats in the Prince Edward Islands need to be intensely studied and the water bodies of Prince Edward Island, which is distinct from Marion Island, need to be studied.

I conclude that a more in depth sampling of the sub-Antarctic region, in combination with state-of-the-art techniques for species delineation in microorganisms are highly needed to assess the true diversity and the biogeographic zoning in this understudied group of organisms.

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SMITH VR (2011) Department of Botany and Zoology, University of Stellenbosch, Private Bag X1, Matieland, 7602, South Africa.

APPENDIX 1: Study site information

Notes including the coordinates, size, altitude, nearest distance from sea, chemical composition and number of algal genera found in the 175 freshwater study sites.

Sample number	Date Collected	Latitude (S) decimal degrees	Longitude (E) decimal degrees	Area (m^2)	Altitude (a.s.l)	Distance from sea (m)	Water body group (text section 2.1)	Total algal genera found	pH	Cond ($\mu S\ cm^{-1}$)	NH_4-N ($mg\ L^{-1}$)	NO_3-N ($mg\ L^{-1}$)	P O_4-P ($mg\ L^{-1}$)	Ca^+ ($mg\ L^{-1}$)	Mg^{2+} ($mg\ L^{-1}$)	K^+ ($mg\ L^{-1}$)	Na^+ ($mg\ L^{-1}$)	Cl^- ($mg\ L^{-1}$)	SO_4^{2-} ($mg\ L^{-1}$)	O.O.F. (text section 2.2) mEq Cl / Σ mEq
1	11/04/07	46.8743	37.8512	1000	39	520	Nellie Humps lakelet	38	5.5	62	0.00	0.00	0.00	0.59	1.35	0.28	10.52	22.07	3.43	0.97
2	11/04/07	46.8737	37.8526	800	28	398	Nellie Humps lakelet	21	5.6	63	0.00	0.00	0.00	0.66	1.36	0.39	11.11	23.84	3.37	0.98
3	11/04/07	46.8727	37.8512	100	34	480	Nellie Humps lakelet	16	5.6	56	0.00	0.00	0.00	0.59	1.26	0.73	10.41	22.07	3.92	0.95
4	11/04/07	46.8722	37.8518	20	30	440	Nellie Humps lakelet	19	4.8	63	0.00	0.00	0.00	0.51	1.24	0.49	10.42	21.19	4.28	0.94
5	11/04/07	46.8754	37.8485	70	45	741	Nellie Humps lakelet	17	5.3	49	0.00	0.00	0.00	0.78	0.98	0.47	8.85	19.42	3.20	0.96
6	11/04/07	46.8767	37.8482	120	43	797	Nellie Humps lakelet	15	5.7	54	0.00	0.00	0.00	0.59	1.13	0.62	9.48	20.31	3.95	0.94
7	12/04/07	46.8622	37.8484	4500	81	380	Glacial lake	17	6.4	75	0.00	0.00	0.00	0.94	1.67	0.31	12.12	26.49	4.20	0.97
8	12/04/07	46.8623	37.8454	15000	82	573	Glacial lake	23	6.0	81	0.00	0.00	0.00	0.62	1.76	0.52	12.85	27.37	4.08	0.97
9	12/04/07	46.8615	37.8431	3000	78	512	Glacial lake	27	6.5	65	0.00	0.54	0.00	1.12	1.52	0.20	11.07	24.72	4.17	0.92
10	12/04/07	46.8613	37.8440	800	78	477	Glacial lake	16	5.6	74	0.00	0.00	0.00	0.62	1.58	0.42	11.83	25.61	4.56	0.96
11	12/04/07	46.8601	37.8448	4200	74	341	Glacial lake	13	5.6	75	0.00	0.00	0.00	0.65	1.57	0.38	12.03	26.49	3.80	0.98
12	12/04/07	46.8587	37.8461	50	69	190	Glacial lake	30	5.9	79	0.00	0.39	0.00	0.67	1.72	0.36	13.14	25.61	4.36	0.93

Sample number	Date Collected	Latitude (S) decimal degrees	Longitude (E) decimal degrees	Area (m^2)	Altitude (a.s.l)	Distance from sea (m)	Water body group (text section 2.1)	Total algal genera found	pH	Cond (µS cm^{-1})	NH_4-N (mg L^{-1})	NO_3-N (mg L^{-1})	P O_4-P (mg L^{-1})	Ca^+ (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	O.O.F. (text section 2.2) mEq Cl / Σ mEq
13	12/04/07	46.8587	37.8462	1000	69	181	Glacial lake	23	5.5	77	0.00	0.00	0.00	0.63	1.59	0.24	12.74	27.37	4.18	0.97
14	12/04/07	46.8587	37.8460	1500	68	190	Glacial lake	21	5.6	81	0.00	0.00	0.00	0.81	1.73	0.26	12.92	29.14	4.30	0.98
15	12/04/07	46.8645	37.8442	7200	88	800	Glacial lake	15	6.3	71	0.00	0.00	0.00	0.75	1.69	0.35	12.01	22.96	4.17	0.95
16	12/04/07	46.8644	37.8503	30	77	438	Glacial lake	23	5.9	77	0.00	0.00	0.00	0.71	1.62	1.30	12.69	26.49	4.09	0.97
17	14/04/07	46.8981	37.8723	5000	51	574	Glacial lake	12	6.4	73	0.00	0.00	0.00	0.85	1.61	0.58	11.65	24.72	3.79	0.97
18	14/04/07	46.8981	37.8732	1800	52	524	Glacial lake	9	5.7	74	0.00	0.00	0.00	0.67	1.62	0.55	11.89	25.61	3.69	0.98
19	14/04/07	46.8983	37.8759	800	59	443	Glacial lake	12	6.8	73	0.00	0.00	0.00	0.68	1.78	0.59	12.02	26.49	4.02	0.97
20	14/04/07	46.9160	37.8816	40	45	728	Glacial lake	5	6.2	93	0.00	0.00	0.00	1.01	2.13	0.55	14.29	30.02	4.54	0.98
21	14/04/07	46.8969	37.8815	700	39	256	Glacial lake	30	6.2	116	0.00	0.00	0.00	1.02	2.49	0.61	17.57	37.08	5.10	0.99
22	14/04/07	46.8962	37.8798	1000	48	150	Glacial lake	15	5.8	122	0.00	0.00	0.00	0.92	2.53	0.84	18.29	38.85	5.35	0.99
23	14/04/07	46.8963	37.8793	1300	49	160	Glacial lake	18	6.5	105	0.00	0.00	0.00	0.84	2.14	0.79	15.90	35.32	4.54	0.99
24	14/04/07	46.8924	37.8743	2000	24	61	Glacial lake	12	6.7	90	0.00	0.00	0.00	1.17	2.20	0.94	12.97	27.37	4.13	0.97
25	14/04/07	46.8925	37.8666	1200	39	633	Glacial lake	19	5.9	73	0.00	0.00	0.00	0.73	1.72	0.54	11.40	22.96	3.98	0.96
26	14/04/07	46.8895	37.8712	9000	19	177	Glacial lake	25	6.8	85	0.00	0.00	0.00	1.20	3.01	0.58	17.59	34.44	5.06	0.98
27	15/04/07	46.8796	37.8295	50	146	2258	Eastern Inland lakelet	19	5.9	75	0.00	0.00	0.00	0.70	1.46	0.85	9.50	22.07	3.30	0.97

Sample number	Date Collected	Latitude (S) decimal degrees	Longitude (E) decimal degrees	Area (m^2)	Altitude (a.s.l)	Distance from sea (m)	Water body group (text section 2.1)	Total algal genera found	pH	Cond (µS cm^{-1})	NH_4-N (mg L^{-1})	NO_3-N (mg L^{-1})	P O_4-P (mg L^{-1})	Ca^+ (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	O.O.F. (text section 2.2) mEq Cl / Σ mEq
28	15/04/07	46.8803	37.8292	15	153	2306	Eastern Inland lakelet	27	6.1	79	0.00	0.00	0.00	1.16	1.59	0.84	9.76	21.19	3.39	0.96
29	15/04/07	46.8833	37.8296	400	290	2400	Crater Lake	14	6.3	64	0.00	0.00	0.00	0.56	1.15	0.32	8.20	18.54	3.51	0.94
30	15/04/07	46.8857	37.8222	300	198	3025	Eastern Inland lakelet	10	5.4	55	0.00	0.00	0.00	0.60	1.08	0.33	7.42	17.66	3.57	0.93
31	15/04/07	46.8872	37.8122	200	280	3783	Eastern Inland lakelet	25	5.6	46	0.00	0.00	0.00	0.42	0.80	0.25	5.59	14.13	2.69	0.93
32	15/04/07	46.8774	37.8170	5000	195	3099	Glacial lake	16	7.1	53	0.00	0.00	0.00	0.53	0.92	0.17	6.50	16.78	3.22	0.94
35	16/04/07	46.8911	37.7751	40	617	5798	Eastern Inland lakelet	7	5.9	39	0.00	0.00	0.00	0.44	0.63	0.30	4.45	12.36	2.37	0.92
36	16/04/07	46.8893	37.8098	200	286	4047	Eastern Inland lakelet	9	5.2	45	0.00	0.00	0.00	1.29	0.79	0.24	5.30	13.24	3.03	0.91
37	16/04/07	46.8901	37.8125	100	277	3900	Eastern Inland lakelet	15	6.0	50	0.00	0.00	0.00	0.64	0.94	0.43	5.91	14.13	2.48	0.94
38	16/04/07	46.8889	37.8114	4000	281	3916	Eastern Inland lakelet	19	6.1	44	0.00	0.00	0.00	0.43	0.78	0.31	5.08	15.89	2.15	0.97
39	18/04/07	46.8630	37.8550	300	6	57	Nellie Humps lakelet	13	6.3	140	0.00	0.47	0.00	1.45	3.11	1.23	21.60	54.74	5.09	1.00
41	18/04/07	46.8636	37.8555	8	7	61	Wallow	6	5.2	214	0.00	0.33	0.09	1.48	4.52	2.14	37.14	66.22	9.81	0.97
42	18/04/07	46.8638	37.8558	90	10	57	Wallow	5	6.2	211	1.51	0.97	0.42	1.21	3.59	2.91	28.77	60.92	8.39	0.95
43	18/04/07	46.8649	37.8568	3	15	128	Nellie Humps lakelet	19	4.4	161	0.00	0.33	0.14	0.91	2.71	1.22	22.44	47.68	6.10	0.98

Sample number	Date Collected	Latitude (S) decimal degrees	Longitude (E) decimal degrees	Area (m^2)	Altitude (a.s.l)	Distance from sea (m)	Water body group (text section 2.1)	Total algal genera found	pH	Cond (µS cm^{-1})	NH_4-N (mg L^{-1})	NO_3-N (mg L^{-1})	P O_4-P (mg L^{-1})	Ca^+ (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	O.O.F. (text section 2.2) mEq Cl / Σ mEq
44	18/04/07	46.8641	37.8574	8	9	45	Nellie Humps lakelet	26	5.1	319	0.00	0.26	0.04	1.76	5.29	2.19	47.35	92.71	11.67	1.00
45	18/04/07	46.8662	37.8596	70	8	71	Wallow	4	6.3	476	2.42	3.23	0.74	2.86	7.67	6.08	63.64	121.85	18.79	0.92
46	18/04/07	46.8687	37.8586	200	8	71	Nellie Humps lakelet	11	5.4	177	0.00	0.61	0.47	1.46	3.29	1.67	26.84	52.98	7.49	0.95
47	18/04/07	46.8869	37.8678	12	9	192	Wallow	14	4.8	93	0.05	0.40	0.09	0.62	1.61	0.83	12.93	29.14	3.48	0.96
48	18/04/07	46.8865	37.8681	120	9	134	Wallow	9	6.0	123	1.81	1.75	0.47	0.89	1.69	2.41	14.66	30.90	5.72	0.83
49	18/04/07	46.8873	37.8705	30	7	22	Nellies	9	5.4	416	0.00	0.54	0.00	2.40	7.90	1.81	59.47	116.55	14.38	1.00
50	18/04/07	46.8867	37.8697	20	5	50	Nellie Humps lakelet	14	7.1	90	0.00	0.47	0.00	1.11	2.33	0.48	12.85	26.49	3.83	0.94
51	18/04/07	46.8866	37.8694	8	7	58	Nellie Humps lakelet	7	5.4	211	0.00	0.61	0.09	0.97	3.07	0.92	32.18	60.04	7.64	0.98
52	18/04/07	46.8781	37.8619	4500	6	20	Nellie Humps lakelet	6	4.5	1562	0.54	2.81	0.14	9.31	28.50	9.47	230.53	443.24	56.67	0.99
53	20/04/07	46.8432	37.7837	300	9	502	Northern lakelet	11	5.6	96	0.00	0.00	0.00	1.63	1.87	0.83	14.72	27.37	4.64	0.96
54	20/04/07	46.8416	37.7862	37500	9	250	Northern lakelet	5	6.5	77	0.00	0.00	0.00	1.07	1.60	0.52	10.72	21.19	3.54	0.96
55	20/04/07	46.8407	37.7886	20	10	153	Northern lakelet	8	6.0	122	0.00	0.00	0.15	1.02	2.18	0.90	18.12	35.32	5.18	0.97
56	20/04/07	46.8403	37.7850	100	12	205	Wallow	8	5.3	104	0.21	0.61	0.15	0.91	1.86	0.65	14.47	31.79	5.19	0.92

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57	20/04/07	46.8408	37.7825	30	16	390	Northern lakelet	17	4.9	87	0.00	0.00	0.00	0.63	1.75	0.85	14.86	30.90	4.48	0.98
58	20/04/07	46.8374	37.7779	80	26	179	Wallow	6	5.1	133	0.15	0.00	0.04	0.75	2.22	0.85	20.50	43.26	4.03	1.02
59	20/04/07	46.8359	37.7738	200	12	170	Wallow	5	6.0	134	0.28	0.54	0.26	1.08	2.34	0.67	19.19	39.73	5.56	0.95
60	20/04/07	46.8343	37.7702	250	13	60	Wallow	8	6.3	1549	0.67	0.76	0.04	7.84	24.77	9.78	243.88	450.31	61.12	1.00
61	20/04/07	46.8375	37.7566	7	57	448	Northern lakelet	8	5.2	96	0.00	0.69	0.00	0.63	1.54	0.81	14.33	28.25	4.31	0.92
62	20/04/07	46.8356	37.7525	20	46	349	Northern lakelet	18	6.3	101	0.00	0.00	0.00	0.82	1.77	0.65	14.34	31.79	4.90	0.97
63	21/04/07	46.8883	37.8047		316	4357	Stream	1	6.9	48	0.00	0.00	0.00	1.03	1.11	0.57	7.24	22.07	2.46	0.99
64	21/04/07	46.8874	37.8078		281	4101	Stream	1	7.0	49	0.00	0.00	0.00	1.47	1.47	0.81	7.89	14.13	2.78	0.93
65	21/04/07	46.8867	37.8116		272	3811	Stream	14	7.5	70	0.00	0.00	0.00	2.30	1.54	1.01	8.49	16.78	2.92	0.95
66	21/04/07	46.8841	37.8143		230	3517	Stream	11	7.3	68	0.00	0.00	0.00	2.12	1.49	0.94	8.46	17.66	2.81	0.96
67	21/04/07	46.8822	37.8178		176	3201	Stream	7	7.2	70	0.00	0.00	0.00	2.19	1.58	1.03	8.47	18.54	3.01	0.96
68	21/04/07	46.8789	37.8239		154	2657	Stream	11	7.9	49	0.00	0.00	0.00	2.02	1.69	0.97	9.08	19.42	2.29	0.99
69	21/04/07	46.8766	37.8284		139	2261	Stream	10	7.4	71	0.00	0.00	0.00	1.97	1.68	1.02	9.09	17.66	2.93	0.95
70	21/04/07	46.8745	37.8314		100	2000	Stream	6	7.5	71	0.00	0.00	0.00	1.96	1.67	1.02	9.14	20.31	2.61	0.98
71	21/04/07	46.8713	37.8363		72	1602	Stream	16	7.6	66	0.00	0.00	0.00	1.82	1.57	0.89	8.83	16.78	2.83	0.95

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72	21/04/07	46.8691	37.8431		59	1089	Stream	19	7.2	74	0.00	0.00	0.00	1.95	1.81	1.25	9.35	17.66	2.62	0.96
73	21/04/07	46.8689	37.8508		35	525	Stream	14	7.6	76	0.00	0.00	0.00	2.23	1.89	0.97	9.24	15.89	3.15	0.93
74	21/04/07	46.8697	37.8563		14	98	Stream	13	7.2	80	0.00	0.00	0.00	2.17	2.21	0.93	9.94	19.42	2.97	0.96
75	21/04/07	46.8731	37.8557	50	19	152	Nellie Humps lakelet	11	4.8	91	0.00	0.00	0.00	0.75	1.54	0.65	12.83	26.49	4.03	0.97
76	29/04/07	46.9219	37.5990	80	36	356	Western and Southern lakelet	10	5.5	115	0.00	0.00	0.00	0.90	2.03	0.87	18.46	34.44	4.79	0.99
77	29/04/07	46.9219	37.5989	300	36	356	Western and Southern lakelet	12	5.5	138	0.00	0.00	0.00	1.14	2.60	1.03	21.14	37.08	5.71	0.98
78	29/04/07	46.9241	37.5975	2500	40	381	Western and Southern lakelet	9	6.2	271	0.00	0.00	0.00	1.76	5.09	1.70	40.04	75.93	10.60	1.00
79	29/04/07	46.9274	37.5972	2500	39	526	Western and Southern lakelet	2	6.4	124	0.00	0.00	0.00	0.93	2.15	0.94	19.54	35.32	5.54	0.97
80	29/04/07	46.9287	37.5965	1200	59	523	Western and Southern lakelet	1	8.5	160	0.00	0.00	0.27	3.53	2.90	1.51	22.92	39.73	4.76	0.99
81	29/04/07	46.9285	37.5938	7500	47	324	Western and Southern lakelet	12	6.6	177	0.00	0.00	0.00	1.27	2.24	1.12	18.58	31.79	4.80	0.98
82	29/04/07	46.9303	37.5881	3600	39	172	Western and Southern lakelet	11	6.2	810	0.00	0.00	0.00	3.99	12.67	5.61	117.25	215.44	29.17	1.00

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83	29/04/07	46.9310	37.5875	1900	30	168	Western and Southern lakelet	11	6.3	896	0.00	0.00	0.00	4.71	16.01	5.72	138.62	249.88	33.41	1.00
84	29/04/07	46.9292	37.5910	900	54	233	Western and Southern lakelet	7	7.2	455	0.00	0.00	0.00	2.45	8.07	2.68	69.19	124.50	17.06	1.00
85	29/04/07	46.9292	37.5899	90	50	188	Western and Southern lakelet	18	6.2	459	0.00	0.00	0.00	2.37	6.97	3.54	72.46	126.26	14.43	1.02
86	29/04/07	46.8802	37.8575	40	38	467	Nellie Humps lakelet	6	4.7	67	0.00	0.00	0.00	0.53	1.04	0.75	10.07	17.66	3.17	0.94
87	29/04/07	46.8821	37.8575	30	40	624	Nellie Humps lakelet	15	4.7	50	0.00	0.00	0.00	0.65	0.71	0.64	7.21	15.01	2.64	0.94
88	29/04/07	46.8817	37.8605	15	31	483	Nellie Humps lakelet	6	5.2	57	0.00	0.00	0.00	0.41	0.91	0.73	8.03	18.54	2.67	0.97
89	29/04/07	46.8806	37.8631	50	24	277	Nellie Humps lakelet	11	5.1	51	0.00	0.00	0.00	0.37	0.83	0.53	8.12	17.66	3.05	0.95
90	29/04/07	46.8802	37.8636	100	21	212	Nellie Humps lakelet	11	4.9	50	0.00	0.00	0.00	0.39	0.74	0.63	8.47	19.42	2.41	0.98
91	29/04/07	46.8792	37.8634	200	10	144	Nellie Humps lakelet	10	4.9	89	0.00	0.00	0.00	0.63	1.50	1.03	14.72	30.02	3.85	0.99
301	17/04/10	46.8800	37.8618	4500	20	268	Nellie Humps lakelet	12	5.4	117	0.37	1.55	0.20	1.67	2.83	1.22	23.04	28.20	7.20	0.81

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302	17/04/10	46.8743	37.8512	4000	40	513	Nellie Humps lakelet	11	4.7	64	0.00	0.00	0.00	1.29	1.66	0.05	14.48	24.67	4.82	0.94
303	18/04/10	46.8897	37.8696	9000	20	256	Glacial lake	8	5.4	68	0.00	0.00	0.00	1.06	1.84	0.00	14.02	26.43	3.53	0.98
304	18/04/10	46.8866	37.8682	2000	10	128	Nellie Humps lakelet	4	6.6	66	0.14	0.56	0.14	1.22	1.58	0.63	11.71	24.67	4.15	0.90
305	18/04/10	46.8808	37.8631	200	25	283	Nellie Humps lakelet	8	5.5	59	0.00	0.00	0.00	0.76	1.24	0.00	11.70	26.43	3.26	0.99
306	19/04/10	46.8703	37.8410		65	1220	Stream	8	7.2	45	0.00	0.00	0.00	1.81	1.40	0.05	8.51	17.62	2.39	0.97
307	19/04/10	46.8653	37.8440	4000	85	850	Glacial lake	10	7.0	67	0.00	0.00	0.00	0.97	1.69	0.00	13.68	24.67	3.89	0.97
308	19/04/10	46.8642	37.8457	32600	83	666	Glacial lake	4	6.3	67	0.00	0.00	0.00	0.86	1.91	0.00	15.33	22.91	4.63	0.94
309	19/04/10	46.8618	37.8436	2500	80	530	Glacial lake	9	5.8	66	0.00	0.00	0.00	0.86	1.70	0.00	13.58	28.20	4.22	0.97
310	19/04/10	46.8612	37.8441	600	80	464	Glacial lake	13	5.8	66	0.00	0.00	0.00	0.78	1.61	0.00	12.61	26.43	4.39	0.96
311	19/04/10	46.8600	37.8450	4000	74	320	Glacial lake	15	5.7	71	0.00	0.00	0.00	0.81	1.71	0.00	13.99	24.67	4.10	0.96
312	19/04/10	46.8589	37.8463	1200	70	215	Glacial lake	11	5.5	73	0.00	0.00	0.00	1.10	1.77	0.00	14.63	26.43	4.13	0.97
313	20/04/10	46.8833	37.8295	1100	286	2390	Crater lake	3	4.4	46	0.00	0.00	0.00	0.72	1.15	0.00	9.42	17.62	3.68	0.93
314	20/04/10	46.8866	37.8269	800	216	2741	Eastern Inland lakelet	14	5.7	28	0.00	0.00	0.00	0.52	0.65	0.00	6.25	15.86	2.32	0.96
315	20/04/10	46.8885	37.8132	225	320	3751	Crater lake	20	5.5	30	0.00	0.00	0.00	0.52	0.74	0.00	6.50	10.57	2.23	0.91

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316	20/04/10	46.8888	37.8116	2000	288	3877	Eastern Inland lakelet	17	5.6	23	0.00	0.00	0.00	0.52	0.68	0.00	5.15	8.81	2.18	0.88
317	20/04/10	46.8894	37.8097	250	285	4047	Eastern Inland lakelet	17	5.5	28	0.00	0.00	0.00	0.45	0.64	0.00	5.26	10.57	2.25	0.90
318	23/04/10	46.8793	37.8632	0.6	13	156	Wallow	6	4.8	53	2.60	1.80	0.00	0.41	0.82	0.00	11.29	17.62	2.59	0.79
319	23/04/10	46.8792	37.8636	200	11	128	Nellie Humps lakelet	10	5.1	49	0.00	0.00	0.00	0.47	1.02	0.00	12.10	19.38	2.89	0.97
320	23/04/10	46.8792	37.8636	1	11	128	Nellie Humps lakelet	12	5.5	61			0.04							
321	23/04/10	46.8808	37.8637	40	23	244	Nellie Humps lakelet	5	5.1	46	0.00	0.00	0.00	0.72	1.04	0.00	10.94	22.91	3.16	0.98
322	23/04/10	46.8828	37.8670	0.6	20	189	Wallow	5	5.9	62	2.90	2.10	0.92	0.85	0.66	0.00	12.27	17.62	3.12	0.70
323	26/04/10	46.9295	37.5881	75	43	361	Western and Southern lakelet	3	5.3	1814	0.00	0.00	0.00	16.83	52.85	14.93	442.41	817.68	123.93	0.99
324	26/04/10	46.9307	37.5884	400	40	480	Western and Southern lakelet	6	4.9	948	0.14	0.30	0.02	9.43	26.56	7.74	239.38	449.37	64.69	1.00
325	26/04/10	46.9310	37.5868	50	22	534	Western and Southern lakelet	12	5.7	1205	0.00	0.00	0.00	10.21	32.53	10.45	294.04	563.92	76.56	1.01
326	26/04/10	46.9338	37.5878	40	48	640	Western and Southern lakelet	9	5.9	362	0.00	0.00	0.00	8.19	9.57	2.77	88.81	162.13	24.20	0.99

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327	26/04/10	46.9353	37.5878	150	48	549	Western and Southern lakelet	9	5.9	434	0.00	0.00	0.00	4.43	13.04	2.53	101.30	186.80	28.46	0.99
328	26/04/10	46.9388	37.5888	1000	49	439	Western and Southern lakelet	12	5.6	237	0.00	0.00	0.00	2.29	6.38	1.92	51.70	95.16	13.86	0.99
329	26/04/10	46.9429	37.5922	15	60	558	Western and Southern lakelet	7	5.7	227	0.00	0.00	0.00	2.42	5.86	1.88	51.03	89.87	13.29	0.99
330	26/04/10	46.9450	37.5945	8000	73	625	Western and Southern lakelet	7	6.2	162	0.00	0.00	0.00	2.15	4.67	1.03	35.48	70.49	9.23	1.00
331	26/04/10	46.9436	37.5914	1000	60	487	Western and Southern lakelet	21	6.1	348	0.00	0.00	0.00	3.58	9.77	2.54	79.97	151.55	21.91	1.00
332	26/04/10	46.9344	37.5949	600	50	1011	Western and Southern lakelet	15	4.7	161	0.00	0.00	0.00	1.53	3.88	0.94	35.86	68.73	8.49	1.00
333	26/04/10	46.9330	37.5948	40	50	868	Western and Southern lakelet	23	4.8	169	0.00	0.00	0.00	1.60	4.05	0.82	36.82	70.49	9.84	0.99
334	26/04/10	46.9318	37.5942	1500	50	734	Western and Southern lakelet	9	5.2	199	0.20	0.50	0.02	1.93	5.08	1.38	43.50	84.59	11.28	0.99
335	26/04/10	46.9308	37.5952	800	50	681	Western and Southern lakelet	24	6.1	180	0.00	0.00	0.00	2.37	4.76	0.84	39.40	72.25	11.37	0.98

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336	26/04/10	46.9288	37.5954	6000	52	549	Western and Southern lakelet	6	6.1	121	0.00	0.00	0.00	2.29	3.24	0.45	27.09	47.58	8.02	0.97
337	26/04/10	46.9290	37.5982	3000	50	740	Western and Southern lakelet	9	5.6	128	0.00	0.00	0.02	1.85	3.16	0.53	27.75	52.87	7.86	0.98
338	26/04/10	46.9253	37.6026	150	56	900	Western and Southern lakelet	15	6.3	128	0.00	0.00	0.00	1.85	3.90	0.39	26.94	54.63	7.77	0.99
339	26/04/10	46.9238	37.5996	1400	40	635	Western and Southern lakelet	7	6.4	146	0.00	0.00	0.02	2.25	4.00	0.79	32.56	61.68	8.46	0.99
340	26/04/10	46.9241	37.5974	1400	40	530	Western and Southern lakelet	7	6.3	238	0.00	0.00	0.00	2.82	6.73	1.52	52.29	91.64	15.66	0.98
341	28/04/10	46.8874	37.8117	150	279	3814	Eastern Inland lakelet	20	5.9	19	0.00	0.00	0.00	0.36	0.38	0.00	4.12	10.57	1.89	0.92
342	28/04/10	46.8888	37.8033		332	4469	Stream	10	6.3	36	0.00	0.00	0.00	1.27	1.10	0.00	6.68	14.10	2.09	0.95
343	28/04/10	46.8904	37.7932	75	420	5200	Eastern Inland lakelet	22	5.2	13	0.00	0.00	0.00	0.53	0.26	0.00	3.50	8.81	2.02	0.89
344	28/04/10	46.8905	37.7932	10	420	5219	Eastern Inland lakelet	10	6.6	22	0.00	0.00	0.00	0.45	0.42	0.00	3.98	10.57	1.82	0.93
345	28/04/10	46.8905	37.7929	60	420	5225	Eastern Inland lakelet	4	5.8	18	0.00	0.00	0.00	0.49	0.39	0.00	3.50	7.05	1.85	0.86
346	28/04/10	46.8881	37.8058		300	4253	Stream	10	6.3	36	0.00	0.00	0.00	1.50	1.19	0.00	6.43	8.81	1.98	0.89

Sample number	Date Collected	Latitude (S) decimal degrees	Longitude (E) decimal degrees	Area (m^2)	Altitude (a.s.l)	Distance from sea (m)	Water body group (text section 2.1)	Total algal genera found	pH	Cond ($\mu S\ cm^{-1}$)	NH_4-N ($mg\ L^{-1}$)	NO_3-N ($mg\ L^{-1}$)	P O_4-P ($mg\ L^{-1}$)	Ca^+ ($mg\ L^{-1}$)	Mg^{2+} ($mg\ L^{-1}$)	K^+ ($mg\ L^{-1}$)	Na^+ ($mg\ L^{-1}$)	Cl^- ($mg\ L^{-1}$)	SO_4^{2-} ($mg\ L^{-1}$)	O.O.F. (text section 2.2) mEq Cl / Σ mEq
347	28/04/10	46.8871	37.8108		279	3863	Stream	14	6.5	47	0.00	0.00	0.00	2.61	1.49	0.30	7.94	15.86	3.76	0.91
348	28/04/10	46.8848	37.8125		250	3662	Stream	3	6.3	46	0.00	0.00	0.00	2.40	1.43	0.25	8.17	10.57	1.83	0.93
349	28/04/10	46.8833	37.8164		200	3328	Stream	7	6.4	46	0.00	0.00	0.00	2.20	1.46	0.25	8.25	12.34	2.11	0.94
350	28/04/10	46.8820	37.8186		174	3115	Stream	4	6.5	52	0.00	0.00	0.00	2.31	1.54	0.28	8.30	8.81	2.20	0.88
351	28/04/10	46.8800	37.8250		159	2595	Stream	7	6.6	49	0.00	0.00	0.00	2.51	1.59	0.29	8.73	10.57	2.61	0.89
352	28/04/10	46.8766	37.8288		140	2220	Stream	9	6.6	49	0.00	0.00	0.00	2.30	1.62	0.27	8.75	8.81	2.27	0.87
353	1/05/10	46.8700	37.8564		11	72	Stream	10	6.2	43	0.00	0.00	0.00	1.79	1.51	0.00	8.97	15.86	2.98	0.94
354	1/05/10	46.8704	37.8542		20	220	Stream	12	6.4	43	0.00	0.00	0.00	2.12	1.77	0.18	9.44	17.62	2.83	0.96
355	1/05/10	46.8693	37.8483	150	40	671	Nellies	15	4.8	55	0.00	0.00	0.00	0.69	1.24	0.00	11.81	24.67	3.69	0.97
356	1/05/10	46.8685	37.8477		40	747	Stream	10	6.1	42	0.00	0.00	0.00	1.61	1.53	0.00	8.85	14.10	2.84	0.92
357	1/05/10	46.8690	37.8439		61	1010	Stream	11	6.6	42	0.00	0.00	0.00	1.83	1.49	0.00	8.59	15.86	2.42	0.96
358	1/05/10	46.8710	37.8396		66	1320	Stream	8	6.8	42	0.00	0.00	0.00	1.61	1.47	0.01	8.56	17.62	2.74	0.96
359	1/05/10	46.8728	37.8333		90	1833	Stream	10	6.7	43	0.00	0.00	0.00	1.70	1.45	0.00	8.56	15.86	2.40	0.96
360	1/05/10	46.8741	37.8321		97	1925	Stream	10	6.8	43	0.00	0.00	0.00							
361	1/05/10	46.8759	37.8409	120	76	1310	Nellie Humps lakelet	12	5.8	34	0.00	0.00	0.00							

Sample number	Date Collected	Latitude (S) decimal degrees	Longitude (E) decimal degrees	Area (m^2)	Altitude (a.s.l)	Distance from sea (m)	Water body group (text section 2.1)	Total algal genera found	pH	Cond (µS cm^{-1})	NH_4-N (mg L^{-1})	NO_3-N (mg L^{-1})	P O_4-P (mg L^{-1})	Ca^+ (mg L^{-1})	Mg^{2+} (mg L^{-1})	K^+ (mg L^{-1})	Na^+ (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	O.O.F. (text section 2.2) mEq Cl / Σ mEq
362	1/05/10	46.8745	37.8414	90	77	1236	Nellie Humps lakelet	13	5.0	36	0.00	0.00	0.00							
363	6/05/10	46.8688	37.8552	65	25	213	Nellie Humps lakelet	20	5.1	121	0.35	0.62	0.17	1.46	3.31	0.36	23.33	42.29	6.44	0.94
364	6/05/10	46.8649	37.8552	45	19	179	Nellie Humps lakelet	18	4.9	64	0.00	0.00	0.00	0.79	1.67	0.00	14.29	26.43	3.98	0.97
365	6/05/10	46.8644	37.8558	10	13	108	Nellie Humps lakelet	16	5.0	82	0.00	0.00	0.00	1.03	2.39	0.22	18.30	28.20	6.48	0.93
366	6/05/10	46.8639	37.8558	80	11	72	Wallow	6	5.3	86	0.70	1.22	0.13	0.64	1.61	0.21	14.73	26.43	4.43	0.87
367	6/05/10	46.8640	37.8554	10	12	85	Wallow	5	4.6	114	0.49	0.79	0.02	0.87	2.44	0.00	21.32	35.24	6.59	0.91
368	6/05/10	46.8638	37.8556	70	10	57	Wallow	6	5.2	100	0.78	0.97	0.13	0.59	1.86	0.68	20.30	37.01	6.02	0.91
369	6/05/10	46.8636	37.8558	80	9	45	Wallow	3	7.3	350	1.02	1.93	0.25	1.15	2.47	1.12	24.48	35.24	6.01	0.85
370	6/05/10	46.8635	37.8555	3	9	45	Wallow	8	5.4	98	0.42	0.68	0.06	0.56	1.69	0.00	21.98	37.01	6.35	0.93
371	6/05/10	46.8629	37.8551	100	8	20	Nellie Humps lakelet	8	5.6	83	0.00	0.00	0.00	0.89	2.23	0.00	21.07	35.24	5.56	0.97
372	6/05/10	46.8641	37.8575	40	4	0	Nellie Humps lakelet	13	5.5	244	0.56	0.89	0.05	1.17	3.14	0.82	38.17	49.34	10.91	0.90
373	6/05/10	46.8699	37.8571	10	10	28	Wallow	24	5.5	124	1.45	2.64	0.38	1.47	3.61	0.40	24.87	51.10	7.68	0.87

Sample number	Date Collected	Latitude (S) decimal degrees	Longitude (E) decimal degrees	Area (m^2)	Altitude (a.s.l)	Distance from sea (m)	Water body group (text section 2.1)	Total algal genera found	pH	Cond ($\mu S\ cm^{-1}$)	NH_4-N ($mg\ L^{-1}$)	NO_3-N ($mg\ L^{-1}$)	P O_4-P ($mg\ L^{-1}$)	Ca^+ ($mg\ L^{-1}$)	Mg^{2+} ($mg\ L^{-1}$)	K^+ ($mg\ L^{-1}$)	Na^+ ($mg\ L^{-1}$)	Cl^- ($mg\ L^{-1}$)	SO_4^{2-} ($mg\ L^{-1}$)	O.O.F. (text section 2.2) mEq Cl / Σ mEq
374	6/05/10	46.8800	37.8481	30	50	994	Nellie Humps lakelet	3	4.6	48	0.00	0.00	0.00	0.68	1.34	0.00	11.66	24.67	4.19	0.96
375	6/05/10	46.8808	37.8446	80	60	1249	Nellie Humps lakelet	3	4.4	41	0.00	0.00	0.00	0.56	1.08	0.00	9.60	17.62	3.82	0.92
376	7/05/10	46.8970	37.8612	2070	50	1152	Nellie Humps lakelet	5	5.8	50	0.00	0.00	0.00	1.25	3.21	1.32	26.90	44.06	7.71	0.97
377	7/05/10	46.8950	37.8627	2000	50	970	Glacial lake	18	6.1	43	0.00	0.00	0.00	0.86	1.43	0.00	9.23	17.62	3.40	0.94
378	7/05/10	46.8928	37.8663	2500	40	645	Glacial lake	12	5.9	56	0.00	0.00	0.00	0.83	1.70	0.00	10.92	22.91	3.82	0.96
379	7/05/10	46.9025	37.8718	7000	47	1002	Glacial lake	13	6.0	51	0.00	0.00	0.00	0.66	1.28	0.00	10.36	19.38	3.39	0.95
380	7/05/10	46.8999	37.8715	800	50	755	Glacial lake	19	6.0	57	0.00	0.00	0.00	1.05	2.87	0.00	13.60	31.72	4.40	0.98
381	7/05/10	46.8992	37.8721	8000	50	655	Glacial lake	9	6.1	58	0.00	0.00	0.00	0.77	1.54	0.00	12.42	26.43	3.55	0.98
382	7/05/10	46.8987	37.8736	4500	50	566	Glacial lake	15	6.1	59	0.00	0.00	0.00	1.54	4.90	0.77	13.09	22.91	3.96	0.96
383	7/05/10	46.8984	37.8764	4000	59	431	Glacial lake	19	6.2	59	0.00	0.00	0.00	0.68	1.64	0.00	12.70	24.67	4.09	0.96
384	7/05/10	46.8974	37.8777	3000	55	306	Glacial lake	10	6.2	58	0.00	0.00	0.00	0.58	1.54	0.00	12.92	26.43	3.60	0.98
385	7/05/10	46.8967	37.8798	5000	48	228	Glacial lake	10	6.3	64	0.00	0.00	0.07	1.64	0.00	14.30	24.67	4.21	0.09	0.91
386	7/05/10	46.8967	37.8819	8000	40	220	Glacial lake	4	6.0	69	0.00	0.00	0.07	1.76	0.00	15.33	26.43	4.50	0.11	0.91
387	7/05/10	46.8924	37.8743	4250	25	57	Glacial lake	13	6.2	77	0.00	0.00	0.08	2.59	0.00	14.74	28.20	5.78	0.08	0.95

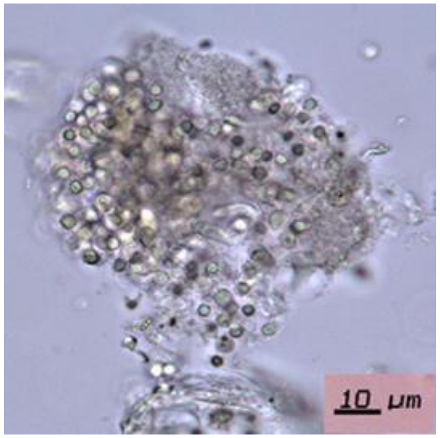
APPENDIX 2: Cyanophyta

Light microscope photographs of some of the Cyanophyta genera present during the algal surveys of Marion Island during 2007 and 2010

1 *Anabaena* Bory de Saint-Vincent *ex* Bornet & Flahault

This specimen resembles *Anabaena cylindrica* Lemmermann, found on Îles Kerguelen and Crozet (Thérézien & Couté, 1977). Trichomes are situated in colourless mucilage. Cells are ellipsoidal and sometimes bended. Heterocysts are larger than the other cells. Akinetes are cylindrical, slightly bend and mostly adjacent to a heterocyst (John *et al*., 2008).

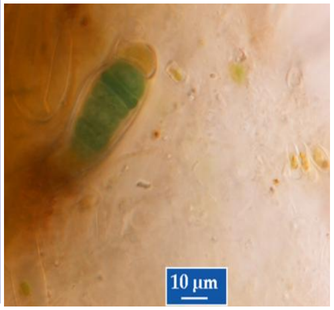
2 *Aphanothece* Nägeli



Very similar to *Aphanothece microscopica* Nägeli, found on Îles Kerguelen (Thérézien & Couté, 1977). The colony is surrounded by a mucilage outer layer. Cells ovoid with rounded ends (John *et al.,* 2008).

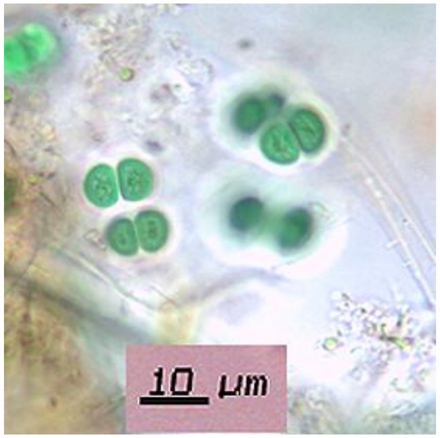
3 *Calothrix* Agardh *ex* Bornet & Flahault

This specimen resembles *Calothrix castellii* (Hassal) Bornet & Flahault, recorded on Îles Crozet and King George Island (Thérézien & Couté, 1977; Vinocur & Unrein, 2000). Filaments are bent, erect and densely aggregated. Filaments are swollen at the base and prostrate. Sheath is close to the trichome and thin. Trichomes attenuate into long hairs (John *et al.,* 2008).



4 *Chroococcus* Nägeli

This genus resembles *Chroococcus minutus* (Kützing) Nägeli, recorded in the freshwaters of Antarctica on Livingston and King George Islands (Vinocur & Unrein, 2000; Zidarova, 2008). Small colony, with 2 to 8 cells. Cells are spherical or ovoid when outer margins are firm (John *et al.,* 2008).

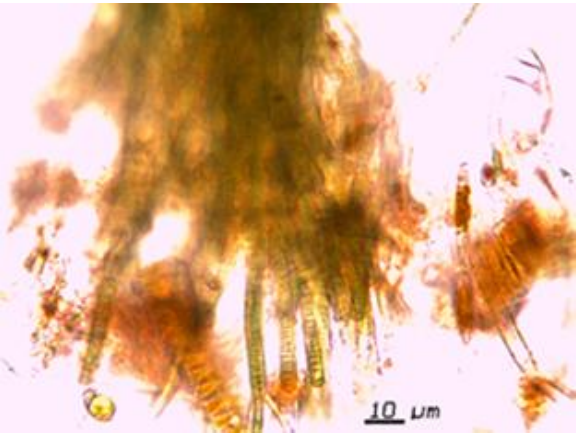


5 *Cylindrospermopsis* Seenayya et Subba Raju

Cylindrospermopsis was not recorded on any other sub-Antarctic island. This *Cylindrospermopsis* species showed the following characteristics: Small, slightly coiled trichomes consisting of barrel-shaped cells forming entwined trichomes. Ellipsoidal, terminal heterocysts situated at both ends, but no heterocysts in an intercalary position. Oval to ellipsoidal shaped akinetes are situated adjacent to the heterocysts (Wehr & Sheath, 2003).

6 *Homoeothrix* (Thuret *ex* Bornet & Flahault) Kirchner

This specimen resembles *Homoeothirx varians* Geitler, found on Îles Kerguelen (Thérézien & Couté, 1977). It is usually found as a tuft group of trichomes. Trichomes slightly tapered and unbranched. Distinct sheaths visible. No heterocysts or akinetes. Cells are twice as wide as long (John *et al.,* 2008).



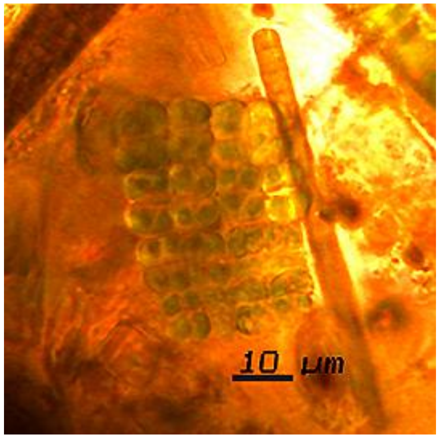
7 *Lyngbya* (Agardh) Gomont

This specimen resembles *Lyngbya martensiana* (Meneghini) Gomont, found on Îles Kerguelen and Crozet (Thérézien & Couté, 1977). It also fits the description of an unknown *Lyngbya* sp. identified by Priddle & Belcher (1982) in the benthic samples of the freshwater lakes on Signy Island. Filaments are long, straight or slightly bend and unbranched with a visible sheath. No constrictions at the cross walls or granules visible. Cells are at least twice as broad as long. End cells are broadly

rounded (John *et al.,* 2008). The filaments are Orange-brown in colour (Priddle & Belcher, 1982).

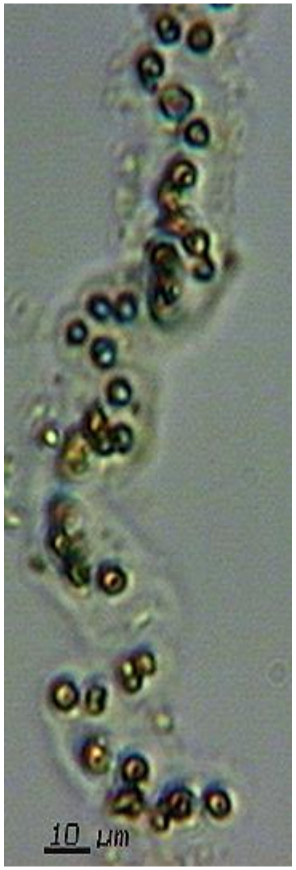
8 *Merismopedia* Meyen

This specimen resembles *Merismopedia glauca* (Ehrenberg) Nägeli, also found on Îles Kerguelen (Thérézien & Couté, 1977) and South Orkney Island (Fritsch, 1912). Colony with many (up to 64) cells that are densely packed in a mucilage layer. Usually small groups of 8 cells densely packed together with other small groups of cells in the colony. Mucilage layer extends slightly beyond outer cells. Cells spherical or ellipsoidal (John *et al.,* 2008).



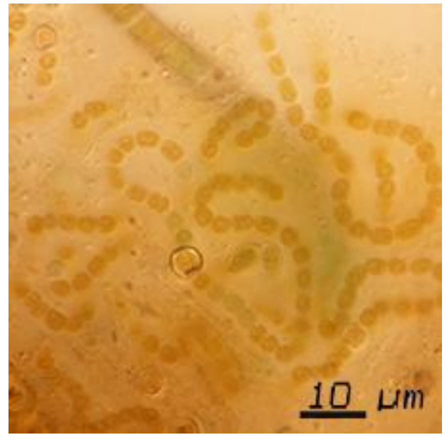
9 *Microcystis* Kützing *ex* Lemmermann

This genus resembles *Microcystis aeruginosa* (Kützing) Kützing, which has also been recorded on Îles Kerguelen (Thérézien & Couté, 1977). Young colonies aresubspherical in shape, but become more elongated when older. Cells are spherical, embedded in a colourless mucilage layer. Cells are gas vacuolated when found in planktonic habitats.



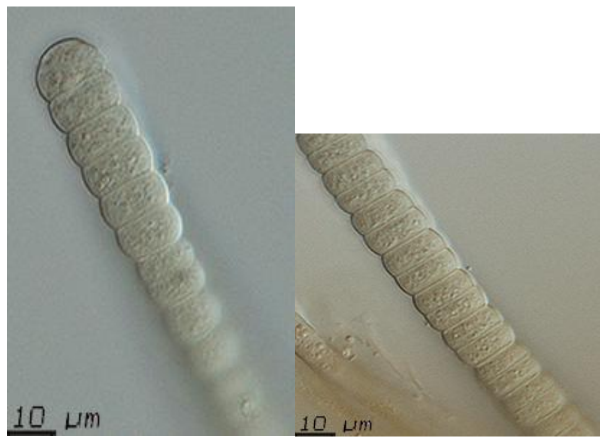
10 *Nostoc* Vaucher *ex* Bornet *et* Flahault

This genus resembles *Nostoc commune* Vaucher, which was found on Îles Kerguelen (Thérézien & Couté, 1977). They consist of small colonies of barrel-shaped cells forming entwined trichomes. Mucilage layer around trichome colourless. Rounded akinetes visible (John *et al.,* 2008).



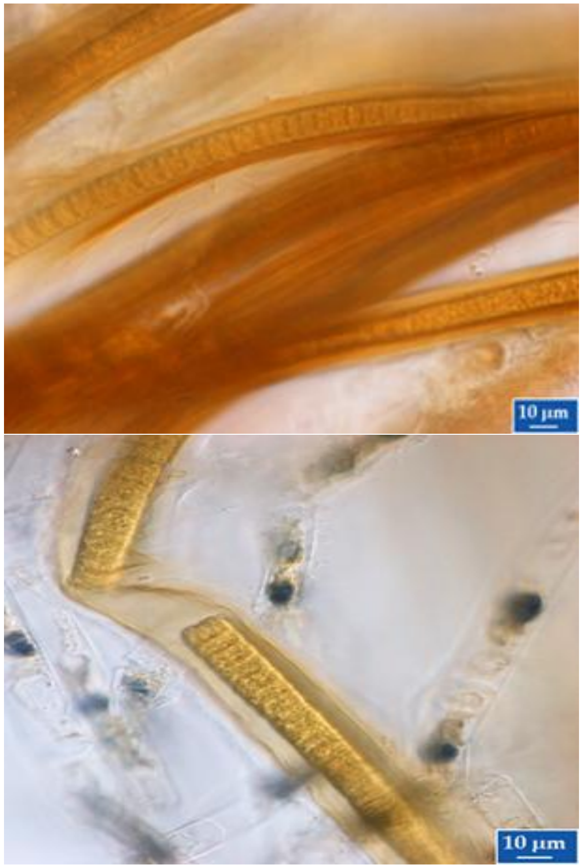
11 *Oscillatoria* Vaucher *ex* Gomont

This *Oscillatoria* resembles *Oscillatoria irrigua* (Kützing) Gomont, which was present in the freshwater lakes of Îles Kerguelen and Crozet (Thérézien & Couté, 1977). Trichomes straight with a slight bend in the apical area. No attenuation towards apex and terminal cells are not capitated. Cross walls narrowed, with granules. Slightly thickened outer membrane. End cells slightly hemispherical (John *et. al*., 2008).



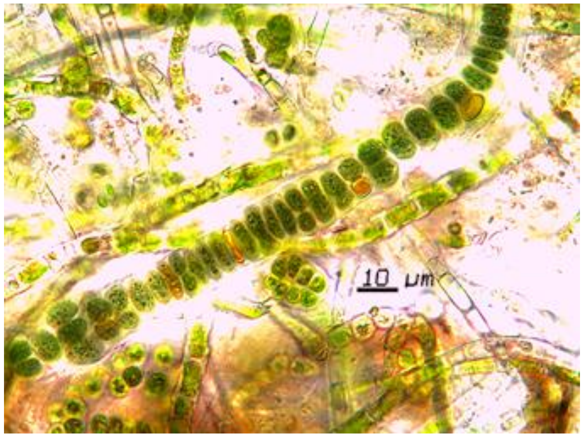
12 *Schizothrix* (Kützing) Gomont

No *Schizothrix* species with a similar description was recorded on any other sub-Antarctic Island. *Schizothrix lardacea* was present on Îles Crozet (Thérézien & Couté, 1977) and Signy Islands (Zidaravo, 2008). This species consists of a single trichome, unbranched with broad mucous sheath. Cross walls are slightly narrowed. Contents uniform. Apical cells slightly elongated and Blunt-conical without calyptra. More than one trichome in broad sheath. Sheath colourless in young filaments and yellow-brown in older filaments. Granules visible inside cells. Usually in a colony forming a mat consisting of many trichomes.



13 *Stigonema* C. Agardh ex Bornet *et* Flahault

This species resembles *Stigonema hormoides* (Kützing) Bornet *et* Flahualt, present on Îles Kerguelen (Thérézien & Couté, 1977). True irregular and sparsely branched in a plane perpendicular to the main axis. Cells appear slightly apart and filaments are small, between 7-15 µm wide. Cells subspherical. The lateral branches appear to be as wide as the main branch. Sheaths are colourless, but become yellow-brown and distinctly laminated in older filaments.



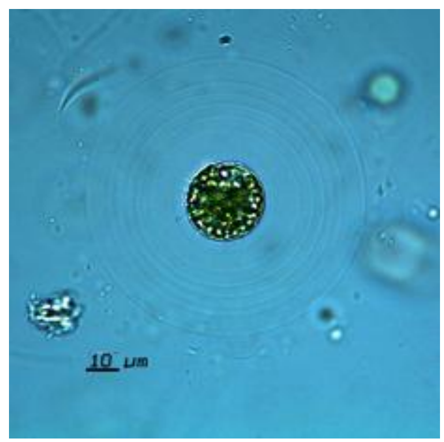
APPENDIX 3: Chlorophyta

Light microscope and SEM photographs of some of the Chlorophyta genera present during the algal surveys of Marion Island during 2007 and 2010

1 ***Ankistrodesmus* Corda**

This species resembles *Ankistrodesmus spiralis* (Turner) Lemmermann, which was recorded on Îles Kerguelen (Thérézien & Couté, 1977). Cells are needle-like and gradually narrowing to acute ends. Colonies consist of 4, 8 or 16 cells, united equatorially. Cells are helically intertwined in the centre and free towards apices (John *et al.*, 2008).

2 ***Asterococcus* Scherffel**



This species resembles *Asterococcus superbus* (Cienkowski) Scherffel, which was present in the lakes on Signy Island (Priddle & Belcher, 1982). Cells are solitary, but also occur in colonies of 2 to 4 cells. Cells have a large broad lamellate and mucilage envelope surrounding them.

3 ***Botryococcus* Kützing**

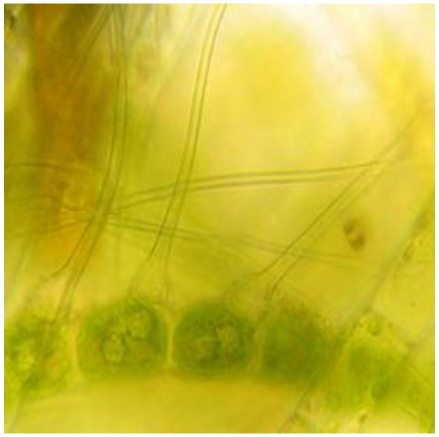
This species resembles *Botryococcus braunii* Kützing, found on Îles Kerguelen (Thérézien & Couté, 1977). Colonies are green or yellow to orange. Colonies consist of irregularly arranged cells embedded within the periphery of tough folded mucilage containing oil globules. Cells are ovoid to obovoid (John *et al.,* 2008).

4 *Binuclearia* Wittrock

This specimen resembles *Binuclearia tectorum* (Kützing), found in the freshwaters of Îles Kerguelen and Crozet (Thérézien & Couté, 1977). Cells are 5 to 13 µm wide and twice as long as wide. Filaments have thickenings between every 2 or 4 cells.

5 *Bulbochaete* Agardh

No record of *Bulbochaete* being present on any other sub-Antarctic Island was found. Filaments are branched. Each cell has a long hair with a bulbous base and two such hairs on a terminal cell. Stages in sexual reproduction are needed for species identification (John *et al.*, 2008).



6 *Carteria* Diesing

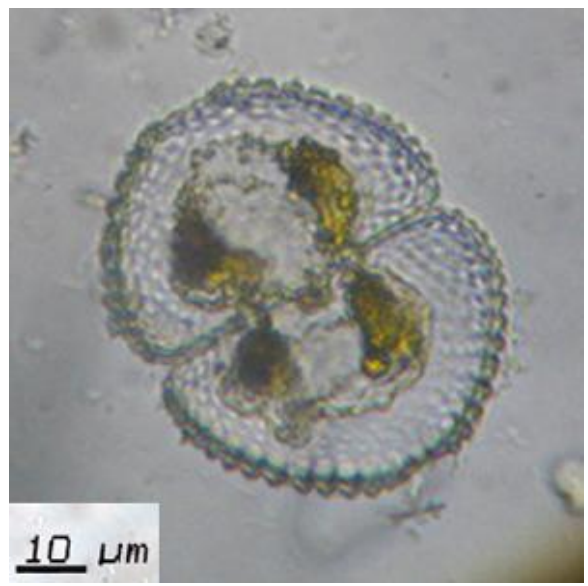
Carteria was not recorded on any other sub-Antarctic Island. Various *Chlamydomonas* species were recorded on Îles Kerguelen, Îles Crozet, Livingston, King George and Signy Islands (Thérézien & Couté, 1977; Priddle & Belcher, 1982; Vinocor & Urein, 2000; Zidaravo, 2008). The main difference between *Carteria* and *Chlamydomonas* is that *Carteria* has 4 flagella and *Chlamydomonas* only has two (John *et al.,* 2008).

***7 Characium* Braun in Kützing**

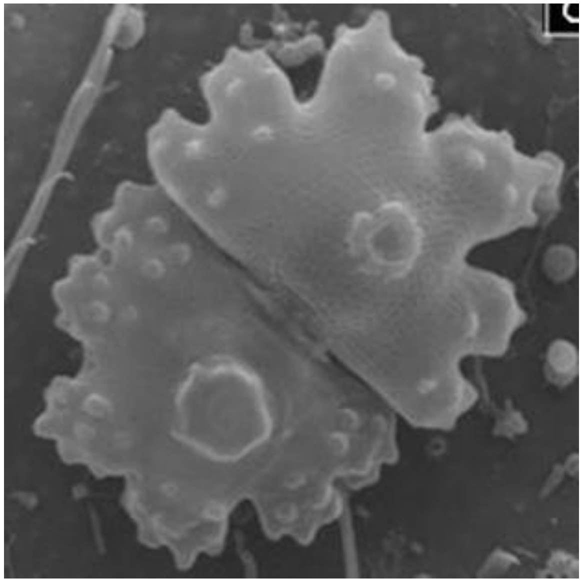
This specimen resembles *Characium obtusum* Braun, found on Îles Kerguelen (Thérézien & Couté, 1977). Cells are epiphytic and solitary. Cells have a short stalk with an expanded mucilaginous disc attached to host algae. Cells usually oval to slightly round at end. No protrusions on cell walls. Cells do not curve towards the apices (John *et al.*, 2008).

8 *Cosmarium* Corda *ex* Ralfs

This species resembles *Cosmarium botrytis* Meneghini *ex* Ralfs, found on Îles Kerguelen (Thérézien & Couté, 1977). Large semicells are truncate-pyramidate (shaped like a pyramid, but apex is terminated abruptly and top of cell flat). Cells walls are ornamented with small, rounded, irregularly disposed granules over the entire face (John *et al*., 2008).



9 *Euastrum* Ehrenberg *ex* Ralfs



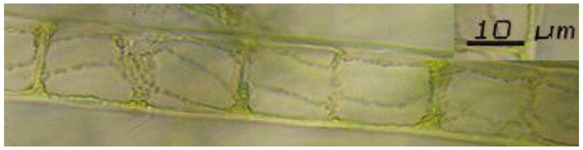
This species fits the description of *Euastrum dubium* Nägeli, found on Îles Kerguelen and Crozet (Thérézien & Couté, 1977). However, the description for *E. dubium* Nägeli states that each semicell has 5 lobes (John *et al*., 2008) while this species has 6 lobes, the same as the *E. dubium* found on Îles Kerguelen and Crozet (Thérézien & Couté, 1977). Semicells are deeply constricted with a narrow, linear sinus slightly dilated towards the outside (John *et al.,* 2008). This SEM photograph of *Euastrum* is 800 x magnified.

10 *Hyalotheca* Ehrenberg *ex* Ralfs

This species resembles *Hyalotheca dissiliens* Brébisson *ex* Ralfs, also present in the freshwaters of Îles Kerguelen (Thérézien & Couté, 1977). This desmid is united by broadly truncate apices into long filaments. Each cell has a slight notch in lateral margin (John *et al.,* 2008).

11 *Microspora* Thuret

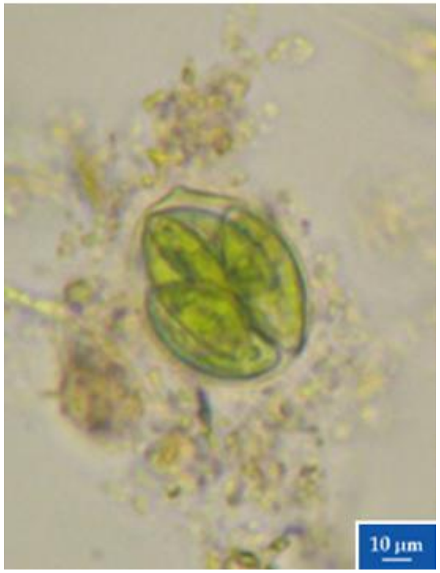
This species resembles *Microspora floccosa* (Vaucher) Thuret. *Microspora* species were only present on Îles Kerguelen and Crozet (Thérézien & Couté, 1977). None of these species fit the description of *Microspora floccosa* found on Marion Island. The junction of H-shaped section between the cells are not evident and the chloroplast forms an open net and bead-like bands.



12 *Mougeotia* Agardh

Mougeotia species were also found on Îles Kerguelen, Îles Crozet, Signy and King George Islands (Thérézien & Couté, 1977; Priddle & Belcher, 1982; Vinocur & Unrein, 2000). None of these was identified to species level, because reproductive stages must be observed to identify it to species level. *Mougeotia* is characterised by its single plate like chloroplast with a linear row of pyrenoids within. Chloroplasts are flat or slightly twisted towards the light (John *et al.,* 2008).

13 *Oocystis* Braun

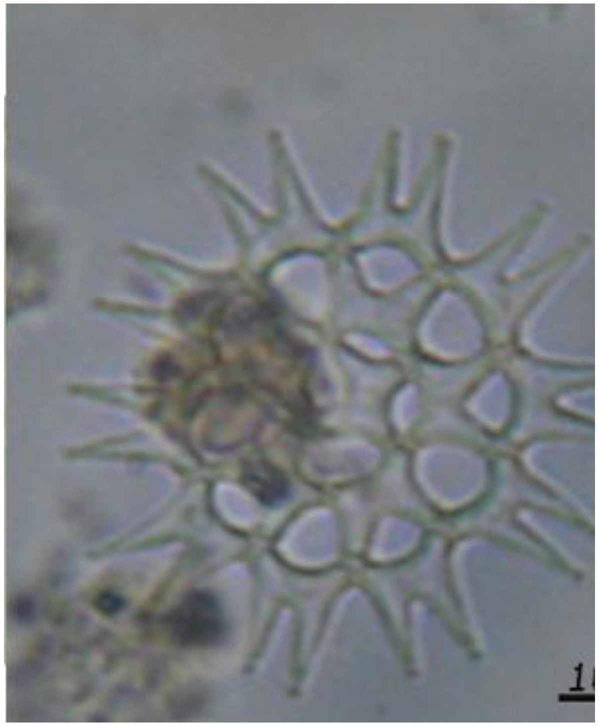


This species resembles *Oocystis solitaria* Wittrock in Wittrock & Nordstedt, found on Îles Kerguelen (Thérézien & Couté, 1977). Cells are solitary or in colonies of 2, 4 or 8. Cells are ovoid to ellipsoidal with apices slightly acute (John *et al.,* 2008).

14 *Scenedesmus* Meyen

This species resembles *Scenedesmus brasiliensis* Bohlin, also recorded on Îles Kerguelen (Thérézien & Couté, 1977). Cells form a coenobium (a colony in which the number of cells is fixed) of 2 or 4 cells. Cells are slightly curved or straight. No mucilaginous envelope present. Small teeth like protrusions present on all the cells (John *et al*., 2008).

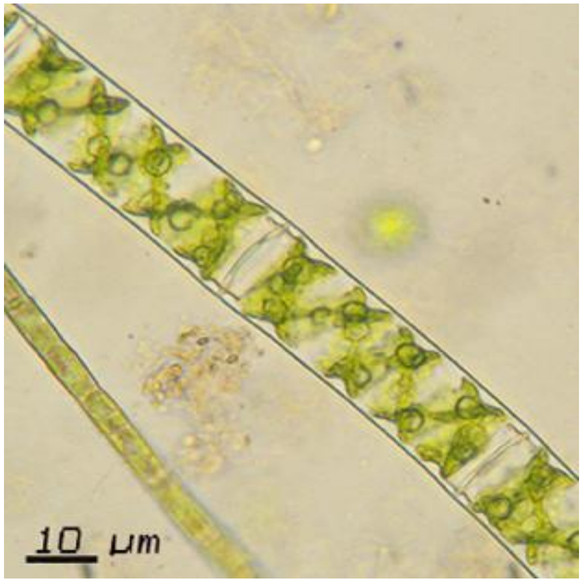
15 *Pediastrum* Meyen



This species resembles *Pediastrum duplex* Meyen. *Pediastrum boryanum* var. *longicorne* Reinsch, was found on Îles Kerguelen, Îles Crozet and Signy Island (Thérézien & Couté, 1977; Priddle & Belcher, 1982). These species are very similar, but *Pediastrum duplex* has distinct intercellular spaces, whereas *Pediastrum boryanum* var. *longicorne* rarely have any (John *et al*., 2008).

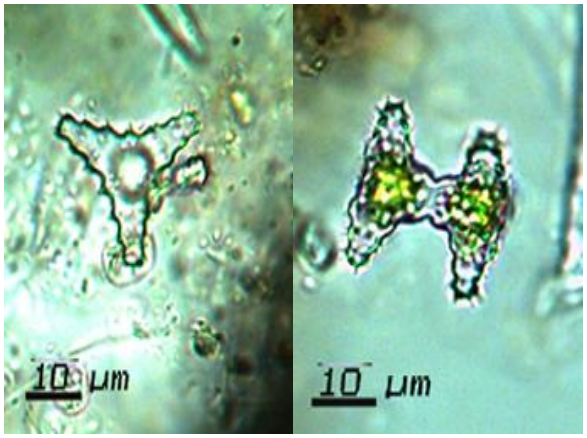
16 *Spirogyra* Link

Spirogyra species were also recorded on Îles Kerguelen, Îles Crozet, Livingston, King George, Macquire and Signy Islands (Thérézien & Couté, 1977; Priddle & Belcher, 1982; Selkirk, 1990; Vinocur & Urein, 2000; Zidaravo, 2008). The only *Spirogyra* species identified to species level on other sub-Antarctic islands was *Spirogyra inflate* var. *australis* Thérézien & Couté on Îles Kerguelen. The ring-like enfold between cells are visible on this photograph of *Spirogyra* from Marion Island. Chloroplast forms a spiral band coiled inside cells.



17 *Staurastrum* (Meyen) Ralfs

This species resembles *Staurastrum cerastes* Lundell found on Îles Kerguelen (Thérézien & Couté, 1977). Cells have a shallow constriction and sinus and a U-shaped notch. Semicells are sub-cylindrical in the lower part and then widens upwards to a strongly incurved tip with 4 short, stout spines. Ornamented with small spikes (John *et al*., 2008).



18 *Stigeoclonium* Kützing

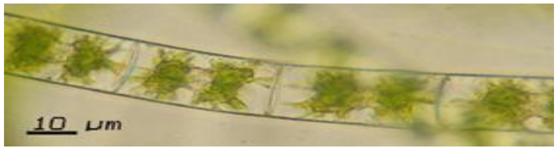
This species resembles *Stigeoclonium tenue* (Agardh) Kützing, found on Îles Kerguelen (Thérézien & Couté, 1977). Filaments are uniseriate and form delicate tufts. They are mostly green to yellow-green. Filaments branch in irregular manner into sub-branches (John *et al.,* 2008).

19 *Tetmemorus* Ralfs *ex* Ralfs

This species resembles *Tetmemorus laevis* (Kützing) Ralfs, found on Îles Kerguelen and Îles

Crozet (Thérézien & Couté, 1977). Cells are large with a slight median constriction. Rounded apices with a median incision (John *et al.,* 2008).

20 *Zygnema* C. Agardh



Zygnema was also recorded on Îles Kerguelen, Îles Crozet, Livingston, Macquire and Signy Islands (Thérézien & Couté, 1977; Priddle & Belcher, 1982, Selkirk, 1990). However, none of the *Zygnema* species were identified to species level as stages in sexual reproduction must be observed for species identification. *Zygnema* has 2 to 4 star-shaped chloroplasts per cell (John *et al.,* 2008).

APPENDIX 4: Chrysophyta, Euglenophyta, Pyrrophyta and Xanthophyta

Light microscope photographs of the Chrysophyta, Euglenophyta, Pyrrophyta and Xanthophyta genera present during the algal survey of Marion Island during 2007 and 2010

1 *Euglena* Ehrenberg

Euglena was also found on Îles Kerguelen, Îles Crozet and King George Island (Thérézien & Couté, 1977; Vinocur & Unrein, 2000), but was not identified to species level. Cells are solitary, with 2 flagella (1 visible). Eyespot visible at anterior. Shape of cell changes with euglonoid movement.

2 *Trachelomonas* Ehrenberg

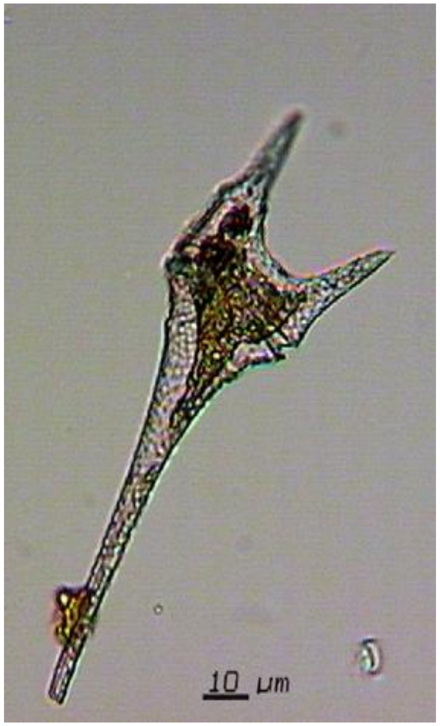
This species resembles *Trachelomonas curta* Cunha found on Îles Kerguelen (Thérézien & Couté, 1977). Apical pole is surrounded by ring-like thickening. Lorica is between 14-20 µm long and transversely oval. Lorica is reddish-brown (John *et al.,* 2008).

3 *Tribonema* Derbes & Solier

This species resembles *Tribonema viride* Pascher*,* found on Kerguelen, Livingston, Signy, Macquarie and King George Islands (Thérézien & Couté, 1977; Priddle & Belcher, 1982; Selkirk, 1990; Vinocur & Unrein, 2000; Zidaravo, 2008). Cells are slightly barrel-shaped with numerous pale green chloroplasts. Cells overlap in mid-region and form H-shape pieces (John *et al.,* 2008).

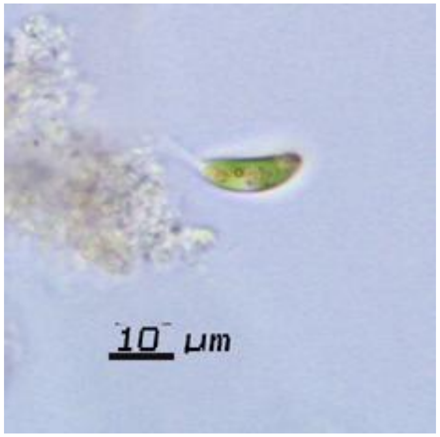
4 *Ceratium* Schrank

Ceratium is not recorded on any sub-Antarctic Island, except for Marion Island. The epitheca of the *Ceratium* forms a long horn and the hypotheca forms two shorter horns. Cell is composed of plates with pores (John *et al.,* 2008).



5 *Characiospsis* Borzi

This species resembles *Characiopsis acuta* Borzi, found on Îles Kerguelen (Thérézien & Couté, 1977). In the photograph the acute apex is not visible. Cells are ellipsoidal to spindle-shaped and taper towards an acute apex. The base narrows into a stalk.



6 *Chyrsosphaera* Parscher

This epiphytic colony resembles *Chrysophaera* sp. found on Signy Island described by Priddle & Belcher (1982). Golden in colour in large colonies on the surface of filamentous algae (Wehr & Sheath, 2003).