Modern and Fossil Terrestrial and Freshwater Habitats on Subantarctic Macquarie Island

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Palaeolake Half Moon is one of ten palaeolake deposits known on Macquarie Island. Looking west from Hill 219 over the deposit, the featherbed and Half Moon Bay.

Certificate of Authenticity

The work in this thesis is original and has not been submitted in any form for a higher degree at any other University or institution. All information and ideas derived from others has been acknowledged within the text.

Helen M. Keenan.

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Table of Contents

Chapter 3. Modern Freshwater Habitats

Chapter 4. Terrestrial Habitats

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Abstract

Macquarie Island is a small subantarctic island situated 1130 km south-south east of Tasmania. It is isolated from any land mass and experiences harsh climatic conditions.

Ten palaeolake sites are known from Macquarie Island. Five were studied in detail to provide information on the Late Quaternary climates of the region, employing diatoms (Bacillariophyta) as the main interpretive tool. To this end, the diatom associations from several modern habitats were examined and catalogued. The five palaeolake sites were located in the north west of the island. They are Palaeolake Half Moon, Palaeolake Cascade, Palaeolake Eagle, Palaeolake Emerald and Palaeolake Cormorant. The modern habitats examined were creeks, mires, soil, feldmark, lichen and nutrient rich areas. A companion study of modern lakes is currently in progress. Eleven major diatom associations were identified from the terrestrial, mire and palaeolake samples.

One hundred and eighty one taxa of diatoms were identified from the modern and fossil samples. The majority of the species found were cosmopolitan, with approximately 10% found only in the subantarctic and/or the Antarctic.

The palaeolake sediments were dated at between 12 900 RC y BP and 3580 RC y BP. Three of the palaeolakes exhibited little change in diatom associations or in sediments over time. These have been interpreted as deep, oligotrophic lakes similar to some modern lakes on the island today. Two of the palaeolakes showed major changes in both sediments and diatom associations. These changes have been interpreted as reflecting a change in the climate of Macquarie Island, with a drier period between 5000 and 3500 y BP.

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Chapter 1

Introduction and Description of Macquarie Island

1.1 Introduction to this project

The subantarctic zone is primarily ocean. There are no large land masses present and only six islands or island groups which are widely separated (fig. 1.1). These are isolated and experience harsh weather conditions which makes reaching the islands, living and working on them difficult. This study on the Holocene and late Pleistocene lake environments on Macquarie Island, a dependency of Tasmania, Australia, suggests that there has been little change in climate or vegetation, but considerable change in landform, of this subantarctic island in the last few thousand years.

At present the climatic history of the subantarctic is poorly known because of the relative paucity of available study sites in the region. However, the study of palaeoclimatic change in the southern hemisphere is potentially of great importance. Some studies have found that the effects of a major climatic change are experienced approximately 1000 years earlier in the southern hemisphere than in the northern hemisphere (Jouzel *et al.,* 1992). If this is true, in general the effects of global warming will be recognised earlier in the south.

There is an abundance of information available from the northern hemisphere on climatic change and the records from the subantarctic and Antarctic appear poor in comparison. Any information gathered on changes in climate to fill these gaps is valuable. Current research focuses on pollen as the major interpretative tool for palaeoclimatic analysis. However, on Macquarie Island, pollen has been shown to be responding more to changes in local conditions than to changes in climate. Investigations of changes in the Holocene vegetation history, using pollen from peat profiles, has found that over time the vegetation is responding to local events, such as uplift (see Bergstrom, 1986; Selkirk, Selkirk & Griffin, 1983). Unlike other areas in the subantarctic, no evidence has been found for climatic change on Macquarie Island. This may be because the climatic changes which have occurred have been of a smaller environmental amplitude than the ecological range of the species which have been examined (Smith, 1987).

Macquarie Island is an important site for palaeoecological studies because it is one of only six land areas in the subantarctic zone. Elsewhere, such as Marion Island and the Kerguelen Islands, global climatic change has been inferred from palynological studies (Hall, 1980; Young & Schofield, 1973). Additional work in these areas is required to determine whether these observed changes are actually due to local events, or are records of actual climatic change.

One method of determining past changes in climate and/or local conditions is to compare the occurrences of modern-day organisms with the fossil distributions. Diatoms have been employed successfully in many areas for this purpose, such as Africa, Europe and North America (Dixit, Cumming, Smol & Kingston, 1992; Gasse, 1986; Haworth, 1976). Diatoms (Bacillariophyta) from palaeolake sediments on Macquarie Island have been chosen as the main analysis tool for this study as they are sensitive to both local and more widespread environmental changes (Smol, Walker & Leavitt, 1991; Chapter 1.4).

Ten palaeolake deposits are currently known on Macquarie Island (Chapter 1.3). These are the sedimentary remnants of former lakes, perched on cliff edges or exposed in creek banks. They have not been reported from anywhere else in the subantarctic. They provide a continuous record of the lake environment over several to many thousands of years. Sampling is relatively simple, requiring only a spade (and sometimes an auger) to obtain the equivalent of a core of sediments from below a modern-day lake. Diatoms are present in almost all of the sediments.

Diatoms have often been found to have specific habitat ranges. Little is known, however, of the ecological preferences of the modern diatoms in the subantarctic (Björk *et al.*, 1991; Chapter 1.3, Chapter 3, Chapter 4). Thus, prior to their use as palaeoindicators in this study it was necessary to determine the species of diatoms now present on Macquarie Island and their ecological ranges. A survey of modern mire, creek and terrestrial habitats was conducted to this end (Chapter 1.5, Chapter 3, Chapter 4). A companion study of modern lakes is underway (T. P. McBride, pers. comm.).

Five palaeolake deposits were studied in detail. The diatom associations present in the sediments were used as a basis for palaeoenvironmental interpretation of the lake basins over time. Other information on the palaeolakes was obtained from the sedimentary record and the types of macrophyte remains within the deposits.

The remainder of this chapter provides background information on Macquarie Island (Chapter 1.2), palaeolakes (Chapter 1.3), diatoms (Chapter 1.4) and the importance of terrestrial and mire work for this study (Chapter 1.5) and outlines the specific aims of the project presented in this thesis (Chapter 1.6).

1.2 The environment of Macquarie Island

1.2.1 Location

Macquarie Island (54°30' S, 158°57' E) is a small, subantarctic island located on an emergent sector of the Macquarie Ridge complex. It is approximately 1500 km SSE of Tasmania and 1130 km SW of New Zealand. It is one of six islands or island groups in the subantarctic (fig. 1.1). The subantarctic is a zone several hundred kilometres wide located directly north of the Antarctic Circle, composed principally of ocean. Macquarie Island has never been attached to any other land mass and so the flora and fauna have arrived via long distance dispersal. Because of the very limited land available in the region, all the subantarctic islands are important as breeding sites for many bird and mammal species, for monitoring southern ocean weather patterns and as sites for palaeoclimatic studies.

1.2.2 Geology and Geomorphology

Macquarie Island is an elongate plateau, between 200 m and 350 m above sea level (a.s.l.), bounded by steep wave cut cliffs which may plunge straight into the sea, or front onto narrow beaches or a broad marine terrace (fig. 1.2). The island is approximately 34 km long and up to 5 km wide, with an area of 120 km^2. The highest point on the island is Mount Hamilton, at 433 m a.s.l. A narrow, sandy isthmus at the northern end of the island, approximately 6 m a.s.l., separates the main plateau from Wireless Hill (fig. 1.3). Included in this volume is the current topographical map of Macquarie Island, produced in 1971 (back pocket). While this map does have flaws, a new edition is still under revision (Selkirk & Adamson, 1995). Place names mentioned in this chapter and elsewhere will either be marked on the topographical map, or on other location maps presented throughout the thesis.

The west coast is deeply embayed, the northern half with sand and cobble beaches edging a broad marine terrace. This terrace, rising at approximately 1.5 mm to 5 mm per year, was

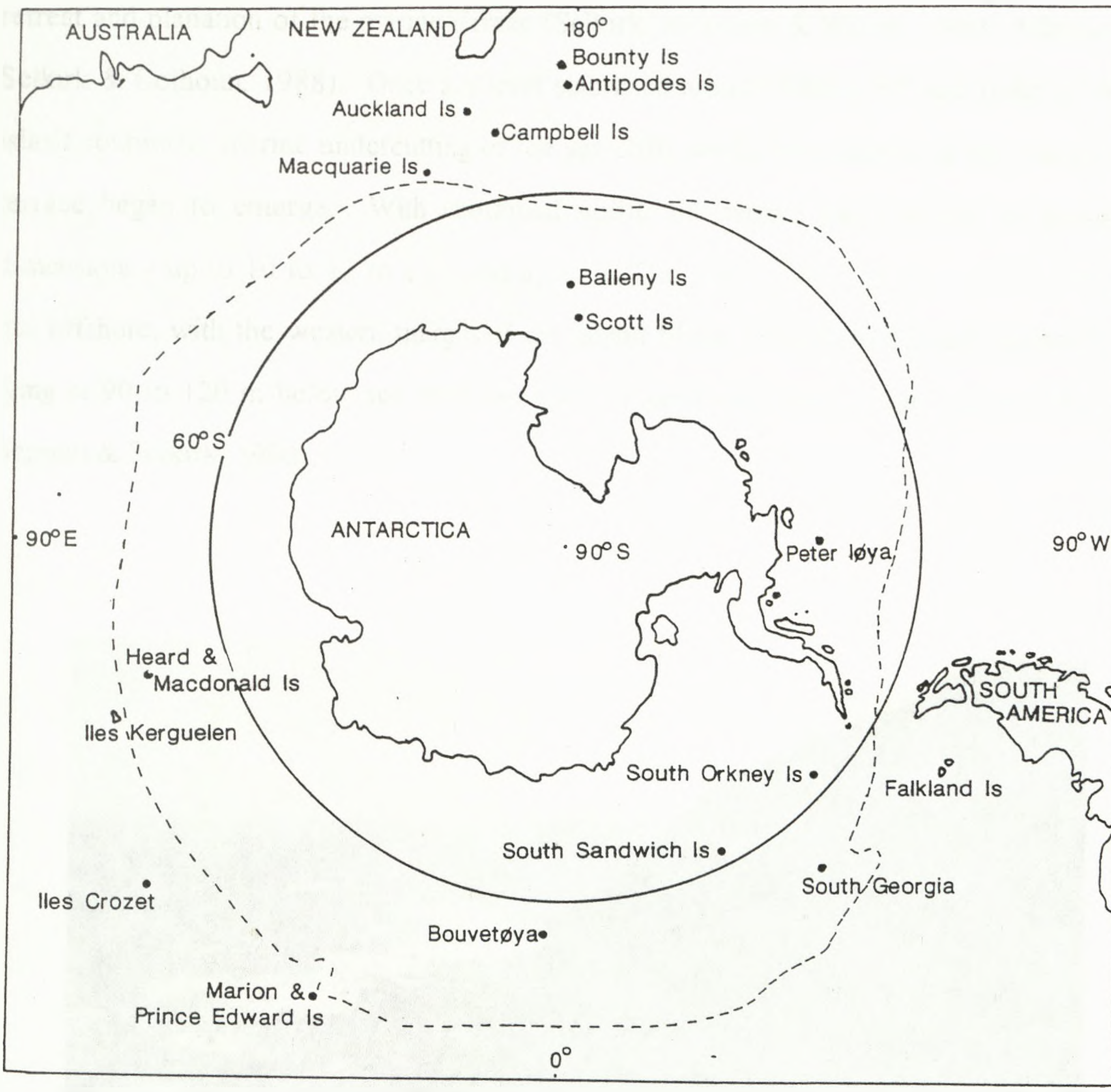


Figure 1.1. Map of the Antarctic and subantarctic regions. The Antarctic convergence is indicated by the dotted line. The six subantarctic islands or island groups are Macquarie, Heard & McDonald, Kerguelen, Crozet, Marion & Prince Edward and South Georgia.

formed by a combination of marine erosion and sea level change. Following the end of the last glacial maximum around 16 000 years before present (y BP), the sea level began to rise at about 15 mm per year. Since this was faster than the estimated uplift for the island, progressive marine erosion at the base of the ocean-facing cliffs occurred, resulting in cliff retreat and planation of the marine terrace (Selkirk, Adamson & Wilson, 1990; Adamson, Selkirk & Colhoun, 1988). Once sea level stabilised around 6000 y BP and uplift of the island continued, marine undercutting of the sea cliffs would have ceased as the wave-cut terrace began to emerge. With continued uplift, the terrace has reached its present dimensions - up to 10 to 15 m a.s.l. and up to 1.5 km wide. More of the marine terrace lies offshore, with the western margin of the island block, thought to be fault-controlled, lying at 90 to 120 m below sea level and up to 3 km to the west of the island (Selkirk, Seppelt & Selkirk, 1990).

Figure 1.2. Steep cliffs at Windsor Bay on the southern coast with a narrow, rocky beach at the base.

Figure 1.3. A narrow isthmus connects North Head with the northern end of the plateau of the main island. Looking south from Wireless Hill towards Perserverence Bluff.

The marine terrace is a complex of featherbed, mires, pools and relict sea stacks (Selkirk, Seppelt & Selkirk, 1990; fig. 1.4). Small areas of quaking mire occur in the north. These are areas where the vegetation - principally bryophytes - has formed a floating carpet over what may have once been open water, similar to the 'kettle hole bogs' of the northern hemisphere (Mickelson & Borns Jr, 1973). This can be seen when movement on the vegetation surface causes ripples to move across the quaking mire..

The east coast is more linear than the west and for much of its length is edged by narrow beaches backed by steep cliffs. Substantial beach development occurs in only a few places on the east coast, with Sandy Bay and Lusitania Bay the most obvious (fig. 1.5). This 'linearity' is controlled by a series of parallel and sub-parallel faults known collectively as the Brothers Fault-line (Ledingham & Peterson, 1984). This structure can be seen spectacularly at the eastern edge of Green Gorge, where a series of uplifted blocks is

Figure 1.4. The featherbed near Duck Lagoon is a complex of pools, mires and relict sea stacks.

obvious and just south of Brothers Point where a very narrow ridge is visible. The Brothers Fault-line can be traced over 80 km, from the Judge and Clerk Islands to the north of the Macquarie Island, SSW along the east coast, through to the Bishop and Clerk Islands to the south (Selkirk, Seppelt & Selkirk, 1990). Faulting can be seen to influence other landforms as well. The scarp above Hurd Point, benches above Lusitania Creek, the long, curving ridge near Handspike Corner (fig. 5.1) and Sawyer Creek waterfall (fig. 1.6), are all inferred to be associated with faults.

Macquarie Island is composed of four main rock types, all volcanic and submarine in origin: pillow basalts, gabbros, dolerites and ultramafics (Williamson, 1988; Christoudoulou, Griffin & Foden, 1984). Sediments of marine origin occur in the intersticies. The rock sequences represent a portion of mid-ocean crustal material, uplifted and tilted. Estimates of rates of uplift for the island vary. Minimum uplift rates which were calculated from the age and height a.s.l. of fossil penguin bones gave a rise of 1.5 mm per year (Colhoun & Goede, 1974). A maximum rate of uplift of 6 mm per year was obtained by Bergstrom (1985) from fossil peats at Green Gorge, later recalculated to 5 mm per year after remeasuring the altitude of the site (Selkirk, Seppelt & Selkirk, 1990). This agreed well with earlier estimates of 4.5 mm per year for the main portion of the island (Colhoun & Goede, 1974). Wireless Hill, considered to be a small block separated from the main body of the island by a fault running across the isthmus, was estimated to be rising at 14.5 mm per year (Selkirk, Selkirk & Griffin, 1983).

Beach deposits of sand, cobbles or shingle are found along the coast wherever the land at sea level is relatively flat. Relict beaches of well rounded cobbles are present in some areas on the plateau, formed when that section of the plateau was at sea level (Ledingham & Peterson, 1984; Varne, Gee & Quilty, 1969). Peat develops wherever vegetation grows in abundance and can be found in most environments on the island except for the feldmark. It may form deposits up to several metres thick in some areas. Heavy rain and subsequent waterlogging of the basal peat can contribute to large landslides in which tonnes of material slip from hillsides (Selkirk, in press, Weller, 1975). Exposed lacustrine deposits (remnants of former plateau lakes) occur in some areas on the island (Chapter 1.3).

Figure 1.5. Sandy Bay is one of the few areas on the east coast with substantial beach development.

1.2.3 Glaciation

Faulting plays a major role in determining landforms on the island (Ledingham & Peterson, 1984). Features once thought to be of glacial origin are now considered to be largely fault-controlled, although there is still some debate on the subject. Early workers, such as Blake and Mawson, suggested the island had been heavily glaciated (Mawson, 1943), a view shared by Taylor (1955) and Löffler & Sullivan (1980). Colhoun and Goede (1974) postulated that there had been much less extensive glaciation, with ice covering approximately 40% of the island's surface. Ledingham and Peterson (1984) suggested there had been only minor glaciation. Selkirk, Seppelt & Selkirk (1990) question even this

Figure 1.6. Sawyer Creek waterfall from the east. The narrow fault scarp is arrowed.

limited glaciation, citing evidence such as the height of the island 18 000 y BP, estimated snowline height and estimated world temperatures at the time. Colhoun (in Selkirk, Seppelt & Selkirk, 1990, p79) agrees with this re-evaluation, commenting that previously held ideas on the extent of glaciation are, at best, uncertain. Selkirk, Seppelt & Selkirk (1990) conclude that Macquarie Island at 18 000 y BP would have had a climate similar to that of the present-day subantarctic Macdonald Island (fig. 1.1) which, at 212 m at its highest point, is free of permanent snow and ice (Selkirk, Seppelt & Selkirk, 1990, pp 79-80).

Figure 1.7. Square Lake from the south. The edge of the fault, visible as a bright green strip, is arrowed.

With permanently wet and cold conditions (see Chapter 1.2.4), there is little evaporation on Macquarie Island, resulting in a great deal of surface water. It lies in deep depressions as ponds, pools or lakes, and forms extensive mires in many places. Many lakes, such as Prion Lake and Brothers Lake in the north and Lake Ainsworth in the south, are fault-controlled. To the west Square Lake is bounded by a fault (fig.1.7), and the presence of small, unnamed lakes with relatively straight edges on the southern flank of Hill 219 is fault-related (fig. 6. 5).

1.2.4 Climate

The climate of Macquarie Island is uniformly cool, wet and windy. The Bureau of Meterology Station is located on the Isthmus at 6 m a.s.l. All data on the island's weather is recorded here. The average temperature is 4.7°C, with little variation throughout the year. Summer temperatures range from 3.9°C to 12.4°C and winter temperatures from 0°C to 8.4°C. Precipitation may fall as rain, hail, sleet, snow or mist on any day of the year. It falls on an average of 308 days per year, with an average of approximately 900 mm per year (Streten, 1988).

Wind speed averages 8.3 m/sec, with six days of gale force winds (greater than 17.5 m/sec) experienced each month (Streten, 1988). There are few sunlight hours each day (an average of 2.2 hrs) due to cloud cover and mist. The low temperatures and low levels of sunlight mean that much of the precipitation stays on the island, rather than being evaporated.

The climate on the plateau is more severe than that at the Meterological Station. For every 100 m rise in altitude the air temperature drops 1°C (Jenkin, 1975) and wind speeds are greater (Selkirk, Seppelt & Selkirk, 1990). There is up to 42% more precipitation on the plateau, as mists rarely reach sea level, but remain on the plateau (fig. 1.8; Selkirk, Seppelt & Selkirk, 1990; Mallis, 1988).

Figure 1.8. Cloud resting on the plateau at Handspike Corner. The mist has lifted from the lower altitudes.

1.2.5 Vegetation

No trees or shrubs grow on Macquarie Island. There are 51 vascular plant species (Hnatiuk, 1993), about 110 bryophyte species, 25 species of green and blue-green algae (Selkirk, Seppelt & Selkirk, 1990), approximately 126 species of fungi (Kerry, 1984), over 200 species of diatoms (this volume) and an unknown number of lichens (Kantvilas & Seppelt, 1992). The tallest plants are *Poa foliosa* tussocks, which can reach over two metres in height (with pedestal development and erosion of the soil between tussocks) and *Stilbocarpa polaris*, which can grow to more than one metre. There is only one truly aquatic angiosperm, *Myriophyllum triphyllum*. Other species, including some bryophytes, grow in submerged habitats. There are five species of pteridophytes, with one lycopod species, *Huperzia australiana*, known from isolated locations mostly in the north (Hnatiuk, 1993).

Taylor (1955) classified the island's vegetation into 5 formations. This was modified slightly by Selkirk, Seppelt & Selkirk (1990) as follows:

Tall Tussock Grassland	Dominated by *Poa foliosa* tussocks. Found in lowland areas and on coastal slopes.
Short Grassland	Dominated by low-growing monocots such as *Festuca contracta* and *Agrostis magellanica*. Occurs in upland areas and on the marine terrace.
Herbfield	Occurs in sheltered areas including coastal terraces, valleys and on slopes up to 380 m a.s.l. *Stilbocarpa polaris* and *Pleurophyllum hookeri* are the dominant species.
Fernbrake	Growing in sheltered, well-watered areas such as creek banks. Dominated by *Polystichum vestitum.*
Mire	Areas where the water table is at or near the surface. The water may be neutral or acidic, depending on the geology of the basin. Angiosperms such as *Ranunculus crassipes,* or bryophytes such as *Sphagnum falcatulum* and *Marchantia berteroana* may be dominant in the mires.
Feldmark	Occurs in areas where the plant cover is less than 50%. Feldmark is usually found in areas with high wind velocities. Generally above 180 m, but in exposed areas may occur as low as 90 m a.s.l. The bryophytes *Ditrichum strictum* and *Rhacomitrium crispulum* and the angiosperm *Azorella macquariensis* are among the most common plants in the feldmark.

Bryophytes are a major component of the flora. They are common in almost every habitat on the island, from coastal zones exposed to salt spray, where *Muelleriella crassifolia* can form dense mats, to the feldmark communities where *Ditrichum strictum* and *Rhacomitrium crispulum* form small polsters or longer stripes. Bryophytes are also common in herbfield and short grassland, and may be the most important component of the flora in mire communities. Inland from Handspike Point, on the northwestern section of the featherbed, is an area where liverworts such as *Riccardia* sp. form continuous mats between *Pleurophyllum hookeri* rows (fig. 1.9). *Marchantia berteroana* can form extensive rafts on the featherbed, excluding most other species.

Figure 1.9. Rows of *Pleurophyllum hookeri* at Handspike Corner. The vegetation between is predominantly a species of the liverwort *Riccardia*.

1.2.6 Mires

Mire is a general term used to describe an area where the water table is at or near the surface (Selkirk, Seppelt and Selkirk, 1990). It includes both 'fen' and 'bog' vegetation formations described by Taylor (1955), where fens are neutral or alkaline mires and bogs are acidic mires. Mires and lakes are abundant on Macquarie Island due to the frequent precipitation and low evaporation.

The size of mires varies greatly, from small - only a few square metres (fig. 1.10)- to very large, such as that on the plateau above Sandell Bay, which is approximately 500 m^2 (fig. 3.6). The conductivity of mire water is within the same range as that of the lakes on the island (table 1.1). The main difference in water chemistry appears to be in pH; no mires had a pH above 7.5 and many were acidic (Chapter 3.1). This situation is different from that of the lakes on the island, where most are circumneutral to alkaline and no acidic lakes exist.

Figure 1.10. Cascade Mire, a small mire situated on the plateau at approximately 150 m a.s.l. Human figure gives scale.

1.2.7 Lakes

Waterbodies are numerous on the featherbed and plateau (fig. 1.11). They range in size from small pools less than 1 m across (fig. 1.12), through small lakes/large pools such as Duck Lagoon and Floating Island Lake (fig. 1.13) to Major Lake, the largest water body on the island, at 0.5 km^2 (fig. 1.14).

Lakes fall into two main trophic categories - mesotrophic to eutrophic, and oligotrophic. Meso/eutrophic lakes are often shallow with abundant macrophytes present. Most are alkaline, with moderate to high conductivity levels. Oligotrophic lakes are more common than meso/eutrophic lakes. They generally have rocky or silty bottoms, are moderately deep, and have very little plant growth, circumneutral pH and low conductivity levels (table 1.1).

The majority of salts in the lake waters are marine in origin (Mallis, 1985; 1988; Buckney & Tyler, 1974; Tyler, 1972). Salt becomes airborne over the ocean when droplets flung into the air at wave crests evaporate, leaving the salt particles to be carried up into the atmosphere by the wind (Mallis, 1985, 1988). Salts are scavenged by moisture in the air, and are deposited on the island in precipitation. As winds are predominantly from the west, most airborne salts are deposited on the western side of the island, with less on the eastern side. This is shown by the higher concentrations of salts in lakes and rain water closest to the west coast, with concentrations diminishing eastwards (Evans, 1970; Tyler, 1972).

There has been some modification of the salt concentrations by the substrates of the lakes. This appears to be greatest where the lake water is in contact with calcareous substrates such as *Globigerina* oozes (Selkirk, Seppelt & Selkirk, 1990, p125). Those lakes with rocky bottoms may have some modification, with waterbodies in peaty substrates having little or no change from sea water ion ratios.

Table 1.1 Characteristics of some waterbodies on Macquarie Island. Except where indicated, data is compiled from T. P. McBride (pers. comm.), and the author's own data. Conductivity and pH values were averaged over 1 - 6 readings per season, taken from 1 to 5 seasons.

Lake	**Size km^2**	**Depth (m)**	**pH**	**Conductivity µS/cm**	**Substrate**	**Nutrient Status**
Ainsworth	0.01	deep	6.4	180	silt/rock	oligotrophic
Brothers	0.02	shallow	7.6	240	peat	eutrophic
Duck Lagoon	0.01	1.25m***	7.3	940 mS	peat/rock	eutrophic
North Duck	0.005	shallow	8.2	190 mS	peat	eutrophic
Floating Is.	0.008*	6.9 m*	8.1	270	peat	mesotrophic
Green Gorge	0.01	deep	6.1	170	silt	mesotrophic
Handspike Tarn	0.008	shallow	6.4	620	peat	mesotrophic
Langdon Pt. N	0.004	shallow	6.4	1020	peat	mesotrophic
Langdon Pt. S	0.008	shallow	7.2	1420	peat	mesotrophic
Major	0.5**	16.2 m**	7.3	220	silt	oligotrophic
Prion	0.03***	32.3 m***	6.1	170	rock/silt	oligotrophic
Pyramid	0.04	deep	6.1	130	rock	oligotrophic
Ess Pond	(36 m^2)***	0.4 m***	6.2	180	peat	eutrophic
Sandell Tarn	(3 m^2)	0.5 m	6.8	230	peat	mesotrophic
Square	0.07***	0.6 m***	7.2	280	silt	eutrophic
Tulloch	0.13	shallow	6.2	180	silt	oligotrophic

Figures from *Gardner (1977); **Peterson (1975); and ***Evans (1970). Deep: > 5 m; shallow < 5 m.

Figure 1.11. Aerial photograph showing some of the many waterbodies on the plateau. Scoble Lake is arrowed. (Photograph J. M. Selkirk).

Figure 1.12. Ess Pond in the north of the island. The narrow connection between the two larger pools is approximately 0.5 m across.

Figure 1.13. Floating Island Lake, a small lake east of the Nuggets, from the south. The two floating islands of vegetation are thought to have slipped into the lake from the west.

1.3 Palaeolakes

Until recently, little work had been conducted on the history of the lakes on Macquarie Island. While some, such as Major Lake and Tiobunga Lake, had been studied morphometrically (Peterson, 1975), attempts to obtain long cores of lake sediments had failed. The longest core obtained was 2 m collected from Scoble Lake (Salas, 1983).

A diagram of the first reported lacustrine deposit located near the Nuggets was prepared by L. Blake (Mawson, 1943). In 1980 a second palaeolake was discovered adjacent to Skua Lake, with sediments found up to 13 m above the present-day water level (P. M. Selkirk, pers. comm.). Analysis of these sediments revealed they were fossil rich with well-preserved macrofossils and microfossils (Selkirk, Selkirk, Bergstrom & Adamson, 1988). Exposures of palaeolake deposits on sea cliffs, valley sides and creek

Figure 1.14. Major Lake, the largest lake on Macquarie Island, from the west. Composite of two photographs.

banks provide a means of seeing and sampling lacustrine deposits without the need to extract cores from the modern lakes.

Palaeolakes of this nature are apparently unique to Macquarie Island. They are important in that they provide long, detailed records of changes within the lakes over time on the island. The changes may be local in effect or more widespread. They are more easily sampled than other areas, such as mires or peat deposits. Consistently, the paleolake deposits have provided the oldest dated organic material on Macquarie Island. Only one older sample of peat has been radiocarbon dated (P. M. Selkirk, pers. comm.).

Ten palaeolake deposits are now known from Macquarie Island. All are at or near the plateau margin (fig. 1.15) and are remnants of former lakes which have been drained by geomorphic processes. Palaeolakes Half Moon, Emerald, Cormorant, Sandell and Toutcher are small deposits perched on the edge of steep cliffs above the featherbed. Palaeolakes Cascade and Eagle and Skua are located behind the cliff edge, with the western edge of Cascade still visible. Palaeolakes Lusitania and Nuggets are located on the eastern side of the island; Nuggets perched on old sea cliffs, and Lusitania on a steep bank above Lusitania Creek, approximately 0.5 km from the coast.

The former lakes were drained by one of two main processes - either by marine undercutting of the cliffs to the seaward edge of the lake, or by downcutting of the outlet stream. Progressive wave action eroded much of the island, resulting in the drainage of many lakes (Selkirk, McBride, Keenan & Adamson, 1991). Undercutting weakened the bedrock below the seaward margin of the lake and the rock eventually slumped, draining the lake and leaving sediment exposed on the cliff margin. Further marine erosion, coupled with active water and wind erosion of the exposed sediments, eroded much of the lacustrine material, leaving only remnants behind. Once sea level stabilised, approximately 6000 y BP, further uplift of the island removed the sea cliffs from the zone of active marine

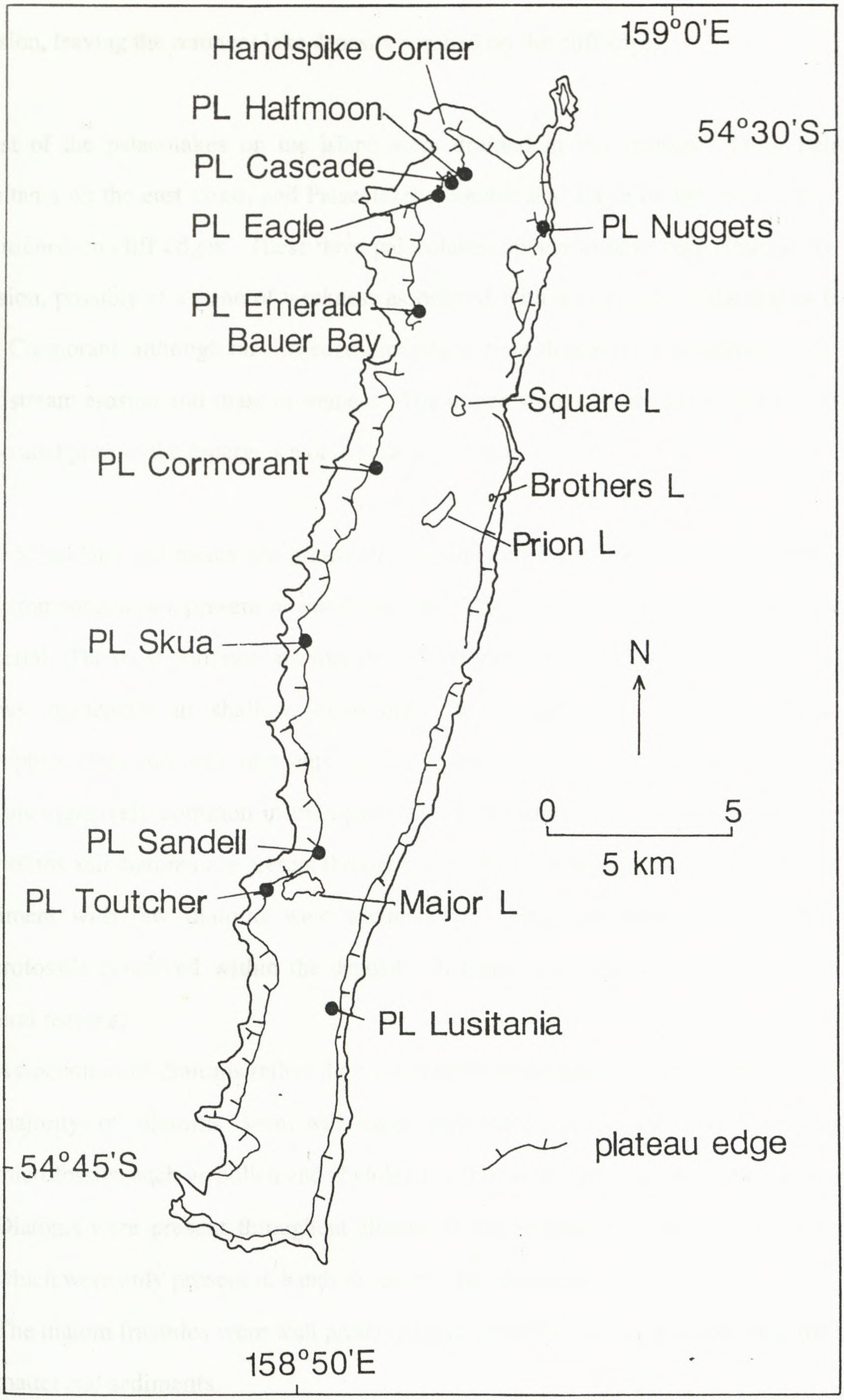


Figure 1.15. Map of Macquarie Island showing the locations of the ten known palaeolake (PL) deposits.

erosion, leaving the remnant lake deposits perched on the cliff edges.

Most of the palaeolakes on the island were drained in this manner. Only Palaeolake Lusitania on the east coast, and Palaeolakes Cascade and Eagle on the west coast are not positioned on cliff edges. These three palaeolakes appear to have been drained by stream erosion, possibly at a zone of weakness associated with a fault-line. Palaeolakes Emerald and Cormorant, although on cliff edges, may have been drained by a combination of marine and stream erosion and mass movement. The upper sediments are too young to have been deposited prior to the emergence of the marine terrace.

The palaeolake sediments are principally diatom-rich clays, with bands of sands, gravels and iron concretions present in some deposits. The sediments are also rich in macrofossil material. The most common macrophyte is *Myriophyllum triphyllum* (fig. 1.16), which still grows abundantly in shallow, mesotrophic to eutrophic lakes on the island today. Bryophyte stem and leaf fragments (fig. 1.17) and parts of insect carapaces and egg cases are also relatively common in the macrophyte-rich bands. Microfossils including pollen, phytoliths and diatoms are present throughout most of the deposits, although some bands of sediment with few diatoms were encountered. From amongst the macrofossils and microfossils preserved within the deposits, diatoms were selected for detailed study for several reasons:

1. Associations of diatoms reflect the environment of the palaeolake at a specific time. The majority of diatoms seen will have originated within the lake, whereas other microfossils, such as pollen and phytoliths will have blown or washed into the lake.
2. Diatoms were present throughout almost all the sediments, compared to macrofossils, which were only present in bands in some of the deposits.
3. The diatom frustules were well preserved and could be easily separated from the organic matter and sediments.
4. Diatom species often have distinct ecological preferences and so are useful for palaeo-environmental interpretation.

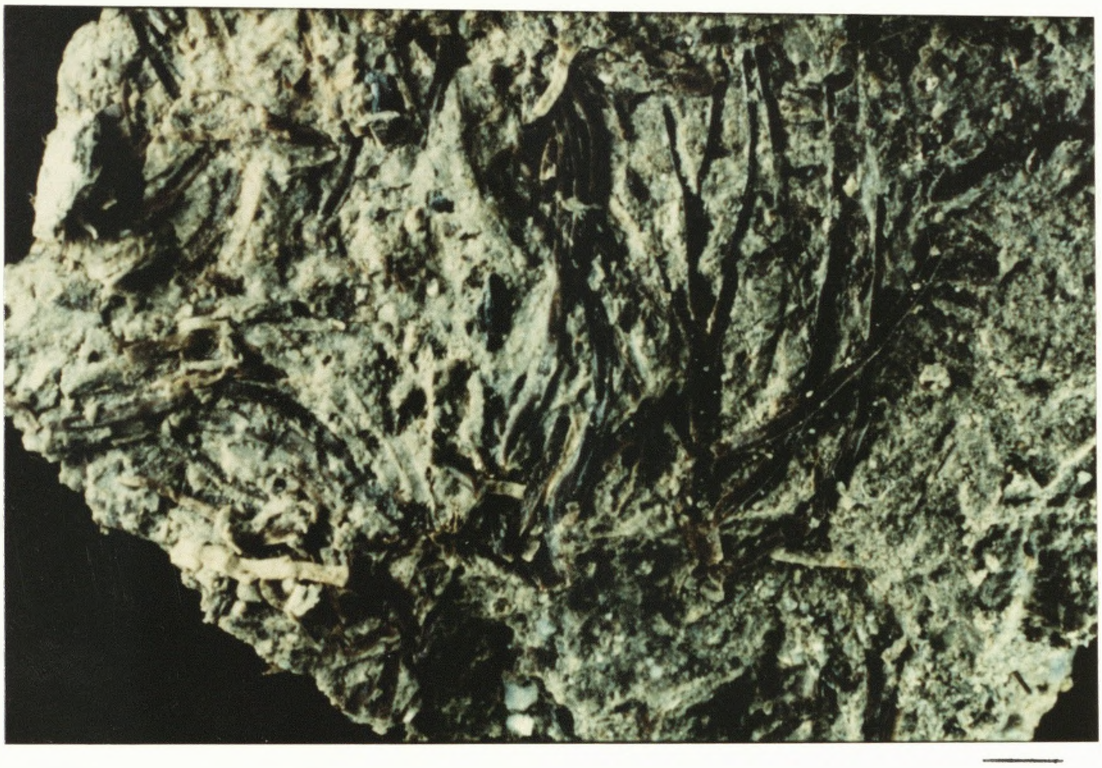


Figure 1.16. *Myriophyllum triphyllum* specimen in sediments from Palaeolake Eagle. Scale bar measures 100 μm (Photograph J. Norman).

Figure 1.17. *Fissidens rigidulus* from Palaeolake Cascade sediments. Scale bar measures 100 μm. (Photograph J. Norman & R. Oldfield).

1.4 Diatoms

Diatoms (Division Bacillariophyta) are single-celled, photosynthetic organisms placed with the algae (Bell & Woodcock, 1983). They are found in all environments - marine, freshwater and terrestrial. Arguably the most important taxonomic feature of diatoms is the cell wall, impregnated with silica. The rigid wall (**frustule**) is very robust - it preserves well in most environments. This is important especially when dealing with fossilised materials as it enables the identification of diatoms to species level or lower, which in turn can provide detailed information about the community structure. In turn, this allows an accurate interpretation of the habitat at the time of deposition to be made.

Diatom species often have specific ecological ranges. They may be restricted to acidic, circumneutral or alkaline conditions; high, moderate or low nutrient levels; low or high ion levels. They may be restricted to particular substrates such as rock, macrophytes, other algae or to certain environments such as soil, mires or lakes.

The majority of diatoms that occur in freshwater environments in the subantarctic and Antarctic are pennate species (elongate), rather than centric (with radial symmetry). No satisfactory explanation has been given for this, but it may be related to the habits of the species - pennate diatoms are generally benthic or epiphytic, attached or motile, while centric diatoms are more commonly planktonic.

The taxonomy of diatoms is based principally on the patterns of silica deposits in the valve. More or less silica in certain places in the cell wall results in distinctive patterns of striae, pores and raphes, each unique to a species. The unique patterns make it possible to obtain details of communities from well-preserved fossil deposits.

The frustule is composed of two halves (**valves**) which fit together like a petri dish, one inside the other. The valves are held together by **girdle elements** situated around the cell like a band. Other elements of the valve are the **striae**, which are rows of very fine punctae that run perpendicular to the **raphe**, an elongate slit which runs along the long axis in most pennate species. **Pores** can also be present - coarser striae which pass right through the valve.

Valves in all the samples of modern materials and palaeolake sediments on Macquarie Island were preserved very well, with most of the valves unbroken. Although broken valves were encountered, very few have been seen with dissolution marks. Dissolution, or the dissolving of silica in the frustule, can occur at high or low pH. This good preservation, plus the specific habitat preferences of certain diatom species, make them ideal for use as palaeoenvironmental indicators.

There have been very few studies made of diatoms from the subantarctic. They include Bunt's (1954) study of Macquarie Island terrestrial diatoms, as well as studies of the diatoms of the Kerguelen Islands by Germain (1937), Bourrelly and Manguin (1954), Le Cohu (1981) and Le Cohu and Maillard (1983; 1986). Some new species were identified and reported, listed as endemic to the Kerguelen Islands (e.g. Le Cohu & Maillard, 1983). Many of the species reported from Kerguelen are also found on Macquarie Island, including many which were reported as endemic to the Kerguelen Islands. Other works, such as Evans (1970) are simply reports of diatoms seen, with no ecological or environmental interpretations of their distribution.

Studies on diatom autecology are plentiful from the northern hemisphere. However, uncertainties as to the applicability of these to Macquarie Island meant that a detailed study had to be undertaken. An investigation into the diatom floras of modern Macquarie Island lakes was begun in 1988 (T.P. McBride, pers. comm.). A range of lake types was covered, from oligotrophic to eutrophic, circumneutral to alkaline, shallow to deep, rocky to silty bottoms, from low to high altitudes, from the east coast to the west coast and with and without vegetation. Collections of epilithic algae, macrophytes and sediment were made in the lakes at least once per year for five years. At the same time samples were collected, measurements of pH and conductivity were made in the field using portable meters. Some water samples were collected for analysis of the major ions. Some of this data will be presented in this study, and has been used in the interpretation of the palaeolake sediments.

1.5 Terrestrial and Mire Studies

While diatoms are principally regarded as aquatic organisms, they also grow abundantly in other moist environments. One habitat common on Macquarie Island is mire, where the water table is at or very near the surface. As a result the vegetation that grows in these areas - including bryophytes and some angiosperms such as *Ranunculus crassipes* - is permanently saturated and so makes an ideal environment for diatoms. These areas have proved to be rich in diatoms, with some associations similar to those found in modern lakes. Other mire sites have diatom associations which are very different from modern lake diatom floras (Chapter 3.4).

The terrestrial sites which were examined were generally rich in diatoms. Only samples of lichen contained few diatom valves. The moderately moist communities of feldmark and creek contained diatom associations similar to those from the mires. The soil sites (which were generally drier) and the nutrient-enriched areas contained very distinct populations of diatoms. Data from a wide range of diatom-rich modern environments provide a useful basis for the interpretation of past environments.

1.6 Aims of the Project presented in this Thesis

The project presented in this thesis had five specific aims:

1. To examine the diatom species present in a range of present-day (or modern) habitats on Macquarie Island.

Modern mires, moss polsters and *Azorella macquariensis* from the feldmark, algae and moss from creeks, lichen, soil, algae and sediment from elephant seal wallows and penguin colonies (nutrient enriched) were studied. Data from modern lakes have been supplied by Dr T.P. McBride and are examined briefly here. Methods are presented in Chapter 2. The results and discussion are presented in Chapter 3 (mires and lakes) and Chapter 4 (terrestrial sites - creeks, feldmark, soil, lichen, nutrient enriched sites).

2. To determine habitat preferences for the diatoms found in modern habitats and to determine whether changes have occurred with time in mires on Macquarie Island.

Methods are presented in Chapter 2, the data and discussion for mires are presented in Chapter 3, the results and discussion for the terrestrial sites are presented in Chapter 4.

3. To identify associations of diatoms occurring in modern habitats.

The methods are presented in Chapter 2, with the interpretation of the results discussed in Chapter 3 (mires and lakes) and Chapter 4 (terrestrial habitats).

4. To document the physical setting, nature of the deposit and diatom associations present in each of the five palaeolakes on the northwestern plateau edge of Macquarie Island. The palaeolakes examined were Half Moon, Cascade, Eagle, Emerald and Cormorant.

The methods are presented in Chapter 2. The site descriptions, results and discussion are presented in Chapters 5 to 9, with each chapter dealing with a separate palaeolake.

5. Interpretation of the palaeolake habitats and environmental conditions using the data from the above aims.

Interpretation and discussion of the palaeolake deposits are presented in Chapters 5 to 9. A discussion of the major findings of the thesis and the conclusions drawn from it are presented in Chapter 10.

Chapter 2

Materials and Methods

2.1. Introduction

Diatom samples from modern habitats were collected from sites principally in the northern part of Macquarie Island. Samples were collected from the five palaeolakes studied, located in the northwest sector of the island. Sampling predominantly in the northern part of the island was done for convenience, with the ANARE reseach station and the majority of field huts located in this area (see map insert). Sample sites were also often located close to walking tracks on the island (see map insert) as weather conditions frequently made travelling on foot off-track dangerous.

Particular sites were chosen at random from within an established set or group of habitats. Five replicate samples at each site were collected and combined to minimise the effects of variation within the sites. Samples of vegetation, soil or algae were collected and treated as a substrate for diatoms. These samples were prepared to free the diatom valves which were either trapped within or attached to the substrate (Chapter 2.3.1).

Fieldwork was conducted over two consecutive summers: November to March 1990/1991 and October to April 1991/1992. Limitation in the equipment available to be taken into the field and on the island in general meant that only pH and conductivity were measured in the field using small portable meters. The meters were calibrated prior to each use either at the ANARE station, or in one of the field huts, using standard solutions.

2.2 Fieldwork

2.2.1 Modern mires

Thirty-two mire sites in the northern part of the island were sampled to provide information on the distribution of modern diatom species (Chapter 3; fig. 3.1). For each mire the dominant vascular and non-vascular macrophyte species were identified and the abundance of each was recorded as percent cover. Where identification was uncertain, samples were collected for comparison with published works or herbarium specimens. Where several non-dominant bryophyte species were present at a site they were not identified, but the percent cover of all these species was combined. Five replicate samples of surface vegetation were collected and placed into labelled plastic or paper bags. Five small holes were then cut into the surface of the mire vegetation with a sharp-edged trowel at these points. These holes were to allow access to undisturbed, decomposing vegetation below the surface. A sample of vegetation from 100-150 mm below the water level was taken, and in certain sites a sample from 250 mm and/or 400 mm depth was also collected. Each of the five samples was placed into a labelled bag. Vegetation was collected as this would be the substrate for many benthic, epiphytic and motile species of diatoms within the mires.

Samples of peat from depth were collected to examine the changes over time within a mire. Vegetation from 100 mm below the surface is partially decayed and compacted, undergoing the chemical and physical transformation into peat. Diatoms from these depths reflect the surface diatom associations from when the vegetation was deposited.

Five replicate water samples were collected one at a time in a polycarbonate tube from points within the mire close to the sampling site. The pH and conductivity of each sample was measured and recorded. The five measurements were then combined to give an average reading for the mire.

One large mire, Sandell, was chosen as a site for studying the heterogeneity of diatom associations within a single mire. Ten samples of surface vegetation and 10 from depth were collected from randomly chosen sites within the mire and analyses conducted on these. Ten pools close to each sample site were also chosen and sampled to assess the differences between mire and pool vegetation. Details of the site, sample locations and descriptions are provided in Chapter 3.5.

2.2.2 Other modern habitats

Samples were collected from a range of terrestrial habitats on Macquarie Island to provide further information on the habitat preferences of some diatom species (Chapter 4). Collections were made in the following habitats:

Creeks	algae and vegetation from within and around creeks
Feldmark	moss polsters and *Azorella macquarienis* cushions
Soil	soil from bare areas
Lichen	lichen from rocks and amongst bryophyte vegetation
Elephant seal wallows	algae and sediment from areas disturbed by elephant seals
Penguin colonies	algae and sediment from areasdisturbed by penguins

Sites were chosen randomly from within each of the habitats. Five replicate samples of the surface soil or dominant vegetation were collected and placed into labelled bags or polycarbonate tubes. Epilithic algae were collected in some sites by scraping a polycarbonate tube over several rocks. The samples were then preserved with 10%

formaldehyde (algae), air-dried (bryophytes) or oven-dried (soil and angiosperms) and stored for analysis on return to Australia. All these samples of vegetation, soil or algae were considered to be substrates for diatoms. Preparation of the samples freed the diatoms for examination (Chapter 2.3). Collection sites and samples are listed in Chapter 4.2.

2.2.3 Palaeolakes

The palaeolake deposits on Macquarie Island are remnants of former lake beds, exposed by lake drainage (Chapter 1.3). After drainage, stream erosion and slumping have been the main geomorphic processes working together on the lake sediment. Erosion has been more effective in some areas than in others - completely removing the sediment in places, and leaving sediment behind in others. These remnants may be exposed in creek banks or on cliff edges and it is these remnants of former lakes which have been sampled.

Depending on the size of the deposit and the number of exposures, one to four sections were taken at each palaeolake site. To minimise the disturbance to the site each section was located in an area already essentially devoid of vegetation. The surface of the exposure was cut back about 15 mm with a square-ended spade to uncover a face minimally affected by oxidation and modern vegetation. This was determined by examining the lacustrine material for rootlets and obvious colour alterations. Oxidised surfaces were orange/brown or brown, unoxidised surfaces were generally blue/grey in colour. Sampling was begun at the base of each exposure to prevent sediment from above falling onto and contaminating lower samples. The sample at the base of the natural exposure was always marked 0 mm, whether the deposit occurred below this or not. Upper samples were labelled according to distance up the slope above the basal sample. Excavation at the base of the natural exposure was started if the lacustrine material continued below this to extend the profile to the base of the lacustrine material. Samples collected from below 0 mm were labelled according to vertical distance below the first sample point.

Each sample was removed from the section with a clean trowel or knife and was placed into a clean polycarbonate tube or plastic bag. This was then labelled with site, date, section number and height above or below the first sample (0 mm). For each sample, details of sediment type, grain size, presence/absence of macrofossils and colour were recorded. Sample information was recorded to provide information on the sediment loading on the lake at the time of deposition and the amount and species of macrophytes growing within the lake at any time. This provides further, independant information on the conditions of the lake at the time that the diatoms were deposited.

Vertical height was determined indirectly by measuring distance along the ground between the lower and next samples, and recording the average slope (using an inclinometer) over the distance. The two measurements were then used to calculate vertical distance between samples trigonometrically. These distances were then employed to obtain depth below the peat/soil surface for each sample.

Where the sediment continued below the base of a natural exposure, an auger was employed to obtain samples from below the surface. The auger had an 85 mm diameter head and a one metre long handle, with an extra metre extension available. The auger was drilled into the sediment at the base of the profile and once the auger head was full of sediment it was carefully extracted from the hole. This was sampled with a clean knife and placed into a plastic bag and labelled. Care was taken to exclude material less than 10 mm from any edge of the auger head and from the base of the core to minimise the possibility of cross-contamination occurring. The depth below the surface was recorded.

2.2.4. Lakes

Sampling of a range of modern lakes was conducted to provide further information on the habitat preferences of modern diatoms on Macquarie Island. Samples of macrophytes, rock scrapings and sediment were collected from a range of lakes for analysis by T.P. McBride.

Conductivity and pH were measured with portable meters when the samples were taken to obtain some information of seasonal and long-term trends in water chemistry on the island. The results from this study have been provided by T. P. McBride and will be referred to within this thesis (McBride, pers. comm.).

2.3 Laboratory Methods

2.3.1 Sample preparation

Diatoms were extracted from all of the samples collected using the following technique.

1. Approximately 1 g (wet weight) of material (plant matter or sediment) was placed into a polycarbonate tube (volume 30 ml).
2. These samples were then placed into an oven at about 80°C and left for two to three days, until a constant dry weight for the material was reached.
3. 10% of 30 volumes H_2O_2 was added to the tubes to digest any organic matter and to "clear" the diatom valves to facilitate identification of species. The tubes were left to sit at room temperature for three to four days, then placed into an oven at approximately 100°C for three to four hours to complete digestion.
4. Any remaining undigested material was placed onto a gauze square held over a clean polycarbonate tube with an elastic band and rinsed six times with distilled water. The diatom valves and excess water were squeezed out between each rinse by compressing the plant remains with a clean spatula. Up to 98% of the diatom valves trapped in the plant material were removed by this method (mean = 2.4; standard deviation = 1). All species of diatoms were removed from the plant material equally well. The undigested plant matter was then discarded.
5. The samples were left overnight to allow the diatom valves to settle out and the following day the liquid in the tube was removed by pipetting or decanting.

6. Samples were rinsed three times with distilled water to remove soluble salts. Between rinses the samples were allowed to sit overnight to ensure all the diatom valves had settled. The water was decanted and the rinsing repeated.
7. Distilled water was added to each sample tube and the sample shaken by hand. Heavier particles were allowed to settle for approximately 20 seconds, and the diatom valves in suspension poured off into a second, clean polycarbonate tube. This procedure was repeated twice to separate the diatom valves from the larger particles. The suspension was then ready for slide preparation.

2.3.2 Slide preparation

Slides were prepared using the following protocol (McBride, 1988).

1. Using a clean pipette, 1 ml of diatom suspension was taken and placed into a clean conical flask.
2. One drop of 10% ammonium chloride was added to the suspension to restore the ionic balance of the liquid and to reduce particle clumping.
3. An aliquot of distilled water was added to dilute the diatom suspension so that there were approximately six to ten valves per field of view in the final product. (Generally between 80 ml and 130 ml of water was added to sediment samples, less to other samples.)
4. The suspension was placed into the well of a specially designed tray, over a coverslip.
5. The tray, which can hold a maximum of six samples, was placed in a desiccator over a bed of silica gel, covered and left for two to three days, or until the water level in the wells dropped below the surface of the cover slips This left the diatom valves sitting on the upper surface.
6. A drop of Naphrax in toluene (refractive index 1.7) was placed on a glass microslide, and the slide placed on a hotplate.
7. A coverslip was removed from the desiccator tray and placed face-up onto a hotplate for one to two minutes to sublime any residual ammonium chloride.

8. Once the Naphrax was heated through, the coverslip was placed, face down, onto the slide. The preparation was allowed to boil for approximately one minute to ensure the Naphrax displaced any air bubbles from within the valves.
9. The slide was removed from the hotplate and pressure applied until the slide was cool enough to touch, compressing the preparation to a minimum thickness. It was allowed to sit for a few hours to allow the mountant to harden. The slide was then ready to count.

2.3.3 Microscope analysis

An Olympus microscope model BH with a 100x oil immersion objective, Differential Interference Contrast attachments, 10x eyepieces and camera was used for counting and identification of diatoms. Between 300 and 500 diatom valves were counted and identified from each slide. Three to five hundred valves has been shown to give a good statistical representation of the population from each sample (Dixit, Cumming, Smol & Kingston, 1992; Birks & Birks, 1980). In this study, 85% of species were encountered after counting 400 valves, 89% after counting 500 valves and only 11% new species encountered between 500 and 1000 valves (fig. 2.1). The majority of the new species seen after counting 500 valves were only represented by one valve and so were considered very rare in the assemblage.

Where the identification of a valve was uncertain, a photograph was taken for later reference. If identification of a species was still uncertain, a coverslip was prepared for Scanning Electron Microscopy. Species were identified with particular reference to published works: Le Cohu and Maillard (1983; 1986), Le Cohu (1981), Bourrelly and Manguin (1954), Patrick and Reimer (1966) and Round, Crawford and Mann (1990).

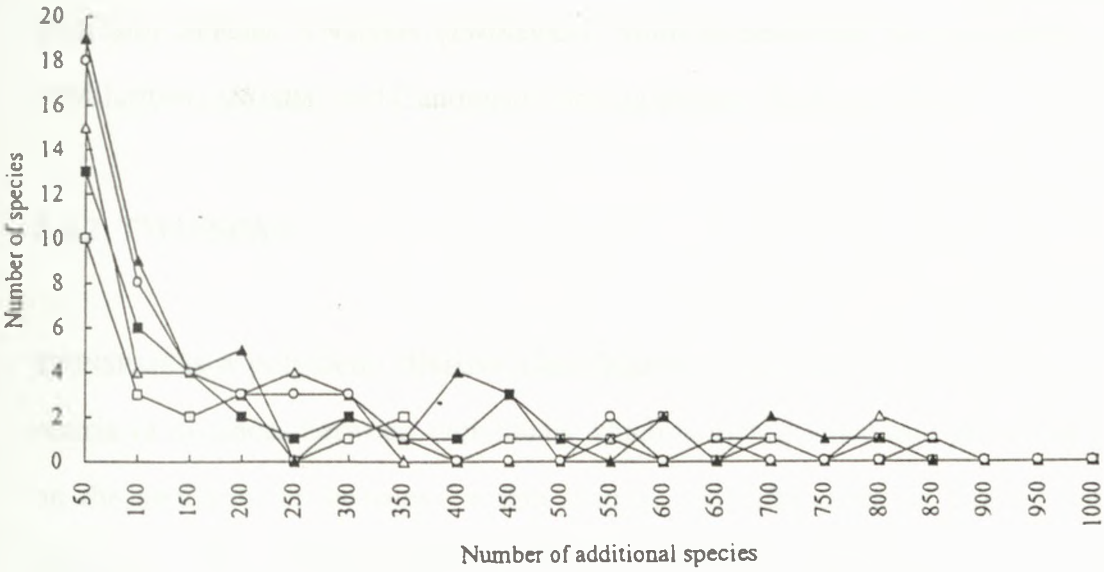


Figure 2.1. Number of additional species encountered per 1000 valves counted. The samples are from palaeolake sediments. Half Moon section 2, 0.9 m depth (▲), Half Moon section 3, 1.8 m depth (○), Cascade section 3, 1.6 m depth (△), Eagle section 1, 1.6 m depth (■) and Cormorant, 3.5 m depth (□).

For Scanning Electron Microscope (SEM) work, prepared samples were settled onto coverslips as above. The cover slips were then placed onto a metal stub and gold coated. SEM examination was principally used for identification of species which were unusual or which were unclear under the light microscope.

2.4 Data Analysis

2.4.1. Data preparation

Data was collected by identifying and counting diatom valves from each sample. This was entered into a computer database (DECODA - Database for ECological COmmunity DAta) which was used to store and manipulate data. Environmental variables for each site were entered into a statistical programme to determine the effects of different environmental variables (e.g. pH, nutrient levels) on the diatom communities.

Four main multivariate techniques were used to analyse the data. These were Two Way INdicator SPecies ANalysis (TWINSPAN), Multi-Dimensional Scaling (MDS), ANalysis Of SIMilarities (ANOSIM) and Canonical Correspondance Analysis (CCA).

2.4.2 TWINSPAN

TWINSPAN is a polythetic divisive classification technique (Gauch, 1982). It produces a matrix of distances between individuals which is then divided into groups or clusters based on the similarity or 'nearness' within groups, and differences or 'farness' between groups (Manley, 1986). The divisions continue until either the specified number of levels is obtained or all groups contain less than the specified number of individuals (Omerod & Edwards, 1987).

An eigenvalue (E) is given at each stage of the analysis which indicates how much of the total variation within the data has been described at that level. The higher the eigenvalue, the better the analysis. TWINSPAN uses Reciprocal Averaging (RA) to ordinate the data prior to the first division, and ordinates each separate group throughout the analysis (Gauch, 1982). This could present a problem when assessing the groups, as it may act to change the focus of the gradients being examined - while one gradient may be important in describing the overall variation in the data, less important factors may affect the groupings further into the analysis.

2.4.3 MDS

MDS is an ordination technique which arranges samples in two, three or higher dimensional space according to the dissimilarity of species composition between samples. Like samples are placed close together, unlike samples are placed far apart (Faith & Norris, 1989). The robustness of MDS, its ability to recover patterns in almost any data set has only recently been recognised (Clarke, 1993; Faith & Norris, 1989; Faith, Minchin & Belbin, 1987; Minchin, 1987)

MDS produces a configuration of samples that is interpreted visually (Clarke, 1993). The reliability of the configurations can be judged by the minimum stress levels for each dimension - the lower the minimum stress (the remainder of variation in the data to be explained), the better the sample configuration. Although stress will increase as the number of samples increases, a good guide is that a stress between 0.1 and 0.2 is interpretable; and less than 0.1 is a good configuration (Clarke, 1993; Kruskal, 1964).

Several types of MDS exist; metric, non-metric (NMDS) (which includes the 'local' and 'global' forms) and hybrid (HMDS). Local NMDS is very robust, and appears to be one of the most effective techniques when used in conjunction with the Bray-Curtis dissimilarity co-efficient (Minchin, 1987; Gauch, Whittaker & Singer, 1981; Fasham, 1977). HMDS is the most recently developed form of MDS. It combines both metric and non-metric forms of MDS and has proved to be more robust than NMDS (Faith & Norris, 1989). HMDS uses a fixed threshold of 0.8 as the highest measure of data interpretability, with values above this seen as misleading. These are discarded prior to the analysis being conducted (Faith, Minchin & Belbin, 1987).

MDS has proven to be far more reliable than Detrended Correspondence Analysis (DCA), another, earlier ordination technique still popular amongst ecologists. DCA is a technique based on RA that attempts to correct the distortion apparent in RA by segmenting the axes and averaging the sample scores in each segment (Field, Clarke & Warwick, 1982; Gauch, 1982). Minchin (1987) showed that DCA did not adequately describe complex models, compressing variation along the second axis towards the end of the first axis, resulting in a tongue-like arrangement of samples. The criticisms of DCA are two-fold - first is its arbitrary 'detrending', and second is its lack of robustness with data that may be unevenly distributed, such as skewed, unimodal or noisy data (Clarke, 1993; Faith, Minchin & Belbin, 1987).

The performance of HMDS and DCA were compared by analysing data from the terrestrial habitats. With the data presented in Chapter 4, both HMDS and DCA analyses were done for each data set and the results compared. In most cases the configurations of the results in two dimensions were similar; in the smaller data sets the differences were negligible. However, taking into account the recognised problems that can occur with DCA, only the HMDS results are presented. DCA was not used in any other analyses

In practice, the HMDS iteration was run with 25 starting configurations and repeated at least five times. If all minimum stress values from all five repetitions were the same to three decimal places, no further runs were made. If differences occurred, the number of starting configurations was increased and the iteration was repeated until minimum stresses from five runs matched (Clarke, 1993).

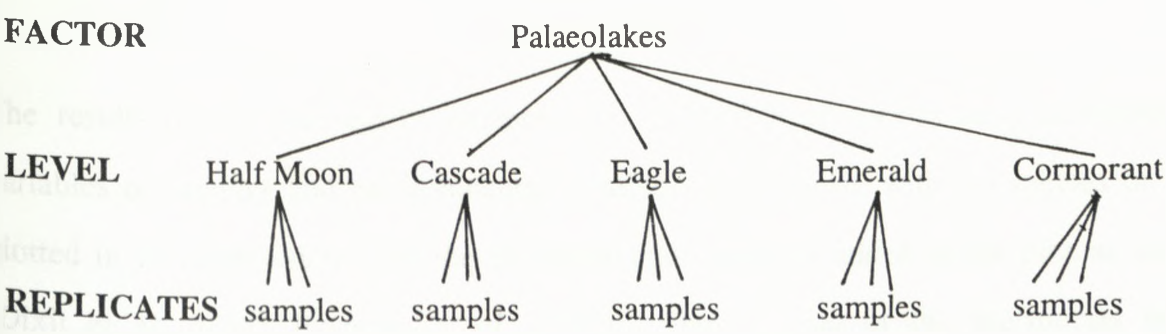
For each analysis, species occurring in less than three samples (if 10 to 25 samples), or less than five samples (if more than 25 samples) were excluded, to reduce 'noise' in the data. The data were all log 10 transformed. The fixed threshold of 0.8 and the Bray-Curtis measure of dissimilarity were used in all runs. TWINSPAN sample groups were drawn onto the plots by hand.

Some larger groups of samples were split prior to the final analyses. This was done primarily to increase the reliability of results. Splitting data and carrying out the separate analyses will reveal more subtle environmental gradients which may be overshadowed by the coarser, obvious gradients (Clarke, 1993). This was conducted by comparing groups of samples within habitats (such as algae and moss samples from creek sites) using ANOSIM.

2.4.4. ANOSIM

Analysis Of Similarities (ANOSIM) is a technique used to assess the degree of similarity or difference between groups of samples. It is a relatively new technique for a pairwise comparison of sites and is a multivariate analogue of the one-way analysis of variance (ANOVA) procedure (Clarke, 1993). The test uses a dissimilarity matrix (such as Bray-Curtis) to determine 'R' where 'R' is the measure of variation *between* sites, divided by the variation *among* sites. The groups of samples are identified *a priori* to remove any subjective influence on the analysis (Clarke & Ainsworth, 1993). For example, groups identified before sampling can be used, such as mires and lakes, wallow, penguin and soil, or Palaeolake Half Moon and Palaeolake Cascade. The dissimilarity matrix is then entered into the ANOSIM program.

Sample labels are randomly rearranged and for each rearrangement the 'R' statistic is calculated. The process is repeated up to 1000 times to give a frequency distribution of 'R' values (Clarke, 1993). The null hypothesis for the test is: H*o*: there is no difference between sample groups. If this is true, the 'R' value will be small and the probability (*p*) values large. If it is not true and there are significant differences between the sample groups, then 'R' will be large and *p* less than .05 (95 % C.I.). The problem of increased type 2 error associated with multiple comparisons is recognised and corrected for by the ANOSIM programme. All ANOSIM tests in this thesis are one-way factor analyses, where the factor is the type of sample groups, the levels are the sample types and the replicates are the samples. For example:



Where analyses have been conducted for the data, results will be presented as a p value and are considered to be significant if $p < .05$.

2.4.5. CCA

Canonical Correspondance Analysis is a multivariate ordination technique based on correspondance analysis, or weighted avarages ordination, which allows direct gradient analyses to be made (Dixit *et al.*, 1989; ter Braak, 1986). It uses environmental variables to ordinate species and site scores, so the axes selected directly relate to the environmental gradients (Dixit *et al.* 1989). The major assumption is that species respond to the environmental gradients in a unimodal fashion (Dixit *et al.*, 1992; Palmer, 1993). CCA simultaneously orders species and sites and chooses best weights of these scores for the environmental variables to give the first axis. Subsequent axes do the same, but are constrained by the need to be uncorrelated with the first axis (Jongman *et al.*, 1987).

While CCA is related to CA and DCA, it apparently has none of the problems associated with the other ordination techniques. Ter Braak (1986) suggested detrending the CCA ordination to reduce the arch effect which occurs commonly in CA. Palmer (1993) in his evaluation of the technique, found no need to conduct detrending as arches will only appear in the data if it is real, not as an artifact. He stated that the arbitrary detrending (a major problem with DCA) was inelegant and often performed poorly with complex or skewed data. CCA perfomed well in many cases: when there were many important gradients, with high noise, complex data sets, skewed data or highly correlated variables (Palmer, 1993).

The results of CCA are easily interpretable. A biplot of species and environmental variables or samples and environmental variables is produced, with the species or sites plotted in two dimensions and the environmental variables added to the plot as arrows (Dixit *et al.*, 1989; Jongman *et al.*, 1987). The position of the site/species points approximate the weighted average (WA) scores of each point to each variable (Jongman *et al.*, 1987). Following Palmer (1993) the Linear Combination (LC) of sample scores, rather than WA, are presented in this thesis as these are considered to be more constrained by the environmental variables than the WA scores. The species/environment correlation scores indicate the amount of variation in the species data which is explained by the variables in the first two axes. The grand mean of the ordination is the centroid of the plot (Jongman *et al.*, 1987). The arrows point in the direction of the maximum change of that variable (Dixit *et al.*, 1989).

Arrows which are placed close together on a plot are correlated, arrows perpendicular to each other are not correlated and those at greater than 90° are inversely correlated. The length of an arrows indicates its relative importance; longer arrows are more strongly correlated with the ordination axes and so account for greater variation in the data sets than shorter arrows (Jongman *et al.*, 1987). The interset correlation coefficents show how well each environmental variable is related to each axis. Where the values are close to one, correlation is high. The goodness of fit of the ordination expresses the percentage of all variance accounted for in two dimensions: it is determined by obtaining the sum of the eigenvalues for the first two axes divided by the sum of all eigenvalues for the ordination. Because of noise in the data, the goodness of fit will never reach 100% (ter Braak, 1986). The significance of variables can be examined with Monte Carlo permutation tests (Dixit *et al.*, 1991). The Monte Carlo tests rearrange the data arbitrarily and calculates the variability in each set, much as is done in ANOSIMs. A p value is calculated for the first axis and the for the entire CCA simultaneously. Where p is less than 0.05, the value is given. CCA has been shown to be useful in the interpretation of diatom associations from both modern and fossil information (e.g. Davis *et al.*, 1990).

2.4.6 Transfer Functions

The use of transfer functions for estimating environmental variables using diatoms is a recognised technique (eg. Gasse, 1986; Gasse & Tekaia, 1983). Transfer functions have primarily been used in the interpretation of palaeo-pH from sediments, especially in the Northern Hemisphere where lake acidification is occurring. Diatoms from modern samples with known pH are identified and counted. All the information obtained on each species from each sample is placed into an algorithm, and for each species an estimate of the pH range and preferred pH can be obtained. The greater the number of samples, the greater the reliability of the transfer function. The greater the range of pH, and the more important this is in describing habitats, the more useful transfer functions are.

The decision was made to use multivariate techniques rather than transfer functions on the Macquarie Island material for several reasons:

1. The number of samples was not large enough to develop a reliable transfer function;
2. While there are extremes of pH in some environments on Macquarie Island (eg. acidic mires, basic lakes) the majority of habitats have circumneutral pH. It became clear from the analyses (TWINSPAN, HMDS, CCA) which species preferred particular pH ranges;
3. Transfer functions rely to a certain extent on the presence of rare species. The occurrence of these species may be due to a particular suite of environmental conditions, not just pH, or it may be due to chance. Making 'precise' estimates of pH based on one or two valves of a single or a few species may be misleading;
4. Other factors, such as moisture availability, conductivity, current and nutrient supply which were estimated in the field, may also affect the distribution of diatom species. Transfer functions based on pH would not take these variables into account and it is often difficult and/or expensive to quantify these other factors. Multivariate analyses take all the factors into account simultaneously and allow more realistic interpretations to be made.

2.5. Diatom Taxonomy

Taxonomy for the most part follows Le Cohu and Maillard (1983; 1986), Le Cohu (1981), Patrick and Reimer (1966), Bourrelly and Manguin (1954) and Manguin (1952). A recent publication by Round, Crawford and Mann (1990) has detailed and compiled many taxonomic changes within the diatom genera. Where these have been published elsewhere or described within the text, the generic names within this volume follow Round, Crawford and Mann (1990). If revisions were proposed in their text, but have not yet been published, then generic names follow those presently established.

Major changes have occurred within the genus *Fragilaria,* which has been split into *Fragilaria, Fragilariforma, Staurosirella, Pseudostaurosira* and *Staurosira* (Round, Crawford & Mann, 1990; Williams & Round, 1987). *Opephora* has been split into two genera, with *Opephora* retained for the marine species and *Martyana* the new genus name for the freshwater species (Round, Crawford & Mann, 1990). Some changes have also occurred within *Achnanthes, Navicula* and *Synedra* (Round, Crawford & Mann, 1990; Williams & Round 1986).

A full species list with authorities and revisions where appropriate is given in Appendix 2. Photomicrographs of the more common, important or unusual diatom species from Macquarie Island are included with Appendix 2. Authorities for all other species of algae, pteridophytes, angiosperms, bryophytes, lichens, mammals and birds mentioned in the text are also supplied in Appendix 2.

Chapter 3

Modern Freshwater Habitats

3.1. Synopsis

Two classes of freshwater sites are recognised: mires and lakes. Each has unique diatom associations determined here. Modern lakes are considered briefly. The spatial variability within mires is examined in detail using Sandell Mire. Mire surface samples contained two distinct diatom associations which were influenced strongly by pH. Variation occurred in the diatom associations in some mires over time: this is examined and the possible environmental causes of these changes are discussed.

3.2. Introduction to Modern Lakes

Waterbodies of every size are abundant on Macquarie Island because of the regular precipitation (Chapter 1.2.4; 1.2.7). Regular sampling of a range of lake types over a number of seasons has been conducted to determine the major diatom associations within these environments. The nutrients available to organisms within the lakes provide a method of dividing lakes into two classes: meso/eutrophic, with nutrients abundant and oligotrophic, with few nutrients available. Information from seven modern lakes has been included in this study and is presented in a summarised form (table 1.1). This is part of a much larger study currently in preparation (T. P. McBride, pers. comm.). Samples were collected from Lake Ainsworth, Major Lake, Pyramid Lake, Ess Pond (all

Sample codes for Figure 3.1.

Mire Sites	
Bauer Bay	BB
Cascade Mire	CM
Douglas Point	DP
Emerald Lake	EL
Eagle Mire	EM
Flat Creek	FC
Floating Island Lake sites 1 and 2	FI1
Floating Island Lake site 3	FI3
Gadget Dam	GD
Green Gorge sites 1 and 2	GG
Handspike Corner site 1	HC1
Handspike Corner site 2	HC2
Hasselborough Bay site 1	HB1
Hasselborough Bay site 2	HB2
Hasselborough Bay site 3	HB3
Jessie Niccol Creek	JN
Langdon Point	LP
North Mountain sites 1 and 2	NM
Red River	RR
Sandell Mire	SM
Sandy Bay	SB
Ski Hut	SK
Square Lake site 1	SQ1
Square Lake sites 2 and 3	SQ3
Tractor Rock	TR
Wireless Hill sites 1, 2 and 3	WH

Lake Sites	
Ainsworth Lake	Ai
Brothers Lake	Br
Duck Lagoon	Du
Ess Pond	Sp
Major Lake	Ma
Pyramid Lake	Py
Scoble Lake	Sc
Square Lake	SQ

oligotrophic), Duck Lagoon, Brothers Lake and Square Lake (all meso/eutrophic: fig. 3.1).

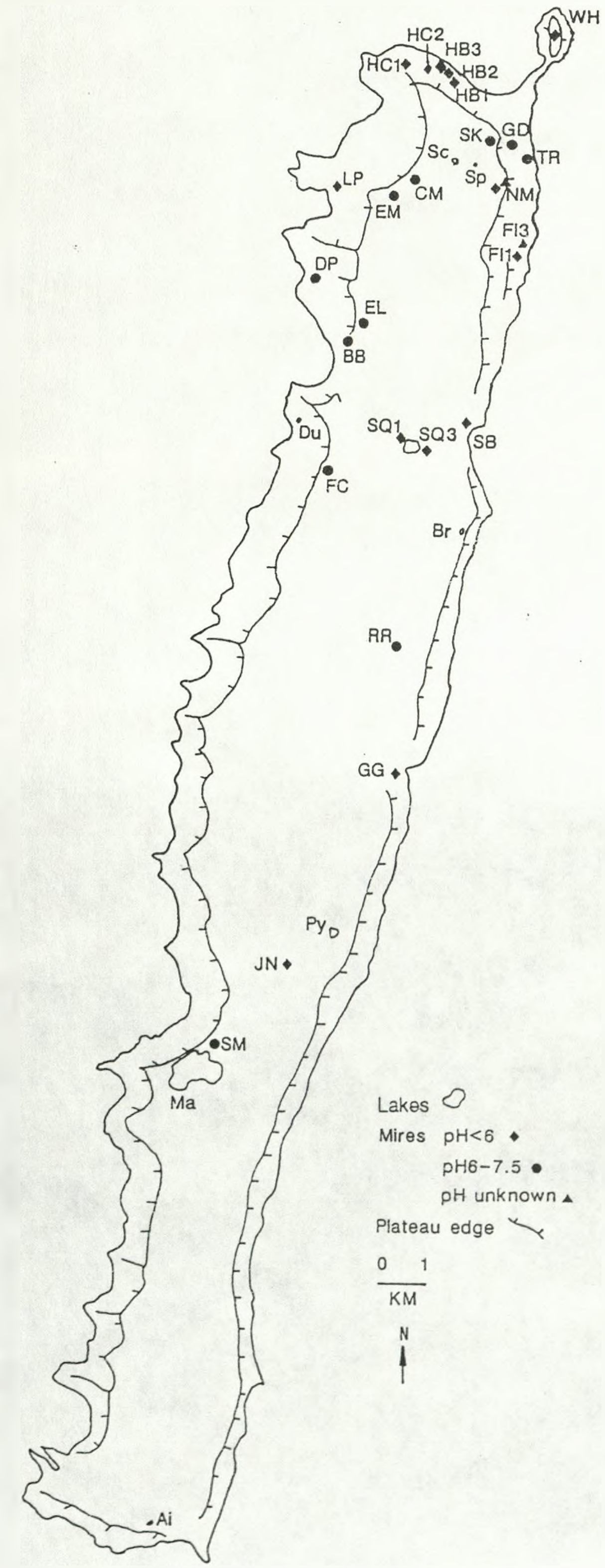


Figure 3.1. Map of Macquarie Island with all mire sample sites and modern lake sample sites indicated. Site codes are listed opposite.

3.3 Introduction to Modern Mires

Mires are abundant on Macquarie Island, where precipitation is frequent and evaporation low (Chapter 1.2.6). Mire vegetation is principally dominated by bryophytes - both mosses and liverworts. Species of *Bryum, Breutelia, Riccardia* and *Marchantia* may form complexes with other species or may form extensive, monospecific carpets (fig. 3.2). Some angiosperm species, such as *Montia fontana, Ranunculus crassipes, Epilobium pedunculare, E. brunnescens* and *Agrostis magellanica* may grow in or around the edges of mires. In some areas angiosperms are the dominant vegetation (fig. 3.3). At Handspike Corner on the featherbed, rows of *Pleurophyllum hookeri* (fig. 1.9) are interrupted by a species of *Riccardia*, a thallose liverwort. Only one species of *Sphagnum* occurs on the island, *S. falcatulum*. It occurs occassionally in acidic mires in the northern two thirds of the island, where it grows in small patches (fig. 3.4; Seppelt, 1980).

Figure 3.2. *Marchantia berteroana* dominated mire at Langdon Point. Marker pen (12 cm in length) gives scale.

Mires have been included in this study for several reasons. Firstly, they are semi-aquatic environments which are rich in diatoms. Studies in the northern hemisphere mires have shown that diatoms are useful in characterising these environments (e.g. Scherer, 1988; Florin, 1970). While some layers in the palaeolake deposits were rich in aquatic angiosperms such as *Myriophyllum triphyllum,* other layers were rich in bryophyte remains. It is possible these layers represent 'mire-like' phases in the palaeolake history (Selkirk, McBride, Keenan & Adamson, 1991). It is important to have information concerning the range of modern Macquarie Island mires and the diatoms present within them in order to be able to interpret possible palaeomire deposits.

Figure 3.3. An angiosperm dominated mire on the featherbed looking south from Douglas Point. The pyramid-shaped Boiler Rocks are in the middle distance, Bauer Bay is visible to the right. The vegetation includes *Poa foliosa* tussocks (P), *Pleurophyllum hookeri* (H) and *Festuca contracta* (F).

Unlike mires in the northern hemisphere, those on Macquarie Island do not form extensive 'raised' or ombrotrophic systems (Damman, 1988). Although similar to these in that most nutrients supplied to mires on the island are from precipitation, the raised condition where peat builds up to elevate the growing portions of the vegetation high above the water table

Figure 3.4. A patch of *Sphagnum falcatulum* (S) growing amongst other bryophytes, *Rannunculus crassipes* (R) and *Agrostis magellanica* (A). Scale bar is 5cm.

does not occur. The input of salts will also be affected by oceanic spray, as has been shown to occur in the lakes (Mallis, 1985; 1988). In some mires the water table is at the surface and the tips of the mosses are the only part of the vegetation above it (fig. 3.5). There is, however, a continuum from saturated mires with a high water table to dryer mires which may only be saturated after prolonged or heavy rainfall.

The study of the mires on Macquarie Island had three aims:

1. To examine the diatoms present in the surface material (bryophytes, angiosperms, algae and sediment) and to identify and categorise any distinct associations of diatoms. This is important in determining whether these were similar to or different from associations of diatoms which occurred in the palaeolake sediments;
2. To examine samples from surface vegetation and samples from depth at different sites to investigate whether the diatom associations in mires on Macquarie Island have

remained static over several hundred years, or whether changes in the most abundant diatoms have occurred;

3. To determine the degree of homogeneity within a large mire.

Figure 3.5. Saturated pool/mire complex east of Square Lake. The yellow-green vegetation is *Sphagnum falcatulum*.

Each of these aims is addressed in turn, with results and discussion for each treated as a distinct unit.

3.4 Mire Sites

Thirty two mire sites in the northern two-thirds of the island were examined. The mire sample sites were chosen objectively and were assigned to one of three broad categories based on the pH of the mire water after sampling. Samples were collected from the three major mire types: acidic (pH <5 to 6.9), circumneutral (pH 7.0 - 7.1) and 'dry' mires (no pH obtained). Sample sites are shown on figure 3.1. Groupings of the sites are arbitrary, based only on the pH.

Acidic Mires

Twelve of the mires sampled proved to be highly acidic, with a pH of less than 5. Dominant macrophyte vegetation included *Marchantia berteroana, Sphagnum falcatulum, Pleurophyllum hookeri, Riccardia* sp. and *Agrostis magellanica.* The main features of each acidic mire are listed in table 3.1.

Thirteen of the sampled mires proved to be moderately acidic, with a pH of 5 - 6.7. The dominant macrophytes varied considerably, however none was dominated by *Sphagnum falcatulum* or *Marchantia berteroana.* Features of the mires are listed in table 3.2.

Neutral Mires

Four mires were sampled which had a pH within the range 7.0 to 7.1. Angiosperms were the dominant vegetation type, with bryophytes accounting for approximately 20% of the total macrophyte cover at each site. Table 3.3 lists the features of these sites.

'Dry' Mires

Three mires were examined which did not have enough free water at the time of sampling to determine pH and conductivity. Table 3.4 lists the features of these sites.

Table 3.1 Acidic mire sites sampled. Species names are listed in full in Appendix 2. Samples are of surface vegetation (e.g. moss, *Marchantia*) and from below the vegetated surface (e.g. 100 mm). Conductivity was measured in units of microseimens per cm (µS/cm).

No.	Location	pH	Cond. µS/cm	Principal macrophytes	Area m^2	Height a.s.l.	Samples
1	Floating Island Lake site 1	4.3	150	*L. crinita* 20% *R. crassipes* 20% *A. magellanica* 30% *P. annua* 15% *M. fontana* 15%	100	50 m	surface veg.
2	Green Gorge site 1	4.2	130	*P. hookeri* 40% *A. magellanica* 30% *L. crinita* 20% Bryophytes 10%	50	10 m	surface moss 100 mm
3	Handspike Corner site 1	4.8	370	*M. berteroana* 60% *J. scheuchzerioides* 20% Other bryophytes 20%	30	20 m	*Marchantia* 100 mm
4	Handspike Corner site 2	4.1	720	*P. hookeri* 20% Bryophytes 80%	100	10 m	bryophytes 250 mm 500 mm
5	Hasselborough Bay site 1	4.3	330	*S. falcatulum* 45% *L. crinita* 25% *A. magellanica* 10% *J. scheuchzerioides* 10% *M. berteroana* 10%	10	20 m	*Sphagnum* 100 mm 250 mm
6	Langdon Point	4.8	620	*P. hookeri* 10 % *L. crinita* 30 % *M. berteroana* 50 % *E. pedunculare* 10 %	10	10 m	surface veg. 100 mm
7	Sandy Bay site 1	3.4	190	*P. hookeri* 20% Bryophytes 80%	10	20 m	surface veg. 100 mm
8	Sandy Bay site 2	4.4	230	*Acaena magellanica* 30% *M. fontana* 30% *P. annua* 40%	100	20 m	surface veg. 100 mm
9	Ski Hut	3.8	170	*P. hookeri* 40% *A. magellanica* 25% *C. perpusilla* 20% Bryophytes 15%	20	200 m	surface moss 100 mm
10	Square Lake site 1	4.0	150	*S. falcatulum* 20 % *L. crinita* 20 % *J. scheuchzerioides* 30 % *A. magellanica* 30 %	10	150 m	*Sphagnum* 100 mm
11	Square Lake site 2	4.7	150	*A. magellanica* 20% *M. berteroana* 15% other bryophytes 60% *A. magellanica* 5%	40	150 m	surface moss 100 mm
12	Square Lake site 3	4.1	150	*S. falcatulum* 50% *R. crassipes* 20% other bryophytes 30%	20	150 m	*Sphagnum* other bryophytes angiosperms

Table 3.2 Mire sites with a pH of 5-7. Species names are listed in full in Appendix 2. Samples are of surface vegetation (e.g. *L. crinita*) and from below the vegetated surface (e.g. 100 mm). Conductivity was measured in units of microseimens per cm (µS/cm).

No.	Location	pH	Cond. µS/cm	Principal macrophytes	Area m^2	Height a.s.l.	Samples
13	Bauer Bay	6.3	430	*R. crassipes* 30% *H. novae-zeelandiae* 10% *Acaena* sp. 30% *M. fontana* 30%	100	20 m	surface veg. 100 mm
14	Douglas Point	6.1	420	*L. crinita* 40% *P. hookeri* 20% *S. polaris* 20% *Acaena* sp. 10% Other angiosperms 10%	10	20 m	surface moss 100 mm
15	Eagle Mire	6.4	150	*Ag.magellanica* 50% *U. hookeri* 40% *L. crinita* 5% *P. annua* 5%	50	160 m	surface veg. surface soil 100 mm
16	Floating Island Lake site 2	6.1	-	*L. crinita* 50% *R. crassipes* 30% *Ag. magellanica* 10% *E. pedunculare* 10%	10	60 m	surface veg. 100 mm surface soil
17	Gadget Dam	6.2	280	*P. hookeri* 35% *Acaena sp.* 10% Bryophytes 5% Bare soil 50%	50	170 m	surface moss surface soil surface algae 100 mm
18	Green Gorge site 2	5.4	140	*Ag. magellanica* 50% *Acaena sp.* 20% *L. crinita* 20% Bryophytes 10%	50	10 m	surface veg. 100 mm
19	Hasselborough Bay site 2	5.5	520	Bryophytes 25% *M. fontana* 50% *J. scheuchzerioides* 10% *P. annua* 15%	15	20 m	surface veg. 100 mm
20	Jessie Niccol Creek	5.9	160	*Ag.magellanica* 50% *Acaena* sp. 20% *L. crinita* 20% Bryophytes 10%	50	140 m	surface veg. surface soil 400 mm
21	North Mountain site 1	5.8	170	*P. hookeri* 60% *R. crassipes* 25% Bryophytes 15%	50	250 m	surface moss 100 mm
22	Tractor Rock	6.7	260	*L. crinita* 30% *P.hookeri* 20% *Ag. magellanica* 20% *Acaena* sp. 10% Bryophytes 20%	500	100 m	surface moss 100 mm 250 mm
23	Wireless Hill site 1	5.6	600	*E. pedunculare* 20 % *M. fontana* 10 % *P. annua* 30 % *Ag. magellanica* 20 % *R. crassipes* 20 %	10	100 m	surface veg. 100 mm
24	Wireless Hill site 2	5.2	520	*P. foliosa* 10 % *M. fontana* 30 % *P. annua* 30 % *R. crassipes* 15 % *Ag. magellanica* 15 %	30	100 m	surface veg. 100 mm
25	Wireless Hill site 3	5.9	710	*Ag. magellanica* 25 % *P. hookeri* 20 % *S. polaris* 10 % *L. crinita* 30 % *R. crassipes* 15 %	30	100 m	surface veg. 100 mm

Table 3.3 Mire sites with a pH of 7-7.1 Species names are listed in full in Appendix 2. Samples are of surface vegetation (*P. hookeri*) and from below the vegetated surface (e.g. 100 mm). Conductivity was measured in units of microseimens per cm (µS/cm).

No.	Location	pH	Cond. µS/cm	Principal macrophytes	Area m^2	Height a.s.l.	Samples
26	Cascade Mire	7.0	270	*P. hookeri* 40% *R. crassipes* 20% Bryophytes 20% *L. crinita* 10% *Ag. magellanica* 10%	10	180 m	surface veg. 100 mm
27	Emerald Lake	7.0	270	*P. hookeri* 40% *R. crassipes* 20% *L. crinita* 10% *Ag. magellanica* 10% Bryophytes 20%	10	170 m	surface moss 100 mm
28	Flat Creek	7.1	590	*L. crinita* 30% *P. hookeri* 20% Bare soil 50%	30	80 m	surface veg. 100 mm
29	Red River	7.0	180	*R. crassipes* 40% *P. annua* 40% Bryophytes 20%	50	10 m	surface veg. 100 mm

Table 3.4 Dry Mires. Species names are listed in full in Appendix 2. Samples are of surface vegetation (e.g. *L. crinita*) and surface soil.

No.	Location	Principal macrophytes	Area m^2	Height a.s.l.	Samples
30	Floating Island Lake site 3	*Acaena* sp. 20% *L. crinita* 10% *E. pedunculare* 30% *R. crassipes* 20% Bare soil 20%	20	50 m	surface veg. surface soil
31	Hasselborough Bay site 3	*U. hookeri* 25% *P. annua* 25% *R. crassipes* 25% *J. scheuchzerioides* 15% *M. fontana* 10%	150	20 m	surface veg.
32	North Mountain site 2	Bryophytes 5% rock/soil 90% algae 5%	20	200 m	surface moss surface soil

3.5 Sandell Mire

One large mire was chosen to investigate possible variations of diatom and macrophyte species within one area. Sandell mire is a large area on the west coast, approximately 1 km north east of Major Lake (fig. 3.1). The mire is about 250 m^2, lying in a depression formed by uplift along a zone inferred to be associated with a fault to the west (fig. 3.6). Immediately to the west of this fault zone is Palaeolake Sandell, exposed in the banks of the creeks draining the mire (fig. 3.7). It has been suggested that the drainage of Palaeolake Sandell was incomplete: that undercutting of the sea cliffs led to only partial drainage of the lake, leaving an *Acaena*-covered mire. Uplift at the fault zone, running NNE-SSW beneath the mire/lake, led to drainage of the western portion of the newly formed mire, leaving exposed sediment. Further erosion of the site and by the creeks draining the mire has exposed more sediment (fig. 3.8: Selkirk *et al.*, 1991).

The Sandell system is a complex of pool, stream and mire. The vegetation is a mixture of bryophytes and angiosperm species such as *Ranunculus crassipes* and *Agrostis magellanica*.

Ten mire sites were chosen within the mire and samples of vegetation were collected for diatom analysis. Table 3.5 lists the main features of the sites. One pool adjacent to each of the mire sites was also sampled, with vegetation collected from within the pool. Table 3.6 lists the features of the 10 sample pools.

Figure 3.6. Sandell Mire. Locations of the sampling sites within the Sandell Mire complex are shown on the overlay. Mire and pool sample sites were 'paired': eg 1 indicates the approximate location of both mire site 1 and pool site 1. The dotted line (arrowed) shows the start of the ridge associated with the mire/palaeolake complex. Major Lake is visible in the distance

Figure 3.7. Rampart-like ridge to the north of the Sandell system. Movement along this ridge is thought to be in part responsible for the drainage of the western part of Sandell Mire. Human figure gives scale. (Photograph P. M. Selkirk.)

Figure 3.8. Palaeolake Sandell from the west. The stream draining Sandell Mire has exposed banded sediments in the creek bank. Sandell Mire (arrowed) is visible in the background.

Table 3.5 Sandell Mire - main features of the 10 chosen sites. Species names are listed in full in Appendix 2, samples are of surface vegetation, or from below the surface. Measurements of conductivity are in microseimens/cm (µS/cm)

No.	pH	Cond. µS/cm	Principal macrophytes	Samples
1	6.2	200	*R. crassipes* 20% *Ag. magellanica* 30% Bryophytes 50%	surface veg 100 mm 250 mm
2	6.4	170	Bryophytes 80% *R. crassipes* 10% *Ag. magellanica* 10%	surface veg 200 mm 400 mm
3	6.7	180	*R. crassipes* 70% Bryophytes 30%	surface veg 200 mm 400 mm
4	6.3	170	Bryophytes 70% *L. crinita* 10% *R. crassipes* 10% *Ag. magellanica* 10%	surface veg 100 mm
5	6.4	190	Bryophytes 60% *M. fontana* 20% *R. crassipes* 10% *L. crinita* 10%	surface veg 100 mm
6	7.5	180	*R. crassipes* 40% *Ag. magellanica* 20% *M. fontana* 10% Bryophytes 30%	surface veg 400 mm
7	6.2	170	*R. crassipes* 40% *L. crinita* 30% *Ag. magellanica* 20% Bryophytes 10%	surface veg 100 mm
8	6.8	180	*R. crassipes* 30% *L. crinita* 10% *Ag. magellanica* 20% Bryophytes 40%	surface veg 100 mm
9	6.7	180	*R. crassipes*20% *L. crinita* 20% *Ag. magellanica* 20% Bryophytes 40%	surface veg 100 mm
10	6.7	160	*A. magellanica* 40% *R. crassipess* 20% *L. crinita* 10% Bryophytes 30%	surface veg 250 mm

Table 3.6 Main features of the 10 Pools sampled at Sandell Mire. Species names are listed in full in Appendix 2, samples are of surface vegetation, or from below the surface. Measurements of conductivity are in microseimens/cm (µS/cm)

No.	pH	Cond. µS/cm	Principal macrophytes	Area m^2	Samples
1	7.1	230	*M. triphvllum*	10	angiosperms
2	9.9	200	*M. triphvllum*	15	angiosperms
3	6.1	200	*R. crassipes, Ag. magellanica*	25	angiosperms
4	6.5	190	*R. crassipes. L. crinita*	10	angiosperms
5	7.6	190	*R. crassipes. C. antarctica*	50	angiosperms
6	8.9	190	*M. triphvllum*	100	angiosperms
7	7.9	190	Cyanophytes	75	cyanophytes
8	7.5	180	*R. crassipes. C. antarctica*	40	angiosperms
9	9.3	190	*C. antarctica*. algae	20	angiosperms
10	6.8	190	Cyanophytes	150	cyanophytes

Table 3.7. Mire surface samples: common species, their mean abundances, ranges and number of samples in which they occurred. *n* = number of samples occurring in, mean = mean abundance (%), SD = standard deviation, range = % range of occurrences. All data from all sites are presented in Appendix 3.

Species Names	*n*	mean	SD	range
Achnanthes abundans	7	4.6	4.8	1-14
Achnanthes confusa	29	9.8	8.3	1-32
Achnanthes confusa var. *atomoides*	14	2.7	1.9	1-7
Achnanthes pseudolanceolata	20	17.3	17.2	1-62
Achnanthidium lanceolatum	10	21.5	22.9	1-68
Achnanthidium microcephalum	15	3.2	3.5	1-12
Aulacoseira granulata	13	5.6	7.9	1-31
Brachysira exilis	13	7.3	7.1	1-22
Cymbella microcephala	10	6.9	8.5	1-30
Diatomella hustedtii	26	16.8	23.3	1-90
Eunotia exigua	23	33.3	32.7	1-89
Fragilariforma virescens	20	4.3	5.5	1-25
Hantzschia amphioxys	4	6.3	4.0	2-12
Martyana martyi	9	2.6	1.7	1-6
Navicula corrugata	7	5.6	5.3	1-17
Nitzschia palea	10	6.4	6.6	1-22
Nitzschia gracilis	4	6.0	5.4	1-15
Nitzschia hantzschiana	7	6.1	4.2	1-12
Pinnularia acoricola	15	9.9	9.3	1-38
Pinnularia circumducta	14	2.7	2.1	1-8
Rhopalodia gibberula	4	4.6	3.5	3-12
Staurosira construens	3	66.3	30.9	2-70
Staurosira construens var. *venter*	6	9.5	10.0	2-30
Synedra rumpens	10	6.9	8.5	1-30

3.6 Results

3.6.1 Mire surface samples

Data from the mire surface samples of vegetation and sediment were analysed to examine the diatoms present and to identify any distinctive associations of diatoms which were present. Percentage abundance diagrams for all mire samples from all sites are presented in Appendix 3. A summary of the most common species, their mean abundance, range and the number of samples they occur in is given in table 3.7.

TWINSPAN divided the 35 mire surface samples into four groups at the second level, with an eigenvalue of E = .165. Samples in each group are listed in table 3.8. Group 1 contained five samples, dominated principally by *Achnanthes confusa, A. pseudolanceolata* and *Diatomella hustedtii.* Group 2 contained 13 samples, with the most abundant species including *Achnanthes confusa, A. pseudolanceolata, Diatomella hustedtii* and *Synedra rumpens.*

Table 3.8 TWINSPAN grouping of mire surface samples.

Group 1	Group 2	Group 3	Group 4
Flat Creek	Eagle Mire	Bauer Bay	Douglas Point
sediment	Emerald Lake	Cascade Mire	Handspike Cnr site 1
Jessie Niccol Creek	Flat Creek vegetation	Floating Is. Lake	Sandy Bay site 1
North Mountain site 2	Floating Is. Lake site 2	site 1	Square Lake site 1
moss	Gadget Dam	site 3	Ski Hut
sediment	Hasselborough Bay	Green Gorge	
Sandy Bay site 2	site 1	site 1	
	site 3	site 2	
	North Mountain site 1	Handspike Cnr site 2	
	moss	Hasselborough Bay	
	Square Lake site 2	site 2	
	moss	Langdon Point	
	Square Lake site 3	Red River	
	moss	Wireless Hill	
	Ranunculus	site 1	
	Sphagnum	site 2	
	Tractor Rock	site 3	

The initial separation of mire surface samples occurred between groups 2 and 3. Group 3 contained 13 samples, listed in table 3.8. The most abundant species varied from sample to sample and included *Achnanthes pseudolanceolata, Achnanthidium lanceolatum, Amphora coffeaeformis, Cymbella microcephala, Eunotia exigua, Nitzschia palea, Pinnularia acoricola* and *Synedra rumpens.* Group four contained five samples, all with abundant *Eunotia exigua* and *Pinnularia acoricola.*

The TWINSPAN of samples agreed quite well with the HMDS of samples in two dimensions (fig. 3.9). The minimum stress was relatively high, at 197, which may be, in part, due to the high number of samples. TWINSPAN groups 1 and 2 were not well separated on the configuration. Both were placed at the left, with samples from both groups adjacent. Group 3 samples were well spread across the centre of the configuration, separated from group 4 samples, at the right. Only the sample from Ski Hut was misplaced, grouped with TWINSPAN group 4, but placed close to group 3 samples by the HMDS.

Samples with *Eunotia exigua* abundant (20% to 59%) or dominant (more than 60%) and few other species present were placed at the right of the configuration. Samples with species other than *E. exigua* abundant were placed at the left. The configuration indicates a continuum of samples, rather than distinct groupings. There was a gradual increase in the number of species present from the right to the left, with *E. exigua* becoming less abundant. The sample from Ski Hut was 'misplaced' because of the presence of *Pinnularia acoricola,* which caused it to be placed in group 4 by the TWINSPAN. It did have more species over all (10 compared to, for example, 5 in Square Lake site 1), which placed it amongst the other samples in group 3 on the HMDS configuration.

At the left of the configuration, where samples with the *Achnanthes confusa, Diatomella hustedtii* and/or *Synedra rumpens* abundant were placed, the pH of the samples was generally neutral to greater than 6. Samples from more acidic sites, where the *Eunotia exigua* and *Pinnularia acoricola* present were placed at the right. This reflects a change in

Sample codes for Figure 3.9

Mire Sites	
Bauer Bay	BB
Cascade Mire	CM
Douglas Point	DP
Emerald Lake	EL
Eagle Mire	EM
Flat Creek	FC
Floating Island Lake site 1	FI1
Floating Island Lake site 2	FI2
Floating Island Lake site 3	FI3
Gadget Dam	GD
Green Gorge site 1	GG1
Green Gorge site 2	GG2
Handspike Corner site 1	HC1
Handspike Corner site 2	HC2
Hasselborough Bay site 1	HB1
Hasselborough Bay site 2	HB2
Hasselborough Bay site 3	HB3
Jessie Niccol Creek	JN
Langdon Point	LP
North Mountain site 1	NM1
North Mountain site 2 moss and sediment	NM2
Red River	RR
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2
Ski Hut	SK
Square Lake site 1	SQ1
Square Lake site 2 moss	SQ2
Square Lake site 3 moss	SQ3m
Square Lake site 3 *Sphagnum*	SQ3s
Square Lake site 3 *Ranunculus*	SQ3v
Tractor Rock	TR
Wireless Hill site 1	WH1
Wireless Hill site 2	WH2
Wireless Hill site 3	WH3

pH. Only those samples with low pH but without abundant *E. exigua* were misplaced.

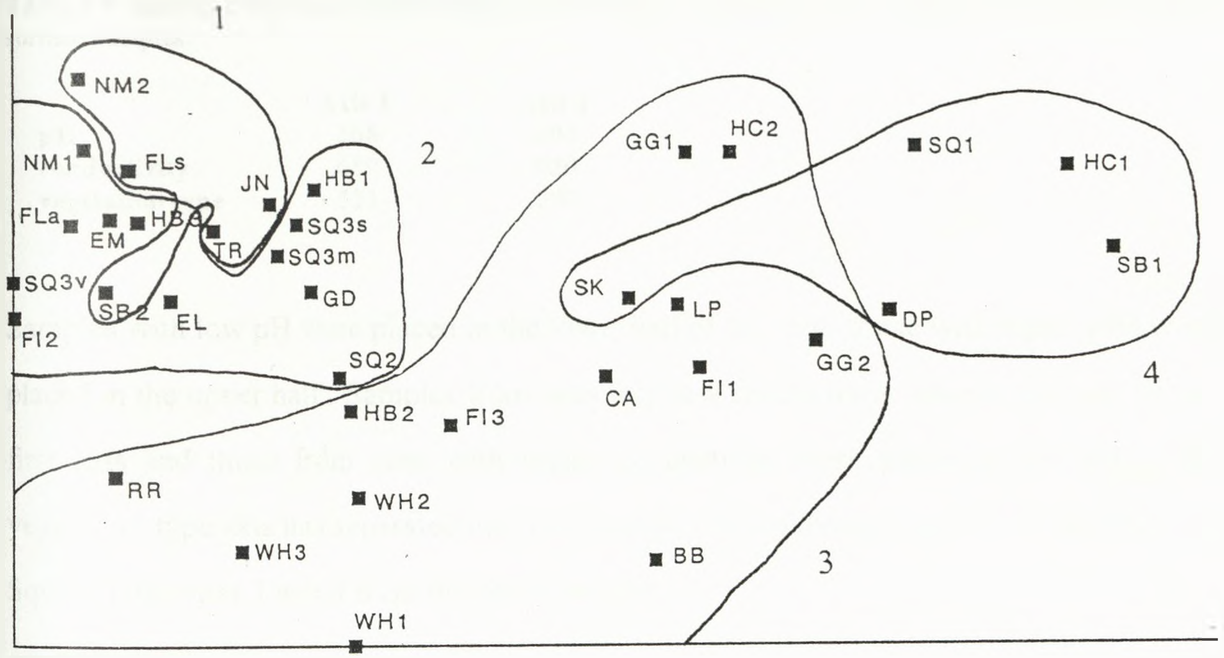


Figure 3.9. HMDS of all mire surface samples in two dimensions. Minimum stress is .197 TWINSPAN groups are marked on the diagram. Sample codes are listed opposite.

Environmental gradients in mire surface samples

The CCA of mire surface samples arranged the samples well across the first two ordination axes (fig. 3.10). Samples from Floating Island Lake site 3, Hasselborough Bay site 2 and North Mountain site 2 were excluded as there was no information on pH or conductivity available for these samples. The eigenvalues for the analysis were E = .192 for axis 1 and E = .161 for axis 2. The goodness of fit for the two dimensional arrangement of samples and species was quite low, at 35%, however the species/environment correlations for axes 1 and 2 were high, at .71 and .55 respectively.

Three environmental variables were included in the final analysis - pH, conductivity and vegetation type. Two variables (height a.s.l. and mire size) were excluded from the final analysis as they contributed little. All three variables were strongly correlated with axis 1, with conductivity least correlated with axis 2 (table 3.9).

Table 3.9 Interset correlation coefficients of environmental variables and the first two CCA axes from mire surface samples.

	Axis 1	Axis 2
pH	.568	.204
conductivity	.689	.020
vegetation type	.533	.290

Samples with low pH were placed in the lower half of the plot; those with higher pHs were placed in the upper half. Samples from sites with low conductivity were at the right of the first axis and those from sites with higher conductivity were placed at the left. The vegetation type axis has separated out those samples from Green Gorge site 1, Ski Hut and Square Lake sites 1 and 3 from the other samples.

There were three species closely correlated with the low end of the pH gradient - *Eunotia exigua, Pinnularia acoricola* and *Nitzschia hantzschiana. Eunotia exigua* is a known acidophile and *P. acoricola* was associated with it in the majority of samples from acidic sites (Dixit, Dixit & Evans, 1988). *Nitzschia hantzschiana* occurred in five sites, with the majority of these with relatively low pHs (4 - 5.5). The species which occurred preferentially in sites with higher pH were placed closer to the arrow at the right hand side of the plot.

Diatomella hustedtii and *Aulacoseira granulata* were placed at the 'high' end of the pH gradient, indicating these species occurred preferentially in sites with circumneutral pH. Many species, such as *Achnanthes abundans, Rhapalodia gibberula* and *Staurosira construens* were placed towards the centre of the graph; these species occurred either in many samples, or in samples with a circumneutral pH. Species such as *Achnanthidium microcephalum* and *Achnanthes confusa* var. *atomoides* appear to be influenced by vegetation type to some degree. Species such as *Hantzschia amphioxys, Nitzschia*

Sample codes for Figure 3.10

Bauer Bay	BB
Cascade Mire	CA
Douglas Point	DP
Emerald Lake	EL
Eagle Mire	EM
Floating Island Lake site 1	FI1
Floating Island Lake site 2	FI2
Gadget Dam	GD
Green Gorge site 1	GG1
Green Gorge site 2	GG2
Handspike Corner site 1	HC1
Handspike Corner site 2	HC2
Hasselborough Bay site 1	HB1
Hasselborough Bay site 2	HB2
Jessie Niccol Creek	JN
Langdon Point	LP
North Mountain site 1	NM1
Red River	RR
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2
Ski Hut	SK
Square Lake site 1	SQ1
Square Lake site 2	SQ2
Square Lake site 3 moss	SQ3m
Square Lake site 3 *Sphagnum*	SQ3s
Square Lake site 3 *Ranunculus*	SQ3v
Tractor Rock	TR
Wireless Hill site 1	WH1
Wireless Hill site 2	WH2
Wireless Hill site 3	WH3

Species codes for Figure 3.10 overlay

Achnanthes abundans	Ac ab
Achnanthes confusa	Ac cf
Achnanthes confusa var. *atomoides*	Ac at
Achnanthes manguinii	Ac ma
Achnanthes pseudolanceolata	Ac ps
Achnanthidium lanceolatum	Ah la
Achnanthidium microcephalum	Ah mc
Aulacoseira granulata	Au gr
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Cymbella kerguelenensis	Cy ke
Diatomella hustedtii	Di hu
Eunotia exigua	Eu ex
Fragilariforma virescens	Fr vi
Hantzschia amphioxys	Ha am
Martyana martyi	Ma ma
Navicula corrugata	Na cg
Nitzschia gracilis	Ni gr
Nitzschia hantzschiana	Ni ha
Nitzschia palea	Ni pa
Pinnularia acoricola	Pi ac
Pinnularia circumducta	Pi ci
Pinnularia gibba	Pi gi
Rhopalodia gibberula	Rh gi
Staurosira construens	Sa co
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru

gracilis, *N. palea* and *Achnanthidium lanceolatum* were placed toward the higher end of the conductivity gradient.

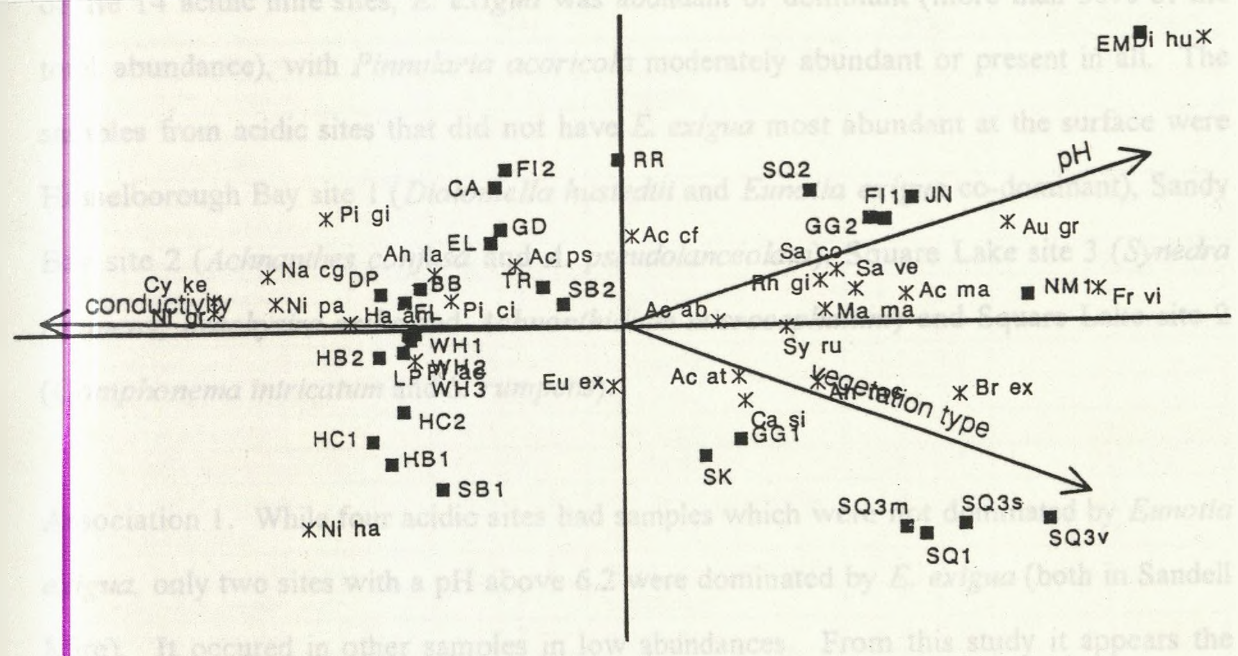


Figure 3.10. Biplot of CCA of mire samples, species and environmental variables. The eigenvalue for axis 1 is .192 and .161 for axis 2. The goodness of fit for the analysis is 35%. Samples and species with low pH are in the lower left of the configuration. Samples with high conductivity are placed in the upper left. Major species from the mire samples are presented on the overlay, scaled to be comparable to the sample plot. The sample and species codes are listed opposite.

Mires as diatom habitats

Diatoms were abundant in all samples from all mires studied. Analysis of the samples revealed two main associations of diatoms:

Association1. *Eunotia exigua/Pinnularia acoricola*

Association 2a. *Achnanthes confusa/A. pseudolanceolata/Achnanthidium microcephalum/ Diatomella hustedtii/Synedra rumpens.*

Sample codes for Figure 3.10

Bauer Bay	BB
Cascade Mire	CA
Douglas Point	DP
Emerald Lake	EL
Eagle Mire	EM
Floating Island Lake site 1	FI1
Floating Island Lake site 2	FI2
Gadget Dam	GD
Green Gorge site 1	GG1
Green Gorge site 2	GG2
Handspike Corner site 1	HC1
Handspike Corner site 2	HC2
Hasselborough Bay site 1	HB1
Hasselborough Bay site 2	HB2
Jessie Niccol Creek	JN
Langdon Point	LP
North Mountain site 1	NM1
Red River	RR
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2
Ski Hut	SK
Square Lake site 1	SQ1
Square Lake site 2	SQ2
Square Lake site 3 moss	SQ3m
Square Lake site 3 *Sphagnum*	SQ3s
Square Lake site 3 *Ranunculus*	SQ3v
Tractor Rock	TR
Wireless Hill site 1	WH1
Wireless Hill site 2	WH2
Wireless Hill site 3	WH3

Species codes for Figure 3.10 overlay

Achnanthes abundans	Ac ab
Achnanthes confusa	Ac cf
Achnanthes confusa var. *atomoides*	Ac at
Achnanthes manguinii	Ac ma
Achnanthes pseudolanceolata	Ac ps
Achnanthidium lanceolatum	Ah la
Achnanthidium microcephalum	Ah mc
Aulacoseira granulata	Au gr
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Cymbella kerguelenensis	Cy ke
Diatomella hustedtii	Di hu
Eunotia exigua	Eu ex
Fragilariforma virescens	Fr vi
Hantzschia amphioxys	Ha am
Martyana martyi	Ma ma
Navicula corrugata	Na cg
Nitzschia gracilis	Ni gr
Nitzschia hantzschiana	Ni ha
Nitzschia palea	Ni pa
Pinnularia acoricola	Pi ac
Pinnularia circumducta	Pi ci
Pinnularia gibba	Pi gi
Rhopalodia gibberula	Rh gi
Staurosira construens	Sa co
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru

gracilis, N. palea and *Achnanthidium lanceolatum* were placed toward the higher end of the conductivity gradient.

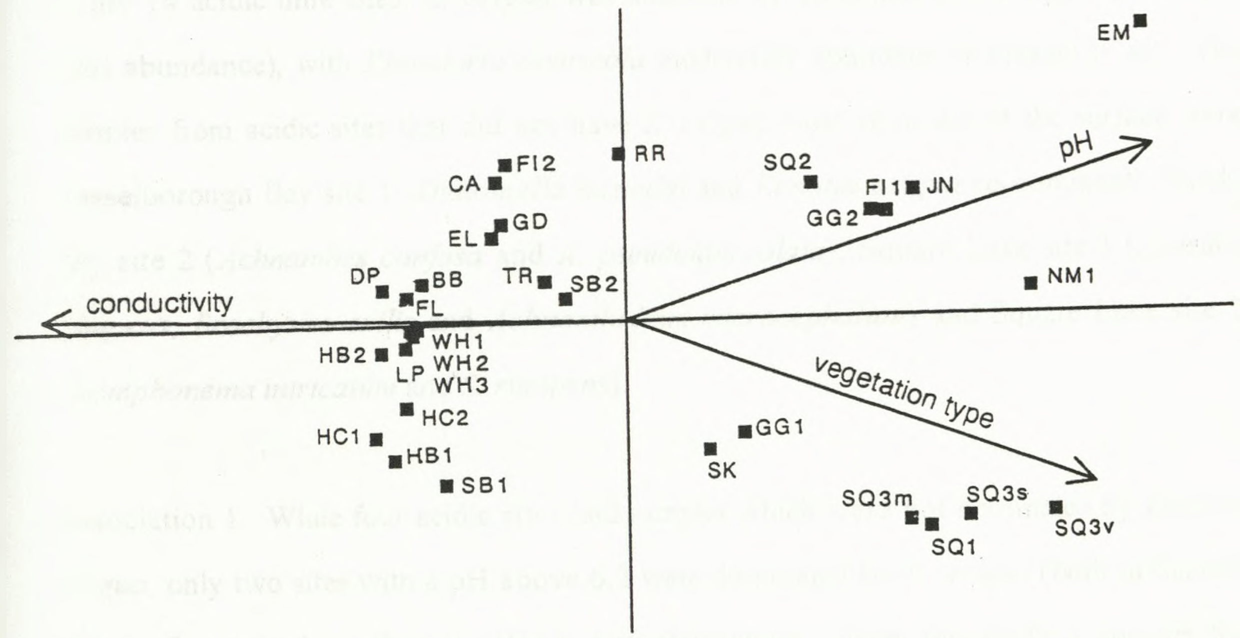


Figure 3.10. Biplot of CCA of mire samples, species and environmental variables. The eigenvalue for axis 1 is .192 and .161 for axis 2. The goodness of fit for the analysis is 35%. Samples and species with low pH are in the lower left of the configuration. Samples with high conductivity are placed in the upper left. Major species from the mire samples are presented on the overlay, scaled to be comparable to the sample plot. The sample and species codes are listed opposite.

Mires as diatom habitats

Diatoms were abundant in all samples from all mires studied. Analysis of the samples revealed two main associations of diatoms:

Association1. *Eunotia exigua/Pinnularia acoricola*

Association 2a. *Achnanthes confusa/A. pseudolanceolata/Achnanthidium microcephalum/ Diatomella hustedtii/Synedra rumpens.*

Eunotia exigua and *Pinnularia acoricola* were most abundant in samples from acidic mire sites. Generally, the lower the pH, the more abundant *E. exigua* becomes. In all but four of the 14 acidic mire sites, *E. exigua* was abundant or dominant (more than 50% of the total abundance), with *Pinnularia acoricola* moderately abundant or present in all. The samples from acidic sites that did not have *E. exigua* most abundant at the surface were Hasselborough Bay site 1 (*Diatomella hustedtii* and *Eunotia exigua* co-dominant), Sandy Bay site 2 (*Achnanthes confusa* and *A. pseudolanceolata*), Square Lake site 3 (*Synedra rumpens, Brachysira exilis* and *Achnanthidium microcephalum*) and Square Lake site 2 (*Gomphonema intricatum* and *S. rumpens*).

Association 1. While four acidic sites had samples which were not dominated by *Eunotia exigua,* only two sites with a pH above 6.2 were dominated by *E. exigua* (both in Sandell Mire). It occured in other samples in low abundances. From this study it appears the *Eunotia exigua/Pinnularia acoricola* association is generally restricted to areas with low pH.

Association 2a. In the remaining samples, the most abundant diatoms were *Achnanthes confusa, A. pseudolanceolata, Achnanthidium microcephalum, Diatomella hustedtii* and *Synedra rumpens.* Other species occurred as most abundant or abundant in few samples, however most have at least one of the more common species abundant. The pH range of these species is great - from low to neutral in the mires, to high in the Sandell Mire pool samples. The actual species mix is, perhaps, determined by factors which are less easy to define such as the amount of available moisture, nutrient availability and interspecific competition. The samples with abundant *Achnanthes pseudolanceolata* and *Achnanthidium lanceolatum* also have at least one of the other species present in moderate abundance. It is more difficult to assign ecological preferences to those species in Association 2a and to those species which do not occur in high abundances or in many samples. Table 3.10 lists the most abundant species and their inferred habitat preferences.

Table 3.10 Inferred pH and habitat preferences for the most common species in mires on Macquarie Island (more than 20% abundance in at least one mire).

Species	Preferred pH	Habitat	pH range	No. samples in which abundant
Achnanthes abundans	6.2 - 7.0	epiphytic, aerophilic	4.1 - 7.1	2
Achnanthes confusa	4.4 - 5.2	epiphytic	3.4 - 7.9	10
Achnanthes confusa var. *atomoides*	6.1	epiphytic	3.4 - 7.1	1
Achnanthes pseudolancelolata	6.2 - 7.0	epiphytic	3.8 - 7.8	12
Achnanthidium lanceolatum	3.8 - 6.3	epiphytic	3.8 - 9.9	6
Achnanthidium microcephalum	7.5	epiphytic	4.1 - 9.9	4
Amphora coffeaeformis	5.6 - 6.5	epiphytic	4.3 - 9.9	5
Aulacoseira granulata	6.0	epiphytic	3.4 - 7.0	2
Brachysira exilis	4.3 - 7.1	epiphytic	3.8 - 7.1	4
Cymbella microcephala	5.9	epiphytic	3.8 - 6.7	1
Diatomella hustedtii	6.4 - 7.1	epiphytic, aerophilic	3.8 - 9.9	13
Eunotia exigua	3.4 - 6.8	epiphytic	3.4 - 7.5	14
Fragilariforma virescens	5.5 - 5.8	epiphytic, aerophilic	4.1 - 9.9	3
Hantzschia amphioxys	5.9	aerophilic	6.3 - 5.9	1
Navicula corrugata	6.7	epiphytic	6.7 - 7.5	1
Nitzschia gracilis	5.6	epiphytic, aerophilic	4.3 - 6.7	1
Nitzschia hantschiana	5.5	epiphytic	4.3 - 7.0	3
Nitzschia palea	5.5 - 6.8	epiphytic	4.3 - 9.9	5
Pinnularia acoricola	6.1 - 6.2	motile, aerophilic	3.4 - 6.8	3
Pinnularia circumducta	5.6	motile, aerophilic	4.8 - 7.0	1
Rhapalodia gibberula	(dry)	aerophilic	4.8 - 7.0	1
Staurosira construens	5.9	epiphytic	4.2 - 5.9	1
Staurosira construens var. *venter*	5.9	epiphytic	4.2 - 5.3	5
Synedra rumpens	4.7 - 8.9	epiphytic	3.4 - 9.3	13

3.6.2 Comparison of modern mires and modern lakes

Modern lakes and mires were compared to provide information on the similarities or differences that exist between the two major aquatic habitats on Macquarie Island. Later chapters (5 to 9) compare diatom associations from the palaeolakes with both modern mire and modern lake samples and so it was important to compare both modern environments initially. Data collected from seven lakes sampled regularly on Macquarie Island have revealed different associations of diatoms to those found in the modern mires (supplied by T. P. McBride, pers. comm.). The ANOSIM of mire and lake samples revealed clear differences between lakes and between lakes and mires. Pyramid Lake and Ess Pond were the only sites which showed no significant difference (table 3.11).

Table 3.11 *P*-values from ANOSIM comparisons of modern mires and seven modern lakes. All comparisons except between Pyramid Lake and Ess Pond were significant.

Lake							
Ainsworth	.002						
Brothers	.002	.004					
Duck	.002	.002	.002				
Ess	.002	.008	.011	.035			
Major	.002	.002	.002	.002	.018		
Pyramid	.002	.028	.036	.015	.10	.048	
Square	.002	.002	.002	.004	.018	.008	.047
	mires	**Ainsworth**	**Brothers**	**Duck**	**Ess**	**Major**	**Pyramid**

A CCA of lake samples was conducted to analyse the influence of the major environmental variables on the diatom associations from lake samples. The CCA placed all samples from each site very close together on the first two axes (fig. 3.11). The eigenvalues for axis 1 and 2 were very large, at .793 and .568 respectively. The species/environment correlations were also very high, at .979 for axis 1 and .965 for axis 2. The goodness of fit for the first two axes was 58%. Five environmental variables were included - trophic status, pH, size conductivity and height a.s.l. Height a.s.l. reflects the amount of sea spray influence on the lake water (Mallis, 1985; 1988). The first four variables were correlated and strongly influenced samples from Major Lake, Ainsworth Lake, Pyramid Lake and Ess Pond. The samples from Duck Lagoon, Brothers Lake and Square Lake were placed closest to the conductivity gradient. All except trophic status were well correlated with axis 1 (table 3.12).

Table 3.12. Interset correlation coefficients for the environmental variables from the CCA of modern lakes.

	Axis 1	**Axis 2**
Trophic status	.274	.320
Size	.589	.620
Height a.s.l.	.876	.249
Conductivity	-.804	-.508
pH	.779	.293

The meso/eutrophic samples, with high conductivity, high pH and a relatively small size

Sample codes for figure 3.11

Ainsworth Lake	AL
Brothers Lake	BL
Duck Lagoon	DL
Ess Pond	ES
Major Lake	ML
Pyramid Lake	PY
Square Lake	SQ

Species codes for figure 3.11 overlay

Achnanthes abundans	Ac ab
Achnanthes confusa	Ac cf
Achnanthes delicatula	Ac de
Achnanthes pseudolanceolata	Ac ps
Achnanthidium lanceolatum	Ah la
Achnanthidium microcephalum	Ah mc
Amphora coffeaeformis	Am ca
Brachysira exilis	Br ex
Cocconeis placentula	Co pl
Cymbella microcephala	Cy mi
Diatomella hustedtii	Di hu
Fragilaria species A	Fr sa
Fragilariforma virescens	Fr vi
Gomphonema affine	Go af
Nitzschia gracilis	Ni gr
Nitzschia palea	Ni pa
Staurosirella pinnata	Sa pi
Synedra rumpens	Sy ru
Synedra vaucheriae	Sy va

were placed adjacent, at the left of axis 1. The other lakes were placed at the right of the first axis, with Pyramid Lake closest to the pH and size gradients, and the other lakes (Ainsworth, Major and Ess) closest to the height a.s.l. gradient. The trophic gradient was the shortest (least influential) and any variation in the samples which may be attributable to the nutrient levels may also be accounted for by the other variables. Ess Pond was placed as an outlier by the analysis, away from other samples. This is possibly because it is small but oligotrophic, with a circumneutral pH.

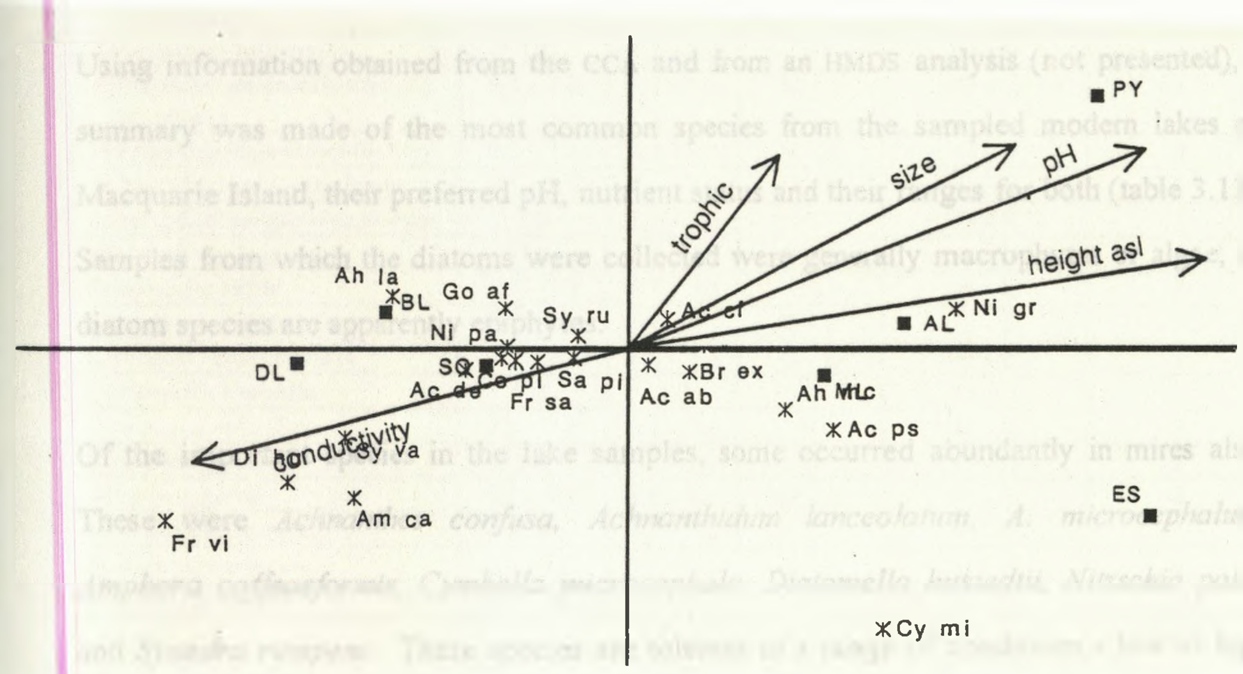


Figure 3.11. Biplot of samples and environmental variables from CCA of seven modern lakes on Macquarie Island. Axis 1 has an eigenvalue of .793, axis 2 has an eigenvalue of .568. The goodness of fit for the first two axes is 58%.The overlay shows the major species from lakes, scaled to be comparable to the sample/environment biplot. Sample and species codes are listed opposite.

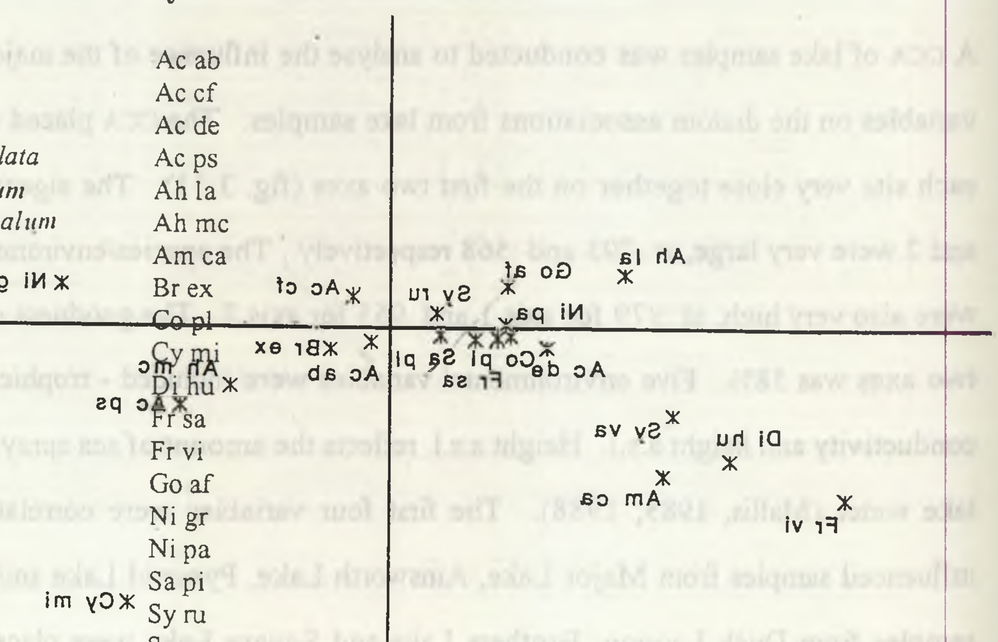
The plot of the major species from lake samples is shown on the overlay of figure 3.11. Oligotrophic species were for the most part grouped around the centroid of the plot. The species tolerant of a range of conditions, such as *Amphora coffeaeformis, Diatomella hustedtii, Fragilariforma virescens* and *Staurosira construens* var. *venter* were strongly

Sample codes for figure 3.11

Ainsworth Lake	AL
Brothers Lake	BL
Duck Lagoon	DL
Ess Pond	ES
Major Lake	ML
Pyramid Lake	PY
Square Lake	SQ

Species codes for figure 3.11 overlay

Achnanthes abundans	Ac ab
Achnanthes confusa	Ac cf
Achnanthes delicatula	Ac de
Achnanthes pseudolanceolata	Ac ps
Achnanthidium lanceolatum	Ah la
Achnanthidium microcephalum	Ah mc
Amphora coffeaeformis	Am ca
Brachysira exilis	Br ex
~~*Cocconeis placentula*~~	Co pl
Cymbella microcephala	Cy mi
Diatomella hustedtii	Di hu
Fragilaria species A	Fr sa
Fragilariforma virescens	Fr vi
Gomphonema affine	Go af
Nitzschia gracilis	Ni gr
Nitzschia palea	Ni pa
Staurosirella pinnata	Sa pi
Synedra rumpens	Sy ru
Synedra vaucheriae	Sy va



were placed adjacent, at the left of axis 1. The other lakes were placed at the right of the first axis, with Pyramid Lake closest to the pH and size gradients, and the other lakes (Ainsworth, Major and Ess) closest to the height a.s.l. gradient. The trophic gradient was the shortest (least influential) and any variation in the samples which may be attributable to the nutrient levels may also be accounted for by the other variables. Ess Pond was placed as an outlier by the analysis, away from other samples. This is possibly because it is small but oligotrophic, with a circumneutral pH.

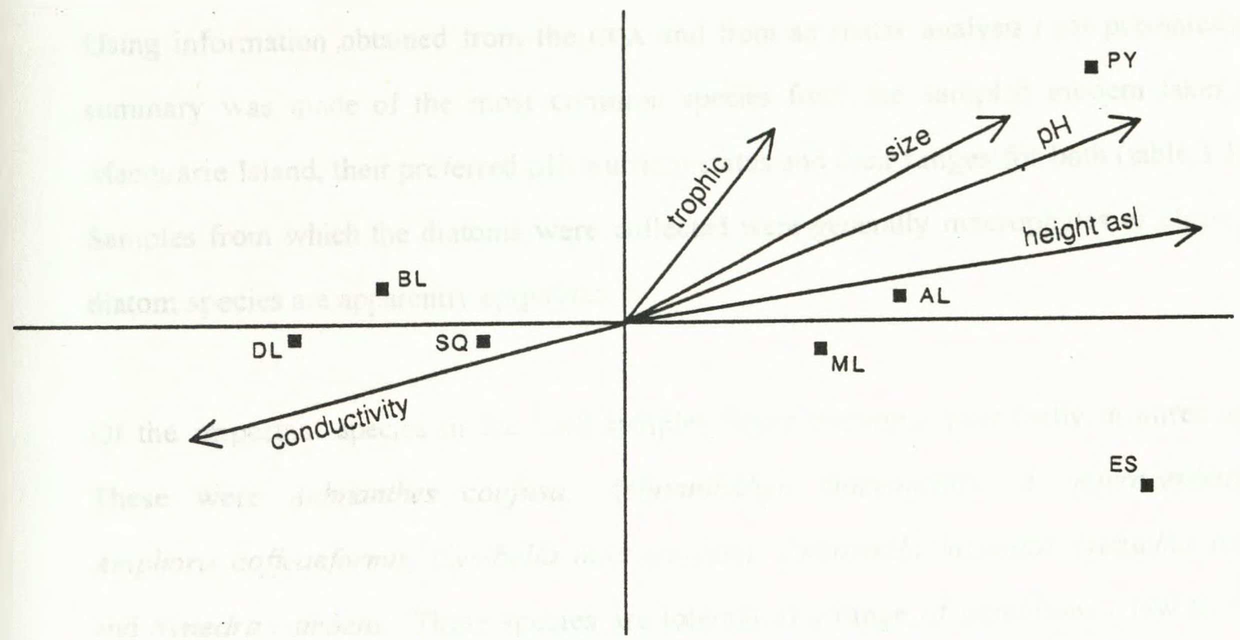


Figure 3.11. Biplot of samples and environmental variables from CCA of seven modern lakes on Macquarie Island. Axis 1 has an eigenvalue of .793, axis 2 has an eigenvalue of .568. The goodness of fit for the first two axes is 58%.The overlay shows the major species from lakes, scaled to be comparable to the sample/environment biplot. Sample and species codes are listed opposite.

The plot of the major species from lake samples is shown on the overlay of figure 3.11. Oligotrophic species were for the most part grouped around the centroid of the plot. The species tolerant of a range of conditions, such as *Amphora coffeaeformis*, *Diatomella hustedtii*, *Fragilariforma virescens* and *Staurosira construens* var. *venter* were strongly associated with the conductivity gradient. These may be able to compete more successfully at increased salinity levels than those species less tolerant of environmental variations. *Achnanthes confusa* and *A. confusa* var. *atomoides* were associated with trophic status and *Achnanthes pseudolanceolata, Achnanthidium microcephalum* and *Nitzschia gracilis* were associated with height a.s.l. *Achnanthes delicatula* ssp. *hauckiana* and *Cymbella microcephala* were placed as outliers, away from all environmental variables. Other environmental factors not accounted for may be influencing the positioning of these species, such as salt spray or nutrient enrichment.

Using information obtained from the CCA and from an HMDS analysis (not presented), a summary was made of the most common species from the sampled modern lakes on Macquarie Island, their preferred pH, nutrient status and their ranges for both (table 3.13). Samples from which the diatoms were collected were generally macrophytes or algae; all diatom species are apparently epiphytes.

Of the important species in the lake samples, some occurred abundantly in mires also. These were *Achnanthes confusa, Achnanthidum lanceolatum, A. microcephalum, Amphora coffeaeformis, Cymbella microcephala, Diatomella hustedtii, Nitzschia palea* and *Synedra rumpens*. These species are tolerant of a range of conditions - low to high pH, low to high levels of nutrient availability, lake or mire conditions. Some species in the lakes are found abundantly in only one nutrient type and within a narrow pH range (e.g. *Gomphonema affine, Achnanthes confusa* var. *atomoides*), whereas others are tolerant of a greater range in conditions (e.g. *Nitzschia palea, Achnanthidium lanceolatum*).

Of those abundant species, one association appears to be restricted to oligotrophic water, although the species occur in both lake and mire environments.

Oligotrophic species:

Achnanthes abundans	*Achnanthes confusa*	*Achnanthidium microcephalum*
Brachysira exilis	*Gomphonema affine*	*Nitzschia gracilis*

Achnanthes confusa var. *atomoides*

Table 3.13. Inferred pH and nutrient status preferences for the most common species in modern lakes on Macquarie Island (more than 20 % abundance in at least one lake). O = oligotrophic, M = mesotrophic, E = eutrophic.

Species	Preferred pH	pH range	Preferred nutrient status	Nutrient status range	No. of lakes in which abundant
Achnanthes abundans	6.2	6.1 - 7.3	O	O - E	1
Achnanthes confusa	6.1 - 6.4	6.1 - 7.3	O	O - E	3
Achnanthes confusa var. *atomoides*	6.1	6.1 - 7.3	O	O - E	2
Achnanthes conspicua var. *brevistrata*	6.1 - 7.6	6.1 - 7.3	M - E	O - E	2
Achnanthes delicatula	7.3	6.4 - 7.3	E	M - E	1
Achnanthes delicatula var. *hauckiana*	6.3 - 7.6	6.1 - 8.1	M - E	O - E	2
Achnanthes engelbrechtii	6.1 - 7.6	6.1 - 8.1	M - E	O - E	4
Achnanthidium lanceolatum	6.1 - 7.6	6.1 - 8.1	O - E	O - E	3
Achnanthidium microcephalum	7.3	6.1 - 7.3	O	O - E	3
Amphora coffeaeformis	7.2	6.1 - 7.3	O - E	O - E	1
Brachysira exilis	6.1 - 7.3	6.1 - 7.3	O	O - E	4
Cocconeis placentula	7.2 - 7.6	6.1 - 8.1	O - E	O - E	3
Cymbella microcephala	7.2 - 7.3	6.1 - 7.6	O - E	O - E	2
Diatomella hustedtii	7.3	7.3	E	O - E	1
Gomphonema affine	7.2 - 7.6	6.1 - 7.6	E	O - E	2
Nitzschia gracilis	6.4	6.1 - 7.3	O	O - E	1
Nitzschia palea	7.2 - 8.1	6.4 - 8.1	M - E	O - E	4
Staurosirella pinnata	7.3	7.2 - 7.3	E	M - E	1
Synedra vaucheriae	6.4 - 7.3	6.1 - 8.1	O - E	O - E	4
Synedra rumpens	6.1 - 7.6	6.1 - 8.1	O - E	O - E	8

Three species appear to prefer eutrophic conditions, occurring abundantly in lakes which have possibly been nutrient-enriched.

Eutrophic species:

Achnanthes delicatula *A. conspicua* var. *brevistrata* *Staurosirella pinnata*

The remaining species are tolerant of a range of nutrient levels, occurring in oligotrophic mires, oligotrophic, mesotrophic and eutrophic lakes. Many of the species also seem to be tolerant of a broad pH range.

Tolerant species:

Achnanthes engelbrechtii *Achnanthidium lanceolatum* *Amphora coffeaeformis*

Cocconeis placentula	*Cymbella microcephala*	*Diatomella hustedtii*
Nitzschia palea	*Synedra vaucheriae*	*Synedra rumpens*
Achnanthes delicatula var. *hauckiana*		

3.6.3 Comparison of modern diatom ranges on Macquarie Island with other parts of the world

An extensive search of the literature was conducted prior to analysis of the samples. *Eunotia exigua* is regarded as an acidophile, commonly found associated with *Sphagnum* in the Northern Hemisphere (Dixit, Dixit & Evans, 1988; Schoeman, 1973). *Sphagnum* is relatively rare on Macquarie Island. However, overseas studies have shown that *E. exigua* is not restricted to *Sphagnum,* but is a more general moss epiphyte, or possibly an aerophile (Scherer, 1988; Kingston, 1984; Conger, 1939). This is in agreement with the data collected from Macquarie Island. *Pinnularia acoricola* is regarded as an aerophile which prefers a pH around 5 (Gasse & Tekaia, 1983; Schoeman, 1970). In samples from Macquarie Island it reached its greatest abundance in mires with a moderate pH, but was common in samples from areas with a lower pH (less than 5) where *Eunotia exigua* was present.

Information on the ecological preferences for the species of Association 2a is limited. Bourelly and Manguin (1954) report *Achnanthes confusa* as an aerophile and *A. pseudolanceolata* as littoral; *D. hustedtii* is regarded as littoral or benthic, preferring fast, cold, oligotrophic water (Larson, 1974; Bourelly & Manguin, 1954); *S. rumpens* is apparently indifferent to salinity and pH, and has been variously described as epiphytic, littoral and planktonic (Dixit, Dixit & Evans, 1988; Gasse, 1986; Haworth, 1976). The environmental information obtained from samples on Macquarie Island generally agrees with this: *A. pseudolanceolata* appears to be an epiphyte, *Diatomella hustedtii* was found abundantly in one eutrophic lake as well as in oligotrophic mires and may be tolerant of a range of nutrient levels.

Those species found in moderate to high abundances in few samples included *Achnanthidium lanceolatum, Amphora coffeaeformis, Cymbella microcephala, Fragilariforma virescens* and *Staurosira construens* var. *venter*. All were most abundant or co-dominant with other species in one or more mires. *Achnanthidium lanceolatum* has been described as epiphytic, littoral and aerophilic on rocks and soil, and prefers oligotrophic water with a circumneutral pH (Gasse, 1986; Le Cohu & Maillard, 1983; Haworth, 1976; van Landingham, 1966). Gandhi (1966) described it as occurring abundantly with mosses.

Fragilaria sensu lato has been recognised as a problematical genus, in terms of ecological preferences (Wolfe, 1991). It has been divided recently into several genera, based on the ultrastructure of the valves and on other characters apparent in uncleaned material (Round, Crawford & Mann, 1990). *Staurosira construens* var. *venter* and *Fragilariforma virescens* have been described as littoral or planktonic, preferring slightly alkaline water (Gasse, 1986; Smol, 1983; Broady, 1976; Schoeman, 1973; Cholonky, 1968). Other workers, however, regard '*Fragilaria*' as preferring more acid conditions, as seems to be the case on Macquarie Island (Hansson & Håkansson, 1992; Flower, Battarbee & Appleby, 1987; Kingston, 1984).

Cymbella microcephala has been described as an aerophile, occurring on rocks, and preferring circumneutral, oligotrophic water (Schoeman, 1973). *Amphora coffeaeformis* is described as being littoral, epiphytic, aerophilic, occurring on rocks, soil and in springs, with a pH optimum of 7.0 - 7.9 (Gasse & Tekaia, 1983; Schoeman, 1973; Patrick & Reimer, 1966).

The information from these mire surface and lake samples shows there are some similarities and some differences in the diatom species preferences on Macquarie Island and elsewhere in the world. *Eunotia exigua* occurs in acidic sites on Macquarie Island, generally becoming increasingly dominant at more acid sites. However, the species in Association 2a are tolerant of a wide range of conditions, occurring abundantly in acidic to neutral mires and in basic lakes. This range of environmental preferences was also observed in diatoms from the Antarctic, where the most common diatoms had wide ecological tolerances (Kaweeka & Olech, 1993). In terms of environmental reconstrution, this makes the interpretation of any samples with abundant *E. exigua* relatively straightforward. Where other species are most abundant, however, environmental reconstructions will not be so clear-cut. Samples dominated by, for example, *Achnanthes confusa, Diatomella hustedtii* and *Synedra rumpens* may be found in areas which could be acidic to neutral to basic, wet or dry, large or small, lake or mire. These species are also found in a wide range of other modern, terrestrial, environments (see Chapter 4; Selkirk, Mcbride, Keenan & Adamson, 1991).

A much more intense study of the Macquarie Island freshwater environments is needed to address these questions adequately. Water samples for analysis of trace elements, repeat sampling over successive months, seasons and/or years, more extensive sampling of as wide a range of mires as possible and perhaps even field and laboratory manipulations of living material would be required to begin to solve the problems raised here.

3.7 Changes with depth in mires on Macquarie Island

Samples of vegetation were collected from mire surfaces to represent the present diatom flora; samples of partially decomposed vegetation from 100 mm to 500 mm depth were also collected to represent diatom associations from the past. Samples from Sandell Mire and Green Gorge were radiocarbon dated to obtain an estimate of the rate of peat accumulation in a mire. The Sandell mire sample was dated at 2135 $\pm$ 600 y BP (SUA 1464: 1.7 m depth) and the Green Gorge sample was dated at 1600 $\pm$ 300 y BP (SUA 1463: 1.3 m depth). These two ages give an approximate rate of peat accumulation in mires of 100 mm/100 y. Assuming similar rates of accumulation in other mires on the island, the age of material from 100 mm, 250 mm, 400 mm and 500 mm is estimated to be 100, 250, 400 and 500 years respectively.

Initial, visual analysis of the data from 25 sites with samples from the surface and from depth indicated 12 mires had changes in the diatom species over time (that is, with depth) and 13 had not. The two groups were then analysed separately to determine the degree of homogeneity within mires over time.

3.7.1 Mires that do not change with depth

Thirty samples from 13 sites were divided by the TWINSPAN classification into 4 groups at level 2, with an eigenvalue of E = .232 at division 1. Samples from surface and depth taken at most sites were grouped together:

Eagle mire
Red River
Bauer Bay
Hasselborough Bay site 2
Wireless Hill site 2
Emerald Lake
Handspike Corner site 1
Square Lake site 1
Square Lake site 2

The samples from the mire surfaces and depth which were separated by the TWINSPAN analysis were:

Jessie Niccol Creek
Floating Island Lake site 2
Flat Creek
Green Gorge site 1

The HMDS of the same samples was run and a minimum stress of .216 in two dimensions was obtained (fig. 3.12). Grouping of samples was generally similar to that from the TWINSPAN analysis except that samples from Jessie Niccol Creek, Flat Creek, Floating Island Lake site 2 were not separated by the HMDS in two dimensions.

Sample codes for Figure 3.12

Bauer Bay	BB
Eagle Mire	EM
Emerald Lake	EL
Finch Creek	FC
Floating Island Lake site 2	FI2
Green Gorge site 1	GG1
Handspike Corner site 1	HC1
Hasselborough Bay site 2	HB2
Jessie Niccol Creek	JN
Red River	RR
Square Lake site 1	SQ1
Square Lake site 2	SQ2
Wireless Hill site 2	WH2

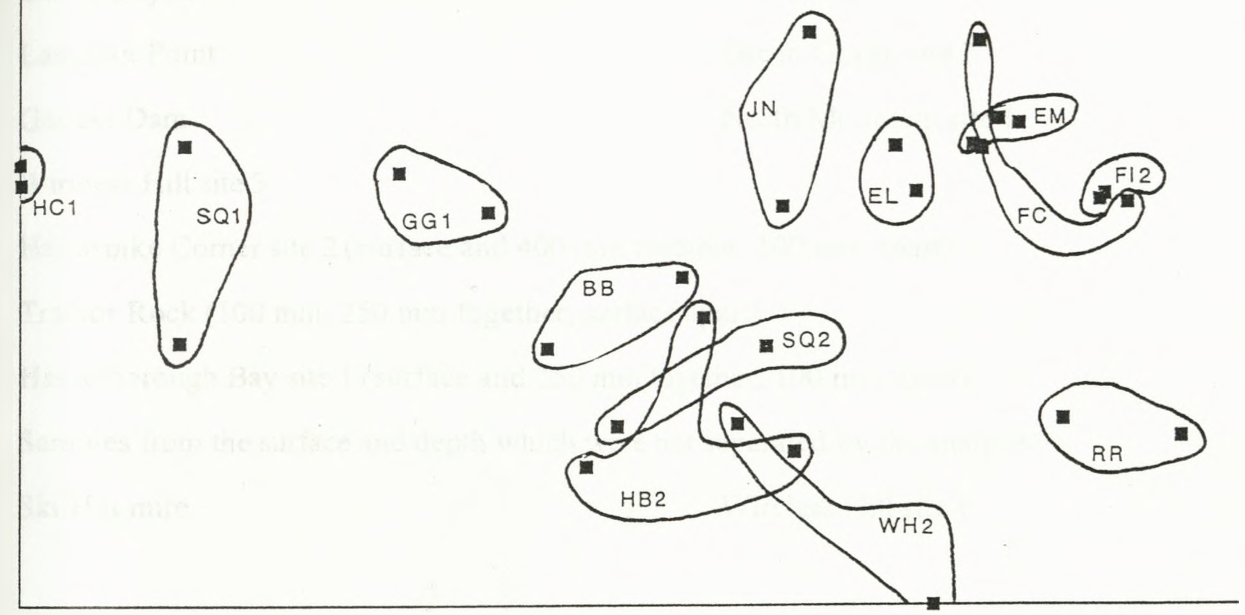


Figure 3.12. HMDS of mire samples in two dimensions that do not change with depth. Minimum stress was .216. Groupings indicate samples from the same sites. Sample codes are listed opposite.

This group of sites showed little variation between diatoms from the surface samples and those from depth. Samples from surface and 100 mm, 250 mm or 500 mm depth can differ quite markedly in the diatom associations present, indicating relatively recent (and possibly dramatic) changes in the local environment. However, the similarities in the diatom associations present at these sites indicate relatively stable environments over time.

3.7.2 Mires that change with depth

Twenty seven samples from 12 sites were analysed to determine the degree of variation which may occur over time in some mires. The TWINSPAN of samples gave 4 groups at level 2, with an eigenvalue of E = .198 at the first division.The analysis placed the two samples from the surface and depth at each site into separate groups, except those from the Ski Hut mire and Wireless Hill site 1.

Samples from surface and depth which were separated by the TWINSPAN analysis:

Sandy Bay site 1

Sandy Bay site 2

Langdon Point

Green Gorge site 2

Gadget Dam

North Mountain site 1

Wireless Hill site 3

Handspike Corner site 2 (surface and 400 mm together, 100 mm apart)

Tractor Rock (100 mm, 250 mm together, surface apart)

Hasselborough Bay site 1 (surface and 250 mm together, 100 mm apart).

Samples from the surface and depth which were not separated by the analysis:

Ski Hut mire

Wireless Hill site 1

The Ski Hut mire surface and 100 mm samples were placed together because of the similarities in the majority of species. While *Eunotia exigua* was dominant in the surface sample, *Achnanthidium lanceolatum* was most abundant at 100 mm depth. However, both species were present in the other sample. The surface sample from Wireless Hill site 1 had *Achnanthidium lanceolatum, Amphora coffeaeformis, Pinnularia acoricola* and *P. circumducta* abundant. The 100 mm sample had *Achnanthes saxonica, Achnanthidium lanceolatum, Fragilariforma virescens* and *Synedra rumpens* abundant. Both shared less common species, such as *Achnanthes confusa* var. *atomoides, Martyana martyi* and *Synedra rumpens*.

As with the TWINSPAN, the HMDS of mire samples that changed with depth in two dimensions placed most samples from the same sites apart, with a minimum stress of .197 (fig. 3.13). Wireless Hill site 1 samples were placed together; these were also grouped by the TWINSPAN analysis. The main difference between the two analyses were in the Tractor Rock and Langdon Point samples, which were separated by the TWINSPAN but grouped by the HMDS. This is due to the great number of shared species in the samples at both sites,

Sample codes for Figure 3.13

Gadget Dam surface	GDa
Gadget Dam 100 mm	GDb
Green Gorge site 2 surface	GG2a
Green Gorge site 2 100 mm	GG2b
Handspike Corner site 2 surface	HC2a
Handspike Corner site 2 250 mm	HC2c
Handspike Corner site 2 500 mm	HC2d
Hasselborough Bay site 1 surface	HB1a
Hasselborough Bay site 1 100 mm	HB1b
Hasselborough Bay site 1 250 mm	HB1c
Langdon Point surface	LPa
Langdon Point 100 mm	LPb
North Mountain site 1 surface	NM1a
North Mountain site 1 100 mm	NM1b
Sandy Bay site 1surface	SB1a
Sandy Bay site 1 100 mm	SB1b
Sandy Bay site 2 surface	SB2a
Sandy Bay site 2 100 mm	SB2b
Ski Hut surface	SKa
Ski Hut 100 mm	SKb
Tractor Rock surface	TRa
Tractor Rock 100 mm	TRb
Tractor Rock 250 mm	TRc
Wireless Hill site 1 surface	WH1a
Wireless Hill site 1 100 mm	WH1b
Wireless Hill site 3 surface	WH3a
Wireless Hill site 3 100 mm	WH3b

despite the variation in the percent abundance of some species.

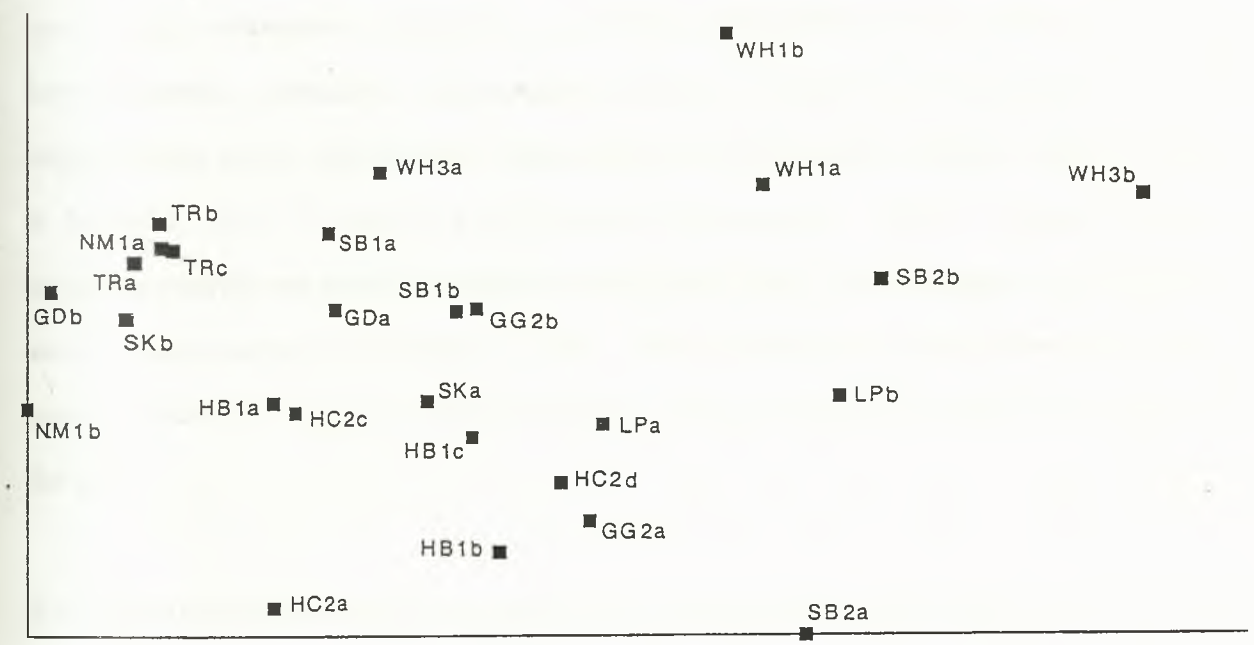


Figure 3.13. HMDS of mire samples that change with depth in two dimensions. Minimum stress was .197. Sample codes are listed opposite.

3.7.3 Changes in diatom associations over time

Changes in the environment of a mire, reflected in the changes of diatom populations down a profile, can occur over time. Florin (1970) recorded the stages in the development of a lake from a mire; Scherer (1988) discussed the changes in the palaeoecology of the Okefenokee swamp; and Collingsworth, Hohn & Collins (1967) showed the succession in a mire since glacial retreat in a bog in Michigan. These three examples exhibit rather dramatic changes over time, and show adequately that as in lakes, diatoms can be useful indicators of environmental change in mires.

Twelve of the 25 mires with samples from depth exhibited some changes in the diatom populations. The nature of the changes can be identified in some mires, despite the broad environmental tolerances of many of the common species. Four mires were apparently drier in the past, with three of these also showing changes in acidity. Sandy Bay site 2, Handspike Corner site 2, Langdon Point and Green Gorge site 2 all had several aerophillic species (eg. *Achnanthes confusa* var. *atomoides, Achnanthidium lanceolatum, Cymbella kerguelenensis, Pinnularia circumducta*) present in high relative abundances in the samples from depth, with *Eunotia exigua* abundant at the surface (Gasse, 1986; Le Cohu & Mallaird, 1983; Haworth, 1976; Bourrelley & Manguin, 1954). Although *Eunotia exigua* is possibly an aerophile elsewhere (Kingston, 1984), it does appear to prefer wet, acidic environments on Macquarie Island. The occurrence of several aerophiles, with lower amounts of *E. exigua,* indicates drier environments may have existed at these sites in the past.

Six sites exhibited what can be interpreted as a change in acidity over time, indicated by the changes in the relative abundance of *Eunotia exigua* and other species with depth. A higher abundance of *E. exigua* and fewer other species indicates a lower pH; where *E. exigua* was less abundant at depth than at the surface with other species common, the site was probably less acidic. The sites which may have been less acidic in the past were: Ski Hut, Handspike Corner site 2, Hasselborough Bay site 1, Sandy Bay site 1, Langdon Point and Green Gorge site 2.

At the remaining five sites, changes in the diatom species over time provided few clues as to the nature of the changes that have occurred. Wireless Hill sites 1 and 3, Tractor Rock mire, North Mountain site 1 and Gadget Dam all have changes from one suite of aerophilic species to a second suite of aerophiles. Both may be indicative of drier environments. However, a second explanation may be that one suite of aerophils is reflecting a drier habitat, while the other is found on emergent macrophyte vegetation. The second habitat would also be reasonably dry, although there would be abundant moisture available close

Table 3.14. List of common and/or abundant species from Sandell Mire surface and pool samples: Their mean, standard deviation (SD), number of samples abundant in (*n*) and range are given. All values except *n* are given as percentages. All data from all sites are presented in Appendix 3.

Species Names	**Mire surface samples**				**Pool samples**			
	n	**mean**	**SD**	**range**	***n***	**mean**	**SD**	**range**
Achnanthes confusa	7	5.4	8.9	1-18	8	5.1	5.3	1-18
Achnanthes pseudolanceolata	10	5.5	3.7	1-12	5	6.2	4.1	1-12
Achnanthidium lanceolatum	6	6	6.4	1-20	7	9.3	8.3	1-22
Achnanthidium microcephalum	4	2.8	1.1	1-4	7	7.9	10.5	1-33
Amphora coffeaeformis					7	17.6	10.9	6-32
Caloneis silicula	10	18.4	21.7	2-68	4	5.8	3.2	1-10
Cymbella gracilis					2	11.5	10.5	1-22
Diatomella hustedtii	8	6.6	3.6	2-12	3	30	19.3	3-47
Eunotia exigua	7	31.4	26.7	4-68				
Navicula corrugata	4	6.3	6.9	1-18				
Nitzschia inconspicua	1	1	-	1	2	20.5	12.5	8-33
Nitzschia palea	3	4.7	1.9	2-6	8	13.6	15.8	1-44
Pinnularia acoricola	6	13.5	12.1	2-39				
Pinnularia circumducta	7	1.9	1.4	1-4				
Stauriosira construens var. *venter*	8	7	5.9	3-22	5	4.6	3.9	1-12
Stauriosirella pinnata					1	18	-	18
Synedra rumpens	8	9.9	9.9	1-26	9	27.8	25.6	4-92

by. Futher work involving detailed sampling would be required to resolve this.

These changes in diatom associations occurred in approximately half the mires sampled. They appear to be reflecting localised changes in the environment of the mire, rather than any broader environmental change. Drainage of a mire, caused by (for example) a peat slide or movement along a fault, may occur from time to time. Conversely, the damming of a site may also occur in the same ways, causing a drier area to become saturated. Changes in pH within a mire are less easily explained, but may be related to a change in the moisture availability, moisture regime, or in the origin of the input (e.g. subsurface flow rather than precipitation),

Once further study of the environmental preferences of the major species on Macquarie Island is completed, more definite statements with regards to the changes in mire habitats over time may be made.

3.8 Sandell Mire

The 10 pool samples and 23 mire samples from 10 sites were analysed together to determine the similarities in diatom association within a large pool/mire complex. The common or abundant species, their average abundances, ranges and the number of samples in which they occur are given in table 3.14. Percentage abundance diagrams for all species with 2% or greater abundance are given in appendix 3. The TWINSPAN gave 4 groups at the second level, with an eigenvalue of E = .128 at division 1. Pool samples separated out from the mire samples almost completely, with pool sites 1, 5, 6, 7, 8, 9 and 10 placed apart in group 4. The surface sample from site 3 was the only mire sample included in group 4.

Group 1 contained pool samples from sites 2 and 3 and three mire samples; 200 mm and 400 mm from site 2 and 400 mm from site 3. The pool samples had *Diatomella hustedtii* and *Amphora coffeaeformis* most abundant, with *Achnanthes coarcta, A. pseudolanceolata* and *Synedra rumpens* moderately abundant. The two 400 mm samples had *Staurosira construens* var. *venter* most abundant, with *Achnanthes coarcta, Amphora coffeaeformis* and *Synedra rumpens* moderately abundant. *Achnanthes coarcta* was most abundant at 200 mm in site 2, with *Staurosira construens* var. *venter* and *Synedra rumpens* present.

Group 2 was the largest, containing all samples from mire sites 1, 4, 5, 6, 7, 8, 9 and 10, plus the surface sample from site 2, 200 mm depth at site 3 and the pool sample from site 4. It was rather heterogeneous in terms of the abundant diatom species (listed below).

Site 1: *Achnanthes manguinii, Achnanthidium lanceolatum, Diatomella hustedtii, Synedra rumpens*

Site 2: (surface) *Fragilariforma virescens*

Site 3: (200 mm) *Achnanthes confusa, F. virescens, S. rumpens*

Site 4: *Caloneis silicula, D. hustedtii, Staurosira construens* var. *venter*

Site 5: *C. silicula, D. hustedtii*

Site 6: *Staurosira construens* var. *venter, Synedra rumpens*

Site 7: *Eunotia exigua, Pinnularia acoricola*

Site 8: *E. exigua, D. hustedtii, P. acoricola*

Site 9: *E. exigua, P. acoricola, A. confusa, Achnanthes pseudolanceolata, D. hustedtii*

Site 10: *E. exigua, P. acoricola, A. lanceolatum, C. silicula*

Groups 3 and 4 were small, with the majority of pool site samples here. Pool sites 1, 7 and 10 were in goup 3, with the surface sample from mire site 3 there also. Group 4 contained samples from pool sites 5, 6, 8 and 9. These had a mixture of abundant species including *Achnanthidium lanceolatum, A. microcephalum, Amphora coffeaeformis, Cymbella*

Sample codes for Figure 3.14

Mire Samples ■

Site 1, surface	1a
Site 1, 100 mm	1b
Site 1, 250 mm	1c
Site 2, surface	2a
Site 2, 200 mm	2c
Site 2, 400 mm	2d
Site 3, surface	3a
Site 3, 200 mm	3c
Site 3, 400 mm	3d
Site 4, surface	4a
Site 4, 100 mm	4b
Site 5, surface	5a
Site 5, 100 mm	5b
Site 6, surface	6a
Site 6, 100 mm	6b
Site 7, surface	7a
Site 7, 100 mm	7b
Site 8, surface	8a
Site 8, 100 mm	8b
Site 9, surface	9a
Site 9, 100 mm	9b
Site 10, surface	10a
Site 10, 100 mm	10b

Pool Samples o

Pool 1	P1
Pool 2	P2
Pool 3	P3
Pool 4	P4
Pool 5	P5
Pool 6	P6
Pool 7	P7
Pool 8	P8
Pool 9	P9
Pool 10	P10

Nitzschia inconspicua, N. palea, Staurosirella pinnata and *Synedra rumpens*. Most species which were abundant in one sample were also present in the others.

The HMDS analysis of Sandell Mire samples agreed quite well wth the TWINSPAN, with the minimum stress in two dimensions of .198 (fig. 3.14). Groups 1 and 2 were placed adjacent by the HMDS, with the majority of samples in Group 2 were placed relatively close together. Groups 3 and 4 were well separated by the HMDS, placed at the left of the configuration. Groups 1 and 2 were less well defined in two dimensions, although most of the samples from each group were placed close together. This was due to the relatively high stress; the TWINSPAN groups would be more separated at higher dimensions.

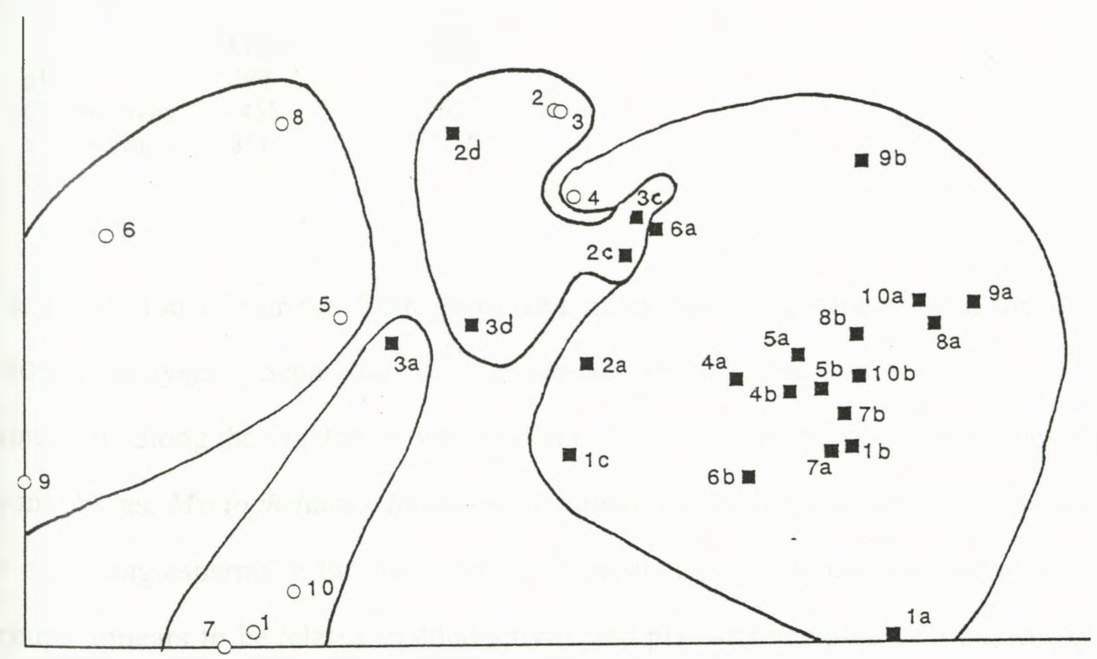


Figure 3.14. HMDS of Sandell mire and pool samples in two dimensions. Minimum stress was .198. TWINSPAN groups are marked on the diagram. The sample codes are listed opposite.

The ANOSIM of Sandell pool and mire surface samples shows that there is a significant difference between the two environments, with $p = .002$. This separation of the samples was also seen in both the HMDS and TWINSPAN analyses.

Environmental gradients in Sandell Mire

The CCA of Sandell mire samples separated the surface and pool samples clearly along the first axis (fig 3.15). The eigenvalues for the first two axes were .486 for axis 1 and .167 for axis 2. The goodness of fit for the sample arrangement on two axes was 51%. The species/environment correlations were high, at .912 and .872 for axes 1 and 2 respectively. Three environmental variables of pH, conductivity and vegetation type were included in the analysis. Conductivity and pH were strongly correlated with axis 2 and vegetation type was correlated with the first axis (table 3.15).

Table 3.15. Interset correlation coefficients of the three sample variables from the CCA of Sandell Mire samples.

	Axis 1	**Axis 2**
pH	.349	-.422
Conductivity	-.455	.153
Vegetation type	.851	-.123

The separation of samples from pools and mires was in agreement with the HMDS and ANOSIM analyses. Separation of the samples by the CCA appears to have occurred principally along the vegetation type gradient. Vegetation in the pools was generally either cyanophytes, *Myriophyllum triphyllum* or *Ranunculus crassipes*, compared to bryophytes or other angiosperms in the mire samples. Separation of the samples within each of the groups appears to be related to conductivity and pH, with samples with higher pH placed at the right of the groups and those with low conductivity at the left.

Major species were grouped around the centre of the plot. *Achnanthes confusa* was placed as an extreme outlier (not shown on fig. 3.15). *Achnanthes austriaca* and *Caloneis silicula* were closely related to conductivity; *Achnanthes confusa* var. *atomoides*,

Sample codes for Figure 3.15

Mire samples

Mire 1	M1
Mire 2	M2
Mire 3	M3
Mire 4	M4
Mire 5	M5
Mire 6	M6
Mire 7	M7
Mire 8	M8
Mire 9	M9
Mire 10	M10

Pool samples

Pool 1	P1
Pool 2	P2
Pool 3	P3
Pool 4	P4
Pool 5	P5
Pool 6	P6
Pool 7	P7
Pool 8	P8
Pool 9	P9
Pool 10	P10

Species codes for Figure 3.15 overlay

Achnanthes abundans	Ac ab
Achnanthes austriaca	Ac au
Achnanthes confusa var. *atomoides*	Ac at
Achnanthes pseudolanceolata	Ac ps
Achnanthidium lanceolatum	Ah la
Achnanthidium microcephalum	Ah mi
Amphora coffeaeformis	Am ca
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Diatomella hustedtii	Di hu
Eunotia exigua	Eu ex
Fragilariforma virescens	Fr vi
Martyana martyi	Ma ma
Navicula corrugata	Na cg
Nitzschia palea	Ni pa
Pinnularia acoricola	Pi ac
Pinnularia borealis	Pi bo
Pinnularia circumducta	Pi ci
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru

Achnanthidium lanceolatum and *A. microcephalum* were related to pH. The majority of species were placed in the bottom left of the configuration. Most of these species were aerophillic, occurring predominately in the mire surface samples (drier), rather than in the pool samples.

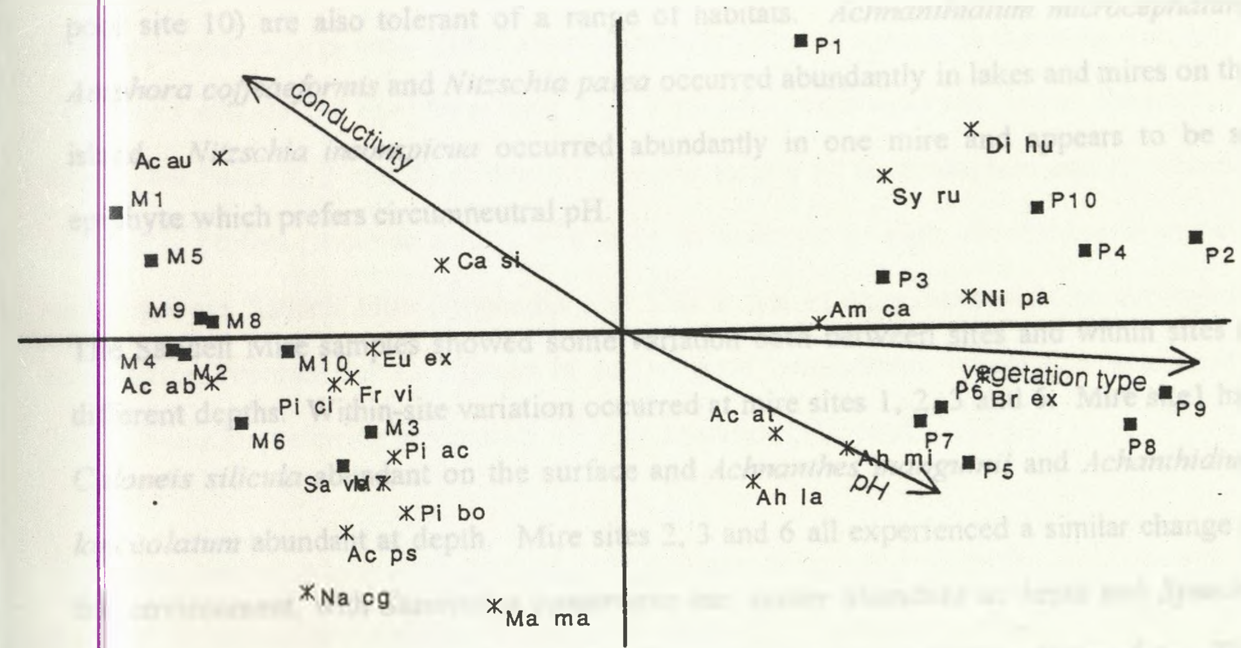


Figure 3.15. Biplot of CCA of samples and environmental variables from Sandell Mire. Axis 1 has an eigenvalue of .486, axis 2 has an eigenvalue of .167. The goodness of fit for the first two axes is 51%. The overlay shows the major species from Sandell Mire sites, scaled to be comparable to the sample/environment biplot. Mire surface samples are at the left of the configuration; pool samples are at the right. Sample and species codes are listed opposite.

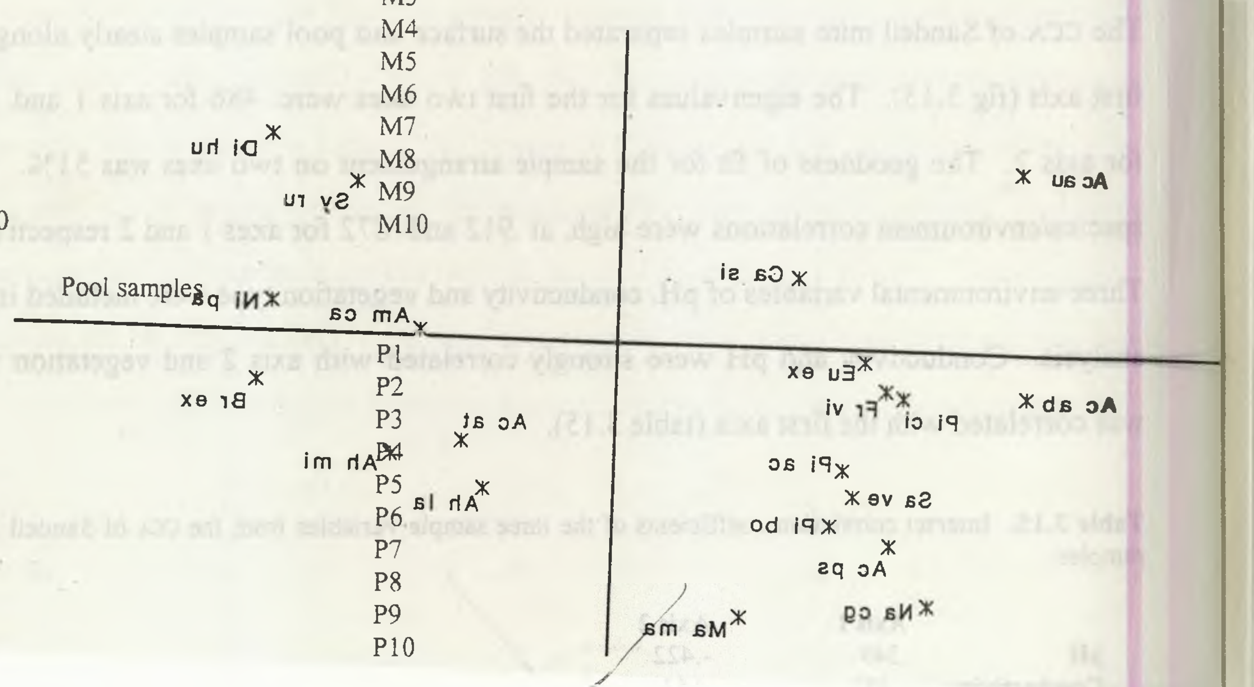
Sandell Mire as a diatom habitat

Sandell Mire is relatively diverse in terms of the diatoms present. The pool samples are distinctive, with either *Diatomella hustedtii* or *Synedra rumpens* most abundant in almost all. The pH in the 10 pools varied from 6.5 (pool site 4) to 9.9 (pool site 2), indicating that these species, especially *D. hustedtii* and *S. rumpens,* are indifferent to pH variations. The type of macrophytes and algae collected from within the pools also varied: *Myriophyllum triphyllum, Ranunculus crassipes, Callitriche antarctica, Agrostis magellanica* or cyanophytes growing in pools with no other vegetation. There was no pattern obvious from the combination of these features and the diatom associations. This indicates that

Sample codes for Figure 3.15

Mire samples

Mire 1	M1
Mire 2	M2
Mire 3	M3
Mire 4	M4
Mire 5	M5
Mire 6	M6
Mire 7	M7
Mire 8	M8
Mire 9	M9
Mire 10	M10



Pool samples

Pool 1	P1
Pool 2	P2
Pool 3	P3
Pool 4	P4
Pool 5	P5
Pool 6	P6
Pool 7	P7
Pool 8	P8
Pool 9	P9
Pool 10	P10

Species codes for Figure 3.15 overlay

Achnanthes abundans	Ac ab
Achnanthes austriaca	Ac au
Achnanthes confusa var. *atomoides*	Ac at
Achnanthes pseudolanceolata	Ac ps
Achnanthidium lanceolatum	Ah la
Achnanthidium microcephalum	Ah mi
Amphora coffeaeformis	Am ca
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Diatomella hustedtii	Di hu
Eunotia exigua	Eu ex
Fragilariforma virescens	Fr vi
Martyana martyi	Ma ma
Navicula corrugata	Na cg
Nitzschia palea	Ni pa
Pinnularia acoricola	Pi ac
Pinnularia borealis	Pi bo
Pinnularia circumducta	Pi ci
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru

Achnanthidium lanceolatum and *A. microcephalum* were related to pH. The majority of species were placed in the bottom left of the configuration. Most of these species were aerophillic, occurring predominately in the mire surface samples (drier), rather than in the pool samples.

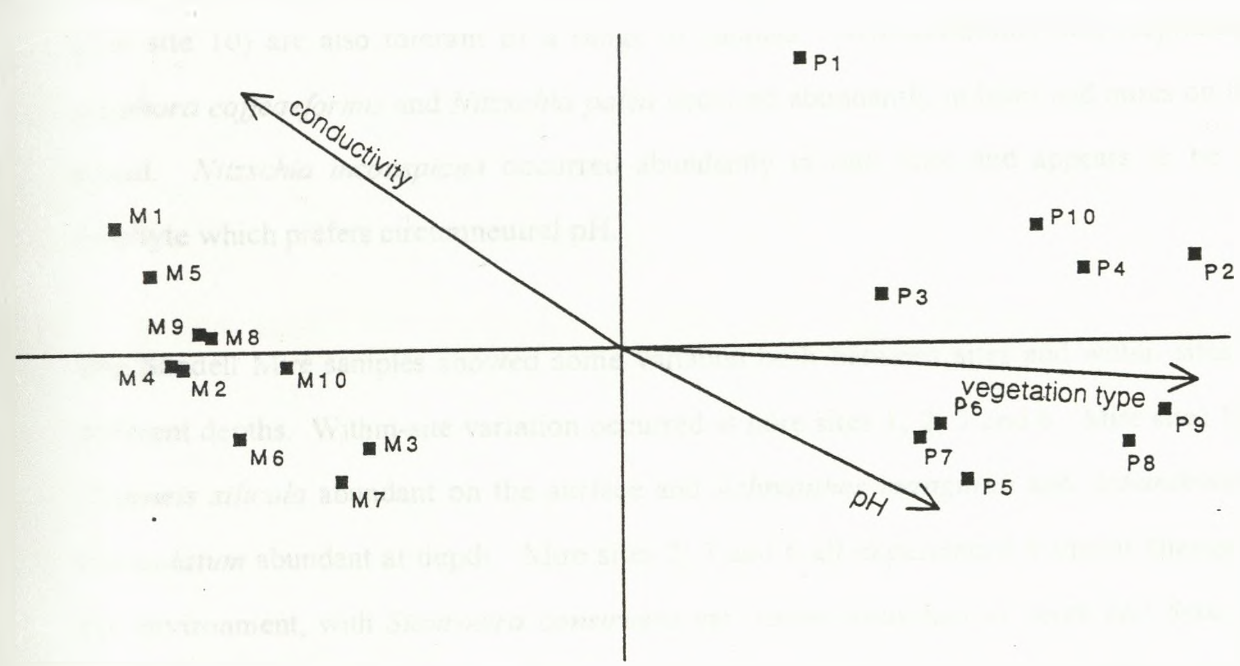


Figure 3.15. Biplot of CCA of samples and environmental variables from Sandell Mire. Axis 1 has an eigenvalue of .486, axis 2 has an eigenvalue of .167. The goodness of fit for the first two axes is 51%. The overlay shows the major species from Sandell Mire sites, scaled to be comparable to the sample/environment biplot. Mire surface samples are at the left of the configuration; pool samples are at the right. Sample and species codes are listed opposite.

Sandell Mire as a diatom habitat

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Achnanthidium microcephalum (most abundant in pool site 8) and *Amphora coffeaeformis* (most abundant in pool site 4, co-dominant with *Nitzschia inconspicua* in pool site 10) are also tolerant of a range of habitats. *Achnanthidium microcephalum, Amphora coffeaeformis* and *Nitzschia palea* occurred abundantly in lakes and mires on the island. *Nitzschia inconspicua* occurred abundantly in one mire and appears to be an epiphyte which prefers circumneutral pH.

The Sandell Mire samples showed some variation both between sites and within sites at different depths. Within-site variation occurred at mire sites 1, 2, 3 and 6. Mire site1 had *Caloneis silicula* abundant on the surface and *Achnanthes manguinii* and *Achanthidium lanceolatum* abundant at depth. Mire sites 2, 3 and 6 all experienced a similar change in the environment, with *Staurosira construens* var. *venter* abundant at depth and *Synedra rumpens* abundant (or co-dominant with *S. construens* var. *venter*) at the surface This suggests a similar change in the environment occurred at these three sites in the past 400 to 100 years. The nature of the event that led to the change from *S. construens* var. *venter* dominated samples to those dominated by *Synedra rumpens* is unclear because of the great environmental tolerance of *S. rumpens.* It is possible that *S. construens* var. *venter* prefers slightly acidic conditions (Wolfe, 1991). The modern pH of the sites is mildy acidic to mildly basic: the change in diatom species may have been due to an increase in pH over time, perhaps due to a change in the hydrology of the immediate area.

Both the TWINSPAN and the HMDS grouped the samples from the surface and depth at the other mire sites together (1, 4, 5, 7, 8 and 9) indicating that these sites experienced little change over time and were relatively similar to each other. Samples from mire site 10 were placed close together on the HMDS plot, but were separated by the TWINSPAN despite showing little change over time. *Eunotia exigua* was most abundant in both, with *Achnanthes pseudolanceolata, Caloneis silicula* and *Pinnularia acoricola* common. The separation by the TWINSPAN was probably because of the presence of one species in one sample and its absence in the other.

The variation in diatoms species composition between the 10 mire sites is surprisingly small over such a large area. There are two important diatom species in the surface samples - *Caloneis silicula* and *Eunotia exigua,* with *Staurosira construens* var. *venter* abundant in three sites (sites 2, 3 and 6) at depth. *Eunotia exigua* is an acidophile and *C. silicula* apparently prefers moderate acidity, occurring in moderate to high abundances in surface samples from Sandell Mire (Appendix 3). This is not in agreement with the ecological information reported for *C. silicula* in the northern hemisphere, where it is said to be littoral/benthic, preferring moderately alkaline conditions (Haworth, 1976).

The other species which were most abundant in one or two mire samples are *Achnanthes coarcta, A. pseudolanceolata, Caloneis silicula* and *Pinnularia acoricola. Pinnularia acoricola* occurs with *Eunotia exigua* regularly in mire samples, preferring low pH and aerophilic conditions. *Achnanthes coarcta* was not found in abundance in any other mire or lake samples and is described as an aerophile, associated with mosses in seepage zones (Schoeman, 1973; Patrick & Reimer, 1966). *Achnanthes pseudolanceolata* appears to be an epiphyte that prefers a mildly acidic environment. The conditions found within Sandell Mire agree with the environmental preferences for these species reported from other parts of the world.

The changes seen in the diatom associations in samples at depth and at the surface in Sandel Mire were not isolated, but were repeated at two or more sites. This indicates that whatever factor was responsible for these changes, the influence was not restricted to one location. It may be that this reflects a change in the geomorphology of the site, such as localised drainage or infilling of an area with sediment. Other changes in the hydrology and vegetation cover and type would all affect the diatom associations present.

Sandell Mire has several streams running through it which drain different parts of the mire. Stream erosion and migration and the subsequent infilling of old stream beds would change the drainage regimes of certain parts of the mire. Areas which were once well-drained may have become boggy, possibly even stagnant. Pools would be cut through and drained and new ones formed.

At the western edge is a fault zone which can be seen most spectacularly just north of the site (fig. 3.7). Analysis of the sediments from Palaeolake Sandell, situated to the west of the mire, revealed changes in the macrophyte vegetation which indicated the formation of a mire over the lake sediments. This possibly occurred when uplift at the fault zone dammed the western portion of the lake/mire, either before or after the palaeolake drained. This was followed by periods of pool formation and infilling (Selkirk, McBride, Keenan & Adamson, 1991).

While it appears that no sites where pools which have been overgrown by vegetation were encountered during the sampling of the mire sites, it is clear that some changes in the local environment have occured in Sandell Mire in the last 500 years. Differences exist between the diatom associations from open water and mire sites even when adjacent to each other: this suggests that there is little interaction between the two environments.

The diatoms present in Sandell Mire were present in the other mires studied on Macquarie Island. The HMDS of the Sandell samples shows there was some variation in and between the mire sites sampled, however samples were grouped towards the right of the plot with few outliers. There was little mixing between the pool and mire samples, indicating some differences exist between open water and mire sites.

3.9 Conclusions Drawn from Chapter 3

The mire sites sampled showed two main associations of diatom species present. Acidic mires (pH less than 6.2) were generally dominated by *Eunotia exigua*, with *Pinnularia acoricola* moderately abundant. Few mires with low pH and all mires with a pH above 6.2 had *Synedra rumpens, Achnanthes confusa* and *Diatomella hustedtii* principally dominant, with other species such as *Achnanthes pseudolanceolata* and *Achnanthidium lanceolatum* also abundant. These species appear to be pH indifferent.

Almost half of the sampled mires exhibited some changes in the diatom suites over time. These changes were difficult to interpret because many of the principal diatoms appear tolerant to a great variation in environments.

The analysis of one large mire and pool complex, Sandell, showed the suites of diatoms which occur in pools within mires differ from those which occur in mire vegetation. There was little variation in the diatoms occurring on the mire surface samples, though changes with depth were seen at some of the sample points. Lake samples show different associations of diatoms from the mires. Major associations are listed in table 3.16.

Table 3.16. Diatom suites from principal modern freshwater habitats on Macquarie Island.

Association	Species	Habitat
1.	*Eunotia exigua/Pinnularia acoricola*	Acidic, oligotrophic mires
2.	*Achnanthes confusa/A. pseudolanceolata/ Achnanthdium microcephalum/Diatomella hustedtii/Synedra rumpens* (some variation in the dominant/abundant species)	Circumneutral, oligotrophic mires and lakes.
3.	*Achnanthes delicatula/A. conspicua* var. *brevistrata/Staurosirella pinnata*	Eutrophic lakes, possibly nutrient-enriched
4.	*Achnanthes engelbrechtii/Achnanthidium lanceolatum.Amphora coffeaeformis/Cocconeis placentula/Cymbella microcephala/Nitzschia palea/Synedra vaucheriae*	Tolerant of a range of conditions.

Chapter 4

Terrestrial Habitats

4.1 Synopsis

Samples were collected from five terrestrial environments: creek, feldmark, soil, lichen and nutrient enriched. The associations of diatom species from each habitat were distinctive. Environmental factors which appear most strongly to influence the associations of diatoms are current (creeks), moisture availability (all habitats) and nutrient enrichment. Species occurring in abundantly freshwater habitats occurred less commonly in the terrestrial samples.

4.2 Introduction

A variety of terrestrial sites was examined to determine which diatom species were able to exist in a broad range of environments and which were restricted to certain habitats. Bunt (1954) examined samples from a range of terrestrial environments including feldmark, wallow, waterlogged 'sub-glacial herbfield' (= mire) and 'wet tussock grassland' (= short grassland). He also studied samples from lakes, ponds and 'fluvio-glacial' deposits. As he only examined ten terrestrial samples and the published list of diatoms from this was limited, it was necessary to conduct a more detailed study as part of this project. The habitats examined and the samples collected from each site are described below.

4.3 Site Descriptions

4.3.1 Creeks

Creeks are common on Macquarie Island, though generally of small size. Despite the high rainfall, the relatively rugged terrain and the closeness of so much of the island to the coast, large rivers rarely have the space to form. The exceptions are Flat Creek, Jessie Niccol Creek, Red River and Sawyer Creek (fig. 1.6), all of which drain large sections of the plateau. Other major watercourses include Nuggets Creek, Stony Creek (draining Square Lake), Finch Creek, Lusitania Creek and the Island Lake Outlet Stream. The creeks are rarely dry because of the almost continual precipitation and the large store of water on the island. There are, however, periods of higher and lower water levels within the creeks.

Vegetation grows extensively around and sometimes within creeks. Bryophytes are common on creek banks and in the splash zones of waterfalls (fig. 4.1). Algae and cyanophytes grow on rocks, bryophytes and other vegetation in streams and in splash zones. Angiosperms such as *Ranunculus crassipes* may be present on stream edges where flow is slow or restricted.

The growth of diatoms within creeks is known to be affected by the strength of the current (Ruttner, 1940; Kolbe, 1932; Hustedt, 1930). Species which secrete a mucilaginous stalk or gelatinous mass for attachment to a substrate may be better able to survive in stronger currents than those species which do not (Mannion, 1986). Planktonic species will not occur in flowing water unless being washed through (Allen, 1920).

Species may be indifferent to current, occur only, or principally in, non-flowing water (limnobiontic, limnophilous), or may occur principally or only in flowing water (rheophilous, rheobiontic) (Mannion, 1986).

Figure 4.1. Bauer Falls, approximately 600 m inland from Bauer Bay. Mosses and algae grow lushly in the splash zones on either side of the creek.

Thirteen creek sites in the northern two thirds of the island were sampled (fig. 4.2). Algae and bryophytes were the main samples taken, collected from within creeks and in the splash zones of waterfalls. Table 4.1 lists the sites and samples collected at each site.

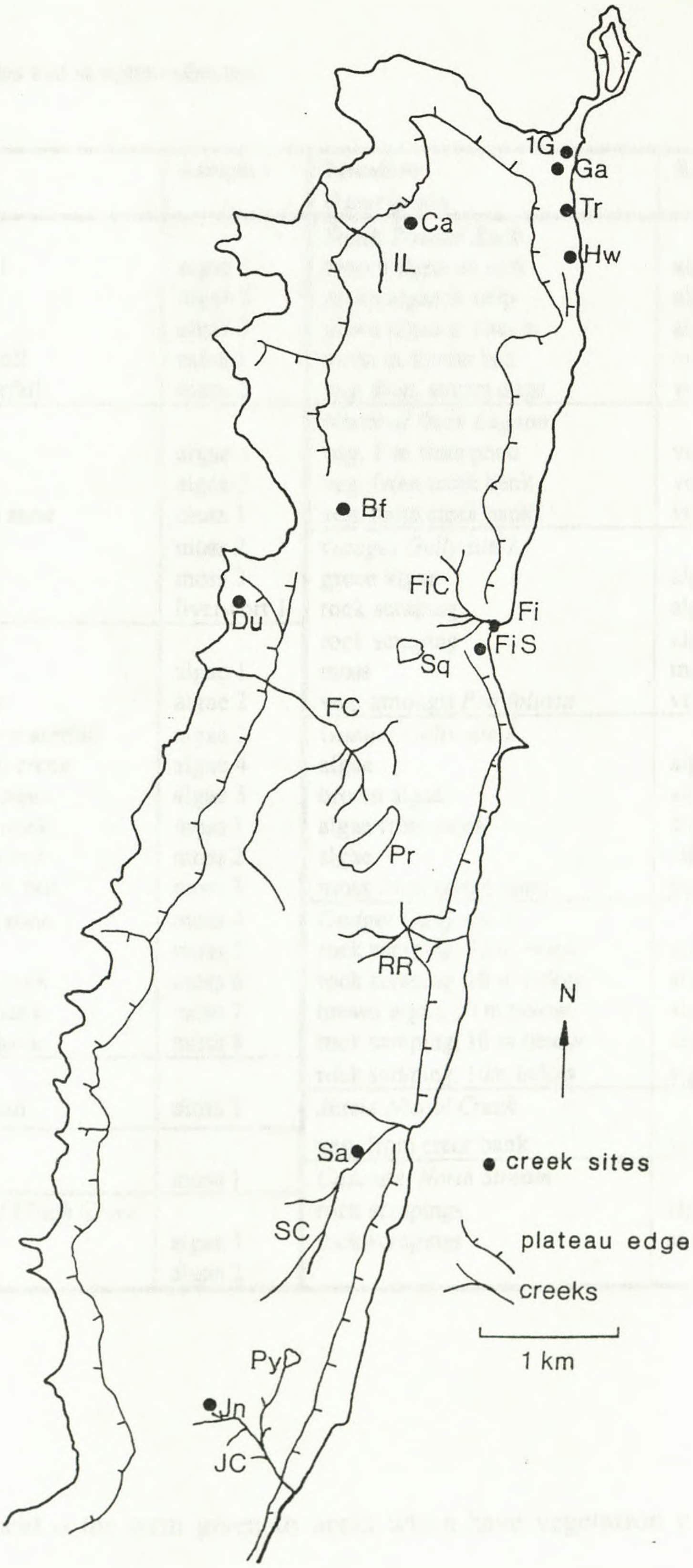


Figure 4.2. Map of Macquarie Island with the creek sample sites marked. 1G = First Gully; Bf = Bauer Falls; Ca = Palaeolake Cascade north stream; Du = north of Duck Lagoon; FC = Flat Creek; FiC = Finch Creek; Fi = Finch Creek site; FiS = waterfall south of Finch Creek; Ga = Gadget Gully (3 sites); Hw = Halfway Hill; IL = Island Lake outlet; JC = Jessie Niccol Creek; JN = Jessie Niccol Creek site; Pr = Prion Lake; Py = Pyramid Lake; RR = Red River; Sa = Sawyer Creek site; SC = Sawyer Creek; Sq = Square Lake; Tr = South Tractor Rock.

Table 4.1 Creek sites and samples collected.

Location Description	Samples	Location Description	Samples
First Gully		*South Tractor Rock*	
algae on waterfall	algae 1	brown algae on rock	algae 1
algae on moss	algae 2	green algae in seep	algae 2
algae on rock	algae 3	green algae in stream	algae 3
moss from waterfall	moss 1	moss in stream bed	moss 1
moss beside waterfall	moss 2	veg. from stream edge	veg. 1
Finch Creek		*North of Duck Lagoon*	
algae from rocks	algae 1	veg. 1 m from pond	veg. 1
algae from seep	algae 2	veg. from creek bank	veg. 2
moss from splash zone	moss 1	veg. from creek bank	veg. 3
moss	moss 2	*Gadget Gully site 1*	
moss	moss 3	green algae	algae 1
Marchantia	liverwort 1	rock scraping	algae 2
Halfway Hill		rock scraping	algae 3
algae from mire	algae 1	moss	moss 1
algae from stream	algae 2	veg. amongst *Poa foliosa*	veg. 1
algae and moss in waterfall	algae 3	*Gadget Gully site 2*	
algae from rock in creek	algae 4	algae	algae 1
algae from south creek	algae 5	brown algae	algae 2
moss from south creek	moss 1	algae from moss	algae 3
moss from stream bed	moss 2	algae	algae 4
moss beside stream bed	moss 3	moss from splash zone	moss 1
moss from splash zone	moss 4	*Gadget Gully site 3*	
mire moss	moss 5	rock scraping, 20 m below	algae 1
moss from north creek	moss 6	rock scraping ,10 m below	algae 2
moss from creek bank	moss 7	brown algae, 10 m below	algae 3
moss from creek bank	moss 8	rock scraping, 10 m below	algae 4
Sawyer Creek		rock scraping, 10m below	algae 5
moss from rock wall	moss 1	*Jessie Niccol Creek*	
Bauer Falls		veg. from creek bank	veg. 1
moss	moss 1	*Cascade, North Stream*	
Waterfall South of Finch Creek		rock scrapings	algae 1
algae from rocks	algae 1	rock scrapings	algae 2
algae from moss	algae 2		

4.3.2 Feldmark

Feldmark or fellfield is the term given to areas which have vegetation cover of less than 50%. Bare gravel areas are common, and the areas are often subject to strong, relatively constant winds (fig. 4.3). Feldmark occurs in most places on the island above 180 m and in very exposed sites may occur down to 90 m a.s.l. (Selkirk, Seppelt & Selkirk, 1990). *Azorella macquariensis* is a small cushion plant that is widespread on the island, but occurs most commonly in the feldmark. The stems of *Azorella* plants are very tightly appressed into the cushions, with only the very tips (5 - 10 mm) raised above the body of the cushion. The leaves are small, with the base close to the main stem and have few coarse hairs (Orchard, 1989). *Azorella* leaves present possibly a drier environment than feldmark mosses, which would retain moisture for longer periods.

Figure 4.3. Feldmark vegetation at approximately 260 m a.s.l. near the southern end of Macquarie Island.

Bryophytes are also common in the feldmark, and can often dominate. Collections of the bryophytes *Ditrichum strictum, Rhacomitrium crispulum, Tortula rubra, Andreaea* sp., *Bryum* sp. and *Dicranaloma billardieri* were made. *Ditrichum strictum* and *R. crispulum* are the two most common bryophytes in this habitat, forming small, dense polsters or longer moss strips (Selkirk, Seppelt & Selkirk, 1990). Sufficient moisture is available, trapped within the leaves of the moss polsters, for diatoms to be present. 'Dry' spells, with strong winds and little precipitation do occur on the island from time to time. However, some diatom species such as *Stauroneis phoenicentron* have been shown to be drought resistant under laboratory conditions and so may survive these periods relatively easily (Evans, 1959).

Samples of bryophytes and *Azorella* were collected from 19 sites in the northern half of the island (fig. 4.4). Table 4.2 lists the sites and samples collected.

Table 4.2 Feldmark Sites and samples collected. Species names are listed in full in Appendix 2.

Location and Description	Sample
North Scoble Lake	
D. strictum	moss 1
Andreaea sp.	moss 2
Ski Hut	
D. strictum	moss 1
Andreaea sp.	moss 2
Azorella	*Azorella* 1
Azorella	*Azorella* 2
Little Prion Lake	
D. strictum, R. crispulum	moss 1
T. rubra	moss 2
Azorella (west)	*Azorella* 1
North Mountain	
D. strictum, R. crispulum	moss 1
T. rubra	moss 2
Andreaea sp.	moss 3
Azorella	*Azorella* 1
Azorella	*Azorella* 2
Azorella	*Azorella* 3
Prion Lake site 1	
D. strictum	moss 1
Andreaea sp.	moss 2
Biggles By-Pass	
D. strictum, R. crispulum	moss 1
T. rubra	moss 2
Azorella	*Azorella* 1
Near 'S' Pond	*Azorella* 1
Azorella	
Sandy/Bauer X-roads	
Azorella	*Azorella* 1
Lake Ainsworth	
moss sp. (west bank)	moss 1
moss spp. (south bank)	moss 2
Gadgets Dam	
Azorella	*Azorella* 1
Azorella	*Azorella* 2
West Scoble Lake	
R. crispulum	moss 1
T. rubra	moss 2
T. rubra	moss 3
D. strictum, R. crispulum	moss 4
Tulloch Lake, south	
R. crispulum	moss 1
T. rubra	moss 2
Azorella (west)	*Azorella* 1
Heartbreak Hill	
bryophytes on rock	moss 1
moss spp.	moss 2
Azorella	*Azorella* 1
Azorella	*Azorella* 2
Halfway Hill	
moss	moss 1
moss	moss 2
Prion Lake site 2	
T. rubra	moss 1
moss sp.	moss 2
Boot Hill	
R. crispulum	moss 1
Azorella (east)	*Azorella* 1
Brothers Lake, North Bank	
Bryum sp.	moss 1
Brothers Track	
bryophytes	moss 1
Pyramid Lake	
moss from west bank	moss 1
moss above track	moss 2

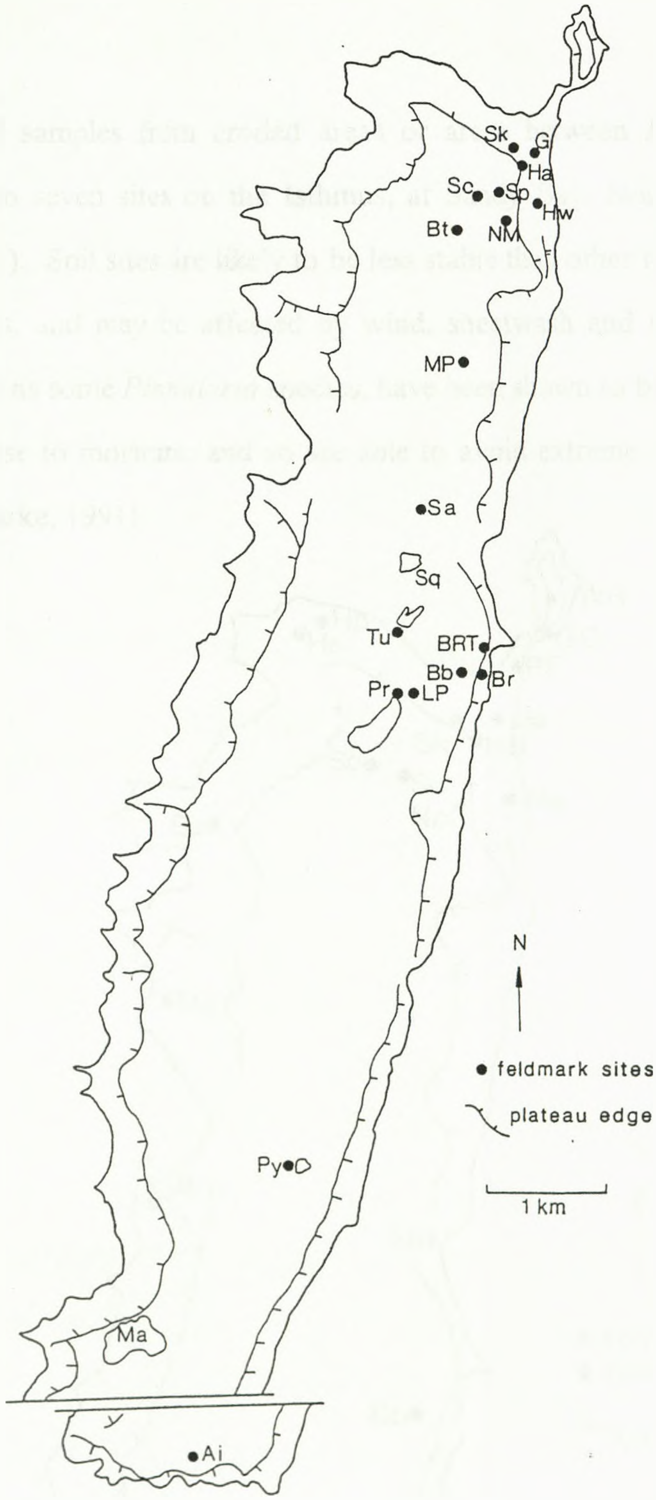


Figure 4.4. Map of Macquarie Island showing the locations of feldmark sample sites. Ai = Lake Ainsworth; Bb = Biggles By-Pass; Br = Brothers Lake; BRT = Brothers Track; Bt = Boot Hill; G = Gadget Dam; Ha = Heartbreak Hill; Hw = Halfway Hill; LP = Little Prion Lake; NM = North Mountain; Pr = Prion Lake; Py = Pyramid Lake; Sa = Sandy/Bauer X roads; Sc = Scoble Lake (2 sites); Sk = Ski Hut; Sp = Ess Pond; Tu = Tulloch Lake.

4.3.3 Soil

Fourteen soil samples from eroded areas or areas between *Poa foliosa* tussocks were collected from seven sites on the Isthmus, at Sandy Bay, North Mountain and Mawson Point (fig. 4.5). Soil sites are likely to be less stable than other terrestrial sites, especially in exposed areas, and may be affected by wind, sheetwash and rainsplash erosion. Motile diatoms, such as some *Pinnularia* species, have been shown to be able to migrate within the soil in response to moisture, and so are able to avoid extreme conditions such as drought (Davey & Clarke, 1991).

Figure 4.5. Map of Macquarie Island showing locations of soil and lichen sampling sites. *Soil sites:* Ga = Gadget Gully; GC = Garden Cove; MP = Mawson Point; NM = North Mountain; RE = Razorback East; Sb = Sandy Bay; WH = Wireless Hill. *Lichen sites:* Bb = Biggles By-Pass; Do = Douglas Point; Ea = Eagle Cave; HH = Heartbreak Hill; Hp = Handspike Pool; Hs = Handspike Corner; Hw = Halfway Hill; MP = Mawson Point: Pr = Prion Lake; Sc = Scoble Lake (2 sites); Sk = Ski Hut; So = Scoble Lake Outlet.

Algae and cyanobacteria are thought to be important stabilisers and initial colonisers of soil in Antarctic fellfield systems, due to the secretion of mucilaginous material which may act to bind soil particles together (Davey, Davidson, Richard & Wynn-Williams, 1991*)*. Table 4.3 lists the sites and the samples collected.

Table 4.3 Soil sites and samples collected.

Location and Description	Sample	Location and Description	Sample
Sandy Bay		*Wireless Hill- western edge*	
walkway	site 1	bare soil	site 1
stairway	site 2	*Colobanthus muscoides* on soil	site 2
Garden Cove		*Mawson Point*	
moss on soil beneath tussocks	site 1	bare soil	site 1
Razorback East		*Gadget Gully*	
algae on soil	site 1	soil between tussocks	site 1
algae on soil	site 2	bare soil	site 2
soil below tussocks	site 3	bare soil	site 3
bare soil & moss	site 4		
North Mountain			
soil	site 1		

4.3.4 Lichen

Lichens are reasonably common on Macquarie Island, with over 100 species descibed to date (Kantvilas & Seppelt, 1992). Lichen were of three growth forms: fruticose - raised above the vegetated surface slightly, such as *Usnea* spp. (fig. 4.6); foliose - growing on rock, with the edges of the lichen raised up from the rock surface; and leprose - growing closely appressed to the rock surface. Twelve samples of several species of lichen were collected from both the coastal fringe and the plateau (fig. 4.5). The sites and samples are listed in table 4.4.

Table 4.4 Lichen sites and samples collected at each site, with lichen growth form indicated.

Location and Description	Sample	Location and Description	Sample
West Scoble Lake *Usnea* sp.	site 1	*Biggles By-Pass* *Usnea* sp.	site 1
Scoble Lake Outlet stream green, foliose lichen	site 1	*North-west Scoble Lake* green, foliose lichen	site 1
Heartbreak Hill green, foliose lichen from rock	site 1	*Halfway Hill* *Usnea* sp. amongst moss	site 1
Douglas Point featherbed *Usnea* sp.	site 1	*Handspike Pool* foliose lichen from rock	site 1
Handspike Corner *Usnea* sp.	site 1	*Eagle Cave* lichen from cave mouth	site 1
Mawson Point red lichen from rock wall	site 1	*Ski Hut* *Usnea* sp.	site 1

Figure 4.6. A species of *Usnea* growing above the featherbed at Hasselborough Bay. Marker pen (12 cm in length) gives scale.

4.3.5 Wallows

Wallows are areas on the coastal fringe where elephant seals *(Mirounga leonina)* lie around during their annual moult. The moulting cycle begins with immature individuals hauling out in November. Adult cows and bulls moult after the breeding season, with cows moulting in January and Febuary and the bulls from Febuary to April.

The moulting seals will establish new wallow areas or return to previous wallows, usually situated amongst *Poa foliosa* tussocks. Often the surrounding vegetation is killed by seals (fig. 4.7; Gillham, 1961). The areas can become quite boggy, especially where drainage is restricted, and will invariably become a foul mixture of faeces, urine, hair and skin (fig. 4.8).

Seal excrement acts to greatly increase the nutrient levels in wallows and surrounding areas, and is known to have a significant effect on the macrophyte vegetation. *Prasiola crispa,* a nitrophilous alga, may be found growing in and around used or abandoned seal wallows (Myrcha & Tatur, 1991; Broady, 1989; Ellis-Evans, 1981Gillham, 1961). *Cotula plumosa*

Figure 4.7. Adult male elephant seals amongst *Poa foliosa* tussocks near Razorback East. Bare soil where the vegetation has been killed is visible.

Figure 4.8. Young elephant seals in a wallow area on the Isthmus where the drainage is impeded.

Table 4.5 Elephant seal affected sites and samples collected.

Location and Description	Sample	Location and Description	Sample
Razorback East *Prasiola* sp. from dry wallow	site 1	*Wallow 2* vegetation from around wallow	 wallow 2
Central Garden Cove bryophytes and *Callitriche* bare soil algae from soil algae from soil	 site 1 site 2 site 3 site 4	*Wallow 3* floating vegetation *Wallow 4* floating vegetation *Wallow 5*	 wallow 3 wallow 4
Handspike Corner veg. from between tussocks	 site 1	floating vegetation bottom scraping	wallow 5a wallow 5b
Wallow 1 floating vegetation	 wallow 1		

and *Poa annua* grow in areas where elephant seals have killed the original *Poa foliosa* tussock and then deserted the area (Selkirk, Seppelt & Selkirk, 1990; Grobbelaar, 1978; Gillham, 1961). Samples from eight seal affected areas around the ANARE station were collected to examine the diatom populations (fig. 4.9). Sites and samples are listed in table 4.5.

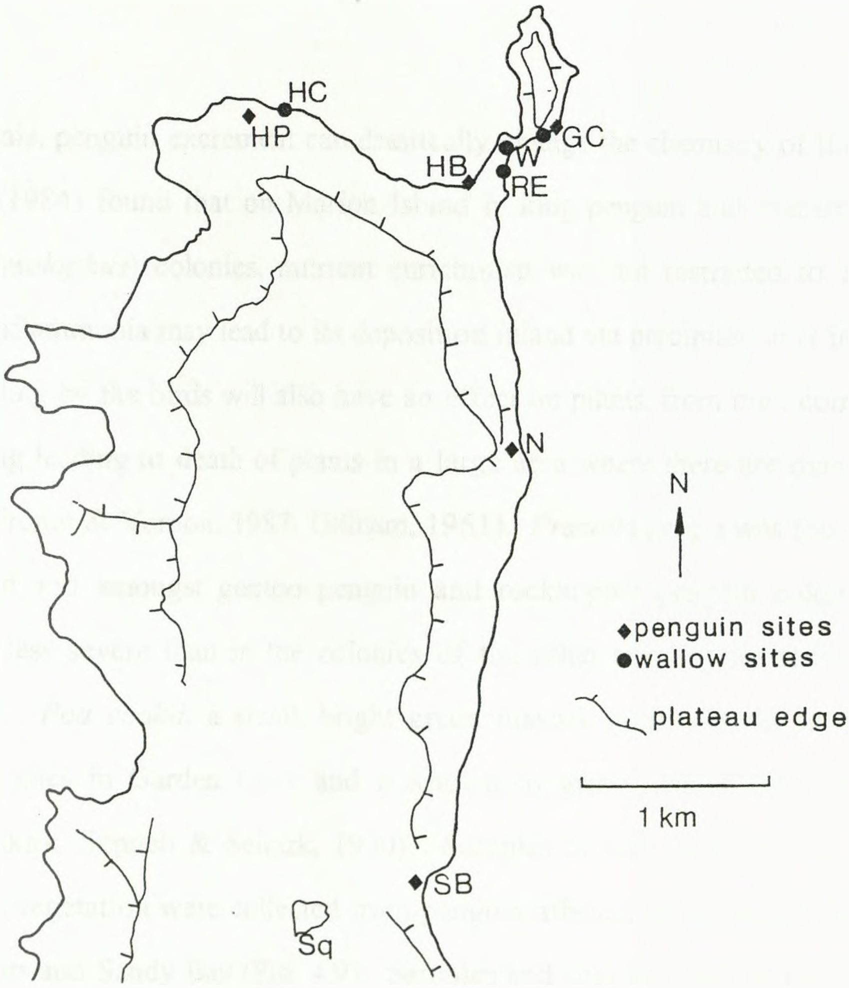


Figure 4.9. Map of Macquarie Island showing the locations of the elephant seal wallow and penguin sampling sites. GC = Garden Cove; HB = Hasselborough Bay; Hs = Hasselborough Beach; HC = Handspike Corner; HP = Handspike Pool; N = The Nuggets; RE = Razorback East; SB = Sandy Bay; Sq = Square Lake; W = wallow sites one to five.

4.3.6 Penguins

Four species of penguin breed on Macquarie Island - gentoo penguins (*Pygoscelis papua papua*; fig. 4.10), king penguins (*Aptenodytes patagonicus*; fig. 4.11), rockhopper penguins (*Eudpytes chrysocome*; fig. 4.12) and royal penguins (*Eudyptes schlegeli*; fig. 4.13). King penguins and royal penguins nest in medium to large sized colonies. King penguin colonies are located on beaches near sea level and royal penguin colonies on beaches or in valleys up to 100 m a.s.l. Rockhopper penguin colonies are situated in very rocky areas on the coastal fringe. Gentoo penguins nest in areas of *Poa foliosa* tussocks, generally in open, relatively flat areas.

As with the seals, penguin excrement can drastically change the chemistry of the local soil. Lindenbloom (1984) found that on Marion Island in king penguin and macaroni penguin (*Eudyptes chrysolophus*) colonies, nutrient enrichment was not restricted to the colony. Volatilization of ammonia may lead to its deposition inland via precipitation (Lindenbloom, 1984). Trampling by the birds will also have an effect on plants, from mild compaction to severe trampling leading to death of plants in a large area where there are many penguins present (Joly, Frenot & Vernon, 1987; Gillham, 1961). *Prasiola crispa* was found growing in areas around and amongst gentoo penguin and rockhopper penguin colonies, where trampling was less severe than in the colonies of the other two species (Broady, 1989; Gillham, 1961). *Poa cookii*, a small, bright green tussock grass was found around the rockhopper colonies in Garden Cove and is known to grow well in areas of nutrient-enrichment (Selkirk, Seppelt & Selkirk, 1990). Samples of soil, algae (*Prasiola crispa),* and angiosperm vegetation were collected from penguin affected areas around the ANARE base, the Nuggets and Sandy Bay (Fig. 4.9). Samples and sites are listed in table 4.6. One sample was collected from a bird affected area (giant petrels, *Macronectes sp.* and black ducks, *Anas superciliosa superciliosa*) around Handspike Pool and has been included as a 'penguin' affected site.

Table 4.6 Penguin affected sites and samples collected.

Location and Description	Sample	Location and Description	Sample
Sandy Bay		*The Nuggets* royal penguins	
Site 1, royal penguins	algae	Site 1, beach	*Prasiola* sp.
Site 2, king penguins	algae	Site 2, upper colony -	*Poa annua*
Hasselborough Beach		*Garden Cove* - Rockhoppers	
King penguins	algae	Site 1	soil
		Site 2	algae
Handspike Pool edge		site 3	soil
birds	*Poa annua*	site 4	algae

Figure 4.10. Gentoo penguins nesting amongst *Poa foliosa* tussocks on the Isthmus.

Figure 4.11. King penguin colony south of Lusitania Bay. Last season's chicks still have brown, downy plumage.

Figure 4.12. Rockhopper penguin in the colony at Garden Cove.

Figure 4.13. Royal penguins on Nuggets Beach.

4.4 Results

Prior to analysis ANOSIMs were run on the data to determine if the sample types contained unique diatom assemblages. The creek and the remainder of the terrestrial samples were analysed separately because of the size limits of the ANOSIM programme (maximum of 125 samples). The terrestrial samples - soil, lichen, feldmark moss and *Azorella,* wallow and penguin - all showed significant differences at $p < 0.05$ (table 4.7). Because the feldmark bryophytes and *Azorella,* and the samples from wallow and penguin areas were only just significantly different (p = .045 in both comparisons), these two data sets were analysed together.

Table 4.7. Pairwise comparisons of the terrestrial sample types excluding creek samples. * represents $p <$ 0.01; + represents p = 0.045

Lichen	*				
Feldmark Moss	*	*			
Azorella	*	*	+		
Wallow	*	*	*	*	
Penguin	*	*	*	*	+
	Soil	Lichen	Feldmark Moss	*Azorella*	Wallow

4.4.1 Creek sites

Two types of samples were collected from the creek sites: algae and macrophytes (bryophytes and angiosperms). Samples of green filamentous algae were collected from rocks within the creek bed where they had been exposed to the strongest currents. Bryophytes and angiosperm samples were collected from adjacent to the creek, either from within the splash zone of a waterfall, or from the creek bank above the water level.

An ANOSIM of the creek algae and macrophyte samples as separate levels showed that the two habitats were significantly different (p = .002). Because of large number of samples,

Table 4.8. List of the most common and/or abundant species from creek samples. Their mean, standard deviation (SD), number of samples abundant in (*n*) and range (R) are given. All values except *n* are given as percentages. All data from all sites are presented in Appendix 3.

Species	Algae samples				Bryophyte samples			
	n	mean	SD	range	n	mean	SD	range
Achnanthes abundans					1	9	0	9
Achnanthes confusa	21	5.3	5.1	1-21	18	11.9	10.8	2-36
Achnanthes confusa var. *atomoides*	19	4.3	3.7	1-13	4	3.8	2.7	1-8
Achnanthes pseudolanceolata	8	2.6	2.0	1-7	17	3.5	4.3	1-19
Achnanthidium lanceolatum	5	1.2	0.4	1-2	1	4.3	5.0	1-18
Achnanthidium microcephalum	4	1.5	0.5	1-2	6	4.2	2.7	1-9
Amphora coffeaeformis	5	6.0	5.6	2-17	4	10.5	12.0	1-31
Caloneis silicula	12	4.3	3.9	1-14	15	7.1	5.0	1-20
Cymbella kerguelenensis	2	6.0	2.0	4-8	5	9.8	4.9	2-14
Cymbella microcephala	5	2.0	1.5	1-5	7	6.1	3.3	1-12
Diatomella hustedtii	13	9.1	12.3	1-43	20	18.3	22.3	1-71
Fragilariforma virescens					4	45.5	42.3	2-95
Navicula corrugata	12	4.3	4.2	1-14	10	5.2	3.6	1-12
Nitzschia palea	16	5.6	5.0	1-20	16	8.7	18.6	1-80
Pinnularia acoricola					2	16.0	14.0	2-30
Stauriosira construens var. *venter*					2	11.0	9.0	2-20
Rhopalodia gibberula	4	4.5	3.8	1-11	9	11.3	7.4	2-22
Synedra rumpens	27	74.9	14.6	22-91	23	28.9	30.2	1-93

the two groups have been analysed separately. The majority of algae samples had *Synedra rumpens* dominant (more than 60% of the total abundance) and the macrophyte samples had other species abundant.

Percentage abundance graphs for all creek samples are presented in Appendix 3. The most common and/or abundant species and their abundances, ranges and the number of samples they occur in are summarised in table 4.8.

Algae samples

The 28 samples of algae from the creek sites were divided by the TWINSPAN into four groups at the second division, with an eigenvalue of E = .337. Samples placed in each group are listed in table 4.9. The majority of samples were dominated by *Synedra rumpens*, with most of the samples from the same sites grouped together. Group 1 contained four samples for which the indicator species were *Achnanthes austriaca, A. abundans* and *Fragilariforma virescens.* Common or abundant species included *Achnanthes confusa, Diatomella hustedtii, Nitzschia palea* and *S. rumpens.* Group 2 contained 10 samples, with the indicator species *Gomponema affine. Achnanthidium lanceolatum, Diatomella hustedtii, G. affine, Nitzschia palea* and *Synedra rumpens* were the most common or abundant species.

Group 3 contained 11 samples. The indicator species separating Group 3 from Group 4 was *Caloneis silicula* (absent from Group 4). Most abundant species included *Achnanthes confusa* var. *atomoides, Nitzschia palea* and *Synedra rumpens.* Group 4 contained four samples with the most common species including *Achnanthidium lanceolatum, Amphora coffeaeformis, Nitzschia palea* and *Synedra rumpens.*

Table 4.9. TWINSPAN grouping of the algae samples from creek sites. The eigenvalue at the first division was .337.

Group 1	Group 2	Group 3	Group 4
Gadget Gully site 1	Cascade North	Gadget Gully site 1	First Gully
algae 1	algae 1	algae 3	algae 1
Gadget Gully site 2	algae 2	Gadget Gully site 2	algae 2
algae 1	Finch Creek	algae 3	algae 3
algae 2	algae 1	Gadget Gully site 3	Waterfall S' Finch Crk
Halfway Hill algae 2	algae 2	algae 1	algae 1
	algae 3	algae 2	
	Gadget Gully site 1	algae 3	
	algae 2	algae 4	
	Gadget Gully site 2	Halfway Hill	
	algae 4	algae 4	
	Halfway Hill	Tractor Rock	
	algae 1	algae 1	
	algae 3	algae 2	
	Waterfall S' Finch Crk	algae 3	
	algae 2		

The sample groupings from the analysis are based on the presence/absence of minor species, or the presence/absence of species usually common, such as *Caloneis silicula*. The grouping together of samples from different sites shows that there is some similarity in the diatom associations in samples of algae from different sites.

The HMDS of creek algae samples in two dimensions also showed this (fig. 4.14). Although there were no distinct grouping of samples, the TWINSPAN groups were separated on the configuration, despite the relatively high minimum stress (.202). This indicated a similar grouping of the samples by both analyses. Samples which had species other than *Synedra rumpens* dominant were placed at the right of the configuration (such as the Finch Creek samples); those samples with *S. rumpens* dominant and with few other species present were placed at the left. Despite *S. rumpens* being present in the majority of samples, its dominance (or not) is clear from both analyses.

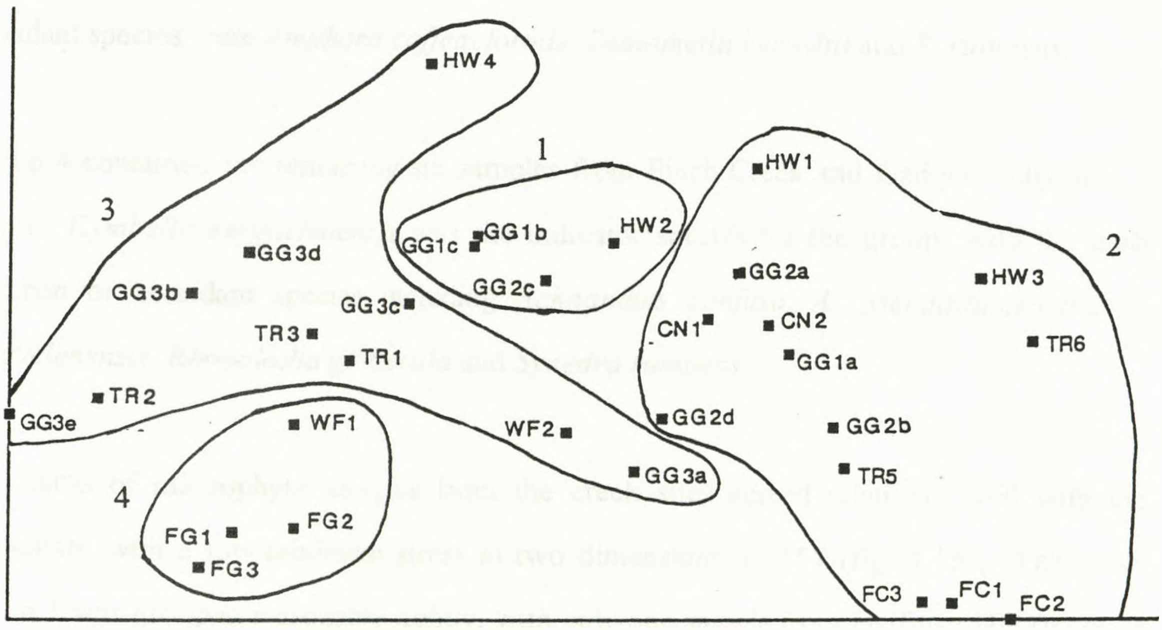


Figure 4.14. HMDS of algae samples from creek sites in two dimensions. Minimum stress is .202. TWINSPAN groupings of samples are indicated, with the numbers refering to the TWINSPAN groups. The samples are arranged with those dominated by *Synedra rumpens* placed at the left of the configuration and those with other species abundant at the right.

Macrophyte samples

The TWINSPAN of samples of bryophytes and angiosperms from creek sites divided the 24 samples into four groups at the second level, with an eigenvalue of E = .211 (table 4.10). Group 1 contained the majority of samples, with 11 samples from Bauer Falls, Duck Lagoon, Gadgets Gully site 1, Halfway Hill, Lusitania Creek, Sawyer Creek and Tractor Rock. Indicator species were *Achnanthes engelbrechtii, A. delicatula* var. *hauckiana* and *Rhopalodia gibberula.* Most common or abundant species included *Achnanthes confusa, Diatomella hustedtii, Pinnularia acoricola* and *Synedra rumpens.*

Group 2 contained four samples from Halfway Hill and Tractor Rock. The indicator species was *Caloneis silicula.* The most abundant species included *Achnanthes confusa, Nitzschia palea* and *Synedra rumpens.* Group 3 contained three samples from First Gully and Halfway Hill. The indicator species for this group was *Brachysira exilis.* The most abundant species were *Amphora coffeaeformis, Diatomella hustedtii* and *S. rumpens.*

Group 4 contained the remaining six samples from Finch Creek and Gadget Gully sites 1 and 2. *Cymbella kerguelenensis* was the indicator species for the group, with the most common or abundant species including *Achnanthes confusa, A. pseudolanceolata, C. kerguelenensis, Rhopalodia gibberula* and *Synedra rumpens.*

The HMDS of macrophyte samples from the creek sites agreed relatively well with the TWINSPAN, with a low minimum stress in two dimensions of .157 (fig. 4.15). TWINSPAN Group 1 was grouped reasonably tightly, with only one sample from Halfway Hill (moss 6) placed close to another group (Group 4). Groups 2 and 3 were spread across the configuration, indicating that there was some heterogeneity in the samples placed in each group. Group 4 was placed relatively close to Group 1. This configuration reflects an increase in the number of species in the samples, from few at the left hand side to many at the right hand side.

Table 4.10 TWINSPAN groupings of the macrophyte samples from creek sites. The eigenvalue at the first division was .211.

Group 1	Group 2	Group 3	Group 4
Bauer Falls moss 1	Halfway Hill	First Gully	Finch Creek
Duck Lagoon veg. 1	moss 5	moss 1	moss 1
Gadget Gully site 1	moss 7	moss 2	moss 2
moss 1	moss 8	Halfway Hill moss 7	moss 3
Halfway Hill	Tractor Rock moss 1		liverwort 1
moss 1			Gadget Gully site 1
moss 2			vegetation 1
moss 3			Gadget Gully site 2
moss 4			moss 1
moss 6			
Lusitania Creek veg. 1			
Sawyer Creek			
moss 1			
moss 2			
Tractor Rock veg. 1			

Sample codes for Figure 4.15

First Gully moss 1	FG1
First Gully moss 2	FG2
Finch Creek moss 1	FC1
Finch Creek moss 2	FC2
Finch Creek moss 3	FC3
Finch Creek liverwort 1	FC4
Halfway Hill moss 1	HH1
Halfway Hill moss 2	HH2
Halfway Hill moss 3	HH3
Halfway Hill moss 4	HH4
Halfway Hill moss 5	HH5
Halfway Hill moss 6	HH6
Halfway Hill moss 7	HH7
Halfway Hill moss 8	HH8
Bauer Falls moss 1	BF1
Tractor Rock moss 1	TRm
Tractor Rock veg. 1	TRv
North of Duck Lagoon veg. 1	ND1
Sawyer Creek moss 1	SC1
Gadgets Gully site 1 moss 1	GG1m
Gadgets Gully site 1 veg. 1	GG1v
Gadgets Gully site 2 moss 1	GG2m
Lusitania Creek veg. 1	LCv

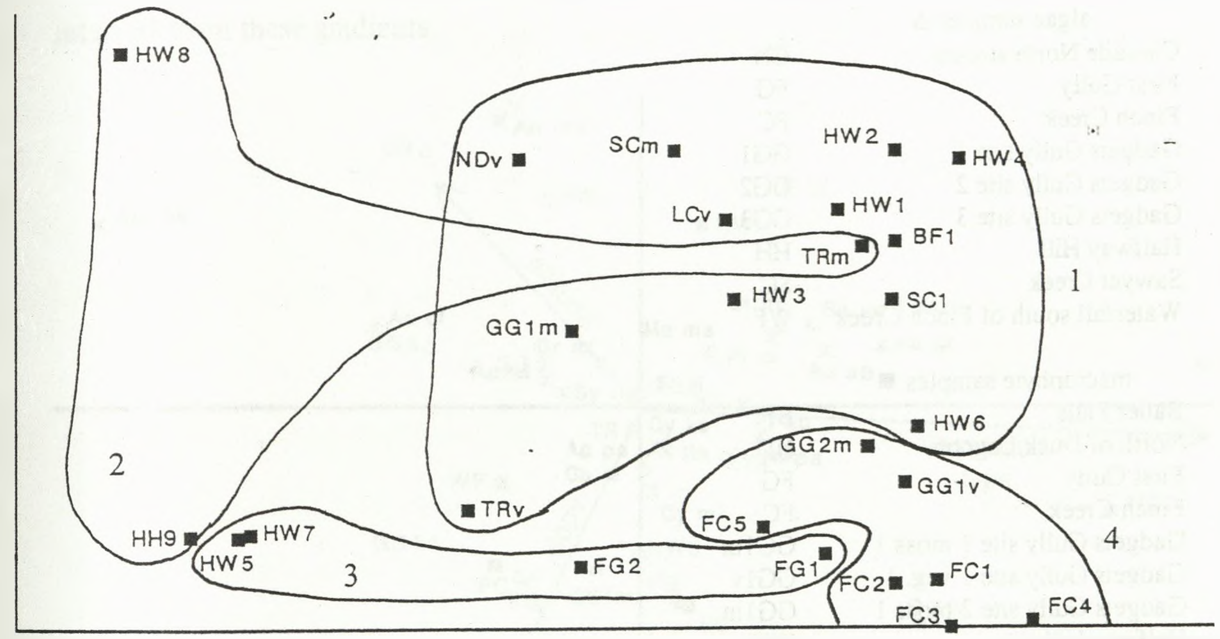


Figure 4.15. HMDS of macrophyte samples from creek sites in two dimensions. Minimum stress is .157. The samples with few species are placed at the left hand side of the configuration and those with many common or abundant species present are placed at the right. Sample and codes are listed opposite.

Environmental gradients in creek samples

The data from both creek sample types were combined and a single analysis using CCA was run with three environmental variables: sample type (macrophyte/algae), slope and altitude. The eigenvalues for axes 1 and 2 were .453 and .172 respecively. Species/environment correlations were .832 for the first axis and .633 for the second. The goodness of fit for the first two axes (percentage variation explained) was high, at 83%. The majority of samples from the same sites were grouped together, with algae samples placed on the left hand side of axis 2 and macrophyte samples placed at the right. The biplots (fig. 4.16) show the relationship of the samples, major species and the environmental variables.

Sample codes for Figure 4.16

algae samples △

Cascade North stream	CN
First Gully	FG
Finch Creek	FC
Gadgets Gully site 1	GG1
Gadgets Gully site 2	GG2
Gadgets Gully site 3	GG3
Halfway Hill	HH
Sawyer Creek	SC
Waterfall south of Finch Creek	WF

macrophyte samples ■

Bauer Falls	BF
North of Duck Lagoon	ND
First Gully	FG
Finch Creek	FC
Gadgets Gully site 1 moss 1	GG1m
Gadgets Gully site 1 veg. 1	GG1v
Gadgets Gully site 2 moss 1	GG1m
Halfway Hill	HW
Tractor Rock moss 1	TRm
Tractor Rock veg. 1	TRv
Sawyer Creek	SC

Species codes for Figure 4.16 overlay

Achnanthes abundans	Ac ab
Achnanthes confusa	Ac cf
Achnanthes confusa var. *atomoides*	Ac at
Achnanthes pseudolanceolata	Ac ps
Achnanthidium microcephalum	Ah mc
Amphora coffeaeformis	Am ca
Aulacoseira granulata	Au gr
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Cymbella kerguelenensis	Cy ke
Cymbella microcephala	Cy mi
Diatomella hustedtii	Di hu
Fragilariforma virescens	Fr vi
Martyana martyi	Ma ma
Navicula corrugata	Na cg
Nitzschia palea	Ni pa
Pinnularia acoricola	Pi ac
Pinnularia circumducta	Pi ci
Rhopalodia gibberula	Rh gi
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru

The three environmental gradients included in the analysis were measured or assessed in the field. Other gradients which may be important, such as size, depth and current can be inferred from these gradients.

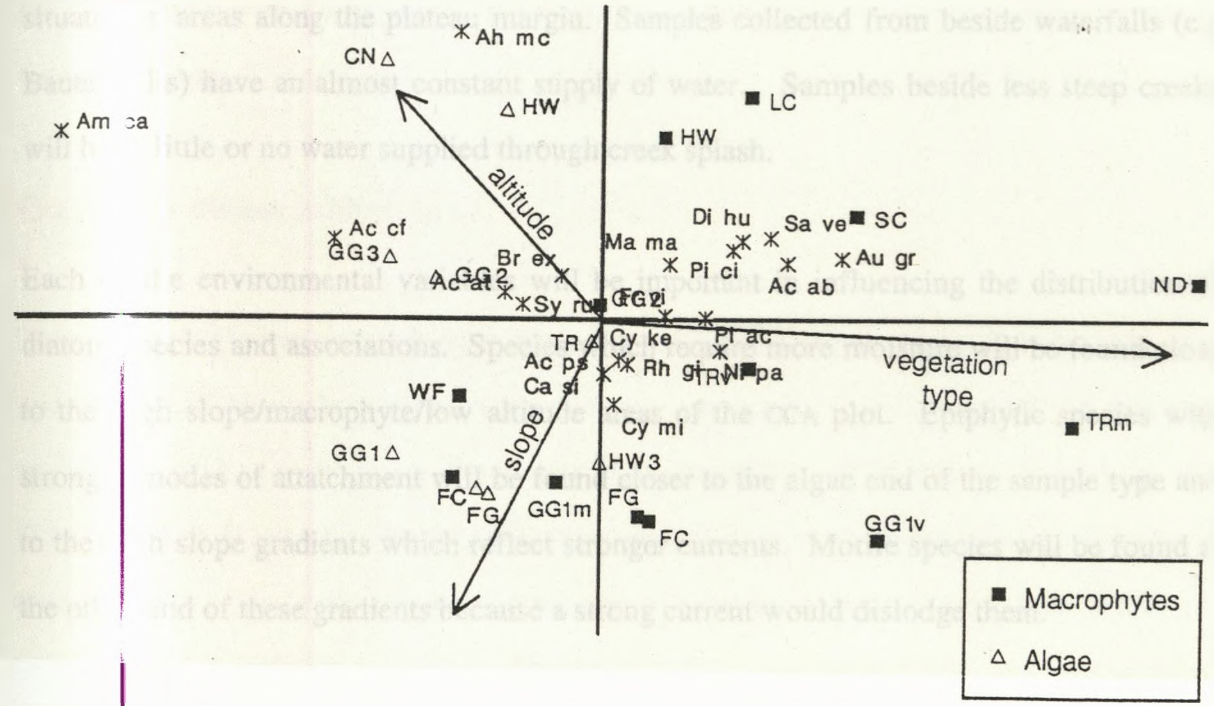


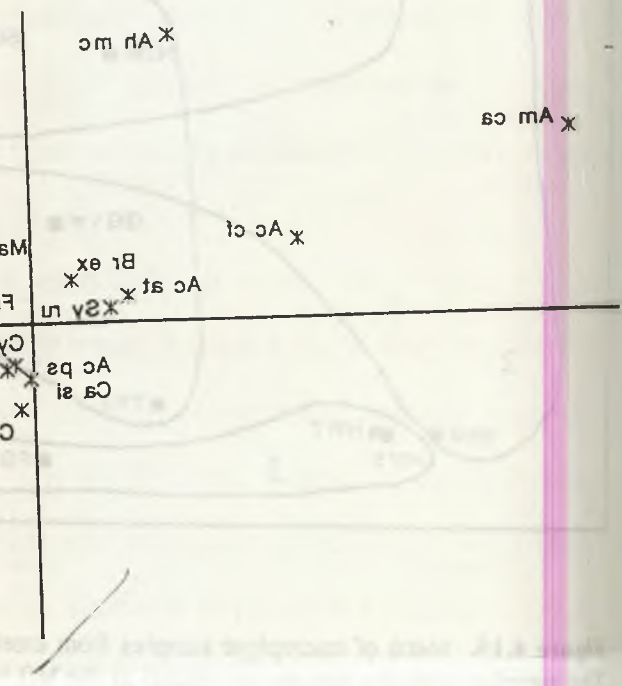
Figure 4.16. Biplot of the CCA of samples and environmental variables from creek sites. Axis 1 has an eigenvalue of .453, axis 2 has an eigenvalue of .172. The goodness of fit for the first two axes is 83%. The overlay shows the major species from creek sites, scaled to be comparable to the sample/environment biplot. Algae samples are at the left of the configuration and macrophyte samples are at the right. Sample and species codes are listed opposite.

Altitude: The size (depth and volume) of each creek can be inferred from altitude. Creeks at high altitudes were generally smaller and shallower because of the smaller catchment. They have a high potential for variation in flow. Altitude will also reflect current, with smaller or shallower creeks from high altitudes often having a lower current. The high altitude creeks were Cascade North, Lusitania and Halfway Hill.

Sample type: Algae samples were collected from rocks within the creek bed itself and macrophytes were collected from beside creeks. The current and moisture regimes of each sample will vary greatly, depending on the exact location within or around the creek. Strong currents will be found within a creek and there will be no current beside a creek.

Sample codes for Figure 4.16

algae samples △	
Cascade North stream	CN
First Gully	FG
Finch Creek	FC
Gadgets Gully site 1	GG1
Gadgets Gully site 2	GG2
Gadgets Gully site 3	GG3
Halfway Hill	HH
Sawyer Creek	SC
Waterfall south of Finch Creek	WF
macrophyte samples ■	
Bauer Falls	BF
~~North of Duck Lagoon~~	ND
First Gully	FG
Finch Creek	FC
Gadgets Gully site 1 moss 1	GG1m
Gadgets Gully site 1 veg. 1	GG1v
Gadgets Gully site 2 moss 1	GG1m
Halfway Hill	HW
Tractor Rock moss 1	TRm
Tractor Rock veg. 1	TRv
Sawyer Creek	SC



Species codes for Figure 4.16 overlay

Achnanthes abundans	Ac ab
Achnanthes confusa	Ac cf
Achnanthes confusa var. *atomoides*	Ac at
Achnanthes pseudolanceolata	Ac ps
Achnanthidium microcephalum	Ah mc
Amphora coffeaeformis	Am ca
Aulacoseira granulata	Au gr
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Cymbella kerguelenensis	Cy ke
Cymbella microcephala	Cy mi
Diatomella hustedtii	Di hu
Fragilariforma virescens	Fr vi
Martyana martyi	Ma ma
Navicula corrugata	Na cg
Nitzschia palea	Ni pa
Pinnularia acoricola	Pi ac
Pinnularia circumducta	Pi ci
Rhopalodia gibberula	Rh gi
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru

The three environmental gradients included in the analysis were measured or assessed in the field. Other gradients which may be important, such as size, depth and current can be inferred from these gradients.

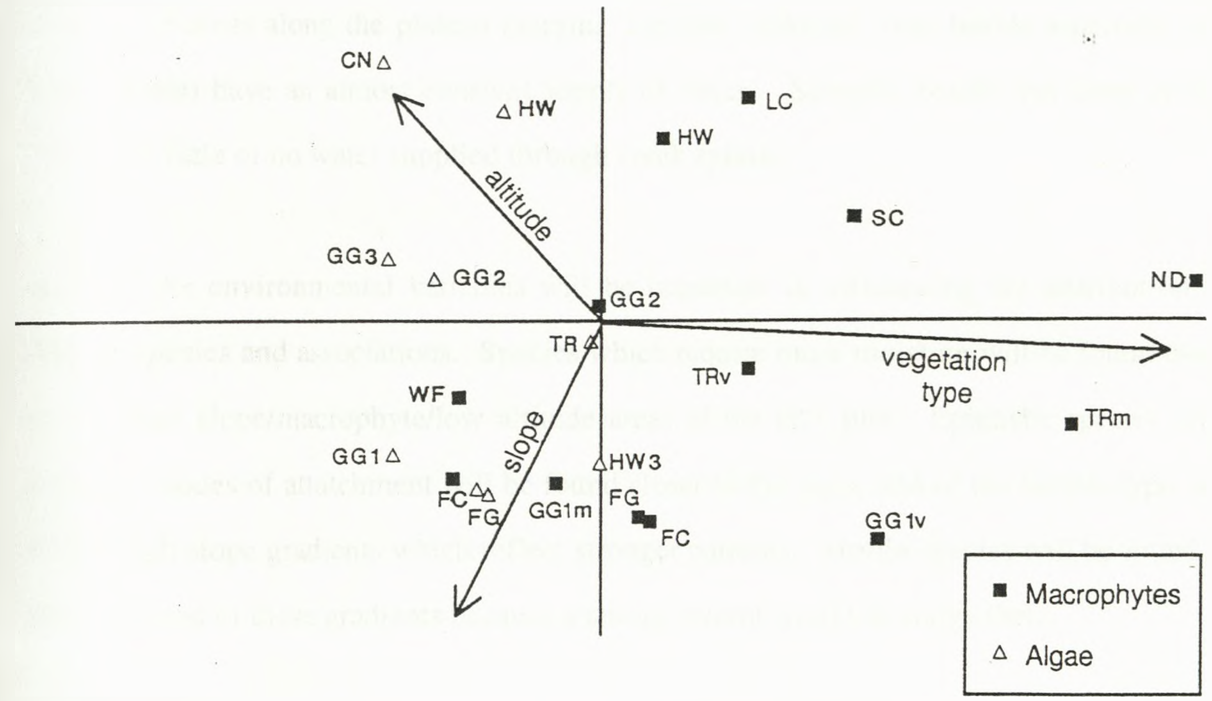


Figure 4.16. Biplot of the CCA of samples and environmental variables from creek sites. Axis 1 has an eigenvalue of .453, axis 2 has an eigenvalue of .172. The goodness of fit for the first two axes is 83%. The overlay shows the major species from creek sites, scaled to be comparable to the sample/environment biplot. Algae samples are at the left of the configuration and macrophyte samples are at the right. Sample and species codes are listed opposite.

Altitude: The size (depth and volume) of each creek can be inferred from altitude. Creeks at high altitudes were generally smaller and shallower because of the smaller catchment. They have a high potential for variation in flow. Altitude will also reflect current, with smaller or shallower creeks from high altitudes often having a lower current. The high altitude creeks were Cascade North, Lusitania and Halfway Hill.

Sample type: Algae samples were collected from rocks within the creek bed itself and macrophytes were collected from beside creeks. The current and moisture regimes of each sample will vary greatly, depending on the exact location within or around the creek. Strong currents will be found within a creek and there will be no current beside a creek.

Changes in the flow will affect moisture as with less water the algae may be exposed and filamentous algae will dry out faster than the macrophytes.

Slope: Steeper creeks will have stronger currents generally. The steepest creek beds were situated in areas along the plateau margin. Samples collected from beside waterfalls (e.g Bauer Falls) have an almost constant supply of water. Samples beside less steep creeks will have little or no water supplied through creek splash.

Each of the environmental variables will be important in influencing the distribution of diatom species and associations. Species which require more moisture will be found close to the high slope/macrophyte/low altitude areas of the CCA plot. Epiphytic species with stronger modes of attatchment will be found closer to the algae end of the sample type and to the high slope gradients which reflect stronger currents. Motile species will be found at the other end of these gradients because a strong current would dislodge them.

The CCA of sites supports the major division of algae and macrophyte samples along the sample type gradient, which was strongly associated with axis 1 (table 4.11). Macrophyte samples were placed at the right of the gradient and algae samples at the left. The major separation of samples agrees with the ANOSIM which showed the groups contained significantly different diatom associations. The majority of samples from high altitudes were placed towards the top of axis 2 and samples from the steep creek sites were placed towards the base of axis 2.

Table 4.11. Interset correlation coefficients of environmental variables and the first two CCA axes from creek samples.

	Axis 1	**Axis 2**
Veg type	.748	- .02
Slope	- .254	- .60
Altitude	- .263	- .50

The common or abundant species were generally clustered around the centroid of the plot (fig 4.16). This indicates that the species important in creeks all have relatively similar environmental tolerances. Species placed towards the left of axis 1 were more common or abundant in the algae samples, while those at the right were found more commonly in the macrophyte samples. This may be related more to the strength of the current in the samples, reflected by the sample type gradient. The position of *Synedra rumpens* close to the centre of the plot, adjacent to the large group of species, occurred because it was so common (in 48 of 52 samples).

Creeks as a diatom habitat

Two distinct groups were obvious from the analyses. Algae (with *Synedra rumpens* dominant) and macrophyte samples were clearly separated by both the ANOSIM and CCA analyses. Within each group there was little separation of the samples by both the TWINSPAN and the HMDS. TWINSPAN groups were distinguished on the presence/absence of minor species. The HMDS showed a gradation of samples from one association of diatoms to another, rather than a separation. On the CCA there was little grouping of the species. This indicates that there were similarities in the samples of algae and macrophytes.

Of the environmental gradients examined, sample type was the most important, separating out the algae and macrophyte samples. This gradient in turn reflected both current strength and moisture availability. Within these sample groups there was a gradation of sites rather than distinct grouping, from wet sites with no current (e.g. moss samples from waterfall splash zones) through moderate to strong current, where desiccation may occur from time to time. This was most obvious in the variation in the abundance of *Synedra rumpens*.

Synedra rumpens was the most abundant and widespread of the diatoms identified from the creek samples. It was abundant or co-dominant in the majority of samples, and was present in all but four. It attained maximum abundance in samples of filamentous algae that were exposed for at least some of the time to rapid currents in the creek beds. The exceptions to this were the macrophyte samples from Halfway Hill (moss samples 5, 7 and 8) where *S. rumpens* was between 65% and 90% of the total abundance.

The location of the sample points within each site appears to have some effect on the abundance of *Synedra rumpens.* Sites with samples with both *S. rumpens* dominant and *S. rumpens* not dominant samples were found, such as Halfway Hill, Gadgets Gully and Tractor Rock. More algae than moss samples had *S. rumpens* most abundant, but this was not exclusively so. The algae samples were generally situated within the flow of the stream, attached to either rocks or macrophytes. Moss samples were more often collected from areas of low flow beside the stream, or in waterfall splash zones.

Replicate samples in each site will not have identical conditions. While the water chemistry will be relatively constant at one site, microhabitats will change from sample to sample. Degree of exposure to current, available moisture at times of low flow, substrate type (loose rock, bedrock, macrophyte) and slope of the stream bed are some factors that may vary greatly within a small area. This variation will affect diatoms by affecting the local conditions and is the reason that not all the samples from the same sites were grouped together by the analyses.

The algae samples may also be more prone to desiccation than moss samples. Despite growing within running creeks, there will be periods when the flow is greatly reduced and so the algae may be exposed to the air occasionally. Filamentous algae will retain less moisture than leafy bryophytes or angiosperms, thus creating a periodically drier environment for diatoms. It is probable that algae in streams experience greater extremes of environment than algae and mosses growing in splash zones adjacent to creeks.

Synedra rumpens is a species which, on Macquarie Island, appears to tolerate a great range of conditions. It is found in almost all habitats in abundances that vary from low (less than 5%) to more than 90% of the total (see remainder of this chapter). In creeks it was most abundant in sampels of algae which appear to experience greater environmental extremes. This indicates it is able to survive rapid, drastic changes and thus would explain its dominance in so many of the creek algae samples. Other species (e.g. *Diatomella hustedtii,* *Fragilariforma virescens*) which are less able to tolerate these changes would not grow in these areas and so *S. rumpens* would be unhindered by interspecific competition.

Other species which were common or moderately abundant in the samples dominated by *Synedra rumpens* were also abundant in samples not dominated by *S. rumpens*. These included *Diatomella hustedtii*, *Achnanthes confusa*, *A. confusa* var. *atomoides* and *Nitzschia palea*. Other species abundant or common in the samples not dominated by *S. rumpens* (and present in those that were) included *Achnanthes abundans*, *Achnanthidium microcephalum*, *Amphora coffeaeformis* and *Caloneis silicula*. These species were found growing as epiphytes on bryophytes and algae in areas that were less affected by current, and possibly less prone to changes in moisture level. The placement of all these species in the central area of the CCA indicates that they are reasonable tolerant of changes in the environment.

The Finch Creek samples were the least likely to have extremes of water availability. The site was a mossy bank supplied with moisture by seepage through the modern peat above it. Abundant species from here included *Cymbella kerguelenensis*, *C. microcephala* and *Rhopalodia gibberula*, which are apparently less tolerant of environmental variations. The other sites not dominated by *S. rumpens* were all from areas where water would be readily available for most of the time.

In creek samples from Macquarie Island, current appears to be the factor most strongly influencing diatom associations. This is inferred from the importance of sample type in separating samples. *Synedra rumpens* dominated samples from fast-flowing streams which may experience dry conditions occasionally. It became co-dominant with other species such as *Diatomella hustedtii* and *Achnanthes confusa*, where the current was not as strong and water availability may have been more constant. In samples where there was no appreciable current (e.g. Finch Creek moss wall) other factors, such as water availability, would be affecting the diatom associations.

Many of the common species in this latter group of samples are thought to be either aerophilic, or able to withstand periods of desiccation, which may indicate that these sites occasionally undergo periods of low or no water supply (table 4.12). This is generally consistent with findings from this study. Stream level was observed to rise or fall, depending on the volume and timing of precipitation in the previous days or weeks, and all sites may have experienced changes in water availability over time.

Stream banks and beds are aquatic to semi-aquatic environments which may undergo periods of increased or decreased current, changes in water availability and the other environmental factors associated with these. The common diatoms in this environment were *Synedra rumpens, Diatomella hustedtii, Achnanthes confusa*, and *A. confusa* var. *atomoides*. While all are capable of surviving and even flourishing in other environments, only *S. rumpens* appears to be able to flourish despite the extremes of environment within the creeks.

There is a gradation in the environmental extremes which is reflected by the percentage abundance of *Synedra rumpens,* compared to other species such as *Diatomella hustedtii* and *Achnanthes confusa.* The stronger the current, the greater the amount of *S. rumpens.* The weaker the current, the lower the amount of *Synedra rumpens* and the greater the abundance of other species.

Reports in the literature of diatom species common from creeks

Appendix 2 lists the both the common and rarer species from Macquarie Island, with information on their environmental preferences which has been obtained from the masses of literature on diatom habitats. *Synedra rumpens* is described in the literature as littoral or epiphytic (Gasse, 1986) and as planktonic (Dixit, Dixit & Evans, 1988). Patrick and Reimer (1966) describe it as being widespread in circumneutral water and in slow flowing creeks. It had also been reported from hot springs (55°C - 60°C) in the Himalayas (Suxena

Venkateswarlu, 1970). Javorski and Lund (1970) found that some planktonic diatom species (including *Synedra* spp.) could survive in wet mud for days at a time. Assuming all identifications of '*Synedra rumpens*' are correct, this would suggest *S. rumpens* is an opportunist, that is indifferent to many environmental conditions, growing in areas where other species may not be able to survive.

Table 4.12. Interpreted environmental preferences for the most common species from creek samples from Macquarie Island.

Species Common in Creeks	Environmental Preferences
Synedra rumpens	Tolerates a range of conditions. Wet/dry, weak - strong current.
Achnanthes abundans *Achnanthes confusa* *Achnanthes confusa* var. *atomoides* *Achnanthes pseudolanceolata* *Achnanthidium lanceolatum* *Achnanthidium microcephaunia* *Amphora coffeaeformis* *Brachysira exilis* *Caloneis silicula* *Diatomella hustedtii* *Fragilariforma virescens* *Martyana martyi* *Navicula corrugata* *Nitzschia palea* *Pinnularia acoricola* *Pinnularia circumducta* *Stauriosirella construens* var *venter*	Aerophillic species, or tolerant of desiccation. Epiphytic on bryophytes and algae. Tolerant of a weak current only.
Cymbella kerguelenensis *Cymbella microcephala* *Rhopalodia gibberula*	Occur in wetter environments. Not tolerant of desiccation or current. Epiphytic.

Of the other common species, *Achnanthes confusa* and *Achnanthes confusa* var. *atomoides* have been described as aerophillic, often associated with filamentous algae (Le Cohu & Maillard, 1983). *Achnanthidium lanceolatum* is said to occur in most habitat types - soil, littoral, crenulated surfaces, as an epiphyte and in streams with a moderate current (Bjork *et al.*, 1991, Gasse, 1986; Haworth, 1976). *Nitzschia palea* is similarly described in the literature as occurring in a variety of habitats, and is known to be able to survive drought (Gasse, 1986; Haworth, 1976; Schoeman, 1973; Evans, 1959;1958). *Navicula* *pseudolanceolata* prefers running water (Germain, 1981) and *Diatomella hustedtii* is described as prefering cold, fast water (Larson, 1974). The reported 'preferred' habitat for the last two species is consistent with the samples being collected from stream beds and waterfalls where the current was moderate to strong.

Achnanthes abundans is found with *A. confusa*, both often associated with filamentous algae (Le Cohu & Maillard, 1983), *Achnanthidium microcephalum* is commonly regarded as a littoral epiphyte and has been described as a crenophile (Gasse, 1986; Patrick & Reimer, 1966). *Caloneis silicula* is described by Haworth (1976) as littoral/benthic and *Amphora coffeaeformis* has been reported from a variety of habitats, including soil, rocks and littoral (Gasse & Tekaia, 1983; Schoeman, 1973; Patrick & Reimer, 1966). *Cymbella kerguelenensis* is an epiphyte and has been described as preferring alkaline, stagnant water, while *C. microcephala* is said to occur on rocks in oligotrophic water (Haworth, 1976; Schoeman, 1973; 1970). *Rhopalodia gibberula* has been described as an alkaphile and an ephiphyte (Gasse, 1986; Gasse & Tekaia, 1983; Schoeman; 1973).

4.4.2 Feldmark Sites

Five replicate samples of bryophytes and *Azorella macquariensis* were collected at each site and prepared following the protocol described in Chapter 2. The 48 feldmark samples from moss polsters and *Azorella macquariensis* were analysed together. The samples had an average of 13 species per sample (SD = 2.6), with a maximum of 19 species and a minimum of seven species with an abundance of 2% or greater. Percentage abundance diagrams are presented in Appendix 3. The most common or abundant species, their abundances, ranges and number of samples they occurred in are summarised in table 4.13.

The samples were divided by the TWINSPAN into four groups at level two, with an eigenvalue of E = .123 at the first division. Samples placed in each group are listed in table 4.14. Group 1 contained six bryophyte and two *Azorella macquariensis* samples, with the most abundant species including *Aulacoseira granulata, Eunotia exigua, Pinnularia circumducta* and *Synedra rumpens.* Most abundant species in the 14 group 2 samples were *Achnanthes confusa, A. manguinii* and *Synedra rumpens,* with *Achnanthes manguinii* var. *elliptica* and *Diatomella hustedtii* moderately abundant. Group 3 contained 15 samples, with the most abundant species varying from sample to sample. They included *Achnanthes manguinii, Aulacoseira granulata, Pinnularia acoricola, P. circumducta, P. lata* and *Synedra rumpens.* Group 4 contained nine samples. Common species included *Achnanthes bioreti, A. confusa, Aulacoseira granulata, Cymbella microcephala, Eunotia exigua, Pinnularia acoricola, P. circumducta* and *P. lata.*

Table 4.14. TWINSPAN grouping of feldmark samples. The eigenvalue at the first division was .123.

Group 1	**Group 2**	**Group 3**	**Group 4**
Biggles By-Pass moss 1	Biggles By-Pass moss 2	Ainsworth Lk moss 1	Ainsworth Lk moss 2
Brothers Lk moss	Halfway Hill moss 1	Biggles By-Pass	North Scoble Lk moss 1
Brothers Trk moss	Heartbreak Hill	*Azorella*	Prion Lk site 1 moss 1
Gadget Dam *Azorella* 1	moss 1	Boot Hill	Ski Hut
Heartbreak Hill	moss 2	moss 1	moss 1
Azorella 2	North Mountain	*Azorella*	moss 2
Little Prion Lk moss 1	moss 1	Gadget Dam *Azorella* 2	*Azorella* 1
Prion Lk site 2 moss 1	moss 2	Halfway Hill moss 2	*Azorella* 2
Prion Lk site 2 moss2	moss 3	Heartbreak Hill	Tullock Lk
	Azorella	*Azorella* 1	moss 1
	Pyramid Lk moss 1	Little Prion Lk	*Azorella*
	S Pond *Azorella*	moss 2	
	Tulloch Lk moss 2	*Azorella*	
	West Scoble Lk	North Mountain	
	moss 1	*Azorella* 2	
	moss 2	*Azorella* 3	
	moss 3	North Scoble Lk moss 2	
		Pyramid Lk moss 2	
		Sandy/Bauer Xroads	
		Azorella	
		West Scoble Lk moss 4	

The TWINSPAN of species from the feldmark samples divided the 10 most common species into two groups at the first division, with an eigenvalue of E = .428. Three aerophillic species - *Achnanthes manguini, A. manguini* var. *elliptica* and *Pinnularia circumducta* - were placed into one group and *Achnanthes confusa, Aulocosira granulata, Cymbella microcephala, Eunotia exigua, Pinnularia acoricola, P. circumducta* and *Synedra rumpens* were placed into the second group.

The TWINSPAN appears to have grouped the samples on the presence/absence of uncommon species. There is some separation of the *Azorella* and bryophyte samples, with more *Azorella* samples in groups 3 and 4. However, this was not exclusive, as there are also *Azorella* samples in groups 1 and 2.

The HMDS of feldmark samples in two dimensions also reflected this, with a minimum stress of .188 (fig. 4.17). The TWINSPAN groups were not well separated, although there was some trend visible, with group 1 at the left of the configuration and group 4 at the right. This may be because of the relatively high stress in two dimensions; however it is more likely to be reflecting a continuum in the species present, and their abundances, in each sample.

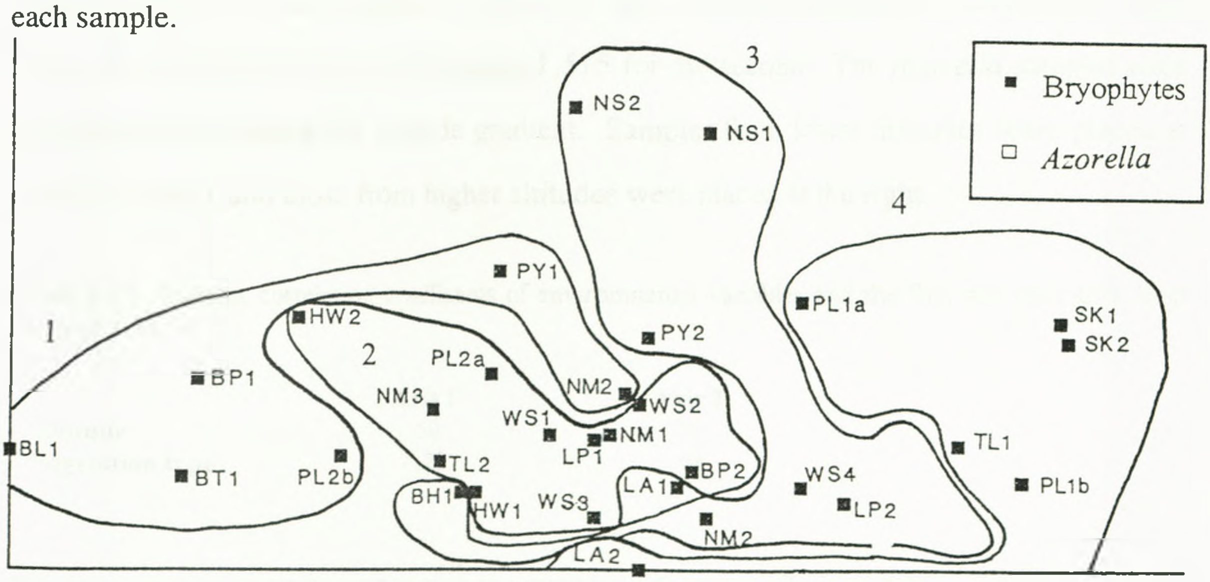


Figure 4.17. HMDS of feldmark samples in two dimensions. Minimum stress is .188. TWINSPAN grouping of samples are indicated, with numbers referring to the TWINSPAN groups. There is a moisture gradient apparent, with samples from drier sites placed at the right to samples from the wetter sites placed at the left of the plot. Sample codes are listed opposite. The *Azorella* samples have been graphed separately to simplify the diagram.

Samples at the right contained generally fewer, less common species such as *Achnanthes bioreti* and *Achnanthes* species B. There was no separation of the *Azorella* samples, although there was a tendancy for them to be placed more towards the right of the configuration. The motile *Pinnularia* species were more abundant (up to 60% of the total abundance) in the samples at the left, with *Synedra rumpens* less common/abundant. There was some overlap between the TWINSPAN groups in the centre of the HMDS configuration, indicating a similarity in the majority of species present in these samples.

Environmental gradients in feldmark samples

The CCA of feldmark samples used only altitude and vegetation type as environmental variables. No other environmental data was recorded at the time of sampling. The eigenvalues of the first two axes of the analysis were low, indicating that the amount of variation descibed by these axes was poor. The two environmental gradients were not strongly correlated with the axes (table 4.15). This suggests that other environmental variables (such as degree of exposure to wind, or substrate) may have a greater affect on the diatom species in this habitat. However, the species/environment correlations were reasonable, with .610 for the first axis and .515 for the second. The *Azorella* samples were grouped together along the altitude gradient. Samples from lower altitudes were placed at the left of axis 1 and those from higher altitudes were placed at the right.

Table 4.15. Interset correlation coefficents of environmental variables and the first two CCA axes from feldmark sites.

	Axis 1	Axis 2
altitude	.50	.29
vegetation type	- .28	.46

The two environmental gradients are possibly reflecting other variables which were not measured in the field. Exposure, temperature extremes, wind and moisture may all be inferred from the two measured variables.

Altitude: All samples were collected from between 100 m and 300 m a.s.l. Variation in the altitude will affect the local conditions. Samples from lower altitudes will generally experience milder conditions, with temperatures dropping with an increase in altitude (1°C drop per 100 m increase). A difference of one or two degrees may mean that samples from higher altitudes will experience more freeze/thaw or frost action, which may affect diatom growth. Wind speeds may also be more severe at higher altitudes, although variations in local topography will affect this greatly. Generally, samples from higher altitudes will be from colder, windier sites. This, in turn, may affect the moisture regime in moss polsters and *Azorella* cushions. Although bryophytes are known to grow into the wind as this is the direction of maximum water supply, drier winds will act to desiccate macrophytes.

Vegetation type: This will also have an effect on the moisture available to diatoms. Bryophytes are more likely to retain moisture than *Azorella* cushions, as bryophytes generally have smaller leaves which are more tightly appressed. As a result, the surfaces of *Azorella* plants may dry out more quickly and more frequently than the bryophytes in the same area.

Species which require moisture would be placed close to the bryophyte end of the vegetation type gradient and at the low end of the altitude gradient. Samples with fewer tolerant species would be placed at the high altitude/*Azorella* ends of the gradients.

The CCA of samples agreed with the HMDS in that there was a spread of samples across both axes with little grouping occurring. There was a tendency for the *Azorella* samples to be placed at the right of the plot, although some samples were at the left of the axis. As with the TWINSPAN and HMDS analyses, there was some intermingling of the bryophyte and *Azorella* samples.

The species biplot has the majority of the common species clustered around the centre (fig. 4.18). Some species, such as *Achnanthes manguinii, Pinnularia lata* and *P. circumducta,* were positioned close to the altitude axis and appeared to be associated with the *Azorella*

Sample Codes for Figure 4.18

Moss samples ■	
Biggles By-Pass moss 1	BP1
Biggles By-Pass moss 2	BP2
Boot Hill moss 1	BH
Brothers Lake moss 1	BL
Brothers Track moss 1	BT
Heartbreak Hill moss 1	HB1
Heartbreak Hill moss 2	HB2
Halfway Hill moss 1	HW1
Halfway Hill moss 2	HW2
Lake Ainsworth moss 1, 2	LA
Little Prion Lake moss 1	LP1
Little Prion Lake moss 2	LP2
North Mountain moss 1	NM1
North Mountain moss 2	NM2
North Mountain moss 3	NM3
North Scoble Lake moss 1	NS1
North Scoble Lake moss 2	NS2
Prion Lake site 1 moss 1, 2	PL1
Prion Lake site 2 moss 1, 2	PL2
Pyramid Lake moss 1, 2	PY
Ski Hut moss 1	SK1
Ski Hut moss 2	SK2
Tulloch Lake moss 1	TL1
Tulloch Lake moss 2	TL2
West Scoble Lake moss 1	WS1
West Scoble Lake moss 2	WS2
West Scoble Lake moss 3	WS3
West Scoble Lake moss 4	WS4

Azorella samples	
Boot Hill	BHa
Biggles By-Pass	BPa
Gadgets Dam *Azorella* 1, 2	GD
Heartbreak Hill *Azorella* 1, 2	HBa
Little Prion Lake	LPa
North Mountain *Azorella* 1, 2, 3	NMa
'S' Pond	ESa
Sandy/Bauer X-roads	SBa
Ski Hut *Azorella* 1, 2	SKa
Tulloch Lake	TLa

Species codes for Figure 4.18 overlay

Achnanthes abundans	Ac ab
Achnanthes austriaca	Ac au
Achnanthes bioreti	Ac bi
Achnanthes confusa	Ac cf
Achnanthes manguinii	Ac ma
Achnanthes manguinii var. *elliptica*	Ac el
Achnanthes pseudolanceolata	Ac ps
Achnanthes species B	Ac sd
Achnanthidium microcephala	Ah mc
Aulacoseira granulata	Au gr
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Cymbella gracilis	Cy gr
Cymbella microcephala	Cy mi
Diatomella hustedtii	Di hu
Eunotia exigua	Eu ex
Fragilariforma virescens	Fr vi
Navicula corrugata	Na cg
Navicula dicephala	Na di
Nitzschia hantzschiana	Ni ha
Pinnularia acoricola	Pi ac
Pinnularia circumducta	Pi ci
Pinnularia lata	Pi la
Pinnularia microstauron	Pi mi
Staurosira construens var. *venter*	Sa ve
Staurosirella pinnata	Sa pi
Synedra rumpens	Sy ru

samples from high altitudes. Other species such as *Achnanthes bioreti, A. abundans, Achnanthidium lanceolata, Aulacoseira granulata, Eunotia exigua* and *Staurosira construens* var. *venter* were more closely correlated with the vegetation type gradient. The occurrence of many aerophilic species along this gradient suggests that it may also be reflecting a shift from moist samples at the left of the first axis, to drier samples at the right. This interpretation is sensible with regards to the samples and environment. Some samples may have been collected from areas which were relatively sheltered and so were not as prone to desiccation by wind as other samples in more exposed areas. The majority of the *Azorella* samples were also placed towards the right of the first axis. As explained, these probably retain moisture less readily than the bryophytes. This inferred moisture gradient agrees with the interpretation from the HMDS analysis, which also reflected a gradient from the wetter bryophyte samples with a greater number of species, to the drier *Azorella* samples, with fewer, aerophilic species.

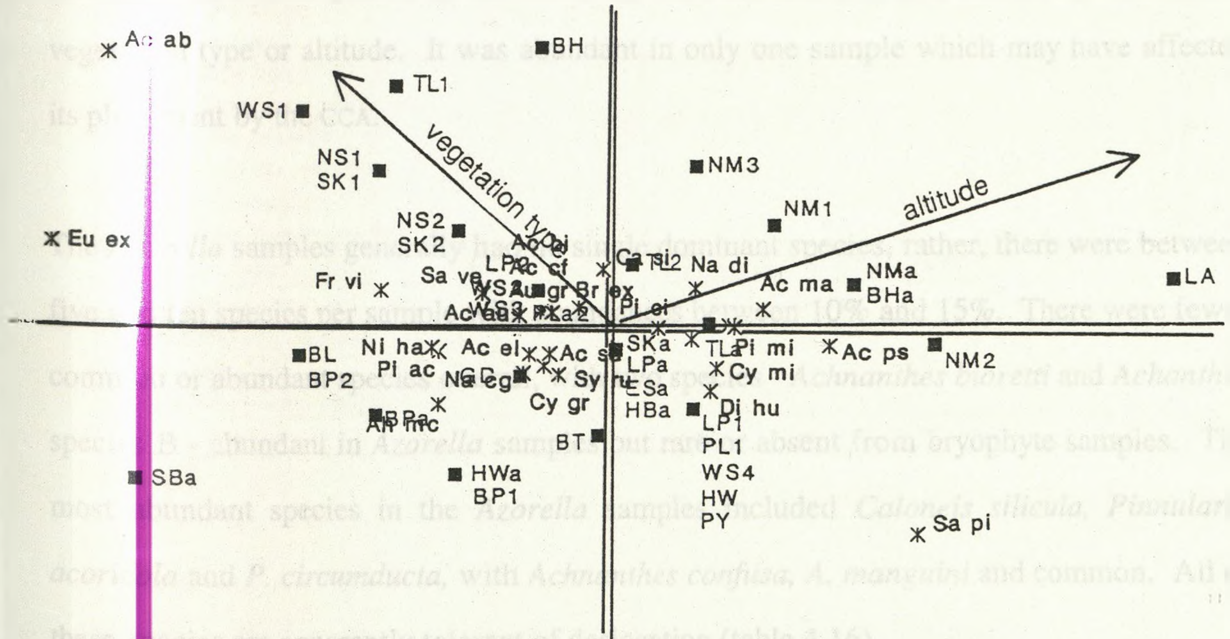


Figure 4.18. Biplot of samples and environmental gradients from the feldmark sites. Axis 1 has an eigenvalue of .07, axis 2 has an eigenvalue of .06. The overlay shows the plot of the major species from the feldmark samples, scaled to be comparable to the sample/environment biplot. Aerophilic species and samples which are inferred to be 'drier' than other samples were placed at the right of axis 1. Sample and species codes are listed opposite.

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Moss samples ■	
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Heartbreak Hill moss 2	HB2
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Halfway Hill moss 2	HW2
Lake Ainsworth moss 1, 2	LA
Little Prion Lake moss 1	LP1
Little Prion Lake moss 2	LP2
North Mountain moss 1	NM1
North Mountain moss 2	NM2
North Mountain moss 3	NM3
North Scoble Lake moss 1	NS1
North Scoble Lake moss 2	NS2
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Prion Lake site 2 moss 1, 2	PL2
Pyramid Lake moss 1, 2	PY
Ski Hut moss 1	SK1
Ski Hut moss 2	SK2
Tulloch Lake moss 1	TL1
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Ski Hut *Azorella* 1, 2	SKa
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Species codes for Figure 4.18 overlay

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Achnanthes austriaca	Ac au
Achnanthes bioreti	Ac bi
Achnanthes confusa	Ac cf
Achnanthes manguinii	Ac ma
Achnanthes manguinii var. *elliptica*	Ac el
Achnanthes pseudolanceolata	Ac ps
Achnanthes species B	Ac sd
Achnanthidium microcephala	Ah mc
Aulacoseira granulata	Au gr
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Cymbella gracilis	Cy gr
Cymbella microcephala	Cy mi
Diatomella hustedtii	Di hu
Eunotia exigua	Eu ex
Fragilariforma virescens	Fr vi
Navicula corrugata	Na cg
Navicula dicephala	Na di
Nitzschia hantzschiana	Ni ha
Pinnularia acoricola	Pi ac
Pinnularia circumducta	Pi ci
Pinnularia lata	Pi la
Pinnularia microstauron	Pi mi
Staurosira construens var. *venter*	Sa ve
Staurosirella pinnata	Sa pi
Synedra rumpens	Sy ru

samples from high altitudes. Other species such as *Achnanthes bioreti, A. abundans, Achnanthidium lanceolata, Aulacoseira granulata, Eunotia exigua* and *Staurosira construens* var. *venter* were more closely correlated with the vegetation type gradient. The occurrence of many aerophilic species along this gradient suggests that it may also be reflecting a shift from moist samples at the left of the first axis, to drier samples at the right. This interpretation is sensible with regards to the samples and environment. Some samples may have been collected from areas which were relatively sheltered and so were not as prone to desiccation by wind as other samples in more exposed areas. The majority of the *Azorella* samples were also placed towards the right of the first axis. As explained, these probably retain moisture less readily than the bryophytes. This inferred moisture gradient agrees with the interpretation from the HMDS analysis, which also reflected a gradient from the wetter bryophyte samples with a greater number of species, to the drier *Azorella* samples, with fewer, aerophilic species.

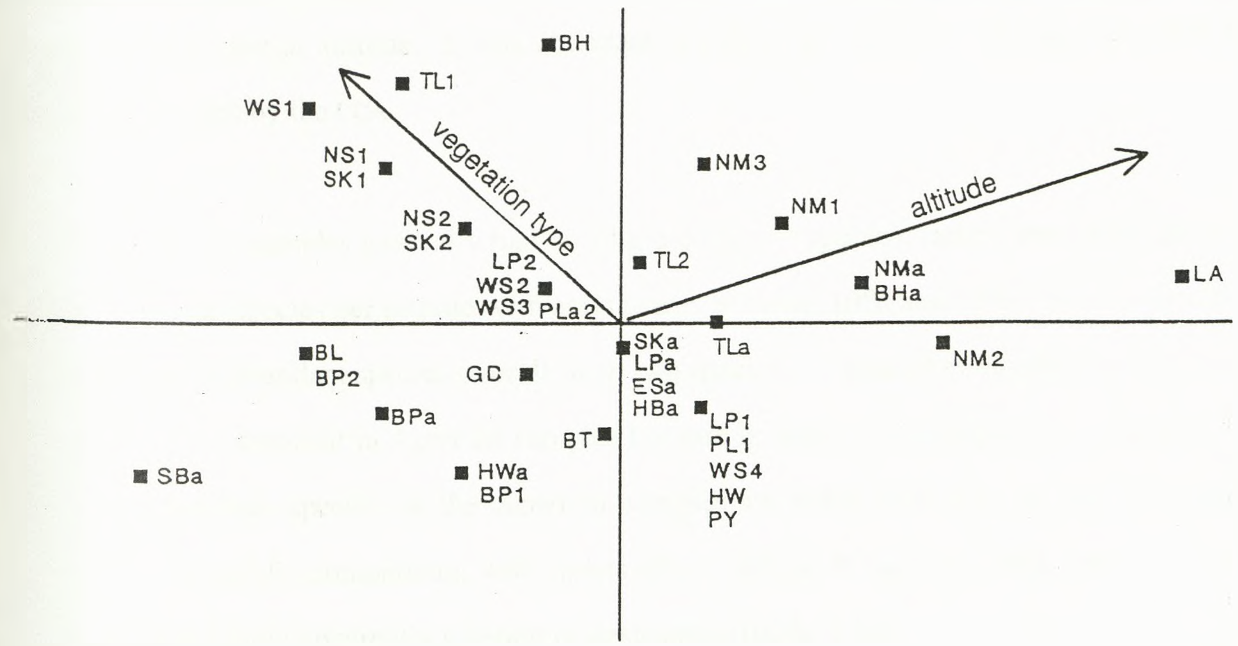


Figure 4.18. Biplot of samples and environmental gradients from the feldmark sites. Axis 1 has an eigenvalue of .07, axis 2 has an eigenvalue of .06. The overlay shows the plot of the major species from the feldmark samples, scaled to be comparable to the sample/environment biplot. Aerophilic species and samples which are inferred to be 'drier' than other samples were placed at the right of axis 1. Sample and species codes are listed opposite.

Feldmark samples as diatom habitats

As an environment for diatoms, the moss polsters and *Azorella macquariensis* habitats would be periodically dry, with strong winds acting to desiccate the surfaces of the plants. There was a significant difference between the two sample types, seen in the ANOSIM analysis. However, *A. macquariensis* and moss samples were intermingled by the HMDS, CCA and TWINSPAN analyses, although there was a tendancy for the *Azorella* samples to be placed together, at one end of the plots or in one TWINSPAN group. *Achnanthes confusa, Caloneis silicula* and *Synedra rumpens* were the most common/abundant species in the moss polsters from the feldmark. Other abundant species included *Achnanthes abundans, A. manguini, Eunotia exigua, Pinnularia acoricola, P. circumducta* and *P. lata.* All these species except *E. exigua* were placed close to the centroid of the CCA plot (fig. 4.17), indicating that they occur in the majority of bryophyte and some *Azorella* samples. *Eunotia exigua* was placed as an outler by the CCA and was not correlated with either vegetation type or altitude. It was abundant in only one sample which may have affected its placement by the CCA.

The *Azorella* samples generally had no single dominant species, rather, there were between five and ten species per sample with abundances between 10% and 15%. There were fewer common or abundant species overall, with two species - *Achnanthes bioretti* and *Achanthes* species B - abundant in *Azorella* samples but rare or absent from bryophyte samples. The most abundant species in the *Azorella* samples included *Caloneis silicula, Pinnularia acoricola* and *P. circumducta,* with *Achnanthes confusa, A. manguini* and common. All of these species are apparently tolerant of desiccation (table 4.16).

Dry conditions must occur in the mosses and *Azorella* from time to time, especially in the outer, more exposed leaves. Mosses in the feldmark are known to grow in the direction of the greatest moisture availability and since most moisture is blown by the wind, growth of the moss polsters and stripes is into the wind (Lewis Smith, 1978). However, there are periods of drier weather when the vegetation is likely to dry out, and so the diatom species that live in such an environment must be tolerant of periodic desiccation. The species that occurred commonly in the feldmark bryophytes were also relatively common in samples from stream environments with little or no current.

Table 4.16. Interpreted environmental preferences of the most common species from the feldmark samples on Macquarie Island.

Species common in the feldmark	Environmental Preferences
Synedra rumpens	tolerant of a range of conditions
Achnanthes abundans *Achnanthes austriaca* *Achnanthes bioretti* *Achnanthes confusa* *Achnanthes manguinii* *Achnanthes manguinii* var. *elliptica* *Achnanthes pseudolanceolata* *Achnanthes* species B *Achnanthidium lanceolatum* *Achnanthidium microcephalum* *Aulacoseira granulata* *Brachysira exilis* *Caloneis silicula* *Cymbella gracilis* *Cymbella microcephala* *Diatomella hustedtii* *Fragilariforma virescens* *Navicula corrugata* *Stauriosira construens* var. *venter*	aerophilic epiphytic tolerant of desiccation
Nitzschia hantzschiana	very tolerant of desiccation
Pinnularia acoricola *Pinnularia circumducta* *Pinnularia lata* *Pinnularia microcephala*	motile, aerophilic
Eunotia exigua	acidophilic, tolerant of desiccation

Reports in the literature of diatom species common in the feldmark

The literature supports the suggestion that feldmark areas are subject to drought conditions periodically. Although there were many species recorded from the 48 samples (over 70) relatively few were abundant or common. This suggests the samples do experience some extremes in moisture availability, as a greater number of species generally reflects a milder environment. Only species tolerant of, or in some way adapted to these changes in conditions will flourish.

Achnanthes confusa, A. manguinii, Achnanthidium lanceolatum, Pinnularia acoricola, P. circumducta and *P. lata* are all reported as aerophilic species (Gasse, 1986; Le Cohu & Maillard, 1983; Germain, 1981; Schoeman, 1973; Ghandi, 1966; van Landingham, 1966, Bourelly & Manguin, 1954). *Pinnularia* species have been shown to be motile, moving deeper into soil as surface layers dry out (Evans, 1959; 1958). These may move further into the moss or *Azorella* plants as the outer leaves become drier. Other species, such as *Eunotia exigua* and *Nitzschia hantshciana,* which are very tolerant of desiccation, would simply 'wait out' the dry period (Dixit, Dixit & Evans, 1988; Haworth, 1976; Conger, 1939).

Species such as *Aulacoseira granulata, Caloneis silicula, Diatomella hustedtii* and *Synedra rumpens* are more commonly thought of as planktonic, benthic, littoral or epiphytic lake species (Dixit, Dixit & Evans, 1988; Gasse, 1986; Bourelly & Manguin, 1954). These species may be tolerant of a wider range of conditions on Macquarie Island than elsewhere, where there are more species adapted to live in specific environments. However, a second possibility is that these species are not tolerant of desiccation, but live deeper within the plants where trapped moisture is less likely to be evaporated.

One species is apparently unusual in its occurrence in the feldmark. *Eunotia exigua* occurs in abundance in one feldmark sample (Prion Lake site 1 moss 1). It is commonly found in acidic environments (Chapter 3; Dixit, Dixit & Evans, 1988; Kingston, 1984; Schoeman, 1973). However, it has also been described as an aerophile (Kingston, 1984; Manguin, 1952), and as an epiphyte on moss (Conger, 1939) and so its low abundance in some samples and high abundance in one sample from a moist bryophyte environment can be easily explained.

4.4.3 Soil sites

Soil samples were collected from a range of environments, with the samples prepared following the protocol in Chapter 2. Bare soil, or filamentous green algae covering soil was collected and the examination of diatoms from soil samples revealed a relatively low number of species with an abundance of 2% or greater, with an average of 12 species per sample (SD = 3). The percentage abundance diagrams are shown in Appendix 3. Common or abundant species are listed in table 4.17, with average abundance, range and number of samples they occur in given.

The TWINSPAN analysis divided the 14 soil samples into four groups at the second level, with an eigenvalue of .269 at the first division. Samples placed in each group are listed in table 4.17. In the four samples in Group 1 the most abundant species varied between samples, but included *Achnanthes manguinii, Caloneis silicula, Luticola mutica, Pinnularia circumducta* and *Synedra rumpens.*

Table 4.17. TWINSPAN grouping of soil samples. The eigenvalue at the first division was .269.

Group 1	Group 2	Group 3	Group 4
Gadget Gully	Mawson Point	Razorback	Garden Cove
site 1	North Mountain	site 1	Razorback
site 2	site 1	site 3	site 2
site3	Sandy Bay		site 4
Wireless Hill	site 1		
site 1	site 2		
	Wireless Hill		
	site 2		

Abundant species in the five samples included in Group 2 were *Achnanthes* species B, *A. manguinii, Caloneis silicula, Navicula lanceolata, Pinnularia acoricola* and *P. circumducta.* Group 3 contained two samples, with *Eunotia exigua, Melosira dickei* and *Luticola mutica* co-dominants at Razorback site 1. *Pinnularia circumducta* was most abundant at Razorback site 3 with of *Luticola neoventricosa* and *Pinnularia kolbei*

Sample Codes for Figure 4.19

Gadgets Gully site 1	GG1
Gadgets Gully site 2	GG2
Gadgets Gully site 3	GG3
Garden Cove site 1	GC
Mawson Point site 1	MP
North Mountain site 1	NM
Razorback East site 1	RE1
Razorback East site 2	RE2
Razorback East site 3	RE3
Razorback East site 4	RE4
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2
Wireless Hill site 1	WH1
Wireless Hill site 2	WH2

moderately abundant. Group 4 contained three samples. *Surirella linearis* and *Pinnularia gibba* were abundant at Razorback and abundant, and *Achnanthes delicatula*, *S. linearis* and *Nitzschia palea* were common in the sample from Garden Cove.

The TWINSPAN agreed well with the HMDS of samples in two dimensions, which had a low minimum stress of .133 (fig. 4.19). Group 1 was at the left of the configuration, groups 3 and 4 at the right and group 2 relativley spread out. TWINSPAN grous 1 and 2 contained similar species, such as *Achnanthes confusa*, *A. manguinii*, *Diatomella hustedtii* and *Synedra rumpens*. Group 3 contained species such as *Luticola mutica*, *Navicula dicephala* and *Pinnularia circumducta*, whicle group 4 contained *Achnanthes delicatula* and *Surirella linearis*.

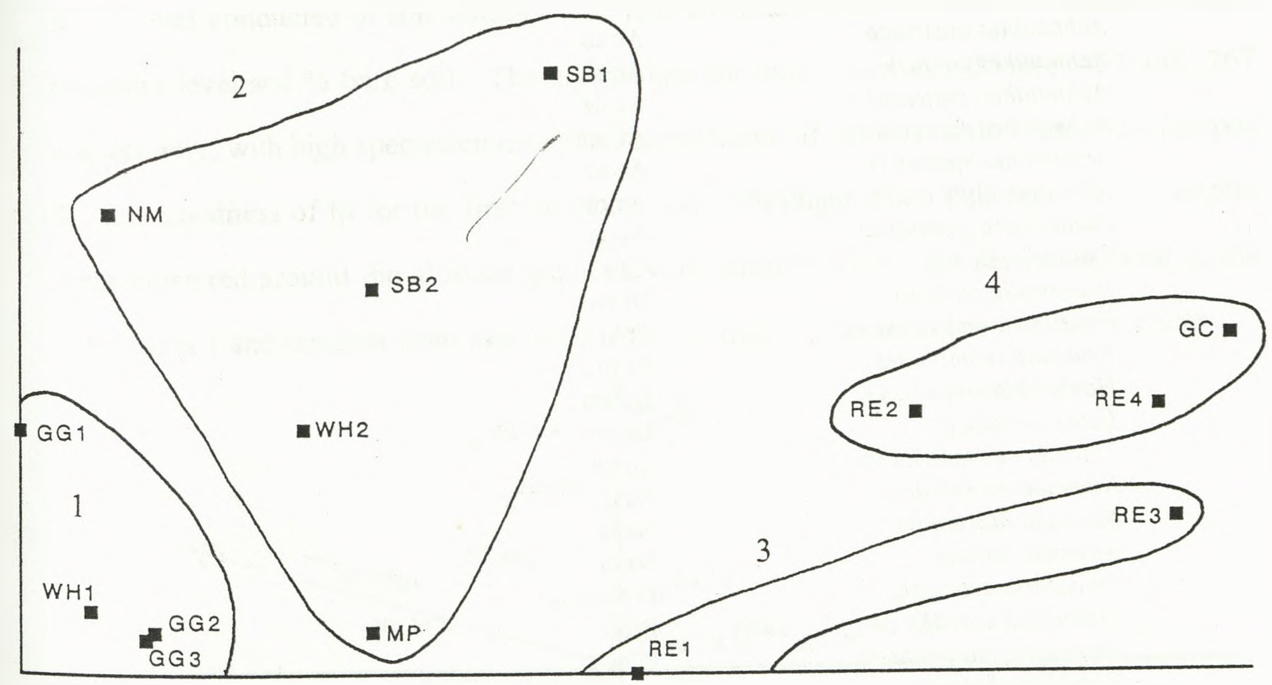


Figure 4.19. HMDS of soil samples in two dimensions. Minimum stress is .133. Two gradients are apparent: nutrient availability along the bottom axis and NaCl levels along the second axis. The TWINSPAN grouping of samples is indicated, with numbers refering to the TWINSPAN groups. Sample codes are listed opposite.

The number of species present in each sample decreased from left to right on the configuration, with an increase in the number of aerophilic species. Some species in groups

Sample Codes for Figure 4.20

Gadgets Gully site 1	GG1
Gadgets Gully site 2	GG2
Gadgets Gully site 3	GG3
Garden Cove site 1	GC
Mawson Point site 1	MP
North Mountain site 1	NM
Razorback East site 1	RE1
Razorback East site 2	RE2
Razorback East site 3	RE3
Razorback East site 4	RE4
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2
Wireless Hill site 1	WH1
Wireless Hill site 2	WH2

Species codes for Figure 4.20 overlay

Achnanthes austriaca	Ac au
Achnanthes confusa	Ac cf
Achnanthes delicatula	Ac de
Achnanthes manguinii	Ac ma
Achnanthes species B	Ac sd
Achnanthidium microcephalum	Ah mc
Aulacoseira granulata	Au gr
Caloneis silicula	Ca si
Diatomella hustedtii	Di hu
Fragilariforma virescens	Fr vi
Frustulia rhomboides	Fs rh
Hantzschia amphioxys	Ha am
Luticola mutica	Lu mu
Luticola neoventricosa	Lu ne
Navicula dicephala	Na di
Navicula lanceolata	Na la
Navicula tantula	Na ta
Pinnularia acoricola	Pi ac
Pinnularia borealis	Pi bo
Pinnularia circumducta	Pi ci
Pinnularia kolbei	Pi ko
Pinnularia lata	Pi la
Pinnularia microstauron	Pi mi
Stauroneis anceps	St au
Synedra rumpens	Sy ru

3 and 4 are tolerant of, or require, nutrient enrichment (see appendix 2), such as *Achnanthes delicatula, Luticola* species and *Surirella linearis*. It appears that these sites have been nutrient enriched in the past. This may represent a nutrient gradient across the lower part of the configuration, from no enrichment at the left to enriched on the right. A second trend can be seen in the configuration, with samples from low altitudes placed at the base and those from higher altitudes placed towards the top. This may be reflecting a salinity gradient, with less NaCl available at higher altitudes.

Environmental gradients in soil samples

A CCA was conducted of soil samples with four environmental variables: nutrients, altitude, moisture level and % bare soil. The eigenvalues for axis 1 and axis 2 were .457 and .267 respectively, with high species/environment correlations of .899 for axis 1 and .934 for axis 2. The goodness of fit for the first two axes was 70% (fig.4.20). The majority of samples were clustered around the altitude gradient, with samples from high above sea level at the left of axis 1 and samples from low altitudes at the right. This was reflected in the HMDS.

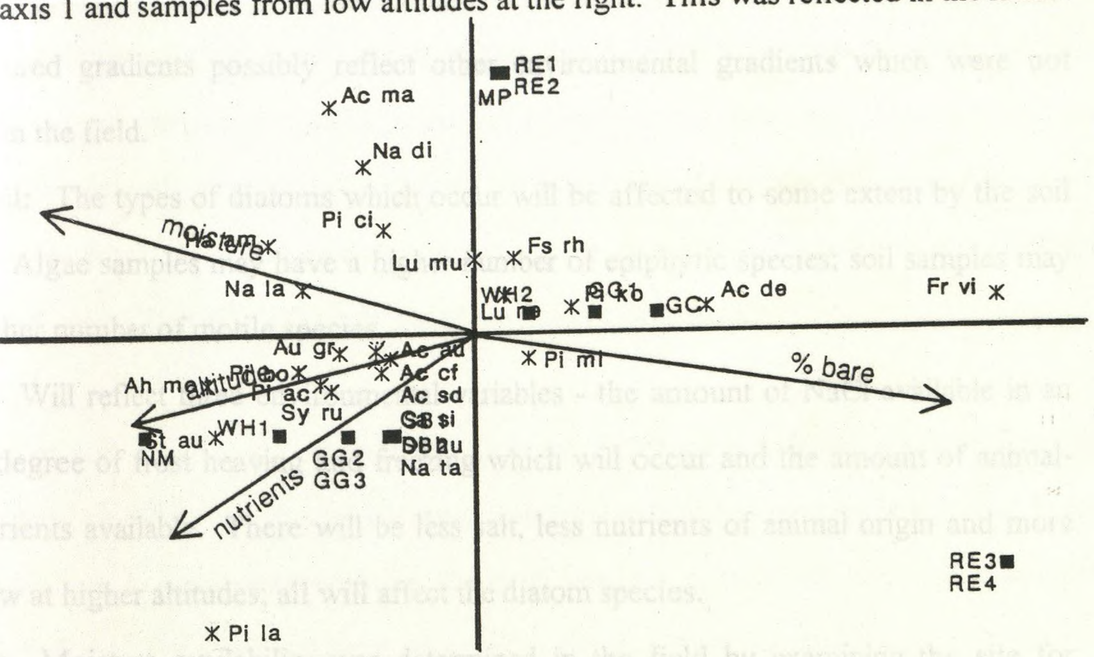


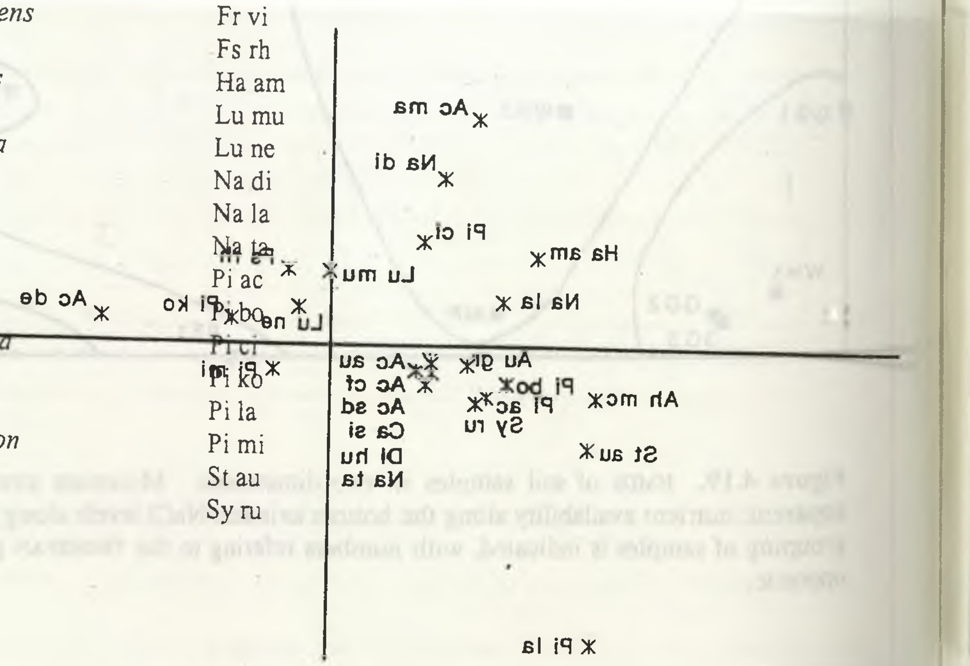
Figure 4.20. Biplot of the CCA of soil samples and environmental variables. Eigenvalues were .457 (axis 1) and .267 (axis 2), with a goodness of fit of 70%. The overlay shows the more abundant species, scaled to be comparable to the sample/environment biplot. Sample and species codes are listed opposite.

Sample Codes for Figure 4.20

Gadgets Gully site 1	GG1
Gadgets Gully site 2	GG2
Gadgets Gully site 3	GG3
Garden Cove site 1	GC
Mawson Point site 1	MP
North Mountain site 1	NM
Razorback East site 1	RE1
Razorback East site 2	RE2
Razorback East site 3	RE3
Razorback East site 4	RE4
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2
Wireless Hill site 1	WH1
Wireless Hill site 2	WH2

Species codes for Figure 4.20 overlay

Achnanthes austriaca	Ac au
Achnanthes confusa	Ac cf
Achnanthes delicatula	Ac de
Achnanthes manguinii	Ac ma
Achnanthes species B	Ac sd
Achnanthidium microcephalum	Ah mc
Aulacoseira granulata	Au gr
Caloneis silicula	Ca si
Diatomella hustedtii	Di hu
Fragilariforma virescens	Fr vi
Frustulia rhomboides	Fs rh
Hantzschia amphioxys	Ha am
Luticola mutica	Lu mu
Luticola neoventricosa	Lu ne
Navicula dicephala	Na di
Navicula lanceolata	Na la
Navicula tantula	Na ta
Pinnularia acoricola	Pi ac
Pinnularia borealis	Pi bo
Pinnularia circumducta	Pi ci
Pinnularia kolbei	Pi ko
Pinnularia lata	Pi la
Pinnularia microstauron	Pi mi
Stauroneis anceps	St au
Synedra rumpens	Sy ru



3 and 4 are tolerant of, or require, nutrient enrichment (see appendix 2), such as *Achnanthes delicatula, Luticola* species and *Surirella linearis*. It appears that these sites have been nutrient enriched in the past. This may represent a nutrient gradient across the lower part of the configuration, from no enrichment at the left to enriched on the right. A second trend can be seen in the configuration, with samples from low altitudes placed at the base and those from higher altitudes placed towards the top. This may be reflecting a salinity gradient, with less NaCl available at higher altitudes.

Environmental gradients in soil samples

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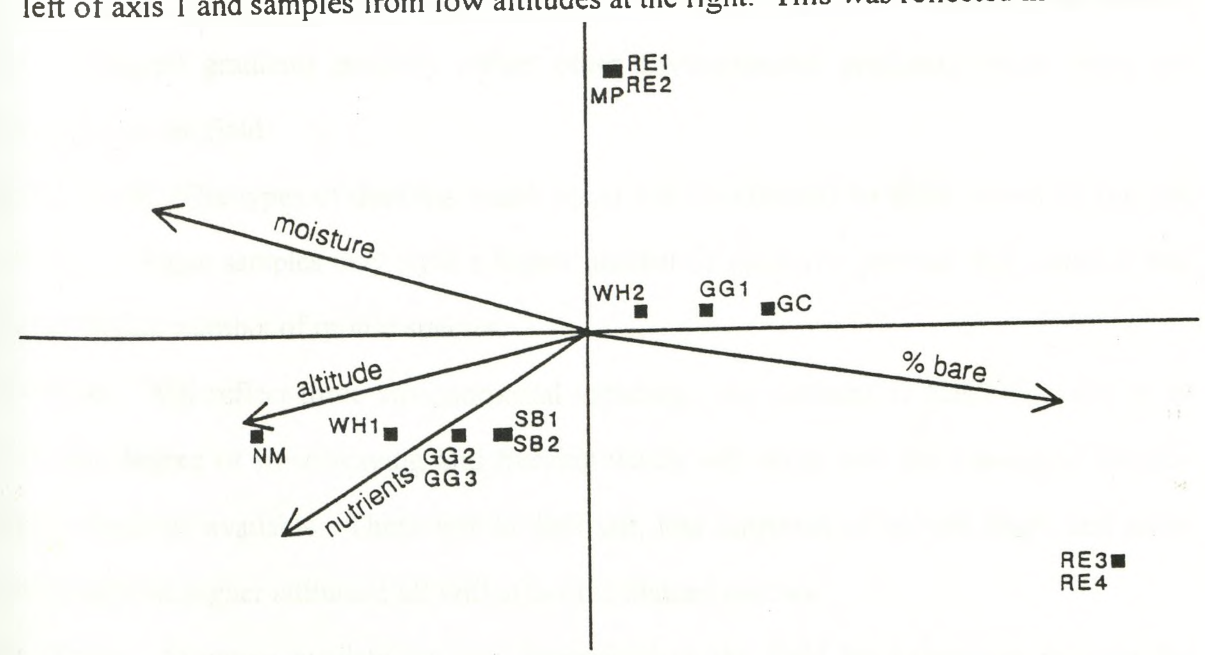

Figure 4.20. Biplot of the CCA of soil samples and environmental variables. Eigenvalues were .457 (axis 1) and .267 (axis 2), with a goodness of fit of 70%. The overlay shows the more abundant species, scaled to be comparable to the sample/environment biplot. Sample and species codes are listed opposite.

The two samples from bare soil at Razorback (1 and 2) were placed away from most samples and closest to the enriched end of the nutrient axis. This, too, was in agreement with the HMDS. The two algae samples from Razorback were separated from the rest of the samples; they had high abundances of *Surirella linearis,* which occurred rarely in the other soil samples. The % bare soil gradient separated the Razorback algae samples, the sample of *Colobanthus muscoides* from Wireless Hill and the moss sample from Garden Cove from all the other samples.

The interset correlations for the four environmental variables included in the analysis show that nutrient enrichment was most strongly correlated with axis 2; altitude moisture and % bare soil were correlated with axis 1 (table 4.18).

Table 4.18. Interset correlation coefficients of environmental gradients and the first two CCA axes fom soil samples.

	Axis 1	Axis 2
altitude	- .526	- .267
moisture	- .676	.409
nutrients	- .454	- .537
% bare	.655	- .181

The measured gradients possibly reflect other environmental gradients which were not measured in the field.

%bare soil: The types of diatoms which occur will be affected to some extent by the soil covering. Algae samples may have a higher number of epiphytic species; soil samples may have a higher number of motile species.

Altitude: Will reflect three environmental variables - the amount of NaCl available in an area, the degree of frost heaving and freezing which will occur and the amount of animal-origin nutrients available. There will be less salt, less nutrients of animal origin and more freeze/thaw at higher altitudes; all will affect the diatom species.

Moisture: Moisture availability was determined in the field by examining the site for seepage from surrounding areas. Indications of more or less constant seepage meant the samples had less chance of desiccation than samples where there was no evidence of seepage.

Nutrients: Although no samples included in this group of soil sites were collected from sites which were obviously animal affected, the examination of samples revealed some diatom species which were abundant in one or two samples and absent in others. These species are regarded in the literature as eutrophic or nutrophilic (see Chapter 4.4.5). Although no evidence of nutrient enrichment or animal disturbance was evident at the time of collection, it was clear from the diatom species present that these samples had been nutrient enriched.

The high altitude and low nutrient arrows were correlated, as expected, as there is a greater chance of nutrient enrichment at lower altitudes because of the greater number of vertebrate species and individuals which occur. Moisture and % bare were negatively correlated, indicating that the sites with less moisture also had less filamentous algae growth.

The CCA of species placed the majority of those species which are regarded as aerophilic closest to the moisture and % bare soil gradients (fig. 4.19). These species include *Luticola mutica, L. neoventricosa, Nitzschia palea* and *Pinnularia circumducta.* Some others also regarded as aerophils were placed closer to the nutrient and altitude axes (e.g. *Pinnularia acoricola, P. lata*). It is probable that these species were more common in samples from sites which were often dry, although wet at the time of sampling.

The CCA of soil samples and species revealed one clear environmental gradient, from no nutrient enrichment to samples which were presumed to have been nutrient enriched in the past. This was in agreement with the HMDS of samples, which also reflected a possible nutrent gradient. The other gradients revealed by the CCA were les obvious on the HMDS.

Soil as a Diatom Habitat

Diatoms inhabit most environments, as long as there is sufficent moisture available. Despite this, there have been relatively few studies of soil as a distinct or recognised habitat for diatoms. Even Bunt's (1954) examination of Macquarie Island terrestrial environments included few soil samples. Soil habitats on Macquarie Island may be wetter than in other parts of the world. However, despite the frequent rainfall and low evaporation, periods of drier weather are experienced. Snow may lie on the ground for weeks at a time during winter and will reduce the amount of moisture available at the soil surface. In summer strong winds can dry out soil surfaces during short periods with no precipitation.

The most common and/or abundant species from the soil samples were *Achnanthes manguinii, Luticola mutica, Pinnularia acoricola, P. circumducta, P. kolbei,* and *P. lata* (table 4.19). Other species which were abundant in a few samples included *Achnanthes* species B, *A. delicatula, Aulacoseira granulata, Eunotia exigua, Melosira dickei, Nitzschia palea* and *Pinnularia borealis.* The three samples with *Surirella linearis* most abundant (Razorback sites 2 and 4, Garden Cove) were all from areas which had probably been nutrient enriched in the past. *Achnanthes delicatula* was also abundant in Garden Cove and is possibly a eutrophic species (see Chapter 4.4.5 for a discussion of this species).

Reports in the literature of diatom species common from soil

The literature supports the above interpretation of the soil sites. *Achnanthes delicatula, A. manguinii, Luticola mutica, L. neoventricosa* and most species of *Pinnularia* regarded as aerophilic (Schmidt, Mäusbacher & Müller, 1990; Dixit, Dixit & Evans 1988; Gasse, 1986; Le Cohu & Maillard, 1983; Germain, 1981; Haworth, 1976; Patrick & Reimer, 1966). Other species, such as *Diatomella hustedtii, Eunotia exigua* and *Synedra rumpens,* which have moderate abundances, were more common in wetter environments, All these species were found to be abundant in mires, creeks and/or in feldmark vegetation. Soil samples which had these species present in moderate abundances were probably more moist for at least some of the time than those with other species (such as *Pinnularia* spp.) abundant. However, they can all apparently tolerate some desiccation. Bunt (1954) found *D. hustedtii* (= '*D. balfouriana*') to be frequent on feldmark soil, indicating it may be more tolerant of desiccation than these results suggest. Björk *et al.* (1991) described *D. balfouriana* as an aerophile.

Table 4.19. Interpreted environmental preferences for the most common species from soil samples from Macquarie Island.

Species common on Soil	Environmental Preferences
Achnanthes manguinii *Achanthes* species B *Caloneis silicula* *Luticola mutica* *Nitzschia palea* *Pinnularia acoricola* *Pinnularia borealis* *Pinnularia circumducta* *Pinnularia lata* *Pinnularia microstauron* *Pinnularia kolbei*	aerophiles, tolerant of extended periods of desiccation
Achnanthes confusa *Aulacoseira granulata* *Diatomella hustedtii*	possibly tolerant of desiccation
Eunotia exigua	acidic environments, possibly an aerophil
Synedra rumpens	very tolerant of a range of conditions
Achnanthes delicatula *Surirella linearis*	eutrophic, possibly tolerant of desiccation

Three environments are encompassed by these soil samples. The nutrient-enriched samples (dominated by *Surirella linearis*); 'dry' samples (dominated by *Luticola mutica*/ *Pinnularia* species) grading through to wetter samples, where species such as *Diatomella hustedtii* and *Synedra rumpens* were moderately abundant.

4.4.4 Lichen sites

Samples of lichen were collected from a variety of habitats. The lichen samples all had low relative abundances of diatom valves in comparison to samples from other areas. There was

Table 4.20. List of the most common and/or abundant species from lichen samples. Their mean, standard deviation (SD), number of samples abundant in (*n*) and range (R) are given. All values except *n* are given as percentages. All data from all sites are presented in Appendix 3.

Species	*n*	mean	SD	range
Achnanthes abundans	4	3.4	4.2	1 - 10
Achnanthes bioretti	1	7.0	-	7
Achnanthes confusa	12	6.4	4.9	1 - 16
Achnanthes confusa var. *atomoides*	4	2.3	2.2	1 - 6
Achnanthes manguini	6	4.2	3.0	2 - 6
Achnanthes species D	2	4.5	4.9	1 - 8
Achnanthidium microcephalum	2	3.5	0.7	3 - 4
Aulocosira granulata	9	5.0	4.2	1 - 12
Brachysira exilis	3	6.0	3.6	3 - 10
Caloneis silicula	11	10.3	11.9	2 - 45
Diatomella hustedtii	3	6.7	5.0	2 - 12
Luticola mutica	3	4.3	4.9	1 -10
Melosira dickei	4	36.5	27.5	12 - 65
Nitzschia palea	5	4.2	3.8	1 - 10
Pinnularia circumducta	5	3.2	2.7	2 - 8
Pinnularia lata	5	7.4	5.9	1 - 15
Stauriosira construens var. *venter*	4	6.3	5.9	2 - 15
Species E	2	9.0	1	8 - 10
Synedra rumpens	10	12.1	8.2	2 - 25

an average of 14 species in each sample with an abundance of 2% or more (SD = 5), with the highest number of species per sample 19 (Mawson Point and Scoble Lake site 3) and the lowest number five (Eagle Cave). Percentage abundance graphs for the sites are presented in Appendix 3, with a summary of the most common species, their mean abundances, range and number of samples they occur in presented in table 4.20.

The TWINSPAN divided the 12 samples into three groups at the second level, with an eigenvalue of E = .206 at the first division. Samples placed into each group are listed in table 4.21. Group 1 contained eight samples. The most abundant species varied, with common species including *Achnanthes confusa*, *A. manguinii, Caloneis silicula, Nitzschia palea, Pinnularia circumducta* and *Pinnularia lata.* Group 2 contained three samples with *Caloneis silicula* co-dominant or most abundant in all samples. Other common species included *Melosira dickei, Pinnularia lata* and *Staurosira construens* var. *venter.*

Table 4.21. TWINSPAN grouping of lichen samples. The eigenvalue at the first division was E = .206.

Group 1	Group 2	Group 3
Biggles By-Pass	Heartbreak Hill	Eagle Cave
Scoble Lake	Handspike Pool	
site 1	Mawson Point	
site 2		
site 3		
Halfway Hill		
Douglas Point		
Handspike Point		
Ski Hut		

Group 3 contained only one sample, in which *Melosira dickei* was dominant, with moderate amounts of *Luticola mutica, L. neoventricosa* and *Nitzschia* sp. A, a species not seen in any other sample. This unusual suite of species placed this sample away from all the others.

Seventy species were included in the analysis; 30 had greater than 2% abundance in one or more samples, with only six occuring in more than five samples in great abundance. (E =

Sample Codes for Figure 4.21

Biggles By-Pass	BB
Douglas Point	DP
Eagle Cave	EC
Halfway Hill	HW
Handspike Point	HP
Handspike Pool	HA
Hearbreak Hill	HB
Mawson Point	MP
North-west Scoble Lake	NW
Scoble Lake Outlet	SO
Ski Hut	SK
West Scoble Lake	WS

.402). These were *Achnanthes manguinii, Caloneis silicula, Luticola mutica, Pinnularia circumducta, P. microstauron* and *Synedra rumpens.*

The TWINSPAN grouping of the samples agreed well with the HMDS analysis, which separated out the three groups distinctly in two dimensions. The minimum stress was very low, at .111 (fig. 4.21).

Group 1 was placed at the right of the configuration. These samples contained the most species, including those such as *Diatomella hustedtii* and *Navicula corrugata.* Group 2, with *Melosira dickei* and other species (*Caloneis silicula, Synedra rumpens*) abundant, was widely spread over the centre of the configuration. The Eagle Cave sample was placed at the extreme left. It had a very high abundance of *Melosira dickei,* with few other species present. There is a species gradient obvious on the configuration: samples with a low number of species were placed at the the left and those with larger numbers of species were placed at the right.

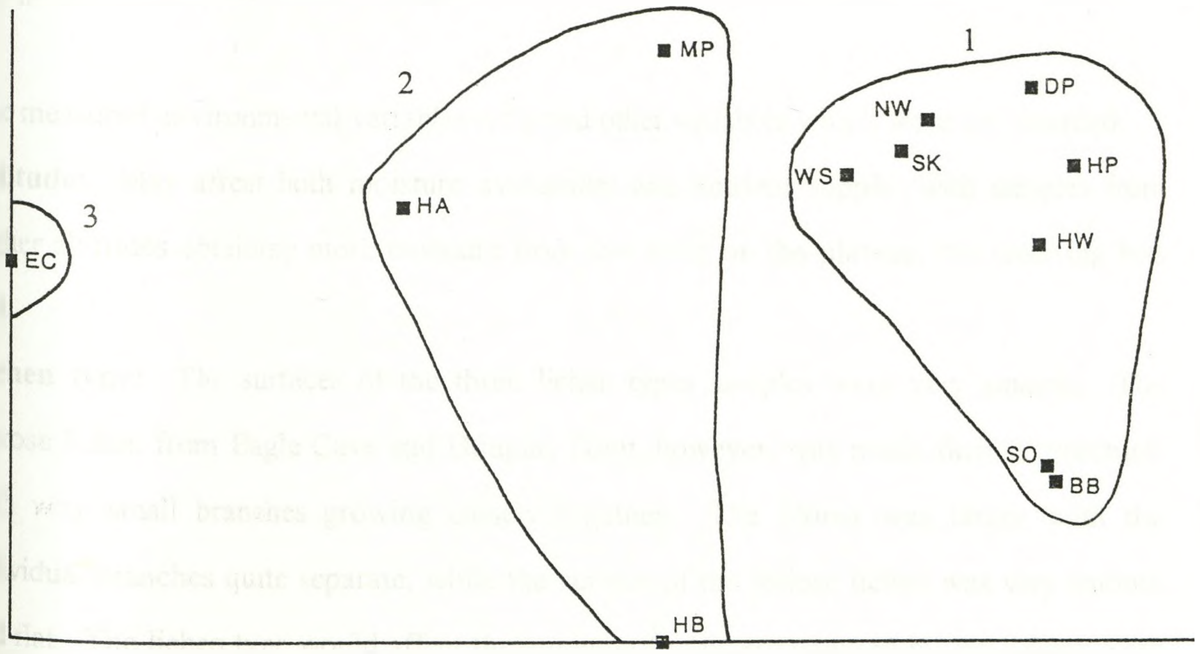

Figure 4.21. HMDS of lichen samples in two dimensions. Minimum stress is .111. There is a gradient in moisture availability evident on the configuration, from drier at the left to wetter at the right. Sample codes are listed opposite.

The HMDS placed the samples from similar altitudes and environments together to a certain extent. All the *Usnea* samples were placed at the right of axis 1, with two samples of foliose lichen from Scoble Lake. Of the four remaining samples, the three placed near the top of the second axis were from rocky sites on the featherbed and the one placed at the bottom centre of the plot was from Heartbreak Hill, at approximately 200 m a.s.l.

Environmental gradients in lichen samples

A CCA of lichen samples was conducted with three environmental variables: moisture, lichen type and altitude. The eigenvalues for axes 1 and 2 were .398 and .180 respectively, and the goodness of fit for the configuration was 56%. Lichen type was strongly correlated with axis 1, and moisture with axis 2. Altitude was correlated with axis 1 and 2 (table 4.22)

Table 4.22. Interset correlation coefficients of environmental variables and CCA axes from lichen samples.

	Axis 1	**Axis 2**
Altitude	- .628	- .542
Lichen Type	.818	- .116
Moisture	.019	- .820

The measured environmental variables reflected other variables which were not recorded.

Altitude: May affect both moisture availability and nutrient supply, with samples from higher altitudes obtaining more moisture from low mists on the plateau, but receiving less salt.

Lichen type: The surfaces of the three lichen types samples were very smooth. The leprose lichen from Eagle Cave and Douglas Point, however, was much finer in structure, with very small branches growing closely together. The *Usnea* was larger, with the individual branches quite separate, while the surface of the foliose lichen was very smooth and flat. The lichen type would affect the amount of moisture retained by the lichens, with more retained by the powdery form than the others.

Sample Codes for Figure 4.22

Biggles By-Pass	BB
Douglas Point	DP
Eagle Cave	EC
Halfway Hill	HW
Handspike Point	HP
Handspike Pool	HA
Hearbreak Hill	HB
Mawson Point	MP
North-west Scoble Lake	NW
Scoble Lake Outlet	SO
Ski Hut	SK
West Scoble Lake	WS

Species codes for Figure 4.22 overlay

Achnanthes abundans	Ac ab
Achnanthes bioreti	Ac bi
Achnanthes confusa	Ac cf
Achnanthes confusa var. *atomoides*	Ac at
Achnanthes manguinii	Ac ma
Achnanthes species B	Ac sd
Achnanthidium microcephala	Ah mc
Aulocaseira granulata	Au gr
Brachysira exilis	Br ex
Caloneis silicula	Ca si
Diatomella hustedtii	Di hu
Luticola mutica	Lu mu
Melosira dickei	Me di
Navicula corrugata	Na cg
Nitzschia palea	Ni pa
Nitzschia hantschiana	Ni ha
Pinnularia circumducta	Pi ci
Pinnularia lata	Pi la
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru

Moisture: This was more difficult to determine. Most samples were classed as dry, with only the powdery lichens (which grew in sheltered areas on rock walls) and the occasional *Usnea* sample growing amongst bryophytes classed as moist.

The CCA of samples also separated out the TWINSPAN groups, with group 1 at the left of the plot, and groups 2 and 3 at the right. Eagle Cave (group 3) was not as separated from the other samples as it was on the HMDS (fig. 4.22). The main separation occurred along the lichen type gradient, with leprose lichens at the right, *Usnea* at the left and the foliose lichens near the centre. Altitude also separated out some samples, with those from higher altitudes generally at the left of the plot. Moisture has some effect on the positioning of samples and is strongly correlated with axis 2; however, it is difficult to determine how the samples have been separated. Samples from north west Scoble Lake, Scoble Lake outlet and Heartbreak Hill were placed closest to the dry end of the gradient; other samples such as Handspike Point and Douglas Point appear to be influenced equally by moisture and other gradients.

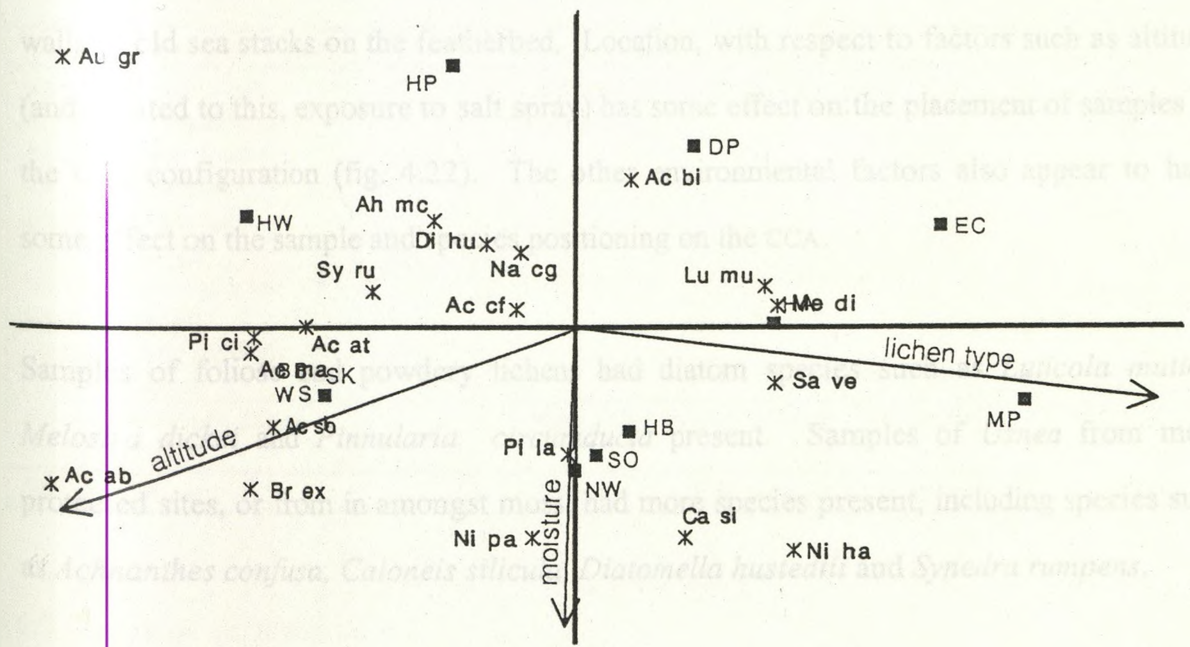

Figure 4.22. Biplot of the CCA of lichen samples and altitude, moisture availability and lichen type. The eigenvalues for axes 1 and 2 are .398 and .180 respectively. The goodness of fit for the first two axes was 56%. The overlay shows the major species from the lichen samples. Sample and species codes are listed opposite.

Sample Codes for Figure 4.22

Biggles By-Pass	BB
Douglas Point	DP
Eagle Cave	EC
Halfway Hill	HW
Handspike Point	HP
Handspike Pool	HA
Hearbreak Hill	HB
Mawson Point	MP
North-west Scoble Lake	NW
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Nitzschia palea	Ni pa
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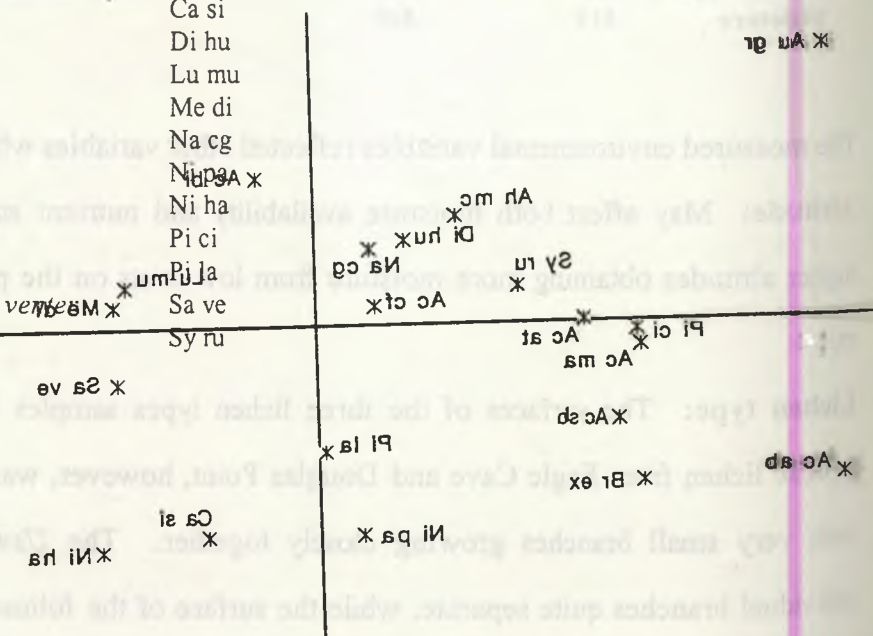
Pinnularia circumducta	Pi ci
Pinnularia lata	Pi la
Staurosira construens var. *venter*	Sa ve
Synedra rumpens	Sy ru



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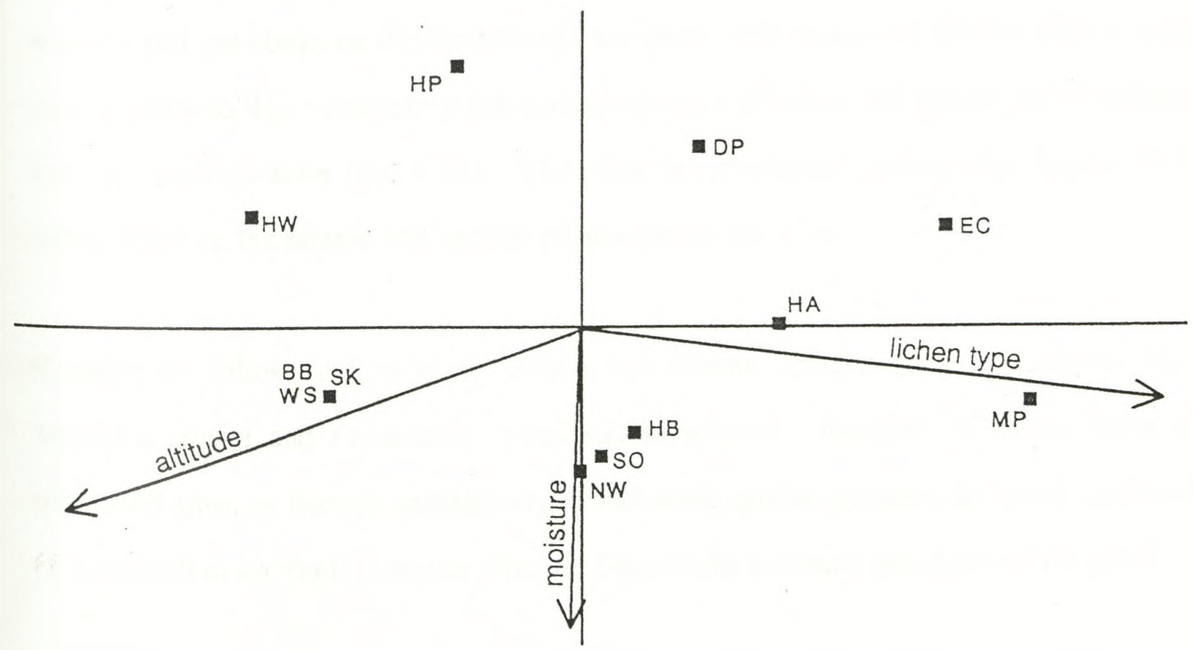

Figure 4.22. Biplot of the CCA of lichen samples and altitude, moisture availability and lichen type. The eigenvalues for axes 1 and 2 are .398 and .180 respectively. The goodness of fit for the first two axes was 56%. The overlay shows the major species from the lichen samples. Sample and species codes are listed opposite.

The species in the lichen samples were separated into three main groups, centred around the origin of the plot (fig. 4.22). Species such as *Luticola mutica, L. neoventricosa* and *Melosira dickei* were placed close to the lichen type gradient; other apparent aerophiles were placed closer to the altitude gradient (e.g. *Achnanthes manguinii, Pinnularia acoricola* and *P. circumducta*). The species which are inferred to be tolerant of a range of conditions (e.g. *Synedra rumpens*), or occur in wetter environments generally (e.g. *Diatomella hustedtii* and *Navicula corrugata*) were placed close to the centre of the two axes.

Lichens as diatom habitats

Lichens as growing substrates for diatoms are very dry, when compared to mosses. Six of the samples taken were *Usnea* sp., a hard, fruticose lichen generally growing above the moss surface, or occassionally amongst loosely packed mosses. Four samples of foliose lichens were collected from rocks and two samples were of a red, leprose lichen growing on walls of old sea stacks on the featherbed. Location, with respect to factors such as altitude (and, related to this, exposure to salt spray) has some effect on the placement of samples on the CCA configuration (fig. 4.22). The other environmental factors also appear to have some effect on the sample and species positioning on the CCA.

Samples of foliose and powdery lichens had diatom species such as *Luticola mutica, Melosira dickei* and *Pinnularia circumducta* present. Samples of *Usnea* from more protected sites, or from in amongst moss, had more species present, including species such as *Achnanthes confusa, Caloneis silicula, Diatomella hustedtii* and *Synedra rumpens.*

Generally all the lichen samples had a low frequency of diatom frustules, with few valves present on the slides when compared with samples from other habitats. There was an increase in the number of species from the powdery samples (at the left of the HMDS and the right of the CCA) which contained few species, to the other samples which contained more species. Table 4.23 lists the most common species and their interpreted habitat preferences.

Diatom species common from lichen in the literature

Information on habitat preferences for the more common species supports the interpretation from this data. The most common species - *Achnanthes manguinii, Luticola mutica, Melosira dickei* and *Pinnularia* spp. are all said to be aerophilic (Gasse, 1986; Le Cohu & Maillard, 1983; Germain, 1981; Bourrelly & Manguin, 1954). This particular association of diatoms is apparently indicative of dry, exposed environments, with two possible indicators being *Pinnularia acoricola* and *Pinnularia circumducta*. *Melosira dickei* was found in few other samples apart from lichen and never in similar, high abundances; it may be that it is unable to compete successfully in areas with more moderate conditions.

Table 4.23. Interpreted environmental preferences for the most common diatom species from lichen samples on Macquarie Island.

Species common on Lichen	Environmental Preferences
Achnanthes confusa *Achnanthes manguinii* *Aulacoseira granulata* *Caloneis silicula* *Diatomella hustedtii* *Luticola mutica* *Luticola neoventricosa* *Melosira dickei* *Nitzschia hantzschiana* *Nitzschia palea*	Aerophilic, epiphytic, tolerant of desiccation.
Pinnularia circumducta *Pinnularia lata*	Aerophilic, motile, tolerant of desiccation.
Synedra rumpens	Tolerant of a wide range of environments

4.4.5 Nutrient enriched sites

Samples of algae and soil were collected from areas which were obviously recently disturbed by vertebrate species. The penguin enriched and elephant seal enriched (wallow)

Table 4.24. List of the most common and/or abundant species from nutrient enriched samples. Their mean, standard deviation (SD), number of samples abundant in (*n*) and range (R) are given. All values except *n* are given as percentages. All data from all sites are presented in Appendix 3.

Species	Wallow samples				Penguin samples			
	n	mean	SD	range	*n*	mean	SD	range
Achnanthes abundans	3	5.3	0.5	5-6				
Achnanthes confusa	4	5.0	1.9	3-8	2	6.5	2.5	4-9
Achnanthes confusa var. *atomoides*	4	3.8	1.1	2-5				
Achnanthes delicatula	10	28.9	23.3	2-72	3	29.0	26.9	10-67
Achnanthes delicatula var. *hauckiana*	1	20.0	-	20	1	9.0	-	9
Cymbella gracilis	1	18.0	-	18				
Diatomella hustedtii	5	7.0	3.9	2-12	2	5.5	4.5	1-10
Luticola mutica	1	5.0	-	5	4	2.0	1.2	4
Luticola neoventricosa	5	7.4	8.8	2-25	6	6.3	5.7	1-18
Melosira dickei	1	2.0	-	2	4	5.5	1.7	4-8
Navicula dicephala					4	9.5	2.7	6-13
Navicula species D	1	15.0	-	15	2	18.5	6.5	12-25
Nitzschia palea	9	10.2	7.7	2-25	3	16.0	8.5	10-28
Pinnularia acoricola	4	7.8	4.3	4-15	1	2.0	-	2
Pinnularia circumducta	6	3.3	0.9	2-4	8	6.0	8.6	1-28
Pinnularia kolbei	8	6.5	3.1	2-12	8	22.9	15.8	8-50
Pinnularia species E	1	12.0	-	12				
Staurosirella construens var. *venter*	1	22.0	-	22				
Species E	3	3.0	0.8	2-4	5	24.4	15.9	6-48
Surirella linearis	2	20.0	18	2-32				
Synedra rumpens	10	5.9	10.8	1-35	4	4.5	3.3	2-15

sites have been analysed together as nutrient enriched sites. The 22 samples had a relatively low average number of species per site (9, ± 3), with a minimum number of three species with a maximum occurrence of 2% or more and a maximum of 14 species per sample. Percentage abundance diagrams are presented in Appendix 3. Species which were common or abundant in one or both sample types are summarised in table 4.24, with mean abundances, ranges and the number of samples in which they occurred given. The Nuggets penguin site 1 and Handspike Point samples were removed prior to the final analyses as they contained few species and were placed as exteme outliers by initial analyses.

The TWINSPAN classification of samples separated out 4 groups at level two, with an eigenvalue of E = .233 at the first division. Table 4.25 lists the samples placed in each group. Group 1 contained four samples in which the abundant or common species included *Achnanthes confusa, A. delicatula, A. delicatula* ssp. *hauckiana, Achnanthidium lanceolatum, Cymbella gracilis, Diatomella hustedtii, Nitzschia palea, Pinnularia acoricola* and *Synedra rumpens.*

Table 4.25. TWINSPAN grouping of nutrient enriched sites. The eigenvalue at the first division was .233.

Group 1	Group 2	Group 3	Group 4
Garden Cove	Sandy Bay	Garden Cove	Garden Cove
wallow site 1	penguin site 1	wallow site 4	wallow site 3
wallow site 2	penguin site 2	penguin site 1	Handspike Pool birds
Handspike Corner	Wallow 1	penguin site 2	Nuggets
wallow	Wallow 2	penguin site 3	penguin site 2
Razorback wallow	Wallow 4	penguin site 4	
Wallow 3	Wallow 5 vegetation		
	Wallow 5 sediment		

Group 2 contained seven samples, with the common species including *Achnanthes confusa, Brachysira exilis, Diatomella hustedtii, Luticola neoventricosa,* and *Nitzschia palea.* Group 3 contained 5 samples. *Achnanthes delicatula, Navicula* sp. D, *Nitzschia palea,* and *P. kolbei* were the abundant species. Group 4 contained three samples in which the most

Sample Codes for Figure 4.23

Wallow sites ■	
Garden Cove site 1	GC1
Garden Cove site 2	GC2
Garden Cove site 3	GC3
Garden Cove site 4	GC4
Handspike Corner	HC
Razorback East	RE
Wallow 1	W1
Wallow 2	W2
Wallow 3	W3
Wallow 4	W4
Wallow 5a	W5a
Wallow 5b	W5b
Penguin sites ○	
Garden Cove sites 1, 2, 3, 4	GC
Hasselborough Beach	HB
The Nuggets site 2	NU2
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2

most abundant species were *Achnanthes delicatula, Pinnularia circumducta* and *Surirella linearis. Nitzschia palea, Pinnularia gibba* and *P. kolbei* were common.

The TWINSPAN of species used a total of 54 species, and had an eigenvalue at the first division of E = .698. Twenty seven species had occurrences of 5% or more in at least one sample. It grouped together species which were moderately abundant to abundant in wallow samples only (*Caloneis silicula* and *Achnanthidium lanceolatum*); those abundant in both wallow and penguin sites (*Synedra rumpens, Nitzschia palea, Achnanthes delicatula* and *Navicula* sp. D) and those abundant in only penguin samples together (*Melosira dickei, Navicula dicephala, N. geniculata, Luticola neoventricosa, Pinnularia* sp. E, *P. gibba* and *P. kolbei*).

The TWINSPAN agreed well with the HMDS, which separated out the four twinspan groups in two dimensions, with a low minimum stress of analysis of .123 (fig. 4.23). Group 3, containing the four penguin samples from Garden Cove, was the most distinct group, placed at the extreme left of the configuration.

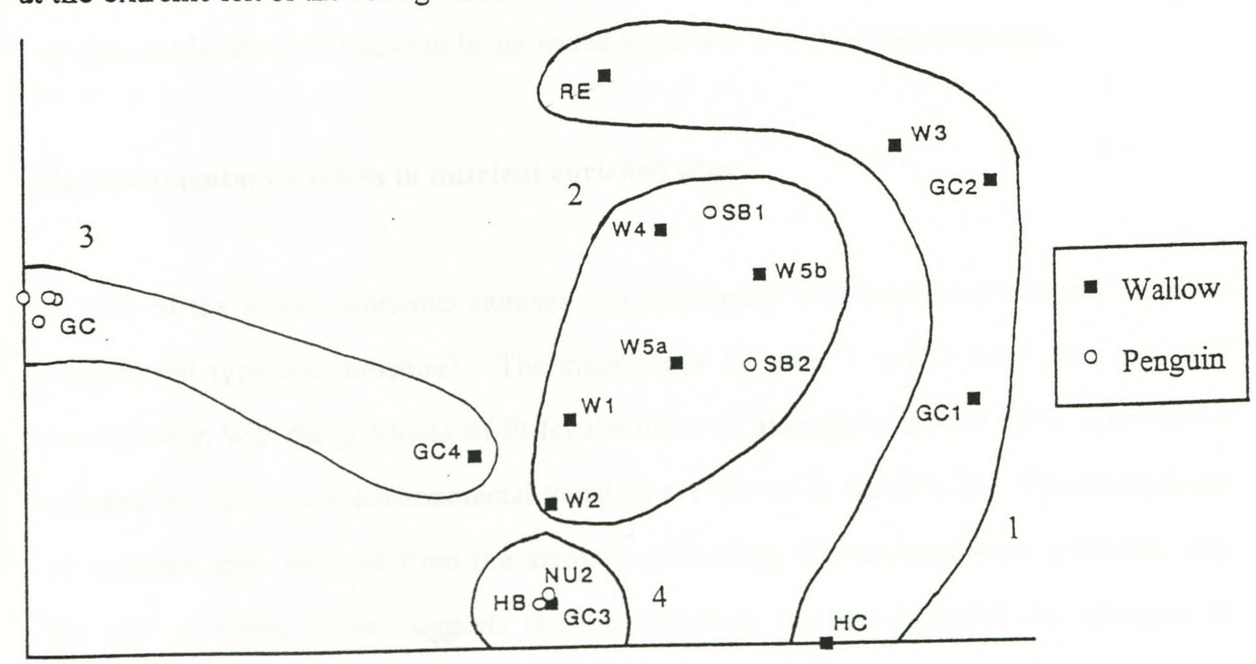

Figure 4.23. HMDS of nutrient enriched samples in two dimensions. The TWINSPAN groupings are indicated, with numbers refering to the TWINSPAN groups. There are two environmental gradients apparent. The available moisture is low in those samples at the left of the plot, and increases towards the right hand side. The level of available nutrients appears to increase from relatively low in the samples near the top of the plot, to high in the samples at the base. Sample codes are listed opposite.

Samples from group 1 were spread out on the configuration, with some placed close to group 2. The Garden Cove samples, which were dominated by *Pinnularia kolbei* and *Pinnularia* species E, also contained other species which were rare or absent in the other samples such as *Luticola mutica, Melosira dickei* and *Navicula dicephala.* Samples with *Achnanthes delicatula* abundant were placed at the base of the configuration, with its abundance decreasing upwards as the abundances of other species such as *Diatomella hustedtii* and *Synedra rumpens* increased.

This may be linked to the nutrient levels, with high levels at the base of axis 2, decreasing upwards. Axis 1 appears to be related to moisture, with the Garden Cove penguin samples at the left and the samples from wet wallows at the right. No samples for nutrient analysis were collected, as the study was preliminary and designed only to highlight any differences in the dominant diatom species in eutrophic and other samples. Any comments with regards to the levels of different nutrients at any site can only be inferences, however it is clear that the levels do vary from site to site, probably dependant on usage history, timing and the species involved. More diatom samples, with matched water or soil samples for the analysis of nutrient levels would have to be collected to answer this question adequately.

Environmental variables in nutrient enriched sites

A CCA of the nutrient-enriched samples was conducted with two environmental variables (vegetation type and moisture). The eigenvalues for axes 1 and 2 were .294 and .175 respectively, with the goodness of fit for the first two axes quite low, at 32%. The biplots of sample, species and environmental variables are shown in figure 4.23. The arrangement of samples some distance from the arrows representing the environmental gradients, plus the low goodness of fit, suggests that an important variable (possibly the influence of nutrients) has not been accounted for. The moisture level of a site was well correlated with axis 1, reflecting a gradient from drier at the left of the plot to wetter at the right. This gradient was also observed on the HMDS configuration. The vegetation type gradient (e.g.

filamentous green algae or *Prasiola crispa*) had a reasonable correlation with the second axis. It has separated the penguin samples (Garden Cove, the Nuggets) and a wallow sample (Razorback) from the other samples. The intraset correlations show that the moisture gradient is strongly correlated with the first axis and that vegetation type is correlated with axis 2 (table 4.26).

Table 4.26. Intraset correlation coefficents of environmental variables and the first two CCA axes .from nutrient-enriched samples.

	Axis 1	Axis 2
moisture	.836	- .045
vegetation type	- .333	- .644

The species/environment biplot gave a good spread of species across the first two axes (fig 4.23). The majority of common or abundant species were either aerophilic or eutrophic species. The aerophilic species occurred in many of the other habitats examined (e.g. soil. lichen); the eutrophic species such as *Achnanthes delicatula* and *Surirella linearis*, occurred rarely, if at all, in the other habitats. The exception to this was the few soil samples which had, apparently, been nutrient enriched.

Species at the left of the plot were either common in penguin samples (*Achnanthidium lanceolatum*, *Melosira dickei*, *Luticola* spp, *Pinnularia circumducta* and *Fragilariopsis antarctica*), or occurred abundantly in one or two of the wallow samples which were placed at the left of the plot (*Cymbella gracilis*, *Stauriosira construens* var. *venter*, *Surirella linearis*). Species at the right of the plot occurred abundantly in wallows, except for *Achanthes delicatula* (in Sandy Bay site 2 and Handspike Corner penguin samples) and *Navicula* species D (in Sandy Bay site 2). Both penguin samples with these species were placed at the right of the plot. Species close to the second axis, such as *Achnanthes confusa* var. *atomoides*, *Pinnularia acoricola* and *Synedra rumpens*, occurred in both sample types equally.

Sample Codes for Figure 4.24

Wallow sites ■

Garden Cove site 1	GC1
Garden Cove site 2	GC2
Garden Cove site 3	GC3
Garden Cove site 4	GC4
Handspike Corner	HC
Razorback East	RE
Wallow 1	W1
Wallow 2	W2
Wallow 3	W3
Wallow 4	W4
Wallow 5a	W5a
Wallow 5b	W5b

Penguin sites ○

Garden Cove sites 1	GC1
Garden Cove sites 2	GC2
Garden Cove sites 3	GC3
Garden Cove sites 4	GC4
Handspike Pool	HP
Hasselborough Beach	HB
The Nuggets site 1	NU1
The Nuggets site 2	NU2
Sandy Bay site 1	SB1
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Achnanthes confusa var. *atomoides*	Ac at
Achnanthes delicatula	Ac de
Achnanthes delicatula ssp. *hauckiana*	Ac ha
Achnanthes inflata	Ac in
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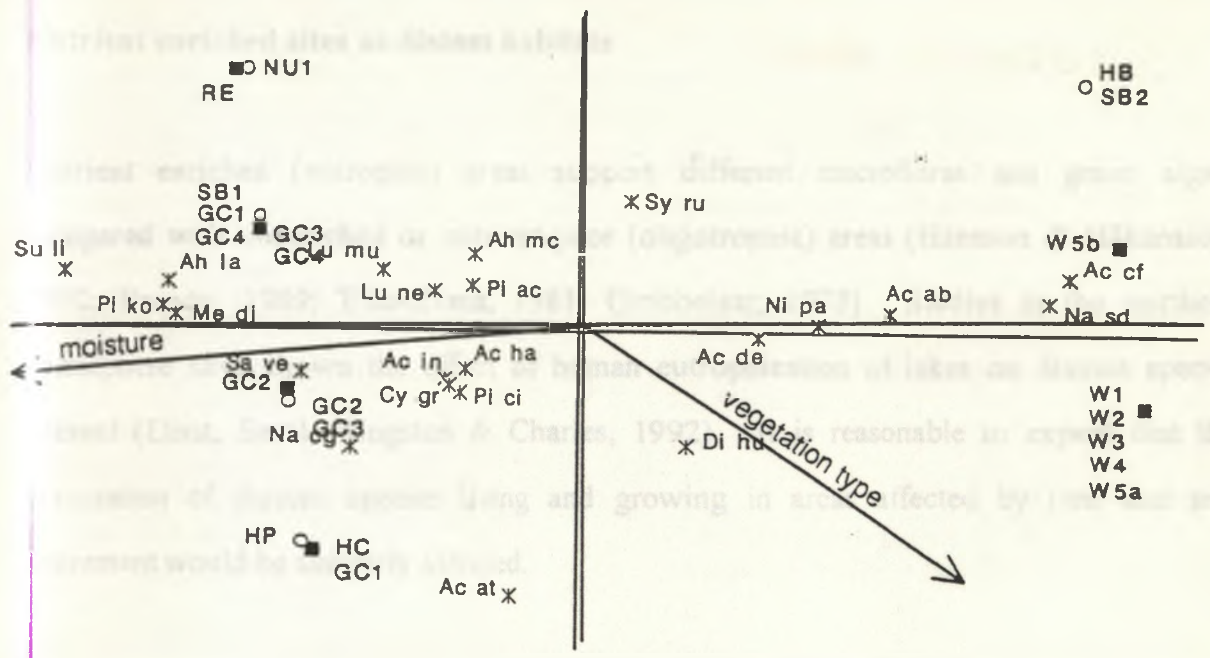

Figure 4.24. Biplot of CCA of Nutrient enriched samples and environmental gradients. The eigenvalues were .294 for axis 1 and .175 for axis 2. The goodness of fit for the first two axes was 32%. The overlay shows the major species from the nutrient enriched samples, scaled to be comparable to the sample/environment biplot. Sample and species codes are listed opposite.

It appears that moisture is an important variable in the nutrient enriched sites, with vegetation type less important. The sample groups - penguin/wallow - support diatom associations with were significantly different (ANOSIM) and were generally separated by the other analyses, although some overlap did occur. At present it is unclear whether the species which occur in wallow and penguin habitats are responding to different nutrients available, or to different moisture levels, with the penguin samples generally from drier areas. It is probable that there is a combined effect. The majority of the eutrophic species appear to also be aerophilic, occurring predominantly in the drier penguin samples. *Achnanthes delicatula* is the only eutrophic species which occurred less frequently in the penguin samples. Where the penguin samples were collected from wetter sites (e.g. Hasselborough Bay and Sandy Bay site 2), *A. delicatula* was abundant. From this, it would appear that *A. delicatula* is less tolerant of desiccation than other eutrophic species.

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Garden Cove site 3	GC3
Garden Cove site 4	GC4
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Wallow 3	W3
Wallow 4	W4
Wallow 5a	W5a
Wallow 5b	W5b
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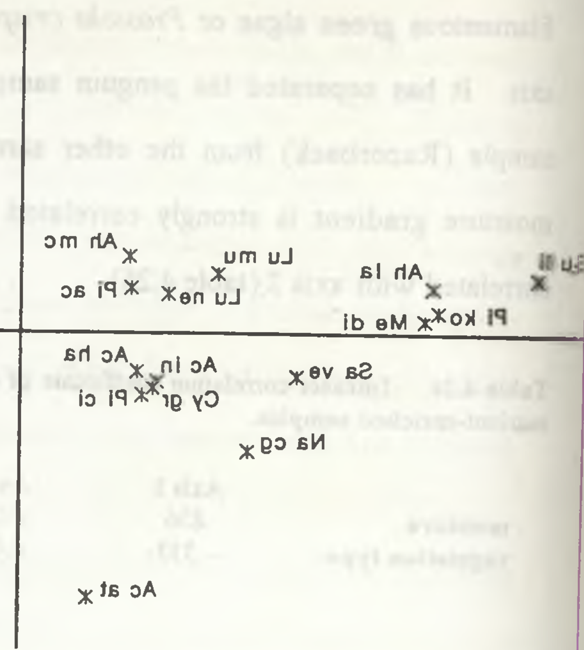
Garden Cove sites 2	GC2
Garden Cove sites 3	GC3
Garden Cove sites 4	GC4
Handspike Pool	HP
Hasselborough Beach	HB
The Nuggets site 1	NU1
The Nuggets site 2	NU2
Sandy Bay site 1	SB1
Sandy Bay site 2	SB2



Species Codes for Figure 4.24 overlay

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Achnanthes delicatula ssp. *hauckiana*	Ac ha
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Achnanthidium microcephalum	Ah mc
Achnanthidium lanceolatum	Ah la
Cymbella gracilis	Cy gr
Diatomella hustedtii	Di hu
Luticola mutica	Lu mu
Luticola neoventricosa	Lu ne
Melosira dickei	Me di
Navicula corrugata	Na cg
Navicula species D	Na sd
Nitzschia palea	Ni pa
Pinnularia acoricola	Pi ac
Pinnularia circumducta	Pi ci
Pinnularia kolbei	Pi ko
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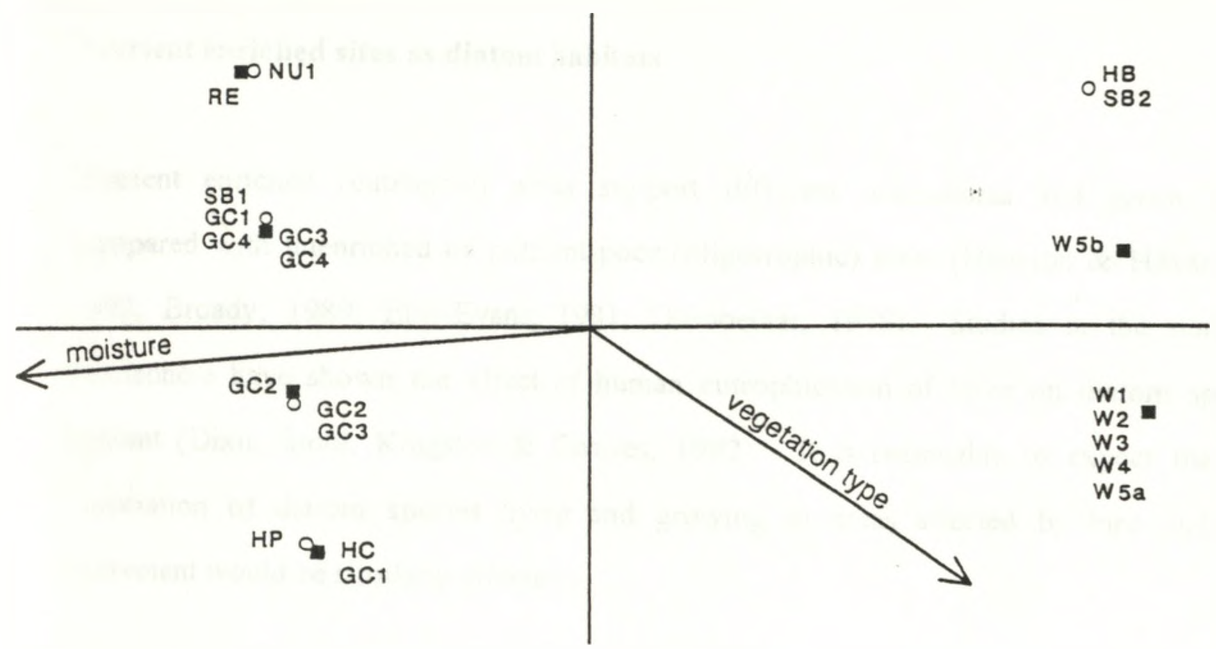
Surirella linearis	Su li
Synedra rumpens	Sy ru



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Nutrient enriched sites as diatom habitats

Nutrient enriched (eutrophic) areas support different macrofloras and green algae, compared with unenriched or nutrient-poor (oligotrophic) areas (Hansson & Håkansson, 1992; Broady, 1989; Ellis-Evans, 1981; Grobbelaar, 1978). Studies in the northern hemisphere have shown the effect of human eutrophication of lakes on diatom species present (Dixit, Smol, Kingston & Charles, 1992). It is reasonable to expect that the association of diatom species living and growing in areas affected by bird and seal excrement would be similarly affected.

From this initial study, the diatom association present in nutrient enriched sites appears to be characterised by several species not found in high abundances in other environments (table 4.23). The most abundant species, *Achnanthes delicatula*, has only been found in such high percentages in nutrient-enriched areas and appears to be a highly eutrophic species. Other species that are found in other environments were also present in moderate abundances in the eutrophic samples. These included *Achnanthes confusa, Caloneis silicula, Diatomella hustedtii, Nitzschia palea* and *Synedra rumpens.* As has been shown in previous sections, these species all seem to be tolerant of a wide range of conditions.

The separation of the majority of 'dry' (collected from soil) and 'wet' (collected from wallows) penguin samples by the CCA and HMDS has occurred because of the disatom associations present. Where more moisture was available, such as within wallows, *Achnanthes delicatula* was more abundant than known aerophiles, suggesting this species is more adapted for eutrophic rather than dry conditions. Other species were also present, including *Achnanthes confusa, Diatomella hustedtii* and *Synedra rumpens.*

The other common or abundant species, such as *Luticola mutica* and *L. neoventricosa*, may also be responding to increases in nutrients, but may also be able to survive in drier conditions. Other species which were abundant in this habitat were *Pinnularia kolbei,*

Table 4.27. Interpreted environmental preferences for the most common species from the nutrient enriched samples from Macquarie Island

Species common in nutrient-enriched areas	Environmental Preferences
Achnanthes delicatula	Occurs only in wallows, eutrophic.
Achanthes abundans *Achnanthes confusa* *Cymbella gracilis* *Diatomella hustedtii* *Surirella linearis*	Occur predominantly in wallows Tolerant of nutrient enrichment
Luticola mutica *Melosira dickei* *Navicula dicephala* *Navicula* species D *Pinnularia kolbei* Species E	Occur predominantly in penguin sites Tolerant of or require nutrient enrichment Aerophilic species
Nitzschia palea *Pinnularia acoricola* *Pinnularia circumducta* *Synedra rumpens*	Occur in wallow and penguin samples Tolerant of nutrient enrichment

Surirella linearis and Pinnularia species E. All are probably eutrophic and aerophilic, growing abundantly on relatively dry soil around the penguin colonies.

Reports in the literature of diatom species common in nutrient enriched sites

The information available from the literature generally supports the conclusions drawn here. Not surprisingly, species regarded as aerophiles were common in samples of soil. *Luticola mutica* and *L. neoventricosa* are known to be aerophilic and tolerant of some pollution (Dixit, Dixit & Evans, 1988; Gasse, 1986; Germain, 1981). Like most *Pinnularia* species, *P. kolbei* is considered to be an aerophile (Le Cohu & Maillard, 1983). Both *P. kolbei* and *Pinnularia* species E, which occurs with it in some samples, are probably eutrophic and aerophilic, growing abundantly on the relatively dry soil around Garden Cove.

The samples from eutrophic areas generally had a different diatom flora present compared with the other environments examined, with the majority of the abundant species present able to tolerate pollution, or which have adapted to live in nutrient-enriched environments. Some species, such as *Diatomella hustedtii* and *Nitzschia palea* were able to survive and compete successfully in such environments. Other species, such as *Synedra rumpens* and

Staurosira construens var. *venter*, may be indifferent to nutrient levels, as both were found in other areas in equal or greater abundances. Species such as *Pinnularia kolbei* and *P. circumducta* may also be responding to factors other than nutrient enrichment, such as moisture availability.

One species that was more common in the nutrient enriched sites than in other areas was *Fragilariopsis antarctica.* This is a reasonably common marine species which occurs in some soils on Macquarie Island. It is possible that the valves are either blown ashore or are transported ashore on the skin, fur or feathers of animals and are then deposited, perhaps once the animal dries, or with the annual moult. The majority of valves of *F. antarctica* encountered were broken, with very few whole valves seen (see Appendix 2, plates). Bunt (1954) also found this species on Macquarie Island. Along with other marine species which were encountered rarely (eg *Coscinodiscus* species A) *F. antarctica* was seen predominantly in the soils close to the sea, or in disturbed sites. It is not known whether the individuals were alive at the time of sampling: however the frequency of broken valves suggests that this is unlikely.

The spread of samples and the differences in diatom species between them may be due to the amounts and kinds of trace elements, how recently the site was disturbed, or other factors that cannot be tested for. However, it is clear that the actual vertebrate species causing the nutrient enrichment had little overall impact on the diatom species and that the effects appeared to be more closely related to usage history, sample type (soil, algae) and moisture availability.

4.6 Conclusions Drawn From Chapter 4

The five terrestrial environments examined had a range of diatom species present, with some overlap between the habitats. The drier nutrient-enriched sites were the most distinctive, with *Achnanthes delicatula* and *Surirella linearis* occurring in high abundances only within these sites.

Samples from streams with strong currents were dominated by *Synedra rumpens*, with amounts of other species present increasing as the current decreased.

Melosira dickei appears to be restricted to dry environments, and was found in greatest abundance in samples of lichen from relict sea stacks on the featherbed.

Species which appear to prefer drier environments occurred in a range of habitats which may experience periodic to almost constant drought. These included *Luticola mutica*, *L. neoventricosa*, *Pinnularia acoricola*, *P. circumducta*, *P. kolbei* and *P. lata*.

Species which appear to tolerate dry conditions occassionally, but prefer moist conditions include *Achnanthes abundans*, *A. confusa*, *A. confusa* var. *atomoides*, *A. manguini*, *Achnanthidium microcephalum*, *Amphora coffeaeformis*, *Aulacoseira granulata*, *Caloneis silicula*, *Diatomella hustedtii*, *Nitzschia palea* and *Synedra rumpens*. Most of these were common and/or abundant in a wide range of wetter environments, such as moss polsters in the feldmark, and vegetation on creek banks or in the splash zones of waterfalls. The majority of these species may be generalists.

Table 4.28 lists the habitats examined, and the suite of diatoms present within each. Diatoms which apparently indicate a particular environment are in boldface.

Table 4.28. Diatom suites from terrestrial habitats on Macquarie Island.

Habitat	Sample Type	Diatom Association
STREAMS	Strong current	**3.** ***Synedra rumpens,*** more than 60 % of total
	Moderate current	**2a.** *Achnanthes confusa/A. confusa* var. *atomoides/Diatomella hustedtii/Nitzschia palea/Synedra rumpens*
	Low/no current	**2b.** As above, plus *Achnanthes abundans/Achnanthidium microcephalum/Amphora coffeaeformis/Caloneis silicula*
FELDMARK	Bryophytes	**4.** *Achnanthes confusa/A. manguinii/Aulacoseira granulata/C. silicula/Pinnularia circumducta/P. lata/S. rumpens*
	Azorella	**4.** *Achnanthes confusa/A. abundans/A. manguinii/Aulacoseira granulata/C. silicula/P. circumducta/S. rumpens,*
SOIL	Dry	**5.** *Achnanthes manguinii/**Luticola mutica**/Pinnularia acoricola/P. circumducta/**P. kolbei/P.** lata*
	Less dry	**6.** *A. confusa/C. silicula/Diatomella hustedtii/S. rumpens*
LICHEN	Dry	**5.** ***Aulacoseira granulata**/Achnanthes manguinii/Luticola mutica/L. neoventricosa/P. acoricola/P. circumducta*
	Less dry	**2a.** *Achnanthes confusa/C. silicula/D. hustedtii/S. rumpens*
NUTRIENT ENRICHED	Dry	**7.** *Pinnularia kolbei/**Pinnularia*** **species E**
	Moist	**8.** ***Achnanthes delicatula**/Luticola mutica/L. neoventricosa/ Nitzschia. palea/Pinnularia kolbei/**Surirella linearis***

Chapter 5

Palaeolake Half Moon

5.1 Synopsis

Palaeolake Half Moon is the most northerly of the palaeolakes known on Macquarie Island. Three sections were sampled in the remnant sediments. Sediments were clay throughout, with three diatom associations present. Palaeolake Half Moon was probably most similar to the modern-day Major Lake and to Palaeolake Eagle

5.2 Introduction and Site Description

Palaeolake Half Moon is the northern-most of the palaeolake deposits known, located on the plateau edge approximately 1000 m south of Handspike Corner, at about 70 m a.s.l. (fig. 1.15). The deposit lies in a small valley bounded to the west by a relict marine cliff and to the north, east and south by converging topographic scarps inferred to be faults. A major topographic scarp curves into the valley from the north, in part defining the northern extent of the valley (fig. 5.1, fig. 5.2). Two more scarps enter the valley from the south-east and partially control the locations of the eastern and southern valley wall (fig. 5.2).

Since the palaeolake drained, the Scoble Lake outlet stream which runs through the site, has slowly eroded the lacustrine material and cut deeply into the deposit in places. The deepest exposure is on the west-facing cliff line overlying weathered bedrock (fig.

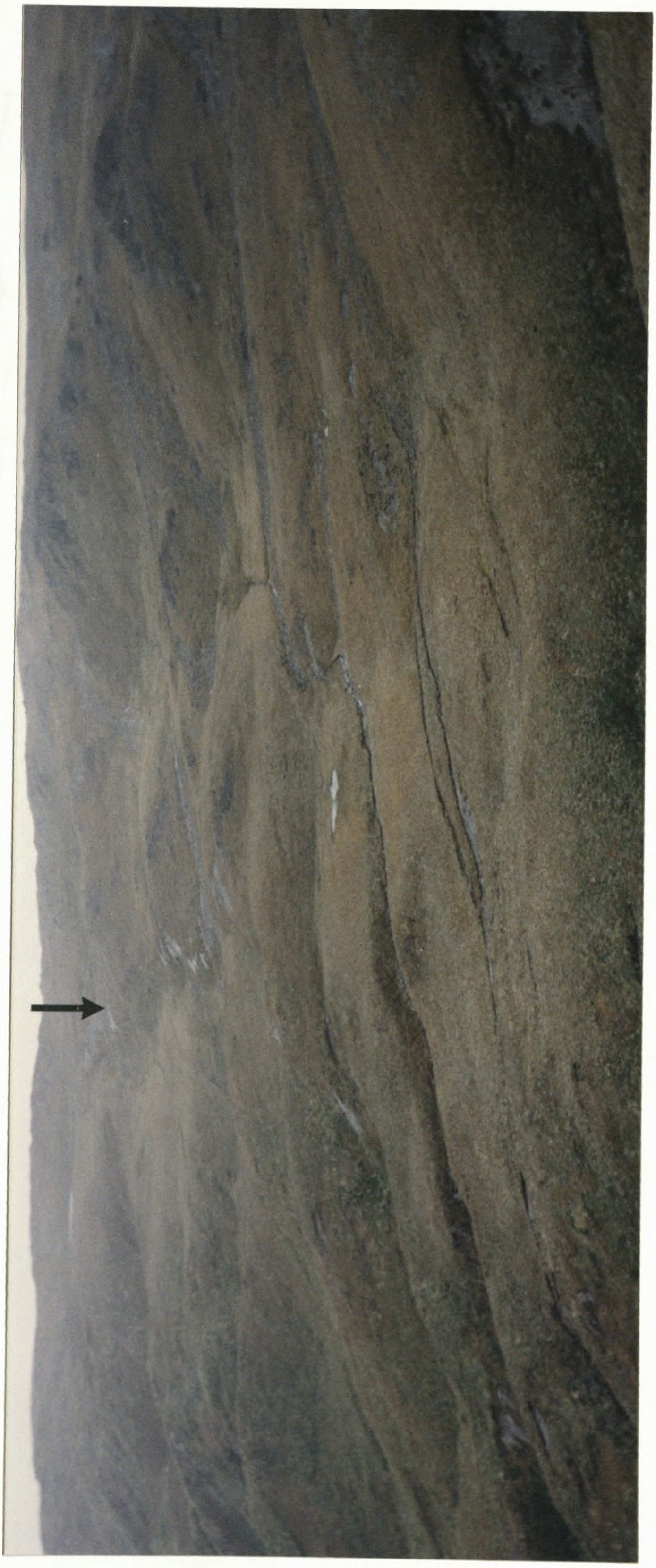


Figure 5.1. Panoramic photograph from Hill 219 looking north. The long fault which curves into the Palaeolake Half Moon valley is arrowed. (Photograph J. M. Selkirk).

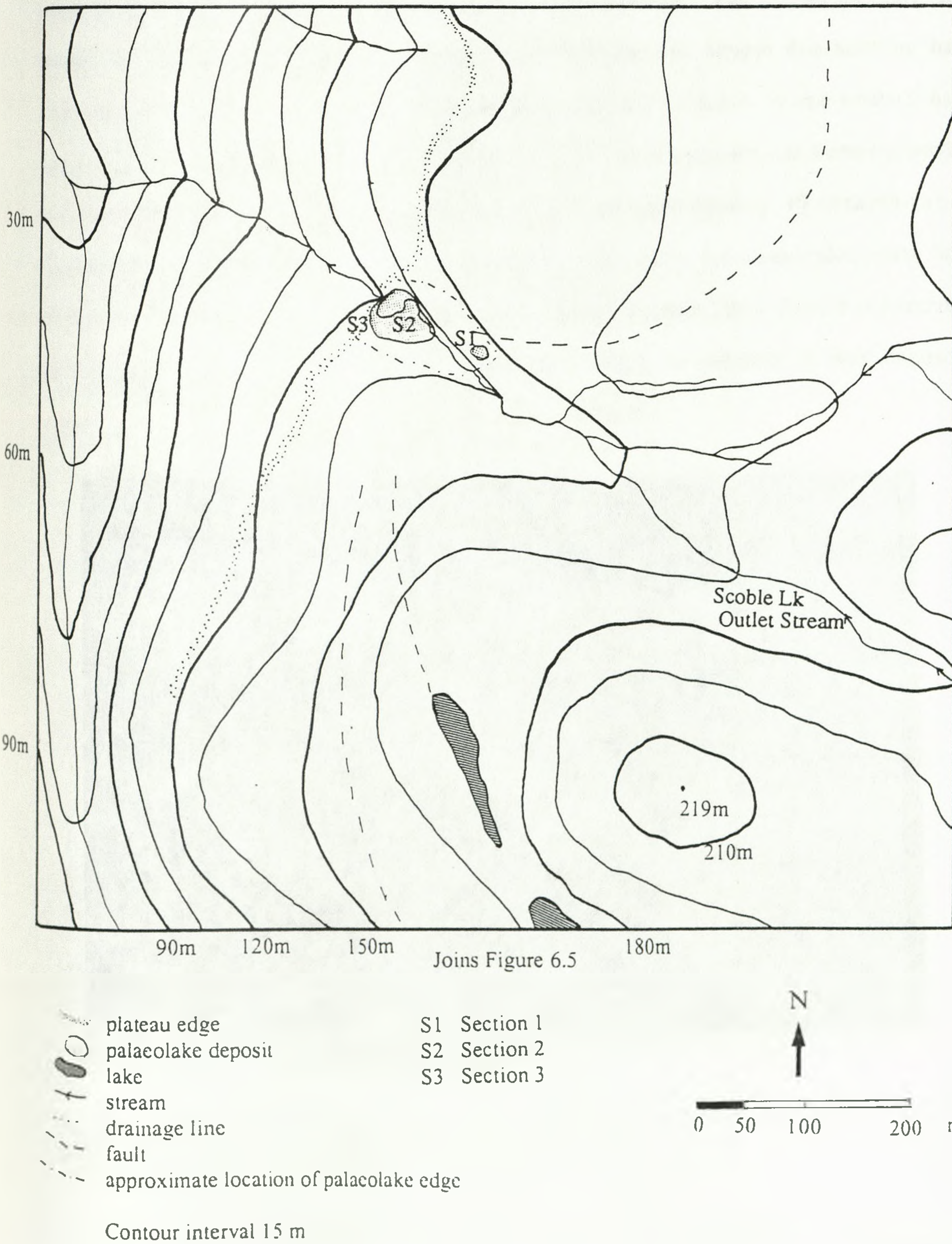


Figure 5.2. Site map of Palaeolake Half Moon. Contours are redrawn from Blake's 1914 map (Mawson, 1944). Other features of the site were taken from stereo air photographs and field observations.

5.3). The deposit extends up to 40 m east from the western-most exposure and up to 40 m south from the northern-most exposure against the valley wall. The lacustrine material is mostly covered with vegetation and peat, but slumping and stream downcutting have exposed parts of the deposit. The most obvious example of this is in the western bank approximately 10 m east of the cliff line, where up to 2 m of sediment has been exposed in a vertical creek bank (fig. 5.4). Three meters above and approximately 40 m north-east of the western-most exposure is a second, smaller deposit, above the steep-sided north bank of the Scoble Lake outlet stream (fig. 5.5). It is unclear whether this sediment is a remnant of an upper level of the main deposit not yet eroded, or whether it was deposited separately, in a small pool to the east of the main palaeolake.

Figure 5.3. The western-most deposit of Palaeolake Half Moon. The brown sediments (arrowed) are visible below the grey of the gravel layer. Human figures give scale.

As with many of the palaeolakes it is difficult to determine the extent of the former lake Half Moon. Much of the deposit has been lost through erosion and so estimates of the past shoreline locations can only be based on the present locations of lacustrine material

Figure 5.4. Sediment in the bank of the Scoble Lake outlet stream which runs through the Half Moon site. Section 2 was taken on the right (arrowed).

Figure 5.5. Upper deposit of Palaeolake Half Moon. The sediment is a small remnant perched 3 metres above the rest of the deposit. Section 1 is arrowed.

and, more generally, on slope detail. The northern shoreline of the lake must have been controlled by the steep slope immediately to the north of the deposit. The locations of the eastern and southern shorelines can also be approximated, as the lake's extent must have been constrained by the valley walls. The exact locations of these shorelines are uncertain as erosion and slumping in the valley have greatly altered the topography since the lake's drainage. Evidence of this can be seen in the six metres of loose gravels and cobbles that now overlie the western-most exposure (fig. 5.3). The western extent of the palaeolake is impossible to determine as it is with most of the palaeolakes, because so much of the former plateau has been eroded (fig. 5.2).

The lacustrine material of Palaeolake Half Moon contains abundant plant fossils. The basal layers of the deposit are rich, blue diatomite which grades upwards into diatomite with thin macrophyte bands. These macrophyte bands, containing *Myriophyllum triphyllum* and moss fragments, becoming thicker with more plant material and less sediment closer to the top (fig. 5.6).

Figure 5.6. *Myriophyllum triphyllum* outcrops where erosion has removed the clayey sediment at the western edge of the palaeolake.

Three samples from Palaeolake Half Moon were radiocarbon dated. Two samples from the stream bed were dated at 10 560 ± 80 RC y BP (SUA 2995; Section 2, 0.6 m) and at 12 970 ± 80 RC y BP (SUA 2996; Section 2, 1.3 m). A sample from the uppermost deposit was dated at 11 110 ± 100 RC y BP (Section 1, 2.2 m). This shows the main deposit and the upper deposit were contemporary. Locations of the three sections sampled are shown in figures 5.2 and 5.7.

Section 1, sampled in the 1990/1991 field season, is on a south-west facing bank of the Scoble Lake outlet stream, approximately 3 m above the main deposit (fig 5.4). It is 4.0 m deep, grading from clay at the base to clay with thin macrophyte bands at 3.3 m. These become thicker and more abundant at 2.6 m. At 2.0 m and 1.9 m there are two narrow iron concretions (each 50 mm wide). Above these the deposit changes to grey clay with gravel inclusions, grading into laminated sand with gravel at 1.3 m. Peat is present above 1.3 m to the modern peat/soil surface at 0 mm. A stratigraphic diagram of Section 1 is shown in figure 5.8.

Section 2 was sampled (summer 1990/1991) in the west bank of the Scoble Lake outlet stream where the exposure was the deepest (fig. 5.4). It extends from a gravel base 0.1 m below creek level, to 2.6 m above the gravel where there is a sharp, horizontal discontinuity between grey lacustrine clays below and the dark brown modern peat overlying it. This discontinuity, which is lower than the upper levels of the deposit, appears to have been formed by stream action eroding some lacustrine material here prior to further downcutting by the stream. The surface was then colonised by vegetation, preventing further erosion of this surface. A thick layer of peat subsequently formed. The lacustrine material is a rich blue/grey with thin bands of macrophytes present throughout. These become thicker nearer the top. A stratigraphic diagram is shown in figure 5.8.

Figure 5.7. Panoramic photograph of the Palaeolake Half Moon valley from Hill 219 (figure 5.5). The overlay shows the locations of the three sections and the Scoble Lake Outlet stream.

Figure 5.7. Panoramic photograph of the Palaeolake Half Moon valley from Hill 219 (figure 5.5). The overlay shows the locations of the three sections and the Scoble Lake Outlet stream.

Key to Figure 5.8

modern peat
clay with macrophytes
clay without macrophytes
iron concretions
sand with gravel inclusions
clay, no diatoms
gravel

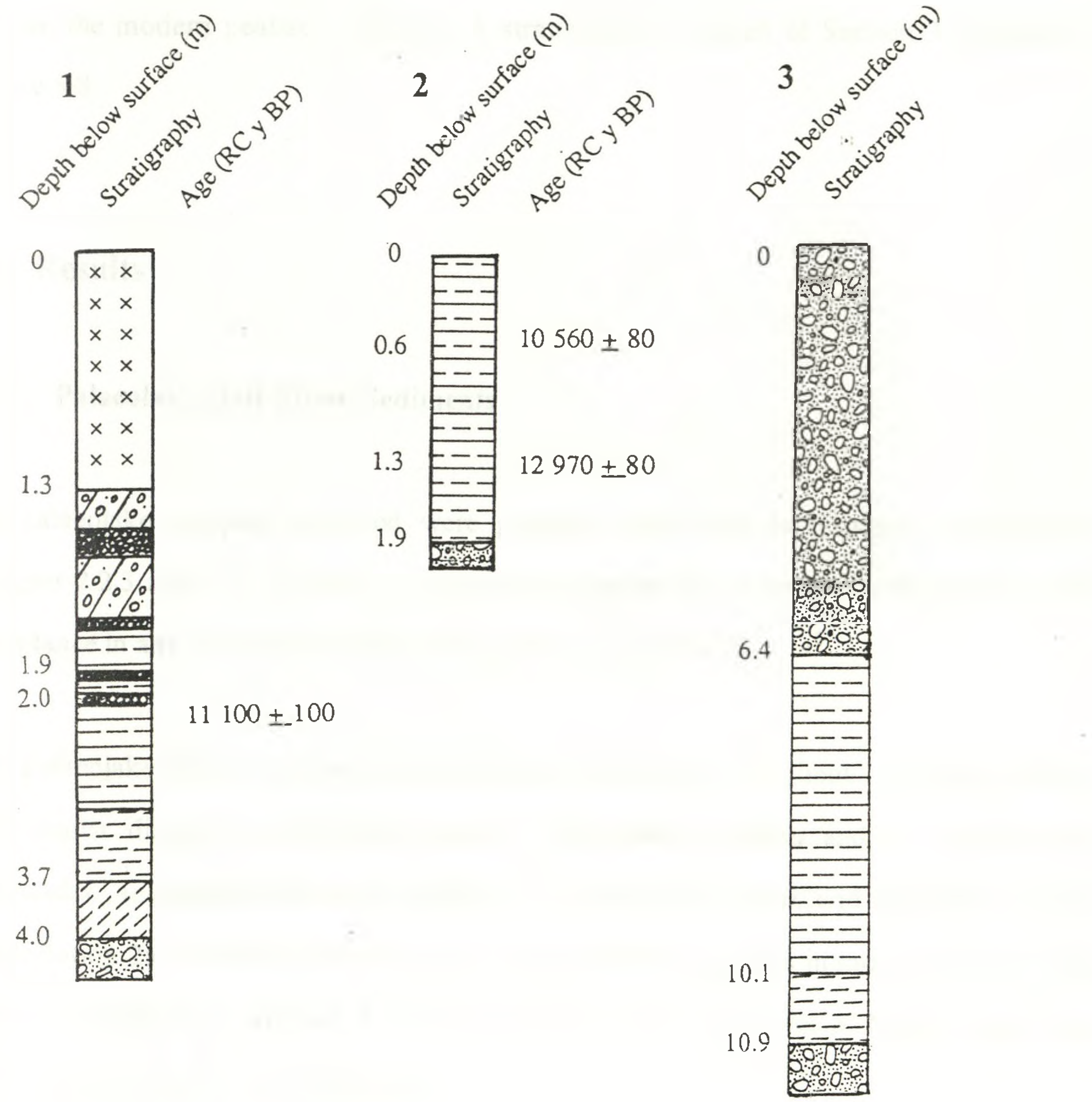


Figure 5.8. The stratigraphy of the three sections from Palaeolake Half Moon. 1 = Section 1, 2 = Section 2, 3 = Section 3. Symbol codes are listed opposite.

Section 3 was the deepest section, sampled in the western-most exposure above the relict marine cliff in the summer of 1991/92 (fig. 5.3). The sediment is 4.5 m thick, with 6.4 m of gravel overlying it, making the section a total of 10.9 m deep. Finely laminated clays at the base overlie massive blue clays derived from weathered bedrock. Macrophyte layers start at 10.1 m and become abundant at 8.8 m. The boundary between lacustrine material and gravel occurs at 6.4 m, and the coarse, unconsolidated gravels and cobbles continue to 0 mm, the modern peat/soil surface. A stratigraphic diagram of Section 3 is shown in figure 5.8.

5.3 Results

5.3.1. Palaeolake Half Moon Sediments

All palaeolake samples collected were prepared following the protocol described in Chapter 2.2.3 and 2.3. Percentage abundance diagrams for all species with more than 2% abundance in any of the three sections are given in Appendix 4..

The Palaeolake Half Moon sediments were rich in diatoms throughout. All three sections had similar diatom associations present. *Achnanthes confusa* and *A. confusa* var. *atomoides, Achnanthidium microcephalum, Diatomella hustedtii,* and *Synedra rumpens* (Association 2a) were the most common and/or abundant species in most samples. Only the top sample from Section 3 (2.2 m) differed from the others in having *Staurosira construens* var. *venter* most abundant.

The TWINSPAN of samples gave four groups at the second level (table 5.1). The eigenvalue was E = .147 at the first division. Group 1 contained five samples from Section 3, with one from section 1. The most abundant species were *Achnanthes confusa, A. confusa* var. *atomoides, Achnanthidium microcephalum, Diatomella hustedtii* and *Synedra rumpens,* which were common to all samples, with other abundant species including *Staurosira construens* var. *venter* (Section 3, 3.0 m, 3.7 m and Section 1, 1.6m), *Achnanthidium lanceolatum* (Section 3, 5.1 m, 4.3 m) and *Fragilariforma virescens* (Section 1, 1.6 m).

Table 5.1. TWINSPAN grouping of the Palaeolake Half Moon samples. Samples are referred to by the section number and depth below the surface in metres (3-5.1 = Section 3, 5.1 m).

Group 1	Group 2	Group 3	Group 4
1-1.3	1-1.6	2-0.5	2-0.1
3-2.2	1-2.1	2-1.5	2-0.3
3-3.0	1-3.7	2-1.3	2-0.7
3-3.7	1-3.0	2-1.7	2-0.9
3-3.9	1-3.3	2-1.9	2-1.1
3-4.3	1-3.7	3-4.6	2-3.9
3-5.1	3-3.4	3-5.5	

Group 2 contained seven samples, with all except 3-3.4 from section 1. *Achnanthes confusa, A. confusa* var. *atomoides, Diatomella hustedtii Pinnularia species A* and *Synedra rumpens,* were present in all samples and *Achnanthidium microcephulum, Gomphonema intracatum* and *Staurosirella construens* var. *venter* were present in six of the seven samples.

Group 3 contained two samples from Section 3 and five from Section 2. *Achnanthes confusa, A. confusa* var. *atomoides, Achnanthidium lanceolatum, A. microcephulum, Diatomella hustedtii, Fragilaria pinnata* and *Synedra rumpens,* were common to abundant in all samples, with *Achnanthidium minutissimum* and *Cymbella gracillis* moderately abundant in six samples.

Group 4 contained the other five samples from Section 2 and the sample from 5.9 m depth in Section 3. *Achnanthidium microcephulum, Diatomella hustedtii, Fragilaria pinnata, Stauriosira construens, Stauriosirella pinnata* and *Synedra rumpens* were present to abundant in all with *Achnanthes minutissima, Martyana martyi* and *Nitzschia inconspicua* present in all but two samples.

The HMDS analysis gave a reasonable spread of samples in 2 dimensions, with a low minimum stress of .142 (fig. 5.9). The placement of samples on the configuration agreed relatively well with the TWINSPAN analysis of samples. Groups 3 and 4 were almost completely separated, although samples from Section 2 which were separated by the

TWINSPAN were placed adjacent by the HMDS. Groups 1 and 2 were less distinct, with some overlap of samples occurring. This can be explained by the low dimensionality of the HMDS plot(the samples may be better grouped in three or four dimensions) and the nature of the TWINSPAN program, which classifies samples according to species presence or absence. Rare species in some samples which appear to be 'misplaced' by the HMDS (e.g. Section 3, 5.1 m, which was placed closer to Group 3 than to other samples in Group 1) may account for their grouping by the TWINSPAN. Two samples from Section 2 (0.1 m and 0.3 m) were placed close together on the HMDS configuration, away from other samples. These had abundant *Diatomella hustedtii* and *Staurosira construens* var. *venter* and *Achanthidium microcephalum* absent. Samples from Section 3, 2.2 m and 3.0 m and Section 1, 1.3 m all had *Staurosira construens* var. *venter* present. It was dominant in 3-2.2. *Diatomella hustedtii* was most abundant in 1-1.3, with *S. construens* var. *venter* moderately abundant.

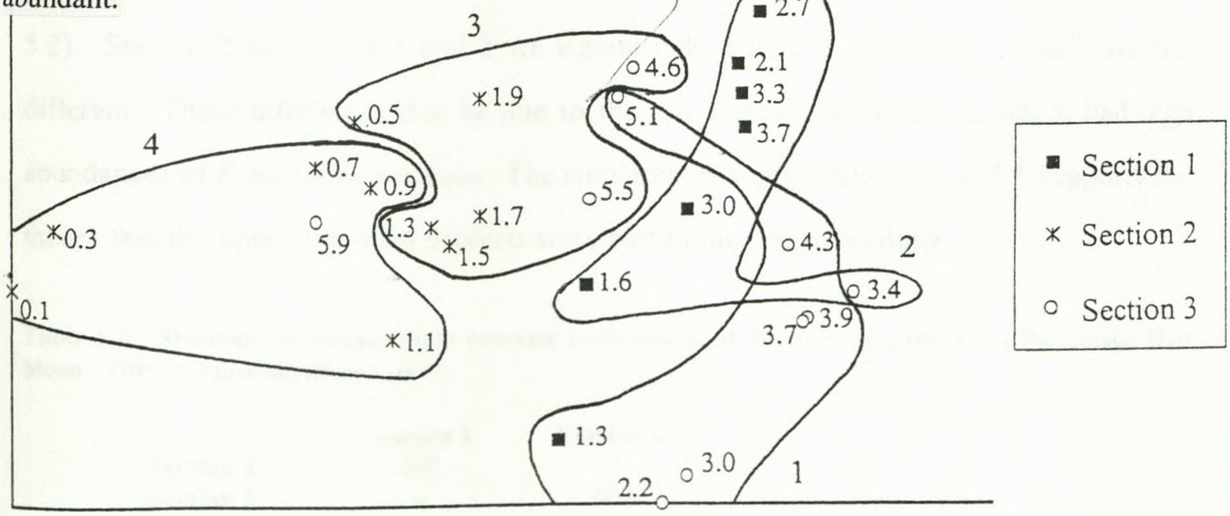


Figure 5.9. HMDS of Palaeolake Half Moon samples in two dimensions. Minimum stress was .142. The samples from the three sections are all intermingled on the plot, indicating similarities between them. twinspan groupings are circled and numbered. The sample sumbers refer to depth in metres below the surface.

The remainder of the samples had *Achnanthes confusa, A. confusa* var. *atomoides*, *Achnanthidium microcephulum, Diatomella hustedtii* and *Synedra rumpens* as the most abundant species. *Diatomella hustedtii* became more abundant in the samples towards the base of axis 2, *A. microcephulum* became more abundant in samples at the top of axis 2. The percent abundance of *Achnathes confusa* increased twoards the right of axis 1 and the abundance of *Staurosira construens* var. *venter* became greater at the left of axis 1.

The sediments are principally dominated by the *Achnanthes confusa/Achanthidium microcephulum/Diatomella hustedtii/Synedra rumpens* association (Association 2a) with few exceptions. Two samples had *Staurosira construens* moderately abundant, and one had *S. construens* var. *venter* dominant.

An anosim of the three sections was conducted to test whether there were significant differences between the sections. The results are given below in a table of *p*-values (table 5.2). Section 2 and 3, and 1 and 2 are significantly different. Sections 1 and 3 are not different. These differences may be due to the few samples in Section 2 which had high abundances of *Diatomella hustedtii*/ The similarity between Sections 1 and 3 supports the theory that the upper and main deposits were part of the one palaeolake.

Table 5.2. Summary of *p*-values from pairwise comparisons of the three sections from Palaeolake Half Moon. The - = a non-significant result.

	Section 1	**Section 2**
Section 2	.002	
Section 3	-	.002

5.3.2 Comparison of Palaeolake Half Moon with other environments

Only information obtained from modern lake and modern mire (surface) samples were used in the analyses. Data from modern lake samples was provided by T. P. McBride. Mire samples which were dominated by *Eunotia exigua* were excluded from the analyses as no palaeolake samples were found dominated by this species. Inclusion of this species served to compress the configuration, with palaeolake and mire samples not dominated by *Eunotia exigua* placed adjacent.

Lakes

The HMDS analysis of samples from seven modern lakes combined with the samples from Palaeolake Half Moon gave four distinct groups, with a low minimum stress of .147 (fig. 5.10). The mesotrophic/eutrophic lakes such as Brothers and Square Lakes were well separated from the other samples. These lake samples were from rocks or *Myriophyllum triphyllum*. The lakes are nutrient-rich, shallow and alkaline with abundant macrophytes and have comparatively high conductivities for Macquarie Island plateau lakes (see table 1.1).

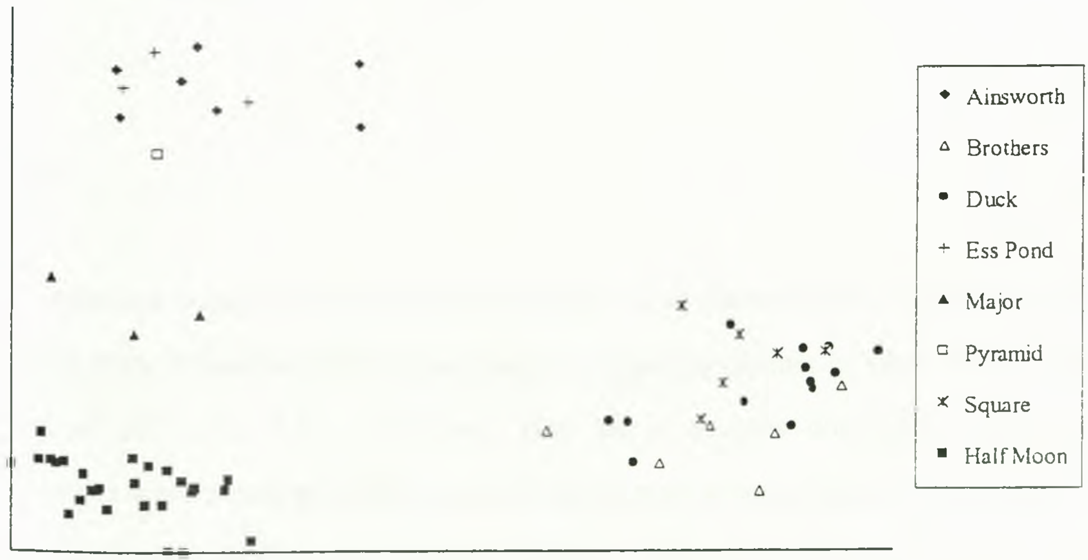


Figure 5.10. HMDS of Palaeolake Half Moon and seven modern lakes in two dimensions. Minimum stress was .147. Four groups are clear - Half Moon, Major Lake, other oligotrophic lakes (Ainsworth Lake, Pyramid Lake and Ess Pond) and meso/eutrophic lakes (Square Lake, Brothers Lake, Duck Lagoon).

A second group of modern lakes was from the oligotrophic lakes such as Ainsworth Lake. These lakes are generally nutrient-poor, deep, with few macrophytes, a pH between 6.1 and 7.3 and have relatively low conductivities. Major Lake, also classed as oligotrophic, was placed away from the other oligotrophic samples, closest to the samples from Half

Moon. Palaeolake Half Moon separated out from almost all of the modern lakes, with the samples grouped in a discrete unit.

An ANOSIM of modern lake samples and Palaeolake Half Moon samples reinforces this grouping. Palaeolake Half Moon was significantly different to all modern lakes (table 5.3).

Table 5.3. Summary of *p*-values from pairwise comparisons of Palaeolake Half Moon and modern lake samples.

	Half Moon
Ainsworth Lake	.002
Brothers Lake	.002
Duck Lagoon	.002
Ess Pond	.002
Major Lake	.002
Pyramid Lake	.003
Square Lake	.002

Mires

A comparison using HMDS of mire surface samples not dominated by *Eunotia exigua* with samples from Palaeolake Half Moon gave two relatively distinct groups, with a minimum stress of .182 (fig. 5.11). The two Half Moon samples dominated by *Staurosira construens* were placed as outliers, apart from the main group of palaeolake samples. The majority of mire samples were grouped together, with only two placed relatively close to the Half Moon samples.

The ANOSIM of mire surface samples and Half Moon samples agreed with the separation of the samples by the HMDS. The *p*-values for the comparisons are listed in table 5.4.

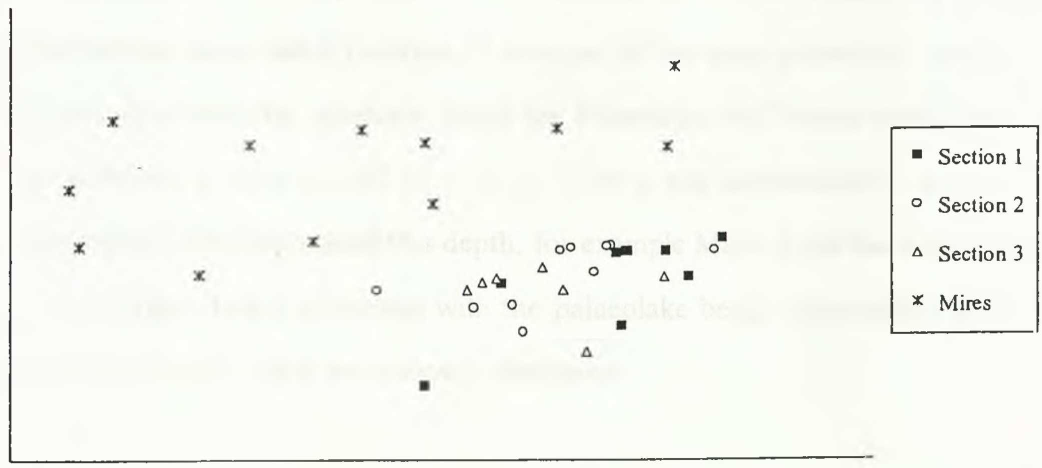


Figure 5.11. HMDS of Palaeolake Half Moon and modern mire samples not dominated by *Eunotia exigua* in two dimensions. Minimum stress was .182. Two groups of samples are obvious, with the Half Moon and mire samples separated.

Table 5.4. Summary of pairwise comparisons of Palaeolake Half Moon and mire surface samples.

	Mires
Half Moon section 1	.006
Half Moon section 2	.003
Half Moon section 3	.002

5.3.3 Palaeolake Half Moon as a diatom habitat

Separation of the Half Moon samples from modern lake and mire samples by the HMDS analyses indicates that no directly comparable environment has yet been found on Macquarie Island for Palaeolake Half Moon. The closeness of Half Moon to Major Lake on the HMDS shows the diatom assemblage was most similar to that in Major Lake (fig. 5.10). From this, it is possible to conclude that Palaeolake Half Moon was probably most similar to Major Lake in terms of environment - that Half Moon was oligotrophic, moderately alkaline, with a low conductivity and macrophytes present but not abundant. The presence of thin bands of *Myriophyllum triphyllum* throughout the sediments supports this. The depth of sediment in Section 3 shows that at this point the water in the palaeolake must have been at least 4.5 m deep at the start of deposition, probably deeper. If the section taken uphill (Section 1) was part of the main palaeolake (and results do not indicate otherwise) the minimum depth for Palaeolake Half Moon would be increased by approximately 6 m to around 10 - 11 m. This is not unreasonable - many of the extant oligotrophic lakes are around this depth, for example Major Lake has a maximum depth of 16.2 m. Again this is consistent with the palaeolake being oligotrophic, as on Macquarie Island mesotrophic lakes are generally shallower.

The main diatom association within Half Moon was Association 2a - *Achnanthes confusa/Achnanthidium microcephulum/Diatomella hustedtii/Synedra rumpens* - which is found in many wet environments on Macquarie Island - mires, creek banks and lakes. It has not been found to occur in sites with environmental extremes - for example where there is low pH or strong currents. The diatom association is consitent with the palaeolake being circumneutral to moderately alkaline. The dominance of ions in Major Lake is only slightly changed from that of sea water (Buckney & Tyler, 1974). This is in the same order as Scoble Lake (Tyler, 1972; Evans, 1970). Palaeolake Half Moon was situted downstream from Scoble Lake and received overflow from it. Because of this, it is probable that Half Moon also had an ionic dominance order similar to that of Major Lake.

There were a few samples dominated by *Staurosira construens* var. *venter* (Association 9a), or with *S. construens* var. *venter* abundant with *Diatomella hustedtii* (Association 9b). This species was not found in great abundances in any modern samples from lakes, mires or terrestrial sites, and so it is impossible to interpret the environment of the palaeolake at the time that the sediments containing Associations 9a and 9b were deposited.

5.4 Comparison of Palaeolake Half Moon with other Palaeolakes

HMDS analyses of Palaeolake Half Moon with each of the other palaeolakes indicates similarities between the sediments from Half Moon and the other four palaeolakes (fig. 5.12). Samples from Palaeolakes Half Moon and Cascade fall into three main groups - Half Moon, Palaeolake Cascade with and without *Cocconeis placentula* (fig. 5.12a). There was no real separation, although there was little 'mixing' of the samples. This indicates Palaeolakes Cascade and Half Moon were reasonably similar.

The sediments from Palaeolake Half Moon and Palaeolake Eagle were more difficult to separate into groups (fig. 5.12b). There were two ouliers from Palaeolake Half Moon (Section 2, 0.1 m and 0.3 m), both with a low abundance of *Synedra rumpens* and *Achnanthes microcephulum* absent. *Caloneis marneri* and *Fragilaira lapponica* were present in these two samples and in no others. The sample dominated by *Staurosira construens* var. *venter* (Section 3, 2.2 m) was placed closer to the samples from Palaeolake Eagle than to the others from Half Moon. The rest of the samples were placed very close to each other.

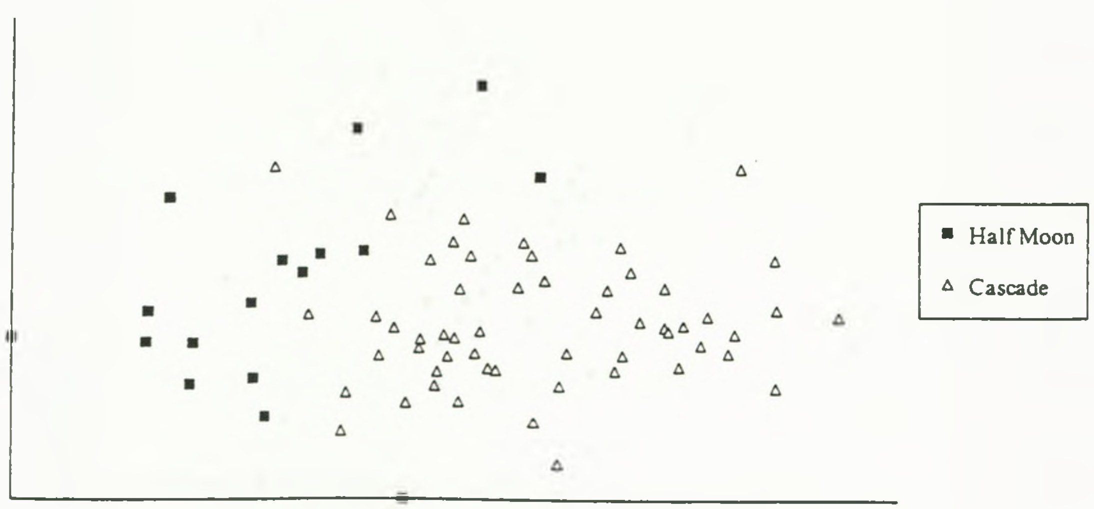


Figure 5.12a. HMDS of Palaeolake Half Moon and Palaeolake Cascade in two dimensions. There was little separation of the samples from the two palaeolakes.

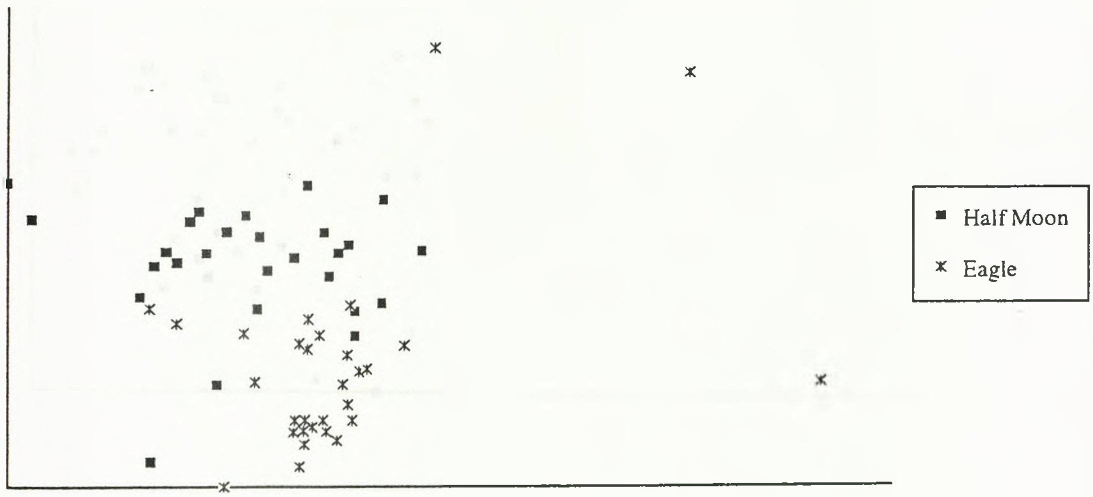


Figure 5.12b. HMDS of Palaeolake Half Moon and Palaeolake Eagle in two dimensions. The samples from the two palaeolakes were very intermingled.

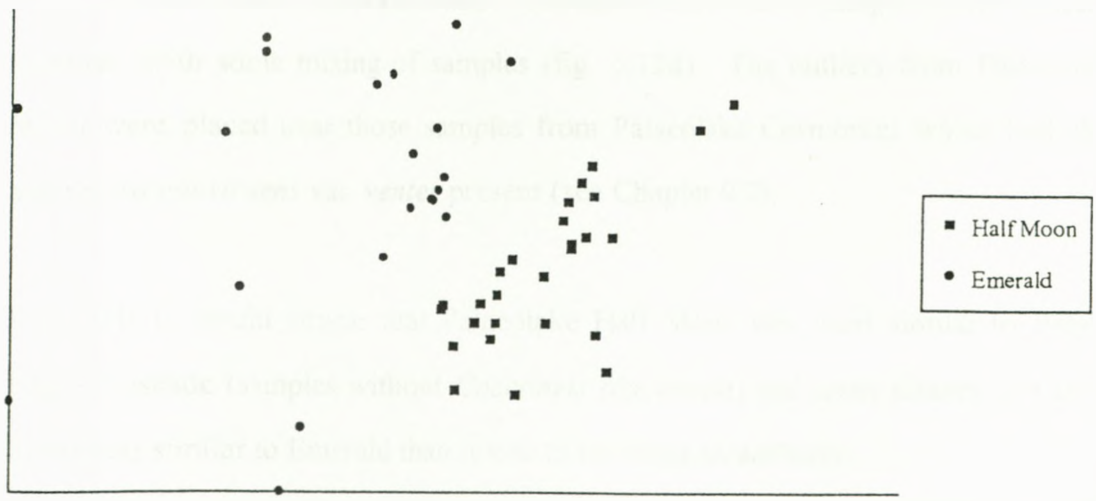


Figure 5.12c. HMDS of Palaeolake Half Moon and Palaeolake Emerald in two dimensions. The samples from the two palaeolakes were reasonably well separated, with those from Emerald much more spread across both axes, indicating a greater variation in the diatom associations.

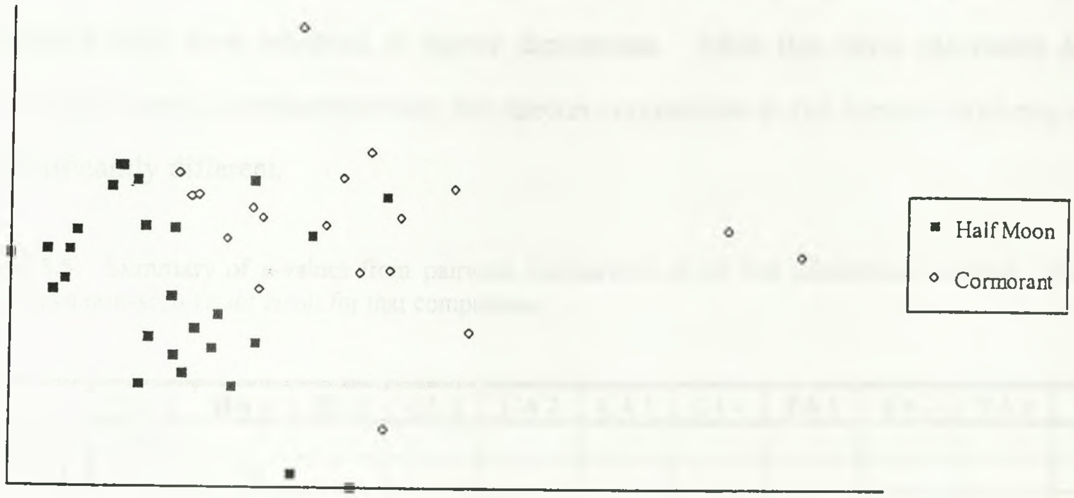


Figure 5.12d. HMDS of Palaeolake Half Moon and Palaeolake Cormorant in two dimensions. There was some intermingling of the samples from the two palaeolakes, although some samples from Cormorant were placed as extreme outliers, indicating a dissimilarity between the diatom associations in these samples and those from Half Moon.

Palaeolake Half Moon and Palaeolake Emerald separated out into two obvious groups, with outliers from Palaeolake Emerald placed well away from the rest of the samples (fig. 5.12c). Palaeolake Cormorant and Palaeolake Half Moon samples were placed close together, with some mixing of samples (fig. 5.12d). The outliers from Palaeolake Half Moon were placed near those samples from Palaeolake Cormorant which had abundant *Staurosira construens* var. *venter* present (see Chapter 9.2).

From this is would appear that Palaeolake Half Moon was most similar to Palaeolakes Eagle, Cascade (samples without *Cocconeis placentula*) and some phases of Cormorant. It was less similar to Emerald than it was to the other palaeolakes.

The ANOSIM comparing these palaeolakes is summarised below, in table 5.5. This table will be referred to in other chapters where palaeolake comparisons are discussed. Palaeolake Half Moon was significantly different to all the other Palaeolakes except

Emerald, which was not significantly different to Half Moon Section 1. Although the samples may have been placed close together by the two dimensional HMDS analyses, separation may have occurred at higher dimensions. While this close placement does indicate that certain similarities exist, the species composition at the various sites may still be significantly different.

Table 5.5. Summary of *p*-values from pairwise comparisons of all five palaeolakes sampled. The * indicates a non-significant result for that comparison.

	HA 1	HA 2	HA 3	CA 1	CA 2	CA 3	CA 4	EA 1	EA 2	EA 3	EM
HA 2	.002										
HA 3	*	.002									
CA 1	.002	.01	.002								
CA 2	.002	.006	.006	.002							
CA 3	.002	.002	.006	.002	.008						
CA 4	.004	.004	.002	.002	*	*					
EA 1	.01	.002	.006	.002	*	.004	.002				
EA 2	.01	.002	.002	.002	.048	.002	.004	*			
EA 3	.002	.002	.01	.002	.004	.018	.002	*	*		
EM	*	.002	.008	.002	*	.008	.002	*	*	*	
CO	.008	.002	.002	.002	*	.004	.002	.02	.01	.046	.002

5.5 Conclusions Drawn from Chapter 5

For most of its history, Palaeolake Half Moon was an oligotophic lake similar in environment to the modern-day Major Lake. The majority of samples had Association 2a present (*Achnanthes confusa/Achnanthidium microcephulum/Diatomella hustedtii/ Synedra rumpens*), with the upper-most sample from Section 3 dominated by *Staurosira construens* var. *venter* (Association 9a) and three samples from Section 2 with *S. construens* moderately abundant (Association 9b). Association 2a appears to represent oligotrophic conditions. At present it is not possible to interpret the sample dominated by *S. construens* var. *venter*, as few modern samples with this species abundant have as yet been collected. The samples with *D. hustedtii* and *S. construens* abundant may represent a slightly different environment, but since *D. hustedtii* does not appear to be able to flourish in extreme environments, it is likely the lake was still oligotrophic.

Palaeolake Half Moon was distinct from all other palaeolakes except Emerald, which was not significantly different from Section 2. Palaeolake Half Moon appeared most similar to Palaeolake Eagle in the HMDS analysis. Interpretations and conclusions about Palaeolake Half Moon are summarised in table 5.6.

Table 5.6. Palaeolake Half Moon - interpretations and conclusions

Diatom Associations	2a. *Achnanthes confusa/Achnanthidium microcephalum/Diatomella hustedtii/Synedra rumpens* 9a. *Staurosira construens* var. *venter* (1 sample) 9b. *Diatomella hustedtii/Staurosira construens* (3 samples)
Vegetation	*Myriophyllum triphyllum* throughout, becoming more abundant as the lake shallowed.
Sediments	Clay, rich in diatoms. Banded *Myriophyllum triphyllum.*
Drainage	Marine undercutting of the sea cliffs.
Depth	+ 10 - 11 m
Size	Unknown. To the east of the western-most exposure it had a maximum estimated extension of 40 m.
Inferred pH	Moderately alkaline.
Inferred Conductivity	Low
Inferred Trophic Status	Oligotrophic
Modern Analogues	Major Lake
Palaeolake Analogues	Eagle very similar Cascade similar in phase without *Cocconeis placentula* Cormorant similar in some phases Emerald least similar

Chapter 6

Palaeolake Cascade

6.1 Synopsis

Palaeolake Cascade is the most complete lacustrine deposit known on the island. The sediments are 7.7 m deep, clay throughout with banded *Myriophyllum triphyllum* and *Fissidens ridigidulus.* Two main diatom associations were present. Analyses of mire and modern lake samples with the Palaeolake Cascade samples show similarities to Major Lake and indicate that Cascade was probably oligotrophic. It was similar to at least some of the sediments in the other palaeolakes examined.

6.2 Location and Site Description

Palaeolake Cascade lies in a broad, flat valley 500 m south of Palaeolake Half Moon, at 130 m a.s.l (fig. 1.16). The deposit is the most complete in terms of lateral extent yet found on Macquarie Island. The northern, southern and western shorelines are still clearly identifiable and the approximate location of the eastern margin has been determined. The cliffs adjacent to the western palaeolake margin were not destroyed by marine erosion, protecting the palaeolake from drainage by cliff undercutting and collapse presumably because bedrock to the west of the palaeolake was more resistant to marine erosion than at other areas along the plateau edge Drainage of Palaeolake Cascade occurred by downcutting of the outlet stream at the western margin of the lake.

To the west, Palaeolake Cascade is bounded by a small rock wall which has been breached at its northern end by stream downcutting (fig. 6.1). Several cobbles with slickensides (fig. 6.2) were found at the site, indicating that the presence of the wall is partially fault controlled. At the northern end the wall is 11 m high, slopes at more than 35° and is oriented at 4°. It curves around to the south-east, becoming less prominent, until the scarp vanishes completely south of the palaeolake (fig. 6.1). As downcutting continued, the two feeder streams - one flowing into the lake from the east, and one from the south - became longer, extending into the area once occupied by the lake. Once the water level fell below the top of the lake sediment, both streams began to cut down into the soft material.

To the north the valley is bounded by a scarp inferred to be associated with a fault zone that runs NNW-SSE. This gives the valley a steep, relatively straight northern margin which rises to about 180 m a.s.l.. Here the slope is interrupted by a relatively flat bench about 30 m wide (fig. 6.3). The bench has two small, elongate lakes on it, with the larger of the two abutting the steep hillside to the north. This slope rises to become Hill 219 and its adjacent ridge which is the watershed between Palaeolake Cascade and the Scoble/Palaeolake Half Moon catchments. The smaller of the two lakes drains via sub surface seepage into the Half Moon valley at the point where an inferred fault enters. The scarp, inferred to be associated with a fault running between Palaeolake Half Moon and Palaeolake Cascade, can be seen in figure 6.3.

There are two major streams which run through the Cascade valley (fig. 6.3). The northern stream ('North Stream') is the longer of the two, and runs into the valley from the east. It originates, in part in the slopes to the south of Boot Hill and in part in the ponds to the south of Scoble Lake. It cuts down through bedrock in its steeper, upper reaches to the east of the palaeolake. Once the stream reaches the broad flat valley it meanders slowly west, cutting through fluvial and peat deposits, then through lacustrine material. A major fluvial deposit is exposed in a north-facing bank of the stream to the east of the

Figure 6.1. The western edge of Palaeolake Cascade, with the point where the outlet stream breached the lake. The small fault associated with the breach curves to the left before disappearing.

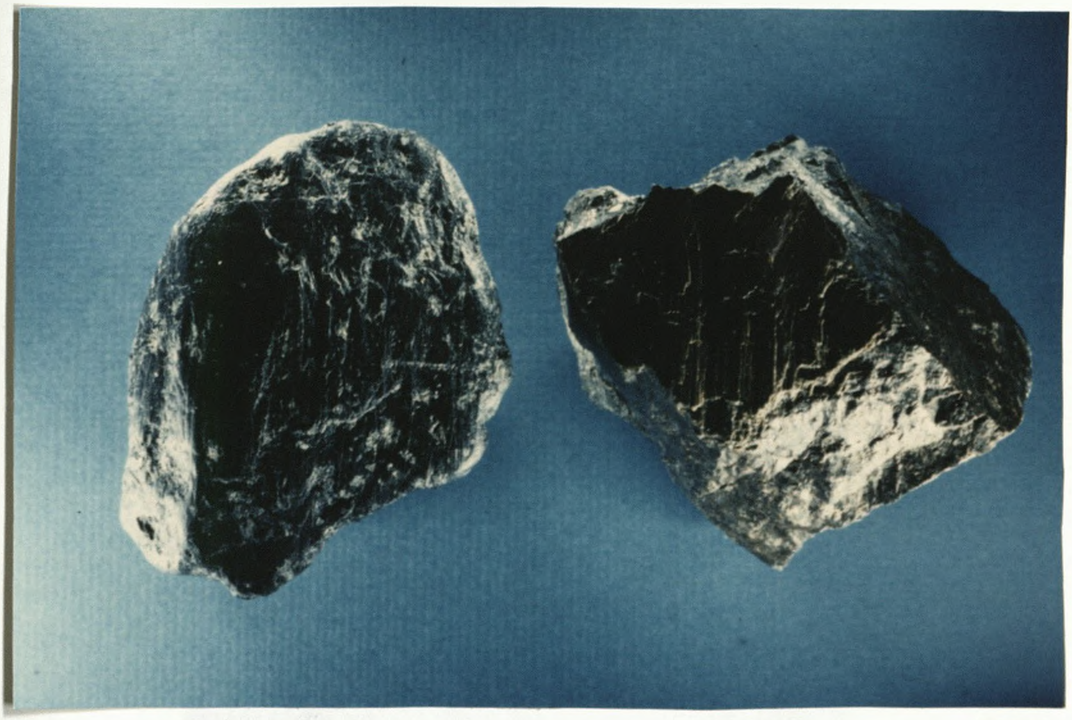


Figure 6.2. Two cobbles collected from just west of the breach wall of Palaeolake Cascade. Slickenslides, striations formed by movement of the rocks within a fault, are visible. (Photograph J. Norman and R. Oldfield.)

Figure 6.3. Panorama photograph of Palaeolake Cascade from the north. The overlay shows the approximate palaeoshoreline (dashed line), locations of the sections (eg. 1 = Section 1). Section 4 is not visible, but its position is indicated. Other marked features are North Stream (N) and South Stream (S), the fluvial deposit (F) and the meander scars associated with North Stream (M).

Figure 6.3. Panorama photograph of Palaeolake Cascade from the north. The overlay shows the approximate palaeoshoreline (dashed line), locations of the sections (eg. 1 = Section 1). Section 4 is not visible, but its position is indicated. Other marked features are North Stream (N) and South Stream (S), the fluvial deposit (F) and the meander scars associated with North Stream (M).

palaeolake sediments (fig. 6.4). It is over three metres deep and contains unconsolidated sands and gravels, with an obvious band of unsorted material in the top of the deposit. There are two lenses of macrophyte material (mainly *Myriophyllum triphyllum*) at different orientations. North Stream has cut a series of meander scars into the peat to the east of the fluvial deposit. The migration of the stream channel has left a series of cut-off pools which are slowly being infilled with vegetation (fig. 1.10).

Figure 6.4. Fluvial deposit on the south bank of North Stream, Palaeolake Cascade. The overlay indicates the stratigraphy of the profile. Location of the fluvial deposit is shown in figure 6.3 and figure 6.5.

The stream to the south ('South Stream') originates on the plateau almost directly south of the palaeolake (fig. 6.3). In its upper reaches it runs through relatively flat, boggy ground, separated from the Island Lake catchment by a low watershed. It steepens downstream, cutting through bedrock before reaching the Cascade valley. Here the stream becomes less steep, but has not cut broad meanders as North Stream has. The channel is quite rocky and relatively straight with high banks. It cuts through a small west-facing fluvial deposit just before a sharp, almost 90° bend to the west where the stream joins another, much smaller drainage line. The stream then runs west, cutting a fairly narrow channel through the lacustrine material until it reaches the west wall (fig. 6.3). Here South Stream turns sharply to the north before joining North Stream just beyond this. The large stream then plunges down through the breach in the wall where it enters the large, rocky gorge which runs into the valley below Palaeolake Half Moon.

Between the two streams is a 'raised' flat-topped area of lacustrine material, visible in figure 6.3, which extends 100 m east of the western convergence of the two streams and reaches a maximum north-south width of 20 m. This lacustrine 'mesa' is for the most part steep-sided (> 30°), with the deepest exposures seen in the deposit along its sides.

The shorelines of the palaeolake were determined using an eye spirit level. Using the top of the west wall as an approximate upper lake level, points at the same level around the valley were determined and were marked onto a base map. An auger was used to check whether lacustrine material was present within and outside these limits. A map of the site, with palaeoshorelines, deposit locations, section locations, the fluvial deposit and auger points is given in figure 6.5. To the north the palaeoshoreline was relatively easy to see, running along the northern fault line. It was less obvious to the south, though it could be seen as a double break of slope - from shallow to steep to shallow. However, the eastern edge of the palaeolake was not obvious and has been inferred.

The deposit is relatively uniform throughout, with rich diatomite interbedded at frequent intervals with thin bands of macrophytes. There are extensive exposures of the lacustrine material, occurring on eroded creek banks or in areas where recent slumping has occurred. As there were thick peat deposits and short herbfield vegetation growing over much of the lacustrine material it was difficult to obtain a complete section in one place. Advantage was taken of areas where natural erosion or slumping had exposed the lacustrine material over several metres and, where possible, a shovel or auger was used to extend profiles.

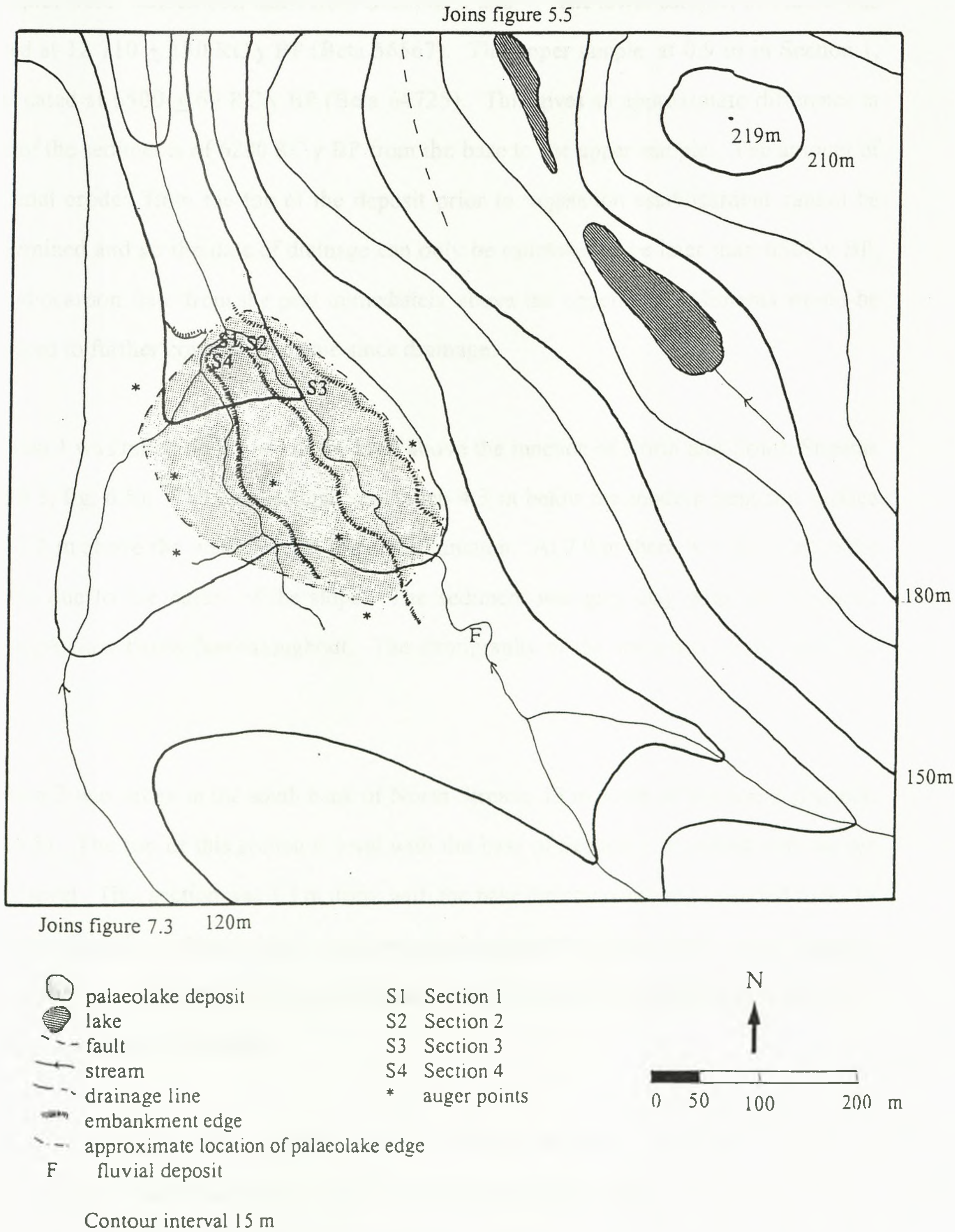


Figure 6.5. Site map of Palaeolake Cascade. Contours are redrawn from Blake's 1914 map (Mawson, 1943). Other features of the site were taken from stereo air photographs and field observations.

Samples were radiocarbon dated from Sections 1 and 4. The lower sample, at 7.2 m, was dated at 12 710 $\pm$ 130 RC y BP (Beta 56567). The upper sample, at 0.9 m in Section 1, was dated at 6500 $\pm$ 60 RC y BP (Beta 64725). This gives an approximate difference in age of the sediments of 6200 RC y BP from the base to the upper sample. The amount of material eroded from the top of the deposit prior to vegetation establishment cannot be determined and so the date of drainage can only be estimated to be later than 6500 y BP. A radiocarbon date from the peat immediately above the uppermost sediments would be required to further constrain the time since drainage.

Section 1 was taken on the end of the bluff above the junction of North and South Streams (fig 6.3, fig. 6.5). The basal sample was taken 4.3 m below the modern peat/soil surface and 3.2 m above the water level at the creek junction. At 2.0 m there is a 90° turn in the profile due to the nature of the slope. The sediment was grey clay with finely banded *Myriophyllum triphyllum* throughout. The stratigraphy of the section is shown in figure 6.6.

Section 2 was taken in the south bank of North Stream, 13 m north of Section 1 (fig. 6.3, fig. 6.5). The top of this section is level with the base of Section 1, matched with an eye spirit level. This section was 1.3 m deep, with the base directly overlying rounded rocks to 200 mm diameter. Above this the sediment and macrophytes were fairly evenly banded. The section has been truncated by past stream erosion at 0 m. A stratigraphic diagram of Section 2 is given in figure 6.6.

Section 3 was taken in the north bank of North Stream, on a steep slope about 11 m north of the current stream bank (fig 6.3, fig. 6.5). The exposure was about 20 m long, with the deepest sediment exposure in the centre, tapering at either end (fig. 6.7). The section was taken in the centre of the exposure and measured 3.0 m vertically from the peat/soil surface to the base of the exposure. The modern peat/lacustrine boundary was at 200 mm. Below this was a uniform grey clay with thin bands of macrophytes throughout. A stratigraphic

Key to Figure 6.6

modern peat
clay with *Myriophyllum triphyllum*
clay with *Fissidens rigidulus*
clay with macrophytes
sand
gravel

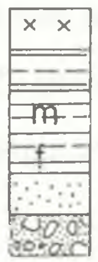


diagram is shown in figure 6.6.

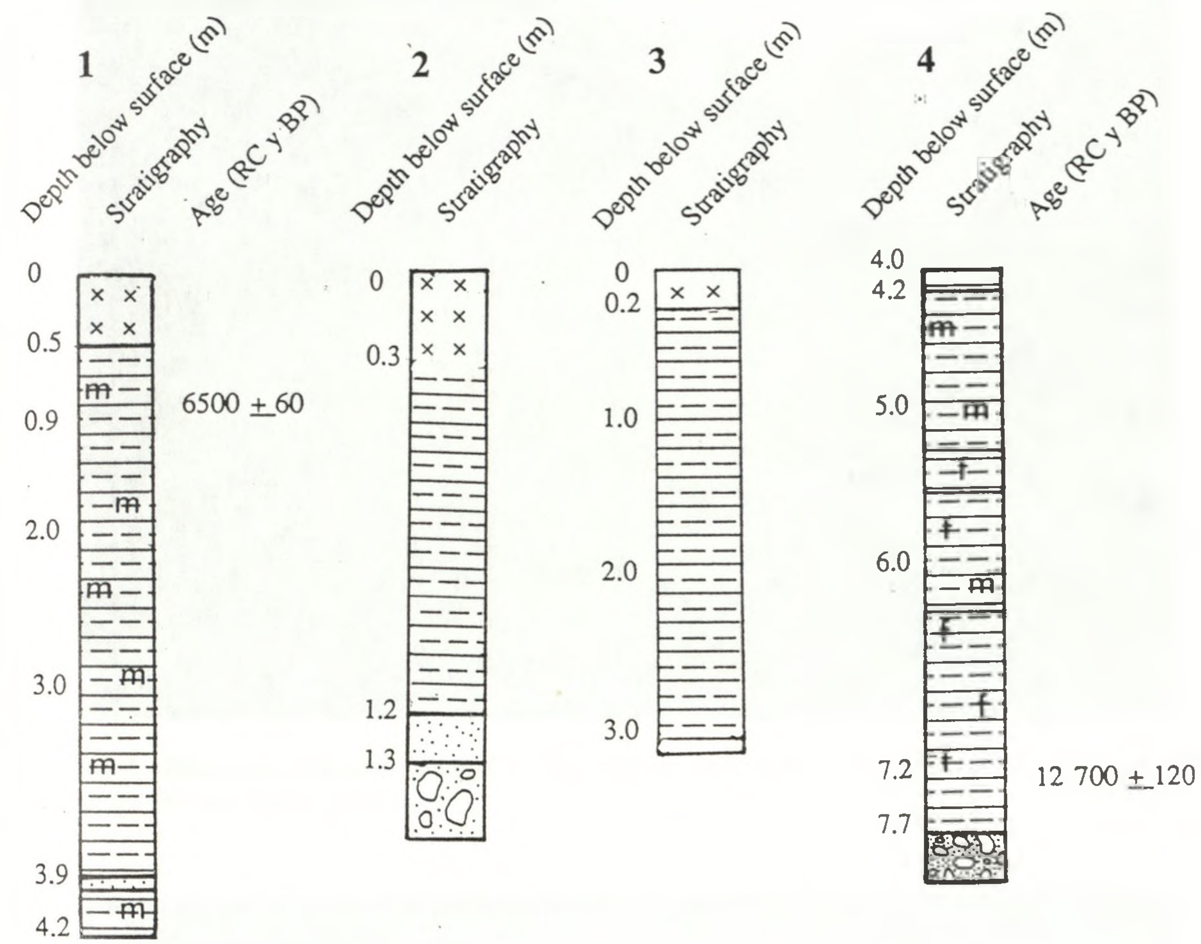


Figure 6.6. The stratigraphy of the four sections from Palaeolake Cascade. 1 = Section 1, 2 = Section 2, 3 = Section 3, 4 = Section 4. Symbol codes are listed opposite.

Section 4 was taken in the north bank of South Stream (fig. 6.3, fig. 6.5). The bank has been eroded almost vertically in part, leaving a bare face of lacustrine material over 2 m high (fig. 6.8). Above this there is modern vegetation growing on a more gentle slope. An auger was used to collect samples from below creek level. *Myriophyllum triphyllum* was present from 4.2 m to 5.0 m From 5.2 m to 6.2 m the moss *Fissidens rigidulus* was abundant, with some *M. triphyllum* present. Below 6.2 m to 7.4 m *F. rigidulus* was present, although it was less abundant than in the upper samples. In the sample from 7.2 m there was some *M. triphyllum,* with no *F. rigidulus* present. Macrophytes were absent from the lower most sample, at 7.7 m. The base of the lacustrine material was encountered at 1.7 m below creek level, overlying loose rock. The stratigraphy is shown in figure 6.6.

Figure 6.7. Palaeolake Cascade, Section 3. The section was taken in the deepest part of the exposure (indicated). Human figure gives scale.

Figure 6.8. Palaeolake Cascade, Section 4. The lacustrine exposure here is over two metres in height. Human figure gives scale.

6.3 Results

6.3.1 Palaeolake Cascade sediments

The percentage abundance diagrams for all species with more than 2% of the total abundance at any depth, from all sections is presented in Appendix 4. Association 2a (*Achnanthes confusa/A. confusa* var. *atomoides/Achnanthidium microcephulum/Diatomella hustedtii/Synedra rumpens*) was dominant in the upper part of the deposit. Association 2c, with the species in 2a plus *Cocconeis placentula*, was present in the lower samples. The change from Association 2a to 2c was abrupt, occurring in Section 1 between 3.0 and 3.2 m and in Section 4 between 4.3 and 4.5 m. It was not associated with any obvious changes in the sediments. *Cocconeis placentula* was present in Section 2 in all samples except for 1.0 m and was present in four samples from Section 3 (1.4 m, 1.8 m, 2.0 m and 3.0 m) in very low abundances.

The discontinuity of *Cocconeis placentula* in Sections 1 and 4 provides a point of overlap for the two sections, independent of the modern geomorphology of the site and the effects of past erosion. Figure 6.9 shows the relationship of the two sections, based on both the top of the present vegetation and the presence/absence of *Cocconeis placentula.*

The TWINSPAN analysis divided the 55 samples from the four sections into two main groups - those with and those without *Cocconeis placentula,* with an eigenvalue of E = .1. At the second division four groups were formed (table 6.1). The low eigenvalue may be due to the great number of samples included in the analysis.

Groups 1 and 2 contained samples without *Cocconeis placentula.* Group 1 had 11 samples from Sections 2, 3 and 4, with the indicator species *Achnanthes minutissima* and *Achnanthidium lanceolatum.* Group 2 had 22 samples: lower samples from Section 1, samples from Section 3 and the majority of samples from Section 4. The indicator species for this group were *Navicula vitabunda* and *Aulacoseira granulata.*

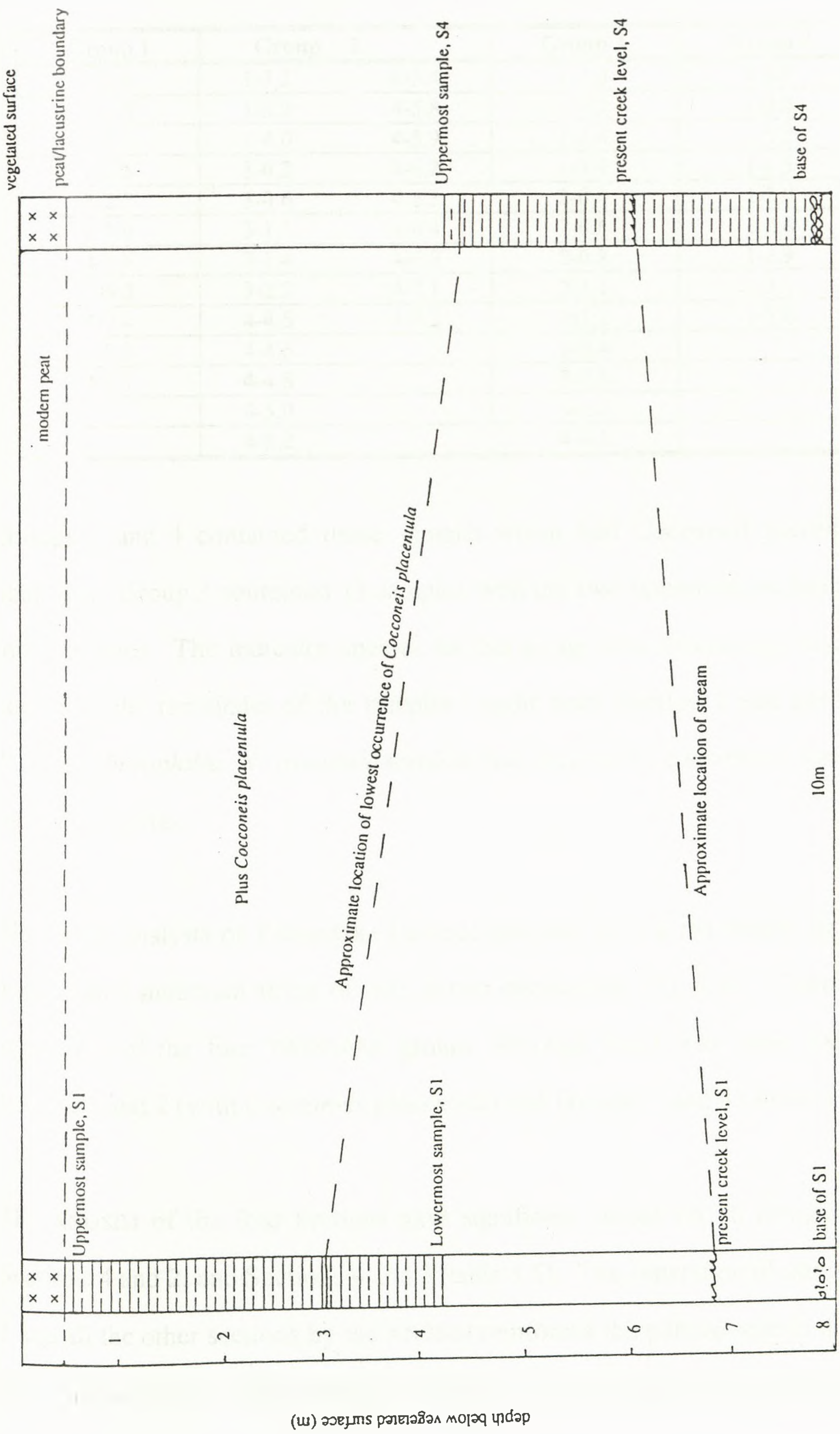


Figure 6.9. Palaeolake Cascade, Sections 1 and 4. The presence/absence of the diatom *Cocconeis placentula* in both profiles provides a point of overlap for the sections, independant of modern-day topography.

Table 6.1. TWINSPAN groupings of the samples from Palaeolake Cascade. The first number refers to the section, the second to the depth, e.g. 2-1.0 is the sample from section 2 at 1.0 m depth.

Group 1	Group 2		Group 3	Group 4
2-1.0	1-3.2	4-5.4	1-1.0	1-0.5
3-1.8	1-3.9	4-5.8	1-1.7	1-0.8
3-2.0	1-4.0	4-5.9	1-2.4	1-1.2
3-2.5	3-0.2	4-6.2	1-3.4	1-1.5
3-2.7	3-0.6	4-6.3	2-0.4	1-2.0
3-3.0	3-1.1	4-6.4	2-0.6	1-2.6
4-5.6	3-1.4	4-6.8	2-0.8	1-2.9
4-6.5	3-2.2	4-7.1	2-1.1	1-3.1
4-7.4	4-4.5	4-7.2	2-1.2	1-3.6
4-7.3	4-4.6		3-0.4	
4-7.7	4-4.8		3-0.8	
	4-5.0		4-4.2	
	4-5.2		4-4.3	

Groups 3 and 4 contained those samples which had *Cocconeis placentula* moderately abundant. Group 3 contained 13 samples, with the two uppermost samples from Section 4 included here. The indicator species for this group was *Achnanthes saxonica.* Group 4 contained the remainder of the samples - eight from Section 1 and one from Section 2. *Navicula bryophilla, N. pseudolanceolata* and *Staurosira construens* var. *venter* were the indicator species.

The HMDS analysis of Palaeolake Cascade samples gave a reasonable spread across both axes, with a minimum stress of .195 in two dimensions (fig. 6.10). There was no distinct separation of the four TWINSPAN groups, although there was some distinction between Groups 1 and 2 (with *Cocconeis placentula*) and Groups 3 and 4 (without *C. placentula*).

The ANOSIM of the four sections gave significant values for all comparisons except for Sections 4 and 2, and Sections 4 and 3 (table 5.5). The separation of samples from Section 1 and all the other sections by the ANOSIM reinforces the pattern seen in the other analyses. This indicates that a major change occurred in the palaeolake, seen in the presence/absence of *Cocconeis placentula.*

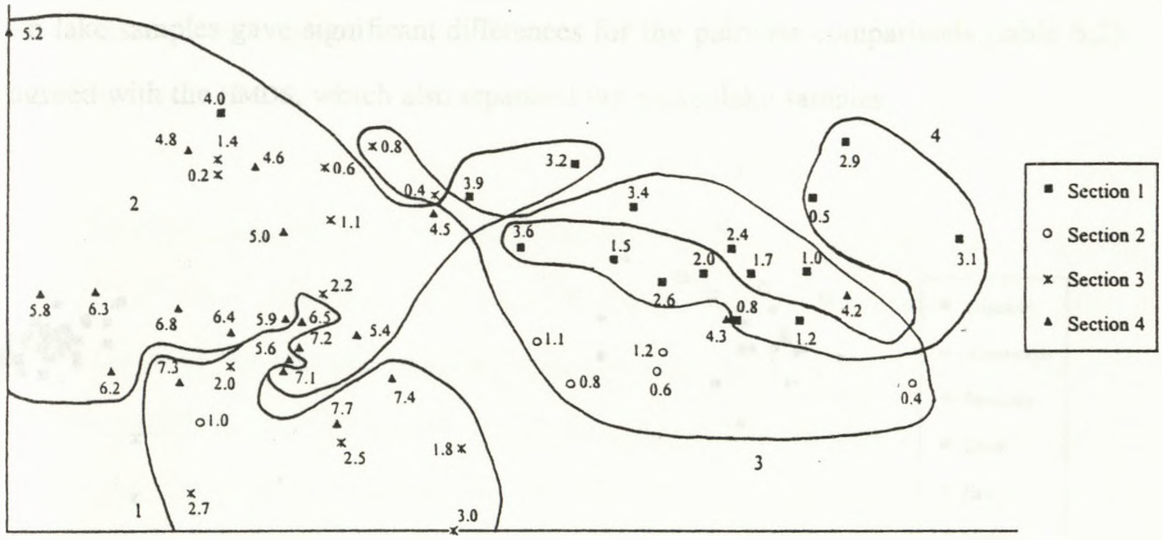


Figure 6.10. HMDS analysis of all samples from Palaeolake Cascade in two dimensions. The minimum stress was .195. There was little separation of the samples in two dimensions. TWINSPAN groups are marked.

The most common and/or abundant species throughout the profile were *Achnanthes confusa*, *Achnanthidium microcephalum*, *Diatomella hustedtii* and *Synedra rumpens*, with other abundant species including *Achnanthes confusa* var. *atomoides*, *Cocconeis placentula* and *Fragilariforma virescens*.

6.3.2 Comparison of Palaeolake Cascade with modern environments

Lakes

The HMDS analysis of Palaeolake Cascade with samples from seven modern lakes gave four distinct groups of samples in two dimensions, with a minimum stress of .193 (fig. 6.11). Palaeolake Cascade samples were clustered tightly, placed away from all other samples. Samples from the oligotrophic Pyramid Lake, Ess Pond and Lake Ainsworth were placed close together. Major Lake samples were placed between the Palaeolake Cascade samples and the other oligotrophic lake samples. The mesotrophic/eutrophic lake samples were grouped together, away from all other samples. The ANOSIM of Cascade samples and the modern lake samples gave significant differences for the pairwise comparisons (table 6.2). This agreed with the HMDS, which also separated the palaeolake samples.

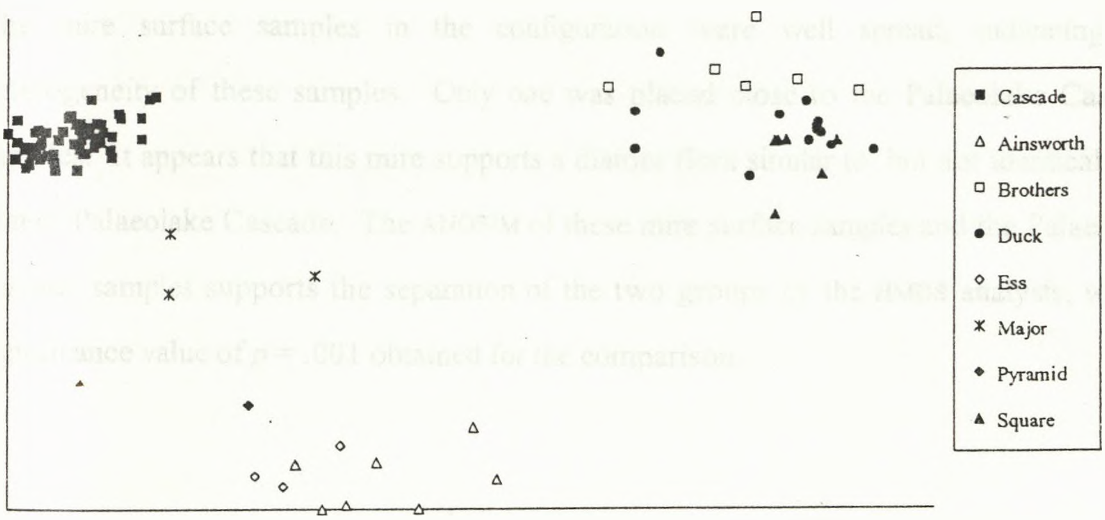


Figure 6.11. HMDS analysis of Palaeolake Cascade and seven modern lakes in two dimensions. Minimum stress was .193. Palaeolake Cascade samples were placed closest to Major Lake samples.

Table 6.2. Table of p-values from pairwise comparisons of Palaeolake Cascade samples and the modern lake samples.

	Cascade S1	Cascade S2	Cascade S3	Cascade S4
Ainsworth Lake	.008	.008	.008	.008
Brothers Lake	.009	.010	.009	.009
Duck Lagoon	.009	.010	.010	.009
Ess Pond	.010	.010	.010	.010
Major Lake	.004	.002	.002	.008
Pyramid Lake	.007	.035	.011	.004
Square Lake	.048	.002	.002	.002

Mires

The HMDS analysis of Palaeolake Cascade (Sections 1 and 4) and mire surface samples (not dominated by *Eunotia exigua*) gave two groups in two dimensions, with a low minimum stress of .121 (fig. 6.12). As in the HMDS analysis of Palaeolake Cascade samples only, the division between those samples with and those without *Cocconeis placentula* can be drawn. Overall, the palaeolake samples were grouped away from the mire samples. As with Palaeolake Half Moon, only mire samples not dominated by *Eunotia exigua* were used for the comparison.

The mire surface samples in the configuration were well spread, indicating the heterogeneity of these samples. Only one was placed close to the Palaeolake Cascade samples. It appears that this mire supports a diatom flora similar to, but not identical with, that of Palaeolake Cascade. The ANOSIM of these mire surface samples and the Palaeolake cascade samples supports the separation of the two groups by the HMDS analysis, with a significance value of $p = .001$ obtained for the comparison.

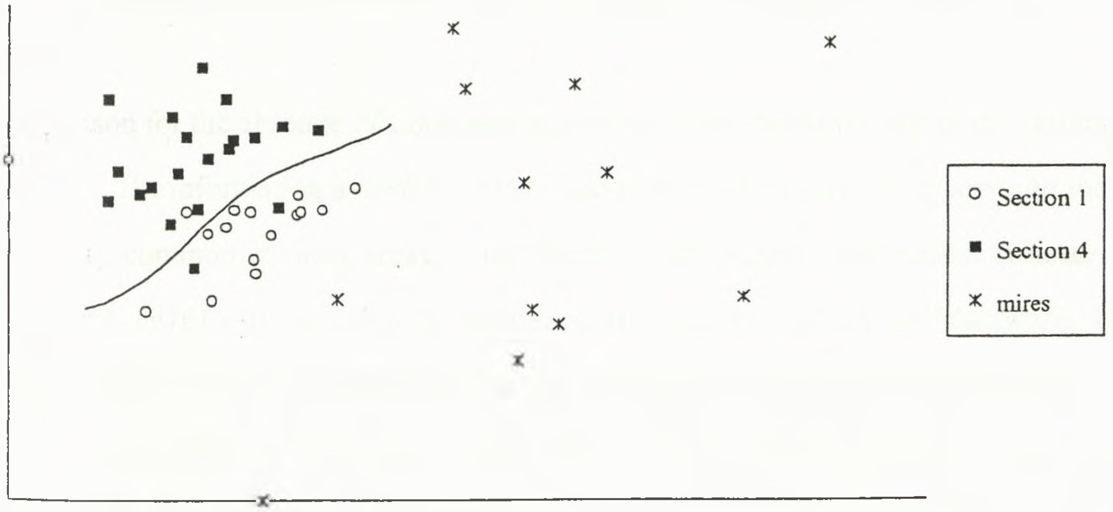


Figure 6.12. HMDS analysis of Paleolake Cascade and mire surface samples not dominated by *Eunotia exigua* in two dimensions. Minimum stress was .121. The samples from Palaeolake Cascade were separated from mire samples. The line drawn between the samples from Palaeolake Cascade separates those with *Cocconeis placentula* (below the line) and those without *C. placentula* (above the line).

6.3.3 Palaeolake Cascade as a diatom habitat

The placement of the Palaeolake Cascade samples near those of Major Lake and their separation from the majority of modern mire samples indicates that the environment of

Palaeolake Cascade was probably most similar to Major Lake, as was Palaeolake Half Moon (Chapter 5.3).

The size of Palaeolake Cascade (~ .008 km^2) was not large by Macquarie Island standards - the estimated shorelines give the palaeolake an area approximately the same size as Floating Island Lake (table 1.1; fig. 1.13). The depth of the palaeolake, based on the depth of sediment and the height of the western breach wall was probably around 11 m at the western end, although weathering and erosion may have lowered the height of the western wall since drainage began. As downcutting at the outlet point and infilling occurred the lake would have become progressively shallower. This is indicated by the bands of *Myriophyllum triphyllum* in the sediment which become thicker and more frequent closer to the top of the sediment, representing more lush growth of the lake vegetation.

The reason for the absence of *Cocconeis placentula* from the lower half of the sediments is unclear. The information available on the ecological preferences of *C. placentula* indicates it is very common in most areas, is indifferent to pH, salinity and current (Gasse, 1986; Haworth, 1976). It occurred in most sampled modern habitats on Macquarie Island, although not in great abundances as well as in sediments from the other palaeolakes. The sudden appearance of *Cocconeis placentula* in the sediments does not appear to be associated with any major environmental change, as the other species present both above and below the discontinuity continue unchanged. Three possible explanations are :

1. *Cocconeis placentula* was introduced to the basin for the first time. This appears unlikely, as it was present throughout sediments of the same age in Palaeolake Eagle, only a few hundred meters to the south over a low watershed (Chapter 7.2, 7.3).
2. Shallowing of the lake allowed *Cocconeis placentula* to establish and flourish. When the lake reached a certain depth *C. placentula* continued to compete successfully with other species as shallowing continued. This appears to be the more likely explanation. It is thought to be a littoral/epiphytic or aerophilic species, and so may only have flourished

as the abundance of *Myriophyllum triphyllum* increased and/or there was sufficient light penetrating to the level of *M. triphyllum* to allow *C. placentula* to grow. However, this does not explain the total absence of the species from the lake in the early stages, as *M. triphyllum* was still present in the lake and would have grown in the shallow margins as well as in the deeper water.

3. An unidentified change in lake water chemistry. At present the environmental preferences for many of the diatom species on Macquarie Island are still poorly understood, although *Cocconeis placentula* is thought to be a fairly ubiquitous, generalist species in more temperate regions and is found in many of the aquatic and terrestrial environments on the island. It is likely that any change in water chemistry drastic enough to allow a species to establish and grow abundantly in a lake where it was not able to do so before would also be reflected in changes in abundance in other species in the lake. This was not the case.

Myriophyllum triphyllum is abundant in the upper part of the deposit, but below 5.2 m, bryophytes are present, becoming moderately abundant towards the base of the deposit. The moss species, *Fissidens rigidulus,* occurs in flowing water in rocky creeks and beside streams and is known from Palaeolake Nuggets sediments (Selkirk & Selkirk, 1982). The moss is well preserved in all sediments, with leaves attached to lengths of stem up to 20 mm long (fig. 1.17). This indicates the *F. rigidulus* probably grew within the lake and the fragments were either deposited *in situ,* or travelled only a short distance before deposition. If the moss had travelled a long distance in a strong current, in a stony creek before being deposited, it is likely that the stems and leaves would be much more fragmented.

Myriophyllum triphyllum does occur in a few bands with the *Fissidens rigidulus*, but here is not as abundant as it is in the upper sediments. The presence/absence of moss does not coincide with the abrupt presence/absence of *Cocconeis placentula*. *Fissidens rigidulus* disappears from the sediments almost 1 m below the first appearance of *C. placentula*. Again, this change could be linked to the increasing light levels as the lake shallowed, which may have allowed *M. triphyllum* to out-compete the moss.

These changes in Palaeolake Cascade - the presence of *Fissidens rigidulus* in the earlier part of the lake's history and the presence of *Myriophyllum triphyllum* and *Cocconeis placentula* in the latter - do not appear be in response to major environmental changes. There is no marked effect on the diatom assemblage above the discontinuity, apart from the appearance of *C. placentula*. The position of the Palaeolake Cascade samples close to Major Lake on the HMDS analysis indicates that, like Palaeolake Half Moon, Cascade was probably most similar to Major Lake - oligotrophic, with few macrophytes, relatively deep, though not large. As infilling occurred and the lake shallowed progressively, more *M. triphyllum* grew, most likely stimulated by the increase in light availability. This is shown in the increase in the thickness and frequency of *M. triphyllum* bands towards the top of the sediments.

6.4 Comparison of Palaeolake Cascade with other Palaeolakes

Because of the great number of samples collected from Palaeolake Cascade, only samples from Sections 1 and 4 were used for the HMDS analysis, as they represented samples from the top of the lacustrine material to the base. These sections were also significantly different to each other in the ANOSIM (table 5.5).

As was shown in Chapter 5.2.4, samples from Palaeolakes Cascade and Half Moon were reasonably similar, although it was possible to distinguish three groups: samples from Half Moon, Cascade samples with *Cocconeis placentula,* and samples from Cascade without *C. placentula* (fig. 5.12a). In the HMDS of Palaeolakes Cascade and Eagle, no such separation of samples occurred. The Cascade and Eagle samples were very intermixed on the two dimensional plot, with a minimum stress of .194 (fig. 6.13a). There were few outliers and no obvious groups formed.

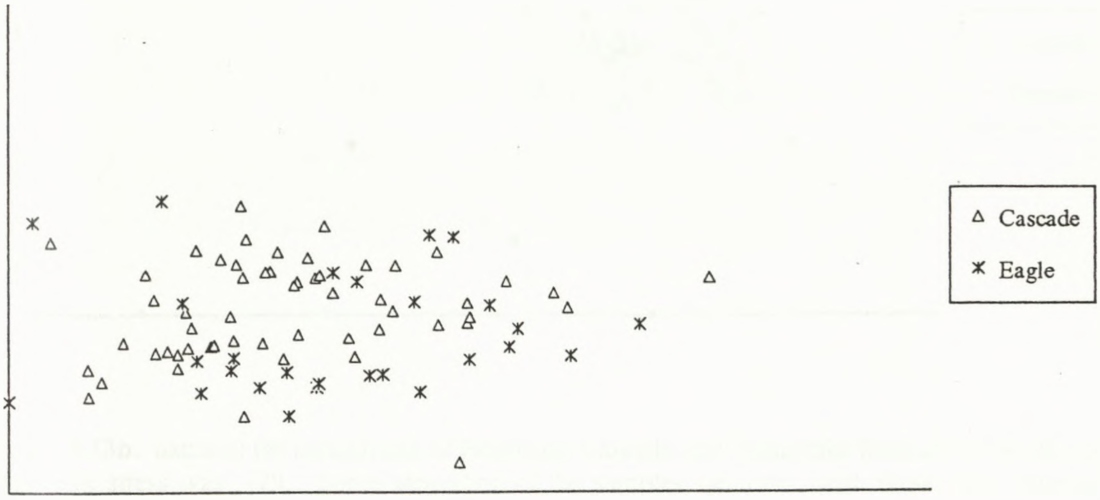


Figure 6.13a. HMDS of the comparison of Palaeolake Cascade and Palaeolake Eagle in two dimensions. Minimum stress was .194. Samples were very intermixed.

Samples from Palaeolakes Cascade and Emerald were mostly grouped together, with some intermingling (fig. 6.13b). The minimum stress in two dimensions was .179. There were some outliers from Palaeolake Emerald - these were mostly samples dominated by species such as *Fragilariforma virescens* and *Pinnularia circumducta*, which occurred in Palaeolake Cascade in low to moderate abundances, not as the dominant or most abundant species.

There was no mixing of the samples from Paleolakes Cascade and Cormorant, although some were placed very close together on the two dimensional configuration, with a minimum stress of .188 (fig. 6.13c). Samples from Palaeolake Cormorant were more spread than those from Palaeolake Cascade, with the outlying samples from Palaeolake Cormorant containing *Martyana martyi, Fragilariforma virescens* or *Staurosira construens* var. *venter* as the dominant or most abundant species.

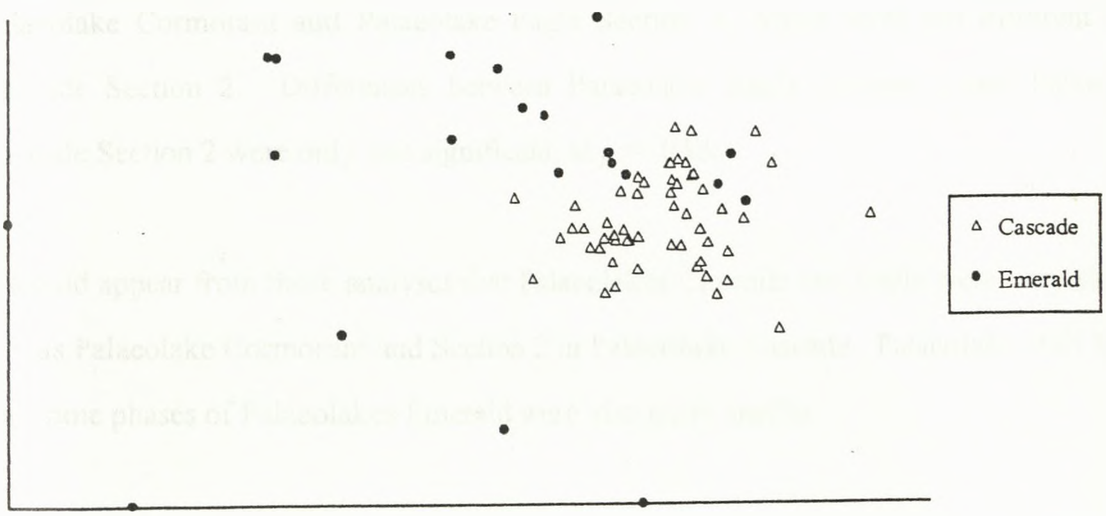


Figure 6.13b. HMDS of the comparison of Palaeolake Cascade and Palaeolake Emerald in two dimensions. Minimum stress was .179. Some separation of the samples occurred, with those from Emerald with unusual diatom associations placed as outliers.

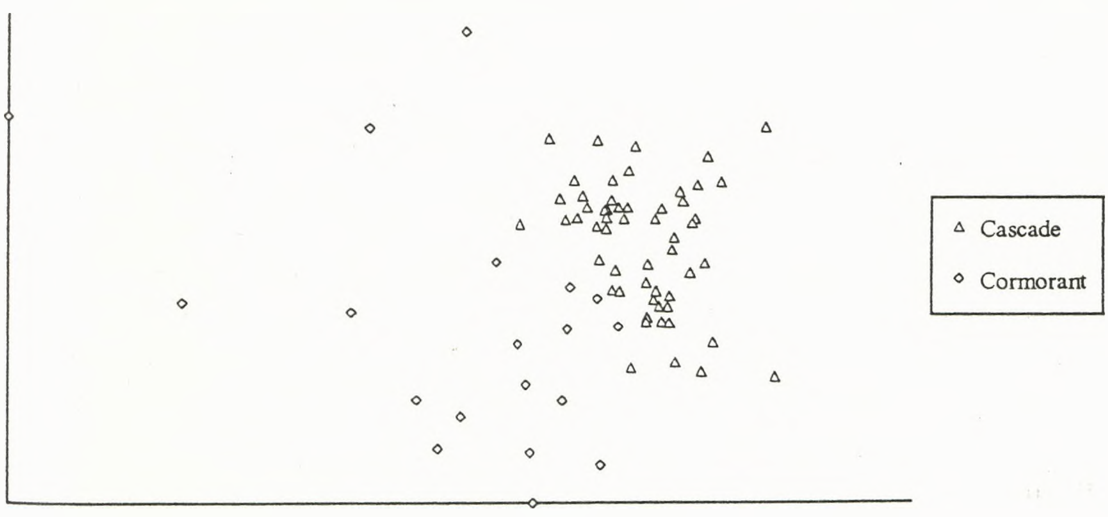


Figure 6.13c. HMDS of the comparison of Palaeolake Cascade and Palaeolake Cormorant in two dimensions. Minimum stress was .188. Samples from Cormorant were more spread than those from Cascade, indicating a greater variation in the diatom associations in Cormorant.

The ANOSIM of Palaeolake Cascade with the other palaeolakes supports the separation of the samples by the two dimensional HMDS configurations. Table 5.5 shows that at the 95%

level, Palaeolake Cascade was significantly different to all other palaeolakes except Palaeolake Cormorant and Palaeolake Eagle Section 1, which were not different from Cascade Section 2. Differences between Palaeolake Eagle Section 2 and Palaeolake Cascade Section 2 were only just significant, at $p = .048$.

It would appear from these analyses that Palaeolakes Cascade and Eagle were very similar, as was Palaeolake Cormorant and Section 2 in Palaeolake Cascade. Palaeolake Half Moon and some phases of Palaeolakes Emerald were also quite similar.

6.5 Conclusions Drawn from Chapter 6

Throughout its history Palaeolake Cascade appears to have been an oligotrophic lake, with an environment similar to the modern day Major Lake.

Two diatom assemblages were present throughout the sediments. Association 2a, with *Achnanthes confusa/Achnanthidium microcephalum/Diatomella hustedtii/ Synedra rumpens*, was present in the upper sediments. Association 2c, with *Cocconeis placentula* moderately abundant with the other species from Association 2a, was present in the lower part of the deposit only. *Fissidens rigidulus* was the dominant macrophyte in Section 4, with *Myriophyllum triphyllum* present above 0.9 m and between 2.0 m and 1.5 m. It became more abundant closer to the top, possibly in a response to the shallowing of the palaeolake over time.

Interpretetations of and conclusions about Palaeolake Cascade are summarised in table 6.3.

Table 6.3. Palaeolake Cascade - interpretations and conclusions.

Diatom Associations	2a. *Achnanthes confusa/Achnanthidium microcephalum/Diatomella hustedtii/ Synedra rumpens* 2c. *Achnanthes confusa/Achnanthidium microcephalum/Cocconeis placentula/D. hustedtii/ S. rumpens*
Vegetation	*Myriophyllum triphyllum* becoming abundant closer to the top *Fissidens rigidulus* abundant in the lower part of the deposit
Sediments	Clay. Rich in diatoms. Banded macrophytes above 7.2 m
Drainage	Stream down cutting at a fault zone at the western edge of the lake
Depth	+ 11 m
Size	approximately 0.008 km^2
Inferred pH	Moderately alkaline
Inferred Conductivity	Low
Inferred Trophic Status	Oligotrophic
Modern Analogues	Major Lake
Palaeolake Analogues	Eagle very similar Half Moon reasonably similar to the *C. placentula* absent phase Emerald similar in some phases Cormorant similar

Chapter 7

Palaeolake Eagle

7.1 Synopsis

Palaeolake Eagle is a small palaeolake deposit located on high cliffs. A second, smaller deposit is situated on an undulating bench 40 m below the main deposit. Sediments were principally diatom-rich clays, with a layer of sediment very poor in diatoms present immediately above the basal sample in all sections. Macrophytes were present in bands above the diatom-poor samples. One diatom association was present throughout the samples. No difference in the diatom associations was seen between the main and lower deposits. Palaeolake Eagle was most similar to Major Lake and very similar to Palaeolakes Half Moon, Cascade and similar to some phases of Palaeolakes Emerald and Cormorant.

7.2 Introduction and Site Description

Palaeolake Eagle is approximately 500 m south west of Palaeolake Cascade, at 150 m a.s.l. (fig. 1.15). It is separated from Palaeolake Cascade by a low ridge that runs north-west, thought to be associated with a fault (fig. 7.2). It is a relatively small remnant of the palaeolake, with much of the lacustrine material eroded by the outlet stream from Island Lake which runs through the site. This stream has cut a relatively steep-sided, straight channel into the bedrock along an inferred fault zone, bisecting the original deposit and leaving two remnants perched on cliff edges (fig. 7.1). The northern deposit, which is the smaller of the two in lateral extent, is south-facing and high above the stream bed (fig. 7.2).

Figure 7.1. Palaeolake Eagle from below. The southern deposit, 40 m above the lower deposit, is arrowed. The small lower deposit is marked with an L.

The larger deposit, 100 m south of the first, is on a small, west-facing cliff approximately 50 m above an undulating bench. This southern exposure is also visible in small gullies on the plateau immediately east of the cliff line, where slumping and erosion have stripped away the surface vegetation and modern peat.

The wave-cut bench, at 100 m a.s.l., occurs only to the south of the stream, with the northern bank of the stream very straight and steep. The bench dips west at approximately 15°, with eroded material from the hillsides above making the top of the bench quite undulating. Close to the stream the bench is being actively eroded, with gullies and slumping evident. One gully, adjacent to the stream and running north into it has a small lacustrine deposit on its eastern side, separate from and 50 m below the main deposit (fig. 7.3). This small deposit is, in all probability, the remnant of a pool fed by the Palaeolake Eagle outlet stream. It will be referred to as the lower deposit.

Figure 7.2. Panoramic photograph of the main Palaeolake Eagle deposit, looking north. The overlay shows the locations of Sections 1 and 2. A flat bench, possibly part of the palaeoshoreline, is visible. The horizon, indicated by an arrow, is the hill that forms the watershed between Palaeolake Eagle and Palaeolake Cascade.

Figure 7.2. Panoramic photograph of the main Palaeolake Eagle deposit, looking north. The overlay shows the locations of Sections 1 and 2. A flat bench, possibly part of the palaeoshoreline, is visible. The horizon, indicated by an arrow, is the hill that forms the watershed between Palaeolake Eagle and Palaeolake Cascade.

Two samples from Section 1 have been radiocarbon dated at 12 200 $\pm$ 130 RC y BP (Beta-56569 - 2.7 m) and 7 030 $\pm$ 80 RC y BP (Beta-64728 - 0.7 m). A sample from the northern deposit was dated at 12 270 $\pm$ 90 RC y BP (Beta-68717, 3.2 m). The lower deposit was radiocarbon dated at 10 380 RC $\pm$ 100 y BP (Beta-56570 - 0.9 m) and, thus, was contemporary with the main deposit.

The approximate locations of the shorelines of Palaeolake Eagle are shown in figure 7.3. As with the other sites, the palaeoshorelines were approximated using a combination of locations and heights of the deposits, plus present-day landform. The relatively flat bench approximately 1.5 m above the top of the deposit (fig. 7.2), runs roughly parallel to the ridge that separates Palaeolakes Eagle and Cascade. This bench is associated with the inferred fault zone which runs through the site and may have formed part of the northern shore. To the east the shore was located approximately using the modern contours and the locations of exposures of the lacustrine material. The southern shoreline must have been constrained by the hillside and approximations of the position of the shore on this hill were made from the estimates of the other shoreline locations. An estimated depth of > 5 m was obtained, using the height of the bench to the north of Section 2 as a guide.

The exact location of the western shoreline is unknown, due to the extent of erosion of both lacustrine and bedrock material. However, because the two deposits were of the same age, the presence of the lower deposit gives a maximum western extent for the palaeolake, just east of the lower deposit (fig. 7.3).

Because of the presence of the bench, drainage of Palaeolake Eagle could not have occurred by marine erosion of cliffs to the west, as it was the cliffs bounding the pre-existing bench that were being eroded by marine activity. Palaeolake Eagle was drained by downcutting of the outlet stream, probably along the zone of weakness where the modern Island Lake outlet stream is still eroding. Continued erosion after lake drainage cut back into the deposit, eventually forming the steep, straight stream bed and removing much of the lacustrine material and the bedrock beneath.

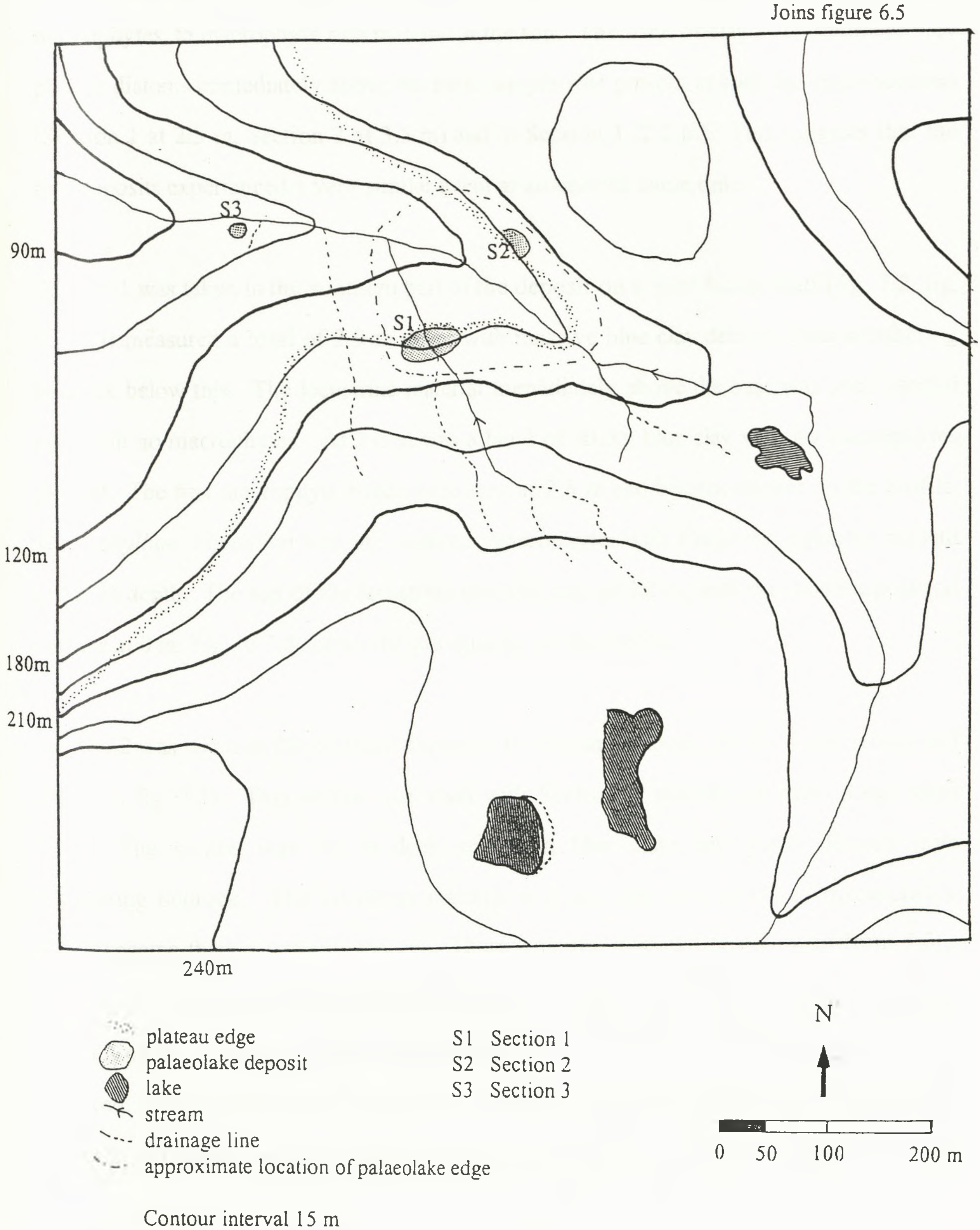


Figure 7.3. Map of Palaeolake Eagle showing major topographic features, section locations, sediment extent and the inferred palaeoshoreline. Contours are redrawn from Blake's 1914 map (Mawson, 1943). Other topographic features are taken from stereo air photographs or from field observations.

The main palaeolake deposit overlies weathered bedrock and grades upwards from massive diatomite at the base, with a diatom-poor band, through to grey clay with banded macrophytes, to macrophyte rich material at the top. The band of clay-sized sediment very poor in diatoms immediately above the basal sample was present in both the upper sections (Section 1 at 2.5 m, Section 2 at 3.5 m) and in Section 3 (2.2 m). This suggests that the two deposits experienced a very similar event at around the same time.

Section 1 was taken in the southern part of the deposit on a west-facing bluff (fig. 7.2, fig. 7.3). It measured a total of 2.9 m deep, with massive blue clay derived from weathering bedrock below this. The lacustrine material immediately above the base was grey banded clay with no macrophytes. At 2.6 m was a band of sticky blue clay with no macrophytes present. The first macrophyte bands were seen at 2.3 m and became thicker up the profile. *Myriophyllum triphyllum* was the common macrophyte, with *Fissidens rigidulus* present at 1.7 m depth. The top of the lacustrine material was at 0.2 m, with the modern peat/soil surface at 0 m. Figure 7.4 shows the stratigraphy of the section.

Section 2 was taken in the northern exposure of the main deposit, on the south-facing cliff (fig. 7.2, fig. 7.3). This section was level with Section 1, determined with an eye spirit level. The section was 4.0 m deep, overlying blue clays and gravel derived from weathering bedrock. The lacustrine material was tan clay with bands of macrophytes, which became thicker towards the top. There was one macrophyte-rich band from 3.2 m to 1.0 m. *Myriophyllum triphyllum* was the most common macrophyte, present throughout the sediments except for one band at 2.5 m depth, where *Fissidens rigidulus* occurred. Sandy gravel was present above 1.0 m to the peat/lacustrine boundary, at 0.5 m. The peat/soil surface was at 0 m. The stratigraphy of Section 2 is shown in figure 7.4.

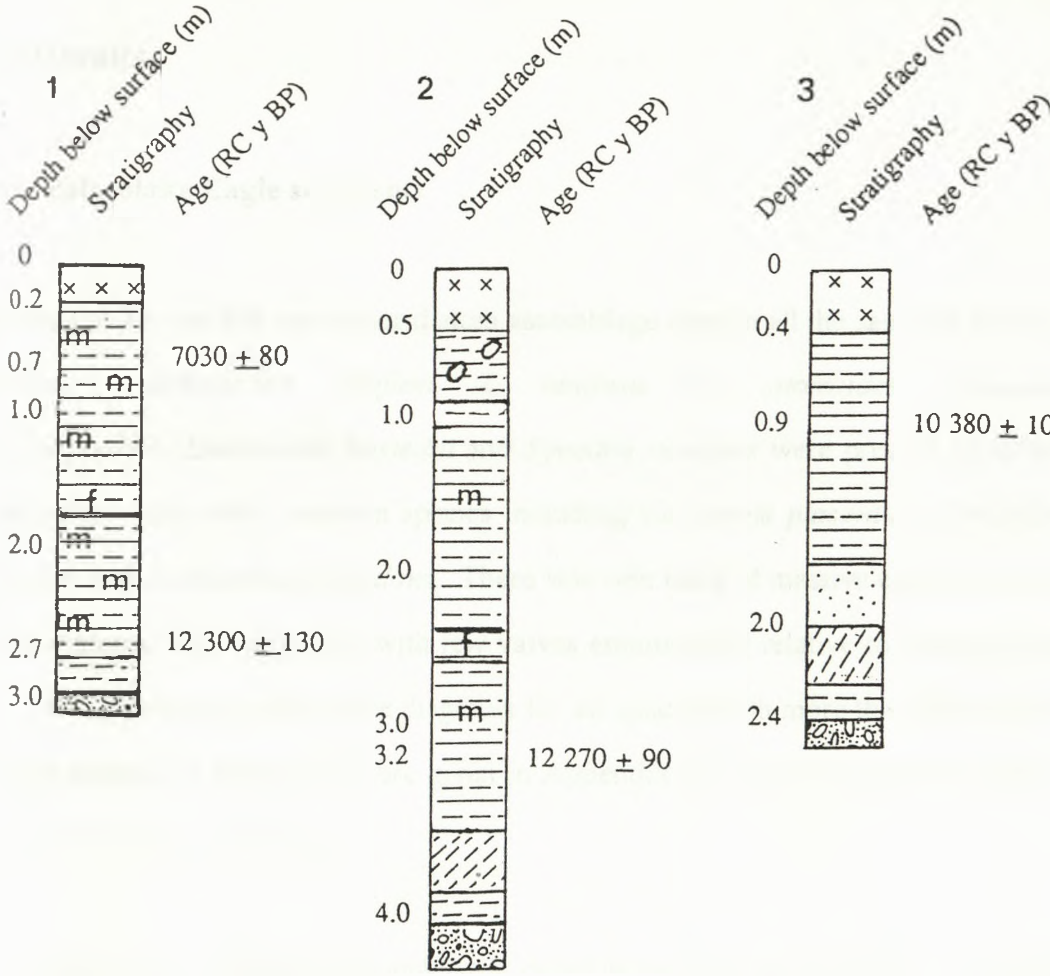


Figure 7.4. Stratigraphy of Palaeolake Eagle, Sections 1, 2 and 3. 1 = Section 1, 2 = Section 2, 3 = Section 3. Location of the sections are shown in figure 7.3. Symbol codes are listed opposite.

Section 3 was situated in the lower deposit, taken on the west-facing slope of a small, north-orientated gully. The deposit was very small, sitting on a narrow, jutting section of rock between the narrow gully to the west and a broader, eroded/slumped section of stream bank to the east. The section sampled was 2.4 m deep, with grey clay below the sediments overlying weathered bedrock. Between 1.9 m and 1.2 m there was a band of solid, fine sand. Above 1.2 m was brown clay with some laminations and very thin macrophyte bands closer to the top. Macrophytes were rare throughout, with occassional fragments of *Myriophyllum triphyllum* seen. Moss stems, less well preserved than those seen in Sections 1 and 2, were present in one sample from 1.5 m depth. The top of the lacustrine material was at 0.4 m, with the peat/soil surface at 0 m. The stratigraphy of Section 3 is shown in figure 7.4.

7.3 Results

7.3.1 Palaeolake Eagle sediments

Association 2a was the one major diatom assemblage seen in all the samples from all three sections. *Achnanthes confusa, A. confusa* var. *atomoides, Achnanthidium microcephalum, Diatomella hustedtii* and *Synedra rumpens* were present to abundant in all samples, with other common species including *Cocconeis placentula, Fragilariforma virescens* and *Achnanthes abundans.* There was one band of massive clays in each section where diatoms were very rare, with few valves encountered relative to inorganic particles (fig. 7.4). Percentage abundance diagrams for all species with more than 2% abundance in any one sample, in all sections, are given in Appendix 4. Samples with few diatoms were excluded from any analyses.

The samples from both the main and lower deposits were analysed together. No difference was seen between the three sections (table 5.5). The TWINSPAN analysis of samples gave 4 groups at the second level, with an eigenvalue of E = 0.9 (table 7.1).

Groups 1 and 2 were separated out from Groups 3 and 4 on the presence of *Navicula geniculata* in groups 1 and 2, and of *Cocconeis placentula* and *Diploneis smithii* in groups 3 and 4. Group 1 contained four samples with at least one from each of the three sections. Group 2 contained 11 samples from all sections. Indicator species were *Gomphonema affine* (Group 1) and *Aulocosira granulata* (Group 2). Group 3 contained nine samples representing all sections, and Group 4 contained three samples representing Sections 1 and 2 only. The indicator species was *G. affine* (present in Group 4 samples).

The HMDS analysis of samples in two dimensions had a minimum stress of .178, with the samples from all sections including those from the lower deposit intermingled (fig. 7.5). This indicated that there was very little difference in the diatom associations between samples from the two sections in the main deposit and those from the lower deposit. The TWINSPAN grouping of samples agreed reasonably well with the HMDS. Groups 1 and 4 were well separated, and there was only a small amount of overlap with Groups 2 and 3.

Table 7.1. TWINSPAN groupings of the samples from Palaeolake Eagle, all sections. The first number refers to the section, the second to the depth of the sample below the surface, e.g. 1-2.1 is from Section 1, 2.1 m depth.

Group 1	Group 2	Group 3	Group 4
1-2.1	1-1.5	1-0.2	1-0.4
1-2.6	1-1.8	1-0.3	2-1.0
2-2.9	2-2.0	1-1.0	2-3.8
3-1.9	2-2.2	1-1.4	
	2-2.5	2-0.5	
	2-3.2	2-0.2	
	3-0.4	2-1.3	
	3-0.8	2-1.7	
	3-0.9	3-2.4	
	3-1.2		
	3-1.5		

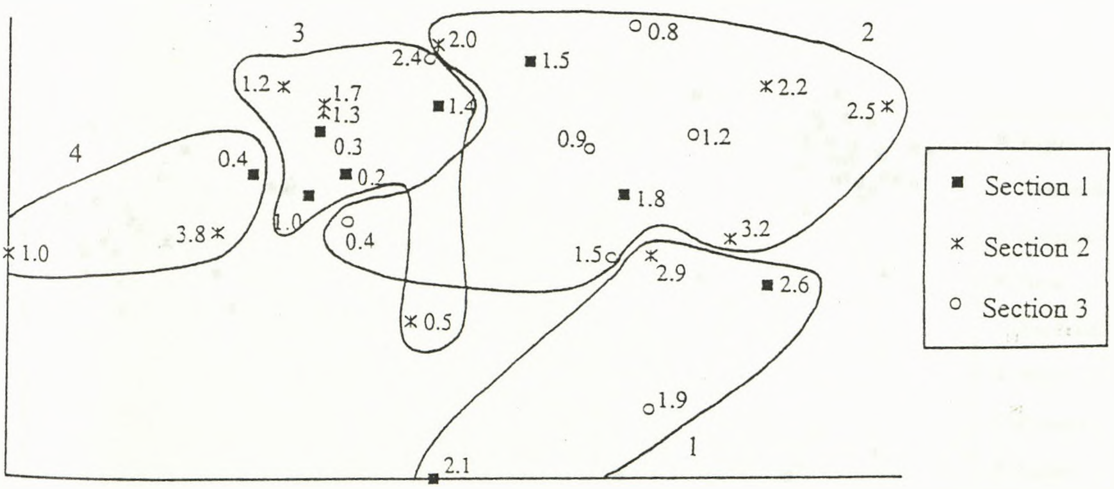


Figure 7.5. HMDS of Palaeolake Eagle samples in two dimensions. Minimum stress was .178. Samples from all sections were intermingled.

The ANOSIM of the three sections from Palaeolake Eagle showed no significant difference between any of the sections. This agrees with both the HMDS and the TWINSPAN analyses of the data.

7.3.2 Comparison of Palaeolake Eagle with modern environments

Lakes

The comparison of Palaeolake Eagle samples with the seven modern lakes by the HMDS separated out the palaeolake samples, Major Lake, the other modern oligotrophic lakes and the mesotrophic/eutrophic lakes (fig. 7.6), with a low minimum stress of .128 in two dimensions. As with Palaeolakes Half Moon and Cascade, Eagle samples were placed closest to those from Major Lake. The ANOSIM of Palaeolake Eagle and modern lake samples showed that the palaeolake samples were different from any of the modern lakes, agreeing with the HMDS in two dimensions. The p-values are listed in table 7.2.

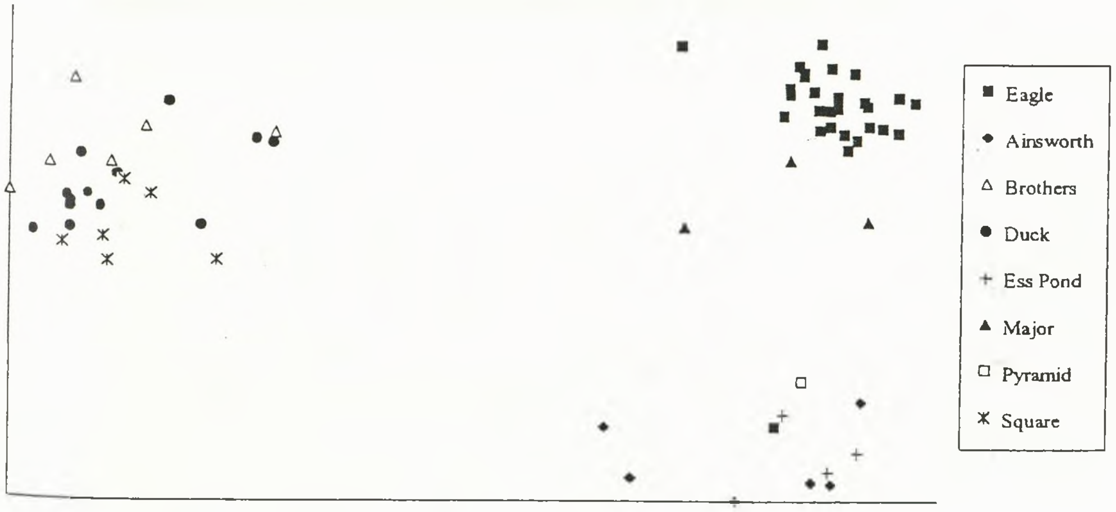


Figure 7.6. HMDS of Palaeolake Eagle and seven modern lakes in two dimensions. Minimum stress was .128. Samples from Palaeolake Eagle were grouped together, closest to samples from Major Lake.

Table 7.2. Summary of *p*-values from pairwise comparisons of Palaeolake Eagle and seven modern lakes.

	Eagle Section 1	Eagle Section 2	Eagle Section 3
Ainsworth Lake	.004	.006	.002
Brothers Lake	.002	.002	.004
Duck Lagoon	.002	.002	.002
Ess Pond	.004	.003	.008
Major Lake	.004	.008	.004
Pyramid Lake	.018	.013	.028
Square Lake	.018	.013	.028

Mires

Mire samples dominated by *Eunotia exigua* were excluded from the analysis. As with the other palaeolakes, the samples from Palaeolake Eagle were placed close to the modern mire surface samples by the HMDS, but were not intermingled, with a minimum stress of .210 in two dimensions (fig. 7.7). This shows there were some similarities between the diatom associations from modern mires with circumneutral pHs and those in the palaeolake. The Palaeolake Eagle samples are grouped together, with the mire samples spread across the plot. The ANOSIM of the mire surface samples and Palaeolake Eagle samples showed a significant difference between the two groups, with $p = .002$.

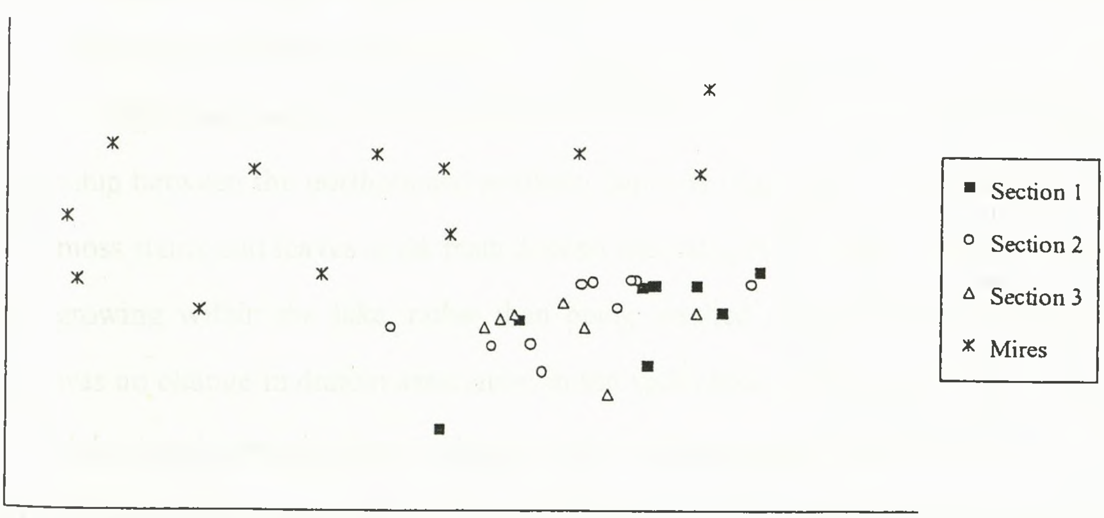


Figure 7.7. HMDS of Palaeolake Eagle and modern mires (not dominated by *Eunotia exigua*) in two dimensions. Minimum stress was .210. Samples from Palaeolake Eagle were grouped together, with mire surface samples spread across the configuration.

7.3.3 Palaeolake Eagle as a diatom habitat

The main deposit of Palaeolake Eagle and the lower pool contained very similar diatom assemblages, shown by the tight grouping of all samples in the analyses. This is understandable, as in all likelihood the water chemistry of the two waterbodies would have been very similar, with the lower pool probably receiving outflow water from the upper lake. However, the lack of *Myriophyllum triphyllum* in the lower deposit, and the fragmented moss stems seen in one band, indicate that the lower pool had few or no macrophytes growing in it. Fragments of *Fissidens rigidulus* were probably either washed out of the main lake and partially broken up before deposition in the lower pool, or were broken off from where the moss was growing in the stream and were washed into the pool.

Palaeolake Eagle contained one diatom assemblage right throughout, Association 2a. The the sediments were principally clays with banded *Myriophyllum triphyllum.* The band of massive clay with few diatoms seen in both the main and lower deposits indicates that the palaeolake underwent some kind of sediment influx at that time. This may have been due to a landslip further west in the basin which caused a mass of sediment to be washed down stream, with only the clay-sized particles reaching the lake to be deposited. Some washed through the lake and were deposited in the pool below. The clay band and the band of *Fissidens rigidulus* seen in the sediments give reference points for determining the relationship between the northern and southern deposits (fig. 7.8). The good preservation of the moss stems and leaves in the main deposit indicates that the macrophytes were most likely growing within the lake, rather than being washed in from the feeder stream(s). There was no change in diatom association in the sediments within or on either side of the *F. rigidulus* band, nor was there a change in the sediment size. This indicates very little change in the environment, with no obvious reason for *F. rigidulus* to occur only in one band.

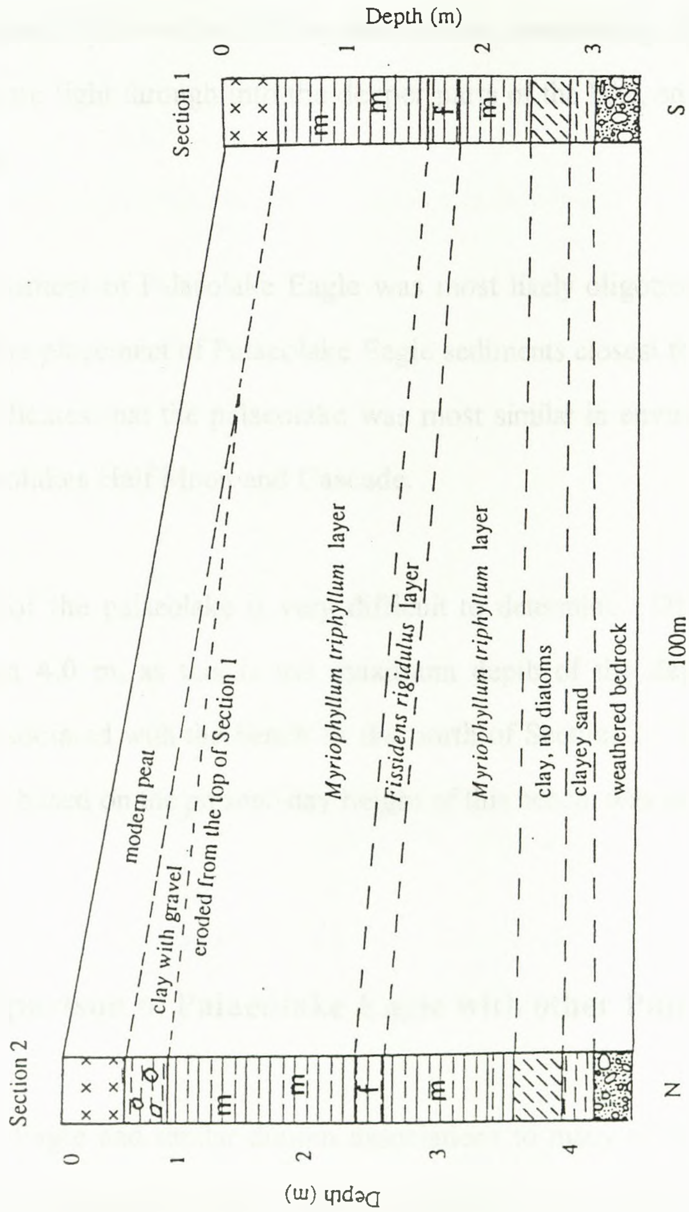


Figure 7.8. Relationship between the southern (Section 1) and northern (Section 2) deposits in Palaeolake Eagle. The coarse upper sediments, still present in Section 2, are absent from Section 1. It is likely these were eroded prior to vegetation becoming established above the exposed sediment.

The upper sediments in Section 2 have no corresponding sediments in Section 1. These were probably eroded from Section 1 prior to vegetation becoming established. This is possible, as the sediments in Section 2 are 1.3 m deeper than those in Section 1. The gravel-rich sediments in Section 2 show that coarser material was being washed into the lake at this time, possibly representing a landslip event in the basin. The bands of *Myriophyllum triphyllum* become thicker and more frequent towards the top, indicating the palaeolake shallowed as infilling and stream downcutting occurred. This would have allowed more light through into the deeper parts of the lake, stimulating the growth of *M. triphyllum*.

The environment of Palaeolake Eagle was most likely oligotrophic throughout the lake's history. The placement of Palaeolake Eagle sediments closest to Major Lake by the HMDS analysis indicates that the palaeolake was most similar in environment to Major Lake, as were Palaeolakes Half Moon and Cascade.

The depth of the palaeolake is very difficult to determine. Obviously it must have been deeper than 4.0 m, as this is the maximum depth of the deposit. Upper levels were possibly associated with the bench to the north of Section 2. The estimated depth of the palaeolake, based on the present-day height of this bench, was more than 5 m.

7.4 Comparison of Palaeolake Eagle with other Palaeolakes

Palaeolake Eagle had similar diatom associations to many of the other palaeolakes. The samples from Palaeolakes Half Moon and Eagle were intermingled (fig. 5.12b), as were those of Palaeolakes Cascade and Eagle (fig. 6.13b). Several Palaeolake Emerald samples were similar to those of Eagle, with the ones that were similar indistinguishable from the Eagle samples (fig. 7.9a). The remainder of the Emerald samples were spread across the two dimensional plot, with some grouping occurring. Almost all of the samples from Palaeolake Cormorant were grouped with those from Palaeolake Eagle (fig. 7.9b). Only samples dominated by *Staurosira construens* var. *venter* were placed away from the main group (see Chapter 9.3.1). The ANOSIM comparing Palaeolake Eagle samples with the other palaeolakes showed that Palaeolake Eagle Section 2 was similar to Cascade Section 2 (table 5.5). Palaeolake Emerald was not significantly different from Palaeolake Eagle, which agrees with the HMDS (fig. 7.9b). The remainder of the pairwise comparisons gave significant differences. Again, this can be explained by the low dimensionality of the HMDS configurations and the fact that some samples may be more similar than others, but the combined effect of the samples gives a significant difference.

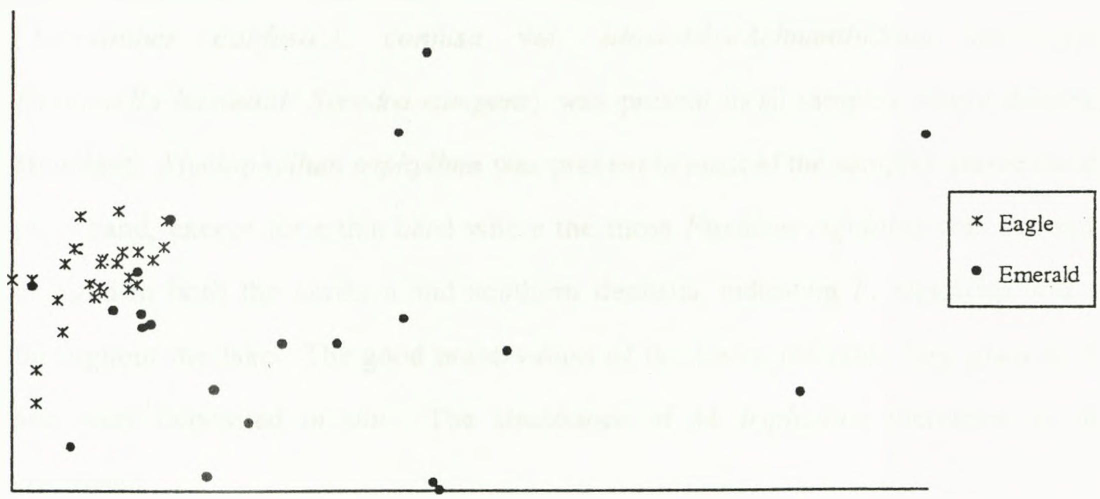


Figure 7.9a. HMDS of Palaeolake Eagle and Palaeolake Emerald in two dimensions. Samples from both palaeolakes were placed close together, with some intermingled.

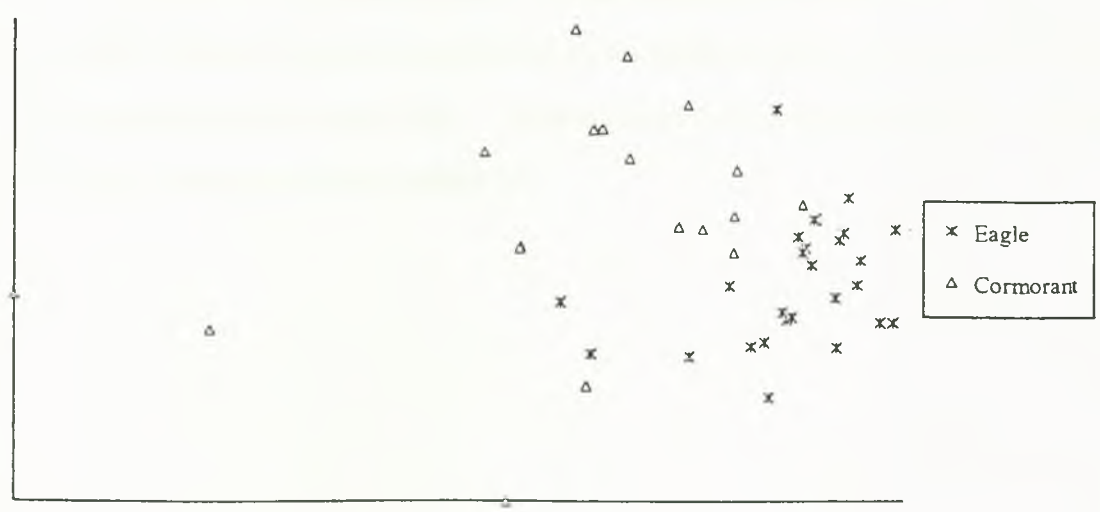


Figure 7.9b. HMDS of Palaeolake Eagle and Palaeolake Cormorant in two dimensions. Samples from both palaeolakes were placed close together, with those from Cormorant dominated by *Staurosira construens* var. *venter* placed as outliers.

7.5. Conclusions drawn from Chapter 7

For the time represented by the sediment deposits, Palaeolake Eagle was most similar in environment to the modern-day Major Lake. It was oligotrophic, with macrophytes growing sparsely in the lake after the one sedimentary event. The diatom Association 2a (*Achnanthes confusa/A. confusa* var. *atomoides/Achnanthidium microcephalum/ Diatomella hustedtii/ Synedra rumpens*) was present in all samples where diatoms were abundant. *Myriophyllum triphyllum* was present in most of the samples above the diatom-poor band, except for a thin band where the moss *Fissidens rigidulus* was present. This occured in both the northern and southern deposits, indicating *F. rigidulus* was present throughout the lake. The good preservation of the fossils indicates they grew in the lake and were deposited *in situ*. The abundance of *M. triphyllum* increased as the lake shallowed.

The lower deposit showed no difference from the main deposit in its diatom association. The sediments of the lower deposit were quite different, with coarser material and fewer, more fragmented macrofossils present. The sedimentary event immediately above the basal samples in the main deposit was also seen in the lower deposit, supporting the theory that the two water bodies were linked. Interpretations of and conclusions about Palaeolake Eagle are summarised below in table 7.3.

Table 7.3. Palaeolake Eagle - interpretations and conclusions.

Diatom Association	2a. *Achnanthes confusa/A. confusa* var. *atomoides/Achnanthidium microcephalum/ Diatomella hustedtii/Synedra rumpens*
Vegetation	Banded *Myriophyllum triphyllum* above the diatom poor band *Fissidens rigidulus* at one depth
Sediments	Clay rich in diatoms except for sample immediately above the base Upper sediments in Section 2 were loose sandy gravel Sediments in Section 3 poorer in macrophytes and generally coarser
Drainage	Stream downcutting at an inferred fault
Depth	+ 5 m
Size	Unknown. It extended no further west than the position of the lower deposit
Inferred pH	Moderately alkaline
Inferrred Conductivity	Low
Inferred Trophic Status	Oligotrophic
Modern Analogues	Major Lake
Palaeolake Analogues	Half Moon similar Cascade Section 2 very similar to Eagle Section 2 Emerald very similar in some phases Cormorant similar in some phases

Chapter 8

Palaeolake Emerald

8.1 Synopsis

Palaeolake Emerald is a very heterogeneous deposit, with sharp changes in sediments and diatom associations. Macrophytes were abundant in one band only. Two bands of sand with no diatoms occurred. Three diatom associations were present, with abrupt changes occurring between them. Some samples were similar to the modern day Major Lake. Other samples contained species which were rare in modern samples from Macquarie Island. Upper sediments are the youngest dated from any palaeolake deposit on Macquarie Island, at 3580 RC y BP. The lake underwent three main phases associated with possible change in precipitation - from deep (wet conditions) to shallow (drier conditions) to deep (wet conditions).

8.2 Introduction and Site Description

Palaeolake Emerald is situated on the plateau edge at about 140 m a.s.l., approximately 1000 m north of Bauer Bay (fig. 1.15). It is in a small, west facing valley immediately north of the much larger Bauer Bay valley, overlooking the featherbed at Boiler Rocks (fig. 8.1). To the east of the Palaeolake Emerald deposit is the small Emerald Lake (fig. 8.2). The palaeolake was bounded to the east by a gentle slope (5°), to the south by a slope of about 20° and to the north by a slope of between 20° and 30°. Relict marine cliffs have truncated the deposit to the west.

Figure 8.1. Palaeolake Emerald from below. The sediments are located on the cliff edge at 140 m above sea level (arrowed).

Figure 8.2. Emerald Lake from the north. The Palaeolake Emerald deposit, not visible, is at the right (west) of the valley.

The eastern, southern and northern shorelines of Palaeolake Emerald were determined approximately. The relatively steep slopes to the north and south of the valley constrain the lateral extent and since the lake must have been within these limits, the lake would not have been very wide at this point. Vertical extent of the water line was impossible to determine, however, the minimum lower limit of the water level is defined by the uppermost sediments. Clearly, much erosion has occurred since drainage.

There are three small streams running through the deposit, which can be seen as gullies in figure 8.1, and on the map of the site (fig. 8.3). All three streams rise in gently sloping, wet ground in the east of the small valley and run approximately parallel with each other towards the west. The northern-most stream is the most deeply incised of the three, beginning to cut through lacustrine material at about one third of the way downstream. The stream has a small tributary, which also cuts through the sediment. Close to where the tributary starts and at about the same level on the main channel, the running water has cut deeply into the lake material and left a small, steep-sided tongue of sediment (fig. 8.4). The stream gradient lowers again at this junction and cuts down through a little more sediment before cutting through beach cobbles and then bedrock near the cliff edge. The presence of beach cobbles provides evidence that Palaeolake Emerald is overlying a relict beach. The two southerly streams have cut into hard, clayey material with no diatoms present and part of the raised cobble beach can be seen on the side of the southern-most stream, below the clay (fig. 8.5).

To the north of the small valley there is a small, flat bench with a small shallow pool at its western end (fig. 8.2). The bench is approximately 15 m wide, and slopes an average of 5° to the west. To the north of this, the hillside rises steeply (20° to 30°) to the top of the plateau at about 200 m a.s.l. Here it flattens out somewhat, to become a gently undulating surface. There has been a peat slump at the eastern edge of the slope above the bench, leaving an unvegetated strip.

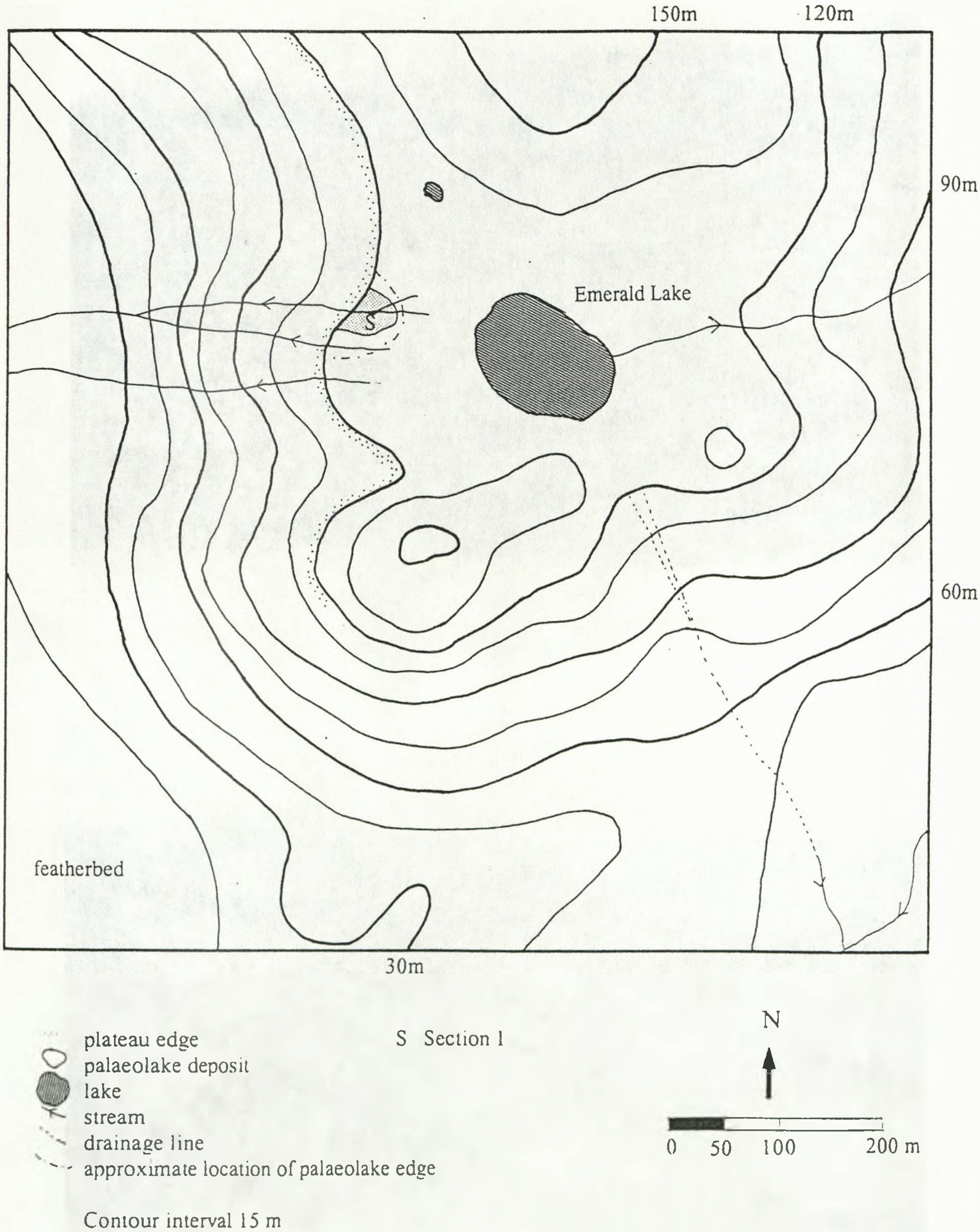


Figure 8.3. Map of Palaeolake Emerald. The contours are redrawn from Blake's 1914 map (Mawson, 1943). Other features of the site have been taken from stereo air photographs or from field observations.

Figure 8.4. Palaeolake Emerald. The macrophyte layer is visible as the dark band running through the sediment. Human figures give scale. (Photograph P.M. Selkirk.)

Figure 8.5. The relict cobble beach below the Palaeolake Emerald deposit outcrops at the cliff edge. The southern most stream is visible.

To the south of Palaeolake Emerald the hillside rises moderately steeply to the top of a ridge at approximately 190 m a.s.l. (fig. 8.2). This ridge, visible at the right of figure 8.1, runs south west, losing height until it ends in steep slopes to the north of Bauer Bay. To the east of this ridge there is a drainage line which runs south into Bauer Bay.

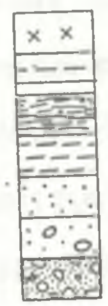
Emerald Lake lies to the east of Palaeolake Emerald (fig 8.3). It is a small lake measuring approximately 100 m by 600 m (fig. 8.2). The watershed between the modern and fossil lakes is fairly low, with a moderately steep eastern side. Slopes here were between 10° and 15°. The top of the slope is approximately 5 m above the current level of water in Emerald Lake. On the western side the slopes average around 5°. The southern and western shores around Emerald Lake are low-lying and quite boggy. To the north and east, however, the shores are steeper and more rocky. Emerald Lake itself contains very little vegetation, with a sandy bottom to the south and west and a rocky bottom to the north and east. It drains via a small outlet stream to the east which descends steeply through bedrock before plunging over a cliff into a large valley which enters northern Bauer Bay.

Two samples for radiocarbon dating were collected from the palaeolake deposit. The lower sample, collected at 4.2 m depth, was dated at 9320 $\pm$ 70 RC y BP (Beta 56571). The second sample was taken from within the large macrophyte band, at 2.2 m depth. It was dated at 3580 $\pm$ 80 RC y BP (Beta 64729). This was the youngest sample dated from any of the palaeolake sediments.

One section was taken in Palaeolake Emerald. Samples collected from the banks of the southerly streams were massive yellow clays that contained no diatoms. It is probable that they are not part of the lacustrine material. Although they appeared laminar on the surface, this may have been caused by stream erosion of the clay. Section 1 was taken in the southern bank of the northern-most stream. It contained abundant microfossils and macrofossils. The section was quite steep, measuring between 15° and 35° over most of its length. It was 5.5 m deep and contained one layer with very abundant macrophytes,

Key to Figure 8.6

modern peat
clay with macrophytes
macrophyte layer
clay, no macrophytes
sand, no diatoms
sand with gravel
gravel



which can be seen as a dark band running through the paler sediments in figure 8.4. Macrophytes became abundant at 3.0 m and were common to 2.0 m. There was little sediment with the macrophytes, with only one band from 2.7 m to 2.9 m with clay present. Above 2.0 m the sediments became coarser, with no macrophytes present. There was one other band which had macrophytes present, from 4.4 m to 3.3 m, however in this band the macrophytes were rarely seen and were quite fragmented, unlike those seen between 3.0 m and 2.0 m. Modern peat started at 0.7 m, with the base of the modern vegetation at 0.5 m. The top of the modern vegetation was at 0 m. Figure 8.6 is a stratigraphic diagram of the section.

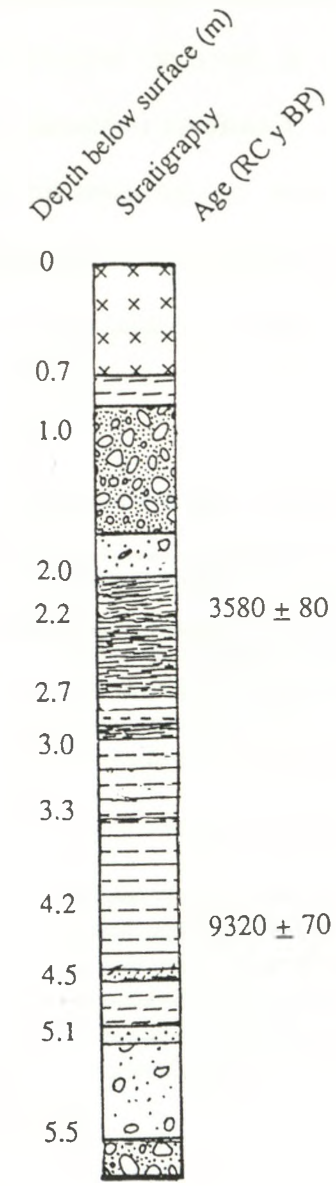


Figure 8.6. Stratigraphic diagram of Palaeolake Emerald, Section 1. Symbol codes are listed opposite.

8.3. Results

8.3.1. Palaeolake Emerald Sediments

The sediments in Palaeolake Emerald were very heterogeneous. Bands of clay, macrophytes, sand and gravel were interbedded throughout (fig. 8.8). Within the sediments were several diatom associations. Association 2a, (*Achnanthes confusa/A. confusa* var. *atomoides/Achnanthidium microcephalum/Diatomella hustedtii/Synedra rumpens*) was present in several bands, illustrated in table 8.1. Association 10a, with abundant *Fragilariforma virescens* occurred at 3 depths. Association 10b, (with *F. virescens* abundant, with *Achnanthes confusa/A. confusa* var. *atomoides/Achnanthidium microcephalum/Pinnularia circumducta*) and Association 10c (*A. confusa/D. hustedtii/F. virescens/S. rumpens*) each occurred at one depth. Percentage abundance diagrams for all species with more than 2% abundance in one or more samples for the section are presented in Appendix 4.

Table 8.1. Changes in diatom associations with depth in Palaeolake Emerald.

Depth (m)	Diatom Association	Diatom species
0.7	2a	*Achnanthes confusa/A. confusa* var. *atomoides/Achanthidium*
2.3		*microcephulum/ Diatomella hustedtii/ Synedra rumpens*
2.7	10a	*Fragilariforma virescens*
2.9	11	*Cymbella kergeulenensis/Diatomella hustedtii/Pinnularia circumducta*
3.0		
3.3	10a	*Fragilariforma virescens*
3.5		
3.7	10b	*Fragilariforma virescens/Achnanthes confusa/A. confusa* var. *atomoides/Achanthidium microcephulum/Pinnularia circumducta*
3.9	2a	*Achnanthes confusa/Achanthidium microcephulum/Diatomella*
4.1		*hustedtii/ Synedra rumpens*
4.2	10c	*Achnanthes confusa/Diatomella hustedtii/Fragilariforma*
4.4		*virescens/Synedra rumpens*
4.5	few diatoms	
4.7	2a	*Achnanthes confusa/Achanthidium microcephulum/Diatomella hustedtii/ Synedra rumpens*
5.1	few diatoms	
5.3	10a	*Fragilariforma virescens*
5.5		

The TWINSPAN analysis of all samples gave four unequal groups at the second level, with an eigenvalue of E = .161 at the first division (table 8.2). Group 1 contained nine samples, all classed as Association 2a. They were divided from group two on the presence of *Achnanthes saxonica, Amphora coffeaeformis* and *Amphora holsatica*. Group 2 contained six samples from Associations 2a, 10a, 10b, and 10c. Group 3 contained three samples from associations 10a and 11.

Group 4 contained two samples from Association 10a. It was separated out from Group 3 by the moderate abundance of *Achnanthes manguini* var. *elliptica*.

Table 8.2. TWINSPAN groupings of the samples from Palaeolake Emerald. Numbers refer to the depth of the sample below the surface, e.g. 0.7 is the sample from 0.7 m depth.

Group 1	Group 2	Group 3	Group 4
0.7	3.7	2.7	3.3
1.1	4.2	2.9	3.5
1.4	4.4	3.0	
1.7	5.3		
2.0	5.5		
2.2			
2.3			
3.9			
4.1			
4.7			

The HMDS analysis of samples from Palaeolake Emerald in two dimensions agreed well with the TWINSPAN grouping of samples, with a very low minimum stress of .078 (fig. 8.7). Groups 1 and 2 were placed adjacent, with the sample from 5.3 m placed as an outlier. It contained abundant *Fragilariforma virescens* and no *Achnanthes confusa* var. *atomoides*, which may explain its positioning. Group 3 was placed close to Group 2, and Group 4 was placed away from all other groups.

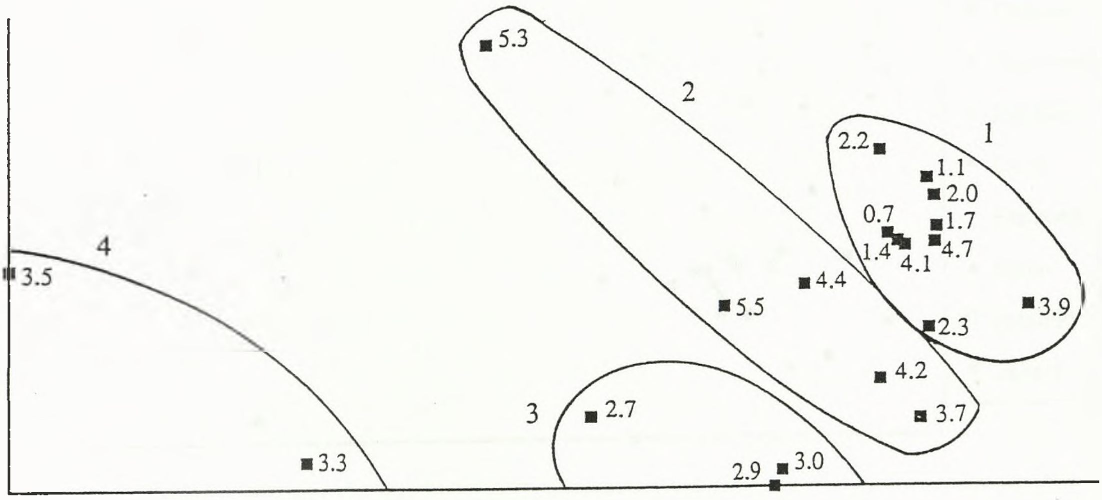


Figure 8.7. HMDS of all samples from Palaeolake Emerald in two dimensions. Minimum stress was .078. TWINSPAN groups are marked on the diagram..

8.3.2 Comparison of Palaeolake Emerald with modern environments

Lakes

The HMDS of Palaeolake Emerald and modern lake samples gave four separate groups in 2 dimensions, with a low minimum stress of .148 (fig. 8.8). The Palaolake Emerald samples were reasonably spread out, with the samples dominated by *Cocconeis placentula* and *Fragilariforma virescens* placed as outliers. Major Lake samples were placed between samples from Palaeolake Emerald and the other oligotrophic lake samples and the meso/eutrophic samples were grouped together. Again, from this it would appear that the majority of Palaeolake Emerald samples were most similar to those from Major Lake. An ANOSIM of the Palaeolake Emerald samples and modern lake samples used in the HMDS analysis was conducted. The p-values for the pairwise comparisons are listed in table 8.3. All were significant, which reinforces the separation of the samples by the HMDS.

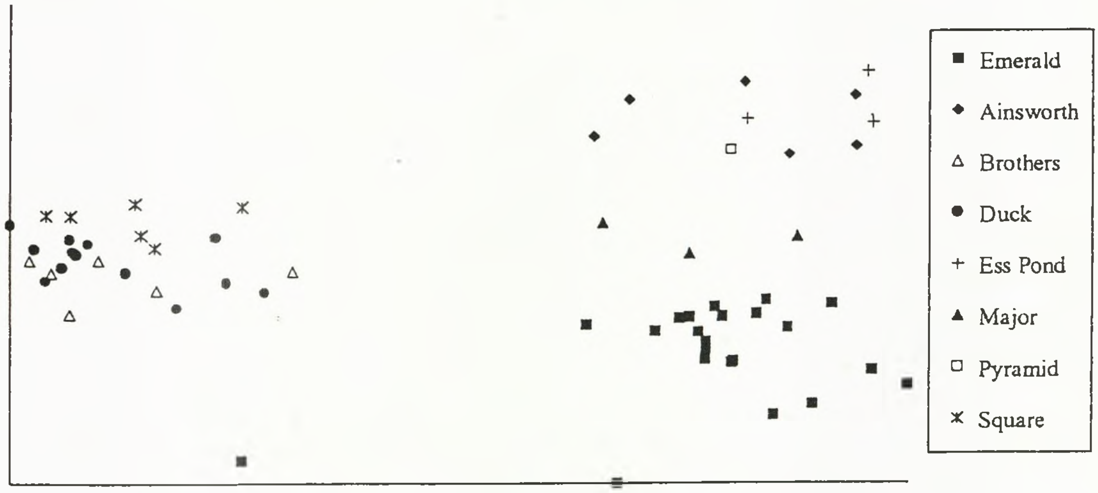


Figure 8.8. HMDS of Palaeolake Emerald and modern lake samples in two dimensions. Minimum stress was .148. Samples from Emerald were placed closest to those from Major Lake.

Table 8.3. Summary of *p*-values from pairwise comparisons of the Palaeolake Emerald samples and modern lake samples.

	Emerald
Ainsworth Lake	.002
Brothers Lake	.002
Duck Lagoon	.002
Ess Pond	.002
Major Lake	.002
Pyramid Lake	.04
Square Lake	.002

Mires

The HMDS of Palaeolake Emerald samples and mire surface samples not dominated by *Eunotia exigua* in 2 dimensions, separated the mire and palaeolake samples, with a minimum stress of .202 (fig. 8.9). The mire surface samples were placed 'around' the majority of the Emerald samples and relatively close to some of them. Samples with *Cymbella kerguelenensis* and *Fragilariforma virescens* abundant or dominant were placed apart from the other samples. The ANOSIM of Palaeolake Emerald and mire surface samples gave a *p*-value of .002, reinforcing the separation of the two groups by the HMDS.

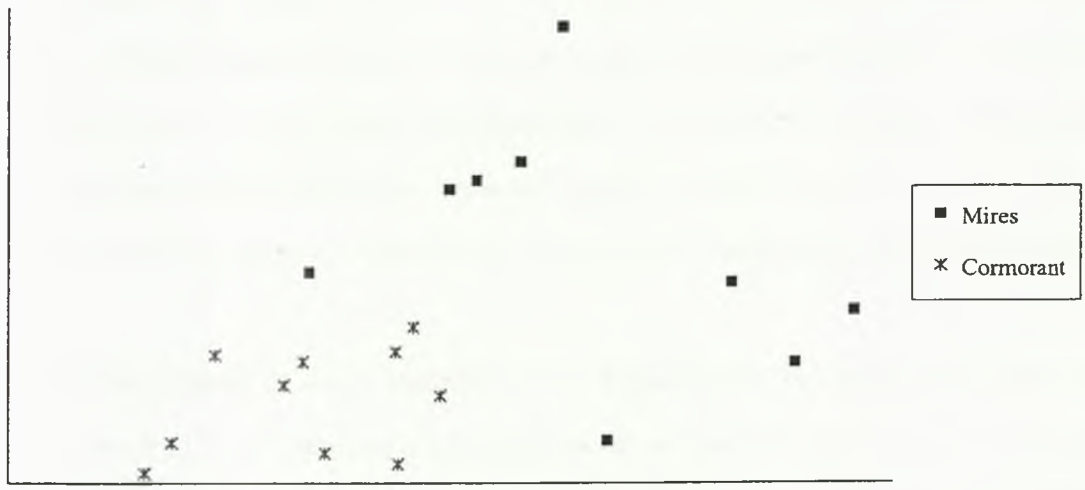


Figure 8.9. HMDS of Palaeolake Emerald and modern mire surface samples not dominated by *Eunotia exigua* in two dimensions. Minimum stress was .202. Samples from Emerald were spread out on the configuration, indicating variation in the samples.

8.3.3 Palaeolake Emerald as a diatom habitat

The phases of Palaeolake Emerald where Association 2a was present were probably most similar to Major Lake in terms of the lake water chemistry. However, the changes in sediments and diatom species throughout the palaeolake history indicate that some major changes in the environment occurred.

The palaeolake was in a very small catchment, unlike Palaeolakes Half Moon and Eagle, which were downstream of, and receiving outflow from, other large lakes (Scoble and Island Lakes respectively) and Palaeolake Cascade, which received drainage from a very large area. Input into Palaeolake Emerald was only from local overland flow and subsurface flow, rather than from a feeder lake or large catchment and so was very dependant on the volume and timing of precipitation.

It is possibly because of this that the sediments of Palaeolake Emerald were so varied in terms of grain size. Heavy precipitation will cause more erosion and mass movement of sediment. This is especially true on Macquarie Island, where periods of unusually heavy rainfall have been linked to major landslip events (J. M. Selkirk, in press). The transport and deposition of large sized sediments are directly related to heavy rainfall. Smaller sediments would be transported more commonly as less water would be needed to do so.

There are two bands of sandy material at 5.1 m and at 4.5 m where no diatoms were present. Both of these represent a major influx of sediment at one time, probably caused by a landslip within the basin. Apart from these two events, below 4.9 m depth the sediment in Emerald is quite coarse sandy clay, sand and gravel. All of this is indicative of moderate to heavy precipitation washing larger-sized particles into the lake. The lack of macrophyte material in these sediments also indicates relative instability in the lake. Large influxes of sediment would be detrimental to vegetation establishment and growth, as repeated burial of the growing material would occur.

Between 4.4 m and 3.3 m there is a thick band of sandy clay with few macrophytes. Again this is indicative of moderate to heavy precipitation. The presence of some macrophytes suggests that the rate of sedimentation was lower. This may be due to a combination of slightly lower rainfall and vegetation establishing within the basin on areas bared by previous landslip events. In turn, this would reduce the area available from which material could be eroded. This reduction in sedimentation would have allowed some vegetation to establish within the lake at this time. Because only two radiocarbon dates were obtained for the palaeolake, it is not possible to determine the actual sedimentation rates. It is possible only to estimate the relative rates - either fast, moderate or slow.

The thick band of macrophyte rich material from 3.0 m to 2.0 m, which had almost no sediment within it, indicates both little rainfall and relatively stable vegetation within the

Table 8.4. The interpreted environment of Palaeolake Emerald, based on the stratigraphy and diatom associations.

Years BP	Depth (m)	Stratigraphy	Diatom Association	Interpreted Environment
	0	modern peat		modern vegetation
	0.7	clay	***2a.*** *Achnanthes confusa, A. confusa* var. *atomoides, Achnanthidium microcephalum, Diatomella hustedtii, Syndera rumpens*	oligotrophic, low sediment input, moderate rainfall
	1.4	gravel		oligotrophic, high sediment input, high rainfall
	1.7	sand with gravel		
	2.0	macrophyte band		shallow, little sediment input low rainfall
3580±80	2.2			
	2.7	clay and macrophytes	***10a.*** *Fragilariforma virescens*	shallow, moderate sediment input, moderate rainfall
	2.9	macrophyte band	***11.*** *Cymbella kerguelenensis, D. hustedtii, Pinnularia circumducta*	shallow, little sediment input, low rainfall
	3.0	clay and macrophytes		shallow, moderate sediment input, moderate rainfall
	3.3		***10a.*** *F. virescens*	
	3.7		***10b.*** *F. virescens, A. confusa, A. microcephala, P. circumducta*	
	3.9		***2a.*** *A. confusa, A. microcephala, D. hustedtii, S. rumpens*	
	4.1			
9320±70	4.2		***10c.*** *A. confusa, D. hustedtii, F. virescens, S. rumpens*	
	4.5	sand	few diatoms	high sediment input, one episode
	4.7	clay	***2a.*** *A. confusa, A. microcephala, D. hustedtii, S. rumpens*	oligotrophic, low sediment input
	5.1	sand	few diatoms	high sediment input, one episode
	5.3	sand and gravel	***10a.*** *F. virescens*	high sediment input
	5.5			

catchment. The increase in macrophyte growth may also reflect a shallowing of the lake at this time. On Macquarie Island the lakes with rich macrophytic growth are generally shallow, with associated high light levels. The macrophytes may have grown and been deposited relatively quickly - however such a thick layer of compressed material with very little sediment supports the theory that there was a period of time during the lake's history where the lake was shallower, with a stable catchment.

Coarser material with no macrophytes is again present above 2.0 m to the uppermost remaining sediments at 0.7 m, indicating a return to higher precipitation and increased sediment input. There may also have been a destabilisation in the catchment vegetation at this time associated with the increase in precipitation, caused either by a landslip event and continued erosion, or by an increase in the erosion on already bare areas. Table 8.4 summarises the changes in the environment interpreted from the sedimentary record.

It is more difficult to interpret the environment of Palaeolake Emerald using the diatom Associations. Only Association 2a has been found in the samples collected from modern environments; this occurs primarily in oligotrophic waters. It is possible to say with certainty only that at the depths where Association 2a was present, the lake was most similar to Major Lake, with a pH close to seven, few macrophytes and oligotrophic. However, it is unlikely that there was great change in the water chemistry over time. The only waterbodies on the island with high conductivities are those coastal lagoons which occasionally receive an inwash of seawater during high seas, such as Duck Lagoon. No other mechanisms for increasing the ions within lake water can be envisioned, and the conductivity probably remained fairly constant over time. It is possible that there was a slight change in pH as the amount of macrophytes increased. As aquatic plants photosynthesise, dissolved carbon dioxide in the water is depleted, bicarbonate ions are actively transported into the leaves and hydroxyl ions excreted, resulting in a rise in the pH of the surrounding water (Kirk, 1994; Smart, 1990). However, if the increase was great, it is likely that the diatom associations would have altered accordingly and have been similar to those seen in the modern alkaline lakes, such as Brothers Lake.

Until modern associations corresponding to those seen in Palaeolake Emerald are found, the interpretation of the palaeoenviroment can only be based on sediments and on the associations which have been found. They have been reported from only one other area in the subantarctic; Birnie (1990) reported a '*Fragilaria*' dominated flora in her lake on South Georgia, but provided no information on lake environment.

The mechanism for drainage of Palaeolake Emerald is uncertain. It is likely that marine undercutting of the sea cliffs was in part responsible. However, the sediment at 2.2 m depth was dated at around 3580 y BP. The height of the marine terrace 3500 y BP was approximately seven metres below what it is now (based on an average estimated rate of uplift of two mm/year). When sea level stabilised around six thousand years ago, the height of the wave-cut terrace below Palaeolake Emerald would have been approximately 5-15 m a.s.l. (current height is 10 to 20 m a.s.l.). From this, it appears unlikely that marine erosion alone was the cause for lake drainage. Marine erosion at the base of the sea cliffs may have weakened the bedrock; further erosion by stream action or some mass movement event may have been ultimately responsible for drainage. Timing of drainage is difficult to determine. Although the upper 1.5 m of sediment has not been radiocarbon dated, it is possible to estimate time of drainage: the depth of the sediment above the top radiocarbon date suggests drainage was probably not earlier than 2500 y BP.

8.4 Comparison of Palaeolake Emerald with other Palaeolakes

The variation in diatom associations in Palaeolake Emerald meant that there were similarities only if the associations also occurred in the other palaeolake samples. Where

Association 2a was present, these were most similar to those samples from Palaeolakes Half Moon (fig. 5.12c), Cascade (fig. 6.13b) and Eagle (fig. 7.9a) and some samples from Palaeolake Cormorant (fig. 8.10). Where Association 10a or 11 was present the samples were placed away from the other palaeolake samples as these were present in no other palaeolakes.

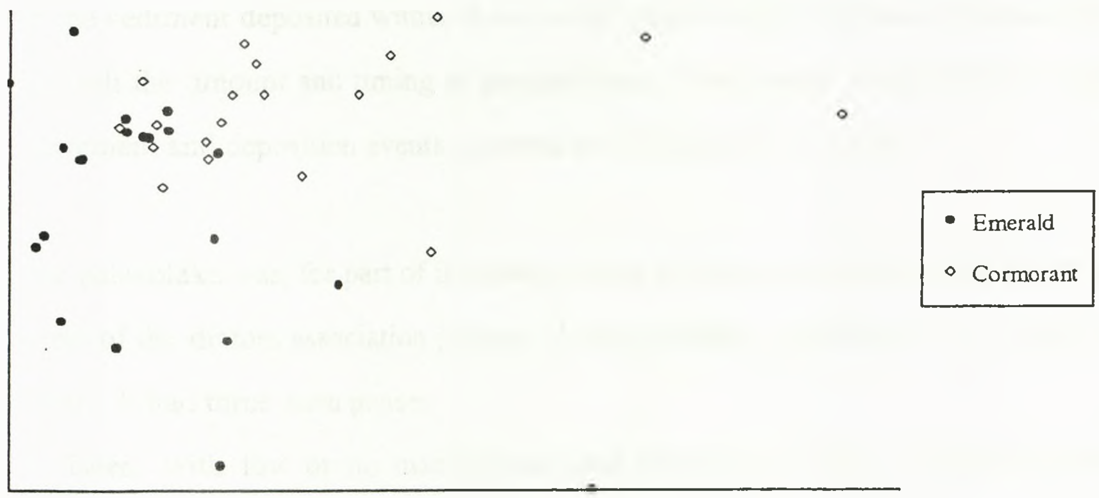


Figure 8.10. HMDS of Palaeolake Emerald and Palaeolake Cormorant in two dimensions. The majority of samples were placed close together, with only samples with species such as *Fragilariforma virescens* abundant placed as outliers

The ANOSIM of the palaeolakes showed that Palaeolake Emerald was not significantly different from Palaeolake Half Moon Section 1, Cascade Section 2 and all sections from Palaeolake Eagle (table 5.5). While there is some intermingling of Emerald and Eagle samples, the majority of the samples from the two palaeolakes are placed close together by the HMDS.

8.5 Conclusions drawn from Chapter 8

Over time, Palaeolake Emerald underwent major changes in the sedimentation rates, amount of macrophyte growth and the diatom associations seen within the sediments. Interpretation of the palaeolake environment is difficult because of the lack of ecological information available for some of the diatom associations. The lake was in a small basin, so the sediment deposited within it was very local in origin and was influenced strongly by both the amount and timing of precipitation. Two events interpreted as single mass movement and deposition events occurred at 4.5 m and 5.1 m depth.

The palaeolake was, for part of its history, most similar to the modern-day Major Lake in terms of the diatom association present. It was probably oligotrophic, with a pH close to seven. It had three main phases -

1. Deep, with few or no macrophytes and moderate to large amounts of sediment washing in. From inception to 3.0 m depth. Indicative of moderate to heavy precipitation, i.e. a wetter climate than in phase 2.
2. Shallow, with a lot of macrophyte growth and very little sediment input. From 3.0 m to 1.7 m. Indicative of less precipitation, i.e. a drier climate than phases 1 and 3.
3. Deep, with no macrophytes and moderate to large amounts of sediment washing in. Above 1.7 m to drainage. Indicative of moderate to heavy precipitation, i.e. a wetter climate than phase 2.

The palaeolake sediments are the youngest dated, with an upper age of 3580 $\pm$ 80 y BP. Drainage of the palaeolake was most likely caused by cliff collapse, although it is unlikely that it was directly related to marine erosion at the base of the sea cliffs below the lake, although this may have been a contributing factor. The interpretations of and conclusions about Palaeolake Emerald, drawn from Chapter 8, are summarised in Table 8.5.

Table 8.5. Palaeolake Emerald - interpretations and conclusions.

Diatom Associations	2a. *Achnanthes confusa/Achanthidium microcephulum/Diatomella hustedtii/ Synedra rumpens* 10a. *Fragilariforma virescens* 10b *D. hustedtii/F. virescens/P. circumducta* 10c. *A. confusa/D. hustedtii/F. virescens/S. rumpens* 11. *Cymbella kerguelenensis/D. hustedtii/P. circumducta*
Vegetation	2.0 m to 3.0 m - banded *Myriophyllum triphyllum*, moss Above and below - no or very few macrophytes
Sediments	Coarse gravels, sands and clays below and above the macrophyte band; little within the band
Drainage	Combination of marine and ?stream or mass movement
Depth	+ 5.5 m
Size	Unknown
Inferred pH	Moderately alkaline
Inferred Conductivity	Low
InferredTrophic Status	Oligotrophic
Modern Analogues	Major Lake where Association 2 was present. No modern analogues for Associations 10a, 10b, 10c and 11
Palaeolake Analogues	Half Moon: similar to phases where Association 2a occurred Cascade: same as Half Moon Eagle: same as Half Moon; 1 influx of sediment Cormorant: where Association 2a occurred. 1 influx of sediment, small catchment, coarse sediments.

Chapter 9

Palaeolake Cormorant

9.1 Synopsis

Palaeolake Cormorant is a small deposit 6.4 m thick. The sediments and diatom associations undergo abrupt changes throughout the deposit, with several diatom associations present. There are no modern analogues for some of these associations. The lake underwent three major changes: a deep phase (wet conditions) followed by a shallower phase (drier), then back to deep (wet). Palaeolake Cornmorant and Palaeolake Emerald show a similar change in the local environment, possibly reflecting a change in climate.

9.2 Introduction and Site Description

Palaeolake Cormorant is the most southerly of the five palaeolakes studied. It is located on the plateau edge at about 220 m a.s.l., approximately 1000 m south of Flat Creek (fig. 1.15). The deposit is small and is located on a west-facing cliff (fig. 9.1). To the south the small, shallow valley is bounded by a steep hill. This curves around to the east, becoming lower and joins, via a low ridge, a rocky knoll about 100 m east of the deposit. Slopes around this knoll and ridge are relatively steep, measuring up to 25°. Running almost due west from the rocky knoll is a narrow ridge, eroded to a bare face on the southern side. On the more gently sloping northern side, the ridge is covered in short tussock grassland (fig. 9.2). To the west, this ridge terminates above the deposit which slopes smoothly down to bedrock and old sea cliffs.

Figure 9.1. Palaeolake Cormorant from the featherbed. The deposit is on a west facing cliff (arrowed).

Figure 9.2. Palaeolake Cormorant. The bare sediments visible are the palaeolake deposit. At the right is the narrow ridge covered in short tussock grassland (arrowed). The sea cliffs are to the west (left).

The shorelines of Palaeolake Cormorant were difficult to define. The deposit was the smallest of the five palaeolakes studied, measuring approximately 60 m north-south, and extending 20 m inland from the cliff edge. The site was very eroded in places, with much of the area bare of lake sediments and thus it was only possible to get a rough estimate of the shoreline locations (fig. 9.3). The southern shoreline was probably against the southern-most slope of the valley, which rises relatively steeply. The eastern shoreline was located to the east of and above the eastern most deposit and may have been close to the eastern ridge bordering the valley, although no deposits were found this far east. The northern shoreline may have been against the steep slope on the northern side of the valley.

There are two small streams running west through the valley, both of which have cut into the deposit, exposing it in the stream banks. The northern stream is incised for half its length, cutting through lacustrine material close to the cliffline (fig. 9.3). The southern stream drains a small, elongate mire located in the valley.

The deposit is exposed on a west facing bluff between the two streams as well as in the stream banks and consists of a dark macrophyte band between clays and gravels. The section was taken on a shallow slope, about five metres south of the northern stream. The deposit was 6.4 m deep, with gravelly clays at the base. Macrophytes were present but not abundant between 6.2 m and 6.1 m. Between this and the next macrophyte band which started at 3.9 m, there were bands of gravel and sandy clays. The second macrophyte layer continued uninterrupted to 2.8 m. From 3.1 m to 1.8 m were bands of gravels, sands and clays with no macrophytes. 1.8 m to 1.0 m was a clay-rich band with few, fragmented macrophyte remains present. The base of the modern peat was at 1.0 m, with the top of the vegetated ridge at 0 m. The stratigraphy of the section is shown in figure 9.4.

Two samples were collected for radiocarbon dating. The lower sample, at 6.2 m, was

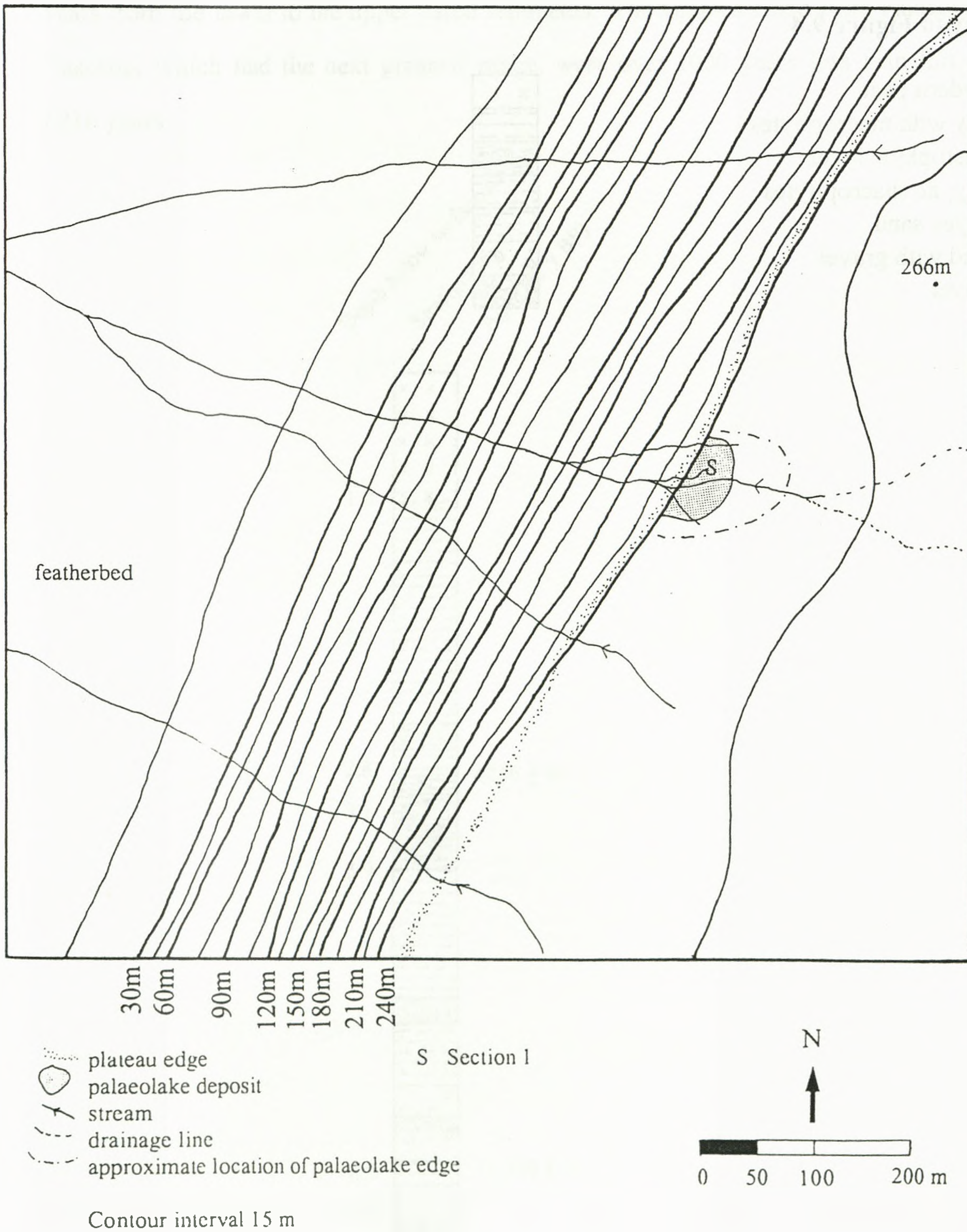
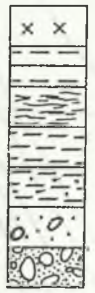


Figure 9.3. Map of Palaeolake Cormorant. Contours are redrawn from Blake's 1914 map (Mawson, 1943). The other details of the site were taken from stereo air photographs and field observations.

Key to Figure 9.4

modern peat
clay with macrophytes
macrophyte layer
clay, no macrophytes
clayey sand
sand with gravel
gravel



dated at 11 780 ± 70 RC y BP (Beta 56568). The second sample was collected from within the thick macrophyte band, at 3.1 m and was dated at 4320 ± 90 RC y BP (Beta 64727). This was the longest dated range in the palaeolake sediments, totaling 7070 years from the lower to the upper dated sediments. The samples dated from Palaeolake Cascade, which had the next greatest range, were over 1000 years less than this, at 6210 years.

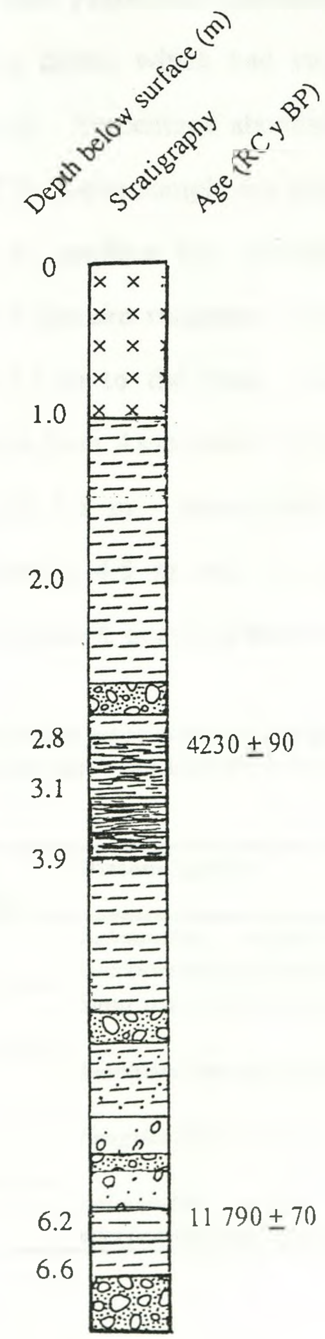


Figure 9.4. Stratigraphy of Palaeolake Cormorant deposit. Symbol codes are listed opposite.

9.3 Results

9.3.1 Palaeolake Cormorant Sediments

The samples collected from Palaeolake Cormorant were all rich in diatoms except for one sample from 5.5 m depth, which had very few diatoms present. The diatom associations varied greatly. Percentage abundance diagrams for each species with an abundance of at least 2 % in one sample are presented in Appendix 4. Association 2a (*Achnanthes confusa, A. confusa* var. *atomoides, Achnanthidium microcephalum, Diatomella hustedtii* and *Synedra* rumpens) was present above 2.3 m to the top of the sediments, and below 4.9 m to the base. Association 2d, with *Martyana martyi* abundant with the species from Association 2a present to abundant, occurred at 4.7 m and between 3.9 m and 3.5 m. Association 10a, with *Fragilariforma virescens* abundant, occurred between 4.5 m and 4.2 m. Association 9a, with *Stauriosira construens* var. *venter* abundant, occurred between 2.8 m to 2.5 m depth (table 9.1).

Table 9.1. Changes in the diatom associations with depth in Palaeolake Cormorant. Not all samples are listed: the samples given for depth (m) indicate the band of samples with that association present.

Depth (m)	Diatom Association	Diatom Species
1 2.3	2a	*Achnanthes confusa/A. confusa* var. *atomoides/Achnanthidium microcephalum/Diatomella hustedtii/Synedra rumpens*
2.5 2.8	10a	*Staur osira construens* var. *venter*
3.1 3.9	2d	*Martyana martyi*, plus Association 2a
4.2 4.5	9	*Fragilariforma virescens*
4.9 6.4	2a	*Achnanthes confusa/A. confusa* var. *atomoides/Achnanthidium microcephalum/Diatomella hustedtii/Synedra rumpens*

These changes in diatom associations were not correlated with the changes in the stratigraphy (fig. 9.4).

The TWINSPAN analysis of Palaeolake Cormorant samples gave four uneven-sized groups at the second level, with an eigenvalue of E = .135 at the first division. Grouping was based principally on rare species. Group 1, with one sample only, was separated from Group 2 by the presence/ absence of *Synedra rumpens*. Group 2 contained 12 samples, the two from Association 9a, one from 10a, one from 2d and the remainder from Association 2a. Group 3 was separated from Group 4 by the presence/absence of *Achnanthes coarcta*. It contained four samples; three from Association 2d and one from Association 9a. Group 4 contained two samples only, both from Association 2a.

Table 9.2. TWINSPAN groupings of the samples from Palaeolake Cormorant. The numbers refer to the depth of the sample below the surface.

Group 1	Group 2	Group 3	Group 4
3.1	1.8	2.8	6.2
	1.0	3.7	6.4
	2.0	3.9	
	2.3	4.7	
	2.5		
	3.5		
	4.2		
	4.5		
	4.9		
	5.1		
	5.4		
	5.9		

The mixing of widely differing samples, and the separation of samples in the same association occurred because of the common species (such as *Diatomella hustedtii,* which was in every sample), which acted to make otherwise disparate samples appear more similar and the occurrence of rare species (such as *Achnanthes coarcta,* or *Stephanodiscus* species A), which made otherwise similar samples appear different.

The HMDS analysis of samples in two dimensions was much clearer in terms of sample placement (fig. 9.5), with a minimum stress of .139. It corresponded well with the TWINSPAN grouping of samples. Group 1, with only one sample (3.1 m) was placed at the top of the graph, away from the other samples. The samples in TWINSPAN Group 2 were tightly grouped by the HMDS. The four samples in Group 3 were the most widely spread, with the sample from 2.8 m depth placed at the extreme right of the configuration. This reflects the heterogeneous nature of this group. The two samples in TWINSPAN Group 4 were placed adjacent, near the samples from Group 1.

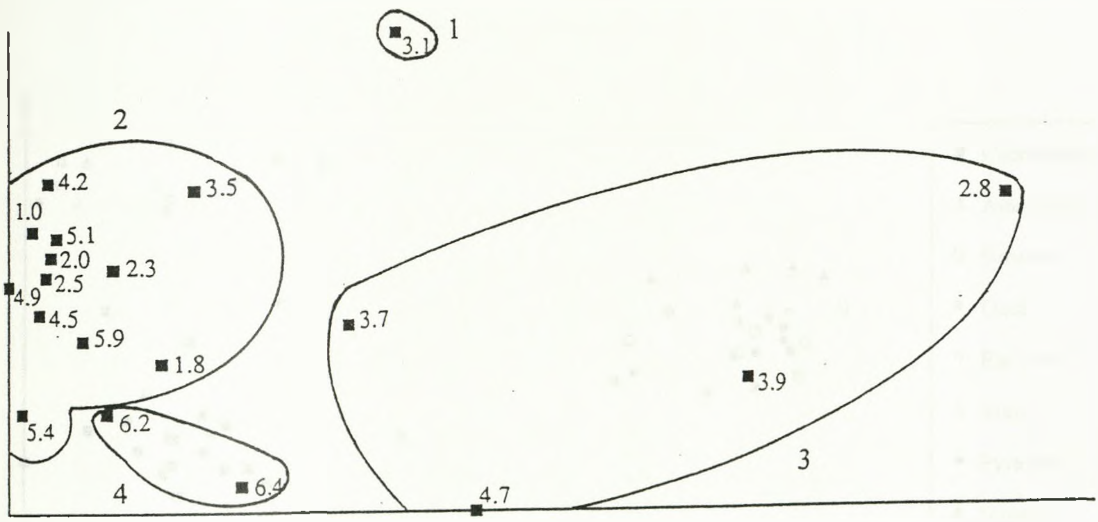


Figure 9.5. HMDS of Palaeolake Cormorant in two dimensions. Minimum stress was .139. TWINSPAN sample groups are marked.

9.3.2 Comparison of Palaeolake Cormorant with modern environments

Lakes

Almost all the samples from Palaeolake Cormorant were placed in a tight group by the HMDS comparison of Palaeolake Cormorant and modern lake samples (fig. 9.6). The two samples dominated by *Staurosira construens* var. *venter* were placed away from all other samples. The samples collected from Major Lake were placed closest to the majority of the palaeolake samples, with those from the other oligotrophic lakes and from the meso/eutrophic lakes grouped separately, away from the Major Lake and Palaeolake Cormorant samples. This indicates that the majority of samples were relatively similar to those from Major Lake. The ANOSIM of the Palaeolake Emerald and modern lake samples gave significant *p*-values for all the comparisons (table 9.3). This agrees with the separation of the modern lake and palaeolake samples by the HMDS.

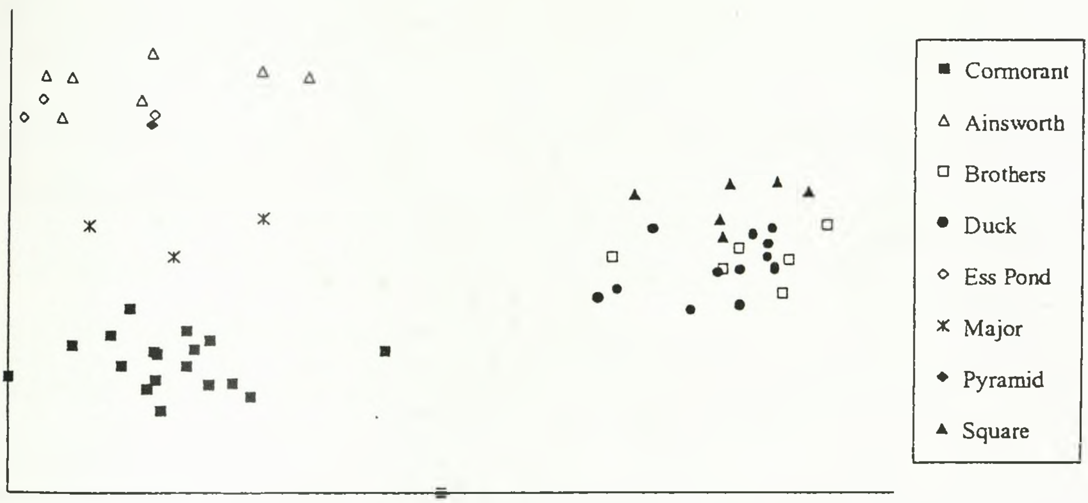


Figure 9.6. HMDS of Palaeolake Cormorant and modern lake samples in two dimensions. Samples from Cormorant were placed closest to those from Major Lake.

Table 9.3. Summary of *p*-values from pairwise comparisons of Palaeolake Cormorant samples and samples from seven modern lakes.

	Palaeolake Cormorant
Ainsworth Lake	.008
Brothers Lake	.002
Duck Lagoon	.002
Ess Pond	.006
Major Lake	.002
Pyramid Lake	.005
Square Lake	.002

Mires

The HMDS analysis of Palaeolake Cormorant and mire surface samples not dominated by *Eunotia exigua* separated the two groups, with samples from 2.8 m and 3.9 m depth placed as outliers (fig. 9.7). The mire and palaeolake samples were placed relatively close together, but were not intermingled, indicating there was some similarity between these mire samples and those from the palaeolake. The ANOSIM commparing the two groups of samples gave a p-value of .002, reinforcing the differences between the mire and palaeolake samples.

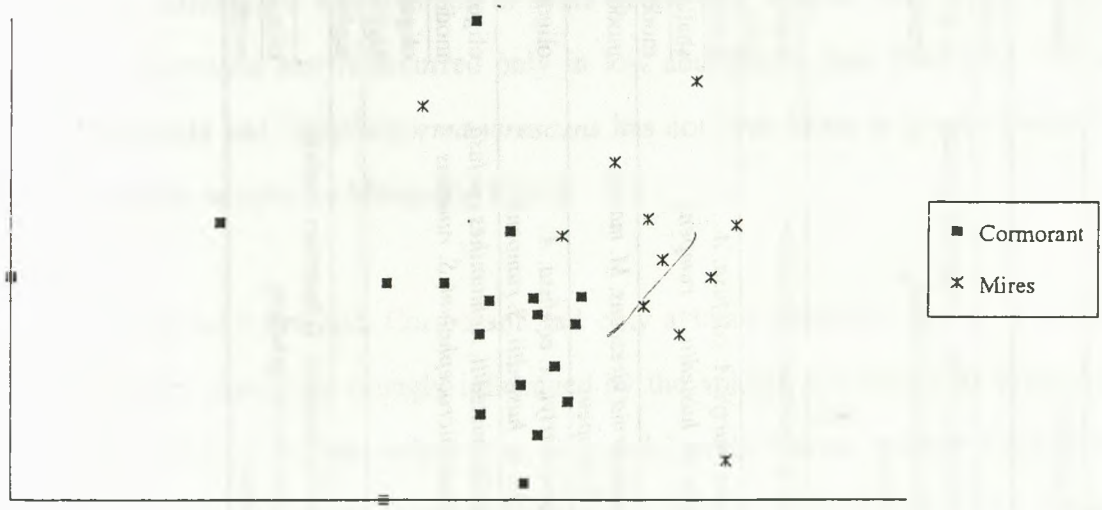


Figure 9.7. HMDS of Palaeolake Cormorant and modern mire samples not dominated by *Eunotia exigua* in two dimensions. Samples from Cormorant were placed close to, but not intermingled with those from the mires.

9.3.3 Palaeolake Cormorant as a diatom habitat

For most of its history, Palaeolake Cormorant had Association 2a present. The HMDS analysis indicates at these times it was most similar to the modern day Major Lake. There were sudden changes in the palaeo-environment, however, seen in both the sediments and the diatom associations.

It is not possible to base the interpretation of the palaeolake sediments on modern

Table 9.4. The interpreted environment of Palaeolake Cormorant, based on the stratigraphy and diatom associations.

Years BP	Depth (m)	Stratigraphy	Diatom Association	Interpreted Environment
	0	modern peat		modern vegetation
	1.0	clayey sand with coarser inclusions	*2a. Diatomella hustedtii, Achnanthes confusa. Achnanthidium microcephalum, Synedra rumpens*	oligotrophic lake, few/ no macrophytes moderate sediment input
	2.5	gravel	*9a. Staurosira construens* var. *venter*	high sediment input
4230+90	2.8	macrophyte band		little sediment input, shallow
	3.1	clay and macrophytes	*2d. Martyana martyi, A. confusa, A.. microcephala, D. hustedtii, S. rumpens*	little sediment input, shallow
	3.6	macrophytes		shallow, little sediment input
	3.9	clay		moderate sediment input
	4.2 4.5	clay	*10a. Fragilariforma virescens, M. martyi, A. confusa, S.rumpens*	moderate sediment input
	4.7	clay and few,very fragmented macrophytes	*2d. Martyana martyi, A. confusa, A.. microcephala, D. hustedtii, S. rumpens*	oligotrophic, some macrophytes
	4.9	sandy clay	*2a. Diatomella hustedtii, Achnanthes confusa, Achnanthidium microcephalum, S. rumpens*	oligotrophic moderate sediment input
	5.3	coarse gravelly sand		oligotrophic high sediment input
	5.6	gravel	no diatoms	high sediment input, one episode
	5.8	coarse gravelly sand	*2a. Diatomella hustedtii, Achnanthes confusa, Achnanthidium microcephalum, Synedra rumpens*	
11 790+70	6.2	macrophytes and clay		oligotrophic, with macrophytes
	6.4	clay and gravel		weathered bedrock

diatom associations because no similar associations have yet been found in any modern samples. As with Palaeolake Emerald, interpretation of the history of Palaeolake Cormorant is based principally on the sedimentary record (table 9.4).

The changes in diatom associations did not correspond with physical changes in the sediments. As with Palaeolake Emerald, determining the environment based on the diatom associations within Cormorant is difficult because of the lack of modern analogues. *Staurosira construens* var. *venter* (Association 9a) has only been found in great abundance in two modern samples from a creek bank on the featherbed near Duck Lagoon, although it was common in some of the peat samples from depth in Sandell Mire. *Martyana martyi* occurred only in low abundances (less than 5%) in modern environments and *Fragilariforma virescens* has not been found in great abundances in any modern samples on Macquarie Island.

Like Palaeolake Emerald, Cormorant had only a small catchment and as a result any sedimentary input was strongly influenced by the volume and timing of precipitation. The palaeolake sediments reflect this. Below 4.2 m there were coarse, unconsolidated materials with only one narrow band where macrophytes were present. The changes in sediment size from gravel to sand to clay were in response to changes in the vegetation cover in the basin and to the volume of precipitation. At 5.6 m is a band of gravel with no diatoms present, the allochthonous sediment most likely being deposited within the lake in one mass movement event, the result of a local landslip.

Between 3.9 m and 3.5 m was a band very rich in macrophytes, with very little sediment present. Above 3.5 m, to the top of the deposit at 1.0 m there was an increase in sediment size again to predominantly clay and sands, with some bands rich in gravel.

This pattern of coarse sediment at the base, changing abruptly to a band with little or no sediment very rich in macrophytes and changing back again to coarse sediment, which then continues to the top of the deposit, is similar to that seen in Palaeolake Emerald. Both palaeolakes span approximately the same time period - Emerald from 9000 to 3000 y BP, and Cormorant from 11 800 to 4000 y BP. The exact timing of the change from heavy precipitation (coarse sediment) to light precipitation (macrophyte band) back to heavy precipitation is difficult to determine. Estimates based on the radiocarbon dates indicate the event in the separate palaeolakes may not have occurred at the same time. A radiocarbon date within the Palaeolake Emerald macrophyte band gave an age of 3580 years, one about 0.7 m above the top of the macrophyte band in Cormorant was dated at 4320 years. It is possible, however, that the increase in macrophyte growth did not occur at around the same time in both lakes, but that one or both experienced some lag when responding to the changed conditions. It would have taken some time for the water level in the lakes to lower, either by subsurface seepage or by evaporation, and it is doubtful that this would have occurred at the same rate in both lakes. Within the basin, vegetation would have taken time to establish on areas bared by landslip events. Until that had occurred, bare surfaces from which sediment could be eroded and washed into the lake would still have been in existence. Establishment of the vegetation within the lakes, and the growth and deposition of it, are other factors which could alter the timing of the response in the separate lakes. More radiocarbon dates would be required to take this further.

From the similarity of the sediments to Palaeolake Emerald, it appears the two palaeolakes were relatively alike at least in terms of local sedimentary events, undergoing a period where macrophytes grew abundantly. As with Emerald, the macrophyte band in Palaeolake Cormorant is probably indicative of a shallower phase, possibly in response to a reduction in precipitation, an increase in evaporation, or a combination of both. Once the volume of precipitation increased, the lake refilled and an increase in sediment loading occurred. The macrophytes were buried and did not re-establish possibly because of the constant input of sediment and the deeper conditions.

Timing of drainage and the means by which it occurred are difficult to determine. It is unlikely that marine erosion was solely responsible. As with Palaeolake Emerald, the base of the wave-cut cliffs would have been above the zone of wave action at the time of drainage - later than 4000 y B.P. While marine erosion may have acted in part to weaken cliffs below Palaeolake Cormorant, a mass movement event, perhaps coupled with stream erosion, is most likely to have been the trigger for drainage.

9.4. Comparison of Palaeolake Cormorant with other Palaeolakes

Palaeolake Cormorant was most similar to Palaeolake Emerald, in terms of the variation in sediments and in the diatom associations, although only two of the diatom associations were shared. Where Association 2a was present, Palaeolake Cormorant was similar to the othe paleolakes. Figures 5.12d, 6.13c, 7.9b and 8.10 compare the HMDS analyses of Palaeolake Cormorant with the other palaeolakes, illustrating the similarities between some of the Cormorant associations and those seen in the others. However, it was the most varied of the five palaeolakes, with major changes in associations occurring throughout the deposit. In the ANOSIM comparison of the palaeolakes, Cormorant was significantly different from all other Palaeolakes except Cascade Section 2 (table 5.5).

9.4 Conclusions Drawn from Chapter 9

Macrophyte growth, diatom associations and the amount of sediment input all went through major and abrupt changes in Palaeolake Cormorant. Interpretation of the palaeolake environment is based primarily on the changes in sediments, as no ecological information exists at present for Associations 2d, 9a and 10a. The catchment of Palaeolake Cormorant was relatively small and so the lake sediments were strongly influenced by the variation in precipitation.

The palaeolake was very similar to Palaeolake Emerald in terms of the changes in sediments seen. It was, for at least part of its history, most similar to Major Lake, and was probably oligotrophic and moderately alkaline. It had three main phases:

1. From formation to 3.9 m. Deep, with few or no macrophytes present. Moderate to high amounts of sediment washing in, with one landslip indicated (5.6 m). At 6.2 m, one band with moderate amounts of macrophytes indicated more stable conditions. Generally, moderate to high precipitation levels are indicated, interpreted as a wetter climate than that of phase 2.
2. From 3.9 to 3.5 m. Shallow, with very abundant macrophytes and little sediment. Indicates a drier climate than that of phases 1 and 3.
3. From 3.1 m to the uppermost sediments. Deep, with few or no macrophytes and increased sediment size. Indicates a return to wetter conditions than that of phase 2.

Palaeolake Cormorant sediments have the longest continuous record for any of the five palaeolake deposits studied, spanning a dated time of around 7000 years. Drainage of the palaeolake was not directly caused by marine erosion of the sea cliffs, although this may have contributed. Mass movement and/or stream erosion are likely to have been the ultimate cause of drainage. The interpretation of and conclusions about Palaeolake Cormorant are summarised in table 9.5.

Table 9.5. Palaeolake Cormorant - interpretations and conclusions

Diatom Association	2a. *Achnanthes confusa/A confusa* var. *venter/Achnanthidium microcephalum/Diatomella hustedtii/Synedra rumpens* 2d. As above, plus *Martyana martyi.* 9a. *Staurosira construens* var. *venter.* 10a. *Fragilariforma virescens*
Vegetation	*Myriophyllum triphyllum* from 3.9 m to 3.5 m. Macrophytes at 6.2 m. Little/no other vegetation.
Sediments	Little sediment between 3.9 m and 3.1 m. Above and below varied from coarse to fine
Drainage	Combination - mass movement/ stream erosion/ marine erosion
Depth	> 6.4 m
Size	Unknown
Inferred pH	Moderately alkaline
Inferred Conductivity	Low
Inferred Trophic Status	Oligotrophic
Modern Analogues	None for associations 2d, 9a or 10a. Major Lake for Association 2a
Palaeolake Analogues	Half Moon: similar where Association 2a occurred Cascade: Section 2 very similar Eagle: as for Half Moon. 1 sedimentary episode Emerald: shared Associations 2a & 10a. Similar changes in sediments, small catchments

Chapter 10

Discussion and Conclusions

10.1 Synopsis

One hundred and eighty one species and varieties of diatoms were identified from modern and fossil samples from Macquarie Island. The majority of species are cosmopolitan, with the remainder apparently to be restricted to the subantarctic and/or Antarctic regions. This is in agreement with studies in other areas in the subantarctic and Antarctic. Eight diatom associations from modern material and three associations from fossil sediments with no modern analogues on Macquarie Island were identified. The only association from the terrestrial and mire environments which was seen in the palaeolake samples was Association 2.

Palaeolakes Cascade and Eagle show little change over time. Palaeolake Half Moon had one major change in diatom species, Emerald and Cormorant underwent several changes in sediments and in diatom associations. Cascade, Eagle and Half Moon were all oligotrophic, relatively deep lakes with circumneutral pHs. Palaeolakes Emerald and Cormorant were similar to this for some of the time, but underwent periods of more or less sediment input and experienced changes in water levels throughout time. The Younger Dryas cooling event of 11 000-10 000 y BP is well documented in the Northern Hemisphere. Evidence for a similar event in the Southern Hemisphere is growing, however, it is not reflected in the palaeolake sediments which span this time period. A possible dry phase on Macquarie

Island between 5000 and 3500 y BP was seen in the sediments of Palaeolakes Emerald and Cormorant, and may be related to a similar episode from South Georgia.

10.2 The Diatoms of Macquarie Island

10.2.1 Comparisons with other areas

One hundred and eighty one diatom taxa have been identified from modern and fossil samples on Macquarie Island. A few taxa are yet to be identified to species level. Few individuals of these taxa were found. Appendix 2 lists all the species identified during this study, with photomicrogaphs of many of the more common and rarer species. Voucher slides for all species are nominated in Appendix 2.

One hundred and thirty four species, subspeices or varieties (74 %) are cosmopolitan, occurring in many areas in both the Northern and Southern Hemispheres. Nineteen species were described from material collected from the Kerguelen Islands and were regarded as endemic by Le Cohu and Maillard (1983; 1986). Only one species, *Brachysira* species A, is possibly a new species (yet to be described). It may be endemic to Macquarie Island, but at present this is very uncertain. Twenty six taxa could not be identified beyond genus level, with only two rare taxa not assigned to a genus.

Very little work has been done on subantarctic diatoms, with the main contributors Germain (1937), Bourrelly and Manguin (1954) and Le Cohu and Maillard (1983; 1986) from the Kerguelen Islands, and Bunt (1954) from Macquarie Island. The assumption by Le Cohu and Maillard that the species identifed from the Kerguelen Islands samples were endemic was premature, as they occur commonly in fossil and modern samples from Macquarie Island also. Bunt's (1954) study on the soil diatoms of Macquarie Island listed 54 taxa, many of which have been renamed, were misidentified, or were taxa which had not been described at the time. Evans (1970) listed some diatoms found during a study of a copepod on Macquarie Island. A study of diatoms from a variety of modern lake environments is in progress (T.P. McBride, pers. comm.).

Fukushima (1970) increased the number of species of diatoms recorded from South Georgia from 44 to 93. He noted that the majority of species was cosmopolitan, with only four species (less than 10%) endemic to the region. This percentage of regional species is similar to that found in this study. In Birnie's (1990) report on climatic change on South Georgia, she used diatoms as indicators of past lake environments. She listed the most common species, with the majority occurring in the island, although many taxa were not identifed beyond genus level (table 10.1).

More research has been conducted into the diatoms of the maritime Antarctic, with some into the diatoms of continental Antarctica also. Broady (1976) recorded 29 species of diatoms as well as other freshwater algae from Signy Island, South Orkney Islands; of those that were identified to species level 11 have been recorded on Macquarie Island. From the diagrams in the paper it is possible to recognise some of the taxa not assigned a species name as occurring on Macquarie Island (eg. Broady's *Achnanthes* species A, which appears to be *A. austriaca*). It is worth noting that Broady did not refer to Bourrelly and Manguin (1954) or Germain (1937), who named many of the subantarctic species which, until these papers, had not been reported or identified from other areas.

Other workers have greatly increased the number of diatom species identified on Signy Island. Oppenheim (1990), Oppenheim and Greenwood (1990), Oppenheim and Paterson (1990) and Oppenheim and Ellis-Evans (1989) have reported over 100 species, with 30 of these occurring on Macquarie Island (table 10.1).

Forty of 102 species, subspecies and forms identified from lake sediments on King George Island, maritime Antarctica, occur on Macquarie Island (Schmidt, Mäusbacher & Müller, 1990). Of all the species identified, the majority were cosmopolitan, five were new species, six occurred on Macquarie Island, two more occurred on Kerguelen Island and 12 have not yet been reported from either. Wassel and Håkansson (1992) reported 123 species from Horseshoe Island, Antarctica, 38 of which occur on Macquarie Island. Twenty two species of diatoms were recorded from Lake Miers, South Victoria Land, seven of which occur on Macquarie Island (Baker, 1967). A survey by Broady (1989) of the terrestrial algae of Marie Byrd Land found no diatoms, which he stated was extremely unusual. No reasons were postulated for this.

Table 10.1. Comparison of diatoms on Macquarie Island with other areas in the subantarctic, maritime antarctic and the antarctic.

Location	Number of Species & subspecies	Number which occur on M. I.	References
Macquarie Island	168	-	This study
	87	-	Evans, 1970
	54	-	Bunt, 1954
Kerguelen Island	279	90	Le Cohu & Maillard, 1986
	35	23	Le Cohu & Maillard, 1983
	161	64	Bourrelly & Manguin, 1954
	33	22	Germain, 1937
South Georgia	26	18	Birnie, 1990
	94	22	Fukushima, 1965
Signy Island	87	28	Oppenheim, 1990
	105	24	Oppenheim & Greenwood, 1990
	7	6	Oppenheim & Paterson, 1990
	28	11	Oppenheim & Ellis-Evans, 1989
	29	11	Broady 1976
King George Island	102	40	Schmidt, Mäusbacher & Müller, 1990
Horseshoe Island	123	38	Wassel & Håkansson, 1992
South Victoria Land	22	7	Baker, 1967
Marie Byrd Land	0	-	Broady, 1989

Most of the freshwater and terrestrial diatom species which occur in the subantarctic and the Antarctic are pennate - very few genera of centric diatoms have been recorded. The most common centric genus seen is *Melosira/Aulacoseira*. The majority of species which do occur are reported as being benthic, epiphytic or motile. No-one has put forward a theory for this, although the same trend is seen in the arctic and the subarctic.

10.2.2 Diatom Associations from modern habitats on Macquarie Island

The mire and terrestrial samples collected from Macquarie Island revealed 8 major diatom associations which occur. These were characterised by one or more dominant species. The species in each association and the environments in which they occur are listed below.

Association 1. *Eunotia exigua/Pinnularia acoricola.*

Acidic Mires. The acidic mires were the most distinctive of all the mires sampled. The lower the pH, the greater the percentage of *Eunotia exigua. Pinnularia acoricola* was always found where *E. exigua* occurred in great abundances. This association was not found in any palaeolake sediments, though it was found in some fossilised mire material.

Association 2a. *Achnanthes confusa* & var. *atomoides/Diatomella hustedtii/Synedra rumpens,* with *A.pseudolanceolata/Achnanthidium microcephalum.*

Association 2b. 2a, plus *Achnanthes abundans/Achnanthidium microcephalaum/Amphora coffeaeformis/ Caloneis silicula/Nitzschia palea.*

Wet areas. This was the most common association, occurring in environments where there were few environmental extremes. These species also appear to have quite broad ecological tolerances, occurring less abundantly in many other, more extreme environments. They were dominant in neutral mires, lakes and beside streams, but also occurred in lesser abundances in other environments. Association 2a occurred principally in mires with circumneutral pH; 2b contained the same species as 2a, with a few more that were also reasonably common. It occurred in streams where the current was low or non-existant. It is interesting to note that this association contains the greatest number of species which appear to be endemic to the subantarctic and Antarctic, such as *Achanthes abundans* and *A. confusa.* This association was most common in the palaeolake sediments.

Association 3. *Synedra rumpens* more than 60% of the total abundance.

Streams with a strong current. This association was dominated by *Synedra rumpens*. It occurred only in samples from streams where the current was quite strong for at least some of the time. It did not occur in any of the palaeolake samples.

Association 4. *Achnanthes abundans/A. manguinii/A. confusa/Aulacoseira granulata/ Caloneis silicula/Pinnularia lata/P. circumducta/Synedra rumpens.*

Feldmark. This occurred in the samples of bryophytes and *Azorella macquariensis* collected in the feldmark. There was no difference seen in the diatom associations between the different species of bryophytes or *A. macquariensis*. The species of diatoms present - some from the associations that are found in wetter habitats and some from those species found in drier habitats - indicate that the feldmark is not an extreme environment for diatoms, but that it does experience periods of drier weather.

Association 5. *Achnanthes manguinii/Aulacoseira granulata/Luticola mutica/L. neoventricosa/Pinnularia acoricola/P. circumducta/P. kolbei/P. lata.*

Dry Areas. This association was found in samples of soil and lichen from dry areas - lichen on rocks not receiving seepage water or soil in exposed areas. This diatom association was reasonably distinctive. Many of the species present are large *Pinnularia* species which are capable of moving to more favourable conditions if necessary (Evans, 1959; 1958). While *Pinnularia* species did occur in the palaeolake sediments and in other wet environments, they were less common.

Association 6. *Achnanthes confusa/Caloneis silicula/Diatomella hustedtii/Eunotia exigua/ Synedra rumpens.*

Moist soil. This association, found on samples of soil in areas receiving some moisture, such as from seeps, has elements of several other associations. The abundance of *Eunotia exigua* suggests it may be slightly acidic; the presence of species from Association 2 suggests that otherwise the environment is not extreme. *Caloneis silicula*, from the stream environments, was also present. It is regarded in the literature as a litoral/epiphytic and so was not unusual here (Appendix 1).

Association 7. *Pinnularia kolbei/Pinnularia* species E.

Dry, nutrient enriched. This was dominated by two species of *Pinnularia*, one of which has not been identified to species level. It occurred in samples of dry soil from within and around penguin colonies and elephant seal wallows. Nutrient enrichment and dryness both appear to be affecting the diatom association. It was not encountered in any of the palaeolake samples.

Association 8. *Achnanthes delicatula/Luticola mutica/L. neoventricosa/Nitzschia palea/ Pinnularia kolbei/Surirella linearis.*

Moist, nutrient enriched. The species present in this association have been described either as nutrophiles or as pollution tolerant. *Achnanthes delicatula* and *Surirella linearis* only occurred in high abundances in these samples. Again, this association did not occur in any palaeolake sample.

10.2.3 Fossil Diatom Associations

The sediments from the five lacustrine deposits studied, dating from 12 970 RC y BP (Palaeolake Half Moon) to 3580 RC y BP (Palaeolake Emerald) were examined for diatoms and macrofossils. Four main diatom associations occurred in the palaeolake sediments - Associations 2, 9, 10 and 11. Associations 2c, 2d, 9a, 9b, 10b and 11 were not recorded in any modern sample from Macquarie Island, while Association 10a occurred in only two modern samples and so was not included with the modern associations. The diatom associations have been used to interpret the palaeoecological conditions of the five palaeolakes where possible and to identify changes in the environment of the palaeolakes over time. The diatom associations from the palaeolake sediments are listed below.

Association 2a. This was the most common of the associations in the sediments, occurring in all palaeolakes. It was the only association present in Palaeolake Eagle.

Association 2c. Association 2a, with *Cocconeis placentula* present to abundant. This association was present only in the upper sediments of Palaeolake Cascade.

Association 2d. Association 2a, with *Martyana martyii* present to abundant. This This species was found in low abundances (less than 10%) in few terrestrial and mire samples.

Association 9a. *Staurosira construens var. venter* dominant. It occurred in two samples from Palaeolake Half Moon and in samples from Emerald and Cormorant. It has been found dominant in only two modern creek samples from near Duck Lagoon.

Association 9b. *Staurosira construens var. venter* dominant with *Diatomella hustedtii*. It occurred in one sample only from Palaeolake Half Moon. It has not been found in any modern sample.

Association 10a. *Fragilariforma virescens* occurred as the dominant species (more than 50 % of the total abundance). No modern analogues have been found on Macquarie Island. Burnie (1990) reported finding *F. virescens* abundant in lake samples from South Georgia. It occurred in Palaeolakes Emerald and Cormorant.

Association 10b. *Fragilariforma virescens* dominant with *Achnanthes confusa, Achnanthidium microcephalum, Diatomella hustedtii* and *Pinnularia circumducta*. It occurred in Palaeolake Emerald only.

Association 10c. *Fragilariforma virescens* present, with species from Associaton 2 - *Achnanthes confusa, Diatomella hustedtii* and *Synedra rumpens* - abundant. This association also only occurred in Palaeolake Emerald.

Association 11. *Cymbella kerguelenensis, Diatomella hustedtii* and *Pinnularia circumducta* dominant. It occurred only in Palaeolake Emerald. It has not been seen in any modern sample.

10.2.4 Rare Species

The majority of the species identified from the modern and fossil samples were classed as rare or very rare - 111 compared to 70 common or very common. Many of the species classed as common or very common occurred in high numbers in specific environments and were rare in others, such as *Eunotia exigua* and *Achnanthes delicatula.* This pattern of community structure has long been recognised in many habitats, and has been noted in diatom communities from many areas (see Patrick and Reimer, 1966 pp79-84 for a review). With increasing environmental extremes, such as more acid or more dry, the number of common species will be reduced, and the number of rarer species increased. This was demonstrated in the acidic mires, streams with strong currents and nutrient-enriched areas on Macquarie Island.

10.3 Palaeolakes - Comparisons and Conclusions

Of the five palaeolakes, Half Moon, Cascade and Eagle were the most similar. They had few changes in the diatom associations and very few changes in the sediments over time. Palaeolakes Emerald and Cormorant underwent many changes in both the diatom associations and in the sediments (table 10.2).

Palaeolakes Half Moon, Cascade and Eagle all had large catchments, with Half Moon downstream from Scoble Lake and Palaeolake Eagle downstream from Island Lake. The catchment for Palaeolake Cascade extended up into the area to the west of Boot Hill (see map insert, back pocket). In contrast, Palaeolakes Emerald and Cormorant had very small catchments, restricted to the areas immediately around the palaeolakes. Input would have been from precipitation and local subsurface seepage and overland flow, rather than drainage from a large catchment area. During drier periods, the lakes may have partially dried up or drained as the input diminished.

Table 10.2. Summary of palaeolake interpretations.

Palaeolake	Half Moon	Cascade	Eagle	Emerald	Cormorant
Diatom Associations	2a, 9a, 9b	2a, 2c	2a	2a,10a, 10b, 10c, 11	2a, 2d, 9a, 10a.
Age RC y BP	10 560 ± 80 12 970 ± 80	6500 ± 60 12 710 ± 120	7030 ± 80 12 200 ± 130	3580 ± 90 9320 ± 70	4330 ± 70 11 790 ± 90
Sediments	Clay	Clay	Clay, clay, no diatoms	clay, gravel sand, macrophytes	clay, gravel, sand, macrophytes.
Macrofossils	*M. triphyllum*	*M. triphyllum* *F. rigidulus*	*M. triphyllum* *F. rigidulus*	*M. triphyllum*	*M. triphyllum*
Modern Analogues	Major Lake	Major Lake	Major Lake	Major Lake & ?	Major Lake & ?
Inferred pH	slightly basic	slightly basic	slightly basic	slightly basic	slightly basic
Inferred Conductivity	low	low	low	low	low
Inferred Nutrient Status	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic	Oligotrophic
Historical Changes	shallowing	shallowing	shallowing, one influx of sediment	deep, to shallow, back to deep	deep, to shallow, back to deep

The ultimate effect of the small catchment size would have been in the reflection of the effects of any major change in the immediate environment within the sediments. In the larger basins, a landslip event may have resulted in only fine sediments reaching the lake and being deposited, as any heavier, larger factions would have been transported a short distance only. While the likelihood of an event such as a landslip within a smaller basin is less, the effect it would have on the lake environment would be greater. Large particles could be transported into the lake by overland flow; the slip could even occur at the lake edge, with all material sliding directly into the lake.

10.4 Palaeolake Sediments - Stability or Change over Time

The palaeolake sediments in Half Moon, Cascade and Eagle show that by 12 900 RC y BP stable lake conditions similar to those that currently exist on Macquarie Island were established and supporting rich diatom floras. Of the five palaeolakes examined, Cascade exhibited very little change in either the diatom associations present or in the sediments, with only the introduction of one species, *Cocconeis placentula,* occurring. Palaeolake Half Moon had stable conditions until some time before drainage, where an unidentified change in the environment occurred, causing a major shift in the diatom association present. Palaeolake Eagle experienced two periods of increased sedimentation, with one influx of sediment soon after lake formation, and another, more sustained increase in particle size prior to drainage. Palaeolakes Emerald and Cormorant both show major changes in the sediments and the diatom associations throughout. These changes are due to localised, within-catchment effects. The palaeolakes with very large catchments - Half Moon, Cascade and Eagle - had comparatively little sediment change, indicating relatively steady sedimentation rates and input. Because the catchments of both Palaeolake Emerald and Palaeolake Cormorant were small, the rate of sediment deposition and the and size of the particles being deposited would be very influenced by the volume and timing of precipitation with any change in precipitation directly influencing the type of sediment being washed into the lake at any one time.

Within the sediments of Palaeolakes Cascade and Eagle there are bands of *Fissidens rigidulus*, which today occurs on the island in running water, and has been reported from Scoble and Tulloch Lakes (Hughes, 1986). The excellent preservation of the moss stems and leaves and the thickness of the bands in which it occurs indicate that it is likely to have grown within the lakes and not that it grew within the streams and was washed in and deposited in the lake. The reason for the presence of the moss in these bands is unknown, but it may be related to lake depth. It occurred principally in the lower parts of the deposits, growing when the lakes were deeper. The diatom assemblages remain unchanged on either side and within the bands. *Fissidens rigidulus* occurs with *Myriophyllum triphyllum* in Palaeolake Cascade sediments and in modern Scoble Lake, although *M. triphyllum* only occurs sparsely in the latter. It may be that *F. rigidulus* grew within

Palaeolake Cascade and Palaeolake Eagle until shallowing of the lakes allowed *M. triphyllum* to out-compete the moss.

Interpretation of the local environments of Palaeolake Emerald and Palaeolake Cormorant are based on primarily on the sedimentary record as the ecological information on the diatom associations present throughout these two palaeolakes is limited. The clayey sands with few or no macrophytes present appear to be indicative of a relatively wet climate, with deep water in the lake and larger sediments being washed in. The bands of gravelly sand with no diatoms present were in all probability laid down each in a single event - heavy rain leading to a landslip and several centimetres of material washing into the lake at once. Landslip events have been shown to be triggered by heavy rainfall (Selkirk, in press). The absence of diatoms in these sediments supports the theory that they belong to separate events and that it was a single influx of sediment each time, with no time for autochthonous materials (diatoms, macrophytes) to be produced and deposited within the lake.

In Palaeolakes Emerald and Cormorant there was a macrophyte-rich layer, which possibly represents an environment which was somewhat drier than the previous. With only small catchments, the volume of water reaching the lake was closely related to precipitation levels. If precipitation was reduced the lake level would have lowered eventually. Lake shallowing may have occurred by sub surface seepage or by evaporation, or a combination of both. Shallowing may have allowed for the lush growth of macrophytes which occurs in many of the shallower, more mesotrophic modern Macquarie Island lakes. The small amounts of sediment within the macrophyte bands supports the theory that there was little precipitation. With a reduction in the amount of rainfall, there would be less erosion of the catchments and less sediment deposition. Any areas bared by previous landslips would have time to revegetate, thus decreasing the area available for sediment to be eroded from and further reducing the volume of sediment being washed into the lake.

Above the macrophyte-rich bands are coarser sediments with no macrophytes. This appears to indicate a return to the deeper condition, with more precipitation eroding and depositing larger particles.

The two palaeolakes show a similar, but not identical trend in sedimentation and lake macrophyte vegetation. The band rich in macrophytes in Palaeolake Cormorant is much thinner than that in Palaeolake Emerald. However, it does occur in between bands of coarser sediments with no macrophytes. The variation in the size of the macrophyte bands in the palaeolakes may be due to differences in the lakes themselves - a longer lag time in the establishment of vegetation, slower rate of shallowing, or lower nutrient or light levels are all factors which would affect the growth of macrophytes.

The diatoms which occur within both these lakes do change with depth; as yet no environmental interpretation can be made as very few or no modern analogues have been found, especially where *Fragilariforma/Staurosira* species (separated from the genus *Fragilaria* by Round, Crawford and Mann, 1990) are abundant. Birnie (1990), in her study of lake sediments on South Georgia, mentioned the surface samples were dominated by *Fragilaria* species. Unfortunately no mention of the lake parameters was made. So while the conditions under which *Fragilaria/Staurosira/Fragilariforma* species can flourish do still occur in the subantarctic, no inferences can be made as to the nature of the conditions of the lakes at this time.

The timing of these possible drier phases is difficult to determine. A radiocarbon date from within the macrophyte-rich band in Palaeolake Emerald gives an age of 3580 $\pm$ 80 y BP. The sediments above the layer rich in macrophytes in Palaeolake Cormorant was dated at 4320 $\pm$ 90 y BP. This indicates the timing of the two shallowing events were not directly coincident. However, data from Birnie (1990) provides evidence for a drier climate on South Georgia lasting approximately 1000 years, from 4800 y BP to 3800 y BP. It is possible that Emerald and Cormorant are reflecting a similar climatic event, although whether this was separate from or related to the one on South Georgia is impossible to determine.

10.5 Climatic Change during the Late Pleistocene and Holocene - Global Change and Evidence from the Antarctic, Subantarctic and Southern America

The end of the last glacial period about 18 000 y BP, was associated with a world-wide amelioration in climate during the Allerød and Bølling interstadials. This has been shown in pollen studies from Europe, North America, Canada and Alaska (eg. Mott, Grant, Stea & Occhietti, 1986; Berger, 1978; Peteet *et al.*, 1987; Engstrom, Hansen & Wright, Jr 1990); from beetle remains in Britain (Atkinson, Briffa & Coope, 1987) and in oxygen isotope studies (eg. Kudrass, Erienkeuser, Vollbrecht & Weiss, 1991; Thompson *et al.*, 1989; Eicher & Siegenthaler, 1976; Dansgaard & Tauber, 1969). Because of the limited amounts of land at similar latitudes compared to the northern hemisphere, information on climatic change in the subantarctic and the Antarctic is limited. Evidence is principally from global sea level changes.

Approximately 11 000 y BP a marked cooling interrupted the progressive global warming at the end of the last glacial period. It was first identified by a reversal in pollen fossils in European peats changing from more temperate forest species to tundra plants (Jouzel *et al.*, 1992). The Younger Dryas climatic shift was originally thought to be localised in Europe, but has since been recognised in Alaska, Canada, northern USA, Mexico, Tibet, the Sulu Sea, Britain and in reefs off the coast of Barbados (Van Copo & Gasse, 1993; Stea & Mott, 1989; Kudrass *et al.*, 1991; Engstrom, Hansen & Wright Jr, 1990; Peteet *et al.*, 1990; Fairbanks, 1989; Atkinson, Briffa & Coope, 1987; Mott *et al.*, 1986; Fairbanks, 1989; Eicher, Siegenthaler & Wegmüller, 1981; Shane, 1987).

Various mechanisms for the sudden reversal in climate have been postulated, including interactions of meltwater from the Arctic ice sheet, oceanic circulation and atmospheric CO_2 (Kudrass *et al.,* 1991), displacement of the north polar front (Engstrom *et al.,* 1990), and changes in oceanic circulation (Peteet *et al.*, 1990). Effects from all of these are restricted to the northern hemisphere only.

Evidence for similar climatic reversals in the southern hemisphere is growing. Studies of pollen profiles from Chile, South Georgia, Tierra del Fuego, West Falkland Island and the Kerguelen Islands indicated possible trends in climate similar to those seen in the northern hemisphere (Heusser & Rabassa, 1987; Heusser & Streeter, 1980; Young & Schofield, 1973). Ice cores from Antarctica have provided good evidence for climatic change from several independent areas: ice core chronology, dust concentrations, O^{18}/O^{16} ratios, CO_2, and CH_4 levels (Jouzel *et al.,* 1987; Jouzel *et al.,* 1992.). They found evidence of a cooler period from 12 800 y to 13 600 y BP from widely separated cores. This is approximately 1000 years earlier than the cooling which occurred in the Northern Hemisphere. This discrepancy in timing is not unusual, as other major climatic events also appear to have occurred earlier in the Southern Hemisphere (Jouzel. *et al.,* 1992.). Further work is required to finalise the dating of the cooling event in the Southern Hemisphere.

Some palynological work in the subantarctic has failed to conclusively support a cooling event coeval with the Younger Dryas. Changes in pollen throughout a profile can generally be attributed to other, more localised events such as uplift and vegetational succession coincident with glacial retreat (Hall, 1980; Barrow, 1983; 1978; Larson. 1974). Bergstrom (1986) and Selkirk, Selkirk and Griffin (1983) recognised changes in the palynology of Holocene peats at a site on Macquarie Island, but attributed these to changes in the local conditions directly related to uplift. Other workers in the subantarctic have also found little to support climatic change (Barrow, 1978; 1983). This is in agreement with the palaeolake data. The palaeolake sediments from Half Moon, Cascade, Eagle and Cormorant do span the Younger Dryas period, however no evidence for cooling at this time was seen in the sediments or in the diatom associations. In fact, Half Moon and Cascade show no changes at all at this time, while the diatom-poor band in Palaeolake Eagle indicates a wetter (ie warmer) environment, with landslips occurring. The large-sized sediments in Palaeolake Cormorant also indicate a wetter environment.

The results from palynological studies are reflecting the tolerance of vascular plants to changes in the environment. Some vascular plants which occur on the islands are tolerant of a broad ecological amplitude and so may have been able to tolerate a cooling event of several degrees during the latest Pleistocene/earliest Holocene (Pickard, Selkirk & Selkirk, 1983). Evidence for this can be seen in the range of *Azorella macquariensis/A. selago* and *Poa foliosa*. *Azorella* is a cushion plant that grows widely in the feldmark on Macquarie Island and elsewhere. It appears to be a coloniser, acting to stabilise soils affected by solifluction, sheetwash erosion or frost heaving. Once established, other species may then begin to establish adjacent to or within the cushion where the soil is stable. Competition with other angiosperm species appears to be the major factor in the distribution of *Azorella*: while it can grow close to sea level on Macquarie Island (eg. at Bauer Bay), it is rare below about 100 m a.s.l. It is, however, widespread on Heard Island at sea level, where the number of vascular plants is much fewer and interspecific competition is apparently less (22 species as opposed to 52 species on Macquarie Island).

Poa foliosa is now almost completely restricted to the coastal flats and slopes. Prior to the introduction of the rabbit (*Oryctolagus cuniculus*) by sealers, *P. foliosa* apparently occurred widely on the plateau also (Scott, J.J., 1985; Brothers, Eberhard, Copson & Skira,1982; Holdgate & Wace, 1961.). Overgrazing by rabbits led to a decrease in the distribution of *Poa foliosa,* with these areas becoming colonised by short tussock grassland. An eradication program by the Tasmanian Parks, Wildlife and Heritage Service (including shooting and the introduction of myxomatosis) has reduced the numbers of rabbits and in some areas *P. foliosa* is re-establishing (Scott, 1988).

Peteet *et al.* (1990) stated that few or one vegetation type(s) in or near a site will limit the sensitivity of the response of the vegetation to a changing climate. Both this 'insensitivity' and the relatively small variation in diurnal and seasonal temperatures, because of the ameliorating effect of the ocean, will act to keep pollen profiles relatively constant as vegetation will not be as affected by climatic variations as in other continental areas (Scott, L, 1985). In sites on Macquarie Island where palynological work has been done generally there is one dominant vegetation type, short tussock grassland, with *Poa foliosa* stands nearby. A drop in temperature of around 3°C would have little effect on the vegetation. This postulated change in temperature would be equivalent to an increase in altitude of about 300 m. Short tussock grassland occurs above 300 m on Macquarie Island in some places and so at least in coastal areas there would be little effect on the vegetation. In the upland areas there would be likely to be an increase in the area of feldmark vegetation, such as was seen in peat profiles from the Kerguelen Islands (Young & Schofield, 1973). However, the preservation of this record in the upland areas is unlikely because of the poor development of peat there.

The diatom and sedimentology results obtained from this study reinforce the apparent lack of evidence for a Younger Dryas-type cooling event in the subantarctic. Although the palaeolake sediments adequately bracket the Younger Dryas, no evidence for a marked cooling on Macquarie Island has been recorded. It is conceivable that diatoms, like vascular plants, are able to tolerate a change of temperature of several degrees. While a change of this magnitude would increase the number of days where the temperature fell below 0°C and also increase the number of days when the lakes would be iced over, it is possible the diatom associations would not respond in an identifiable manner. The species common in the lake sediments at this time - principally those in Association 2a - have been shown to be generalists, occurring in a range of habitats on Macquarie Island and elsewhere (eg *Synedra rumpens* - Appendix 1, Chapter 4). Diatoms can survive in Arctic and subarctic areas where few months of the year are ice free (eg Wolfe, 1991). A reduction in diatom production and growth would occur during the colder months; this is unlikely to be recorded in the sediments as little or no allochthonous sediment would be being deposited at this time either.

Jouzel *et al.* (1987) found non-biological evidence for a cooler period between 13 600 and 12 800 y BP. While this is at the oldest limit of the palaeolake sediments, they still do cover part of this, and so the problem in finding evidence of a cooling event on Macquarie Island is not due to a lack of material of a suitable age. The repetition of results on Macquarie Island in pollen, diatoms and sedimentology suggests that either the analysis tools used are not sensitive enough or that there was no marked cooling on Macquarie Island at this time. It is recognised that the ocean has an ameliorating effect on the climate of subantarctic islands (Scott, L., 1985). Macquarie Island has one of the most equitable climates in the world - with a very low diurnal and seasonal temperature range. This constancy may have buffered the temperature drop enough to allow the majority of species to survive in established habitats.

There is, however, evidence of environmental change occurring on Macquarie Island after the Younger Dryas. Birnie (1990) reported a drier (and possibly cooler) period on South Georgia, occurring between 4800 and 3500 y BP. The two palaeolakes with the youngest sediments still present - Emerald and Cormorant - both exhibit what has been interpreted as evidence for a change in climate from wetter conditions to drier, back to wetter prior to drainage.

While no supporting evidence has been found in the vascular plant/palynological studies for this change, it is possible that these species would not be affected as obviously or as directly as the palaeolake sediments. Further work on pollen analysis from peat and mires is needed to take this question further. It is impossible to conclude whether this drier period on Macquarie Island is related to the one which occurred on South Georgia; however, if one island can experience such a phenomenon, it is not inconceivable that a second island, in the same broad climatic zone, could experience a similar event at approximately the same time.

10.6 Conclusions

The majority of the diatom taxa which occur on Macquarie Island are cosmopolitan. Only 10% can be considered to be endemic to the subantarctic or to the Antarctic. One hundred and eighty one species, subspecies and varieties of diatoms were identified from modern and fossil samples collected from Macquarie Island. Eight diatom associations were identified from modern mire and terrestrial samples on the island. These became more distinct with increases in environmental extremes. The only modern terrestrial/mire association seen in the palaeolake sediments was composed of species with wide ecological amplitudes that occurred in a number of environments. Four diatom associations - 2, 9, 10 and 11 - were seen in the palaeolake samples collected. Three of these were not found in or were extremely rare in modern samples.

Lake environments were well established by 12 900 RC y BP, with the lakes with large catchments relatively stable until drainage. The sediments of Palaeolakes Emerald and Cormorant reflect what may have been a drier period on the island from approximately 5000 to 3500 y BP.

Palaeolakes Half Moon, Cascade and Eagle were oligotrophic, relatively deep lakes with some macrophyte growth and circumneutral pH. Palaeolakes Emerald and Cormorant had several changes during their existence. They were similar to the three other palaeolakes for some periods, but also underwent a period of shallowing when macrophytes grew profusely, as well as times of heavy sediment input.

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Appendix 1.

Diatom Species Preferences in the Literature.

Key to symbols used in appendix 1.

Habitat	Salinity	pH	Current
ae = aerophile	i = indifferent	i = indifferent	i = indifferent
b = benthic	b = brackish	acp = acidophile	lb = limnobiontic
c = crenophile	e = euryhalobe	acb = acidobiont	lp = limnophilous
ca = cave	hb = halophobe	circ = circumneutral	rb = rheobiontic
e = epiphyte	hf = halophile	alb = alkalbiont	rp = rheophilic
l = littoral	hp = halophobe	alp = alcaliphile	
p = planktonic		alp = alkaliphile	
ro = rock			
so = soil			

Species	Environmental Preferences				References	Comments
	Habitat	Salinity	pH	Current		
Achnanthes abundans					1	with filamentous algae
Achnanthes austriaca	b,e,l	i,hb	alp		2,3	rare in lakes
Achnanthes clevei	e,p	i	alp	lp	3	
Achnanthes coarctata	ae,ca	i	alp		4,5	moss, seeps
Achnanthes confusa	ae				6	with *A. abundans*
Achnanthes confusa var. *atomoides*	ae				6	with type species
Achnanthes conspicua var. *brevistrata*		hb	alp		7	
Achnanthes delicatula	ae	hf,m	alk		6,8	
Achnanthes engelbrechtii	e,l	b,e			9	
Achnanthes hungarica	e,l				10	lakes, rivers, swamps
Achnanthes inflata	ae,l	i,b	7.5-8.5	re	5,6,9	
Achnanthes minutissima	b,e,l,ro	i	i,alp		2,3,5	
Achnanthes pseudolanceolata	l				11	
Achnanthes stauroneioides					11	in peat bogs
Achnanthidium lanceolatum	c,e,l,ro,so	i	circ-alp	re	2,3,5,12	abundant with bryophytes in dry lakes
Achnanthidium microcephalum	c,e,l	i	i,alp	i	3,4	
Amphora coffeaeformis	e,l,ro,so	30-40%	alp		3,5,10	in springs
Amphora veneta	e,l,p	i	alp		5	oligotrophic
Aulacoseira granulata	l,p	i	alp		9,10,13	eutrophic lakes & streams
Caloneis bacillum	b,c,l		circ-alp		5	oligotrophic
Caloneis silicula	b,l	i,hf	alp	i	3	
Cocconeis placentula	a,e,l,ro	i,hf	i,alp	i	2,3	
Coscinodiscus species A					4	marine
Cymbella kerguelenensis	e,p,ro	i	alp-8	i	6	alkaline, stagnant water
Cymbella microcephala	ro		7-7.1		5,14	oligotrophic

Species	Environmental Preferences				References	Comments
	Habitat	Salinity	pH	Current		
Diatoma vulgare	e,p	i	alb	rp	3	sewage tolerant
Diatomella hustedtii	b,l				1,11	cold, fast, oligotrophic water
Diploneis smithii	ae,l	e	alp		2,15,16	brackish water
Diploneis subovalis	b,l	e	7.3-8.0		5,7,17	high nutrient levels
Eunotia exigua	ae,e,l	i	alk		5,15,18	epiphytic on moss
Eunotia lunaris	ae,l	i	acp		3,5,10,13	
Eunotia pectinalis	l		6.5		5	oligo-eutrophic
Fragilariforma virescens	ae,e,l,p	hp-hb	i	i	19,20	pH optimum < 7
Fragilariopsis antarctica					4	marine
Frustulia rhomboides	b	hp	acp		5,18	
Frustulia vulgaris	l		circ	i	12,16,17	wet moss
Gomphonema affine		i	alp		16	limnophilous
Gomphonema angustatum	e	i	circ-alp	i	16	oligo-mesotrophic
Gomphonema gracile	l,p		7.1-7.4		5,16	oligotrophic
Gomphonema intricatum	e,l,p	i	alp	lb	3,13	moss, seeps
Gomphonema olivacatum		i	alp		3,5,13,16	cool, flowing water
Hantzschia amphioxys	ae,l,ro,so	i	i, alp	i	2,3,5,8	
Luticola mutica	ae,b,e,l	i,hf	circ-alp	i	2,3,8,18	nutrient-rich sites
Luticola neoventricosa	ae		circ		2,12	nutrient-rich sites
Martyana martyi	l	i,e	alp	lp	3,11,20	common in lakes
Melosira dickei	ca,ro				11,16,21,22	amongst mosses
Navicula bryophila	ae	i	i,6.0		3,5,11	common in peat bogs
Navicula bryophyloides					11	abundant in peat bogs
Navicula cincta		hp/b	alp,8.1	rp	3,5	
Navicula contenta	ae,ro		i,alp	i	3,5	
Navicula corrugata	ae,b,l				6	
Navicula dicephala			i,alp		3,5	
Navicula geniculata					11	rare from lakes
Navicula gregaria			alp		8	
Navicula lanceolata	l,b	i,m	alp		3	high mineral content
Navicula minima	ae,b,l	i	circ-alp		3,18	
Navicula pseudocitris	b,l				6	
Navicula pseudoscutiformis	b,l	i	i,circ	i	3,18	
Navicula radiosa		i	i	i	3	
Navicula rhynchocephala	b,e,l	i,hf	alp	i	3,5	neutral-sightly alkaline
Navicula tantula	ro	i	6.0-7.8		2,3,5,8	
Navicula vitabunda	b,e,l,ro	hb-hp	alp	lp	3	
Neidium iridis		i	i,acp	lb	2,3,18	
Nitzschia dissipata		i	alp-alb	rp	3	
Nitzschia gracilis	e,l,p	i,hb	i	i	2,3	freshwater
Nitzschia hantzschiana	l	acp			2,3	
Nitzschia palea	e,l,p,ro	i	i,7-8.4	i	2,3,5,8	eutrophic
Pinnularia acoricola	ae		5		2,8	
Pinnularia appendicula	ro		5.0-6.9		5,10	
Pinnularia borealis	ae,l,so	i	i,acp		2,3,6,9	
Pinnularia circumducta	ae				6	
Pinnularia divergentissima			acp		5,16,18	cold water
Pinnularia gibba	a,ae,c,l	i	i,acp		5,10,18	
Pinnularia interrupta			circ		9	
Pinnularia kolbei	ae				6	common in peat bogs

Species	Environmental Preferences				References	Comments
	Habitat	Salinity	pH	Current		
Pinnularia lata	ae,l,ro	i,hp	acp		2,5,6	
Pinnularia microstauron	ae,l	i,e	acp		2,3,13,18	
Pinnularia subcapitata			acp		18	
Pinnularia viridis	ae,l	i	circ-acp	i	2,5,18	wet rocks, moss
Rhopalodia gibberula	e,l,ro	e,m	acp		2,5,13	
Sellaphora seminulum	ae,b,cr,	i,hf	i	i	2,3,5,8	favours nutrient variations
Sellaphora pupula	b,c,e,l	i	i	i	2,3,5,18	oligohalobe
Stauroneis anceps	l	hb	i,acp	lb	2,3,5,18	
Stauroneis phoenicenteron	l	i	i	i	3,5,13	eutrophic
Staurosira construens	l,p	i	alp	i	2,3	
Staurosira construens var. *venter*	b,l,p	i	alp	i	2,3,5	with type species
Staurosirella pinnata	l,p	i,hf	alp	i	2,3,13	
Surirella angustata		i	alp	rb	3	
Surirella linearis	l,p	i	acp		2,3	acid environments
Surirella ovata		i	6.0		5	
Synedra acus	e	i	alp		3,5,18	
Synedra rumpens	e,l	i	alp	i	2,5,18	
Synedra ulna	e,l,p	i,e	alp		2	
Synedra vaucheriae	e,l	i	alp	i	2,3	

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Appendix 2.

List of all species mentioned in all chapters.

Diatoms

Names follow Round, Crawford and Mann (1990), Le Cohu & Mallaird (1983;1986) Germain(1981; 1937), Patrick & Reimer (1966), Bourelly & Manguin (1954) and Manguin (1952). Includes rare species not mentioned in the text, but included in other appendicies. Slide numbers refer to the nominated voucher slides lodged in the Herbarium in the School of Biological Sciences, Macquarie University, New South Wales.

Species Names	Slide number
Achnanthes abundans Manguin	CA-3-177
Achnanthes austriaca Hust.	CA-3-177
Achnanthes bioretti Germain	TD-SKHT
Achnanthes clevei Grun.	EM-3-234
Achnanthes coarctata (Bréb.) Grun.	CA-3-204
Achnanthes confusa Manguin	CA-3-177
Achnanthes confusa var. *atomoides* Manguin	CA-3-177
Achnanthes conspicua var. *brevistrata* Hust.	HA-A-90
Achnanthes delicatula Kütz.	EM-3-306
Achnanthes delicatula ssp. *haukiana* (Grun.) LB et Ruppel	EM-3-215
Achnanthes engelbrechtii Cholonky	EA-1-122
Achnanthes hungarica Grun.	LKa-EMLS
Achnanthes inflata Kütz.	EA-1-90
Achnanthes lapponica Hust. var. *ninkei* (Guerm. & Mang.) Reim.	TT-NMTN
Achnanthes manguinii Hust.	EA-1-90
Achnanthes manguinii var. *elliptica* Manguin	CA-3-233
Achnanthes marginulata Kütz.	MRp-SP7
Achnanthes modesta Manguin	CCs-HHa
Achnanthes pseudoaffinis Maillard	Tm-PrL
Achnanthes pseudolanceolata Hust.	CA-3-254
Achnanthes saxonica Krasske	CA-3-204
Achnanthes species A	EA-3-331
Achnanthes species B	TA-EPL
Achnanthes stauroneioides Manguin	AL89-2
Achnanthes subsalsoides Hust.	EA-1-128
Achnanthes subsalsoides var. *sterwennwensis* Germain et Chaumont	TM-HH1
Achnanthidium lanceolatum ((Breb.) Grun.) Round	EA-1-90
Achnanthidium lanceolatum var *lanceolatoides* ((Sou.) Reim.) Round	HA-A-70
Achnanthidium microcephalum (Kütz.) Round	CA-3-204
Achnanthidium minutissimum (Kütz) Round	CA-3-204
Amphora caffeaeformis Ag.	CA-3-204
Amphora holsatica Hust.	EA-1-25
Amphora ovalis (Kütz.) Kütz.	EM-3-100
Amphora ovalis var. *lybica* (Ehr.) Cleve	MRd-SM2
Amphora veneta Kütz.	SQ90-4
Aulacoseira granulata ((Ehr.) Ralfs.) Round	CA-3-204
Brachysira exilis (Kütz.) Round & Mann	EA-1-122
Brachysira serians (Kütz.) Round & Mann	CA-4-105

Species name	Slide number
Brachysira species A	AL90-4
Caloneis bacillum (Grun.) Meresch.	CCv-DLa
Caloneis marnieri Manguin	EA-2-147
Caloneis silicula (Ehr.) Cleve	CA-4
Campylodiscus noricus Ehr.	FD91-3
Cocconeis fluviatilis Wallace	MRb-SM4
Cocconeis placentula Ehr.	EA-1-25
Cocconeis therezieni Manguin	LKs-EMLN
Coscinodiscus Ehr. species A	MRd-HSCR
Ctenophora pulchella ((Ralfs.) Kütz.) Round & Mann	LKa-EMLE
Cyclotella meneghiniana Kütz.	FH91-14
Cymbella angustata (Rabh.) Cleve	CA-4-0
Cymbella cesatii (Rabh.) Cleve	FD91-5
Cymbella gracilis (Rabh.) Cleve	EA-1-50
Cymbella kerguelenensis Germ.	EA-3-93
Cymbella microcephala Grun.	EA-3-235
Cymbella species A	CA-2-147
Cymbella species B	CA-1-100
Cymbella ventricosa Kütz.	EM-3-100
Diatoma vulgare Bory	EM-3-323
Diatomella hustedtii Manguin	CA-3-177
Diploneis ovalis var. *oblongella* (Naegeli) Cleve	TS-WH
Diploneis smithii (Bréb.) Cleve	CA-3-254
Diploneis subovalis Cleve	L-BBP
Eunotia exigua (Bréb.) Grun.	MRa-NFIL
Eunotia lunaris (Ehr.) Grun.	EA-3-169
Eunotia pectinalis var. *rostrata* (Kütz.) Grun.	TT-NMTN
Fragilaria capucina var. *mesolepta* (Rabh.) Grun	FD91-2
Fragilaria intermedia Grun.	AL89-5
Fragilaria species A	TAZ-NMT3
Fragilaria species B	TAZ-NMT3
Fragilaria species C	DL89-2
Fragilaria vaucheriae (Kütz.) Bove Petersen	CA-1-255
Fragilaria vaucheriae var. *longissima* (Kütz.) Bove Petersen	AL88-2
Fragilariforma virescens (Ralphs) Williams & Round	EM-3-195
Fragilariopsis antarctica (Castracane) Hust.	CO-1-128
Frustulia pulchra Manguin	CA-1-270
Frustulia rhomboides (Ehr.) De Toni	CO-1-21
Frustulia species A	MRb-GAGT
Frustulia species B	EA-3-148
Frustulia vulgaris (Thwaites) De Toni	AL88-5
Gomphonema affine Kütz.	CA-3-177
Gomphonema affine var. *kerguelenense* Manguin	BL88-3
Gomphonema angustatum (Kütz.) Rabh.	AL89-1
Gomphonema angustatum var. *productum* Grun	MRb-SBPL
Gomphonema gracile Ehr	MRa-SM9
Gomphonema intricatum Kütz.	CA-3-254
Gomphonema longiceps var. *subclavata* (Grun.) Grun.	EM-3-77
Gomphonema olivaceum (Hornemann) Bréb.	CCa-WFb
Gomphonema parvulum (Kütz.) Grun.	EM-3-100

Species name	Slide number
Hantschia amphioxys (Ehr.) Grun.	EM-3-77
Luticola mutica (Kütz.) Mann	CCw-1GU
Luticola neoventricosa (Hust.) Mann	EM-3-306
Martyana martyi (Herib.) Round	CA-3-204
Melosira dickei (Thwaites) Kütz.	TAZ-HH1
Melosira species A	TS-RE
Navicula bryophila Petersen	W1-V
Navicula bryophyloides Manguin	EA-1-25
Navicula cincta (Ehr.) Kütz.	Tm-PvL
Navicula contenta Grun.	W-GC2
Navicula corrugata Manguin	EA-1-25
Navicula dicephala (Ehr.) W. Sm.	HA-A-70
Navicula elegans W. Sm.	MRa-MAHS
Navicula geniculata Germ.	CA-3-204
Navicula gregaria Donk.	AL88-2
Navicula hustedtii Krasske	EA-3-26
Navicula ignota Krasske var. *palustris*	LKa-EMLN
Navicula lanceolata (Ag.) Ehr.	CA-3-204
Navicula minima Grun.	CA-3-177
Navicula paludosa Hust.	BL90-2
Navicula pseudocitris Manguin	CA-3-177
Navicula pseudoscutiformis Hust.	CA-1-85
Navicula radiosa Kütz.	CCa-FCb
Navicula rhynchocephala Kütz.	EA-1-122
Navicula saxophila Bock.	TM-HASP
Navicula species A	CA-4-307
Navicula species B	CA-3-58
Navicula species C	EA-1-187
Navicula species D	EM-3-161
Navicula subrhynchocephala Hust.	MRa-SM1
Navicula tantula Hust.	Tm-HH1
Navicula vitabunda Hust.	EA-1-122
Nedium affine (Ehr.) Cleve	MR-90-1
Nedium iridis (Ehr.) Cleve	CO-1-390
Nitzschia aff. *communis* Rabh.	HA-A-10
Nitzschia dissipata (Kütz.) Grun.	EA-1-25
Nitzschia gracilis Hantzsch.	EM-3-77
Nitzschia hantzschiana Rabh.	EA-1-128
Nitzschia inconspicua Grun.	CA-3-233
Nitzschia littoralis Grun.	CCa-HSP
Nitzschia palea (Kütz.) W. Smith	EA-1-247
Nitzschia palea var. *debilis* Kütz.	BL89-2
Nitzschia species A	RK91-5
Nitzschia tryblionella var. *debilis* (Arnott) A. Mayer	CCa-FCa
Nitzschia vermicularis (Kütz.) Grun.	SQ90-4
Pinnularia acoricola Hust.	MRa-DSPT
Pinnularia appendiculata (Ag.) Cleve	CA-3-204
Pinnularia borealis Ehr.	EA-1-26
Pinnularia circumducta Manguin	EM-3-234
Pinnularia divergens W. Sm.	MRc-SM9

Species name	Slide number
Pinnularia divergentissima (Grun.) Cleve	EM-3-215
Pinnularia gibba Ehr.	EM-3-23
Pinnularia globiceps Gregory	EM-1-148
Pinnularia interrupta W. Smith	EA-1-247
Pinnularia kolbei Manguin	EM-3-323
Pinnularia lata (Bréb.) W. Smith	EA-1-128
Pinnularia legumen Ehr.	CCm-FCd
Pinnularia microstauron (Ehr.) Cleve	MRb-NOTC
Pinnularia microstauron var. *elongata* Manguin	W-GC2
Pinnularia obscura Krasske	CO-1-347
Pinnularia species A	CA-3-233
Pinnularia species B	MRb-PALG
Pinnularia species C	CA-3-283
Pinnularia species D	MRb-SQW
Pinnularia species E	P-HSB
Pinnularia subcapitata Greg.	MR-91-1
Pinnularia subsolaris (Grun.) Cleve	EA-1-50
Pinnularia viridis (Nitzsch.) Ehr.	CCv-LCa
Rhopalodia gibberula (Ehr.) O. Mull.	EM-3-215
Rhizosolenia species A	TAZ-GD2
Sellaphora seminulum (Grun.) Mann	CO-1-435
Sellaphora pupula (Kütz.) Mann	HA-A-10
Species A	EM-3-306
Species D	TS-GG3
Stauroneis anceps Ehr.	C0-1-521
Stauroneis phoenicenteron Ehr.	CA-3-204
Stauroneis pygmeae Krieger	EM-3-161
Stauroneis smithii var. *sagitta* (Cleve) Hust.	EM-3-483
Staurosira construens ((Ehr.) Grun.) Williams & Round	MRa-JNCL
Staurosira construens var. *venter* ((Ehr.) Grun.) Williams & Round	MRa-JNCL
Staurosirella lapponica (Grun.) Williams & Round	HA-A-10
Staurosirella pinnata (Ehr.) Willliams & Round	CA-3-177
Staurosirella pinnata var. *lanculetta* ((Schum.) Hust.) Williams & Round	W-GCC
Stephanodiscus species A	EA-1-25
Surirella angustata Kutz.	CCa-GGc
Surirella linearis W. Smith	CA-3-233
Surirella ovata Kütz.	DL90-2
Surirella species A	WA91-4
Synedra acus Kutz.	Tm-HH4
Synedra rumpens Kutz.	CA-3-177
Synedra ulna (Nitzsch.) Ehr.	CCs-HHb
Synedra vaucheriae Kütz.	CA-3-233

Angiosperms

Names follow Hnatiuk (1993).

Acaena magellanica (Lam.) Vahl
Agrostis magellanica Lam.
Azorella macquariensis Orchard
Callitriche antarctica Engelm. ex Hegelem.
Colobanthus muscoides Hook.f.
Cotula plumosa (Hook.f.) Hook.f.
Coprosma perpusilla ssp. *subantarctica* Orchard
Epilobium brunnescens (Cockayne) P. H. Raven et Engelhorn ssp. *brunnescens*
Epilobium pedunculare A. cunn.
Festuca contracta Kirk
Juncus scheuchzerioides Gaudichaud
Hydrocotyle novae-zeelandiae DC.
Luzula crinita Hook.f.
Montia fontana L. ssp. *fontana*
Myriophyllum triphyllum Orchard
Pleurophyllum hookeri Buchan.
Poa annua L.
Poa cookii (Hook. f.) Hook.f.
Poa foliosa (Hook. f.) Hook.f.
Ran unculus crassipes Hook.f.
Stilbocarpa polaris (Hombr. et Jacquinot ex Hook.f..) A. Gray
Uncinia hookeri Boott

Pteridophytes

Names follow Hnatiuk (1993).

Huperzia australiana (Herter) Holub
Polystichum vestitum (G. Forst.) C. Presl

Bryophytes

Names follow Seppelt (1981).

Andreaea sp.
Bryum sp.
Dicranaloma billardieri (Brid.) Lindb.
Ditrichum strictum (Hook.f. et Wils.) Hampe
Fissidens rigidulus Hook.f. et Wils.
Marchantia berteroana Lehm. et. Lindenb.
Muelleriella crassifola (Hook.f. et Wils.) Dus.
Rhacomitrium crispulum (Hook.f. et Wils.) Hook.f. et Wils.
Riccardia sp.
Sphagnum falcatulum Besch.
Tortula rubra Mitt.

Lichens

Usnea sp.

Green algae (Chlorophyta)

Prasiola crispa (Lightfoot) Meneghini

Mammals

Names follow Anon. (1987).

European rabbit *Oryctolagus cuniculus* L. 1758
Southern elephant seal *Mirounga leonina* L. 1758

Birds

Names follow Anon. (1987).

Rockhopper penguin *Eudpytes chrysocome* Forster 1781
Royal penguin *Eudyptes schlegeli* Finsch 1876
King penguin *Aptenodytes patagonicus* Miller 1788
Gentoo penguin *Pygoscelis papua papua* Forster 1781
Macaroni penguin *Eudyptes chrysolophus* Brandt 1837
Southern giant petrel *Macronectes giganteus* Gmelin 1789
Northern giant petrel *Macronectes halli* Gmelin 1789
Black duck *Anas superciliosa superciliosa* Gmelin 1789
Great skua *Stercorarius lonnbergi* Mathews 1912

Plate 1

1 *Pinnularia* species E
2 *Pinnularia* species E
3 *Pinnularia kolbei*
4 *Pinnularia microstauron*
5 *Pinnularia gibba*
6 *Pinnularia circumducta*
7 *Pinnularia acoricola*
8 *Pinnularia appendicula*
9 *Pinnularia borealis*
10 *Pinnularia appendicula*

Scale bar is 10 μm

Plate 1

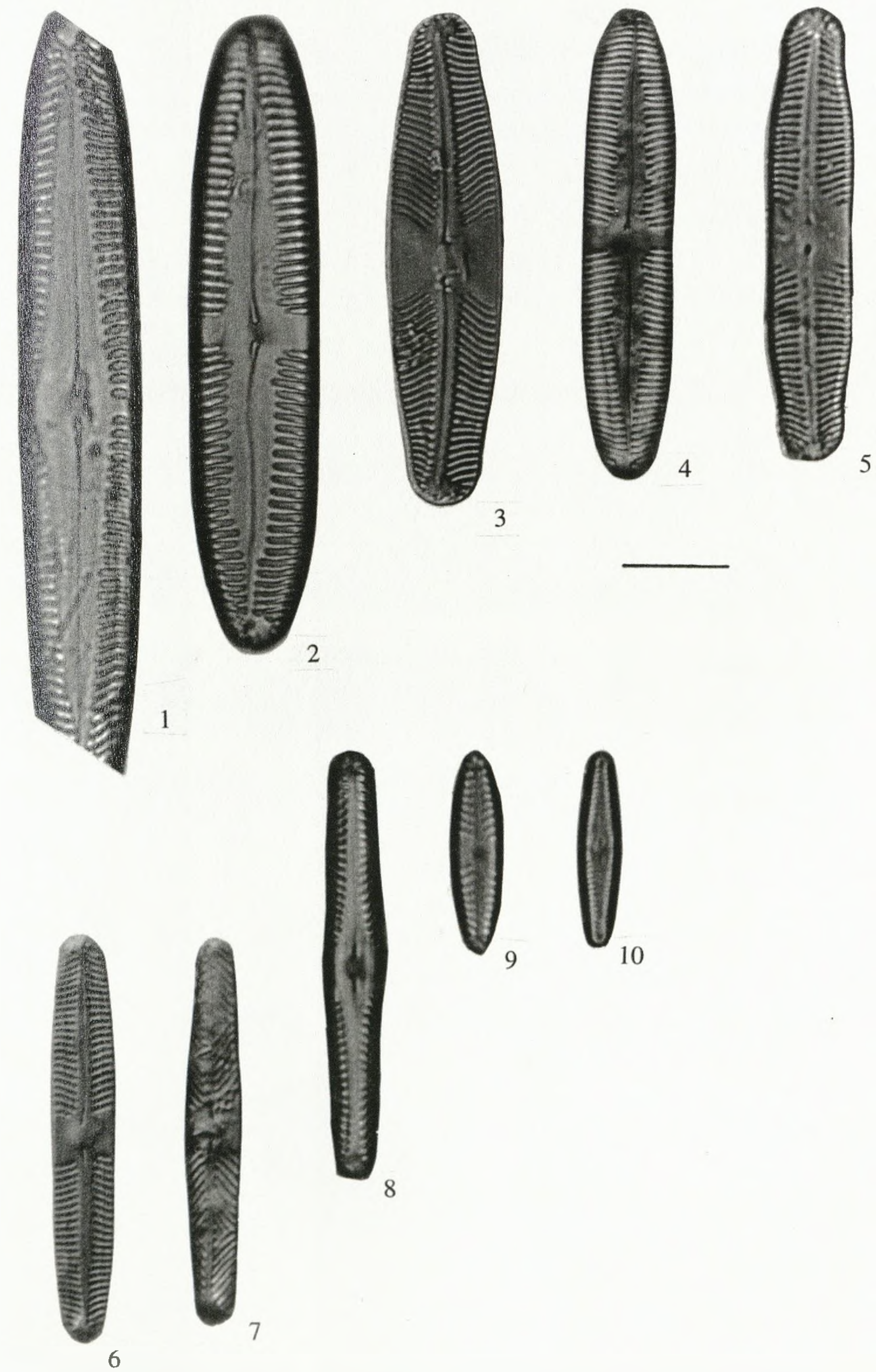


Plate 2

1 *Navicula cuspidata*
2 *Rhopaladia gibberula*
3 *Diploneis smithii*
4 *Cocconeis placentula*
5 *Caloneis bacillum*
6 *Stauroneis smithii* var. *sagitta*
7 *Surirella linearis*
8 *? Cocconeis* sp.
9 *Fragilariopis antarctica*
10 *Hantzschia amphioxys*

Scale bar is 10 μm; separate scale for figure 10 is also at 10 μm.

Plate 2

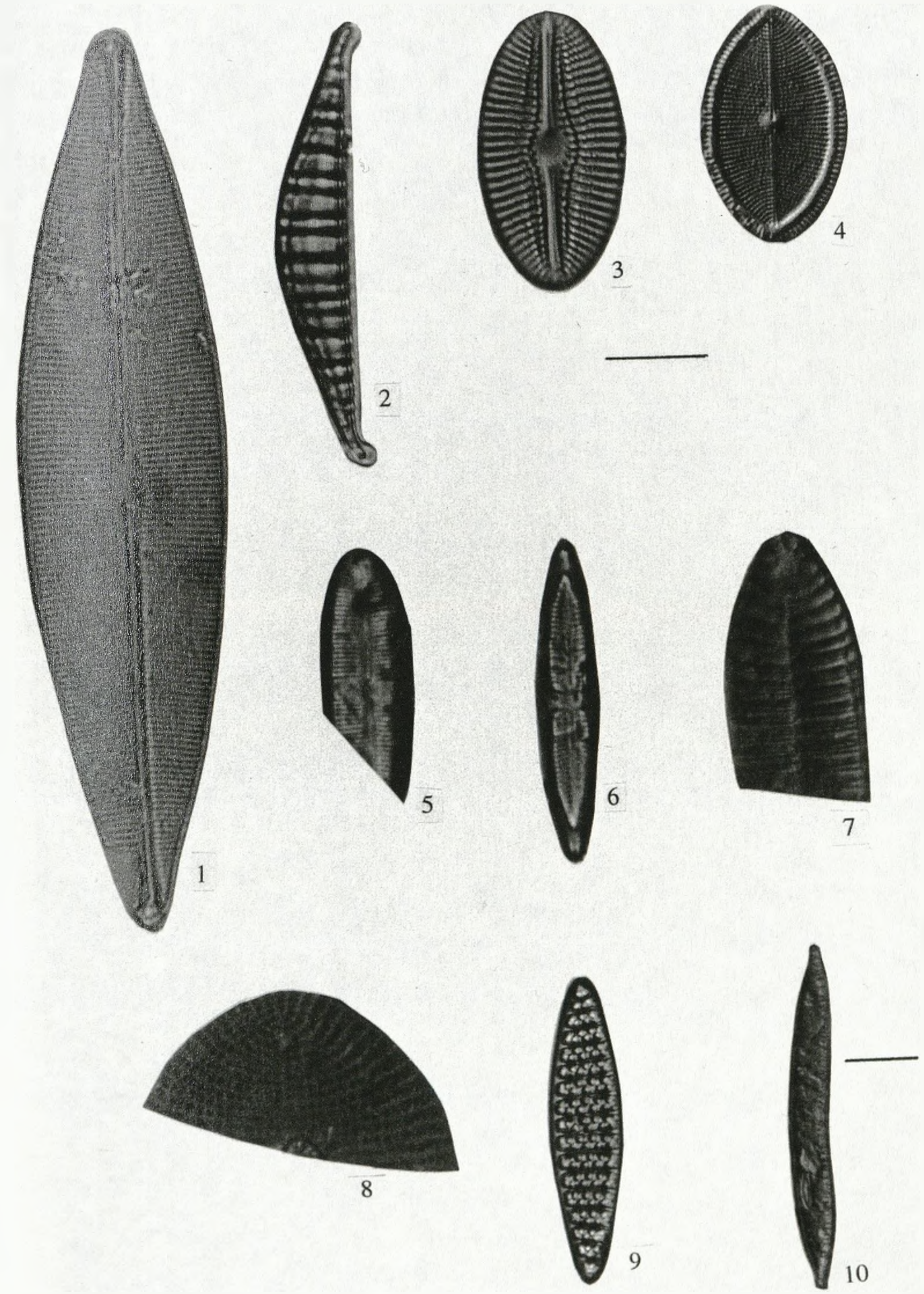


Plate 3

1	*Synedra rumpens*
2	*Nitzschia palea*
3	*Nitzschia hantzschiana*
4	*Nitzschia dissipata*
5	*Gomphonema affine*
6	*Diatomella hustedtii* - girdle view
7	*Diatomella hustedtii* - valve view
8	*Luticola neoventricosa*
9	*Luticola neoventricosa*
10	*Luticola mutica*
11	*Caloneis silicula* - valve view
12	*Caloneis silicula* - valve view
13	*Caloneis silicula* - girdle view
14	*Melosira ?dickei*
15	*Cocconeis therezeni*
16	*Amphora coffeaeformis*
17	*Cymbella gracilis*
18	*Cymbella kerguelenensis*
19	*Cymbella microcephala*
20	*Diatoma vulgare*

Scale bar is 10 µm

Plate 3

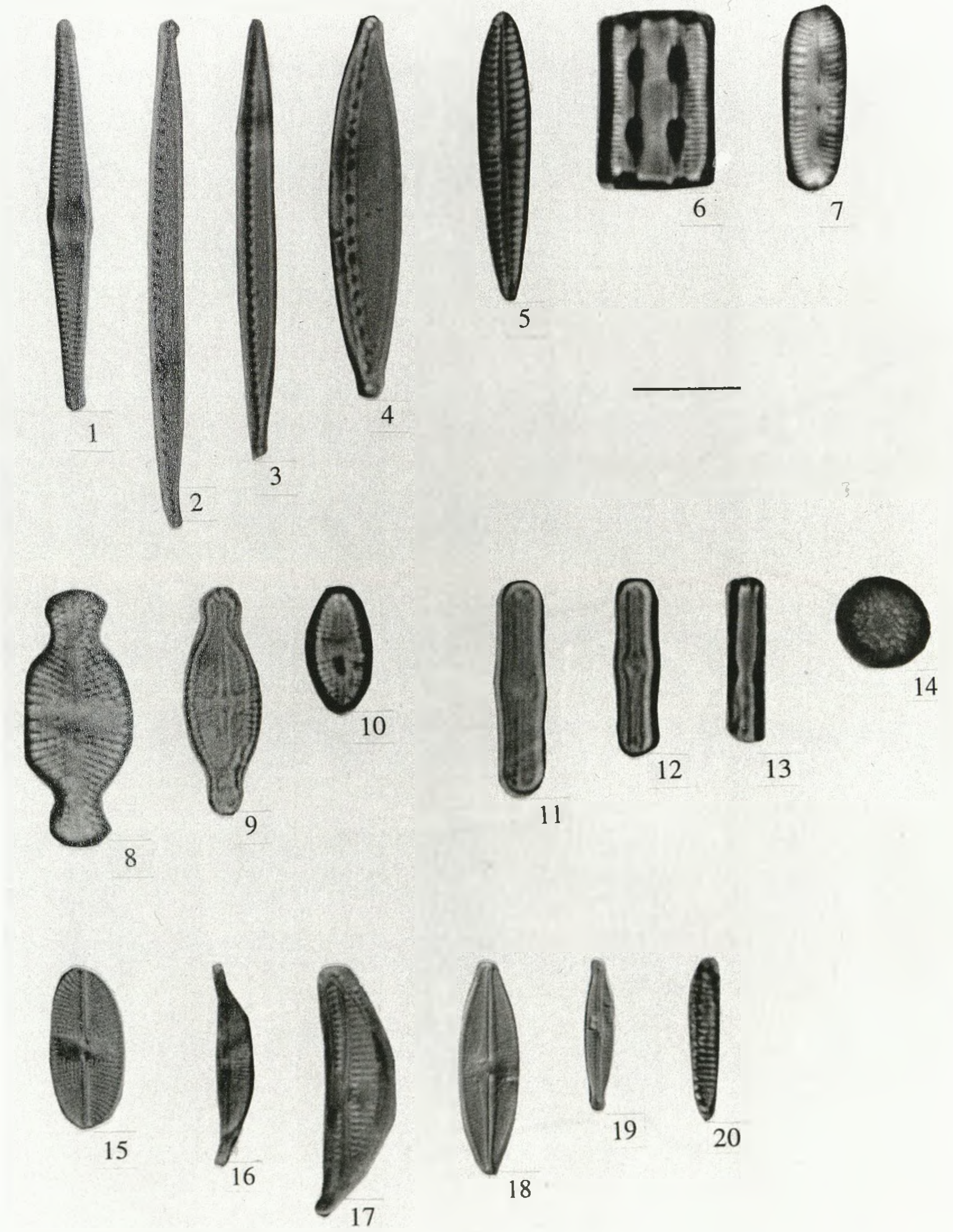


Plate 4

1 *Achnanthes delicatula* - raphe valve
2 *Achnanthes delicatula* - rapheless valve
3 *Achnanthes manguinii*
4 *Achnanthes austriaca*
5 *Achnanthes engelbrechtii*
6 *Achnanthes delicatula* ssp. *hauckiana*
7 *Achnanthes delicatula* ssp. *hauckiana*
8 *Achnanthes stauronoides*
9 *Achnanthes minutissima*
10 *Achnanthes minutissima*
11 *Achnanthes abundans*
12 *Achnanthes abundans*
13 *Achnanthes confusa*
14 *Achnanthes confusa*
15 *Achnanthes pseudolanceolata*
16 *Achnanthes pseudolanceolata*
17 *Achnanthidium lanceolatum*
18 *Achnanthidium lanceolatum*
19 *Achnanthidium lanceolatum* var. *lanceolatiodes*
20 *Achnanthidium lanceolatum* var. *lanceolatiodes*
21 *Achnanthidium microcephalum*

Scale bar is 10 µm

Plate 4

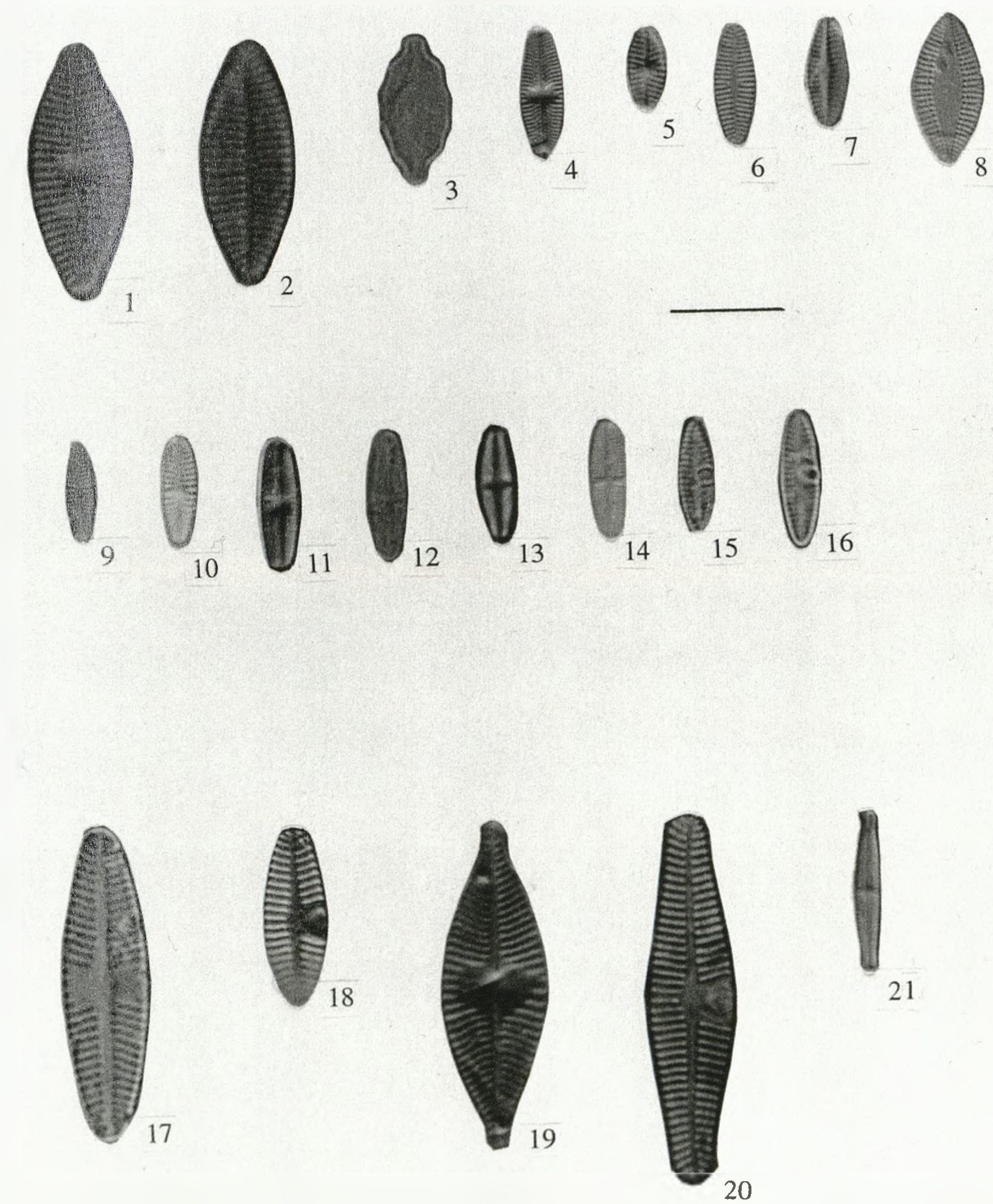
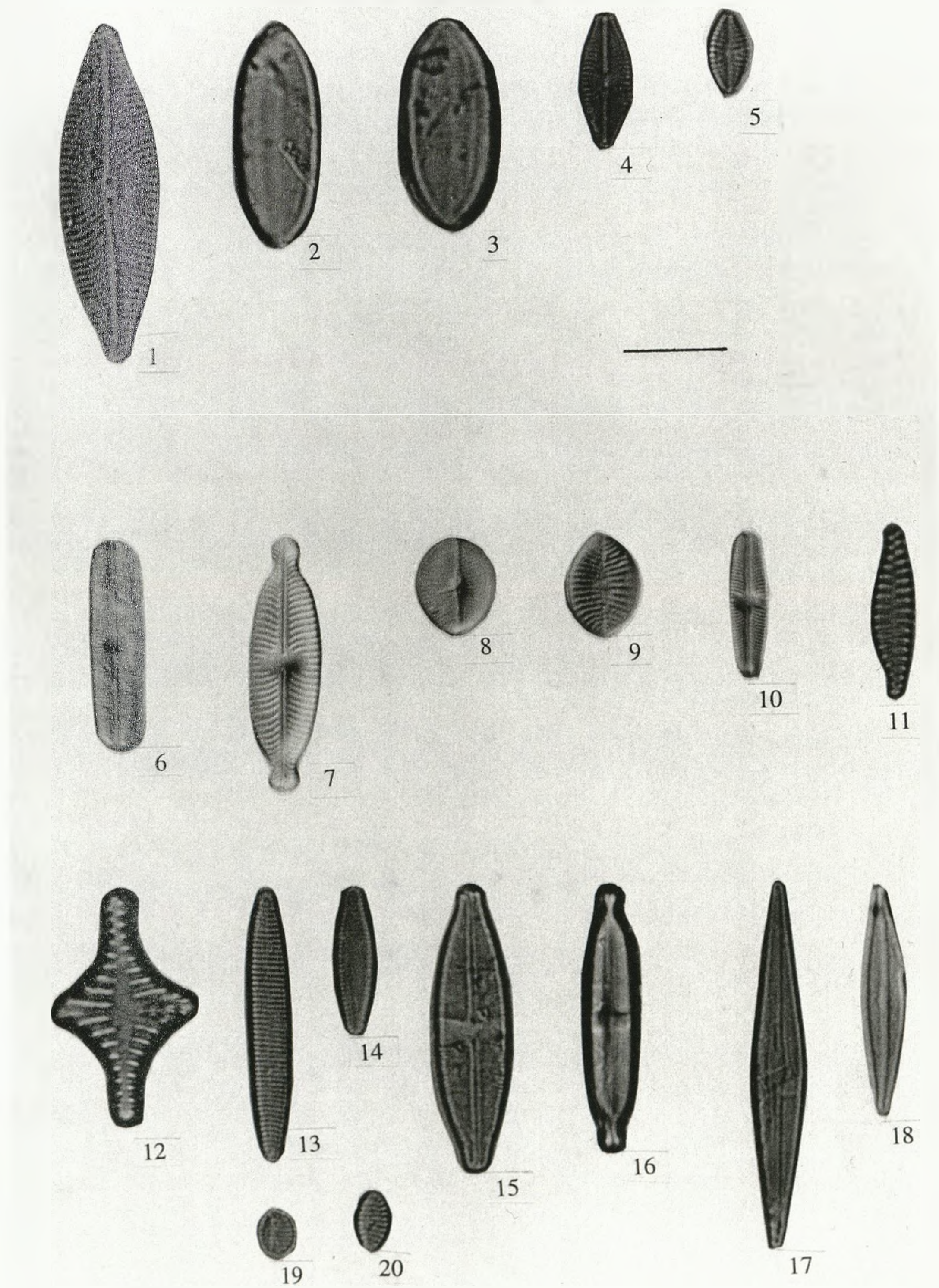


Plate 5

1 *Navicula* species B
2 *Navicula tryblionella* var. *debilis*
3 *Navicula tryblionella* var. *debilis*
4 *Navicula geniculata*
5 *Navicula corrugata*
6 *Navicula bryophyloides*
7 *Navicula dicephala*
8 *Navicula pseudocutiformis*
9 *Navicula pseudocutiformis*
10 *Sellaphora seminulum*
11 *Staurosira construens* var. *venter*
12 *Staurosira construens*
13 *Fragilariforma virescens*
14 *Fragilariforma virescens*
15 *Stauroneis anceps*
16 *Stauroneis phenicenteron*
17 *Brachysira exilis*
18 *Brachysira exilis*
19 *Staurosirella pinnata*
20 *Staurosirella pinnata*

Scale bar is 10 μm

Plate 5



AC AB	*Achnanthes abundans*
AC AU	*Achnanthes austriaca*
AC BI	*Achnanthes bioreti*
AC CF	*Achnanthes confusa*
AC AT	*Achnanthes confusa* var. *atomoides*
AC CL	*Achnanthes clevei*
AC CO	*Achnanthes conspicua*
AC CO	*Achnanthes conspicua* var. *brevistrata*
AC DE	*Achnanthes delicatula*
AC HA	*Achnanthes delicatula* var. *hauckiana*
AC EN	*Achnanthes engelbrechtii*
AC MA	*Achnanthes manguinii*
AC EL	*Achnanthes manguinii* var. *elliptica*
AC PS	*Achnanthes pseudolanceolata*
AC SA	*Achnanthes saxonica*
AC SD	*Achnanthes* species B
AH LA	*Achnanthidium lanceolatum*
AH MI	*Achnanthidium microcephalum*
AM CA	*Amphora coffeaeformis*
AM HO	*Amphora holsatica*
AU GR	*Aulacoseira granulata*
BR EX	*Brachysira exilis*
CA SI	*Caloneis silicula*
CO PL	*Cocconeis placentula*
CY GR	*Cymbella gracilis*
CY KE	*Cymbella kerguelenensis*
CY MI	*Cymbella microcephala*
DI HU	*Diatomella hustedtii*
DI VU	*Diatoma vulgare*
EU EX	*Eunotia exigua*
EU RO	*Eunotia rostrata*
FR VI	*Fragilariforma virescens*
FR AN	*Fragilariopsis antarctica*
FR VI	*Frustulia rhomboides*
GO AF	*Gomphonema affine*
GO IN	*Gomphonema intricatum*
HA AM	*Hantzschiana amphioxys*
LU MU	*Luticola mutica*
LU NE	*Luticola neoventricosa*
MA MA	*Martyana martyi*

ME DI	*Melosira dickei*
NA BR	*Navicula bryophila*
NA CG	*Navicula corrugata*
NA DI	*Navicula dicephala*
NA EL	*Navicula elegans*
NA GE	*Navicula geniculata*
NA HU	*Navicula hustedtii*
NA LA	*Navicula lanceolata*
NA PS	*Navicula pseudocutiformis*
NA RH	*Navicula rhynchocephala*
NA SE	*Navicula seminulum*
NA SD	*Navicula* species D
NA TA	*Navicula tantula*
NA VI	*Navicula vitabunda*
NE VI	*Nedium viridis*
NI GR	*Nitzschia gracilis*
NI HA	*Nitzschia hantzschiana*
NI IN	*Nitzschia inconspicua*
NI PA	*Nitzschia palea*
PI AC	*Pinnularia acoricola*
PI AP	*Pinnularia appendicula*
PI BO	*Pinnularia borealis*
PI CI	*Pinnularia circumducta*
PI GI	*Pinnularia gibba*
PI KO	*Pinnularia kolbei*
PI LA	*Pinnularia lata*
PI MI	*Pinnularia microstauron*
PI SU	*Pinnularia subsolaris*
PI SE	*Pinnularia* species E
RH GI	*Rhopalodia gibberula*
SA CO	*Staurosira construens*
SA VE	*Staurosira construens* var. *venter*
SA PI	*Staurosirella pinnata*
SA SD	*Staurosirella* species D
SP EB	Species B
ST AN	*Stauroneis anceps*
SU LI	*Surirella linearis*
SY RU	*Synedra rumpens*
SY VA	*Synedra vaucheriae*
OTHER	Other species with less than 2% abundance

Species code list for Appendix 3.

Appendix 3
Diatom Percentage Abundance Graphs

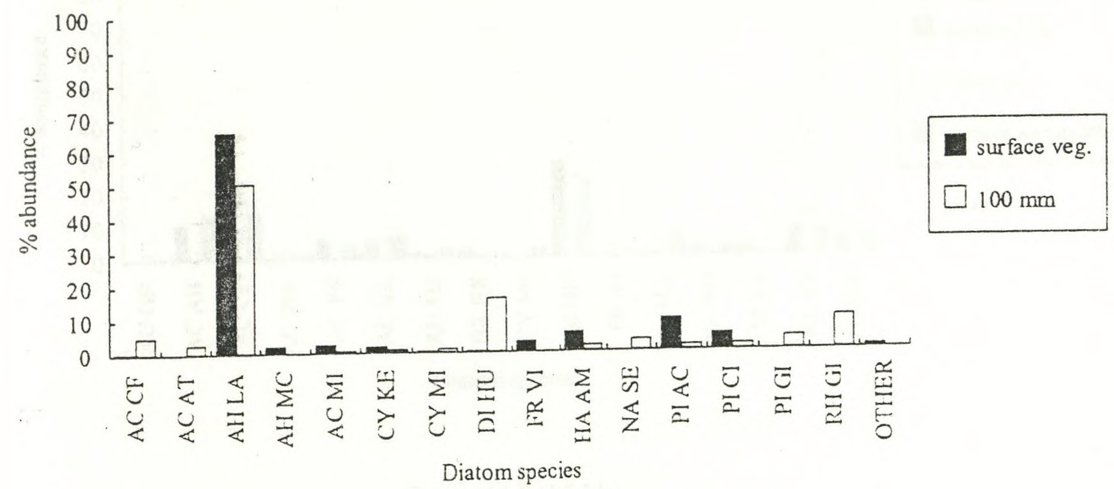
Mire and Terrestrial Sites

The locations of mire and terrestrial sites are presented in the text on the following figures:

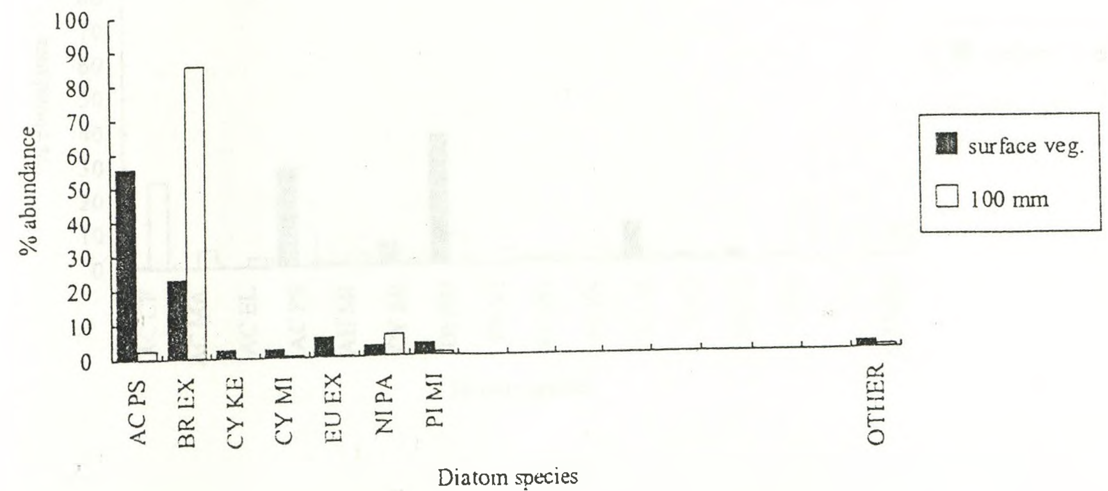
Figure 3.1 (Mire sites)
Figure 4.2 (Creek sites)
Figure 4.4 (Feldmark sites)
Figure 4.5 (Soil and Lichen sites)
Figure 4.9 (Wallow and Penguin sites)

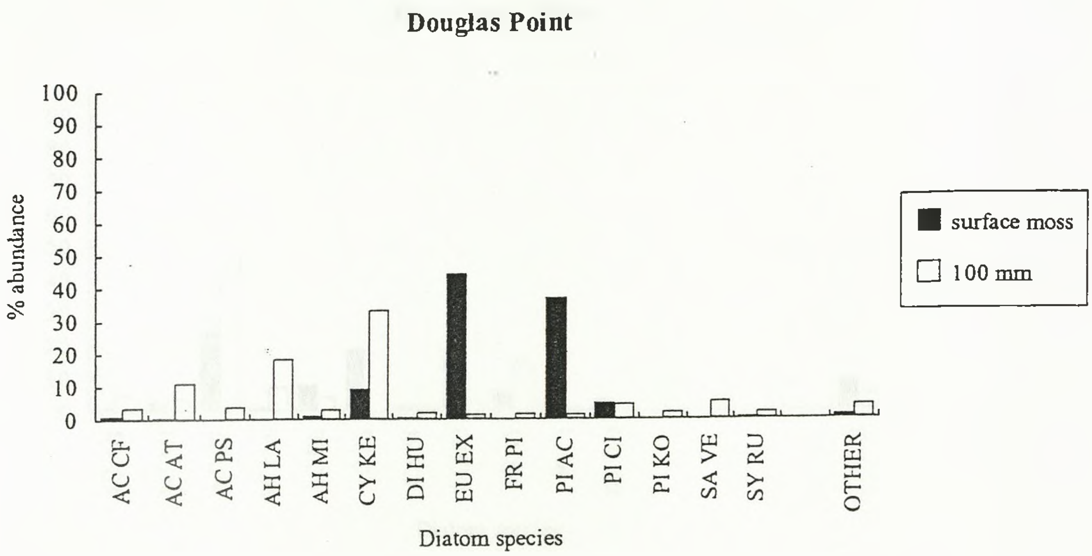
Mire Sites

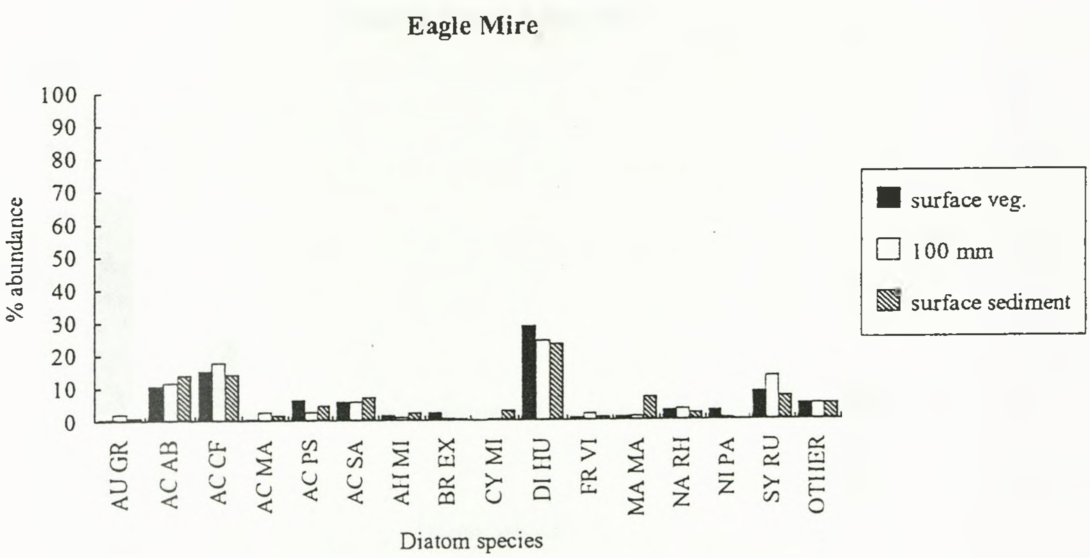
Bauer Bay

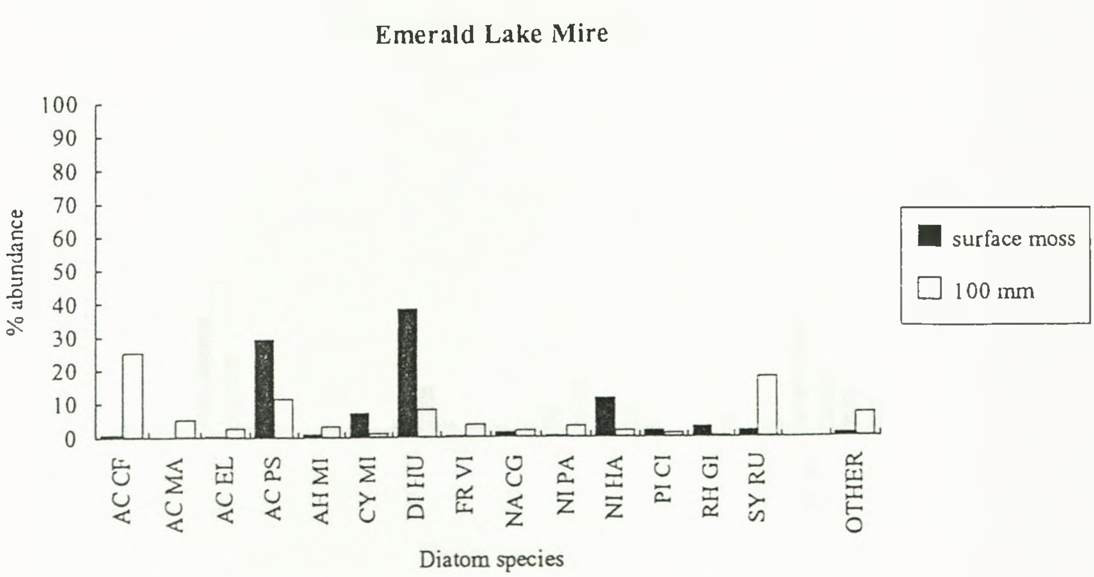


Cascade Mire

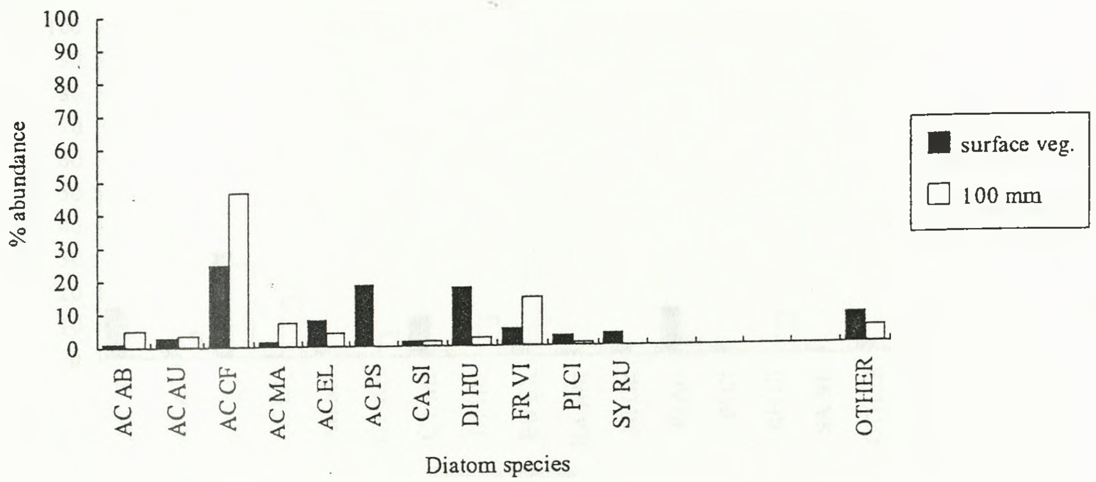



Douglas Point
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC CF
AC AT
AC PS
AH LA
AH MI
CY KE
DI HU
EU EX
FR PI
PI AC
PI CI
PI KO
SA VE
SY RU
OTHER
Diatom species
surface moss
100 mm

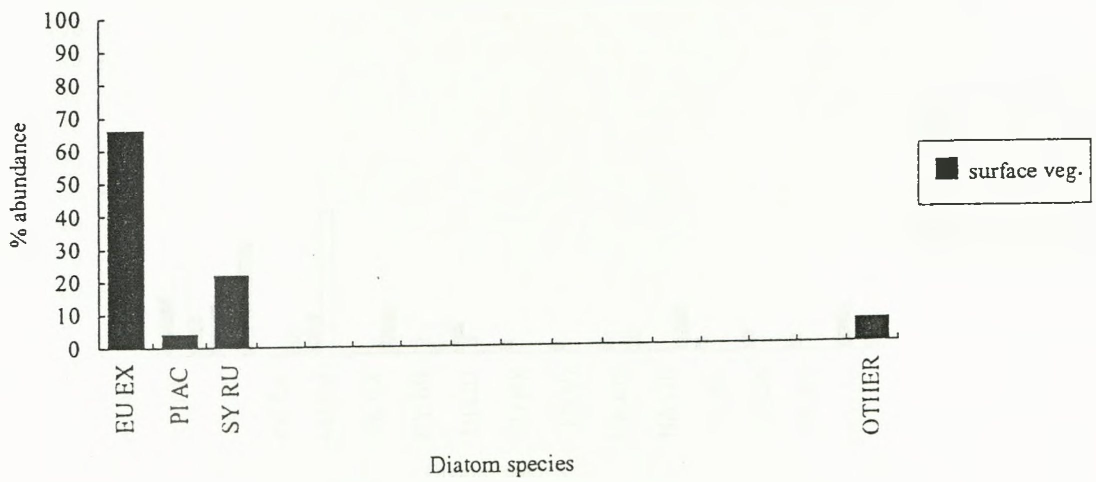

Eagle Mire
% abundance
100
90
80
70
60
50
40
30
20
10
0
AU GR
AC AB
AC CF
AC MA
AC PS
AC SA
AH MI
BR EX
CY MI
DI HU
FR VI
MA MA
NA RH
NI PA
SY RU
OTHER
Diatom species
surface veg.
100 mm
surface sediment


Emerald Lake Mire
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC CF
AC MA
AC EL
AC PS
AH MI
CY MI
DI HU
FR VI
NA CG
NI PA
NI HA
PI CI
RH GI
SY RU
OTHER
Diatom species
surface moss
100 mm

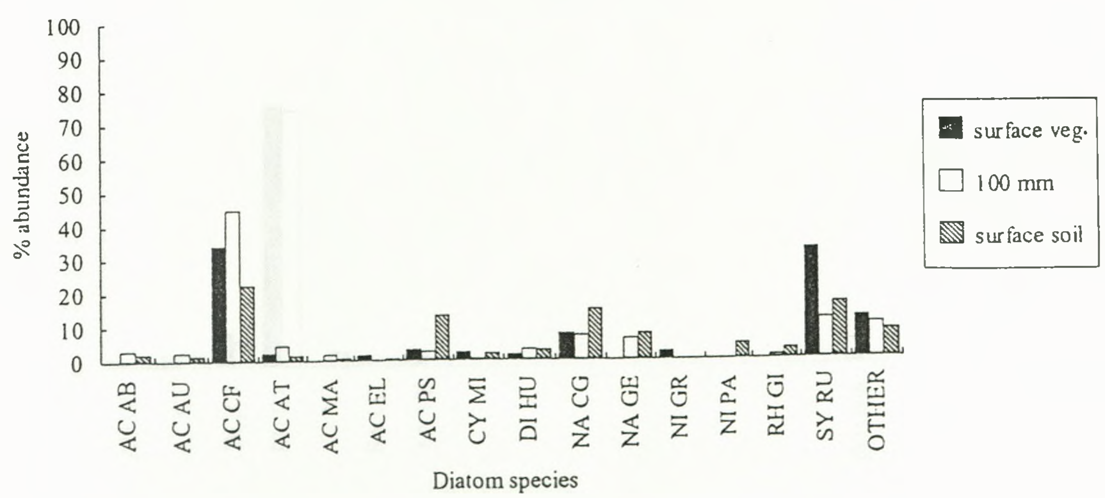
Flat Creek Mire



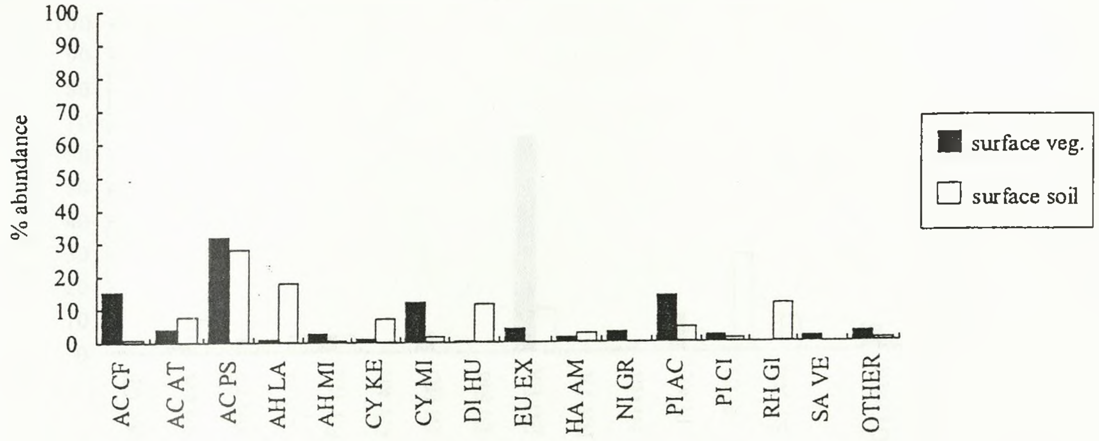
Floating Island Lake site 1



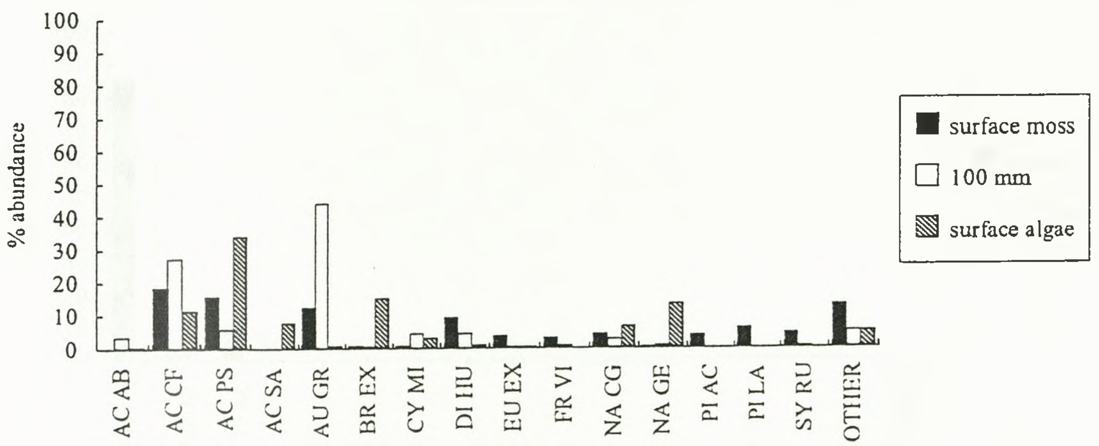
Floating Island Lake site 2



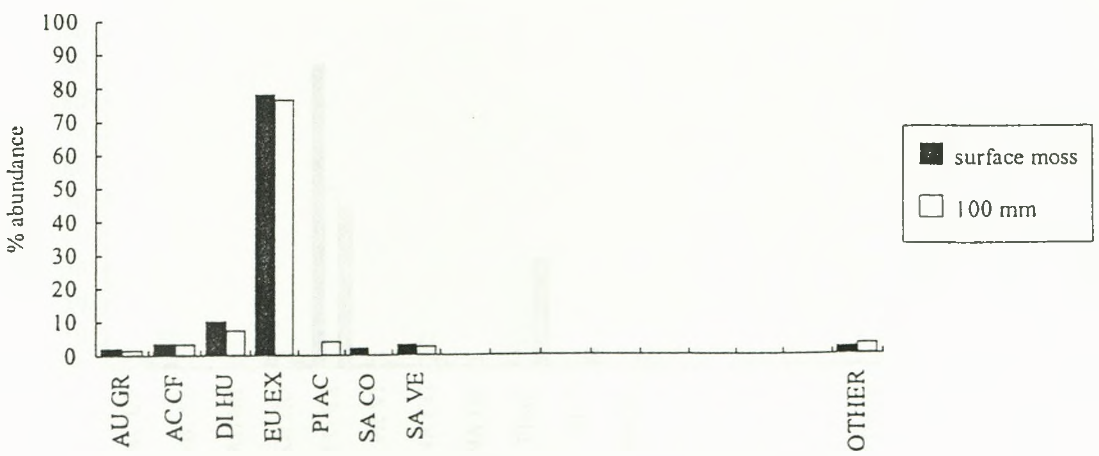
Floating Island Lake site 3

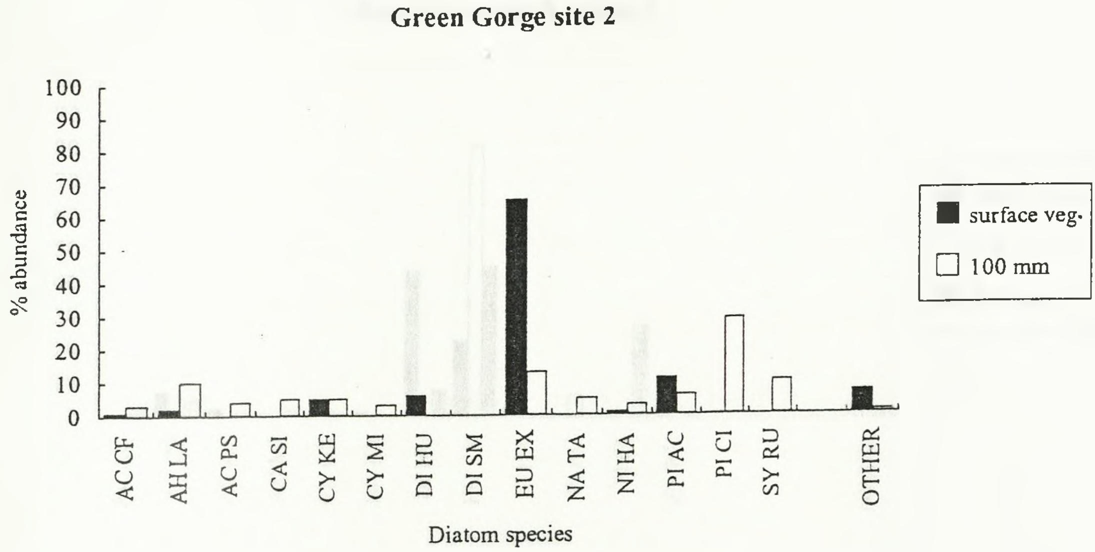


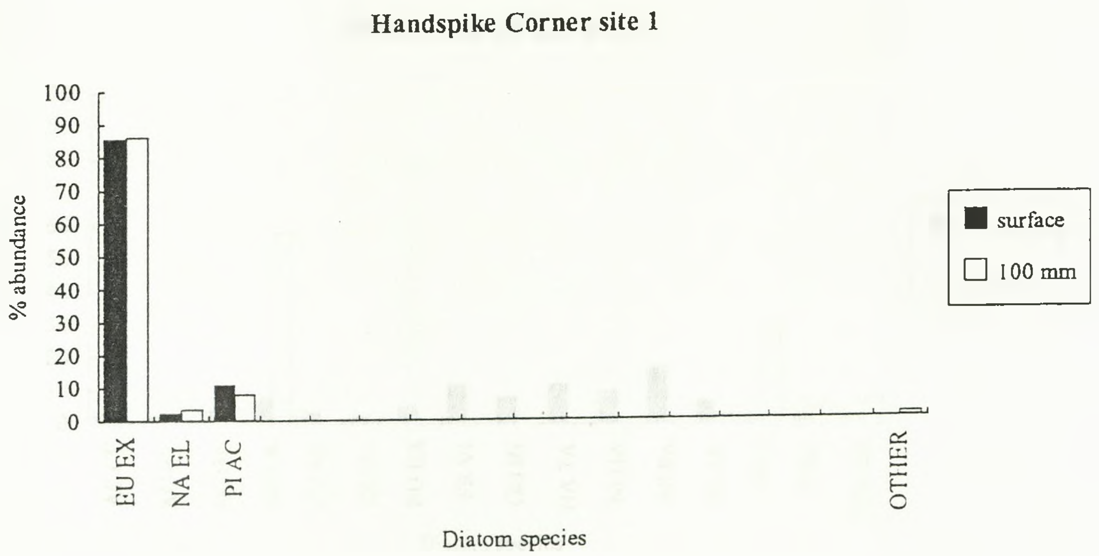
Gadget Dam

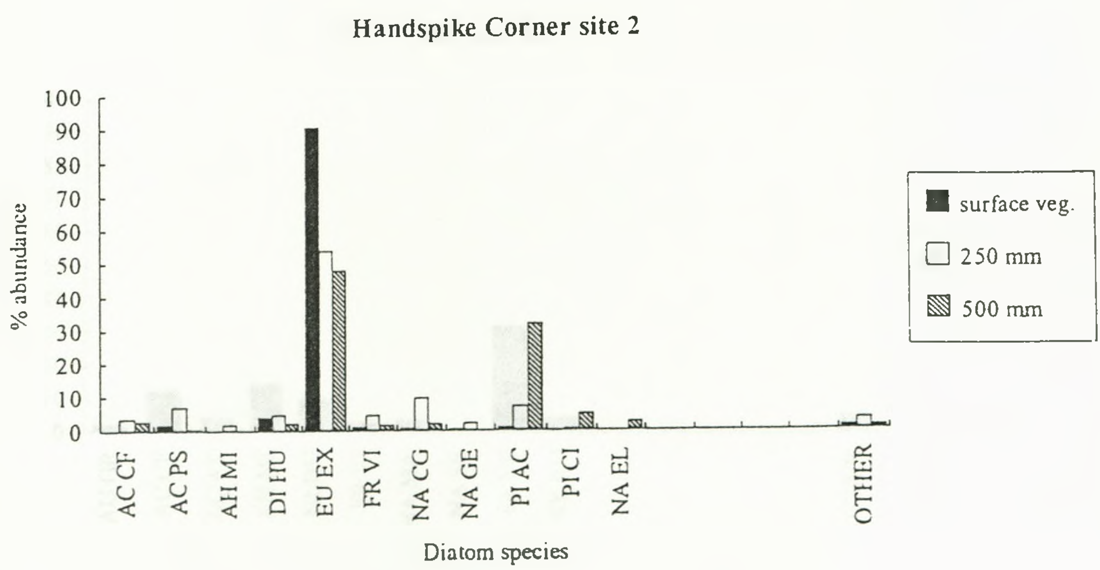


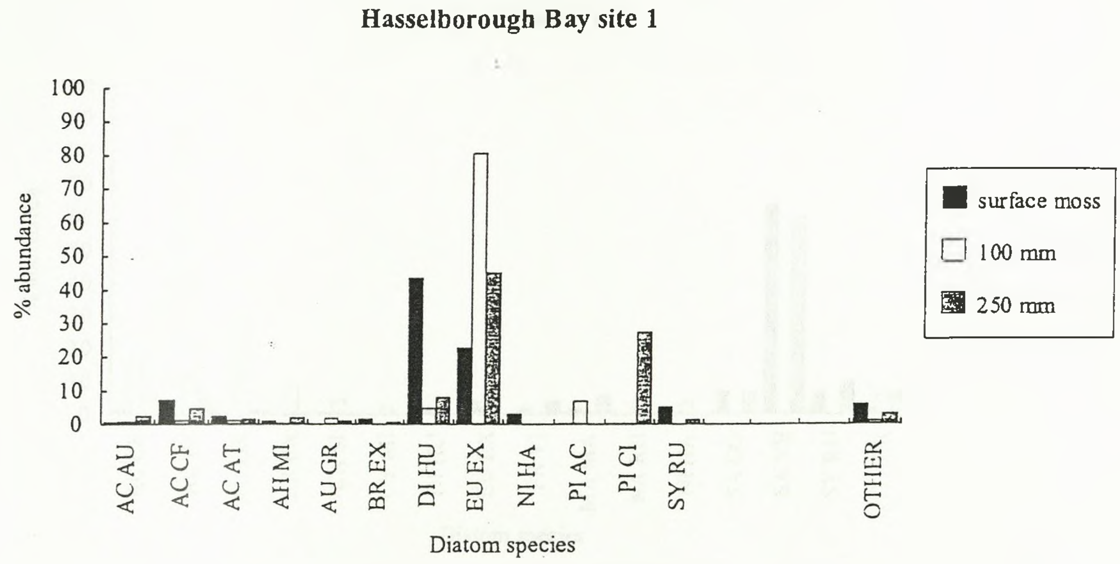
Green Gorge site 1

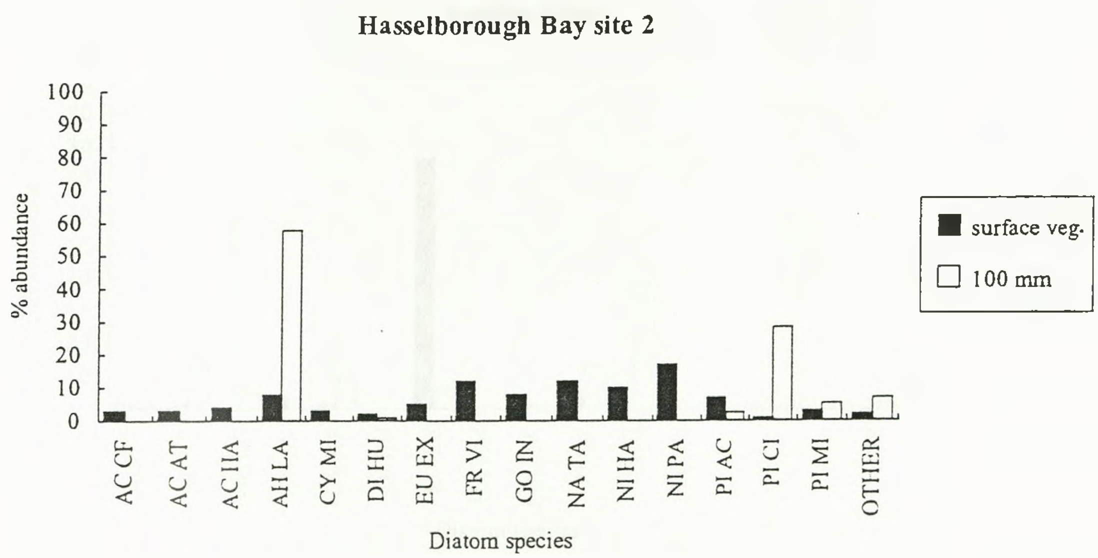


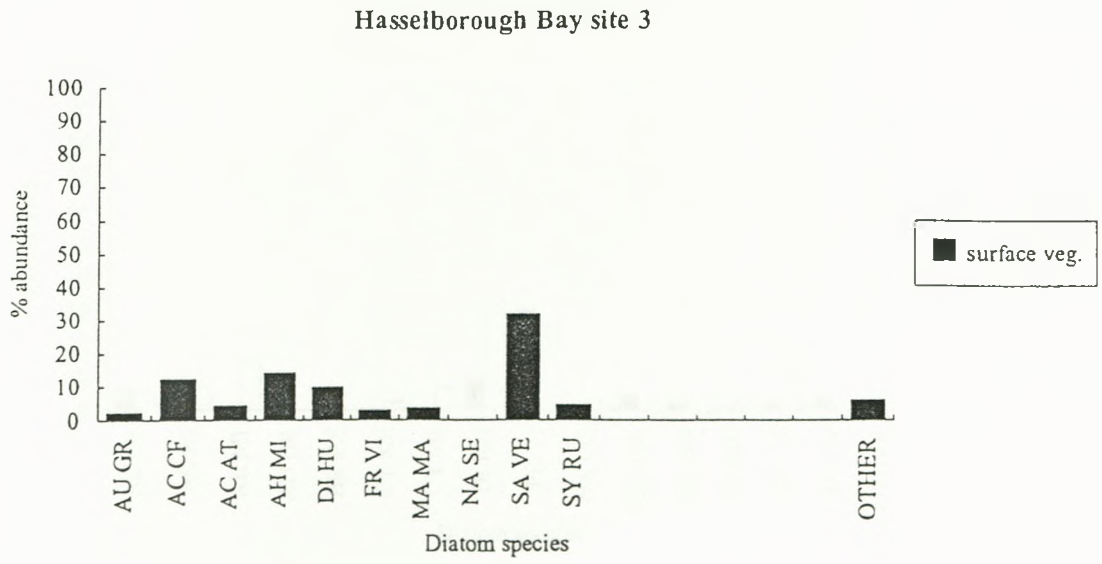

Green Gorge site 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
100 mm
AC CF
AH LA
AC PS
CA SI
CY KE
CY MI
DI HU
DI SM
EU EX
NA TA
NI HA
PI AC
PI CI
SY RU
OTHER
Diatom species

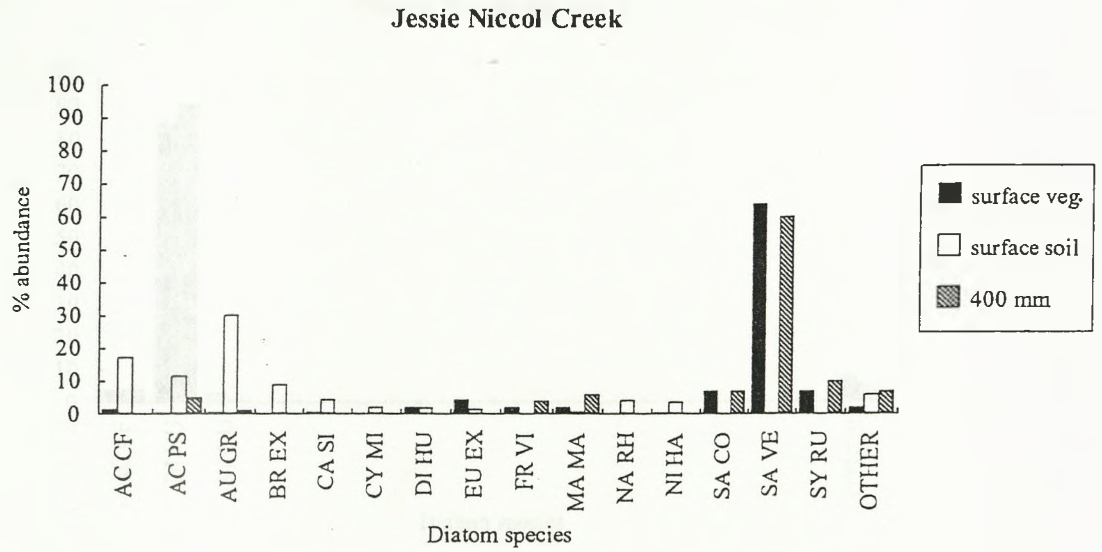

Handspike Corner site 1
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface
100 mm
EU EX
NA EL
PI AC
OTHER
Diatom species

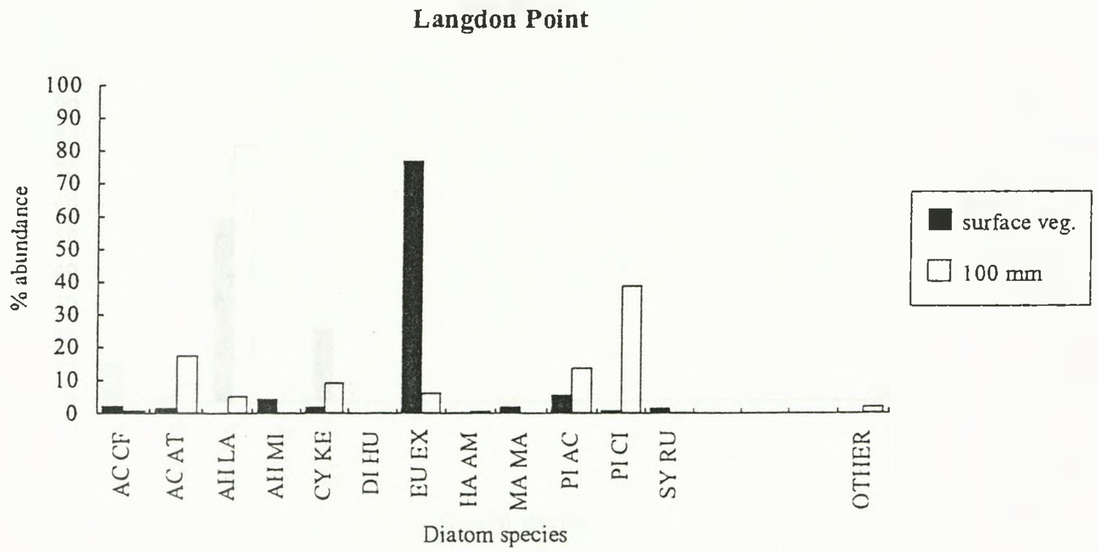

Handspike Corner site 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
250 mm
500 mm
AC CF
AC PS
AH MI
DI HU
EU EX
FR VI
NA CG
NA GE
PI AC
PI CI
NA EL
OTHER
Diatom species

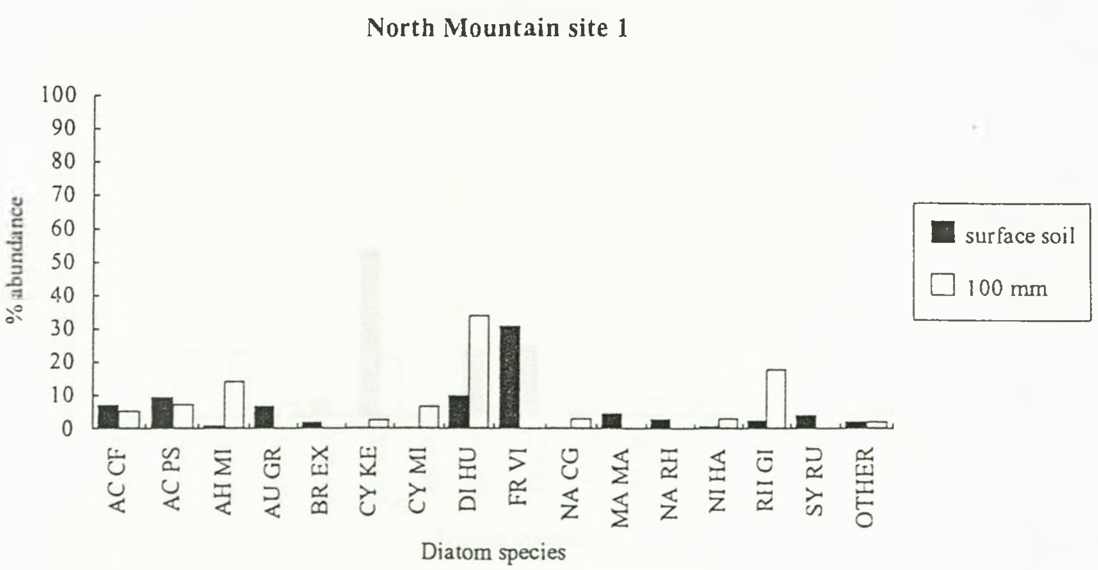

Hasselborough Bay site 1
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface moss
100 mm
250 mm
AC AU
AC CF
AC AT
AH MI
AU GR
BR EX
DI HU
EU EX
NI HA
PI AC
PI CI
SY RU
OTHER
Diatom species

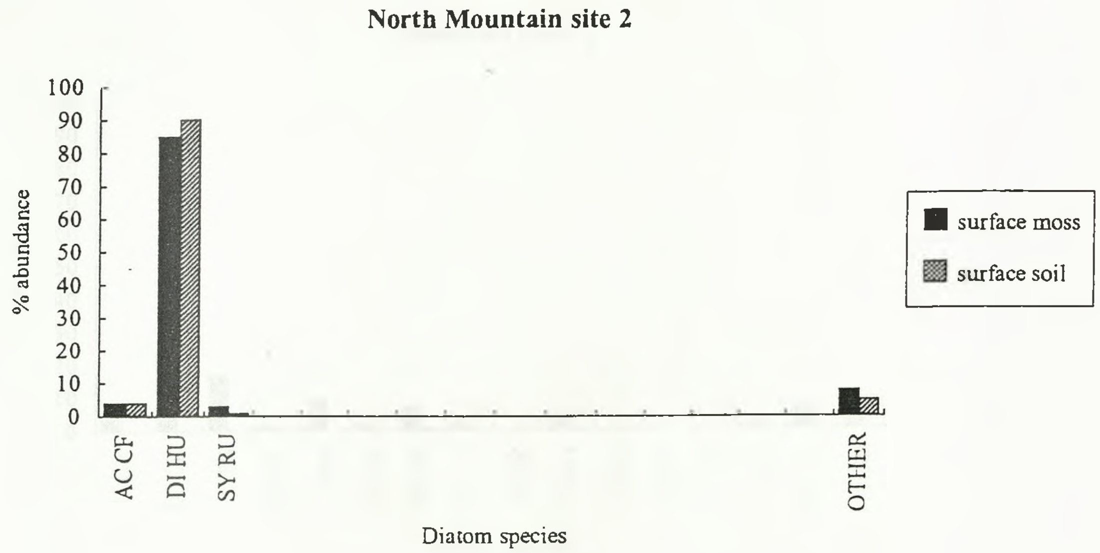

Hasselborough Bay site 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
100 mm
AC CF
AC AT
AC HA
AH LA
CY MI
DI HU
EU EX
FR VI
GO IN
NA TA
NI HA
NI PA
PI AC
PI CI
PI MI
OTHER
Diatom species

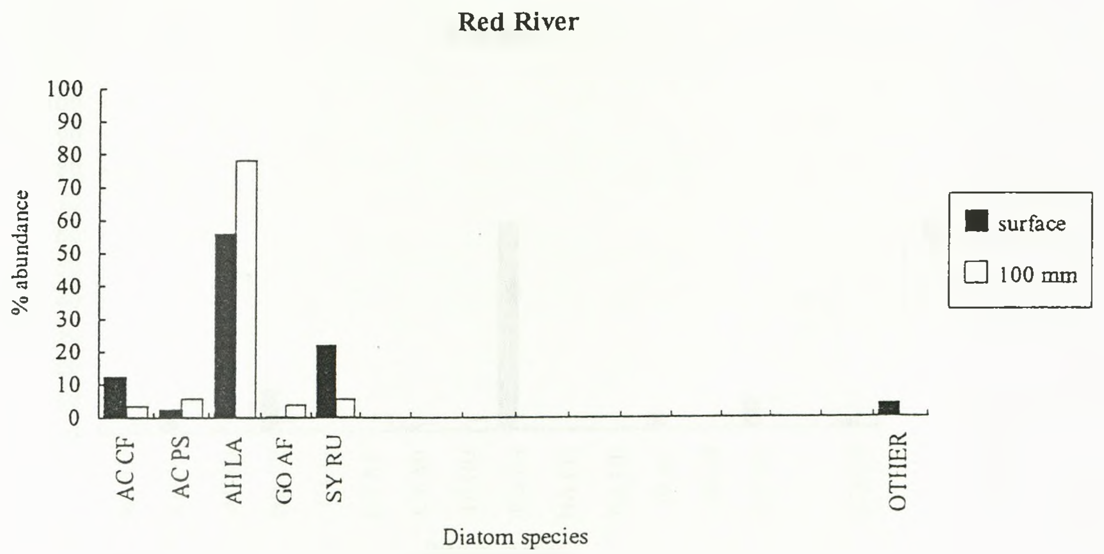

Hasselborough Bay site 3
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
AU GR
AC CF
AC AT
AH MI
DI HU
FR VI
MA MA
NA SE
SA VE
SY RU
OTHER
Diatom species

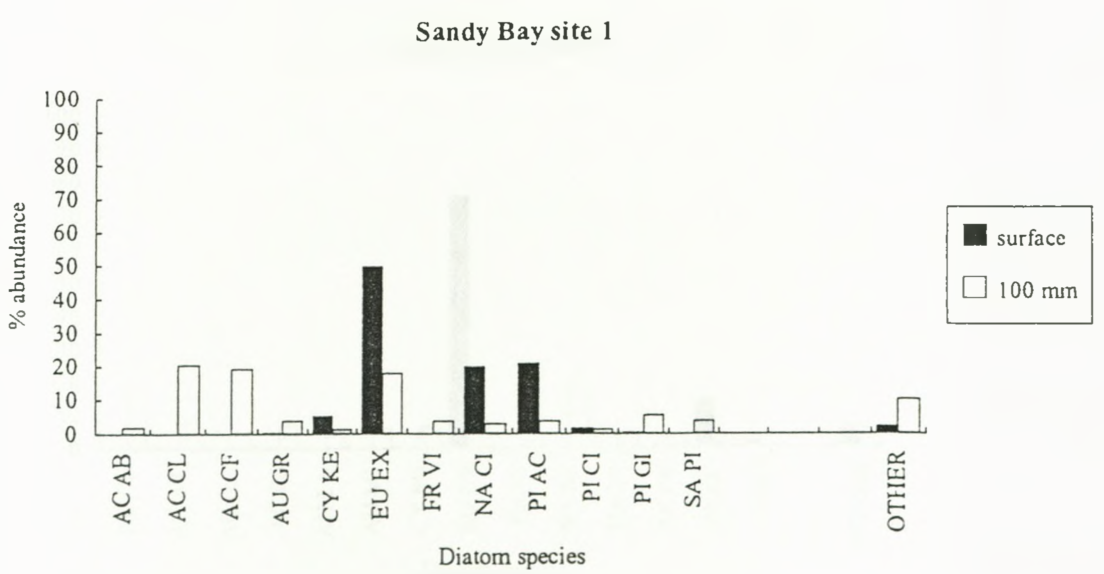

Jessie Niccol Creek
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
surface soil
400 mm
AC CF
AC PS
AU GR
BR EX
CA SI
CY MI
DI HU
EU EX
FR VI
MA MA
NA RH
NI HA
SA CO
SA VE
SY RU
OTHER
Diatom species

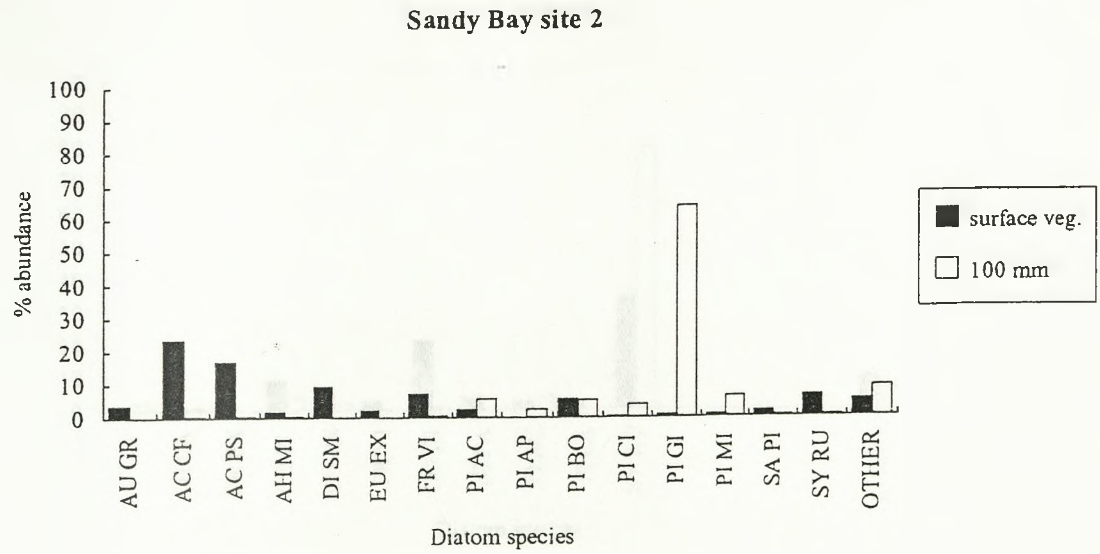

Langdon Point
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
100 mm
AC CF
AC AT
AH LA
AH MI
CY KE
DI HU
EU EX
HA AM
MA MA
PI AC
PI CI
SY RU
OTHER
Diatom species

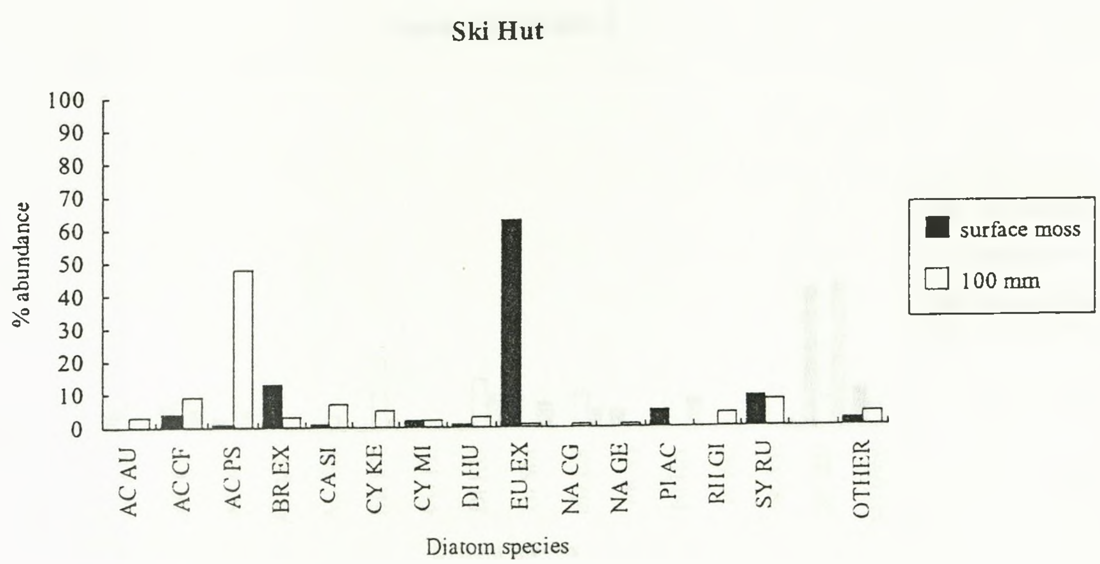

North Mountain site 1
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface soil
100 mm
AC CF
AC PS
AH MI
AU GR
BR EX
CY KE
CY MI
DI HU
FR VI
NA CG
MA MA
NA RH
NI HA
RH GI
SY RU
OTHER
Diatom species

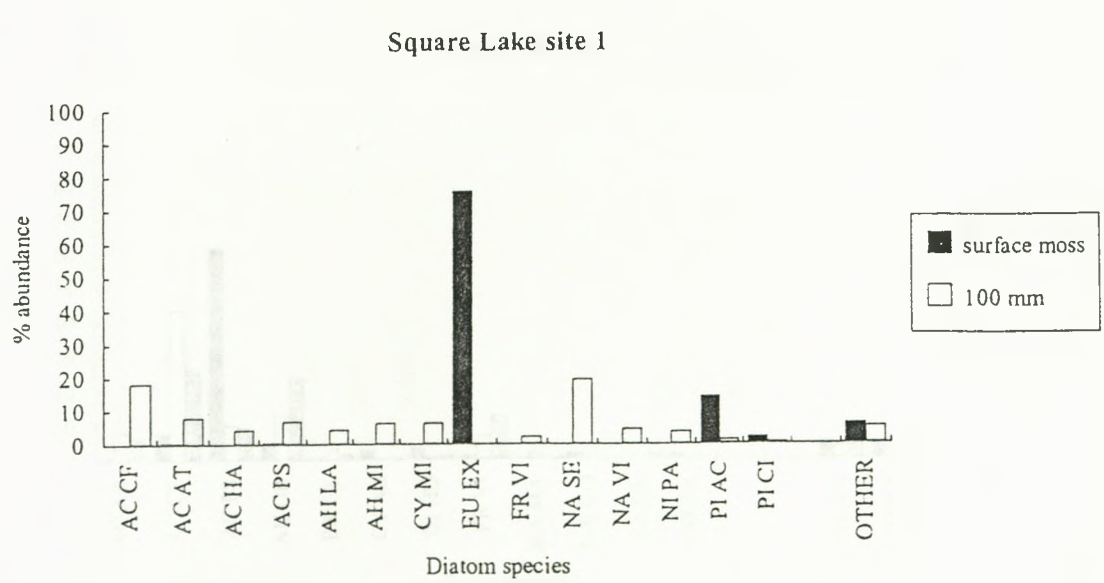

North Mountain site 2
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC CF
DI HU
SY RU
OTHER
Diatom species
surface moss
surface soil

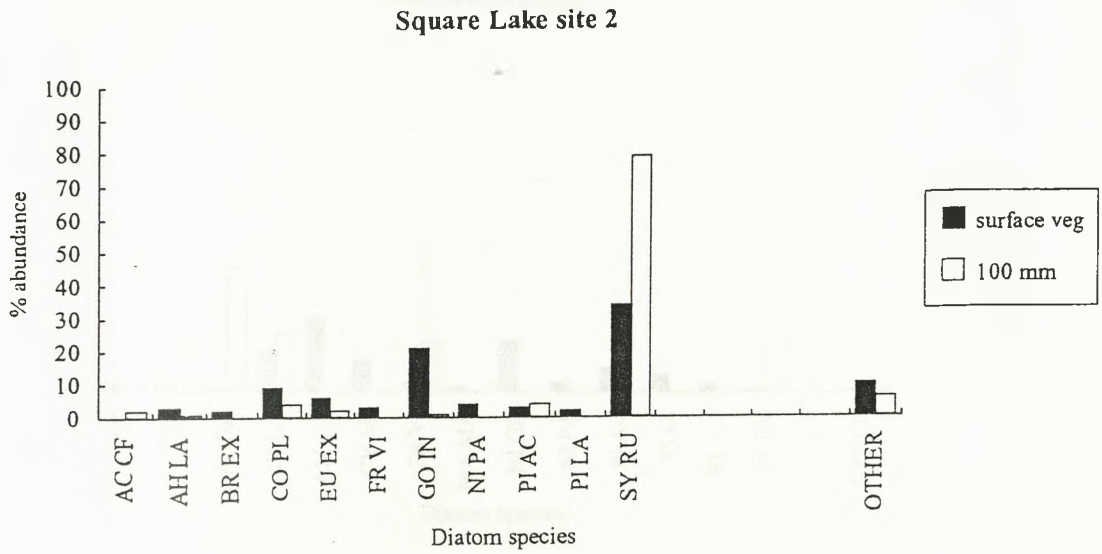

Red River
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC CF
AC PS
AH LA
GO AF
SY RU
OTHER
Diatom species
surface
100 mm

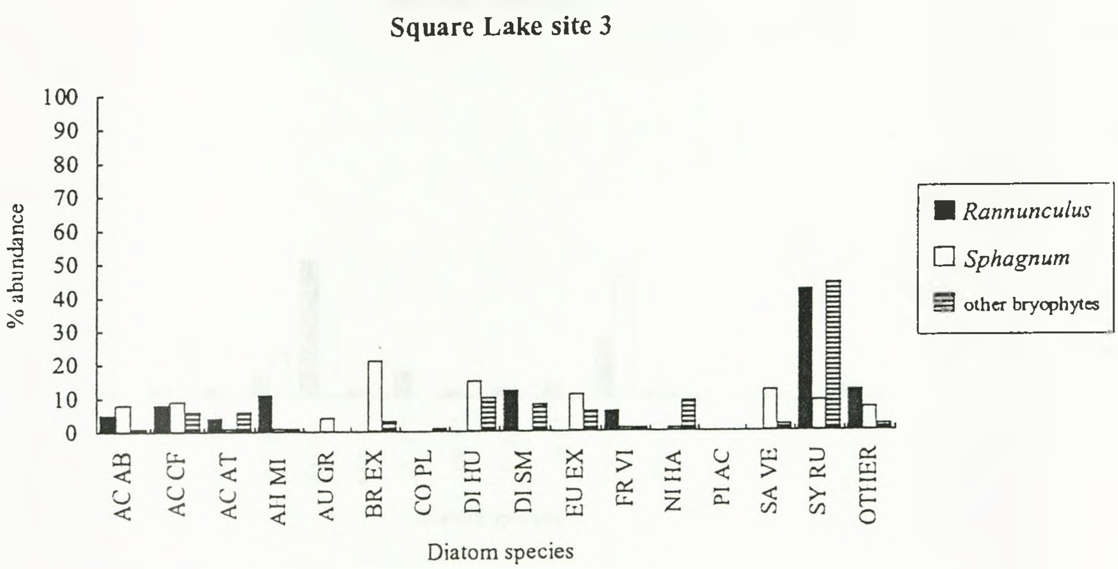

Sandy Bay site 1
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC AB
AC CL
AC CF
AU GR
CY KE
EU EX
FR VI
NA CI
PI AC
PI CI
PI GI
SA PI
OTHER
Diatom species
surface
100 mm

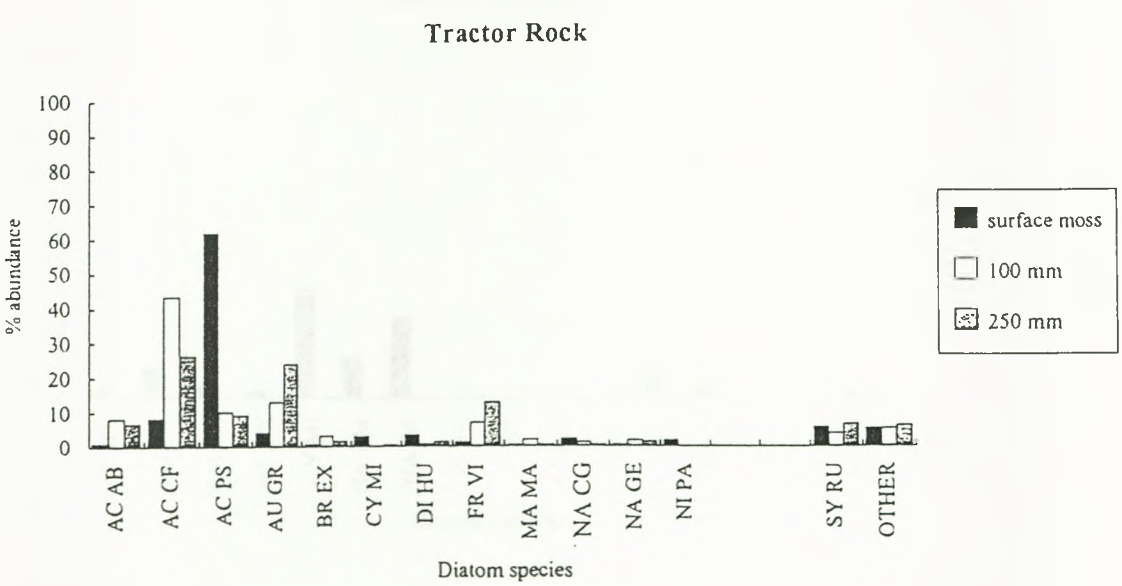

Sandy Bay site 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
100 mm
AU GR
AC CF
AC PS
AH MI
DI SM
EU EX
FR VI
PI AC
PI AP
PI BO
PI CI
PI GI
PI MI
SA PI
SY RU
OTHER
Diatom species

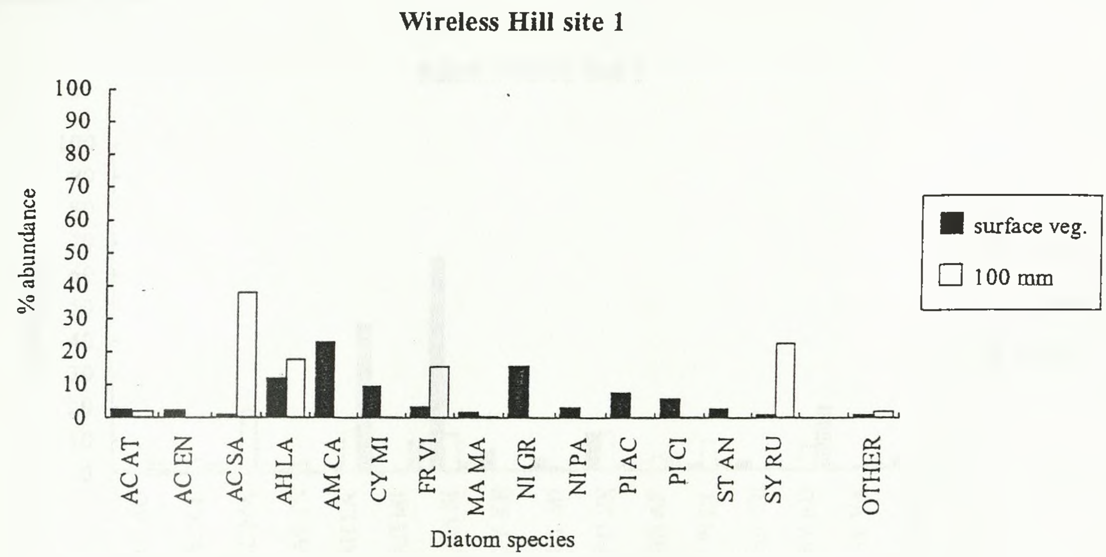

Ski Hut
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface moss
100 mm
AC AU
AC CF
AC PS
BR EX
CA SI
CY KE
CY MI
DI HU
EU EX
NA CG
NA GE
PI AC
RH GI
SY RU
OTHER
Diatom species

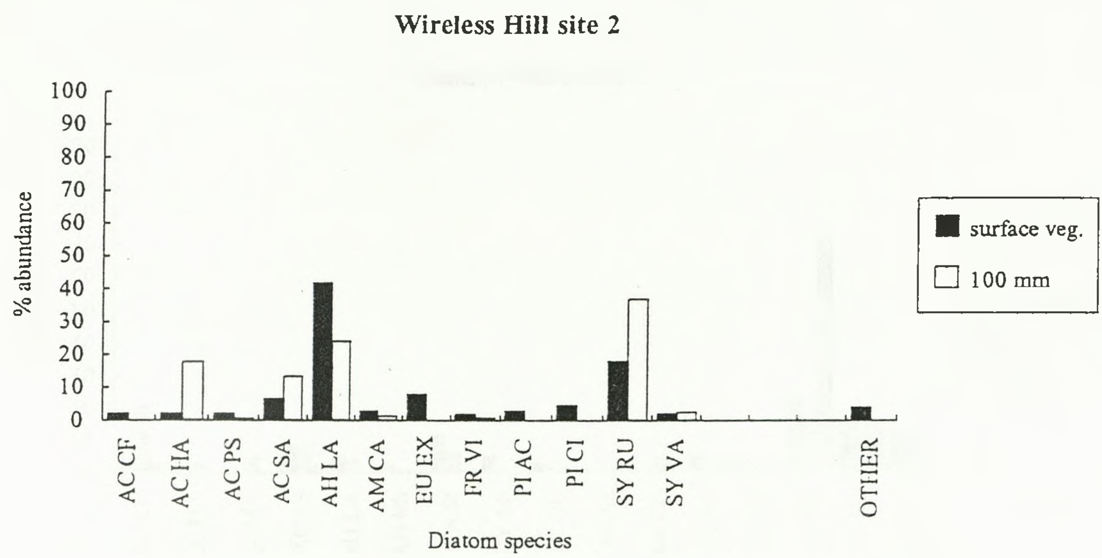

Square Lake site 1
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface moss
100 mm
AC CF
AC AT
AC HA
AC PS
AH LA
AH MI
CY MI
EU EX
FR VI
NA SE
NA VI
NI PA
PI AC
PI CI
OTHER
Diatom species

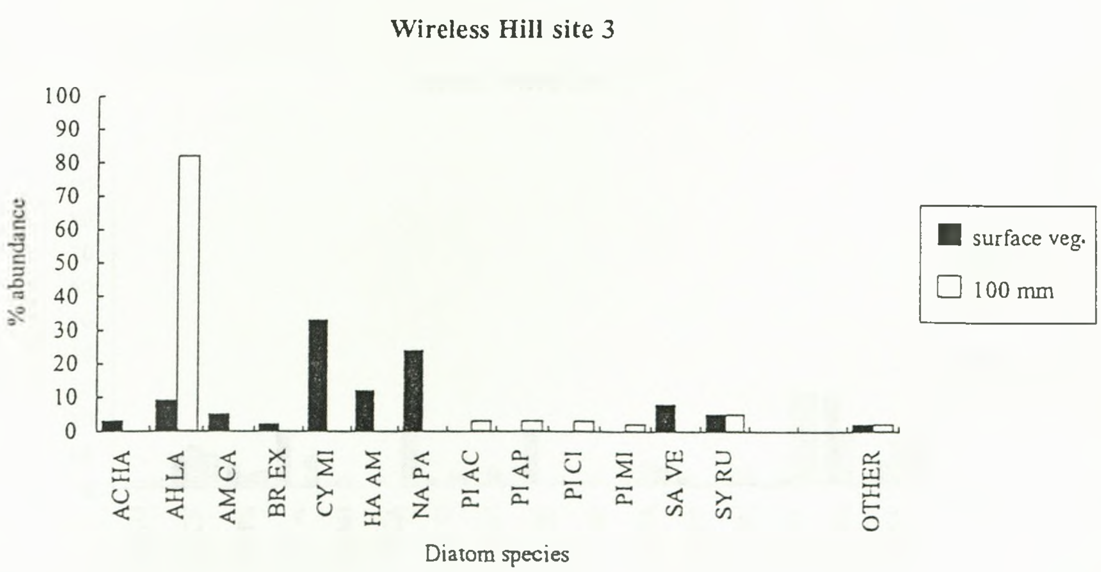

Square Lake site 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg
100 mm
AC CF
AH LA
BR EX
CO PL
EU EX
FR VI
GO IN
NI PA
PI AC
PI LA
SY RU
OTHER
Diatom species


Square Lake site 3
100
90
80
70
60
50
40
30
20
10
0
% abundance
Rannunculus
Sphagnum
other bryophytes
AC AB
AC CF
AC AT
AH MI
AU GR
BR EX
CO PL
DI HU
DI SM
EU EX
FR VI
NI HA
PI AC
SA VE
SY RU
OTHER
Diatom species


Tractor Rock
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface moss
100 mm
250 mm
AC AB
AC CF
AC PS
AU GR
BR EX
CY MI
DI HU
FR VI
MA MA
NA CG
NA GE
NI PA
SY RU
OTHER
Diatom species

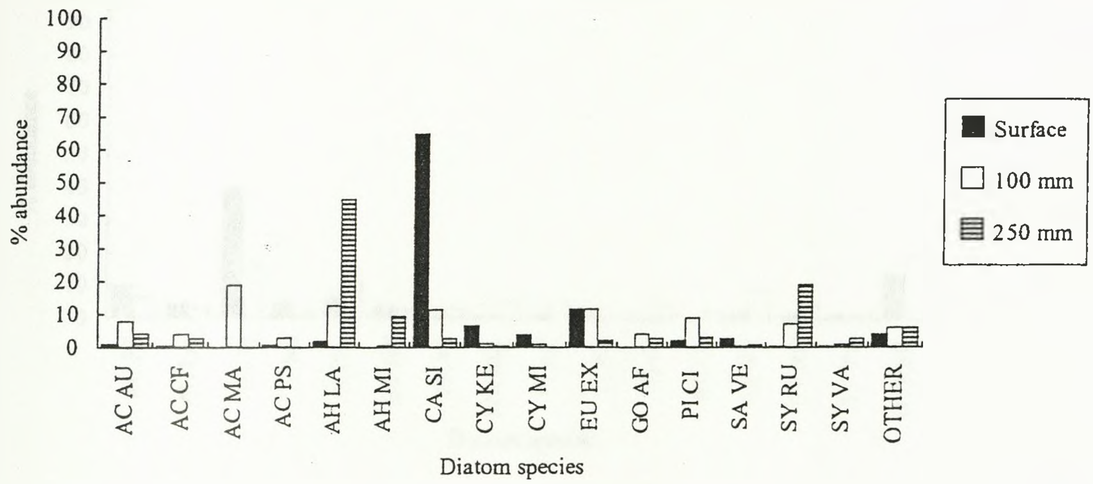

Wireless Hill site 1
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
100 mm
AC AT
AC EN
AC SA
AH LA
AM CA
CY MI
FR VI
MA MA
NI GR
NI PA
PI AC
PI CI
ST AN
SY RU
OTHER
Diatom species


Wireless Hill site 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
100 mm
AC CF
AC HA
AC PS
AC SA
AH LA
AM CA
EU EX
FR VI
PI AC
PI CI
SY RU
SY VA
OTHER
Diatom species

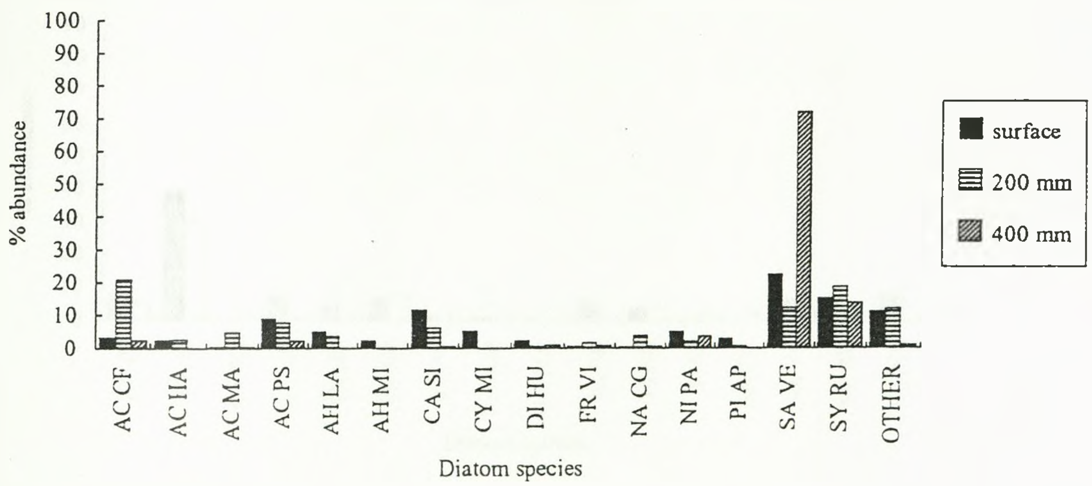

Wireless Hill site 3
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface veg.
100 mm
AC HA
AH LA
AM CA
BR EX
CY MI
HA AM
NA PA
PI AC
PI AP
PI CI
PI MI
SA VE
SY RU
OTHER
Diatom species

Sandell Mire

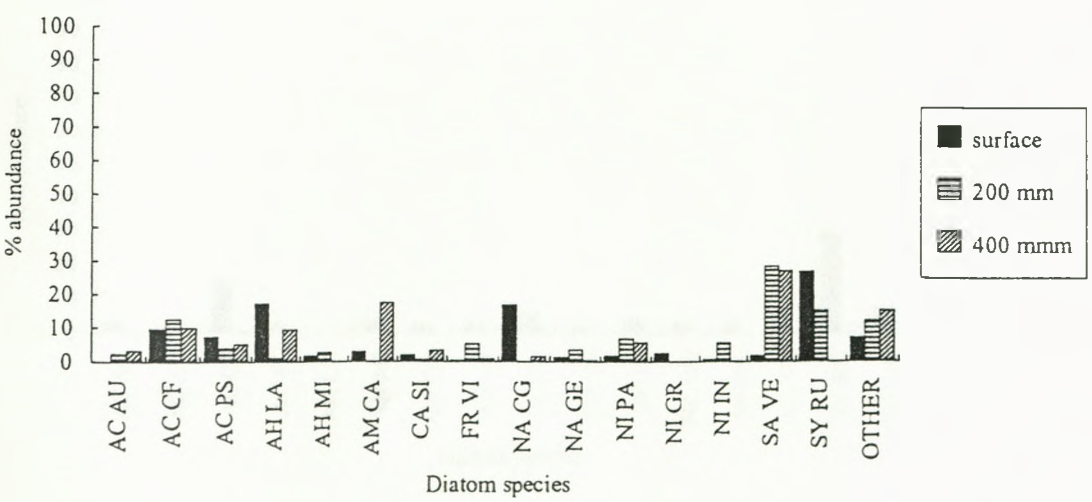
Sandell Mire Site 1



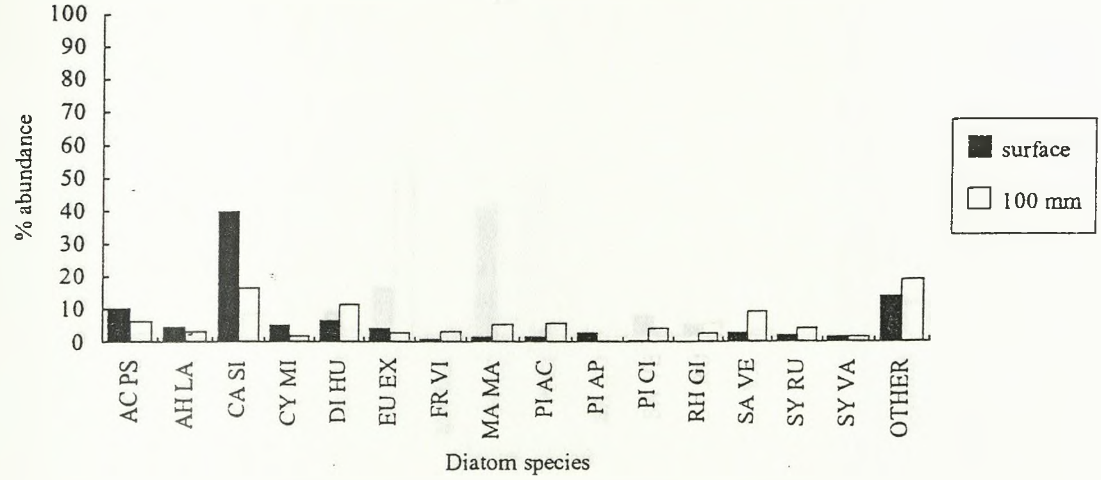
Sandell Mire Site 2



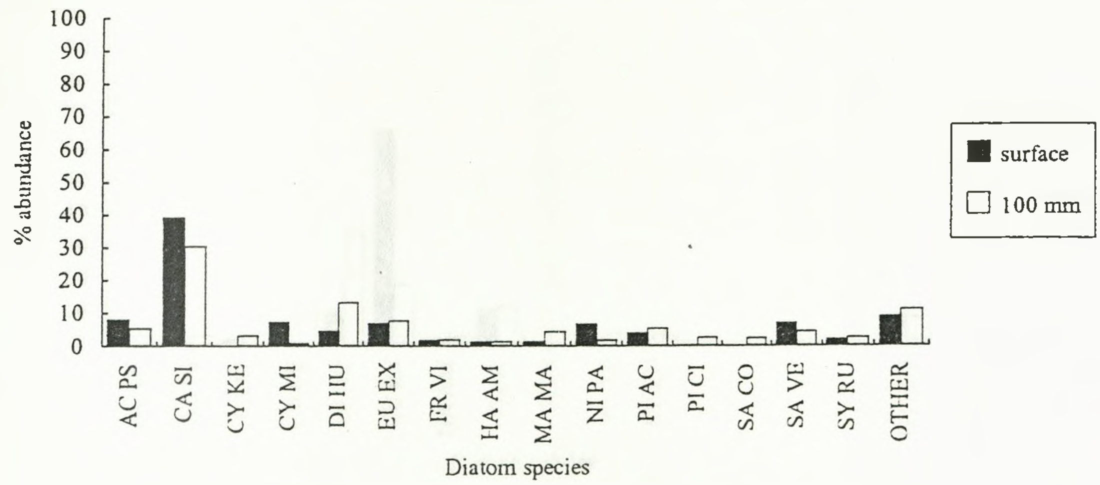
Sandell Mire Site 3



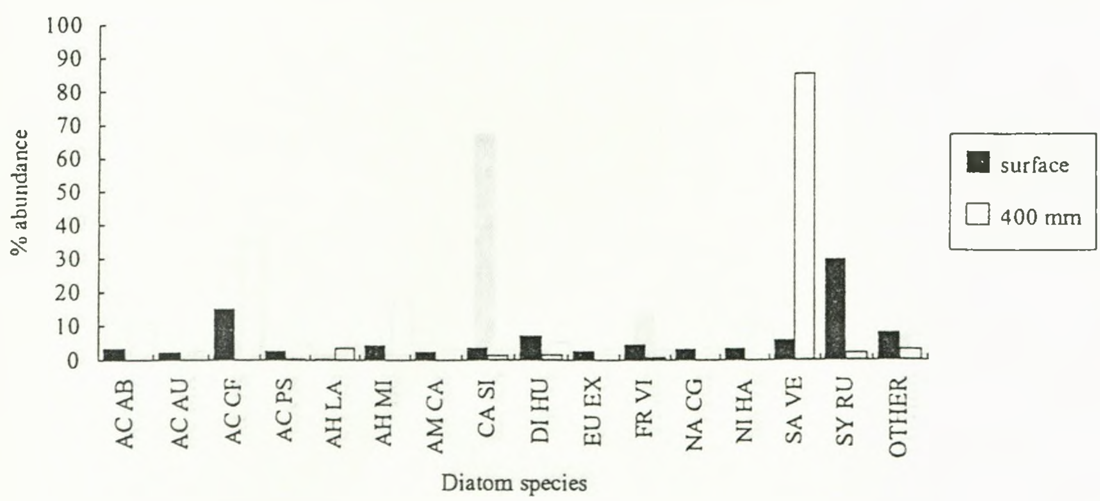
Sandell Mire Site 4



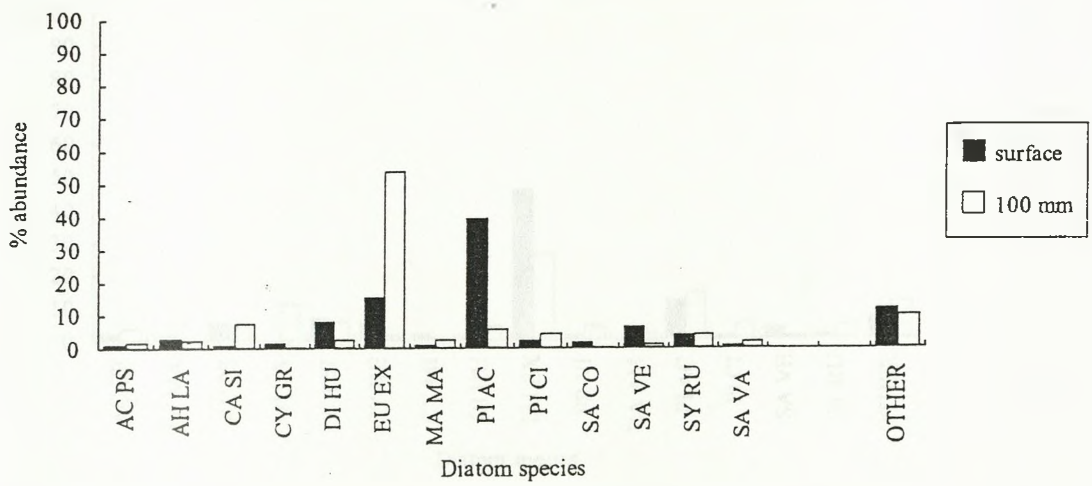
Sandell Mire Site 5



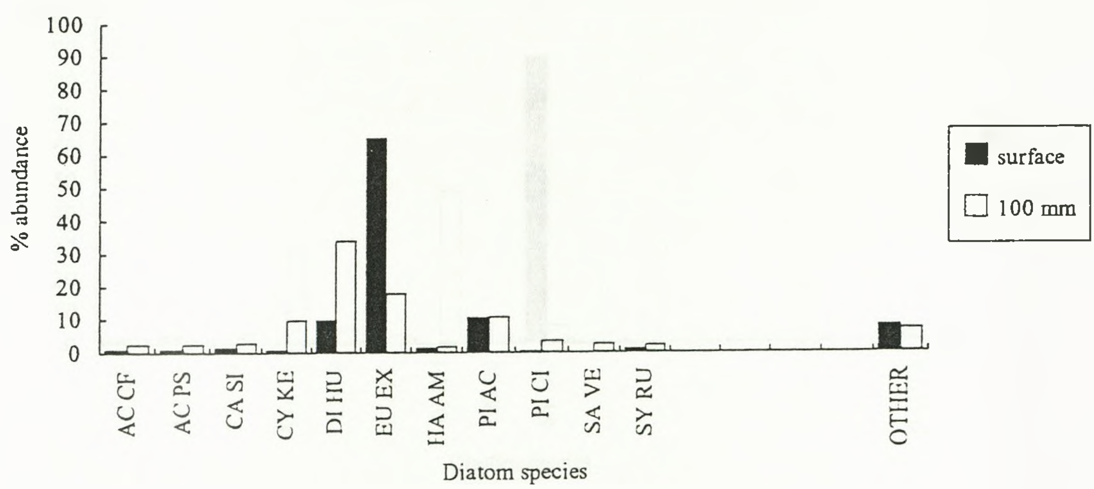
Sandell Mire Site 6



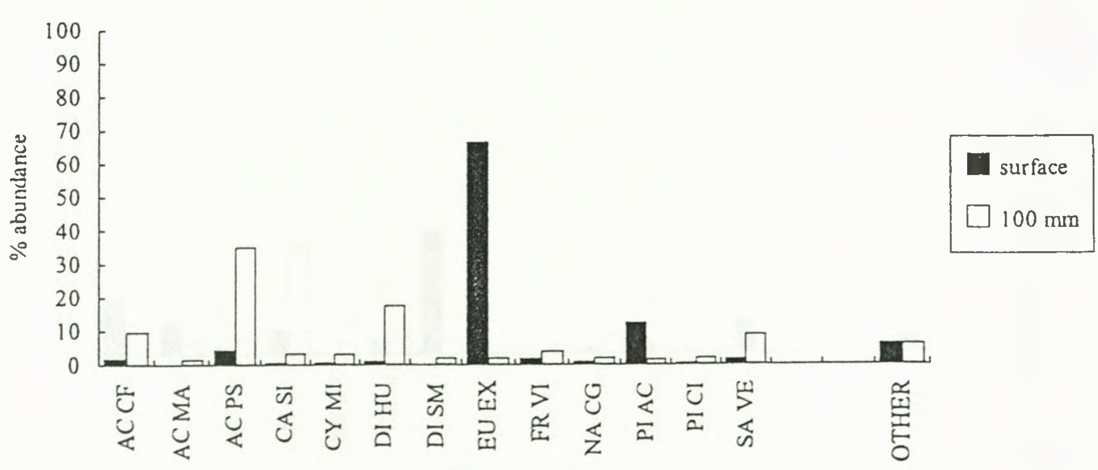
Sandell Mire Site 7

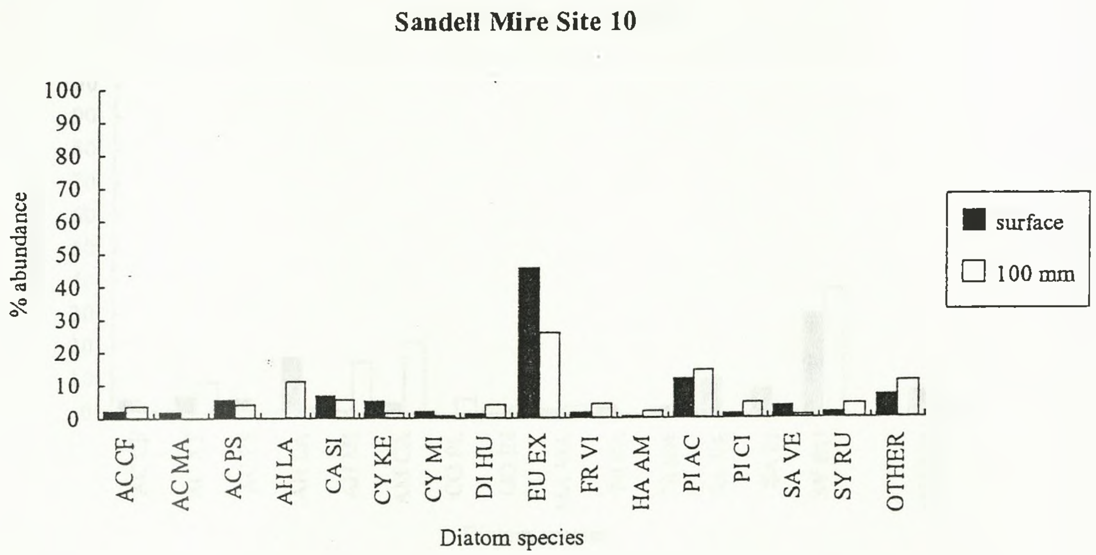


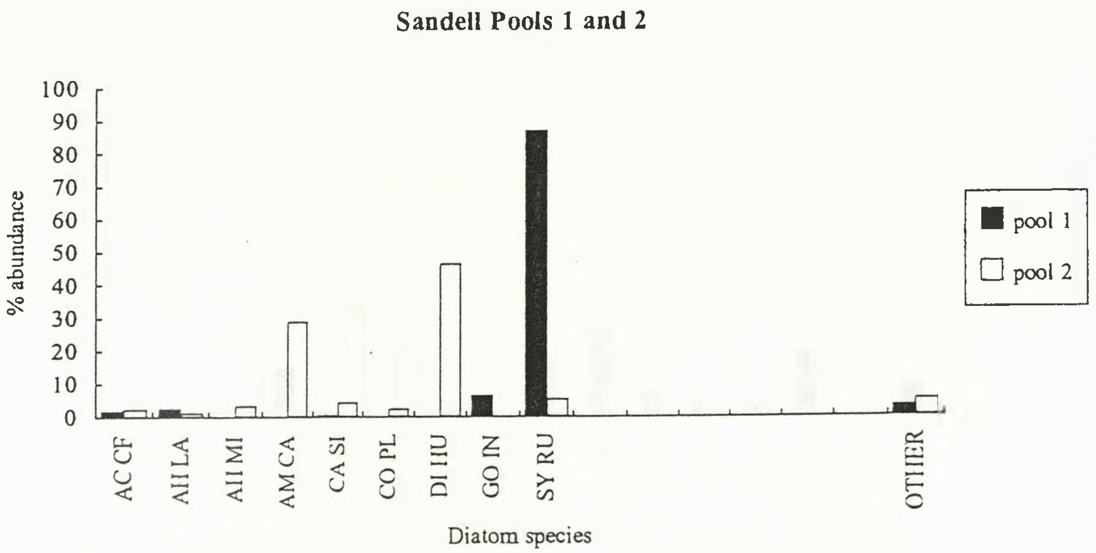
Sandell Mire Site 8

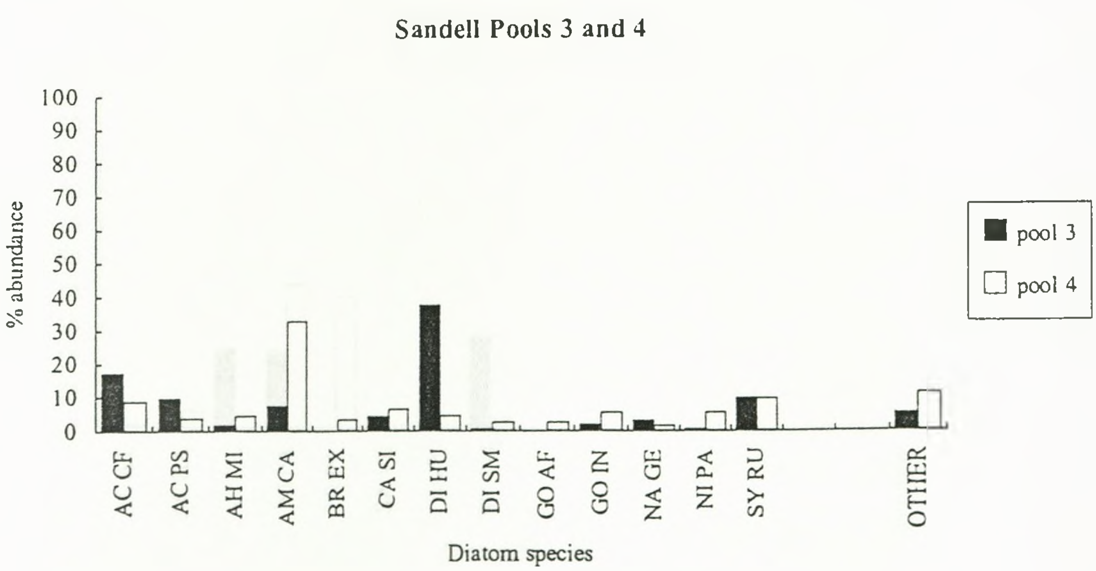


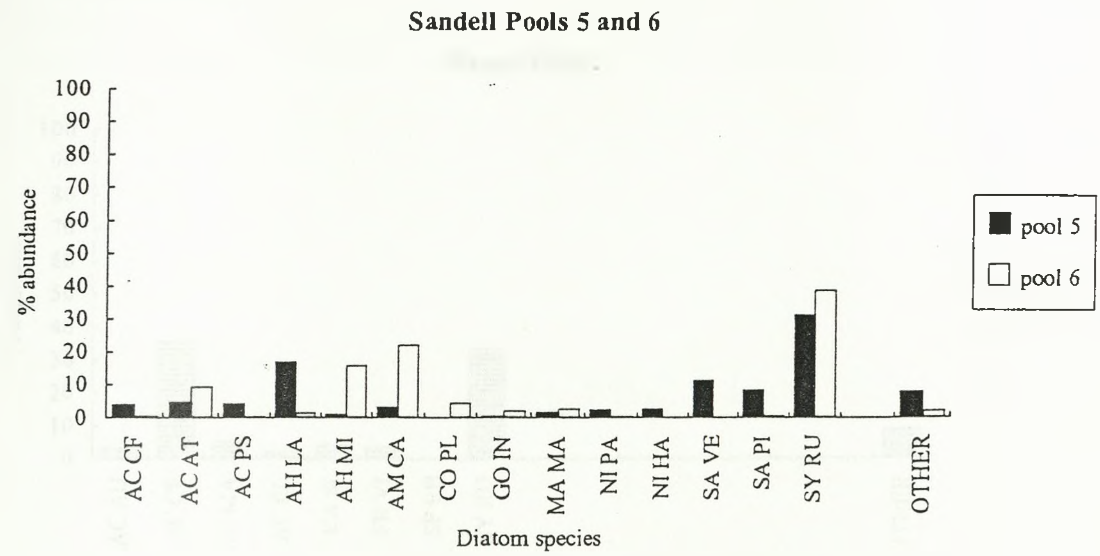
Sandell Mire Site 9

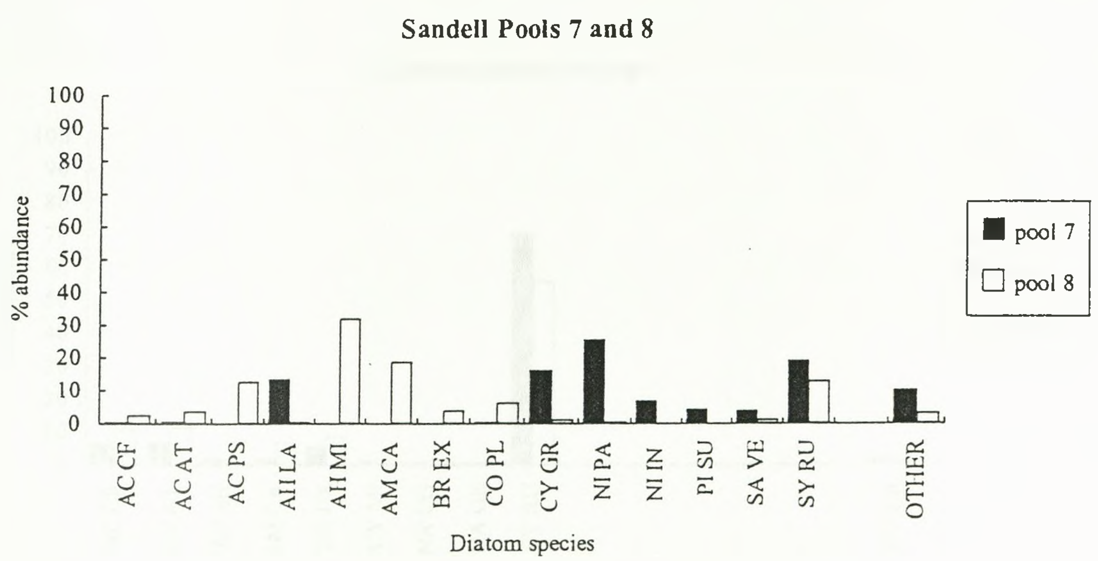


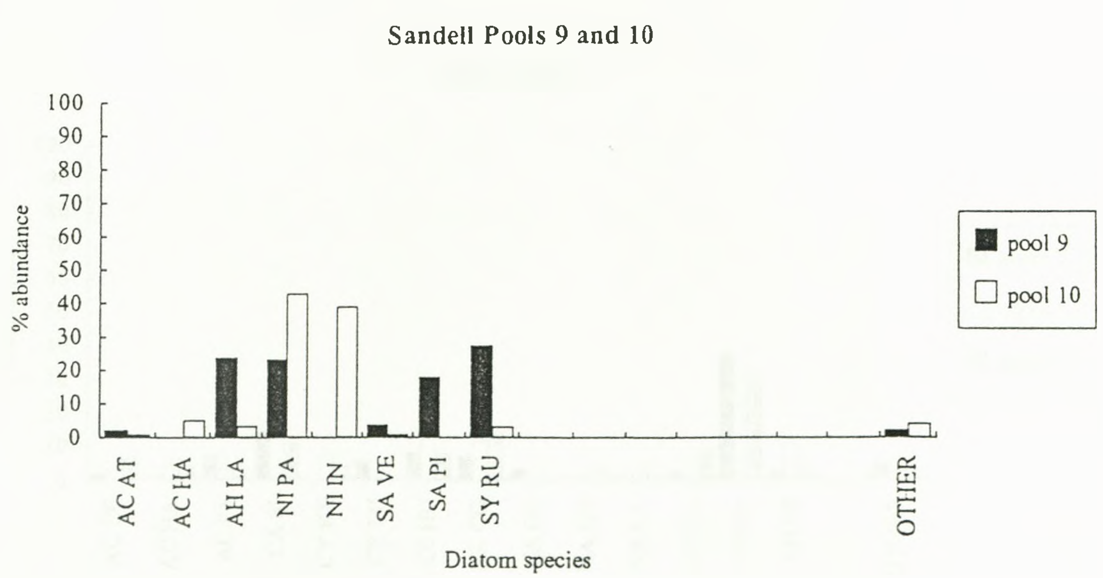

Sandell Mire Site 10
100
90
80
70
60
50
40
30
20
10
0
% abundance
surface
100 mm
AC CF
AC MA
AC PS
AH LA
CA SI
CY KE
CY MI
DI HU
EU EX
FR VI
HA AM
PI AC
PI CI
SA VE
SY RU
OTHER
Diatom species


Sandell Pools 1 and 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
pool 1
pool 2
AC CF
AH LA
AH MI
AM CA
CA SI
CO PL
DI HU
GO IN
SY RU
OTHER
Diatom species

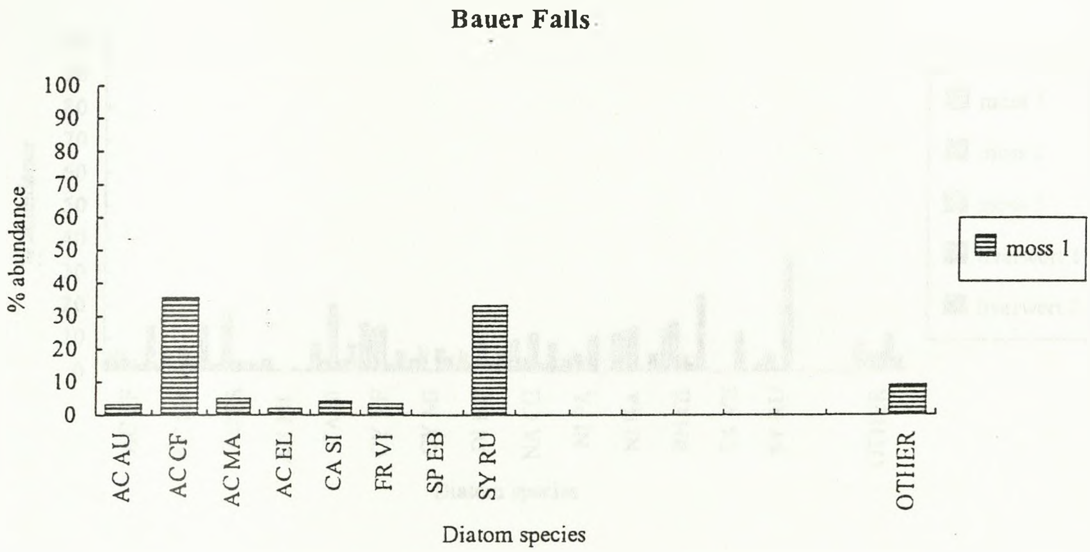

Sandell Pools 3 and 4
100
90
80
70
60
50
40
30
20
10
0
% abundance
pool 3
pool 4
AC CF
AC PS
AH MI
AM CA
BR EX
CA SI
DI HU
DI SM
GO AF
GO IN
NA GE
NI PA
SY RU
OTHER
Diatom species

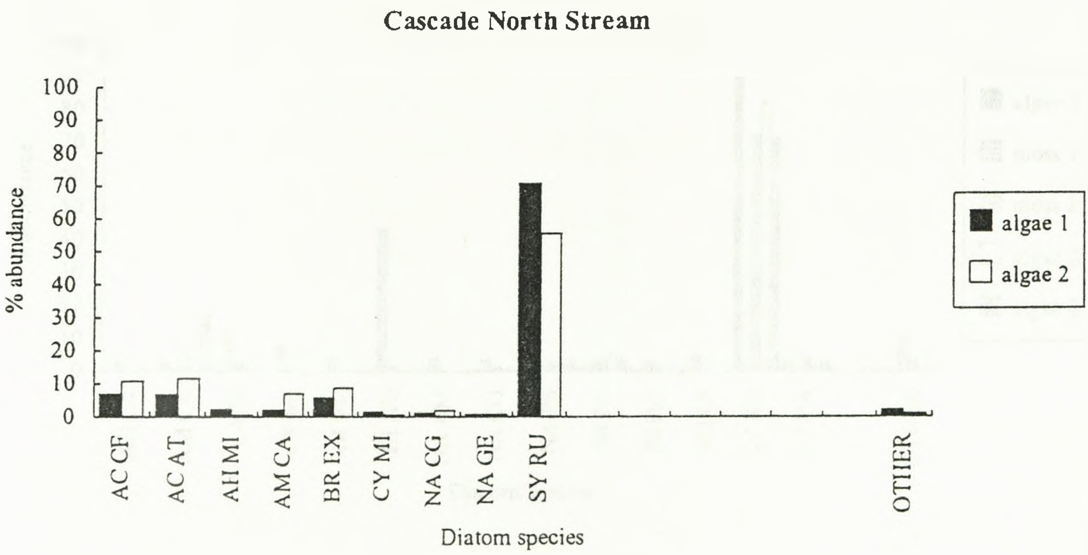

Sandell Pools 5 and 6
100
90
80
70
60
50
40
30
20
10
0
% abundance
pool 5
pool 6
AC CF
AC AT
AC PS
AH LA
AH MI
AM CA
CO PL
GO IN
MA MA
NI PA
NI HA
SA VE
SA PI
SY RU
OTHER
Diatom species

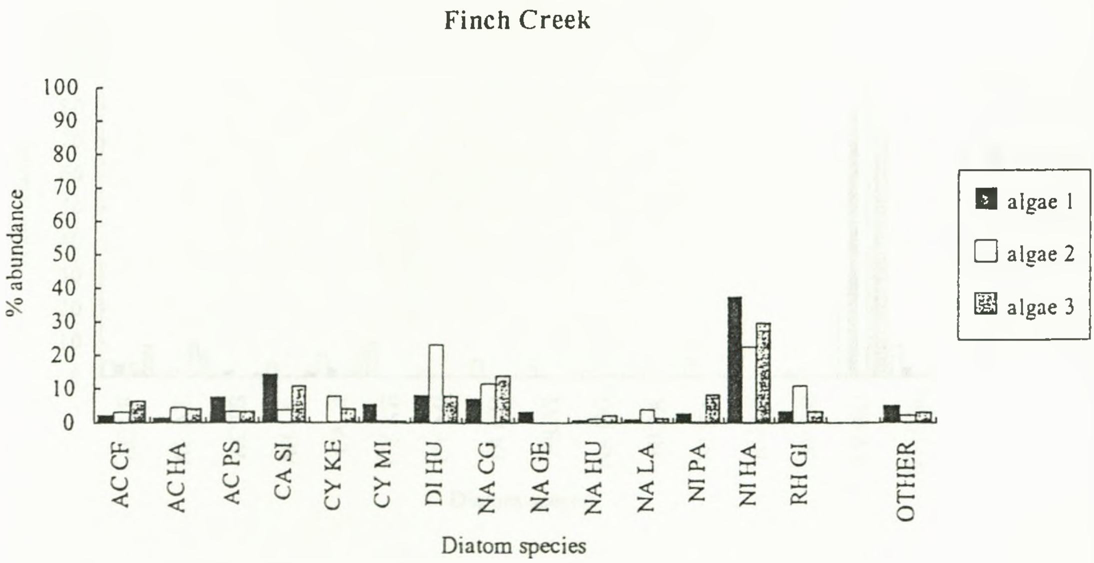

Sandell Pools 7 and 8
100
90
80
70
60
50
40
30
20
10
0
% abundance
pool 7
pool 8
AC CF
AC AT
AC PS
AH LA
AH MI
AM CA
BR EX
CO PL
CY GR
NI PA
NI IN
PI SU
SA VE
SY RU
OTHER
Diatom species


Sandell Pools 9 and 10
100
90
80
70
60
50
40
30
20
10
0
% abundance
pool 9
pool 10
AC AT
AC HA
AH LA
NI PA
NI IN
SA VE
SA PI
SY RU
OTHER
Diatom species

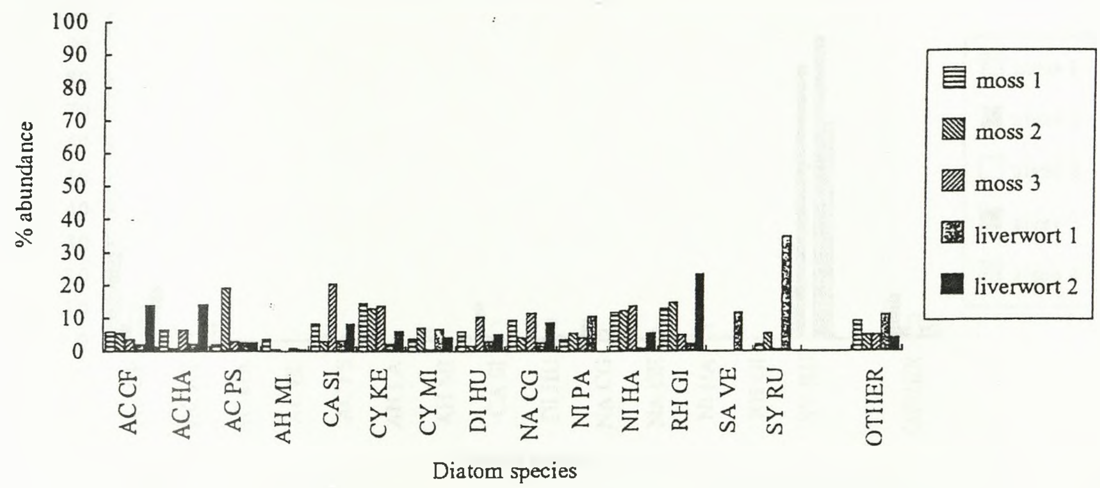
Creek Sites


Bauer Falls
100
90
80
70
60
50
40
30
20
10
0
% abundance
moss 1
AC AU
AC CF
AC MA
AC EL
CA SI
FR VI
SP EB
SY RU
OTHER
Diatom species

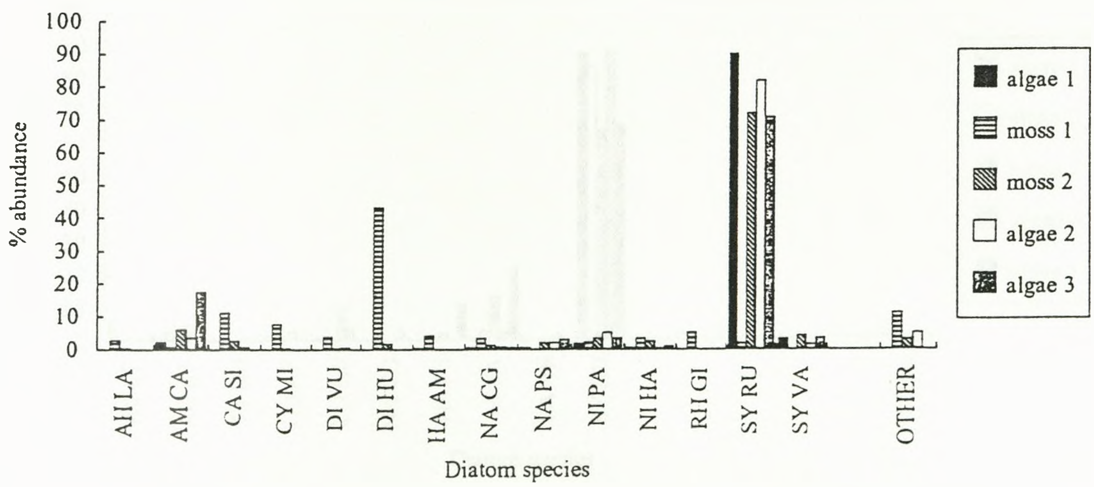

Cascade North Stream
100
90
80
70
60
50
40
30
20
10
0
% abundance
algae 1
algae 2
AC CF
AC AT
AH MI
AM CA
BR EX
CY MI
NA CG
NA GE
SY RU
OTHER
Diatom species


Finch Creek
100
90
80
70
60
50
40
30
20
10
0
% abundance
algae 1
algae 2
algae 3
AC CF
AC HA
AC PS
CA SI
CY KE
CY MI
DI HU
NA CG
NA GE
NA HU
NA LA
NI PA
NI HA
RH GI
OTHER
Diatom species

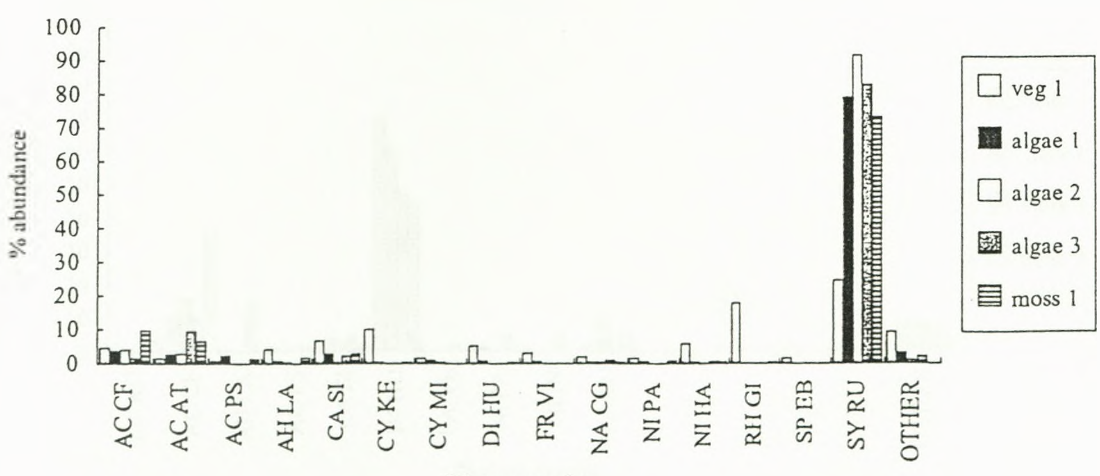
Finch Creek



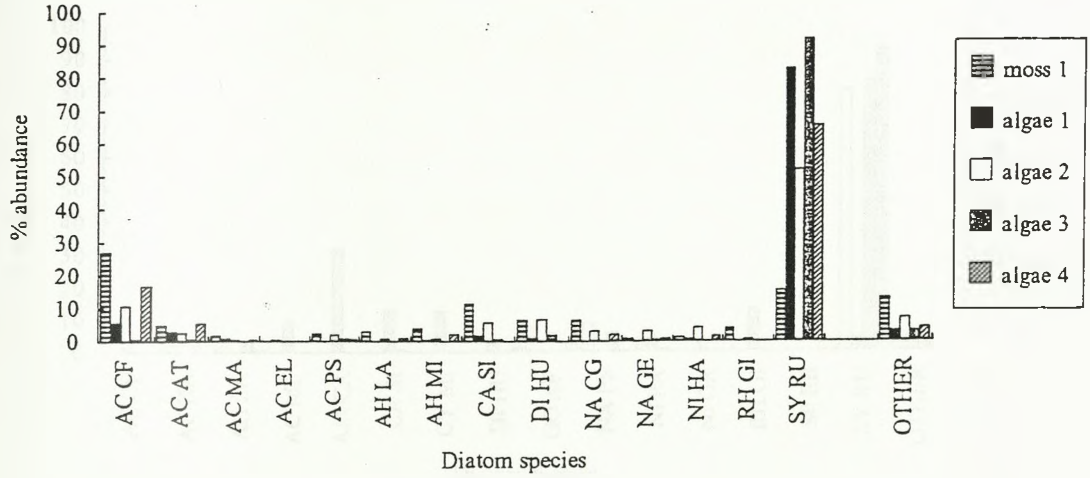
First Gully



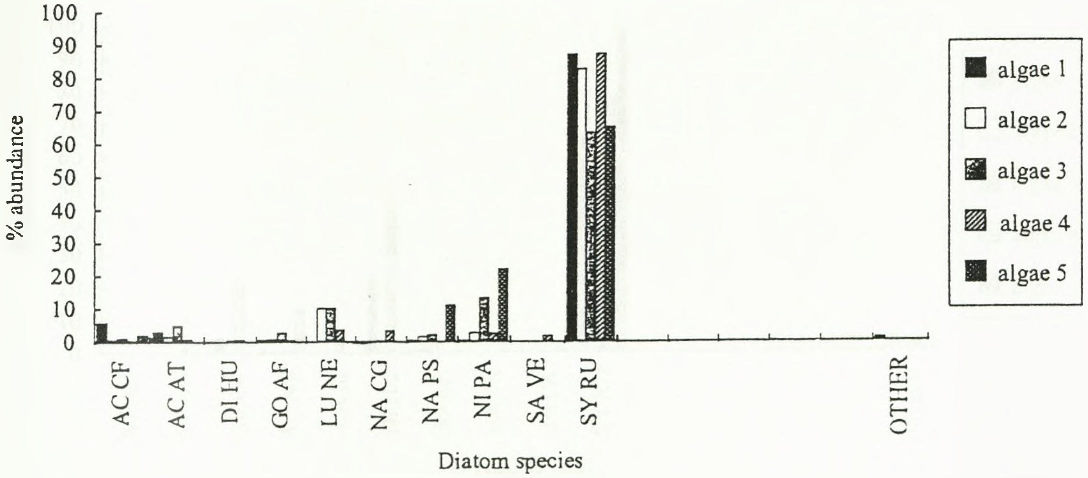
Gadget Gully site 1



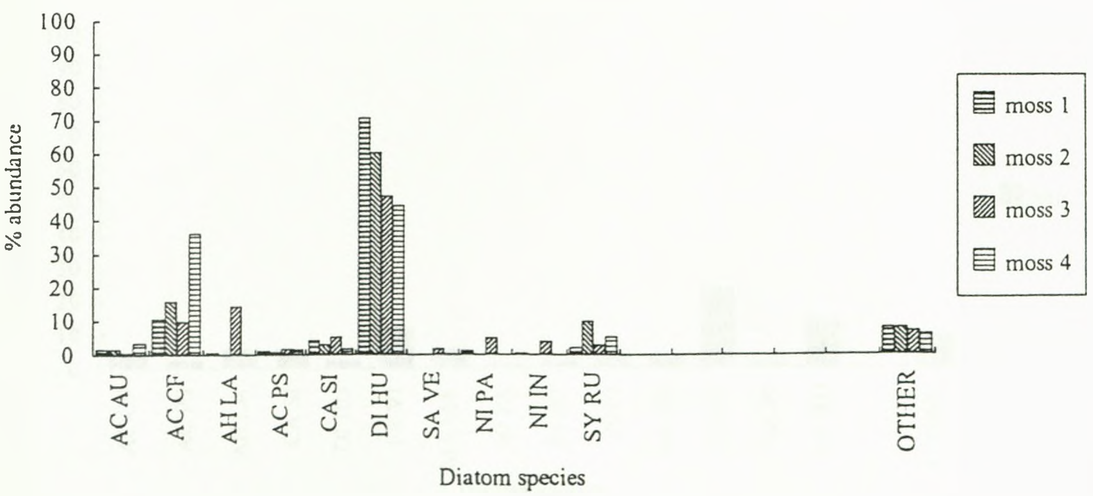
Gadget Gully site 2

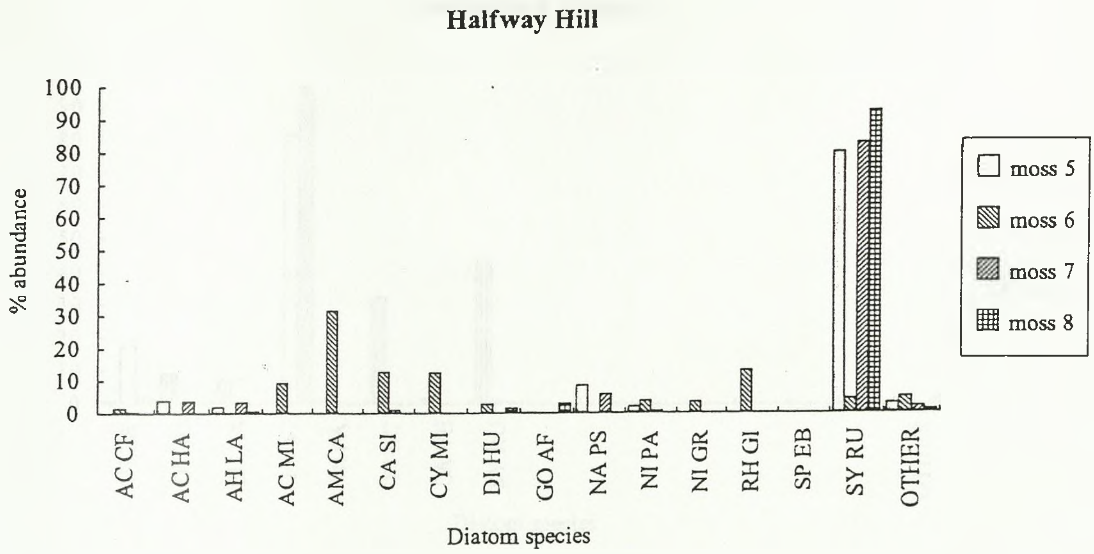


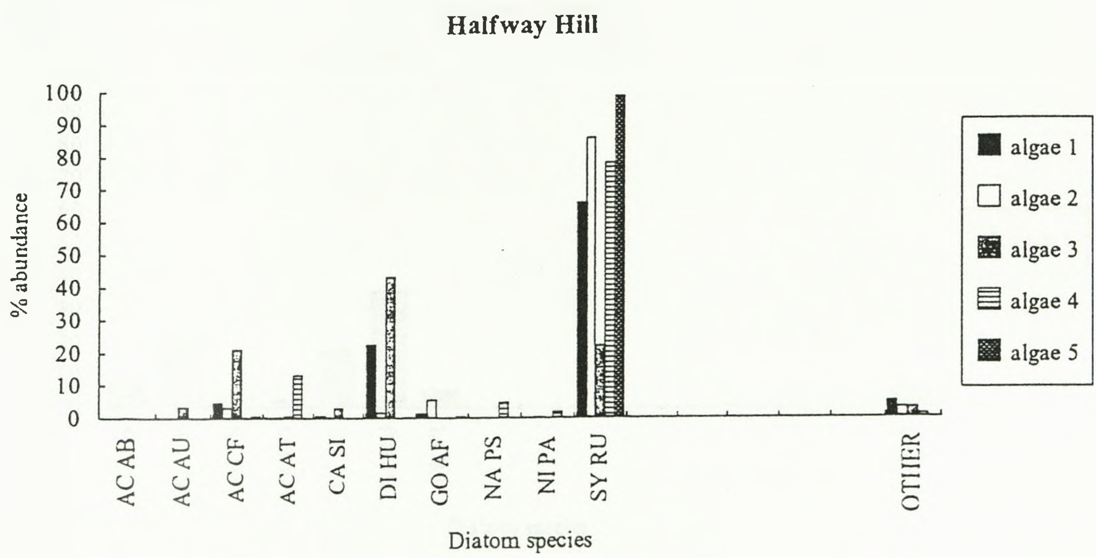
Gadget Gully site 3

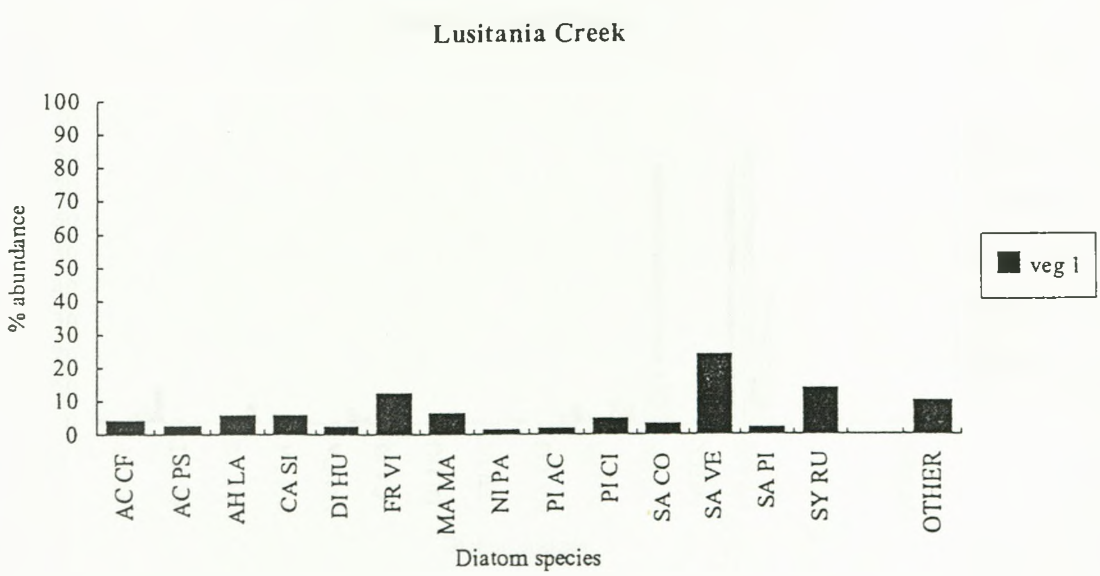


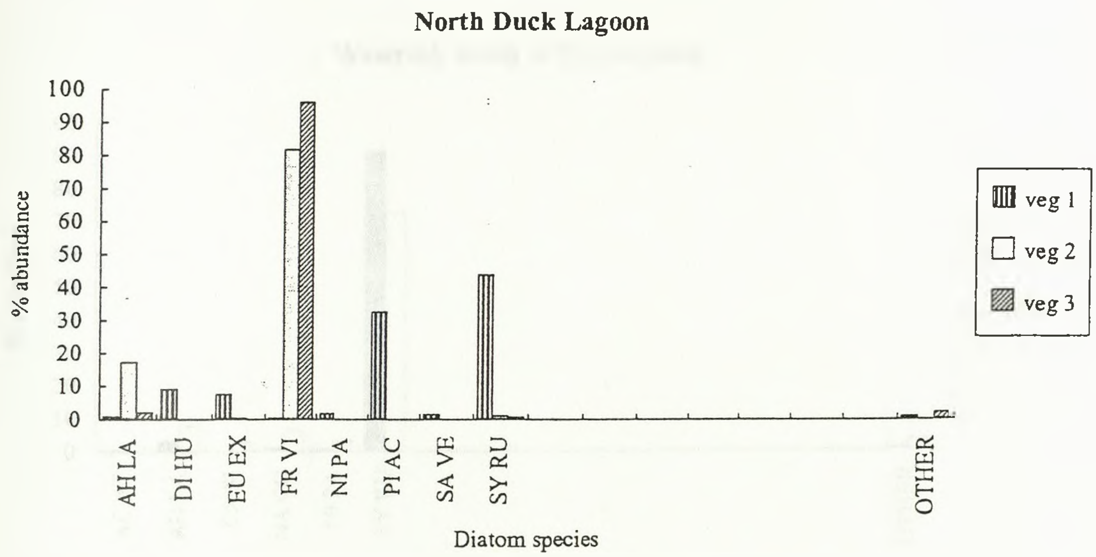
Halfway Hill

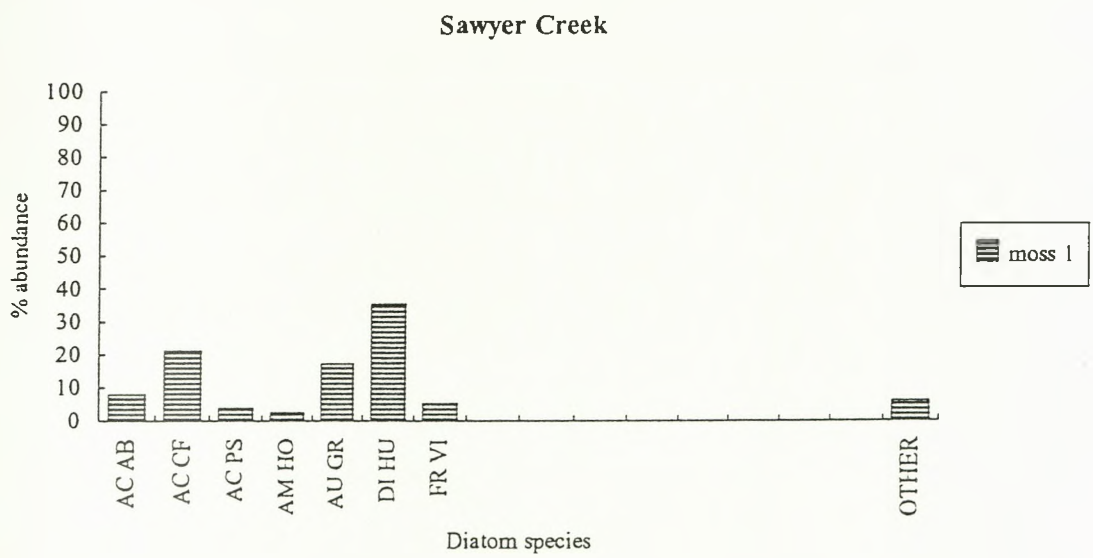


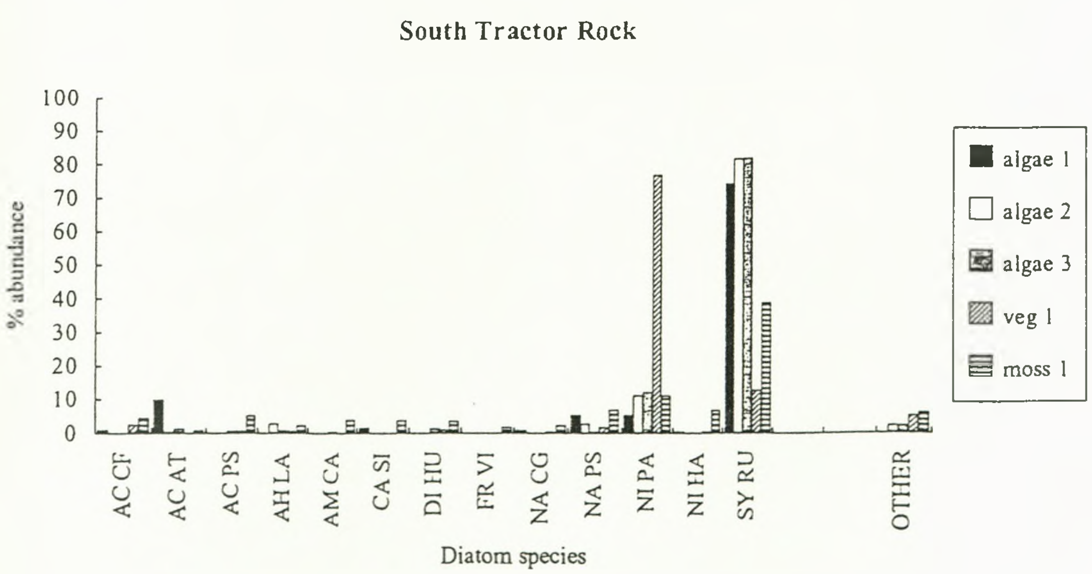

Halfway Hill
100
90
80
70
60
50
40
30
20
10
0
% abundance
AC CF
AC HA
AH LA
AC MI
AM CA
CA SI
CY MI
DI HU
GO AF
NA PS
NI PA
NI GR
RH GI
SP EB
SY RU
OTHER
Diatom species
moss 5
moss 6
moss 7
moss 8

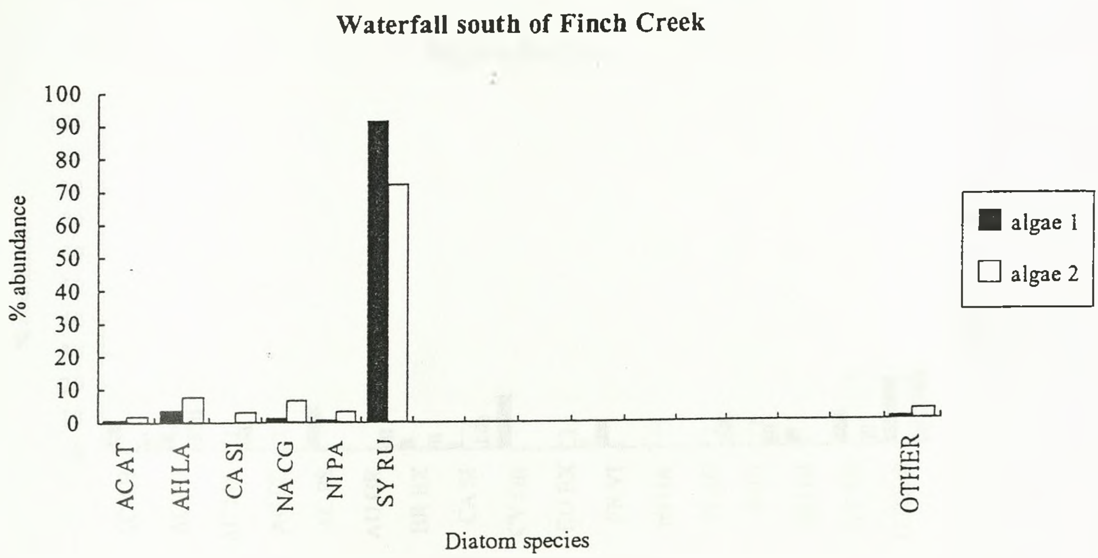

Halfway Hill
100
90
80
70
60
50
40
30
20
10
0
% abundance
AC AB
AC AU
AC CF
AC AT
CA SI
DI HU
GO AF
NA PS
NI PA
SY RU
OTHER
Diatom species
algae 1
algae 2
algae 3
algae 4
algae 5


Lusitania Creek
100
90
80
70
60
50
40
30
20
10
0
% abundance
AC CF
AC PS
AH LA
CA SI
DI HU
FR VI
MA MA
NI PA
PI AC
PI CI
SA CO
SA VE
SA PI
SY RU
OTHER
Diatom species
veg 1

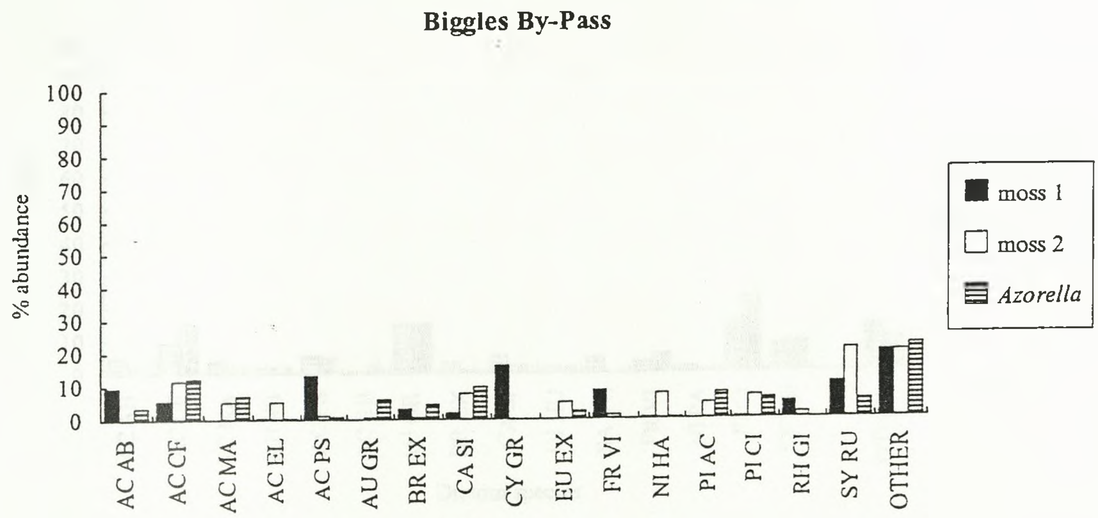

North Duck Lagoon
% abundance
100
90
80
70
60
50
40
30
20
10
0
AH LA
DI HU
EU EX
FR VI
NI PA
PI AC
SA VE
SY RU
OTHER
Diatom species
veg 1
veg 2
veg 3

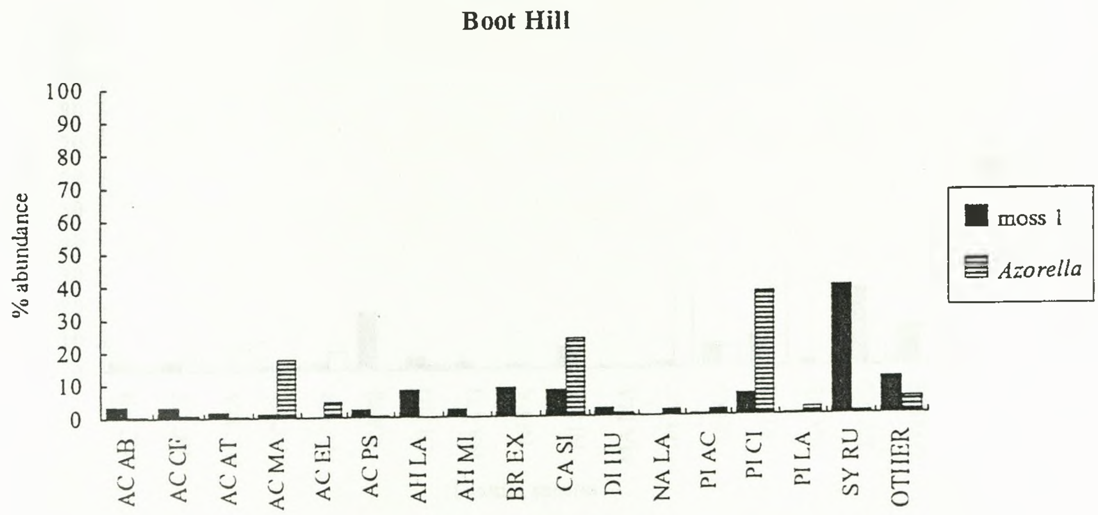

Sawyer Creek
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC AB
AC CF
AC PS
AM HO
AU GR
DI HU
FR VI
OTHER
Diatom species
moss 1

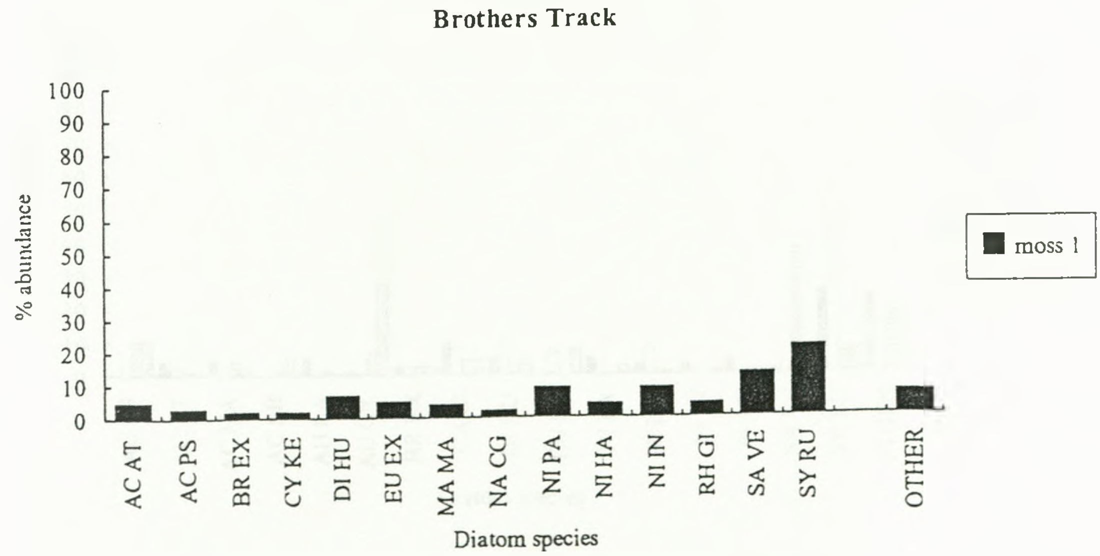

South Tractor Rock
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC CF
AC AT
AC PS
AH LA
AM CA
CA SI
DI HU
FR VI
NA CG
NA PS
NI PA
NI HA
SY RU
OTHER
Diatom species
algae 1
algae 2
algae 3
veg 1
moss 1


Waterfall south of Finch Creek
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC AT
AH LA
CA SI
NA CG
NI PA
SY RU
OTHER
Diatom species
algae 1
algae 2

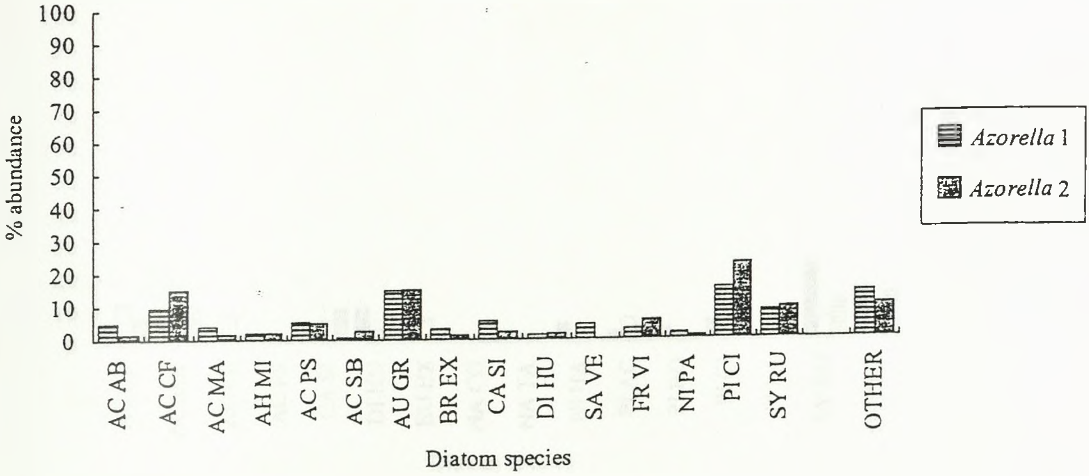
Feldmark Sites



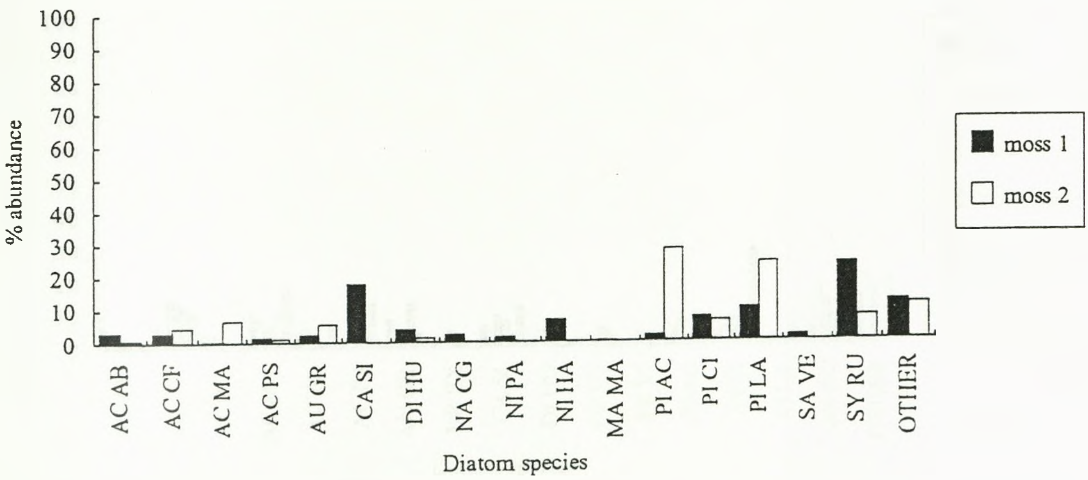




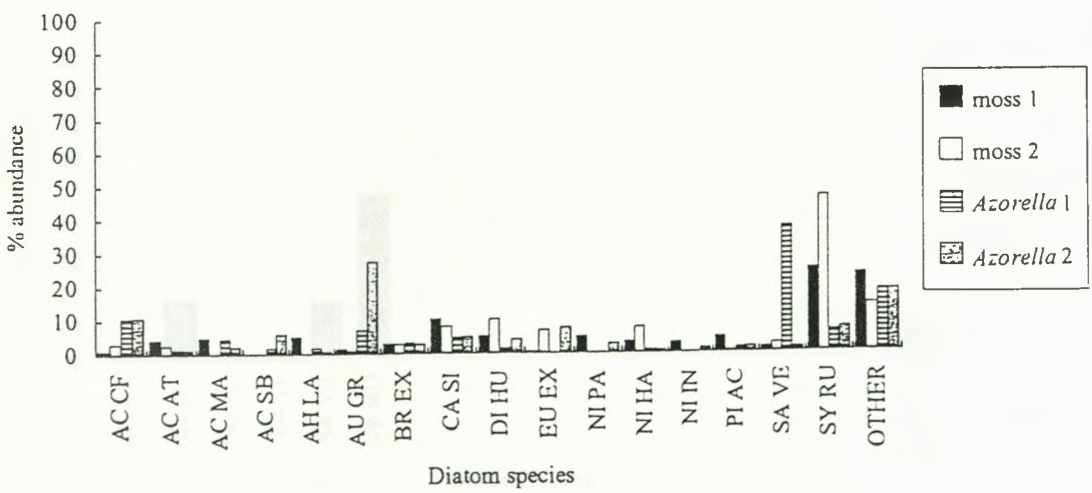
Gadget Dam



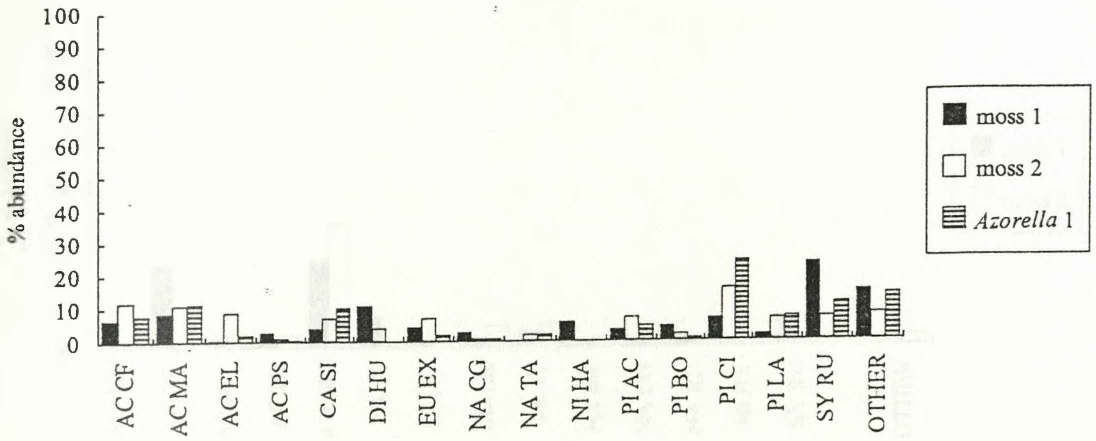
Halfway Hill



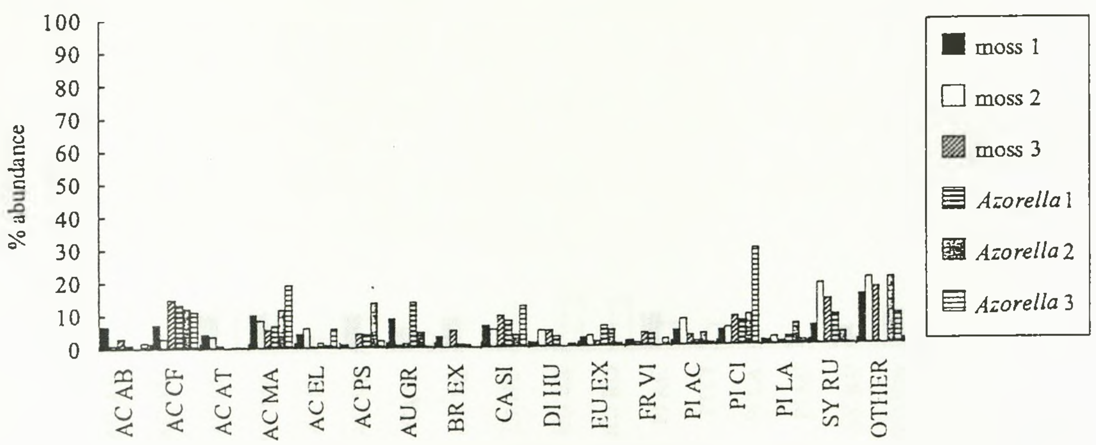
Heartbreak Hill



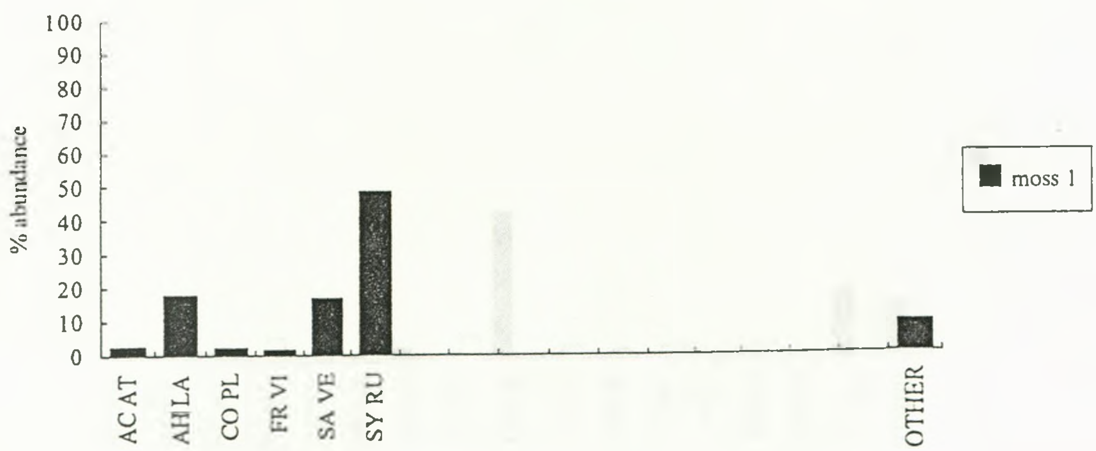
Little Prion Lake

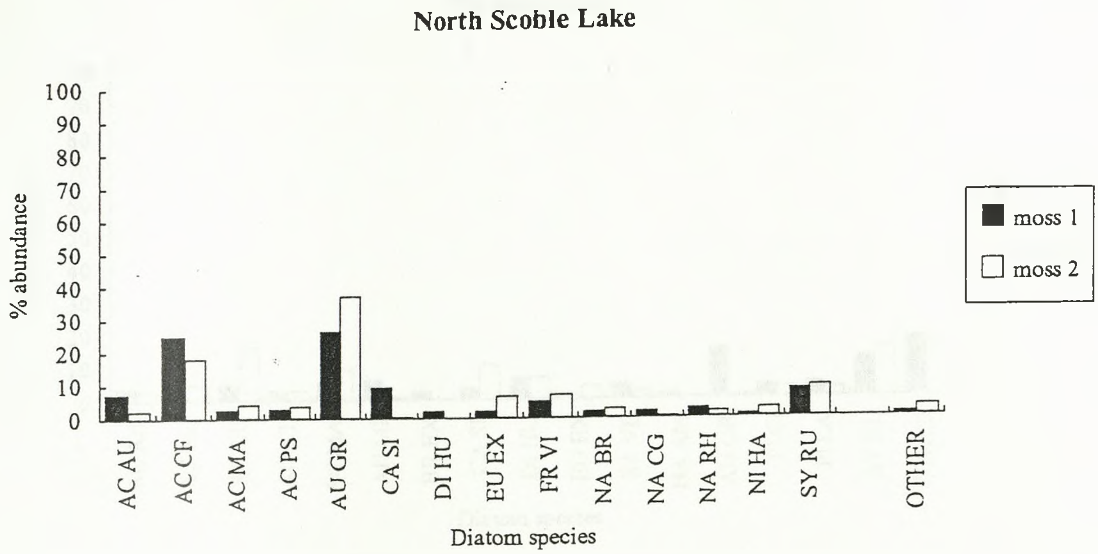


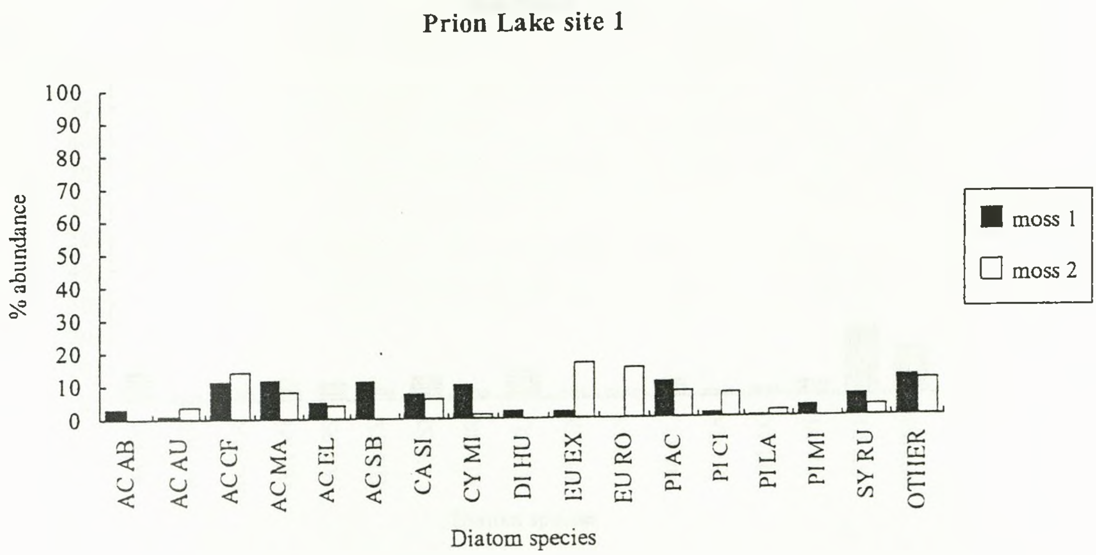
North Mountain

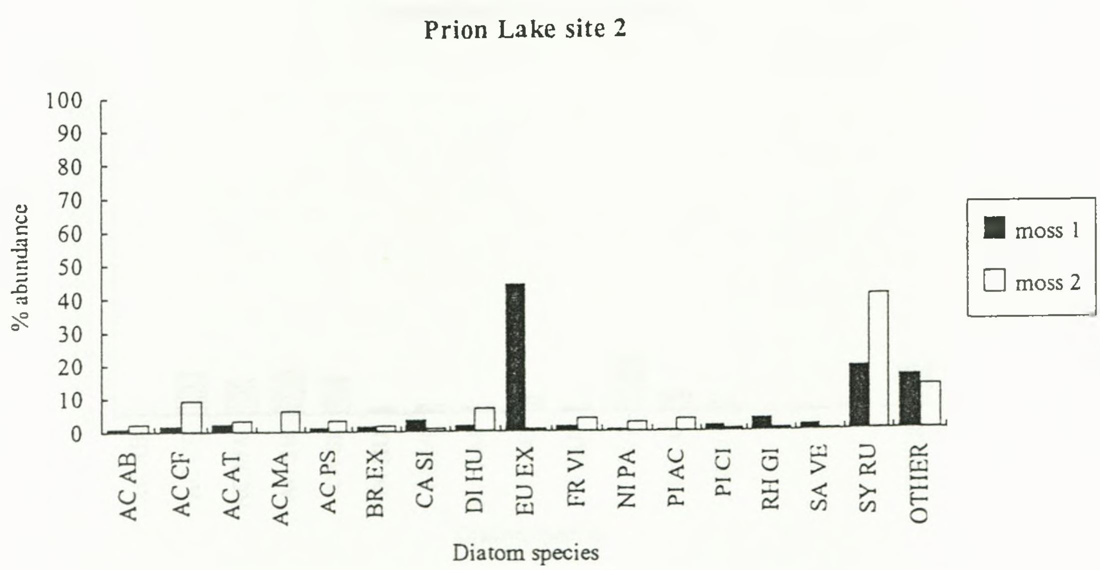


North Brothers Lake

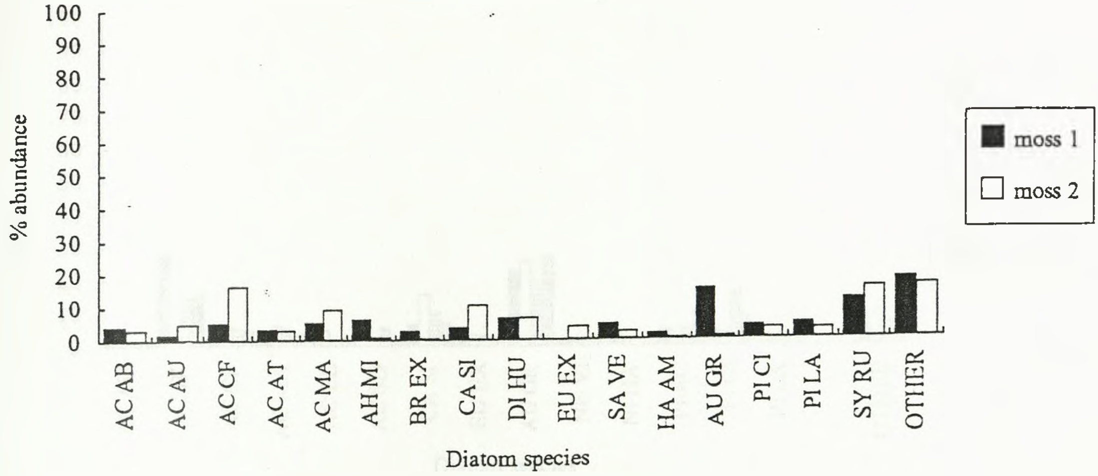



North Scoble Lake
% abundance
100
90
80
70
60
50
40
30
20
10
0
moss 1
moss 2
AC AU
AC CF
AC MA
AC PS
AU GR
CA SI
DI HU
EU EX
FR VI
NA BR
NA CG
NA RH
NI HA
SY RU
OTHER
Diatom species

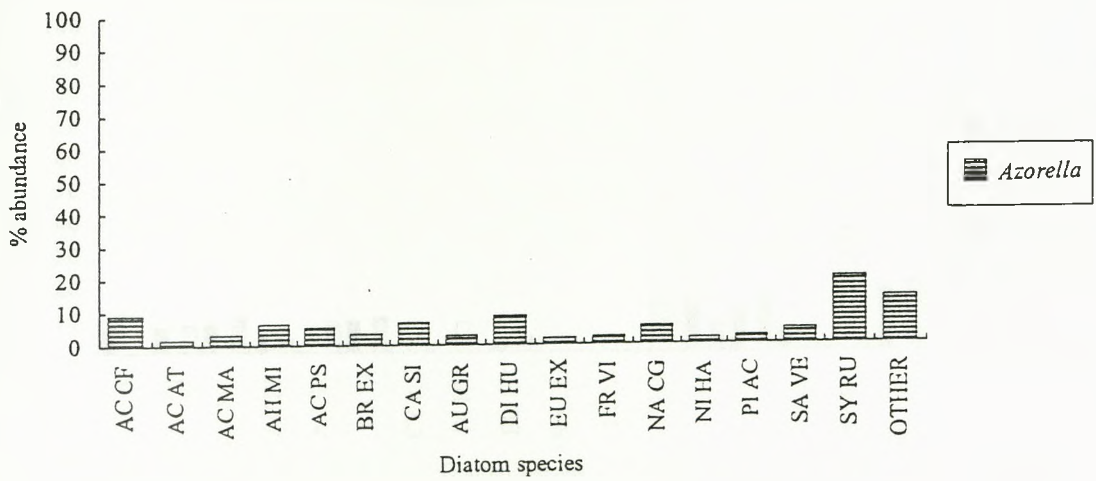

Prion Lake site 1
% abundance
100
90
80
70
60
50
40
30
20
10
0
moss 1
moss 2
AC AB
AC AU
AC CF
AC MA
AC EL
AC SB
CA SI
CY MI
DI HU
EU EX
EU RO
PI AC
PI CI
PI LA
PI MI
SY RU
OTHER
Diatom species


Prion Lake site 2
% abundance
100
90
80
70
60
50
40
30
20
10
0
moss 1
moss 2
AC AB
AC CF
AC AT
AC MA
AC PS
BR EX
CA SI
DI HU
EU EX
FR VI
NI PA
PI AC
PI CI
RH GI
SA VE
SY RU
OTHER
Diatom species

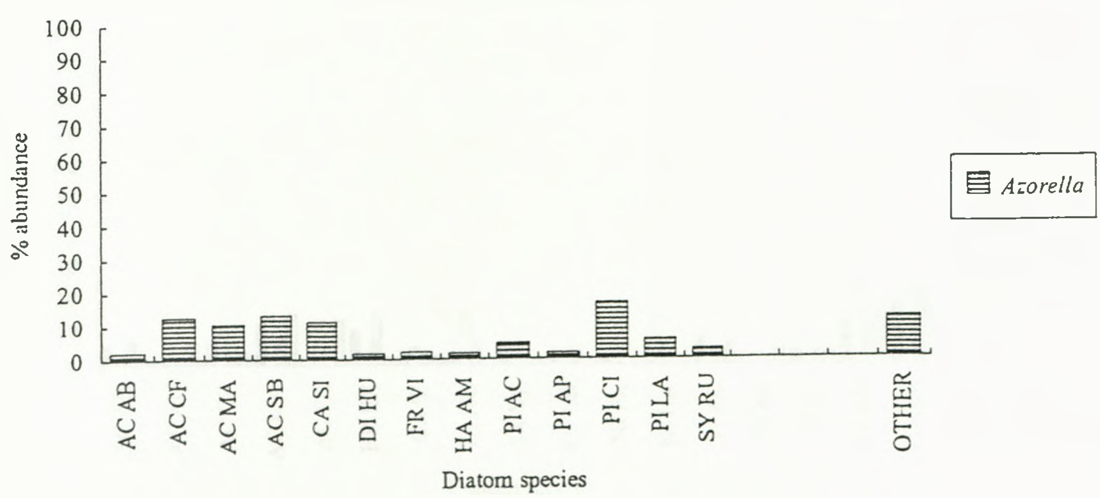
Pyramid Lake



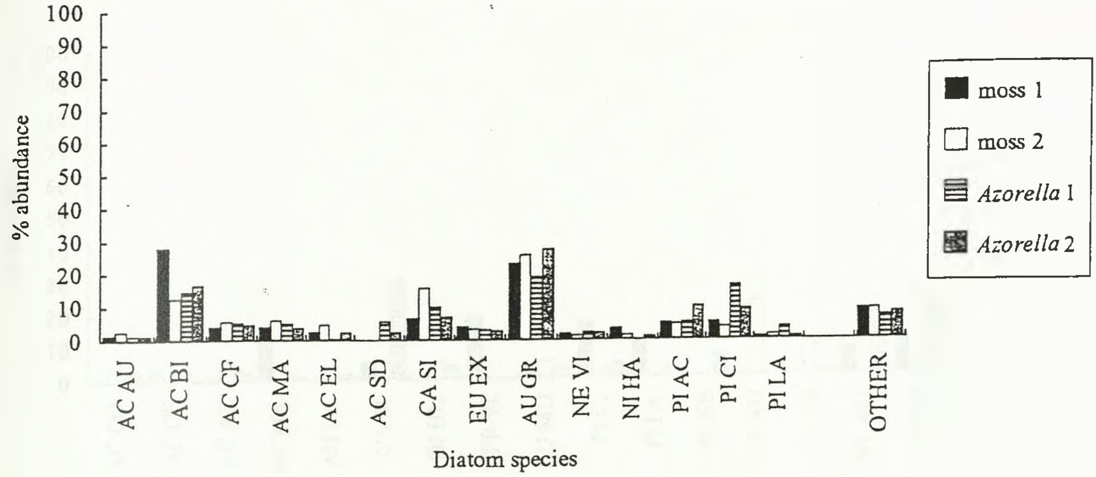
Ess Pond



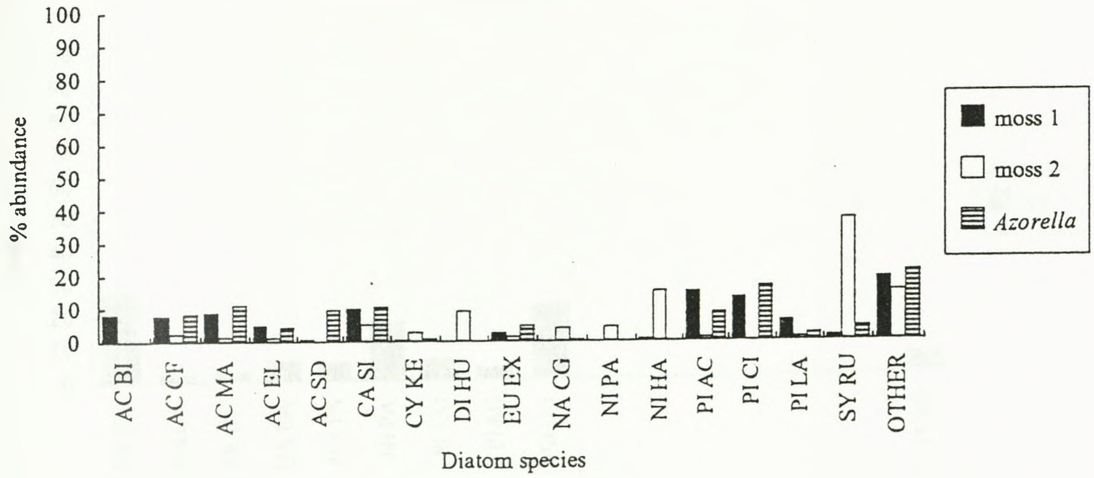
Sandy/Bauer Cross Roads



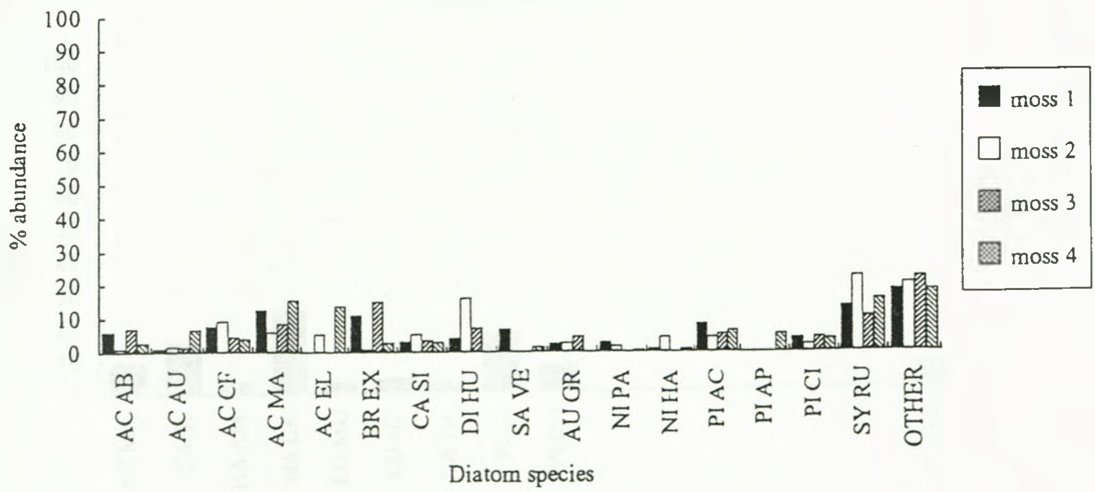
Ski Hut



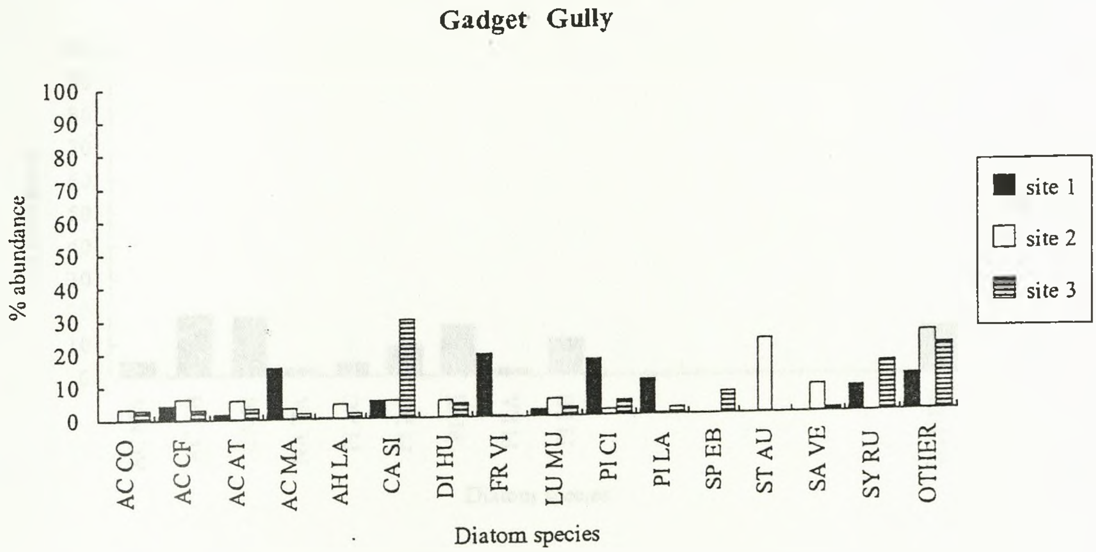
Tulloch Lake South

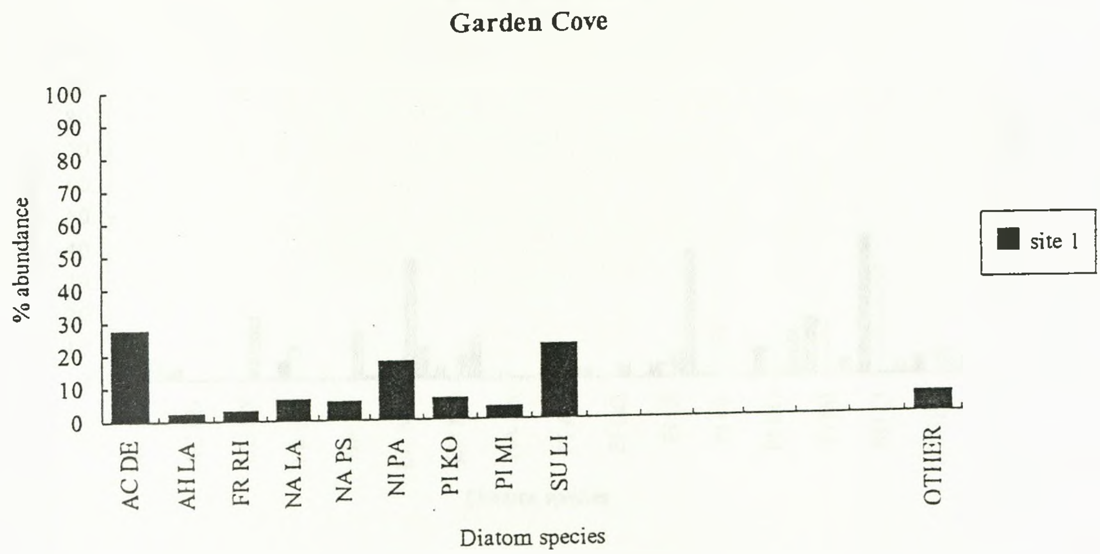


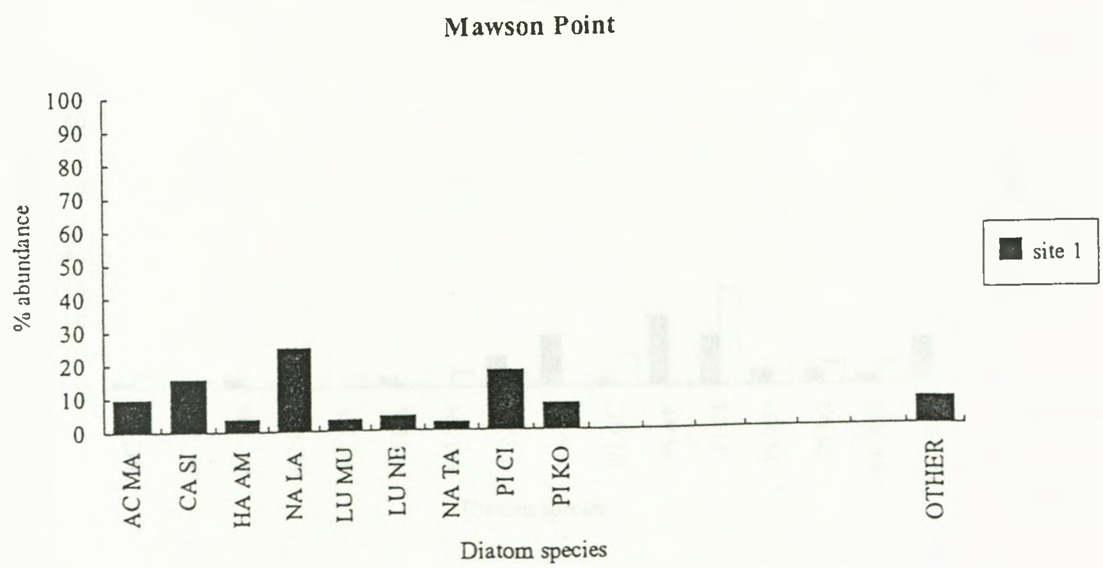
West Scoble Lake



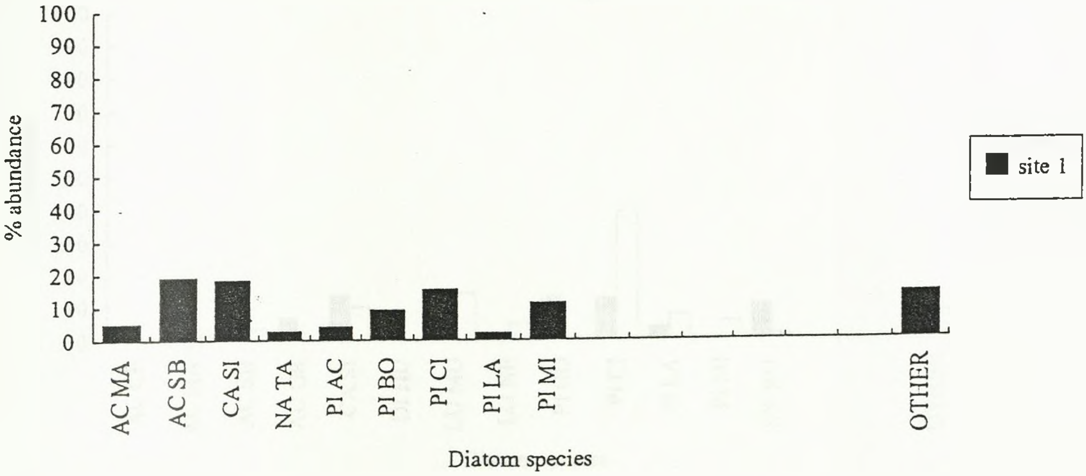
Soil Sites


Gadget Gully
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC CO
AC CF
AC AT
AC MA
AH LA
CA SI
DI HU
FR VI
LU MU
PI CI
PI LA
SP EB
ST AU
SA VE
SY RU
OTHER
Diatom species
site 1
site 2
site 3

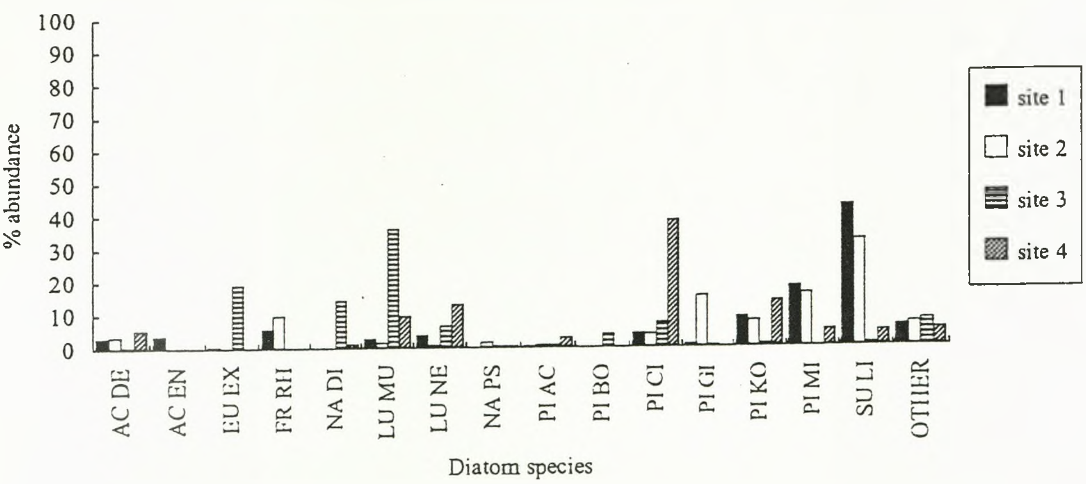

Garden Cove
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC DE
AH LA
FR RH
NA LA
NA PS
NI PA
PI KO
PI MI
SU LI
OTHER
Diatom species
site 1


Mawson Point
% abundance
100
90
80
70
60
50
40
30
20
10
0
AC MA
CA SI
HA AM
NA LA
LU MU
LU NE
NA TA
PI CI
PI KO
OTHER
Diatom species
site 1

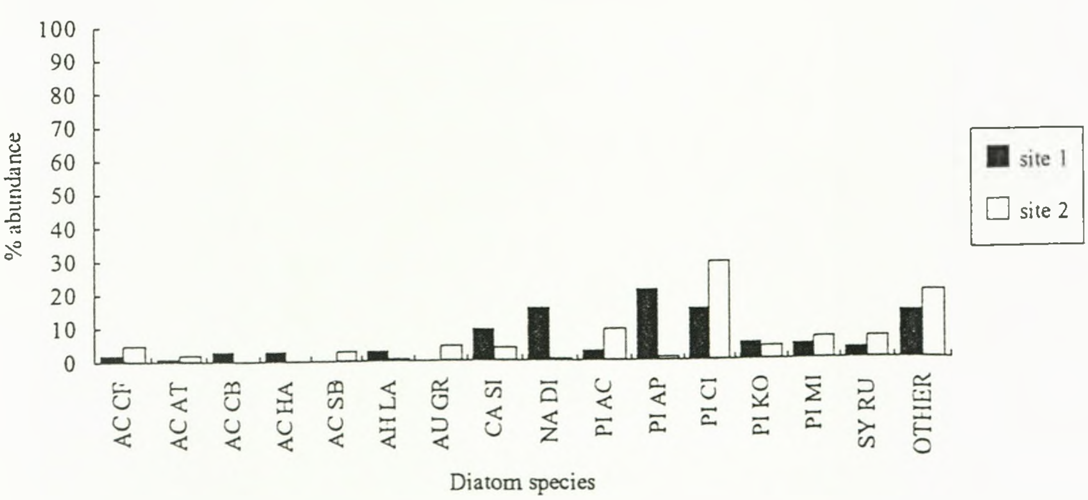
North Mountain

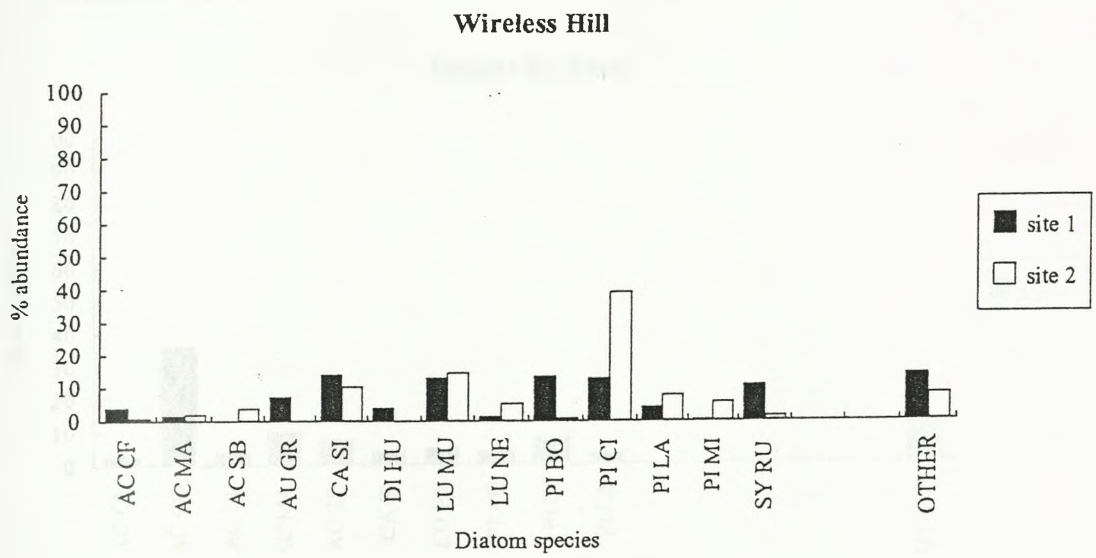


Razorback East

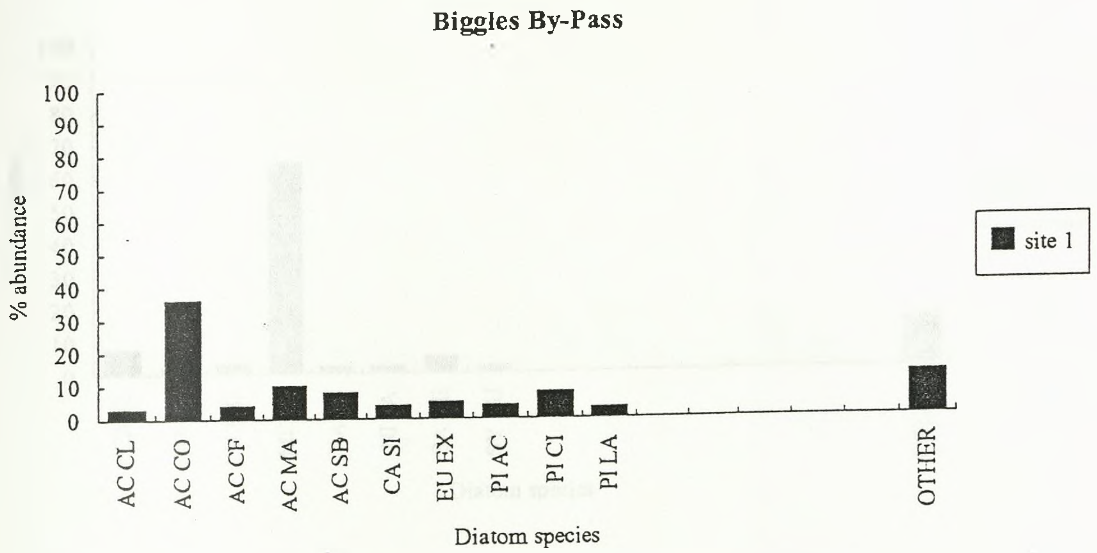


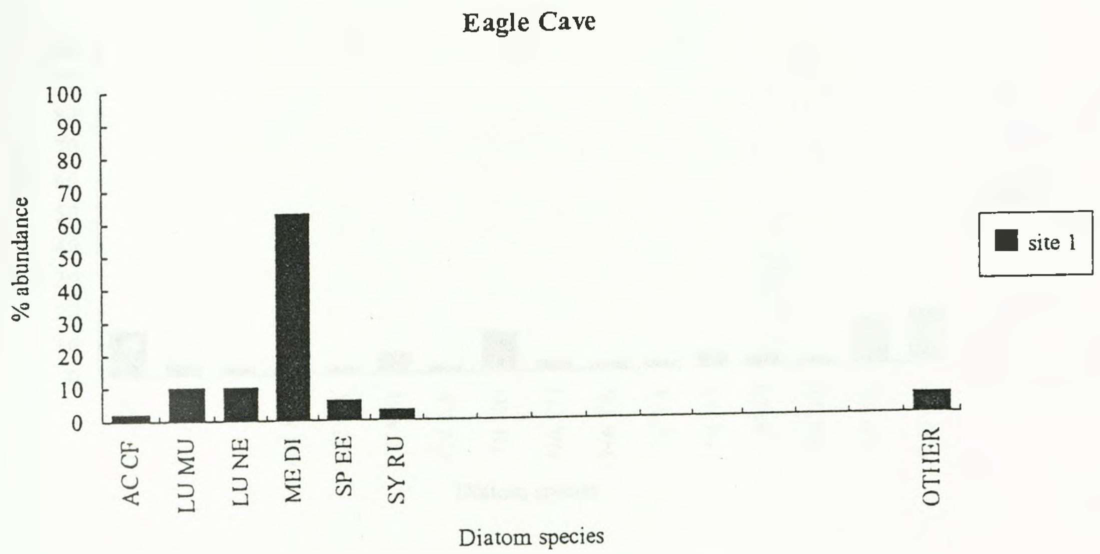
Sandy Bay

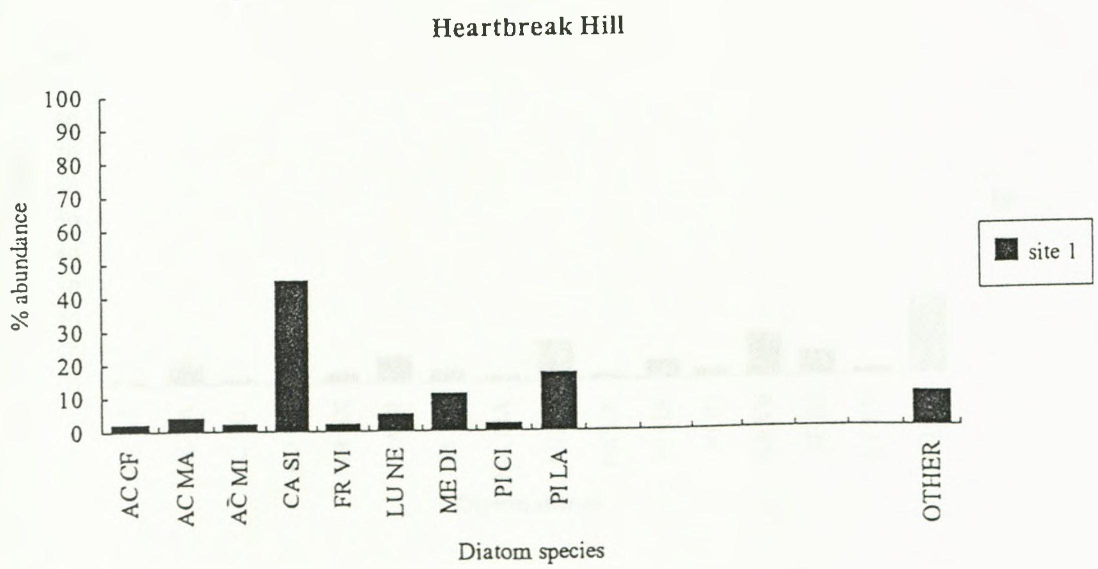



Wireless Hill
% abundance
100
90
80
70
60
50
40
30
20
10
0
site 1
site 2
AC CF
AC MA
AC SB
AU GR
CA SI
DI HU
LU MU
LU NE
PI BO
PI CI
PI LA
PI MI
SY RU
OTHER
Diatom species

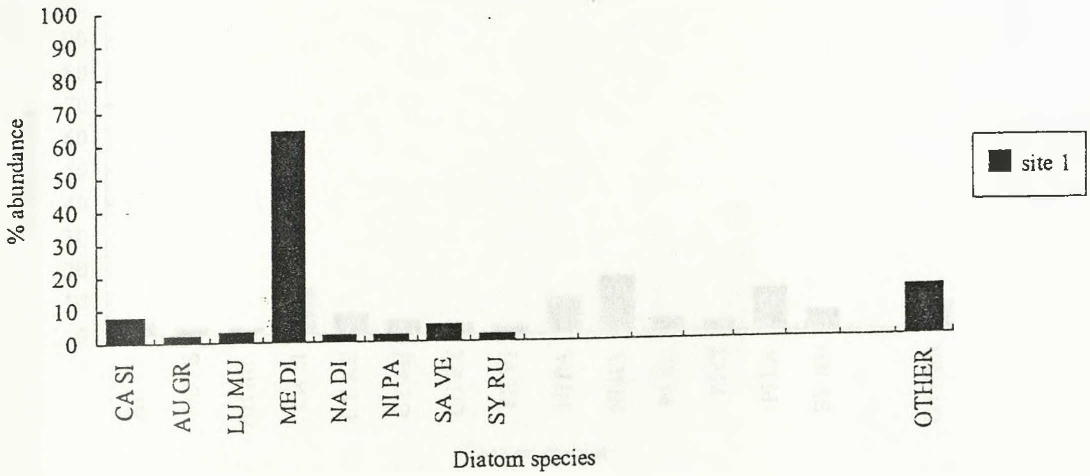
Lichen Sites



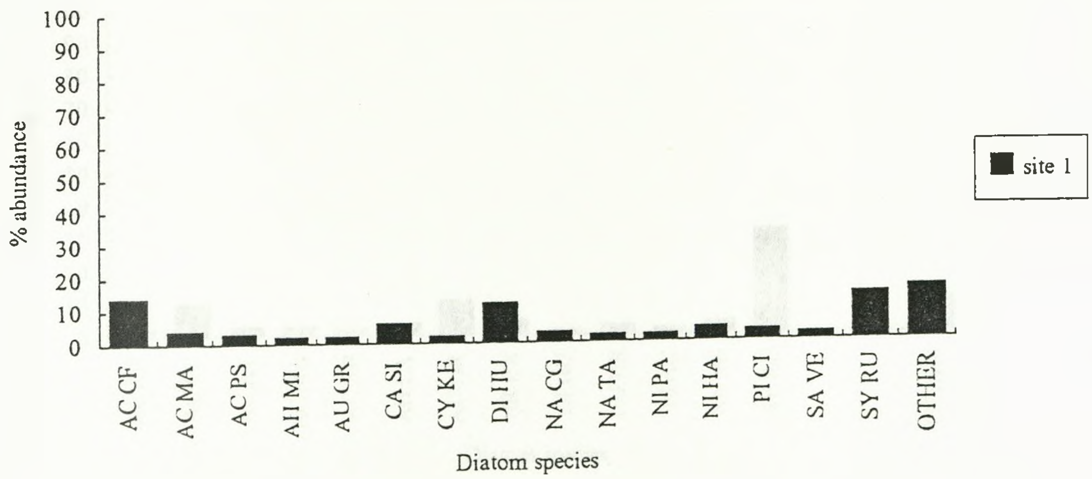




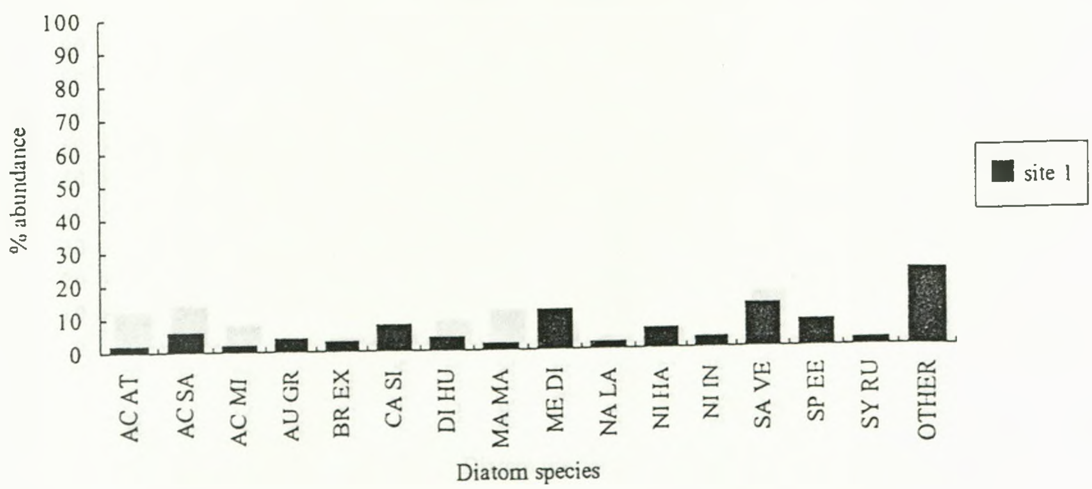
Handspike Pool

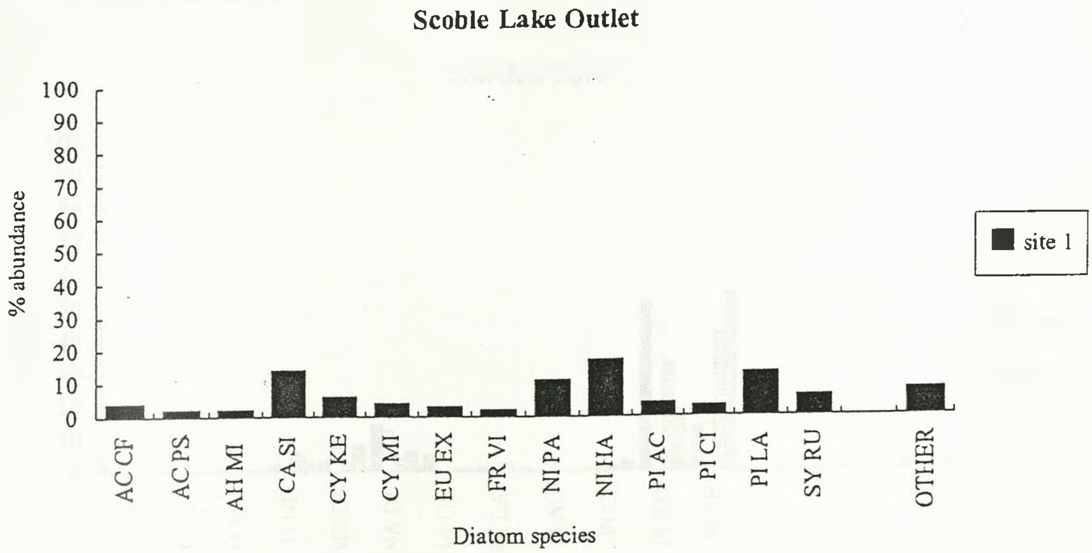


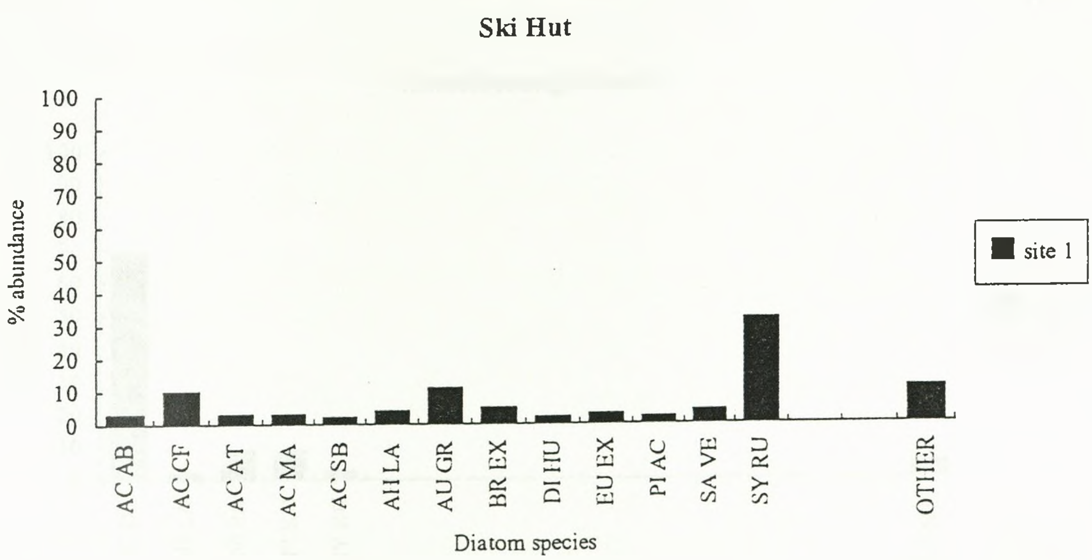
Handspike Point

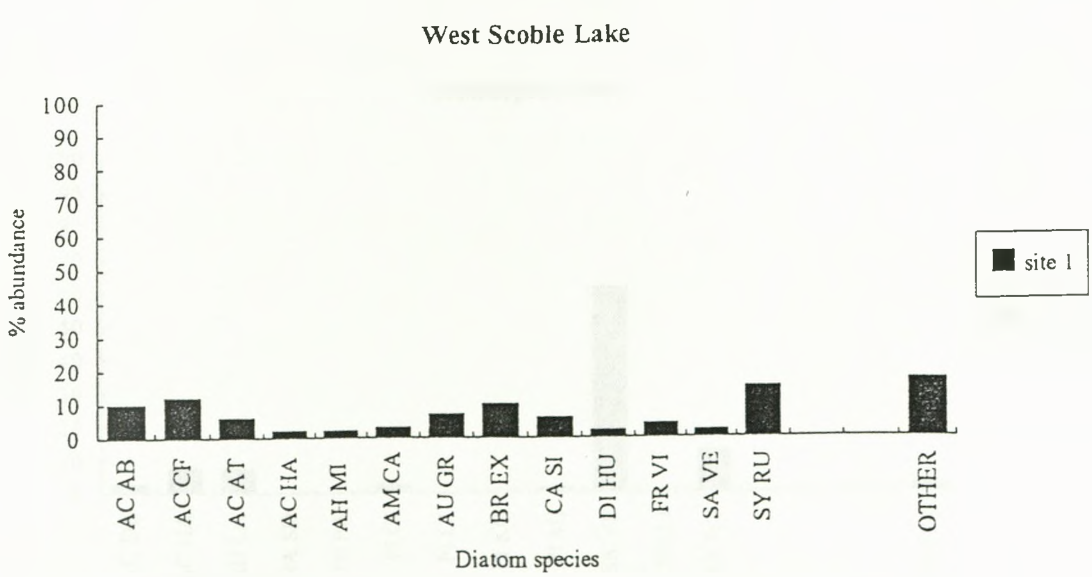


Mawson Point



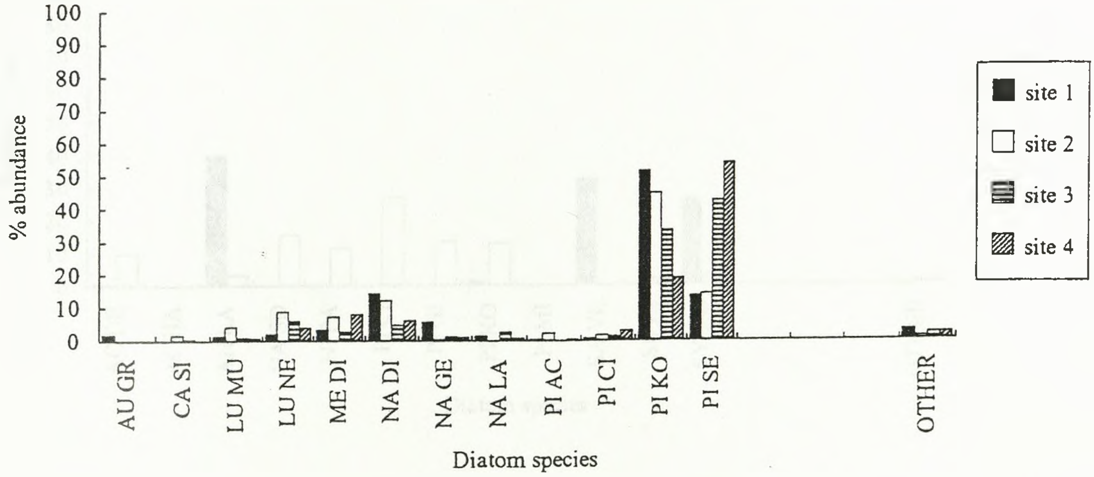

Scoble Lake Outlet
100
90
80
70
60
50
40
30
20
10
0
% abundance
site 1
AC CF
AC PS
AH MI
CA SI
CY KE
CY MI
EU EX
FR VI
NI PA
NI HA
PI AC
PI CI
PI LA
SY RU
OTHER
Diatom species


Ski Hut
100
90
80
70
60
50
40
30
20
10
0
% abundance
site 1
AC AB
AC CF
AC AT
AC MA
AC SB
AH LA
AU GR
BR EX
DI HU
EU EX
PI AC
SA VE
SY RU
OTHER
Diatom species

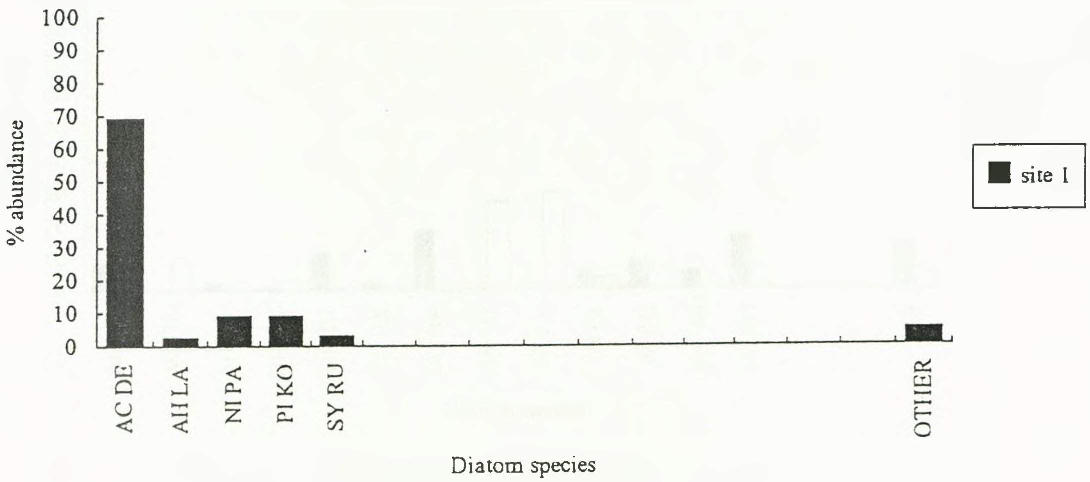

West Scoble Lake
100
90
80
70
60
50
40
30
20
10
0
% abundance
site 1
AC AB
AC CF
AC AT
AC HA
AH MI
AM CA
AU GR
BR EX
CA SI
DI HU
FR VI
SA VE
SY RU
OTHER
Diatom species

Penguin Sites

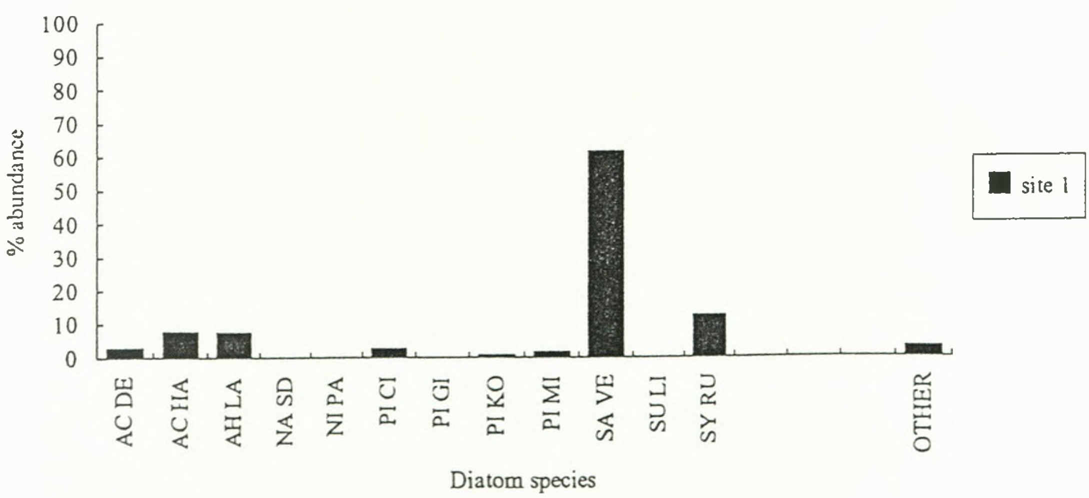
Garden Cove



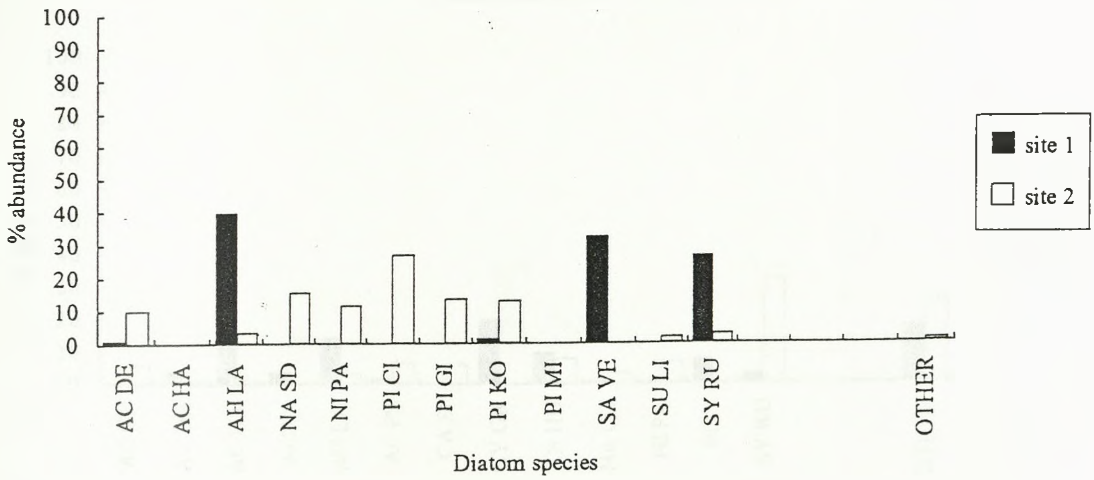
Hasselborough Beach



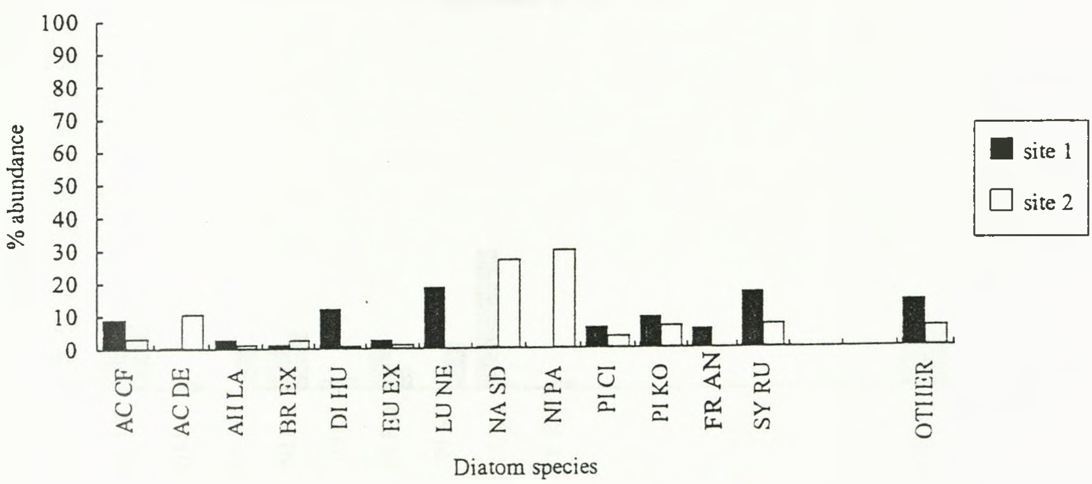
Handspike Pool



The Nuggets

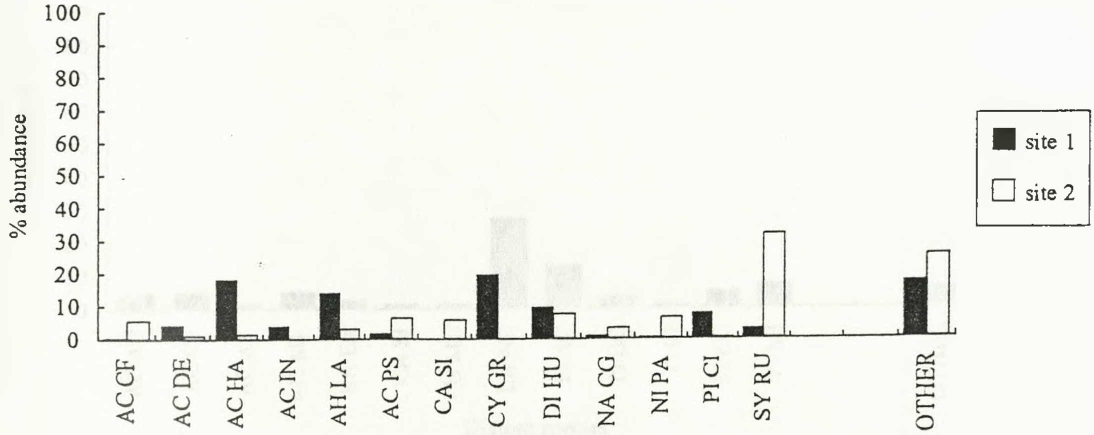


Sandy Bay

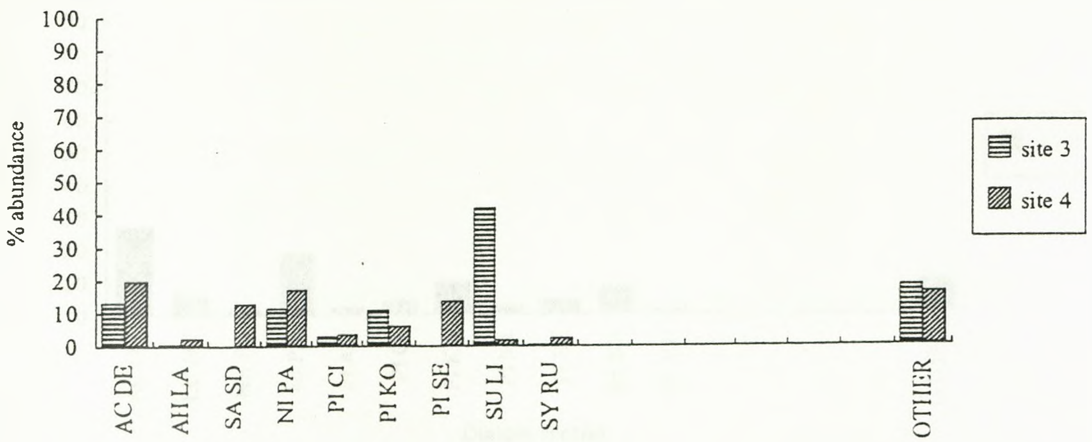


Wallow Sites

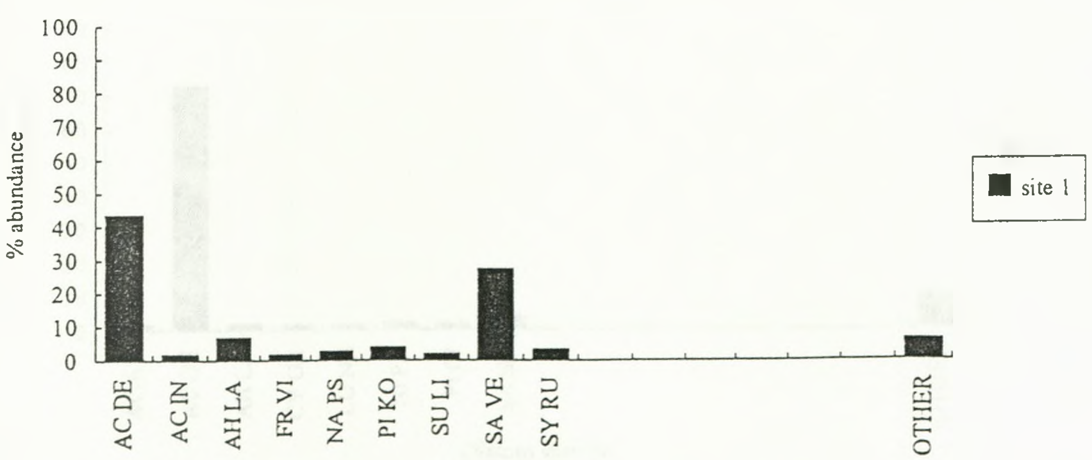
Garden Cove

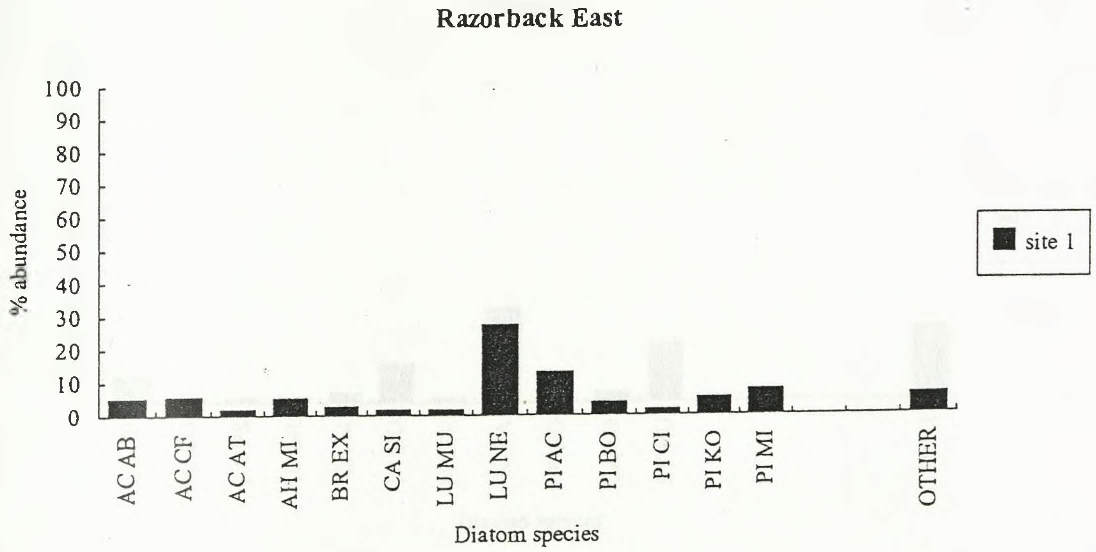


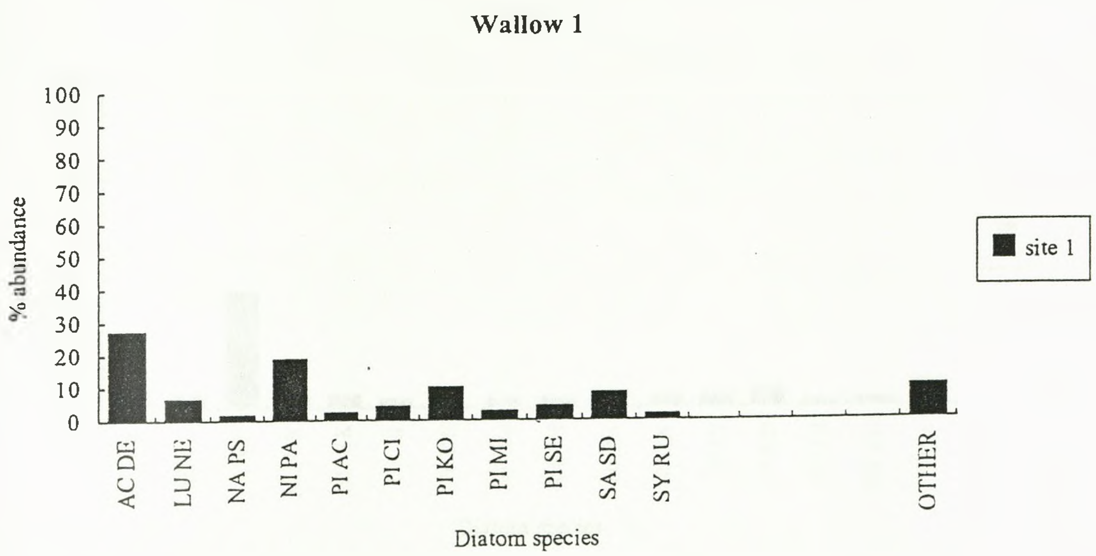
Garden Cove

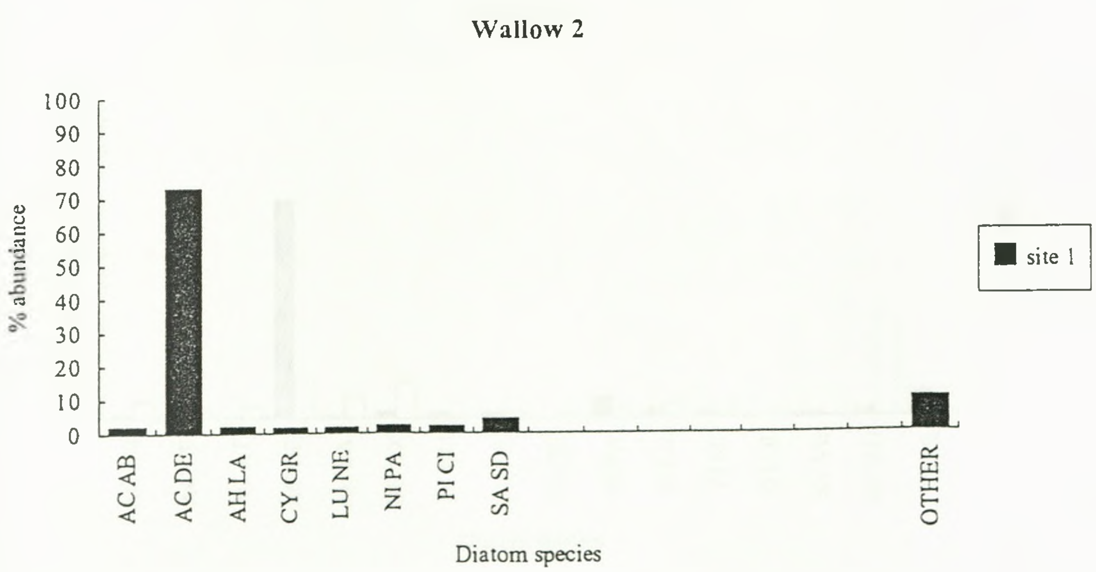


Handspike Corner

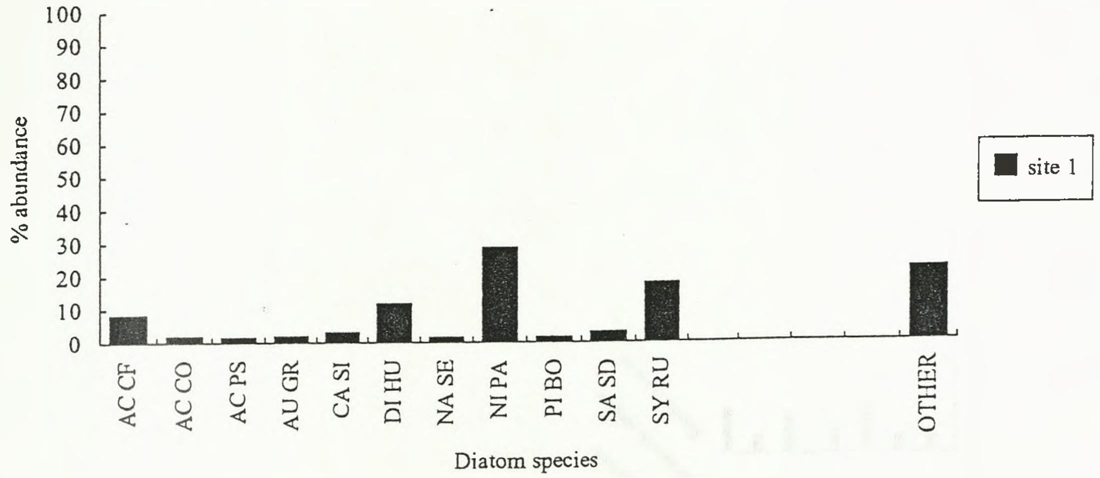



Razorback East
100
90
80
70
60
50
40
30
20
10
0
% abundance
site 1
AC AB
AC CF
AC AT
AH MI
BR EX
CA SI
LU MU
LU NE
PI AC
PI BO
PI CI
PI KO
PI MI
OTHER
Diatom species

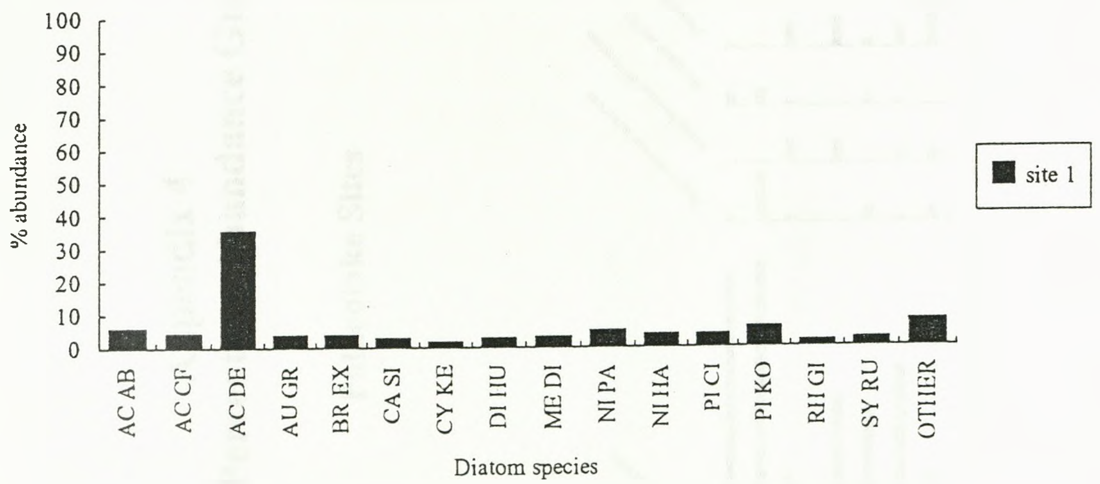

Wallow 1
100
90
80
70
60
50
40
30
20
10
0
% abundance
site 1
AC DE
LU NE
NA PS
NI PA
PI AC
PI CI
PI KO
PI MI
PI SE
SA SD
SY RU
OTHER
Diatom species


Wallow 2
100
90
80
70
60
50
40
30
20
10
0
% abundance
site 1
AC AB
AC DE
AH LA
CY GR
LU NE
NI PA
PI CI
SA SD
OTHER
Diatom species

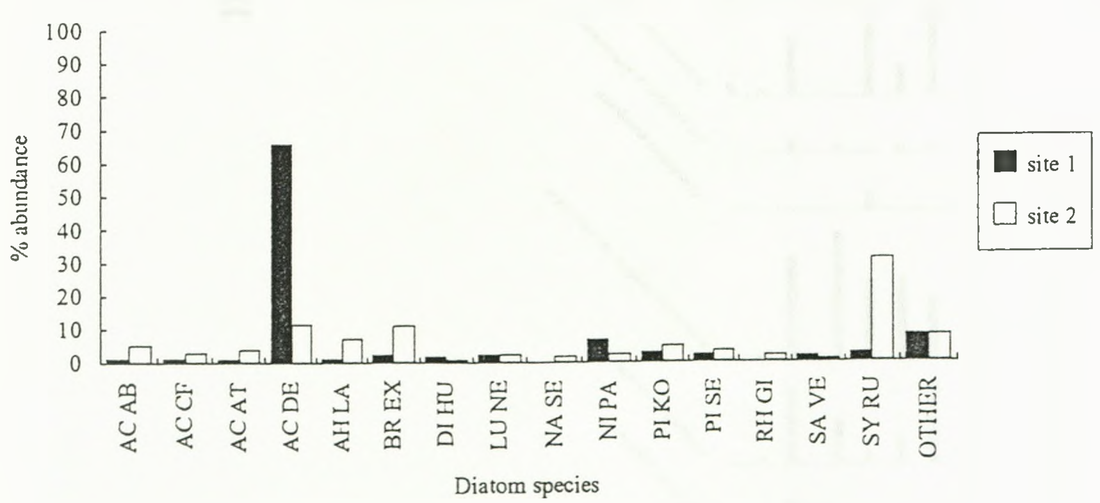
Wallow 3



Wallow 4

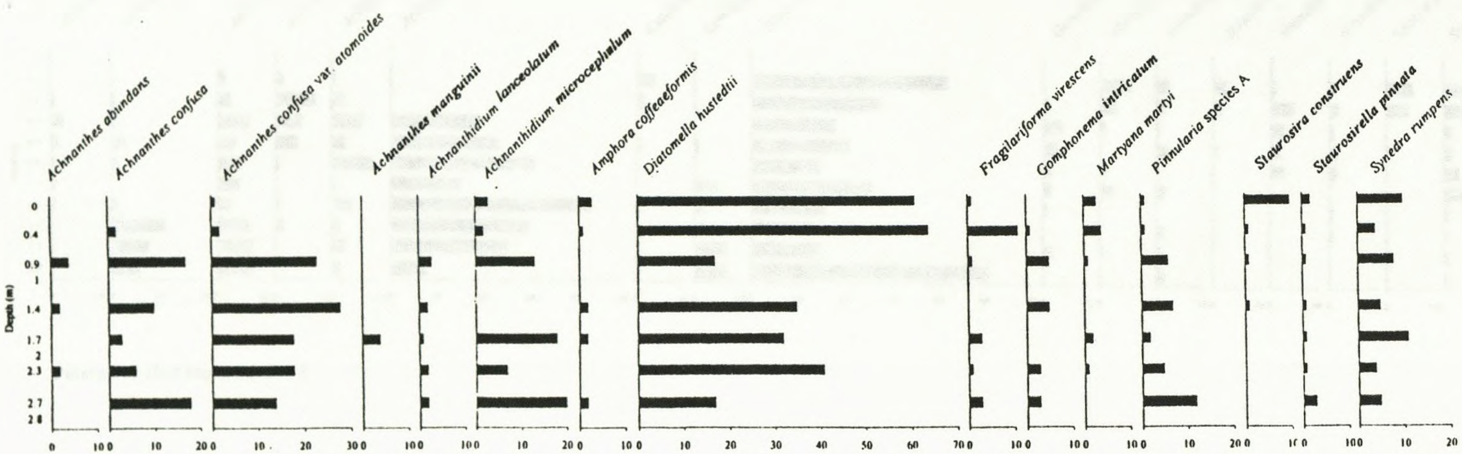


Wallow 5

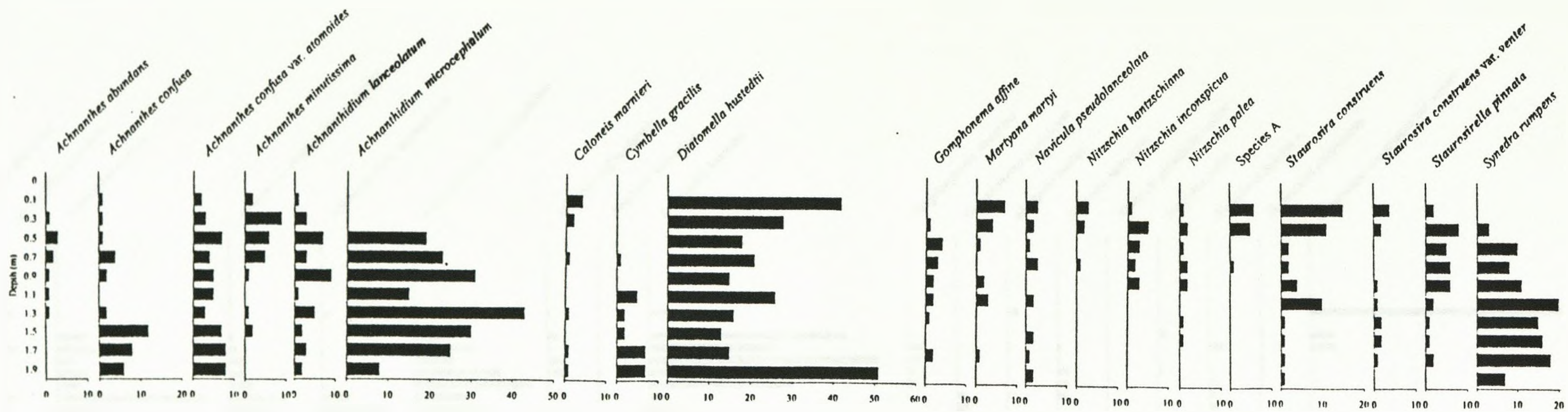


Appendix 4
Diatom Percentage Abundance Graphs

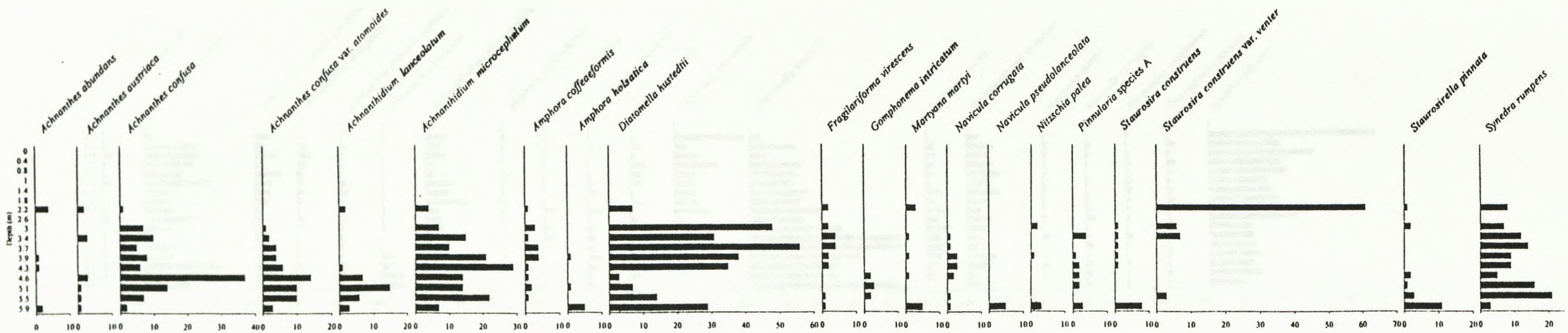
Palaeolake Sites



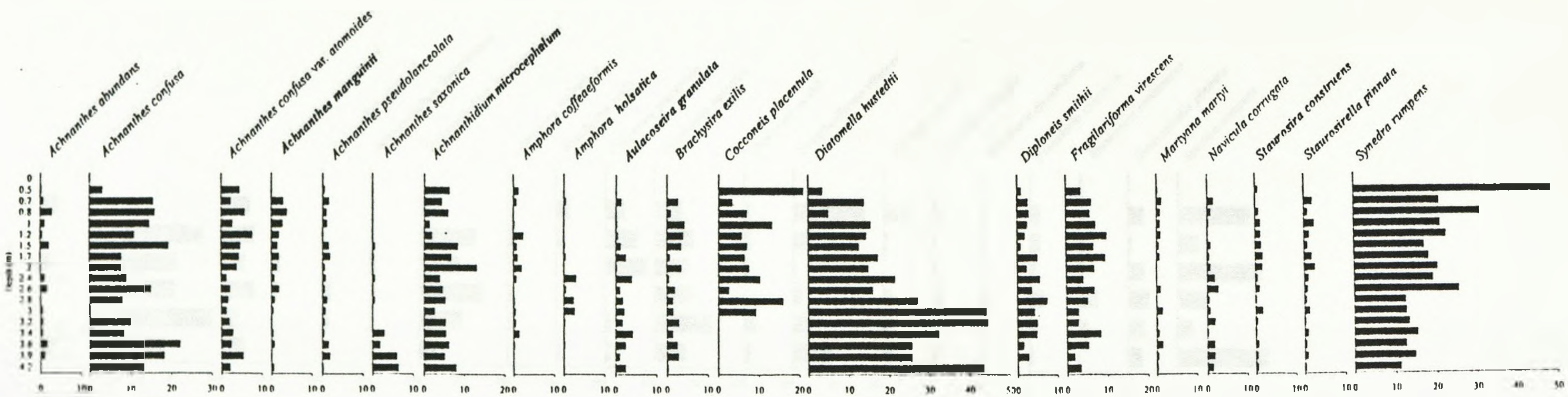
Palaeolake Half Moon Section 1



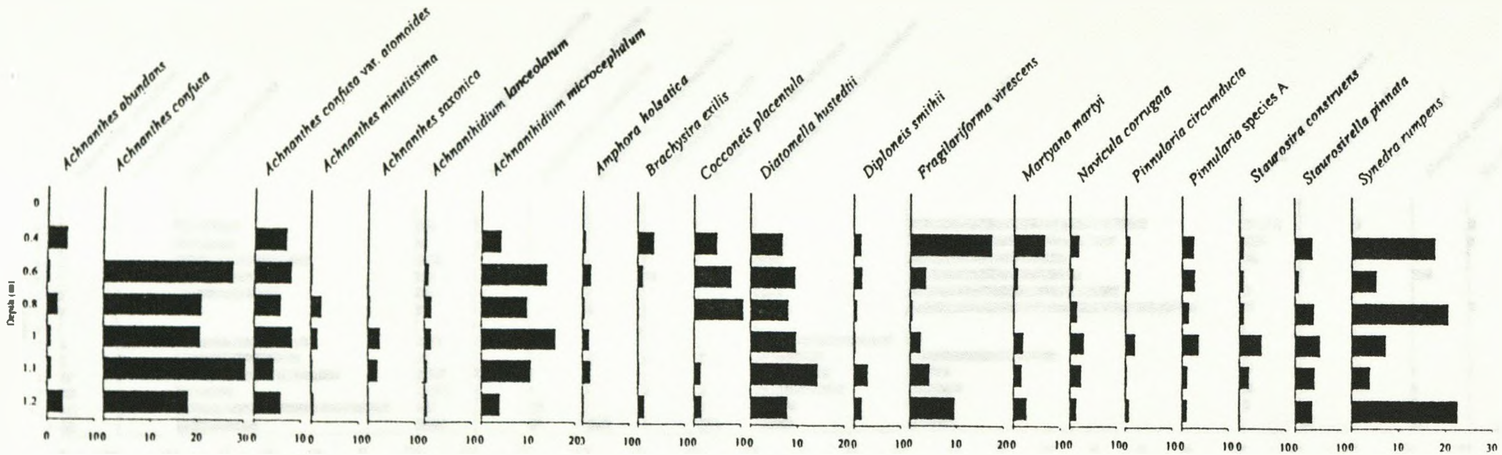
Palaeolake Half Moon Section 2



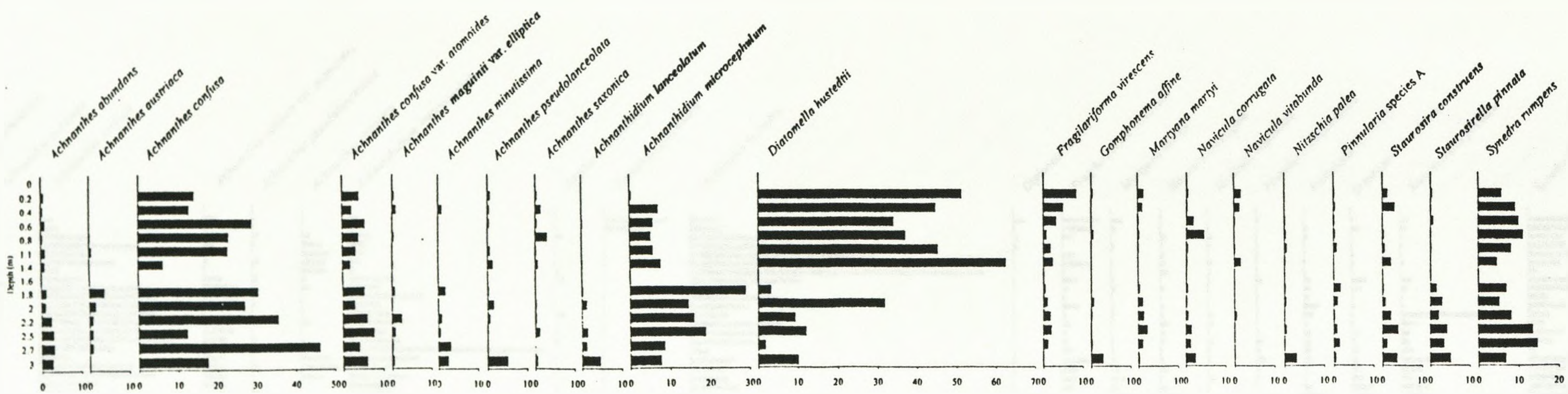
Palaeolake Half Moon Section 3



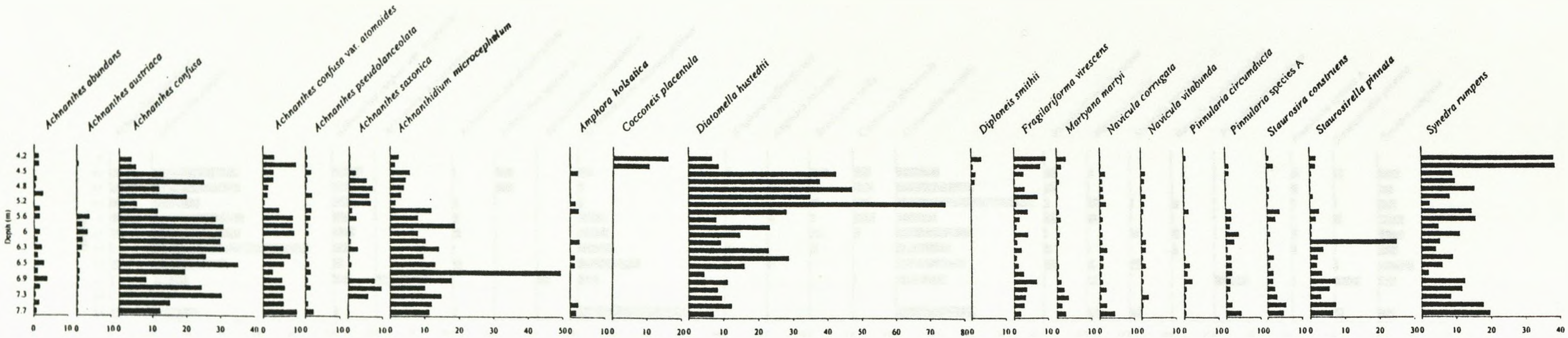
Palaeolake Cascade Section 1



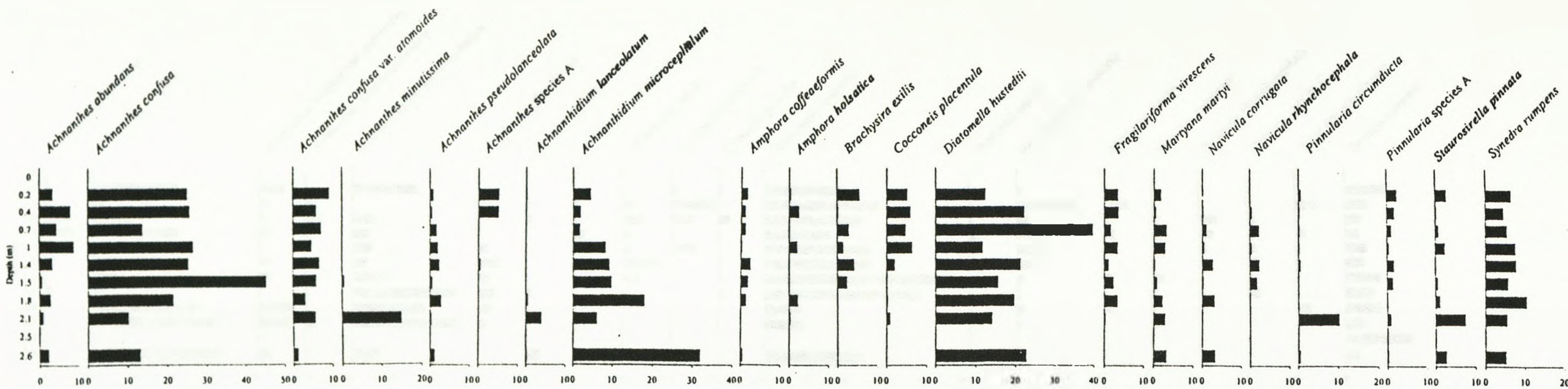
Palaeolake Cascade Section 2



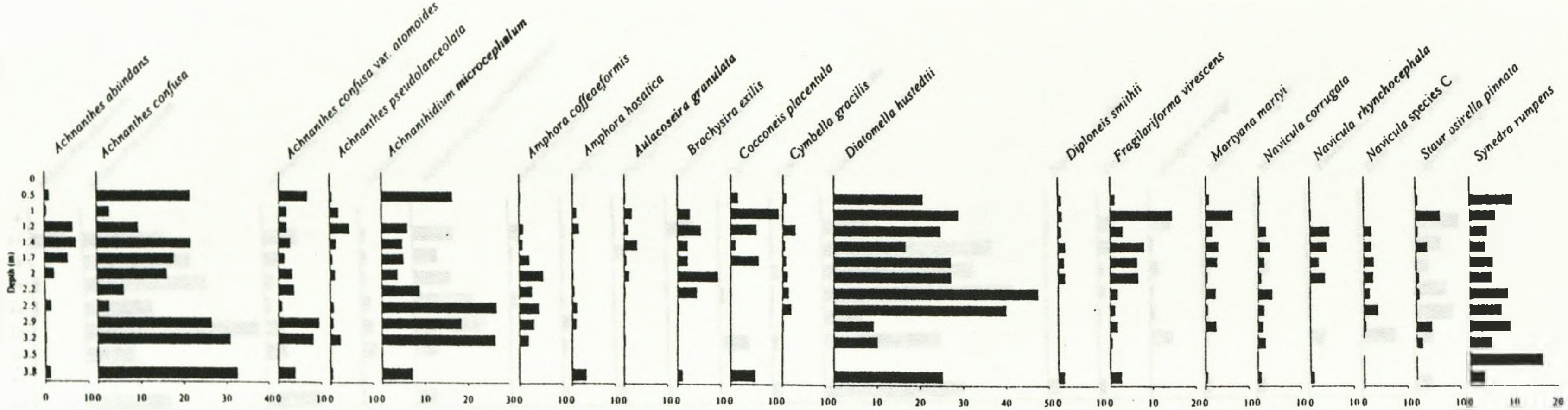
Palaeolake Cascade Section 3



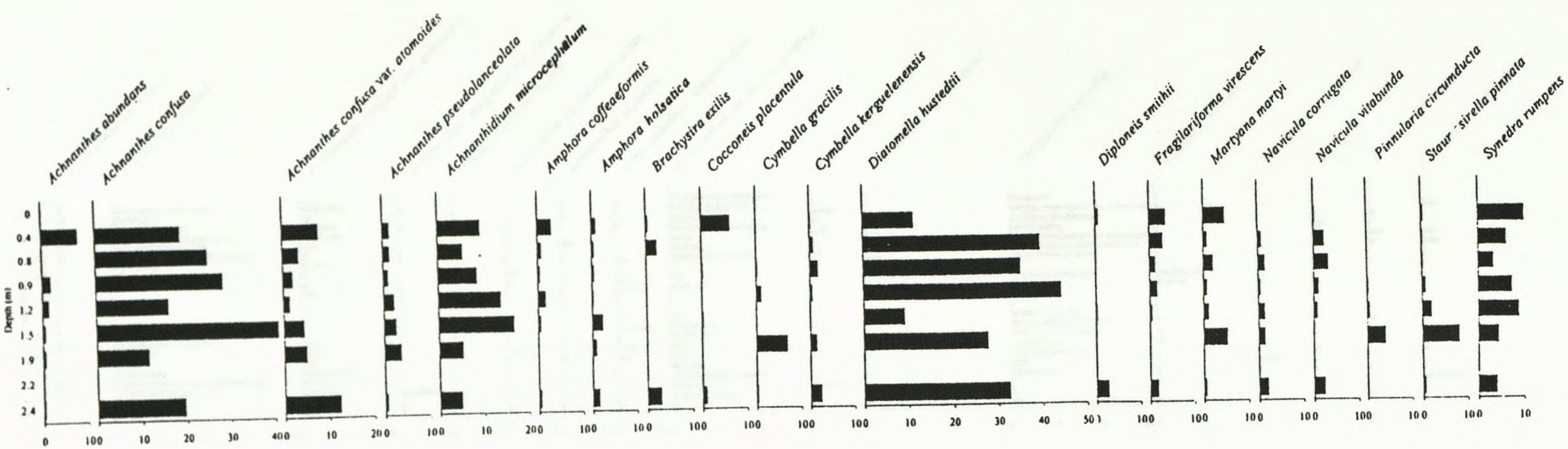
Palaeolake Cascade Section 4



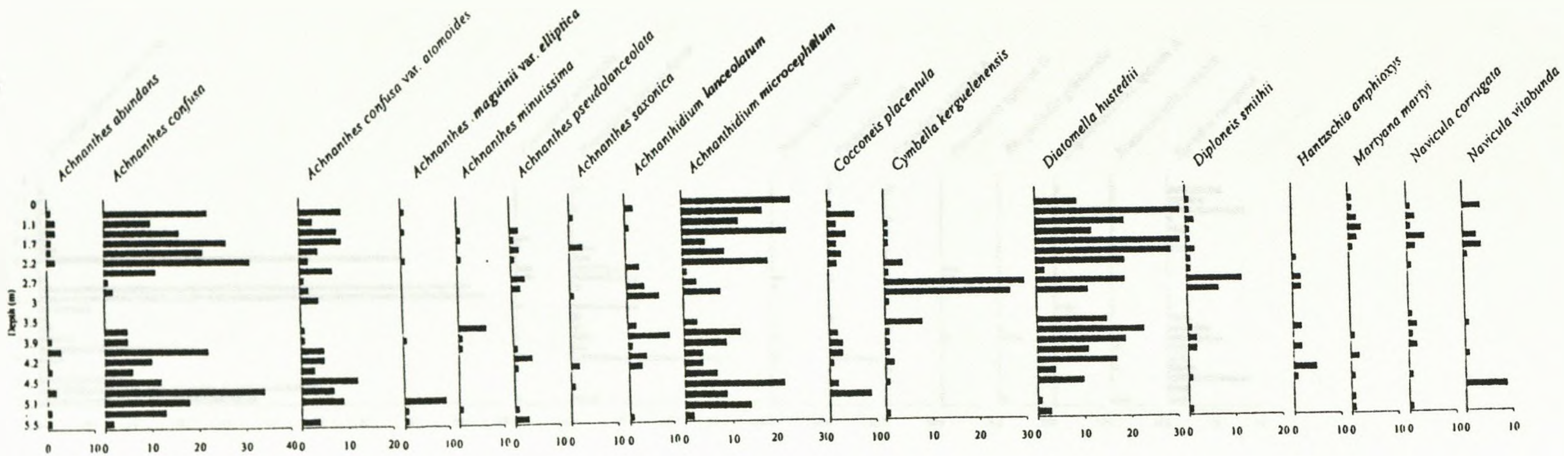
Palaeolake Eagle Section 1



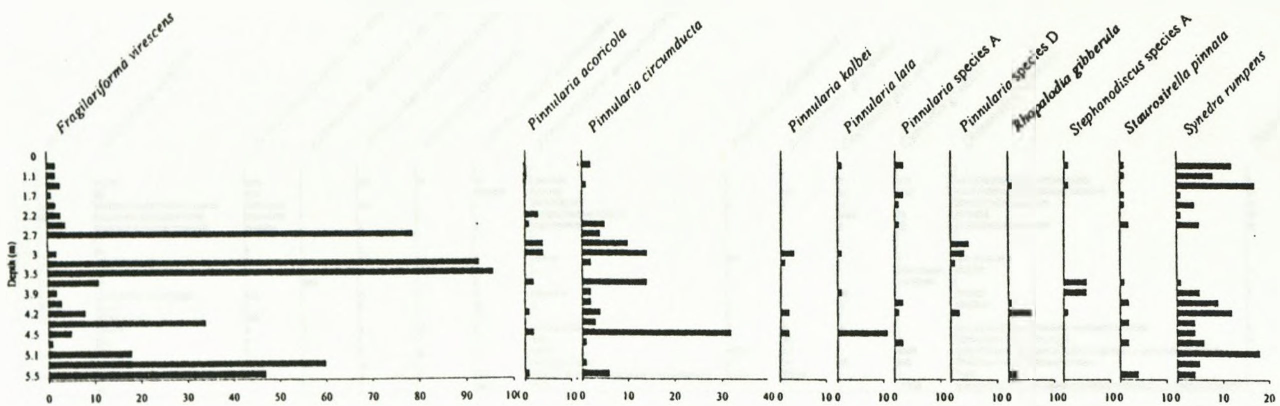
Palaeolake Eagle Section 2



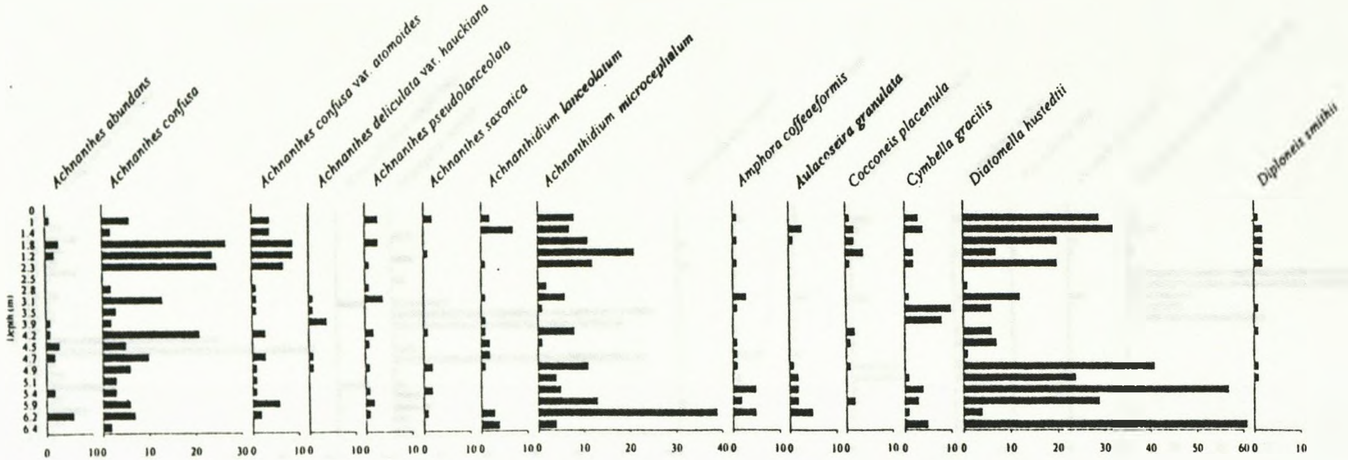
Palaeolake Eagle Section 3



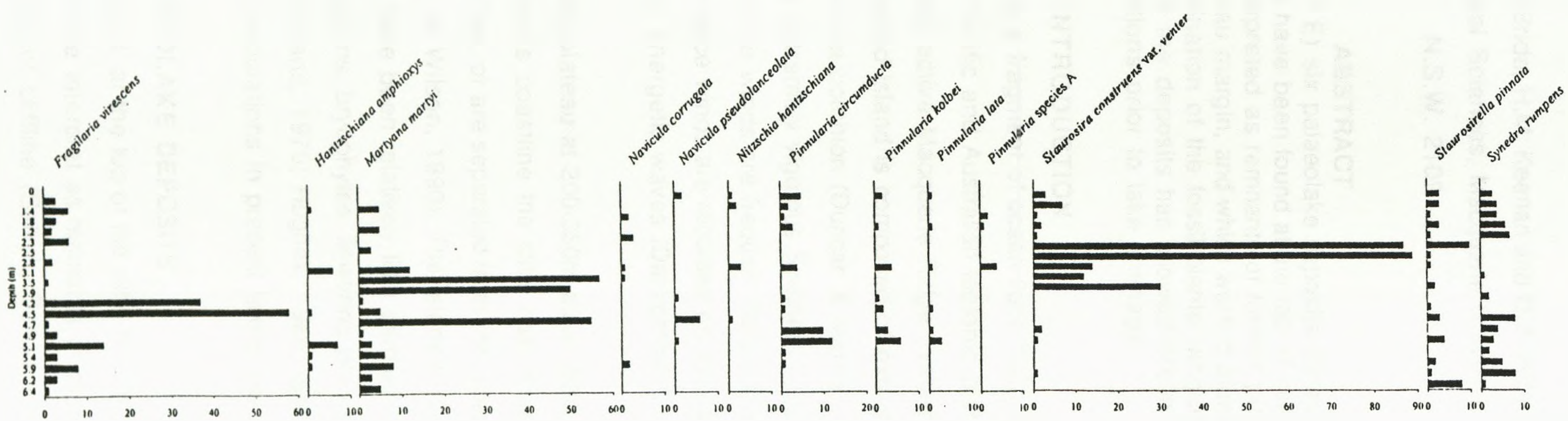
Paleolake Emerald Section 1



Paleolake Emerald Section 1 (cont)



Palaeolake Cormorant Section 1



Palaeolake Cormorant Section 1 (cont)

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