FRESHWATER DIATOMS ON SUB-ANTARCTIC MACQUARIE ISLAND: AN ECOLOGICAL SURVEY OF 14 LAKES

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(with two text-figures, three tables and three appendices)

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A survey of the diatom (Bacillariophyceae) populations in 14 lakes and ponds on sub-Antarctic Macquarie Island identified 102 species from 34 genera, including species considered endemic to the sub-Antarctic region. Multivariate analysis of the diatom communities divided the lakes into two broad groups; oligotrophic plateau lakes dominated by species including *Brachysira exilis, Fragilaria capucina* var. *gracilis, Psammothidium abundans, Ps. confusum* and *Ps. confusum* var. *atomoides*, and lowland peat-based lakes dominated by species including *Fragilaria pulchella, Planothidium lanceolatum* and *Pl. quadripunctatum*. Factors relating to lake elevation rather than water pH or conductivity appeared to have most influence on the lake diatom communities.

Key Words: Macquarie Island, sub-Antarctic, diatoms, Bacillariophyceae.

INTRODUCTION

Sub-Antarctic Macquarie Island (fig. 1) is located at 54°38'S, 158°53'E, approximately midway between Australia and the Antarctic continent within the sub-Antarctic biogeographical zone, a region of islands in the southern Atlantic and Indian oceans. Macquarie Island is politically part of Tasmania and is listed as a World Heritage Area because of its geological and natural significance. The island is part of an undersea ridge raised above the surface by tectonic action and the nearest large land masses are mainland Tasmania, approx 1470 km NNW, and New Zealand approx 1130 km NE (Commonwealth of Australia 1996). An undulating plateau generally 200–250 m above sea level covers most of the island's 34 x 5.5 km area. The climate is moist, windy and cool (yearly average 5°C) with low seasonal variation (Selkirk *et al.* 1990). Numerous lakes and extensive waterlogged areas are present. The lake waters are of low salinity, which is mostly derived from sea spray (Tyler 1972). This paper presents findings from the first extensive survey of the diatoms in freshwater habitats on Macquarie Island and compares these findings with surveys on other sub-Antarctic islands. Diatoms are unicellular algae characterised by silica cell walls consisting of two overlapping halves called valves. Diatom taxonomy is based on the shape and patterning of the valves rather than the living forms. Diatoms inhabit marine, freshwater and moist terrestrial environments throughout the world. The structure of diatom communities is sensitive to water quality and diatoms can provide a powerful tool for assessing and monitoring water quality and environmental conditions. The presently available literature on sub-Antarctic diatoms identifies floras containing a number of endemic taxa and many similarities exist between diatom floras of widely scattered islands (Van de Vijver & Beyens 1999). Diatom studies are available for Kerguelen Island: (Germain 1937, Bourrelly & Manguin 1954, Le Cohu 1981, Le Cohu & Maillard 1983, 1986, Van de Vijver *et al.* 1998); Crozet Isles (Pierre 1977, Van de Vijver & Beyens 1999, Van de Vijver *et al.* 2002); and Heard Island (Van de Vijver *et al.* 2004). The available publications on Macquarie Island diatoms (Bunt 1954, Evans 1970, Keenan 1995, McBride & Selkirk 1999, McBride *et al.* 1999 and Saunders *et al.* 2008) do not include a comprehensive illustrated flora.

SAMPLES AND ANALYTICAL METHODS

Rock scrapings, submerged vegetation and bottom sediment were collected from 14 lakes and ponds (table 1) during summer visits to Macquarie Island (details in appendix 1). Samples of 15–25 ml were taken within a 10–40 cm depth range near the shore and preserved with formaldehyde until processed. The submerged vascular plant *Myriophyllum triphyllum* Orchard was present in most lakes and was included in collections as a diatom substrate. Rock surfaces for scraping were not available in the peat-based lakes. Water pH, conductivity and temperature were measured at the time of sample collection and water samples were taken for later analysis. Figure 1 shows the location of the lakes and ponds from which collections were made. Of the 26 named water bodies on the island, the 14 sampled included representative types spanning most of the island. Water bodies on Macquarie Island are variously named as lake, lagoon, pond or tarn but for simplicity in this paper the water bodies sampled are all referred to as lakes. Evans (1970) proposed a classification system for Macquarie Island water bodies that can be used to categorise the lakes in this study. Duck Lagoon, Green Gorge Tarn, Handspike Tarn and Langdon Point Pond are type "a", peat-based ponds on the coastal terrace; Brothers Lake, "S" Pond, Skua Lake and Square Lake are type "b" ponds occurring on highmoor peat beds on the plateau; Lake Ainsworth, Ifould Lake, Major Lake, Prion Lake, Pyramid Lake and Tulloch Lake are type "c" lakes occurring on tundra soils on the plateau. Major Lake is the island's largest lake, having an area of 0.5 km^2 and maximum depth of 16 m. "S" Pond is tiny compared with the plateau lakes (max width about 10 m, max depth about 40 cm) but was included in the sampling program because Evans (1970) used it as a study site and listed its diatom flora.

To prepare the diatom material for examination, about 20 ml of 34% hydrogen peroxide was added to the sample in a covered vial and left at room temperature for at least a week to partially oxidise the material without violent

TABLE 1
Sampling sites and number of samples collected per year from 1988 to 1993

Year	Lake Ainsworth	Brothers Lake	Duck Lagoon	'S' Pond	Green Gorge Tarn	Handspike Tarn	Ifould Lake	Langdon Point Pond	Major Lake	Pyramid Lake	Prion Lake	Skua Lake	Square Lake	Tulloch Lake
1988	2	3	1		1				3	2		4		2
1989	5	3	8	2	1	2	3	2	3	-	1	3		
1990		2	4	1	1				1	1	1		2	2
1991		1	2		1						1		2	
1992		3		1						2	2		4	4
1993	1				1				2					2

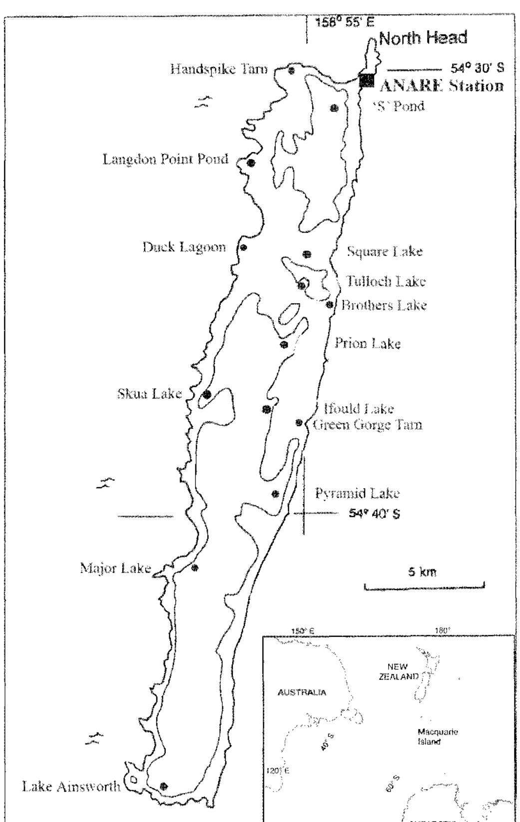

FIG. 1 — Macquarie Island, showing locations of lakes and ponds that were sampled.

reaction. Oxidation was completed by placing the vial in an oven at 100°C for 15 minutes. The cleared diatom valves were allowed to settle on to a cover slip from suspension then mounted in Naphrax on a microslide (McBride 1988). At least 300 valves were identified and counted on each microslide. Species were identified at 1000x magnification under a light microscope (Olympus Vanox) fitted with Nomarski interference contrast. The principal taxonomic reference was that of Van de Vijver *et al.* (2002) because of its sub-Antarctic specificity and status as the only comprehensive illustrated flora for a sub-Antarctic island. Other taxonomic references were Krammer & Lange-Bertalot (1997), Germain (1981), Le Cohu (1981), Le Cohu & Maillard (1983, 1986) and John (1983). Recent revisions of diatom taxonomy have been incorporated to maintain consistency with Van de Vijver *et al.* (2002) and these changes considerably rearrange the genera, e.g., *Achnanthidium, Planothidium* and *Psammothidium* have been separated from *Achnanthes*, and *Adlafia, Diadesmis, Naviculadicta, Lecohuia, Eolimna, Geissleria, Luticola* have been separated from *Navicula*. The similarity of the diatom community in the same lake in different years was assessed using Twinspan ordination (Minchin 1990), where the samples were arranged in an order determined by the relative abundance of each diatom species in the sample (appendix 1 lists samples in the Twinspan order). For six of the lakes ("S" Pond, Major Lake, Skua Lake, Duck Lagoon, Handspike Tarn and Langdon Point Pond) the samples from each lake grouped together without mingling with the samples from other lakes. For the other lakes some intermingling of samples from different lakes occurred but generally the samples from each lake were grouped together. Therefore it was considered appropriate to combine the data from each lake for further analysis. Multivariate analysis using Decorana (Minchin 1990) was used to align the lakes along theoretical environmental gradients based on similarities in their diatom communities.

RESULTS

Over 32 000 diatom valves were counted in samples from the 14 lakes and a total of 102 species in 34 genera were identified (details in appendix 2). Figure 2 shows the arrangement of the lakes when Decorana Axis 1 is plotted against Axis 2. Table 2 and appendix 3 show the major species observed in each lake with the order of the lakes according to Axis 1 of the Decorana ordination. The high Eigenvalue of Axis 1 (0.79) suggests this ordering of the lakes relates to a strong environmental gradient. Four of the plateau lakes – Lake Ainsworth, Prion Lake, Pyramid Lake and Tulloch Lake – are grouped together, as are Major Lake and Skua Lake. Ifould Lake and Square Lake are placed towards the group of coastal terrace lakes. The coastal terrace lakes – Brothers Lake, Duck Lagoon, Green Gorge Tarn, Handspike Tarn and Langdon Point Pond – form a closely spaced group suggesting their communities are very similar. "S" Pond is an outlier especially when its position on Axis 2 is taken into account.

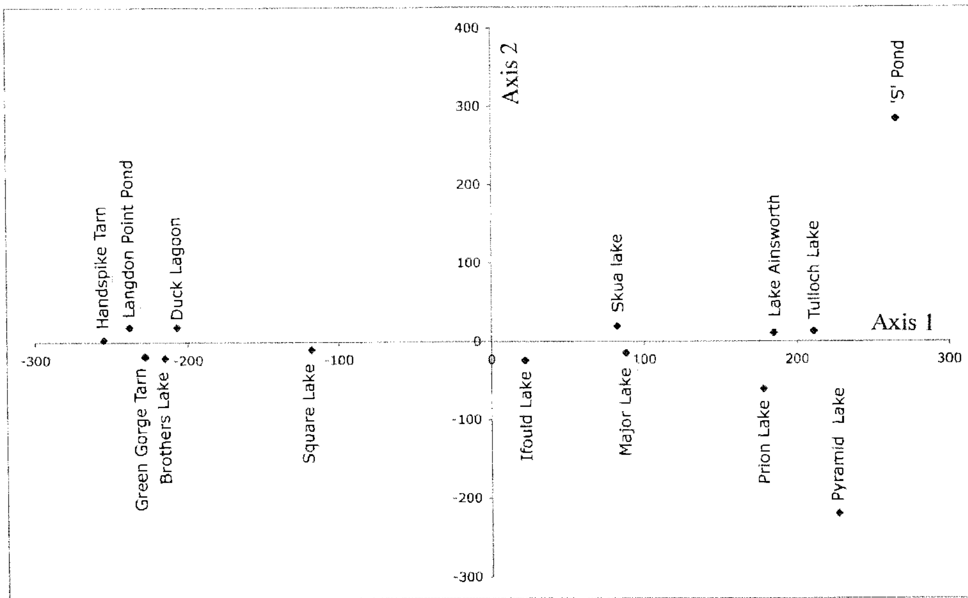

FIG. 2 — Arrangement of lake diatom communities along environmental gradients. Decorana Axis 1 (Eigenvalue 0.79) plotted against Axis 2 (Eigenvalue 0.49) showing the positions of lake diatom communities in this theoretical space. All species were included and data were the relative abundance of each species without transformation. These ordination axes represent environmental gradients that influence the structure of the diatom communities.

TABLE 2
Diatom species in Macquarie Island lakes

	'S' Pond	Pyramid Lake	Tulloch Lake	Lake Ainsworth	Prion Lake	Major Lake	Skua lake	Ifould Lake	Square Lake	Duck Lagoon	Brothers Lake	Green Gorge Tarn	Langdon Point Pond	Handspike Tarn
Achnanthidium minutissimum	-	-	-	-	-	##	##	###	#	-		-		
Amphora coffeaeformis			-		-	-	#	-	###		-	-		
Aulacoseira distans	###	-	-				-	-						
Brachysira exilis	###	#	###	###	#	#	-		-					
Cocconeis placentula			-			-	-	##	##	###	##	##		
Cymbella microcephala					-	#	#	##	#		-			
Diatomella balfouriana		-	-			#	##	##		-				
Eunotia curvata		###	-	-	#				-		-			-
Fragilaria capucina var vaucheriae	-	-	-	#		##	##	#	###	##	#	-	##	
Fragilaria capucina var gracilis		###	###	###	###	###	###		-					
Fragilaria capucina var rumpens				##		-		#		-				
Fragilaria exigua				-					-	###			##	
Fragilaria pulchella	-	-	-	-	-	##	-	###	###	##	###	###	-	###
Gomphonema affine				-	-	-			#	-	###	-	-	
Gomphonema intricatum		-	-	-	-	-	#		-	-	-			
Lecohuia geniculata	-	-	-	-	##	-	-	-						
Naviculadicta seminulum	-	-	-	-	#	-	-	-	-	-	-		##	#
Nitzschia gracilis	-	-		-		-			###	#	##			
Planothidium aueri	-	-	-		-	-	-	##				-		
Planothidium deliculatum									-	##			###	-
Planothidium lanceolatum				-		-	-	-	-	#	#	###	###	###
Planothidium quadripunctatum			-	-	-	-	-	-	-	###	##	#	###	###
Psammothidium abundans	###	-	###	-	-	#	###	-	-	-	-	-		
Psammothidium confusum	-	##	###	##	###	#	-	###	-		-	-	-	
Psammothidium confusum var atomoides		###	###	#	##	#	-	#		-	-	-	-	-
Psammothidium oblongellum	-		-		-	-	-			-			##	
Psammothidium therezienii	###			-	-		-	-						
Staurosira pinnata						-	###		-	##	-		-	
No of species observed	26	37	41	39	34	49	47	42	42	43	28	22	20	11

Relative abundances of major species and total species numbers in each lake. The symbol ### represents >10% relative abundance, ## represents 5–10%, # represents 2–5%, - represents <2%.

DISCUSSION

On Macquarie Island, as elsewhere in the sub-Antarctic region, araphid species (without a raphe slit on either valve face), especially *Fragilaria*, and monoraphid species (having a raphe slit on one valve face), especially *Achnanthes* and the genera formerly within *Achnanthes* formed major, sometimes dominant members of the lake diatom communities. Van de Vijver & Beyens (1999) consider a number of species (revised names in parentheses) to be confined to the sub-Antarctic zone: *Achnanthes confusa* (*Psammothidium confusum*), *A. germainii* (*Ps. germainii*), *Diatomella hustedtii* (*D. balfouriana*), *Pinnularia microstauron* var. *elongata* (*Pi. subantarctica* var. *elongata*). These species are well represented on Macquarie Island, reinforcing the view that a characteristic freshwater diatom flora exists in the sub-Antarctic, even though confined to small islands separated by long ocean distances. Saunders *et al.* (2008) identified 208 diatom species from 34 genera in samples from 50 ponds and lakes on Macquarie Island, compared to 102 species from 34 genera identified in the present study. The larger number of samples examined by Saunders *et al.* (2008) could be expected to reveal more species. If sampling had included soils and bogs a higher number of species would be expected in both studies. For example, an endemic species, *Gomphonema isabellae*, was later identified from a mire adjoining Green Gorge Tarn (Van de Vijver & McBride 2006) but was not observed in the samples forming the basis of this paper. It is difficult to comment on the higher number of species reported by Saunders *et al.* (2008) without seeing the full species list on which the number is based. On Île de la Possession (Crozet Archipelago) Van de Vijver & Beyens (1999) identified 210 diatom taxa from 127 lake and stream samples. The most abundant genera were *Fragilaria, Achnanthes* and *Navicula*, the same genera found on Macquarie Island (including the revised genera formerly within *Achnanthes* and *Navicula*). The higher species diversity on Île de la Possession may be explained by the greater habitat diversity, notably pH values ranging from 4.9 to 10, compared with values from 6.4 to 9.7 in the 14 Macquarie Island lakes examined in this study. Saunders *et al.* (2008) found a broader pH range of 5.5–9.95 by sampling 50 Macquarie Island lakes.

Some species, such as *Achnanthes clevei, Amphora coffeaeformis*, and *Cocconeis placentula*, are present or abundant on Macquarie Island but apparently absent from Kerguelen or Crozet islands. Only one species, *Fragilaria pulchella*, was observed in every lake. Four species were observed only in plateau lakes: *Brachysira exilis, Psammothidium therezienii, Lecohuia geniculata, Aulacoseira distans,* while one species, *Planothidium deliculatum*, was observed only in coastal terrace lakes. The diatom communities in the nine plateau lakes were generally more diverse with an average of 40 species, compared with the five coastal terrace lakes with an average of 24 species. The community of "S" Pond was distinct in having the centric species, *Aulacoseira distans*, as a major component. Its outlier status in the ordination matches its physical situation as a small, shallow and peat-based water body located at 220 m on the plateau. The other lakes at elevations about 200 m are large type "c" lakes. *Psammothidium confusum, Ps. confusum* var. *atomoides* and *Fragilaria capucina* var. *gracilis* typify the plateau lake communities. *Planothidium lanceolatum, Pl. quadripunctatum* and *F. pulchella* typify the coastal terrace lake communities (table 2). Two of the *F. capucina* morphotypes proposed by Van de Vijver *et al.* (2002) appear to have different habitat preferences: the slender form, *F. vaucheriae* var. *gracilis* (formerly *F. vaucheriae* var. *longissima*), is abundant only in type "c" plateau lakes whereas *F. vaucheriae* var. *vaucheriae*, while present in the plateau lakes, is abundant mostly in type "a" coastal terrace lakes. *Planothidium deliculatum* was abundant only in the two lakes, Duck Lagoon and Langdon Point Pond, which had the highest conductivities. *Brachysira exilis* appears confined to the plateau lakes. *Eunotia curvata* was abundant in Pyramid Lake, which had the lowest pH.

There is broad agreement in the number of species observed in this study (shown in parentheses) with the number of species observed by Evans (1970) who listed a total of 84 (102) species in five ponds and lakes, 41 (34) species in Prion Lake, 25 (26) species in "S" Pond, and 37 (43) species in Duck Lagoon. The study by Bunt (1954) examined terrestrial diatoms and is not directly comparable. Comparison between environmental variables and lake position on Decorana Axis 1 (table 3) suggests the lake diatom communities are influenced to some extent by silica concentrations and by conductivity and pH. Silica concentrations are lowest in the plateau lakes and increase in a clear pattern along the axis to the coastal lakes suggesting a strong effect on the diatom communities. Conductivity also generally increases along the axis. The pattern of pH along the axis shown is less clear and shows highest values near the centre suggesting pH has less influence than silica concentrations and conductivity. Saunders *et al.* (2008), using a larger data set, found conductivity, pH and silicate concentrations made independent, significant contributions to explaining variation in the species data.

For most lakes, nitrate concentrations were below the detection limit, limiting the discrimination available. Within the group of similar coastal terrace lakes, Duck Lagoon and Brothers Lake were below detection limits while Langdon Point Pond was over 60 times the detection limit, suggesting nitrate concentrations were not a strong factor. A further consideration is that the values shown in table 3 are a "snapshot" and represent lake water quality at one point in time or the average of a limited number of readings. Water conductivity and nitrate concentrations in coastal terrace lakes are highly variable due to seawater ingress during storms and seasonal inputs from seal wallows and penguin rookeries (Evans 1970).

The environmental gradient corresponding to the order of lake communities along Axis 1 (table 3) seems to be related to lake elevation. There is a clear progression from the type "c" plateau lakes with elevations over 140 m asl through the type "b" plateau lakes (75–99 m asl) to the type "a" coastal terrace lakes. The environmental gradient linked to elevation that is influencing the communities could be temperature, a parallel situation to the terrestrial vegetation on Macquarie Island which shows marked altitude zonation. Based on thermograph data, Evans (1970) reports temperatures in Duck Lagoon on the coastal terrace were consistently several degrees higher than those for Prion Lake or "S" Pond on the plateau. This difference may be sufficient to affect the structure of the diatom communities in lakes at different elevations.

In addition to temperature, elevation affects the inputs of nutrients and ions from sea spray, which decrease with distance from the west coast due to the prevailing westerly weather patterns (Saunders *et al.* (2008)). The resultant changes in water chemistry could also produce an elevation-related pattern in lake diatom communities.

TABLE 3
Lake water quality and elevation

	'S' Pond	Pyramid Lake	Tulloch Lake	Lake Ainsworth	Prion Lake	Major Lake	Skua lake	Ifould Lake	Square Lake	Duck Lagoon	Brothers Lake	Green Gorge Tarn	Langdon Point Pond	Handspike Tarn
pH measured Oct/Nov1988		6.3		6.5		7.1	7.5		9.6	7.9	9.1	7.5		7.0
pH measured Nov/Dec 1989	7.3			7.2	7.2	7.4	8.1	8.0	9.9	9.7	8.4	8.2	7.1	7.1
pH measured Dec1990		6.5	6.7		7.6	7.5			9.5	8.1		7.6		
pH measured Dec 1992			6.6						9.6	9.0				
Average pH	7.3	6.4	6.7	6.9	7.4	7.3	7.8	8.0	9.7	8.7	8.8	7.8	7.1	7.1
Conductivity (µS/cm) measured Oct/Nov 1988		140		200		240	270		300	850	250	230		610
Conductivity (µS/cm) measured Nov/Dec 1989	360			210	170	270	285	190	305	960	250	240	1240	740
Conductivity (µS/cm) measured Dec 1990		98	121		92	169			212	1020	161	148		
Conductivity (µS/cm) measured Dec 1992			150						280	810				
Average Conductivity	360	119	136	205	131	226	278	190	274	910	220	206	1240	675
Silicate (mg/L) measured Oct/Nov1988		0.75		0.10		0.22	2.2		0.15	1.3	9.8	7.5		3.5
Silicate (mg/L) measured Nov/Dec1989	0.16			0.12	0.16	0.22	0.39	6.5	0.37	0.55	12	4.9	1.8	4.3
Nitrate (mgN/L)	<0.042	n.d.	n.d.	<0.042	<0.042	<0.042	<0.042	<0.042	<0.042	<0.042	<0.042	0.11	2.66	0.56
Altitude (m)	220	200	190	240	160	200	140	220	99	5	75	10	5	5

Water pH and conductivity were measured in the field using portable meters (ICI Stick pH meter and Hanna HI 8633 portable conductivity meter). Silicate concentrations were determined at Macquarie Island Base by colourimetric analysis (Hach model DREL/1C Direct–Reading Environmental Laboratory). Nitrate concentrations were determined by the Australian Government Analytical Laboratories (Kingston, Tasmania) in lake water samples transported in prepared plastic bottles. The value of 0.042 mgN/L was the detection limit for nitrate. nd = no data.

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APPENDIX 1

Order of samples in list follows Twinspan ordination based on relative abundance of diatom species in each sample without transformation and including all species

Lake	Date of collection	Particulars of sample
"S" Pond	29 Nov 1990	Brown slime at southeast margin in 20 cm depth
"S" Pond	19 Dec 1991	Algae and submerged moss at east edge in 10 cm
"S" Pond	29 Feb 1992	Myriophyllum tips at east edge in 10 cm
"S" Pond	02 Dec 1989	Filamentous algae and gelatinous mud in 10 cm depth at north edge
"S" Pond	01 Dec 1989	Filamentous algae and moss in 10 cm depth at south edge
Prion Lake	26 Nov 1990	Submerged moss at northeast corner in 20 cm depth
Pyramid Lake	17 Mar 1992	Rock scrapings at east edge in 10 cm depth
Prion Lake	31 Jan 1992	Algae and submerged moss from rocks
Lake Ainsworth	10 Nov 1988	Rock scrapings at west margin near skua club
Lake Ainsworth	08 Mar 1993	Rock scrapings at southwest edge in 25 cm, 1 m from shore
Lake Ainsworth	06 Dec 1989	Moss at south margin 3 m from shore in 50 cm depth
Lake Ainsworth	06 Dec 1989	Rock scrapings at south margin near southwest corner in 20 cm depth
Lake Ainsworth	06 Dec 1989	Rock scrapings at east margin near northeast corner in 20 cm
Lake Ainsworth	06 Dec 1989	Submerged moss at east margin near northeast corner in 20 cm
Lake Ainsworth	06 Dec 1989	Submerged moss at east margin near northeast corner in 20 cm
Pyramid Lake:	17 Mar 1992	Submerged moss from rocks at edge
Prion Lake	01 Mar 1991	Rock scrapings at northern edge
Prion Lake	21 Dec 1989	Submerged moss at northern margin in 20 cm depth
Prion Lake	13 Jan 1992	Submerged vegetation
Tulloch Lake	26 Nov 1990	Submerged moss at northwest margin in 30 cm depth
Tulloch Lake	26 Nov 1990	Rock scrapings at northwest margin in 30 cm depth
Lake Ainsworth	10 Nov 1988	Rock scrapings at southeast corner remote from skua club
Pyramid Lake	08 Nov 1988	Submerged bryophyte *Ditrichum strictum*
Pyramid Lake	08 Nov 1988	Rock scrapings
Pyramid Lake	27 Nov 1990	Submerged moss at northwest edge in 20 cm depth
Tulloch Lake	31 Oct 1988	Submerged moss at 30 cm depth at eastern edge
Tulloch Lake	02 Mar1992	Submerged moss and algae at west shore
Tulloch Lake	10 Dec 1992	Submerged moss at northwest corner in 20 cm depth
Tulloch Lake	10 Dec 1992	Rock scrapings at northwest corner in 20 cm depth
Tulloch Lake	20 Mar 1993	*Myriophyllum* at southern end 150 m east of outlet in 50 cm depth
Tulloch Lake	20 Mar 1993	Rock scrapings at southern end 150 m east of outlet in 50 cm depth
Tulloch Lake	31 Oct 1988	Rock scrapings at 20 cm depth at eastern edge
Tulloch Lake	31 Jan 1992	Submerged moss and algae at western edge in 20 cm depth

Appendix 1 cont.

Lake	Date of collection	Particulars of sample
Major Lake	08 Nov 1988	Submerged bryophyte *Ditrichum strictum* in 10 cm depth
Major Lake	23 Nov 1988	Rock scrapings at site without bird use and 50 m west of skua club
Major Lake	10 Mar 1993	*Myriophyllum* in 30 cm depth 1.5 m from shore
Major Lake	10 Mar 1993	Rock scrapings in 30 cm depth 1.5 m from shore
Major Lake	11 Dec 1989	Rock scrapings at water sampling site in 30 cm depth
Major Lake	11 Dec 1989	Rock scrapings at western margin near outlet in 30 cm depth
Major Lake	11 Dec 1989	Rock scrapings at western margin near outlet in 30 cm depth repeat digestion
Major Lake	27 Nov 1990	Rock scrapings with moss and algae at western margin in 20 cm depth
Major Lake	23 Nov 1988	Rock scrapings from southwest corner near? Skua club
Skua Lake	01 Nov 1988	*Myriophyllum* from edge 200 m east of water sampling site
Skua Lake	14 Dec 1989	*Myriophyllum* at shoreline near water sampling site in 30 cm depth
Skua Lake	14 Dec 1989	Rock scrapings near water sampling site at shoreline in 20 cm depth
Skua Lake	14 Dec 1989	*Myriophyllum* at shoreline near outlet in 30 cm depth
Skua Lake	01 Nov 1988	Rock scrapings from edge 200 m east of water sampling site
Skua Lake	01 Nov 1988	*Myriophyllum* near water sampling site at western end of south margin
Skua Lake	01 Nov 1988	Rock scrapings near water sampling site at western end of south margin
Ifould Lake	13 Dec–1989	Submerged moss at eastern edge near outlet in 20 cm depth
Ifould Lake	13 Dec 1989	Rock scrapings at western margin near outlet in 10 cm depth
Green Gorge Tarn	11 Mar 1993	*Myriophyllum* in 20 cm depth
Ifould Lake	13 Dec 1989	*Myriophyllum* at southeast margin on shore
Square Lake	10 Dec 1992	Rock scrapings at eastern end of northern edge in 15 cm depth
Square Lake	10 Dec– 992	*Myriophyllum* at eastern end of northern edge in 15 cm depth
Square Lake	10 Dec 1992	Rock scrapings at east end of northern edge in 15 cm depth
Square Lake	10 Dec 1992	*Myriophyllum* at east end of northern edge in 15 cm depth
Square Lake	26 Nov 1990	*Myriophyllum* at surface at southeast corner
Square Lake	26 Nov 1990	Rock scrapings at southeast corner in 30 cm depth
Square Lake	01 Mar 1991	*Myriophyllum* at northeast edge.
Green Gorge Tarn	04 Nov 1988	*Myriophyllum* at middle of southeast edge
Green Gorge Tarn	14 Dec 1989	*Myriophyllum* east end of northern margin on surface
Green Gorge Tarn	28 Nov 1990	*Myriophyllum* at surface at eastern margin
Brothers Lake	31 Jan 1992	Myriophyllum at northern edge in 20 cm depth
Green Gorge Tarn	30 Nov 1991	*Myriophyllum*
Square Lake	01 Mar 1991	Rock scrapings at northeast edge
Brothers Lake	03 Nov 1988	*Myriophyllum* and algae at northeast edge
Brothers Lake	03 Nov 1988	*Myriophyllum* at northern margin near northeast corner
Brothers Lake	03 Nov 1988	Rock scrapings from mid northern margin
Brothers Lake	28 Nov 1990	*Myriophyllum* at surface at eastern margin
Brothers Lake	17 Dec 1991	Floating algae and submerged moss at northern edge in 20 cm depth
Brothers Lake	16 Mar 1992	*Myriophyllum* at northern edge in 20 cm depth
Brothers Lake	21 Dec 1989	Rock scrapings at northern margin in 30 cm depth
Brothers Lake	21 Dec 1989	*Myriophyllum* at northern margin in 50 cm depth and 2 m from edge
Brothers Lake	21 Dec 1989	*Myriophyllum* at surface near water sampling site
Brothers Lake	28 Nov 1990	Rock scrapings at northwest margin in 20 cm depth
Duck Lagoon	13 Nov 1988	Rock scrapings from eastern edge
Duck Lagoon	26 Nov 1990	Rock scrapings at northern site in 50 cm depth
Duck Lagoon	01 Dec 1989	Bottom detritus at southeastern margin 2 m from edge in 50 cm depth
Duck Lagoon	01 Dec 1989	Filamentous algae in about 30 cm depth and 2 m from edge of southeastern margin
Duck Lagoon	26 Nov 1990	*Myriophyllum* at surface at southern site
Duck Lagoon	28 Feb 1991	Floating vegetation at northern edge
Duck Lagoon	22 Dec 1989	*Myriophyllum* at southwest shore on surface
Duck Lagoon	22 Dec 1989	*Myriophyllum* at northeast shore on surface
Duck Lagoon	22 Dec 1989	*Myriophyllum* at eastern shore on surface
Duck Lagoon	22 Dec 1989	*Myriophyllum* at northwestern shore 3 m from at edge in 80 cm depth
Duck Lagoon	01 Dec 1989	Rock scrapings from 30 cm depth near at northern shore
Duck Lagoon	26 Nov 1990	Rock scrapings at southern site in 50 cm depth

Appendix 1 cont.

Lake	Date of collection	Particulars of sample
Duck Lagoon	02 Feb 1991	Rock scrapings at southern bank.
Duck Lagoon	22 Dec 1989	Sediment at northeastern margin near edge in 30 cm depth
Duck Lagoon	26 Nov 1990	Bottom detritus in 30 cm depth
Handspike Pond	27 Nov 1989	Marginal vegetation in about 10 cm depth at southwestern edge
Handspike Pond	27 Nov 1989	Fibrous mud at edge in 30 cm depth
Langdon Point Pond	26 Dec 1989	Peat scrapings at western margin in 20 cm depth
Langdon Point Pond	26 Dec 1989	Rock scrapings in 40 cm depth near eastern shore

APPENDIX 2
Diatom species observed in Macquarie Island lakes and ponds

Achnanthes clevei Grunow
Achnanthes inflata Kützing
Achnanthes lapponica var. *ninkei* (Guermeur & Manguin) Reimer
Achnanthes linearis W. Smith
Achnanthidium minutissimum (Kützing) Czarnecki
Achnanthidium modestiforme (Lange-Bertalot) Van de Vijver
Adlafia bryophila (Petersen) Lange-Bertalot
Amphora coffeaeformis Agardh
Amphora copulata (Kützing) Schoeman & Archibald
Amphora veneta Kützing
Aulacoseira distans (Ehrenberg) Simonsen
Brachysira exilis (Kützing) Round & Mann
Caloneis bacillum (Grunow) Mereschkowsky
Caloneis marnieri Manguin
Cocconeis neothumensis Krammer
Cocconeis placentula Ehrenberg
Cymbella gracilis (Rabhenhorst) Cleve
Cymbella microcephala Grunow
Diadesmis arcuata (Heiden) Lange-Bertalot
Diadesmis subantarctica Le Cohu & Van de Vijver
Diatomella balfouriana Greville
Diploneis subovalis Cleve
Encyonema vulgare Krammer
Eolimna minima (Grunow) Lange-Bertalot
Eunotia aff. *subarcuatoides* Alles, Nörpel & Lange-Bertalot
Eunotia curvata (Kützing) Lagerstedt
Eunotia paludosa Grunow
Fragilaria capucina var. *gracilis* (Kützing) Lange-Bertalot
Fragilaria capucina var. *rumpens* (Oesrrup) Hustedt
Fragilaria capucina var. *vaucheriae* (Kützing) Lange-Bertalot
Fragilaria exigua Grunow
Fragilaria pulchella (Ralfs) Lange-Bertalot
Frustulia rhomboides (Ehrenberg) de Toni
Frustulia subantarctica Van de Vijver & Beyens nov. spec.
Geissleria paludosa (Hustedt) Lange-Bertalot
Gomphonema affine Kützing
Gomphonema intricatum Kützing
Gomphonema stonei Reichardt
Gomphonema subantarctica Van de Vijver & Beyens nov. spec.
Gomphonema tumidum (Skvortzov & Meyer) Lange-Bertalot & Reichardt
Lecohuia geniculata (Germain) Lange-Bertalot
Luticola mutica (Kützing) Mann
Mastogloia recta Hustedt
Navicula cincta (Ehrenberg) Kützing
Navicula cincta var. *heuflerii* (Grunow) Grunow
Navicula gregaria Donkin
Navicula hustedtii Krasske
Navicula lanceolata (Agardh) Ehrenberg
Navicula muticopsis Van Heurck
Navicula pseudocitris Manguin
Navicula pseudoscutiformis Hustedt
Navicula pupula Kützing
Navicula rhyncocephala Kützing
Navicula subrhyncocephala Hustedt
Naviculadicta elorantana Lange-Bertalot
Naviculadicta seminulum Grunow
Neidium affine Ehrenberg
Neidium iridis (Ehrenberg) Cleve
Nitzschia aff. *linearis* (Agardh) W. Smith
Nitzschia dissipata (Kützing) Grunow
Nitzschia frustulum (Kützing) Grunow
Nitzschia gracilis Hantzsch
Nitzschia inconspicua Grunow
Nitzschia vermicularis (Kützing) Grunow
Nupela chilensis (Krasske) Lange-Bertalot
Pinnularia acoricola Hustedt
Pinnularia acidicola var. *elongata* Van de Vijver & Le Cohu
Pinnularia appendicula (Agardh) Cleve
Pinnularia borealis var. *scalaris* (Ehrenberg) Rabenhorsr
Pinnularia gibba Ehrenberg
Pinnularia lata Brébisson
Pinnularia microstauron (Ehrenberg) Cleve
Pinnularia obscura Krasske
Pinnularia subantarctica var. *elongata* (Manguin) Van de Vijver & Le Cohu
Pinnularia viridis Nitzschia
Planothidium aueri (Krasske) Lange-Bertalot
PLanothidium cyclophorum (Heiden) Van de Vijver
Planothidium deliculatum (Kützing) Round & Bukthiyarova
Planothidium lanceolatum (Brébisson) Lange-Bertalot
Planothidium quadripunctatum (Oppenheim) Sabbe
Psammothidium abundans (Manguin) Bukthiyarova & Round
Psammothidium confusum (Manguin) Van de Vijver
Psammothidium confusum var. *atomoides* (Manguin) Van de Vijver
Psammothidium germainii (Manguin) Sabbe
Psammothidium incognitum Van de Vijver
Psammothidium manguinii (Hustedr) Van de Vijver
Psammothidium oblongellum (Oestrup) Van de Vijver
Psammothidium stauroneioides (Manguin) Bukthiyarova
Psammothidium therezienii (Le Cohu & Maillard) Van de Vijver
Stauroforma exiguiformis (Lange-Bertalot) Flower, Jones & Round
Stauroneis anceps Ehrenberg
Stauroneis gracilior (Ehrenberg) Reichardt
Stauroneis kriegeri Patrick
Stauroneis phoenicenteron Ehrenberg
Staurosira alpestris (Krasske ex Hustedt) Van de Vijver
Staurosira circula Van de Vijver & Beyens
Staurosira jolinae Van de Vijver
Staurosira leptostauron Ehrenberg
Staurosira pinnata Ehrenberg
Surirella angusta var. *constricta* Hustedt
Surirella linearis W. Smith
Surirella ovata Kützing

APPENDIX 3
Pooled relative abundances of all taxa in each lake

	'S' Pond	Pyramid Lake	Tulloch Lake	Lake Ainsworth	Prion Lake	Major Lake	Skua Lake	Island Lake	Square Lake	Duck Lagoon	Brothers Lake	Green Gorge Tarn	Langdon Point Pond	Handspike Tarn
Achnanthes clevei	-	-	-	-	-	6.84%	-	10.29%	6.78%	0.04%	-	-	-	-
Achnanthes inflata	-	-	-	-	-	-	0.09%	0.21%	0.14%	0.26%	0.41%	-	-	-
Achnanthes lapponica var. *ninkei*	0.13%	0.07%	0.07%	0.16%	0.46%	-	0.09%	-	-	-	-	0.11%	-	-
Achnanthes linearis	-	-	-	-	-	-	0.32%	-	-	-	0.12%	0.46%	-	-
Achnanthidium minutissimum	0.13%	0.50%	0.72%	1.94%	1.56%	15.30%	6.45%	12.24%	4.68%	0.04%	-	0.46%	-	-
Achnanthidium modestiforme	-	-	0.04%	-	-	2.87%	0.83%	0.72%	-	-	-	0.11%	-	-
Adlafia bryophila	1.03%	0.64%	0.22%	1.21%	1.24%	0.07%	-	-	-	-	-	-	-	-
Amphora coffeaeformis	-	-	0.07%	-	0.33%	1.71%	3.18%	1.85%	19.61%	-	0.06%	0.11%	-	-
Amphora copulata	-	-	-	-	-	-	-	-	0.03%	-	-	-	-	-
Amphora veneta	-	-	-	-	-	-	-	-	0.03%	-	-	-	-	-
Aulacoseira distans	15.94%	1.35%	0.69%	-	-	-	0.28%	0.21%	-	-	-	-	-	-
Brachysira exilis	37.16%	2.41%	20.49%	18.62%	3.46%	2.81%	1.01%	-	0.03%	-	-	-	-	-
Caloneis bacillum	0.06%	0.50%	0.14%	0.16%	0.13%	-	0.18%	-	0.03%	-	-	-	-	-
Caloneis marnieri	-	-	-	-	-	-	0.05%	0.10%	-	-	-	-	-	-
Cocconeis neothumensis	-	-	-	-	-	-	-	-	0.07%	-	-	-	-	-
Cocconeis placentula	-	-	0.07%	-	-	1.03%	0.78%	7.30%	8.68%	10.21%	6.16%	7.90%	-	-
Cymbella gracilis	-	0.28%	1.48%	4.05%	0.65%	3.35%	0.37%	-	-	-	-	-	-	-
Cymbella microcephala	-	-	-	-	0.39%	3.35%	4.51%	7.82%	4.75%	-	0.12%	-	-	-
Diadesmis arcuata (Heiden)	-	0.07%	-	-	-	-	-	-	-	-	-	-	-	-
Diadesmis subantarctica	-	-	-	-	0.07%	-	-	-	-	0.04%	-	-	-	-
Diatomella balfouriana	-	0.14%	0.79%	-	-	2.53%	6.17%	7.92%	-	1.67%	-	-	-	-
Diploneis subovalis	-	-	-	-	-	0.07%	-	-	0.03%	-	-	-	-	-
Encyonema vulgare	-	-	-	-	-	-	-	-	0.07%	-	-	-	-	-
Eolimna minima	-	-	-	-	-	-	-	0.10%	0.03%	0.39%	2.01%	0.11%	-	-
Eunotia aff subarcuatoides	-	0.07%	-	-	-	-	-	-	-	-	-	-	-	-
Eunotia curvata	-	42.56%	0.11%	1.46%	2.93%	-	-	-	0.03%	-	0.12%	-	-	0.16%
Eunotia paludosa	-	-	0.07%	0.08%	0.33%	-	-	-	-	-	-	-	-	-
Fragilaria capucina var. *gracilis*	1.61%	14.38%	15.33%	38.38%	44.33%	31.90%	30.20%	3.19%	1.63%	-	-	-	-	-
Fragilaria capucina var. *rumpens*	-	-	-	5.10%	-	0.14%	-	-	-	0.13%	-	-	-	-
Fragilaria capucina var. *vaucheriae*	0.26%	0.07%	0.58%	4.37%	-	5.41%	6.58%	3.50%	16.08%	6.87%	2.61%	1.95%	5.31%	-
Fragilaria exigua	-	-	-	0.08%	-	-	-	-	0.10%	28.97%	-	-	4.99%	-
Fragilaria pulchella	0.19%	0.92%	0.14%	0.16%	0.20%	6.71%	0.92%	12.86%	14.89%	5.54%	48.14%	66.78%	0.97%	28.73%
Frustulia rhomboides	1.87%	0.07%	0.04%	-	-	0.07%	0.05%	-	-	-	-	-	-	-
Frustulia subantarctica	-	-	-	-	-	-	-	0.10%	-	-	-	-	-	-
Geissleria paludosa	-	-	-	-	0.39%	0.07%	-	-	0.07%	0.47%	0.12%	0.34%	0.64%	-
Gomphonema affine	-	-	-	0.81%	0.46%	0.07%	-	-	3.02%	0.09%	17.05%	0.46%	1.45%	-
Gomphonema intricatum	-	0.21%	0.72%	0.49%	0.65%	0.75%	2.03%	-	0.24%	0.04%	0.18%	-	-	-
Gomphonema stonei	-	0.85%	0.43%	0.08%	0.59%	0.21%	-	1.23%	5.36%	0.77%	-	1.60%	-	1.41%
Gomphonema subantarctica	-	-	-	-	-	0.07%	-	0.41%	-	-	-	-	-	-
Gomphonema tumidum	-	-	-	-	-	-	-	0.10%	-	-	0.06%	0.11%	-	-
Lecohuia geniculata	0.19%	0.78%	0.83%	0.16%	8.28%	0.41%	0.51%	0.41%	-	-	-	-	-	-
Luticola mutica	-	-	-	-	-	-	-	-	-	0.04%	-	-	-	-
Mastogloia recta	-	-	-	-	-	0.07%	-	-	-	-	-	-	-	-
Navicula cincta	-	-	0.07%	0.16%	-	0.21%	-	-	-	-	-	-	-	-
Navicula cincta var. *heufleri*	-	-	-	-	-	-	0.09%	-	-	-	-	-	-	-
Navicula gregaria	-	-	-	0.32%	-	0.07%	-	-	-	0.04%	-	-	-	-
Navicula hustedtii	-	-	-	-	-	-	-	-	-	0.09%	-	-	-	-
Navicula lanceolata	-	-	-	-	-	-	-	-	-	-	0.06%	-	1.29%	-
Navicula muticopsis	-	-	0.07%	-	-	-	-	-	-	-	-	-	-	-
Navicula pseudocitris	-	-	-	-	-	-	0.09%	-	-	0.17%	0.41%	-	-	-
Navicula pseudoscutiformis	-	0.14%	0.14%	-	0.33%	1.44%	2.30%	0.62%	-	0.17%	-	-	0.81%	-
Navicula pupula	-	0.21%	-	0.16%	0.39%	-	0.05%	-	-	0.09%	0.06%	-	-	-
Navicula rhyncocephala	0.06%	1.77%	1.62%	1.94%	0.33%	0.27%	0.18%	0.21%	-	-	-	-	-	-
Navicula subrhyncocephala	-	-	-	-	-	-	-	-	0.20%	0.82%	-	-	-	-
Naviculadicta elorantana	1.29%	-	-	0.08%	0.13%	0.14%	0.18%	-	0.03%	0.09%	-	-	1.13%	2.51%
Naviculadicta seminulum	1.03%	1.13%	0.90%	0.24%	2.87%	0.89%	1.01%	0.41%	0.07%	1.89%	1.07%	-	6.76%	2.98%
Neidium affine	-	-	-	-	-	-	-	-	-	-	-	0.11%	-	-
Neidium iridis	-	0.07%	0.40%	-	-	0.07%	-	-	-	-	-	-	-	-
Nitzschia aff. *linearis*	-	0.07%	0.25%	2.35%	0.07%	1.03%	0.87%	0.10%	2.31%	-	1.66%	-	-	-
Nitzschia dissipata	-	-	-	-	-	0.62%	0.05%	0.10%	0.07%	0.60%	-	-	-	-
Nitzschia frustulum	0.90%	2.20%	1.08%	0.08%	0.98%	2.19%	1.06%	0.93%	0.78%	-	-	-	-	-
Nitzschia gracilis	0.26%	0.35%	-	0.08%	-	0.07%	-	-	12.21%	3.09%	7.70%	-	-	-
Nitzschia inconspicua	-	-	-	0.08%	-	-	-	-	0.88%	1.67%	1.07%	-	-	-
Nitzschia vermicularis	-	-	-	-	-	-	-	-	0.03%	-	-	-	-	-
Nupela chilensis	-	-	-	-	-	-	-	-	0.17%	-	-	-	-	-
Pinnularia acoricola	0.06%	0.14%	-	0.49%	0.07%	-	-	-	-	-	-	-	0.16%	-
Pinnularia acidicola var. *elongata*	-	-	-	-	-	-	-	0.10%	-	-	-	-	-	-
Pinnularia appendicula	-	-	-	-	-	-	-	0.72%	-	0.30%	-	-	-	-
Pinnularia borealis var. *scalaris*	-	0.07%	-	-	-	-	-	0.10%	-	-	-	-	-	-
Pinnularia gibba	0.13%	-	0.18%	-	-	0.07%	-	-	-	0.04%	-	-	-	-
Pinnularia lata	-	-	0.04%	-	-	-	-	-	-	-	-	-	-	-
Pinnularia microstauron	0.45%	-	-	-	-	-	0.05%	0.21%	-	0.04%	-	-	0.16%	0.16%
Pinnularia obscura	0.39%	-	0.07%	-	-	-	-	-	-	-	-	-	-	-
Pinnularia subantarctica var. *elongata*	-	0.07%	-	0.16%	0.07%	-	-	-	-	0.04%	-	-	-	-
Pinnularia viridis	-	-	-	0.24%	0.20%	0.07%	-	-	0.03%	-	-	-	-	-
Planothidium aueri	0.06%	0.35%	0.07%	-	1.30%	1.10%	0.74%	9.36%	-	-	-	0.23%	-	-
Planothidium cyclophorum	-	-	-	-	-	-	0.05%	0.21%	0.34%	-	0.12%	0.11%	-	-
Planothidium delicatulum	-	-	-	-	-	-	-	-	0.24%	8.45%	-	-	19.00%	0.63%
Planothidium lanceolatum	-	-	-	0.08%	-	0.27%	0.37%	0.51%	0.75%	2.53%	3.91%	13.75%	15.14%	10.68%
Planothidium quadripunctatum	-	-	0.47%	0.89%	0.13%	0.96%	1.01%	0.41%	1.53%	12.40%	0.06%	3.44%	31.72%	49.45%
Psammothidium abundans	18.58%	0.50%	10.43%	1.21%	0.91%	2.87%	13.12%	1.54%	0.14%	0.04%	0.06%	0.11%	-	-
Psammothidium confusum	1.42%	7.86%	15.04%	6.96%	17.93%	3.15%	0.23%	20.68%	0.20%	-	0.24%	0.11%	0.64%	-
Psammothidium confusum var. *atomoides*	-	17.35%	25.32%	3.72%	6.39%	2.67%	0.18%	2.16%	-	0.13%	0.71%	0.23%	1.13%	0.16%
Psammothidium germainii	-	-	-	0.08%	-	-	-	-	-	-	-	-	-	-
Psammothidium incognitum	1.03%	1.42%	0.22%	0.08%	0.52%	0.34%	0.09%	-	-	-	-	-	-	-
Psammothidium manguinii	0.13%	0.42%	0.29%	1.54%	0.85%	0.34%	0.37%	0.10%	-	-	-	-	-	-
Psammothidium oblongellum	0.19%	-	0.04%	-	0.07%	0.07%	0.83%	-	-	0.04%	-	-	6.28%	-
Psammothidium stauroneioides	-	-	-	0.32%	-	-	-	0.10%	-	-	-	-	-	-
Psammothidium therezienii	15.42%	-	-	1.21%	0.07%	-	0.28%	0.21%	-	-	-	-	-	-
Stauroforma exiguiformis	-	-	-	-	-	0.14%	0.14%	-	-	0.09%	0.06%	-	1.13%	-
Stauroneis anceps												0.04%		
Stauroneis gracilior	-	-	-	-	-	-	-	0.10%	-	-	-	-	-	-
Stauroneis kriegeri	-	-	-	-	-	-	-	-	-	0.04%	-	-	-	-
Stauroneis phoenicenteron	-	-	0.04%	0.16%	-	-	0.05%	-	-	-	-	-	0.16%	-
Staurosira alpestris	-	-	0.07%	-	-	0.07%	1.06%	0.10%	-	0.30%	0.47%	1.37%	-	3.14%
Staurosira circula	-	-	-	-	-	-	-	-	0.24%	-	-	-	-	-
Staurosira jolinae	-	-	-	-	-	0.14%	0.87%	0.51%	-	2.10%	-	-	-	-
Staurosira leptostauron	-	-	-	-	-	-	0.09%	-	-	-	-	-	-	-
Staurosira pinnata	-	-	-	-	-	1.71%	9.99%	-	0.07%	9.06%	0.12%	-	1.13%	-
Surirella angusta var. *constricta*	-	-	-	-	-	-	-	-	0.03%	-	-	-	-	-
Surirella linearis	-	-	0.14%	-	-	0.07%	-	-	-	0.04%	-	-	-	-
Surirella ovata	-	-	-	-	-	-	-	0.10%	-	0.04%	-	-	-	-