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ISSN 1366-7300

ENVIRONMENTAL CHANGE RESEARCH CENTRE

University College London

RESEARCH REPORT

No. 2

The palaeolimnology of Antarctic lakes using diatom water quality transfer functions

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A Report to NERC AST Award: GST/02/428

1993

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1.0 ORIGINAL OBJECTIVES AND CHANGES

Physical, chemical and biological analyses of lake sediment cores can provide integrated records of lake and catchment changes on a range of time scales. One of the most powerful palaeolimnological techniques is diatom analysis. Diatoms are unicellular siliceous algae and the occurrence and abundance of individual species is strongly related to lake-water chemistry. The relationships between diatom species and chemical variables such as pH or trophic status can be modelled for present day conditions and the relationships can be applied to sediment cores to reconstruct past pH or nutrient conditions. This approach has been used extensively in Europe and North America to identify environmental changes related to lake acidification and eutrophication, and to test hypotheses about their causes.

In the Antarctic the palaeolimnological approach has not been rather restricted and therefore the original proposal had the ultimate aim "to explore the potential of sediments in Antarctic lakes for reconstructing environmental change on a range of time scales". Specifically the effect of nutrient enrichment caused by increasing fur seal populations was to be examined by reconstructing the trophic status of lakes at Signy Island. A 3 stage research programme was devised:

(a) The creation of a regional diatom:water quality database for the Maritime Antarctic.

(b) The development of a series of diatom:water quality transfer functions, especially a diatom:nutrient transfer function.

(c) The application of the transfer functions to dated sediment cores from one or more selected sites.

This scheme was adopted and the original objectives have been met successfully. In two Antarctic field seasons surface sediment samples, sediment cores, and water samples were collected from a range of lakes on Livingston Island and Signy Island (Fig. 1). 59 sites were used to create a diatom:water quality data base. From this a diatom:nutrient transfer functions have been developed and applied to ^{210}Pb dated cores from 3 sites. In addition 2 long cores have been successfully ^{14}C dated, and the number of sediment cores examined in the project has been increased to include diatom analysis at a further 3 sites.

2.0 DEVELOPMENT OF METHODS AND TECHNIQUES

2.1 Diatom taxonomy

Although many diatom taxa are cosmopolitan there are a number of unique and unusual forms common in the Antarctic. In this study a total of 184 taxa were found, of which at least 40 are unknown or have not been ascribed to published taxa (a full species list is given in Appendix 1). It was therefore apparent early in the project that there was a need for a series of diatom workshops involving other diatomists working on Antarctic material, to co-ordinate existing results, and agree on a working taxonomy. An informal meeting on Antarctic and Arctic diatoms was organised at the 6th International Diatom Symposium in San Francisco (1990). This has led to a workshop at BAS (Sept. 30 - Oct. 4th 1991) and subsequent workshops in Canada (Kingston, Ontario 5-7th Oct. 1992, Ottawa 17-21st Oct. 1993). These have identified critical groups of taxa and have made recommendations for an agreed taxonomy. The reports from the workshops are included in Appendix 2.

2.2 Radiometric dating

A reliable chronology is an essential prerequisite for environmental reconstruction, and we now have an excellent chronology for sites on Signy Island. To our knowledge this is the first time ^{210}Pb chronologies, covering the past 150 years, have been obtained from the Antarctic (see 4.3.2), and a paper together with Dr P.G. Appleby is currently in preparation. For the dating of longer time periods the ^{14}C technique was used, and due to the low carbon content of the sediment, AMS (accelerator mass spectrometry) techniques were necessary. The method was successfully applied and dates obtained from both bulk mud and aquatic moss material (see 4.3.2).

2.3 Data handling

The data are stored on the ECRC DISCO database running under ORACLE on a UNIX workstation. This has facilitated rapid data analysis via transfer to commercial and inhouse packages.

3.0 PROGRESS IN RELATION TO THE SCHEDULE OF WORK

Sampling, diatom analysis, database construction and sediment dating are now completed. ^{14}C dates were not available until August 1993 therefore analysis of these results and hence the Holocene sequences is still at a preliminary stage. The data analysis and reporting of the results from three short cores is well underway with two papers in press (Jones 1993 and Jones *et al.* 1993) and a number in draft (see 7.0).

On the basis of the success of the AST project to March 1993 BAS were able to provide an extra 6 months salary for Dr V. Jones which enabled the diatom analysis of an extra 3 sites.

4.0 SUMMARY OF RESULTS AND DATA

4.1 Creation of a regional diatom:water quality database for the Maritime Antarctic

Water chemistry variables were measured at 59 sites. Principal components analysis (PCA) illustrates (Fig. 2) that the lakes from Livingston and Signy Islands have quite distinct water chemistries with the former having higher dissolved silica, and lower potassium and nitrate values than the Signy Island sites, a pattern which is probably related to geological differences between the two islands.

Surface sediment diatom assemblages at the 59 sites were grouped using classification techniques and species characterising eutrophic coastal and oligotrophic inland sites were identified (Fig. 3).

The water chemistry and diatom data were amalgamated to create a regional dataset of 59 sites. Canonical correspondence analysis (CCA) was used to assess the response of diatom species to environmental gradients (Fig. 4). Patterns of diatom distribution and abundance are clearly related to the main chemical gradients of the lakes, and conductivity, potassium, chlorophyll *a*, sodium and ammonium make significant ($p<0.05$) and independent contributions to explaining the variation in the diatom assemblages (Jones *et al.* 1993).

4.2 Development of a series of diatom:water quality transfer functions especially a diatom:nutrient transfer function.

After deletion of rare taxa the combined diatom chemistry dataset of 84 taxa and 59 sites was submitted to weighted averaging (WA) regression and calibration to develop transfer functions for all nutrient variables. A WA model was also developed for 'trophic index', a variable indicating general trophic status derived from the first component of a PCA of the nutrient chemistry. Since chemical variables and the relationships between diatom abundance and chemical gradients were highly skewed all variables were log-transformed. Preliminary data screening identified several outlying observations that had large residuals (ie. large differences between inferred and observed chemistry). Separate multivariate analysis of the unscreened modern and fossil data together show the two datasets to have similar dispersion and since the outlying samples did not strongly influence estimates of model coefficients they were retained as representing the true range of diatom / chemical variability.

After examination of the performance of each WA model (in terms of r^2 between measured and diatom inferred water chemistry and root means squared error of prediction (RMSEP)) the following predictive models were retained: NH_4, Chlorophyll-a, total phosphorous and trophic index. Table 1 lists summary statistics for all taxa used in the WA models, together with their optima and tolerances for these four chemical variables. Figures 5-8 show plots of optima and tolerances for the most abundant taxa and illustrate their distribution along these chemical gradients.

Results of the performance of the WA models are listed below and, together with the Figures 9-12, illustrate the highly significant relationships between observed and diatom inferred chemistry for all selected variables.

Variable	RMSEP	r^2
NH_4	0.33	0.64
Chlorophyll a	0.31	0.68
Total phosphorous	0.39	0.61
Trophic index.	0.43	0.81

4.3 Application of the transfer function to dated sediment cores from selected sites

This involved a number of stages

4.3.1 Sediment coring

Short Kajak cores (up to 40 cm long) were taken from 38 sites on Livingston Island, lithostratigraphic measurements (dry weight, loss on ignition and wet density) were made on all cores and the sediment dried and archived for future use. Signy Island sites were chosen for environmental reconstruction and a series of Kajak and longer sequences (Livingstone cores) were taken from 10 lakes, lithostratigraphic measurements were made and cores were archived for future use.

4.3.2 Radiometric dating

(i) ^{210}Pb dating

This has been completed for 3 cores by Dr P.G. Appleby, Department of Mathematics and Theoretical Physics, University of Liverpool. The analysis for two sites (Sombre and Heywood Lakes) was funded from the AST, whilst additional funding for the third site was provided by BAS. At Heywood Lake sediment accumulation rates were fairly constant up to ca. 1955-1960 and since 1960 there has been a major increase in accumulation rates, including a very high period in the mid 1970s. The mean sediment accumulation rate since the mid 1970s is 3 times the pre-1955 value (Fig. 13). At Sombre Lake sediment accumulation rates were stable up to c. 1950, since then sediment accumulation rates have increased about 3 fold, including an episode of very rapid accumulation in the early 1960s. Moss Lake was more difficult to date using the ^{210}Pb method and the chronology in Fig. 13 is based on the ^{137}Cs profile. Results suggest a very low accumulation rate below 6cm with higher sediment accumulation from c. 1958 onwards. However, these results are rather speculative and need to be confirmed by dating a second core.

(ii) ^{14}C dating

Long (>2.5m) sequences from Sombre and Heywood Lakes were dated using the AMS ^{14}C technique by the NERC facility at East Kilbride (Figs 14 & 15). The results suggest that organic sediment began to accumulate in both lakes at approximately the same time, with basal dates of 6125+-55 BP for Sombre Lake and 5890+-55 BP for Heywood Lake. These dates probably represent the approximate onset of deglaciation in this area. The Holocene sediment accumulation rates for the two sites are also similar. At both sites aquatic moss remains give consistently younger ^{14}C ages when compared to the bulk dates which are probably influenced by older carbon from catchment sources.

4.3.3 Diatom analysis and the application of a nutrient transfer function

(i) Heywood Lake

Diatom analysis shows little change in the structure of the diatom assemblage which is dominated by *Achnanthes renei*, *Navicula seminulum* and *Navicula australomediocris* over the last c. 300 years (Fig. 16). Chlorophyll *a* reconstructions using the diatom model suggest that values have been relatively stable over this period. However, the reconstructed value of 3μgl^{-1} at the surface does not compare very well with the measured chlorophyll *a* value of 9.9 μgl^{-1}. This is because species such as *N. seminulum* and *N.australomediocris* which are common in the core have relatively low optima for chlorophyll *a*, and it is therefore probable that factors other than nutrients (eg. light, availability of habitats) influence the composition of the diatom assemblage at this site.

A complete sediment sequence from this site (Fig. 17) suggests that chlorophyll *a* values were higher below 70 cm, before about 2000 years BP.

(ii) Sombre Lake

The diatom assemblages show considerable changes in the recent past (Fig. 18) with a clear increase in *Cymbella minuta* and declines in the abundances of *Navicula seminulum* and *Achnanthes renei.* Chlorophyll *a* reconstructions suggest that an increase in chlorophyll *a* has occurred from about 1980 from a value of 2 to 7 μgl^{-1}. The modern measured value is 6.8μgl^{-1}.

Over a Holocene time scale the results of diatom analysis (Fig. 19) show many shifts in community composition (Jones 1993) and trophic reconstruction suggests that chlorophyll *a* values have fluctuated. There is a evidence for higher values below 70 cm, before about 2100 years BP.

(iii) Moss Lake

The diatom assemblages are fairly stable at this site in the recent past (Fig. 19) although there is an decline in the abundance of *F. virescens* var. *exigua* and *N. seminulum* var. *radiosa* and an increase in *A. minutissima.* Reconstructed chlorophyll *a* values are stable at about 2 μgl^{-1} throughout the period, the current measured chlorophyll *a* value is 1.8 μgl^{-1}. Over a longer time period (Fig. 20) diatom evidence suggests that chlorophyll *a* values may have fluctuated between 1 and 3 μgl^{-1}.

(iv) Amos, Gneiss and Tranquil Lakes

Short cores from these sites have also been analyzed for diatoms. Radiometric dating has not been undertaken at these sites. There are few changes in the diatom assemblages in the recent past at Amos Lake (Fig. 21) and results of chlorophyll *a* reconstruction suggest that the lake has been relatively nutrient rich for some time. Gneiss and Tranquil Lakes (Figs. 22 & 23) show considerable fluctuations in their diatom assemblages which probably reflect catchment changes rather than changes in water quality. The results of Chlorophyll *a* reconstruction suggest that these site have always been nutrient poor.

5.0 CONCLUSIONS REACHED

Antarctic lake sediments are suitable for palaeoecological investigations, and can be used at decadal to millennial time scales for environmental reconstruction.

Results of trophic reconstruction (chlorophyll *a*) are available from 6 lakes. Synchronous changes in nutrient status in the past may be related to climate and/or animal populations. There is evidence for a recent (last 10 years) increase of nutrients at Sombre Lake which corresponds with a measured increase in total phosphate values, associated with an increase in the fur seal population. However, at Heywood and Amos Lakes where fur seals have also expanded, there is no diatom floristic evidence or reconstructed chlorophyll *a* data for nutrient enrichment, and some other factor must be determining the composition of the diatom assemblages at these sites eg. light, or habitat availability. At Moss, Gneiss and Tranquil lakes, there is no evidence for an increase in chlorophyll *a* levels, and these sites are not presently affected by fur seals, and have no measured increase in phosphate values.

For longer time periods nutrient reconstruction is more problematic because some of the diatom species do not have good analogues in the surface sediment data set. However, the preliminary results of this project suggest that nutrient levels were possibly higher than today at times in the past in lakes on Signy Island.

6.0 FUTURE LINES OF RESEARCH ARISING FROM THE PROJECT

These have taken a number of directions

(a) The award of a NERC/CASE studentship with BAS (GT4/93/2776/G) to Prof. R.W. Battarbee and Dr V.J. Jones "Palaeolimnology and climate change in Antarctica". The studentship will further the lithostratigraphic and dating work on long cores analyzed in this project.

(b) There will be continued collaboration with BAS on palaeolimnology. For example, another core (Tranquil Lake) is currently being ^{210}Pb dated. Samples already obtained will also provide an excellent opportunity to examine recent climate change and deglaciation at Signy Island. Together with Dr C. Ellis-Evans a diatom:water quality transfer function is currently being created for the Larseman and Vestfold Hills in the Eastern Antarctic, this will provide comparison between continental and maritime situations, as well as extending the geographical range of the training set.

(c) The Antarctic/Arctic diatom taxonomy workshops will continue, with a view to the production of a diatom iconograph. Careful taxonomic harmonization is essential for biogeographical studies of polar regions, and for comparisons of recent pollution histories. It will also enable the diatom transfer functions derived in this project to be used by other workers in the Antarctic.

7.0 PUBLICATIONS LIST

Jones, V.J., Juggins, S. & Ellis-Evans J.C. (1993). The relationship between water chemistry and surface sediment diatom assemblages in maritime Antarctic lakes. *Antarctic Science* 5 (4) (in press)

Jones, V.J. (1993). The use of diatoms in lake sediments to investigate environmental history in the maritime Antarctic: an example from Sombre Lake, Signy Island. *Antarctic Special Topic* (in press)

<u>Papers in draft</u>
Jones, V.J. & Appleby P.G. ^{210}Pb dating of Antarctic lake sediments from Signy Island, South Orkney Islands. To be submitted to the Journal of Palaeolimnology.

Jones, V.J. & Juggins, S. A diatom nutrient transfer function for the maritime Antarctic. To be submitted to Freshwater Biology.

Jones, V.J. Diatom taxonomy and Ecology in the maritime Antarctic. To be submitted to Bibliotheca Diatomologia.

Jones, V.J. Holocene environmental change on Signy Island. To be submitted to The Holocene.

8.0 ADDITIONAL COMMENTS

This project has evolved almost entirely as it was designed and has been extremely successful in meeting its aims and objectives. We would like to thank BAS for providing logistical support, for funding Dr V.J. Jones for a further 6 month period, and for providing additional funds for both ^{210}Pb dating and conference expenses.

The results of project are very timely given the developing interest in Antarctic palaeolimnology by other workers. There are major opportunities for this kind of work in other parts of the Antarctic, especially related to studies of climate change, and we are very enthusiastic to maintain the momentum this special topic has generated.

Table 1 List of occurrences, abundances and tolerances for the species used in the Transfer function.

TaxonId	Taxon	No. occur	Max. abun	N2	Lower-tol	Chlorophyll-a	Upper-tol	Lower-tol	NH4	Upper-tol	Lower-tol	Total P	Upper-tol	Lower-tol	Trophic index	Upper-tol
						Optimum			Optimum			Optimum			Optimum	
AC001A	Achnanthes lanceolata	48	18.9	23.7	0.28	0.72	1.83	1.36	4.26	13.37	1.14	3.98	13.94	-1.24	-0.49	0.27
AC008A	Achnanthes exigua	12	4.4	5.5	0.20	0.38	0.72	0.50	1.25	3.17	0.75	2.28	6.91	-1.38	-1.00	-0.63
AC013A	Achnanthes minutissima	31	49.0	7.2	0.81	1.64	3.34	2.20	4.79	10.45	3.68	6.67	12.10	-0.47	-0.03	0.41
AC016A	Achnanthes delicatula	62	12.7	26.4	0.51	1.67	5.43	2.77	14.15	72.33	2.13	11.98	67.28	-0.82	0.37	1.55
AC031A	Achnanthes rostrata	1	2.5	1.0		5.17			95.00			7.50			1.51	
AC040A	Achnanthes pinnata	18	17.1	8.1	2.08	3.96	7.52	8.93	49.13	270.16	16.57	72.43	316.53	0.48	1.56	2.63
AC135A	Achnanthes mollis	46	22.0	19.3	0.20	0.72	2.58	0.95	3.35	11.77	1.58	4.85	14.94	-1.26	-0.42	0.43
AC136A	Achnanthes subatomoides	48	40.4	9.9	0.35	1.62	7.58	2.36	12.23	63.51	2.72	15.52	88.49	-0.65	0.47	1.59
AC137A	Achnanthes incognita	33	9.9	9.8	0.19	0.68	2.51	1.79	5.41	16.29	2.15	4.58	9.78	-0.84	-0.25	0.34
AC138A	Achnanthes germainii	26	1.9	17.6	0.29	1.02	3.61	1.97	7.64	29.66	1.45	7.24	36.17	-0.83	0.05	0.92
AC144A	Achnanthes renei	47	35.3	14.5	0.50	2.13	9.01	2.72	10.58	41.24	2.59	13.26	67.92	-0.57	0.53	1.63
AC145A	Achnanthes metakryophila	63	26.6	29.2	0.26	0.68	1.80	0.96	3.28	11.13	1.22	3.52	10.13	-1.23	-0.58	0.08
AM004A	Amphora veneta	9	1.1	5.9	0.84	1.81	3.92	3.73	6.82	12.47	4.72	7.94	13.37	-0.41	0.13	0.66
BR001A	Brachysira vitrea	1	2.1	1.0		0.55			0.50			9.00			-0.90	
BR008A	Brachysira minor	41	6.9	22.1	0.24	0.53	1.19	1.14	2.98	7.84	0.93	3.33	11.98	-1.18	-0.66	-0.14
CA002A	Caloneis bacillum	40	6.4	19.1	0.33	0.78	1.82	0.95	3.34	11.75	2.12	5.00	11.83	-1.12	-0.46	0.20
CM031A	Cymbella minuta	12	43.2	4.4	1.86	3.08	5.09	7.16	11.31	17.87	8.61	11.38	15.04	0.26	0.60	0.94
FR001A	Fragilaria pinnata	52	46.1	19.0	0.22	0.50	1.10	0.55	1.67	5.06	0.98	3.43	11.96	-1.38	-0.84	-0.30
FR002B	Fragilaria construens var. binodis	21	41.9	7.5	2.51	5.14	10.56	7.71	18.56	44.69	11.94	30.57	78.27	0.39	0.87	1.34
FR002C	Fragilaria construens var. venter	4	1.3	2.6	1.49	4.82	15.52	5.00	14.06	39.57	7.17	22.10	68.09	-0.00	0.71	1.43
FR005D	Fragilaria virescens var. exigua	26	17.1	8.6	0.22	1.31	7.73	3.06	7.07	16.34	3.50	7.91	17.89	-0.85	0.03	0.90
FR018A	Fragilaria elliptica	1	5.7	1.0		9.99			49.60			131.74			2.16	
GO003A	Gomphonema angustatum	18	20.2	2.9	0.95	1.58	2.61	3.88	12.33	39.20	3.58	10.03	28.16	-0.31	0.38	1.07
GO003B	Gomphonema angustatum var. productum	6	2.3	3.8	1.54	2.65	4.57	3.71	32.03	276.64	2.82	30.02	319.98	-0.31	1.16	2.64
GO004A	Gomphonema gracile	36	2.7	18.7	0.48	1.14	2.71	0.77	4.54	26.83	1.31	6.51	32.37	-1.19	-0.14	0.92
GO013A	Gomphonema parvulum	40	5.9	22.4	0.69	2.28	7.56	1.87	8.39	37.75	2.81	12.87	58.90	-0.65	0.37	1.40
NA005A	Navicula seminulum	54	56.1	17.4	0.13	0.49	1.87	0.71	2.73	10.47	1.45	4.76	15.58	-1.42	-0.61	0.20
NA005C	Navicula seminulum var. radiosa	16	36.9	6.2	0.81	1.99	4.92	1.42	7.00	34.56	1.91	9.07	43.14	-0.58	0.45	1.48
NA007B	Navicula cryptocephala var. veneta	43	15.0	15.4	0.28	0.90	2.87	0.74	3.36	15.22	2.72	7.06	18.29	-1.10	-0.31	0.48
NA023A	Navicula gregaria	57	35.6	15.7	0.74	2.17	6.35	2.84	14.78	76.93	3.08	13.89	62.69	-0.55	0.52	1.60
NA025A	Navicula mutica	5	1.0	3.1	1.12	2.90	7.49	2.53	15.55	95.48	2.28	17.71	137.35	-0.17	1.01	2.18
NA036A	Navicula perpusilla	41	7.6	15.1	0.13	0.47	1.72	1.42	4.07	11.62	1.45	4.07	11.43	-1.31	-0.68	-0.05
NA045A	Navicula bryophila	5	4.9	2.1	1.00	1.74	3.03	1.04	3.24	10.04	4.03	5.85	8.49	-0.72	-0.14	0.45
NA046A	Navicula contenta	23	4.0	7.6	0.35	0.68	1.33	1.12	2.85	7.23	1.37	3.67	9.80	-1.06	-0.66	-0.26
NA056A	Navicula cuspidata	6	1.2	3.6	0.50	1.41	3.99	1.21	7.58	47.45	1.22	8.64	61.10	-1.03	0.23	1.50
NA057A	Navicula elginensis	21	1.2	14.4	0.28	1.34	6.31	1.97	11.45	66.38	2.63	14.54	80.41	-0.88	0.36	1.59
NA066B	Navicula capitata var. hungarica	37	16.9	13.8	0.58	1.88	6.09	2.82	11.41	46.07	2.13	9.19	39.65	-0.68	0.25	1.19
NA084A	Navicula atomus	37	7.5	12.2	0.69	1.94	5.47	4.85	34.55	246.05	4.29	34.18	272.22	-0.29	1.08	2.44
NA086A	Navicula tantula	34	38.2	13.0	0.39	0.66	1.10	0.71	2.12	6.34	1.77	3.98	8.94	-1.25	-0.73	-0.22
NA150A	Navicula naumanii	32	8.2	8.1	0.30	1.05	3.69	1.24	4.34	15.27	1.55	4.17	11.22	-1.05	-0.25	0.56
NA734A	Navicula australomediocris	40	17.1	21.4	0.37	1.21	3.89	2.33	8.50	30.99	1.58	7.79	38.40	-0.94	0.15	1.25
NA735A	Navicula tabellariaeformis	5	3.6	1.7	0.24	0.95	3.73	1.37	5.41	21.38	1.93	5.09	13.38	-0.81	0.03	0.86
NA740A	Navicula bicephala	5	1.2	3.2	1.09	2.01	3.72	1.34	5.02	18.78	2.31	13.16	74.77	-0.65	0.08	0.81
NI005A	Nitzschia perminuta	67	21.5	36.4	0.48	1.49	4.58	1.56	7.80	39.00	2.17	9.86	44.77	-0.85	0.18	1.21
NI008A	Nitzschia frustulum	59	50.7	13.5	0.17	0.90	4.73	2.14	9.28	40.26	3.04	8.98	26.55	-1.07	-0.02	1.04
NI009A	Nitzschia palea	26	2.5	12.1	0.80	2.45	7.49	2.66	20.35	155.67	3.36	27.55	225.64	-0.48	0.92	2.32
NI017A	Nitzschia gracilis	53	16.7	16.8	0.59	1.83	5.66	1.79	7.02	27.59	1.39	8.26	49.04	-0.76	0.10	0.97
NI033A	Nitzschia paleacea	38	60.0	6.8	0.36	0.96	2.58	1.92	5.89	18.03	1.61	5.08	15.96	-1.24	-0.40	0.45
NI197A	Nitzschia hamburgiensis	31	11.8	9.4	0.85	2.34	6.47	1.90	7.70	31.18	1.59	10.77	72.93	-0.69	0.23	1.15
PI008A	Pinnularia divergens	5	1.4	2.3	0.13	0.58	2.58	0.93	2.37	6.00	0.47	2.26	10.85	-1.50	-0.65	0.21
PI011A	Pinnularia microstauron	46	6.4	23.1	0.87	2.35	6.37	2.92	13.52	62.55	3.73	17.71	84.01	-0.30	0.66	1.63
PI011G	Pinnularia microstauron var. brebissonii	4	1.3	3.3	1.13	3.98	14.00	6.26	9.41	14.15	7.96	12.33	19.09	0.22	0.58	0.93
PI022A	Pinnularia subcapitata	25	1.1	16.5	0.41	1.15	3.22	1.44	6.75	31.60	1.03	5.58	30.34	-1.10	-0.04	1.01
PI169A	Pinnularia ignobilis	18	3.2	10.1	0.22	0.59	1.55	2.01	6.21	19.18	1.74	4.06	9.46	-0.87	-0.23	0.40
SA001A	Stauroneis anceps	44	14.3	19.0	0.32	1.50	6.99	1.19	5.29	23.43	1.47	6.68	30.30	-0.88	0.15	1.18

onId	Taxon					Chlorophyll-a			NH4			Total P			Trophic Index	
		No. occur	Max. abun	N2	Lower-tol	Optimum	Upper-tol	Lower-tol	Optimum	Upper-tol	Lower-tol	Optimum	Upper-tol	Lower-tol	Optimum	Upper-tol
06A	Stauroneis phoenicenteron	16	5.2	3.7	0.52	1.45	4.03	2.12	8.44	33.52	2.46	9.62	37.59	-0.70	0.22	1.13
02A	Synedra rumpens	68	36.5	28.4	0.60	2.10	7.30	2.56	7.66	22.94	2.12	8.45	33.73	-0.54	0.30	1.13
940	Temporary sp. 60	22	4.7	9.7	0.31	0.70	1.58	0.50	1.79	6.35	1.36	4.12	12.52	-1.34	-0.61	0.11
941	Temporary sp 59	18	4.7	8.6	0.25	0.49	0.97	0.98	2.21	4.97	0.98	3.56	12.93	-1.05	-0.74	-0.44
944	Temporary sp. 56	13	3.5	5.4	0.38	0.54	0.76	0.41	1.36	4.47	1.03	2.82	7.74	-1.24	-0.81	-0.39
946	Temporary sp. 54	22	2.2	13.2	0.25	0.78	2.46	1.72	6.60	25.25	1.63	6.10	22.82	-1.12	-0.28	0.56
947	Temporary sp. 53	31	13.3	10.6	0.83	2.44	7.12	5.04	14.09	39.34	2.99	17.61	103.73	-0.30	0.55	1.41
948	Temporary sp 52	8	1.4	4.8	0.32	0.76	1.77	0.47	2.50	13.38	0.95	3.30	11.49	-1.55	-0.63	0.29
950	Temporary sp 50	1	6.5	1.0		0.09			0.50			1.00			-1.21	
952	Temporary sp 48	10	4.8	4.0	1.47	3.69	9.29	3.60	17.37	83.81	3.39	13.63	54.84	-0.31	0.67	1.65
953	Temporary sp 47	2	1.8	1.2	0.93	1.02	1.11	2.14	2.72	3.44	4.25	5.12	6.17	-0.68	-0.54	-0.40
955	Temporary sp. 45	5	6.1	3.5	3.26	5.13	8.07	18.37	37.12	75.01	8.68	26.10	78.51	0.72	1.09	1.46
957	Temporary sp. 43	4	2.3	3.4	2.51	4.44	7.85	16.71	21.67	28.11	10.78	33.75	105.64	0.64	0.89	1.14
959	Temporary sp. 41	6	2.5	2.9	3.21	4.84	7.30	15.78	21.19	28.45	29.03	80.99	225.95	0.82	0.96	1.10
960	Temporary sp 40	3	1.0	1.8	3.26	5.63	9.72	20.92	28.50	38.84	27.54	54.97	109.73	0.70	0.99	1.27
961	Temporary sp. 39	1	1.2	1.0		4.58			34.00			20.50			1.08	
962	Temporary sp. 38	1	1.7	1.0		5.17			95.00			7.50			1.51	
963	Temporary sp. 37	1	1.7	1.0		8.70			16.33			33.70			1.06	
964	Temporary sp. 36	11	2.5	5.5	0.09	0.57	3.77	2.32	6.54	18.46	0.50	3.24	21.13	-1.27	-0.24	0.80
969	Temporary sp. 31	2	2.9	1.4	3.11	3.54	4.02	222.43	273.85	337.16	259.51	302.70	353.08	2.51	2.60	2.70
975	Temporary sp. 25	28	3.6	13.3	0.22	1.24	6.84	1.34	4.23	13.35	2.25	6.88	21.08	-1.19	-0.27	0.65
976	Temporary sp. 24	2	1.1	2.0	1.01	1.89	3.54	4.41	27.69	173.99	5.51	44.54	360.01	0.05	0.96	1.87
977	Temporary sp. 23	45	13.1	19.0	0.36	0.99	2.69	1.24	3.75	11.31	1.98	5.05	12.84	-1.00	-0.34	0.32
978	Temporary sp. 22	38	6.4	13.2	0.41	1.33	4.39	1.27	4.56	16.34	2.26	6.05	16.19	-0.94	-0.15	0.64
980	Temporary sp. 20	4	2.4	1.9	0.92	1.75	3.31	5.97	9.85	16.24	6.95	8.11	9.47	-0.10	0.20	0.50
986	Temporary sp. 14	27	1.2	19.2	0.46	1.47	4.68	1.93	10.72	59.54	1.61	12.19	92.30	-0.94	0.26	1.47
988	Temporary sp. 12	25	24.3	4.2	0.44	1.66	6.21	2.31	9.74	40.97	1.59	10.24	65.90	-0.85	0.33	1.52
992	Temporary sp. 8	53	8.4	34.7	0.38	1.23	4.05	1.30	6.81	35.63	1.54	8.57	47.69	-0.98	0.13	1.23
996	Temporary sp. 4	51	10.9	14.0	0.48	1.22	3.06	1.56	5.62	20.33	1.68	5.06	15.24	-0.70	0.12	0.93

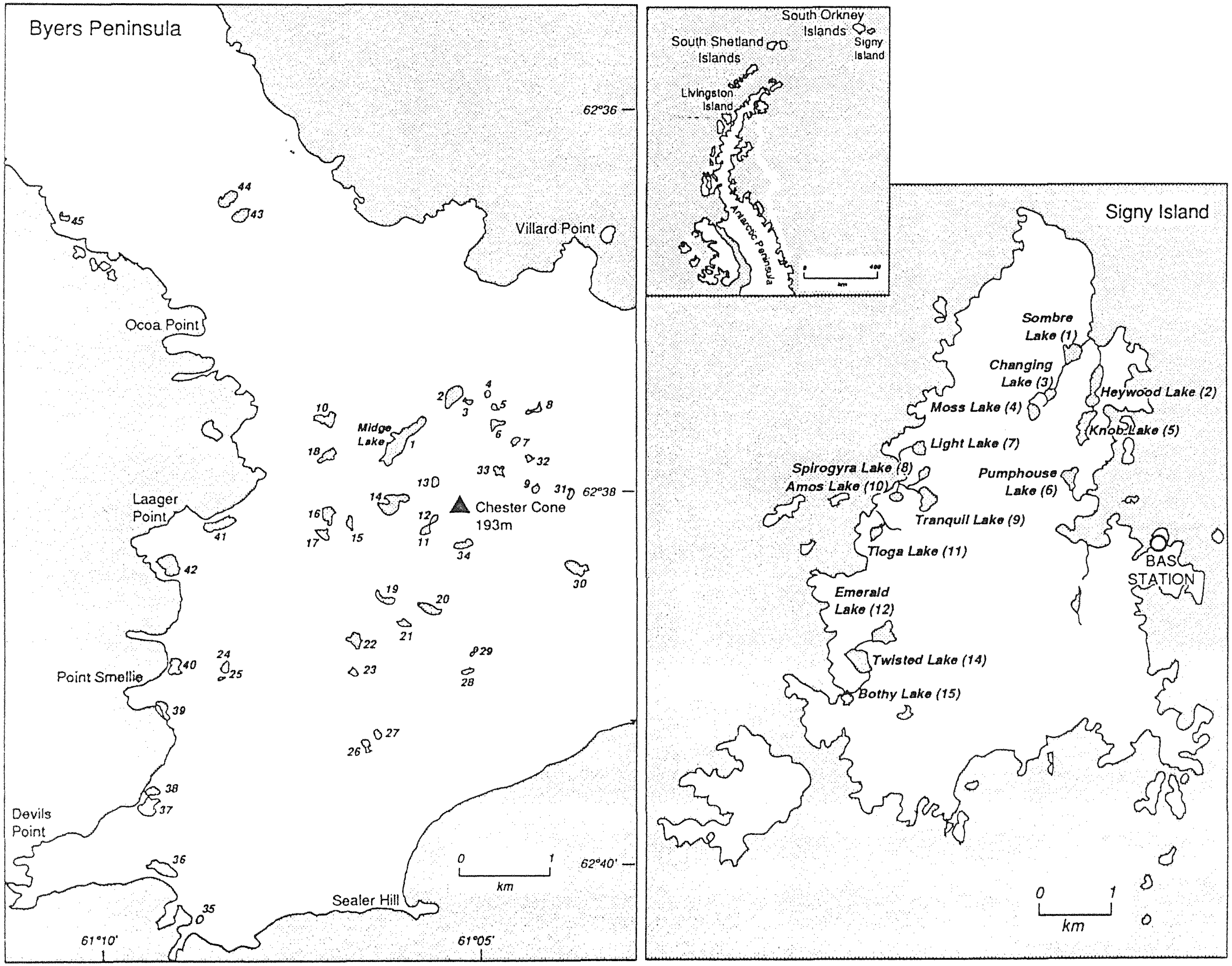


Figure 1 Location of the study sites

Figure 2 Principal components analysis (PCA) correlation biplot. Symbols for lake sites are according to the groups defined by cluster analysis (see inset). LN=Livingston Island sites SG=Signy Island sites.

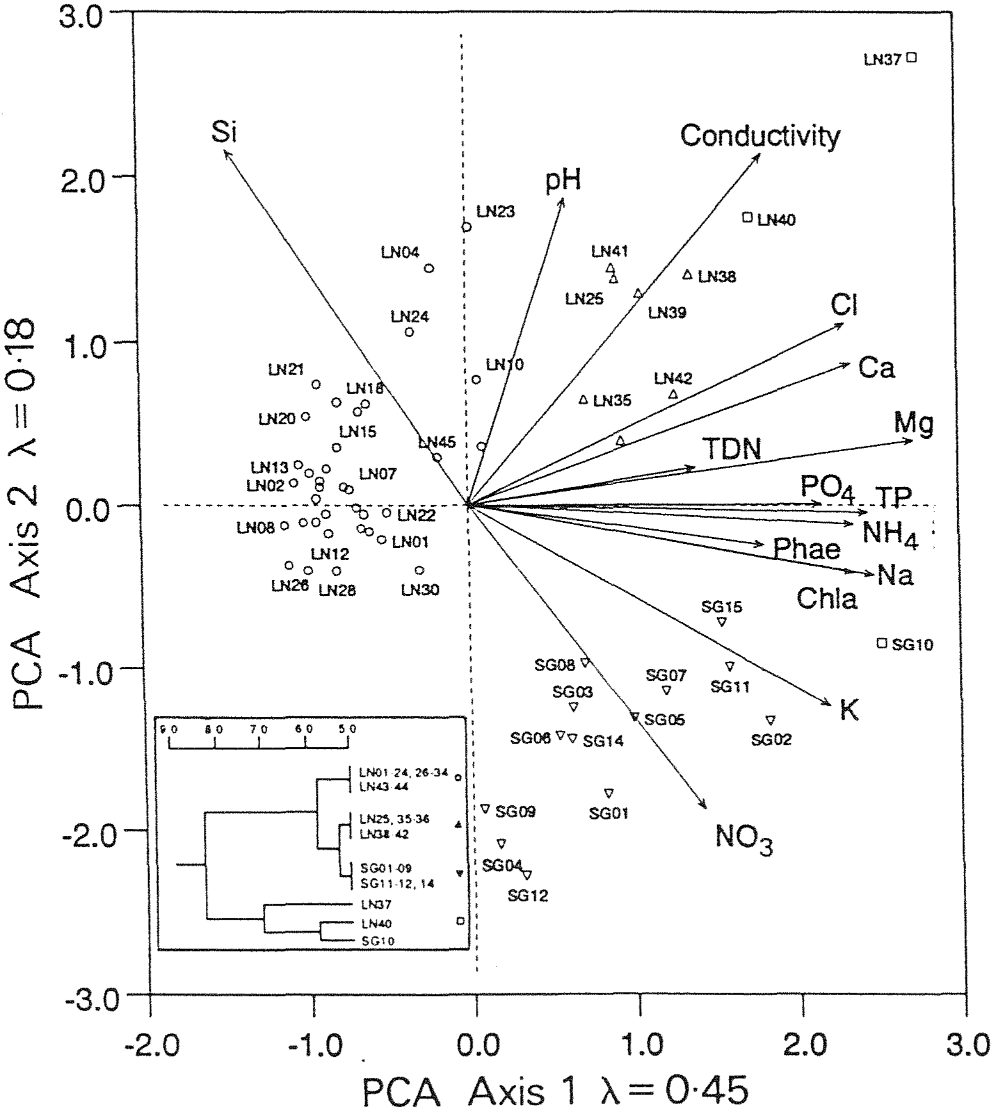
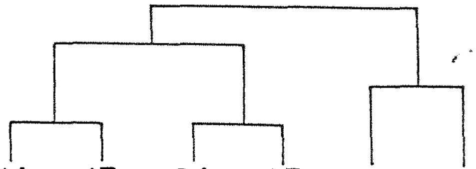


Figure 3 TWINSPAN results showing groups of sites (top) and associated mean percentage diatom abundances.+<2%○2-5%◯5-10%●>10%
Group 1A= Sites SG2, SG5-6, SG8, SG10-11, SG15 Group 1B=SG1, SG3-4, SG7, SG9, SG12-14 Group 2A=LN1-7, LN9-10, LN14-19, LN21-24, LN27, LN31 Group 2B=LN8, LN11-13, LN20, LN26, LN28-30 LN32-34, LN36, LN43-45 Group 3A=LN35, LN38-40 Group 3B=LN25, LN37, LN41-42.



	1A	1B	2A	2B	3A	3B
Achnanthes pinnata	◯	+				
Cymbella minuta	+	◯				
Achnanthes minutissima	+	●	+			
Navicula sp. 2	○	○		+		
Achnanthes subatomoides	◯		+	○		
Gomphonema anglgracile	○	○	+	○		
Stauroneis anceps	+	○	○			
Achnanthes renei	●	+	○	◯		
Achnanthes mollis	○	○	○	+		
Navicula seminulum	◯	◯	●	○		
Fragilaria vaucheriae		○	+	+	+	
Nitzschia perminuta	◯	◯	○	○	◯	◯
Pinnularia microstauron	○				○	
Synedra rumpens	◯	○	+	○	○	+
Navicula cf. australomediocris	○		+	+		
Navicula cf. atomus	○			+	+	+
Fragilaria pinnata	+	+	●	◯		
Navicula australomediocris	○	+	+	◯		
Navicula cryptocephala var. veneta		+	○		+	+
Navicula tantula			◯	○		
Brachysira minor			○	+	+	
Achnanthes delicatula	◯		+	○	+	◯
Achnanthes metakryophila	+	○	○	●	+	+
Nitzschia paleacea			○	○	◯	+
Nitzschia gracilis	+	+	+	○	◯	+
Achnanthes lanceolata			○	○	○	+
Nitzschia frustulum	○	+	○	+	○	●
Navicula gregaria	○	+	○	+	●	●
Nitzschia hamburgiensis				+	◯	
Fragilaria construens var. binodis	+	○			●	◯
Pinnularia sp. 1				+	◯	+
Navicula capitata var. hungarica			+	○	○	●

Figure 4 Canonical correspondence analysis (CCA) ordination diagram showing the relationship between sites and (a) environmental gradients and (b) diatom species. In (a) the sites are grouped according to the TWINSPAN results.

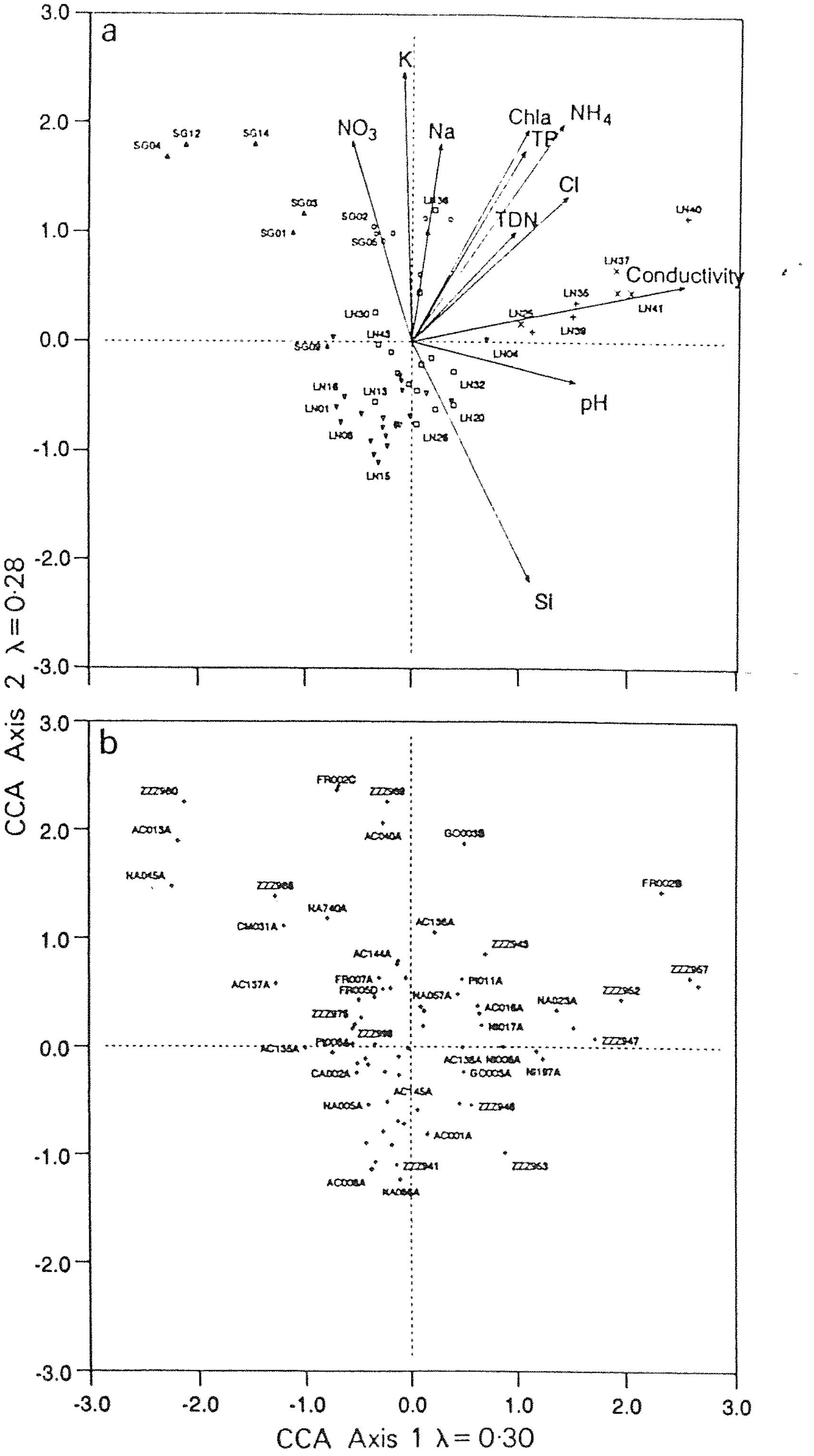


Figure 5 Species relationships with chlorophyll *a*, illustrating optima and tolerances.

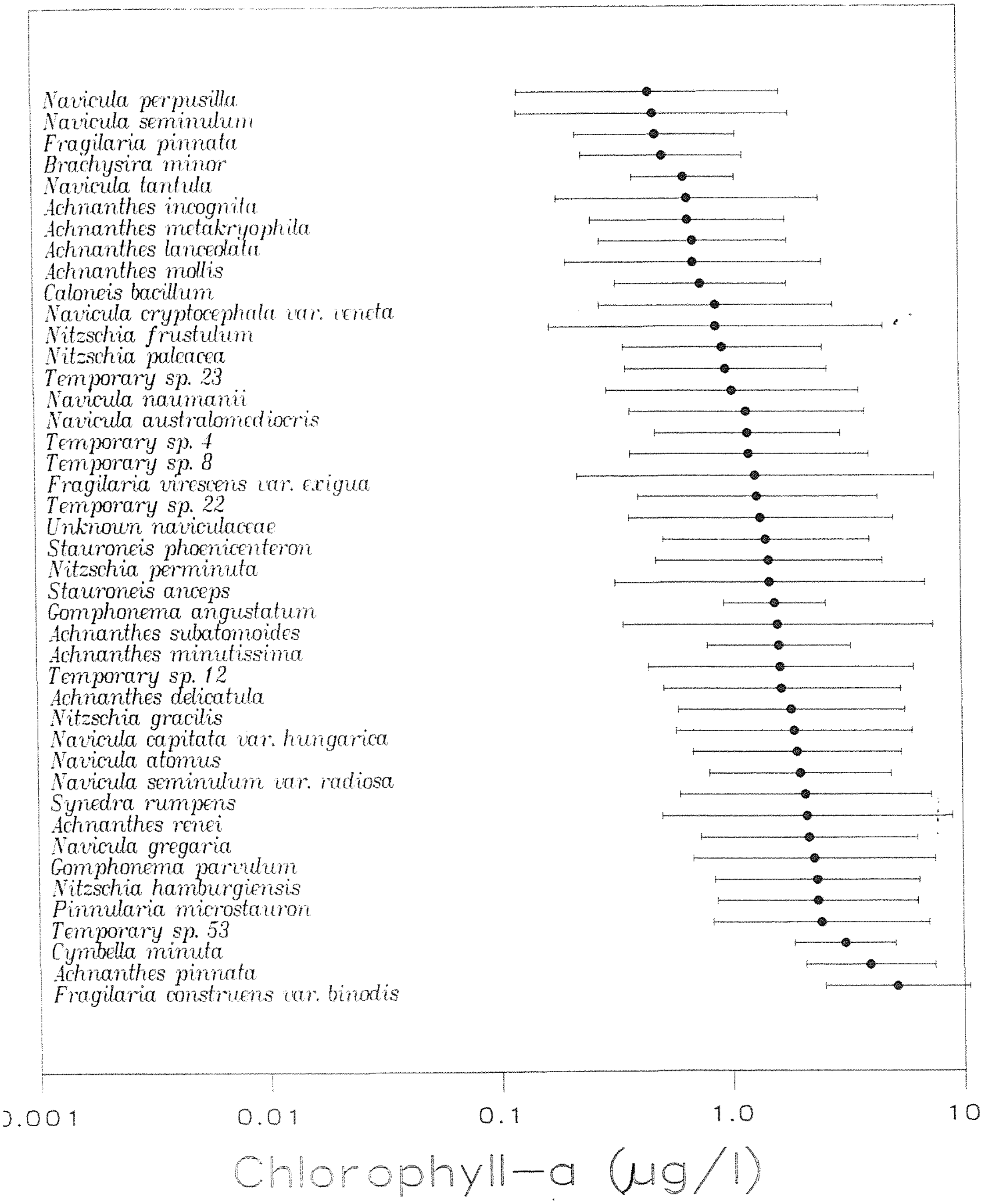


Figure 6 Species relationships with total phosphate, illustrating optima and tolerances.

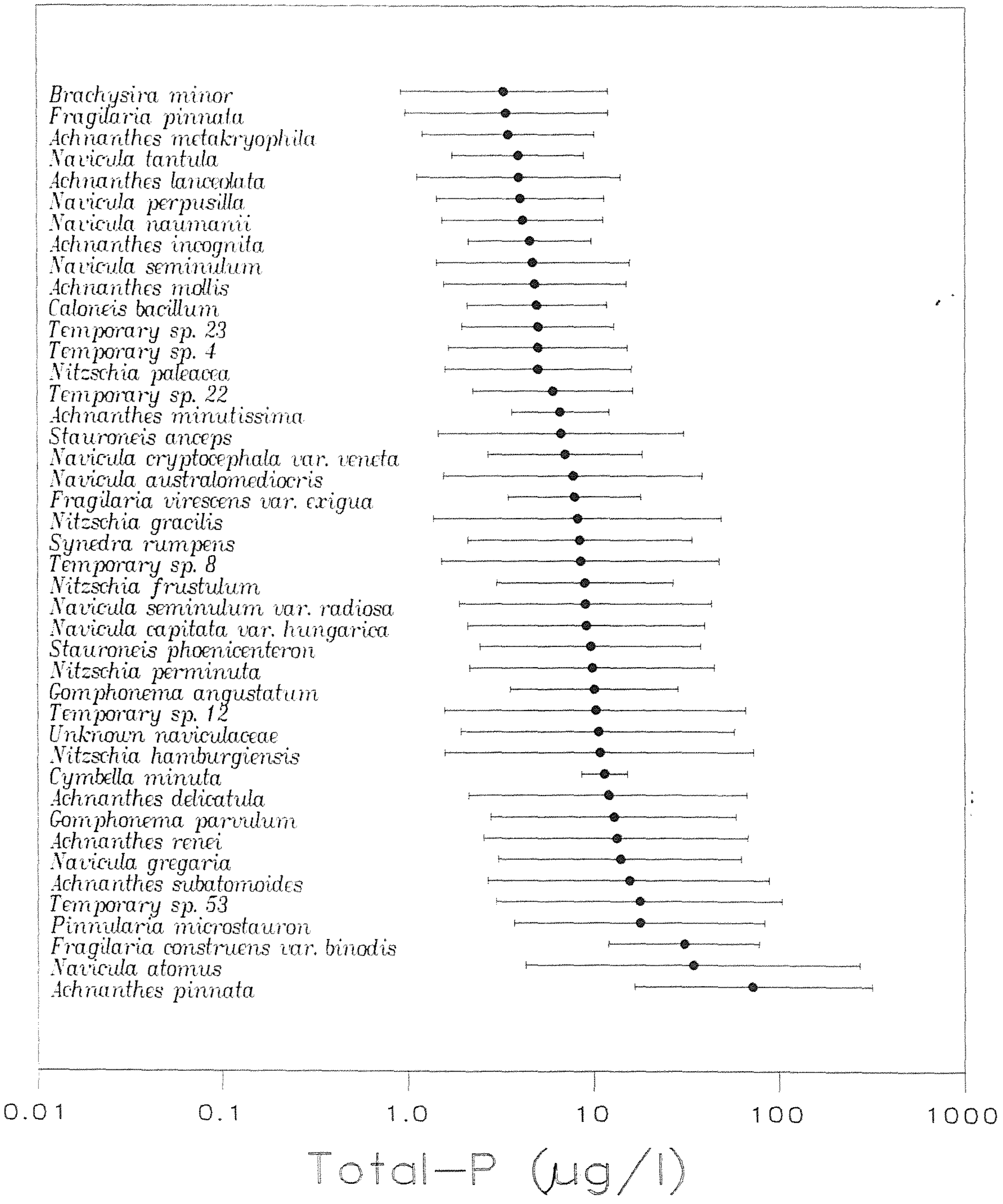


Figure 7 Species relationships with ammonium, illustrating optima and tolerances.

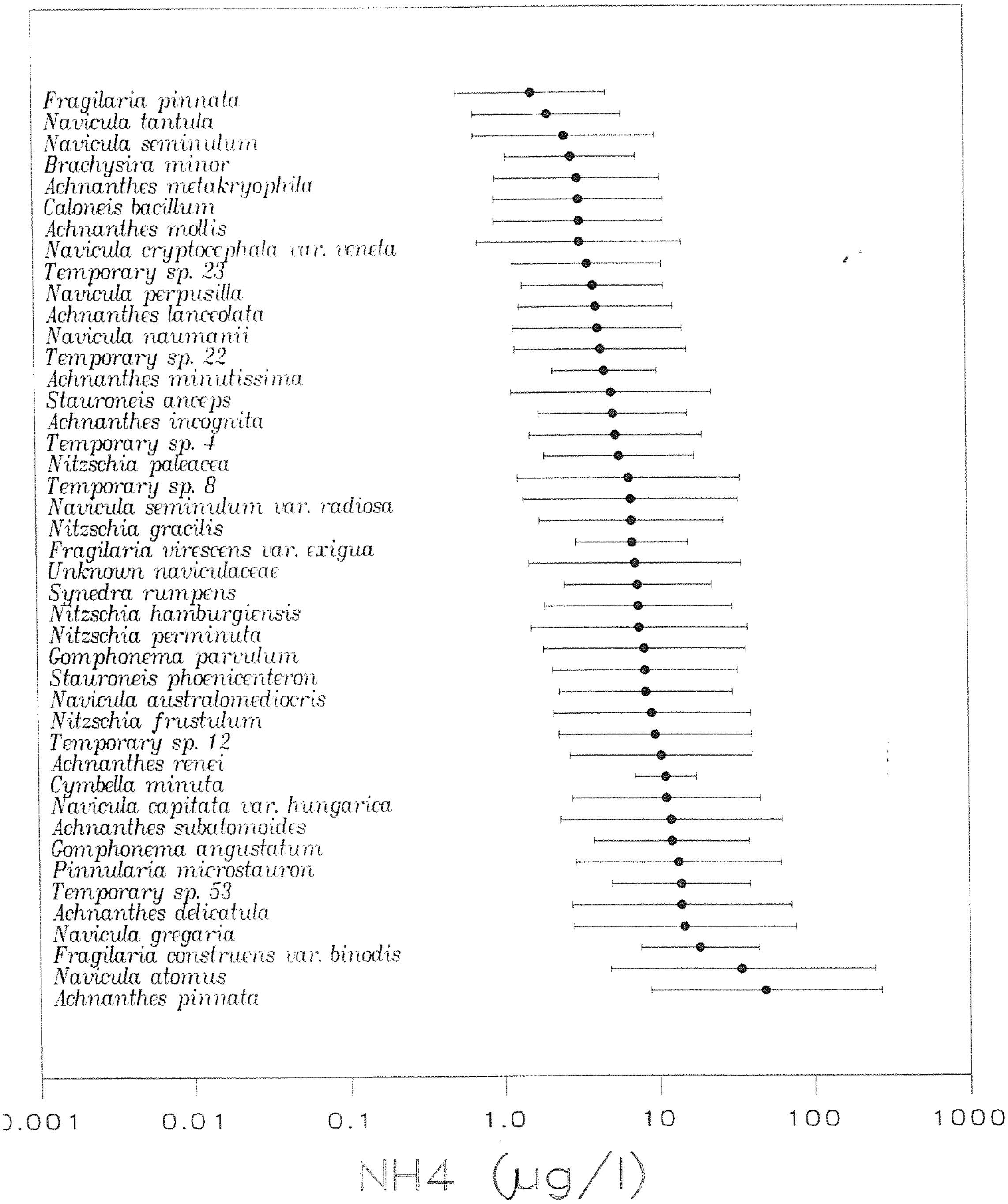


Figure 8 Species relationships with the Trophic Index, illustrating optima and tolerances.

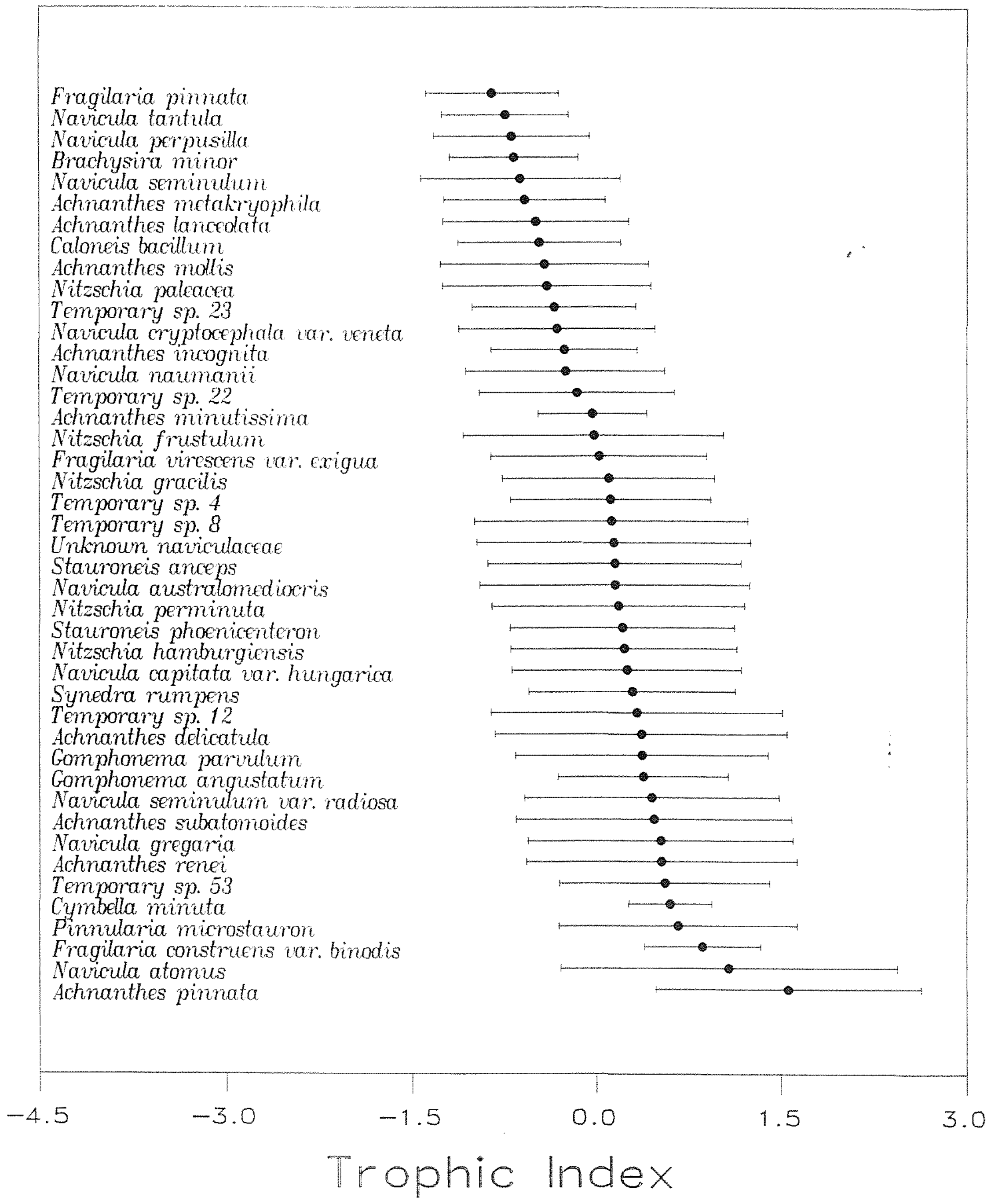


Figure 9 Observed versus estimated values for chlorophyll *a*.

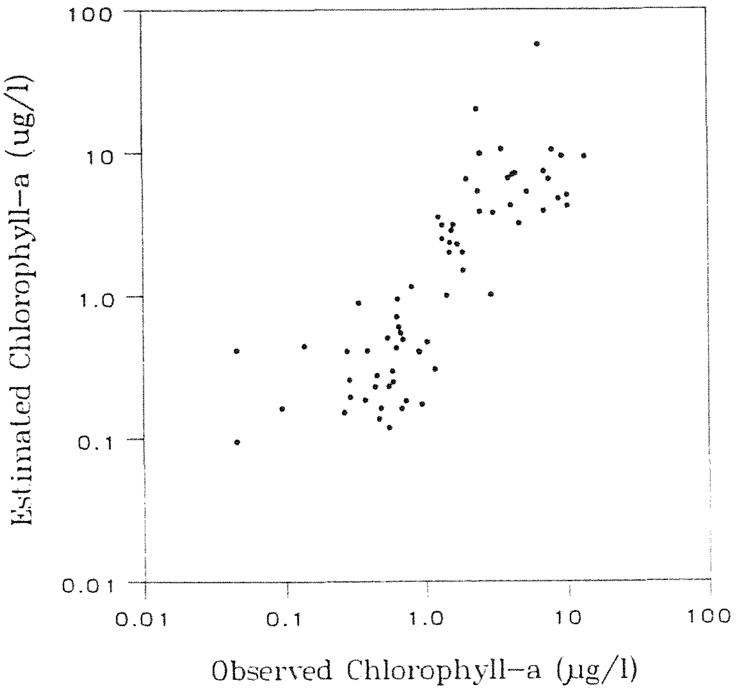


Figure 10 Observed versus estimated values for total phosphate.

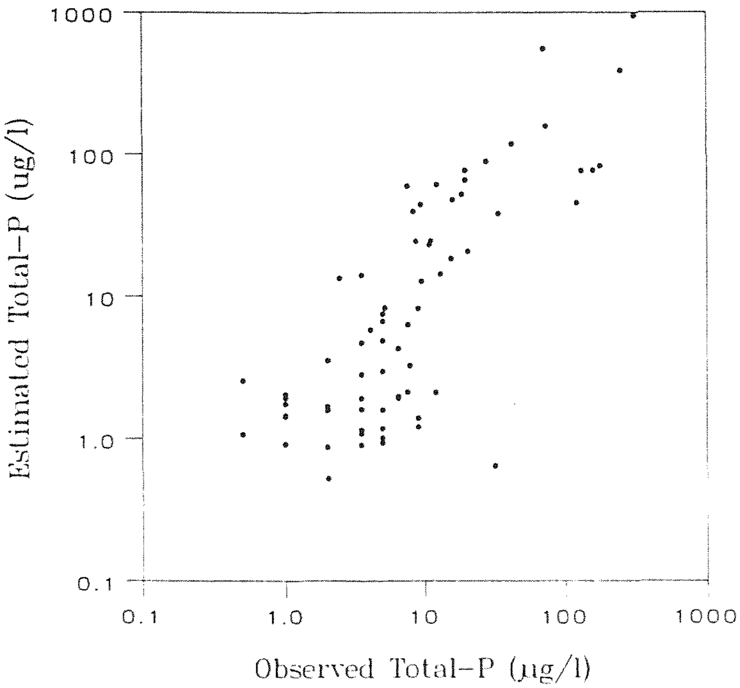


Figure 11 Observed versus estimated values for ammonium.

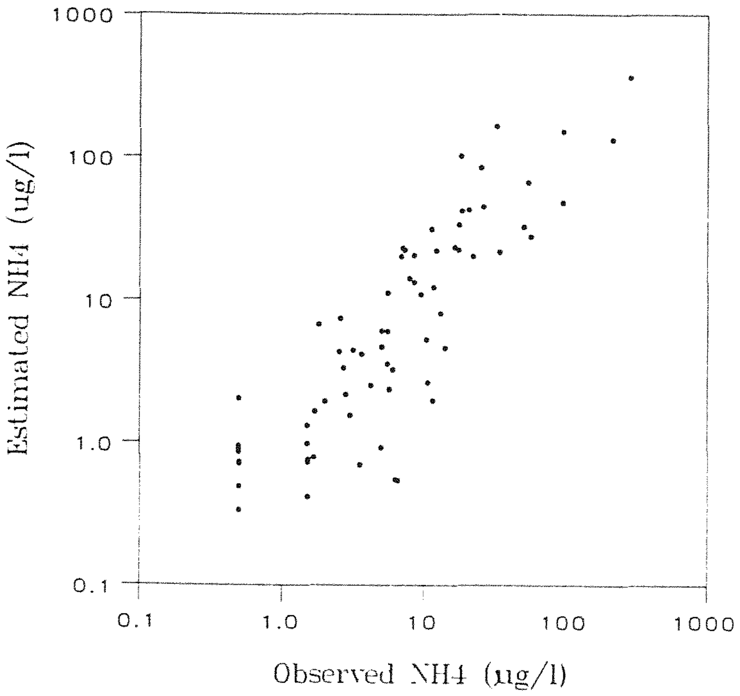


Figure 12 Observed versus estimated values for trophic index

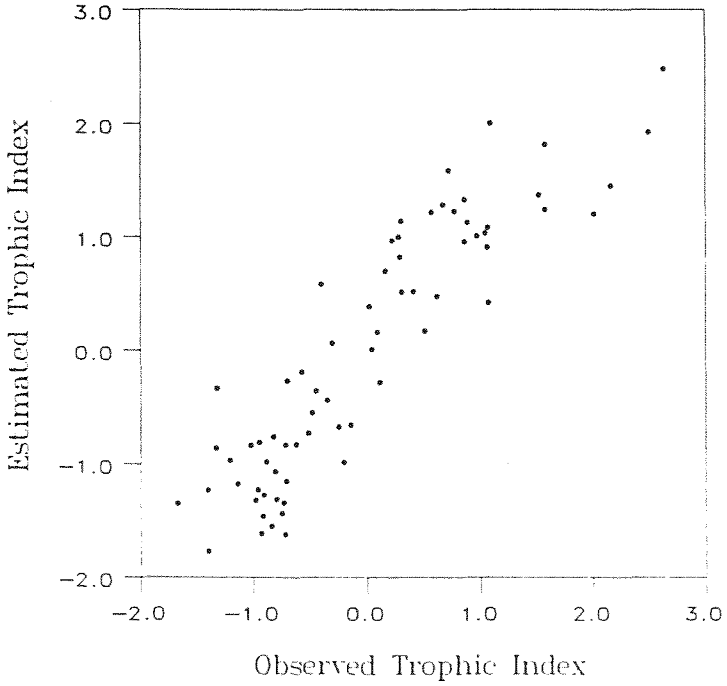


Figure 13 Age-depth profiles for Sombre, Heywood and Moss Lakes based on ^{210}Pb dating

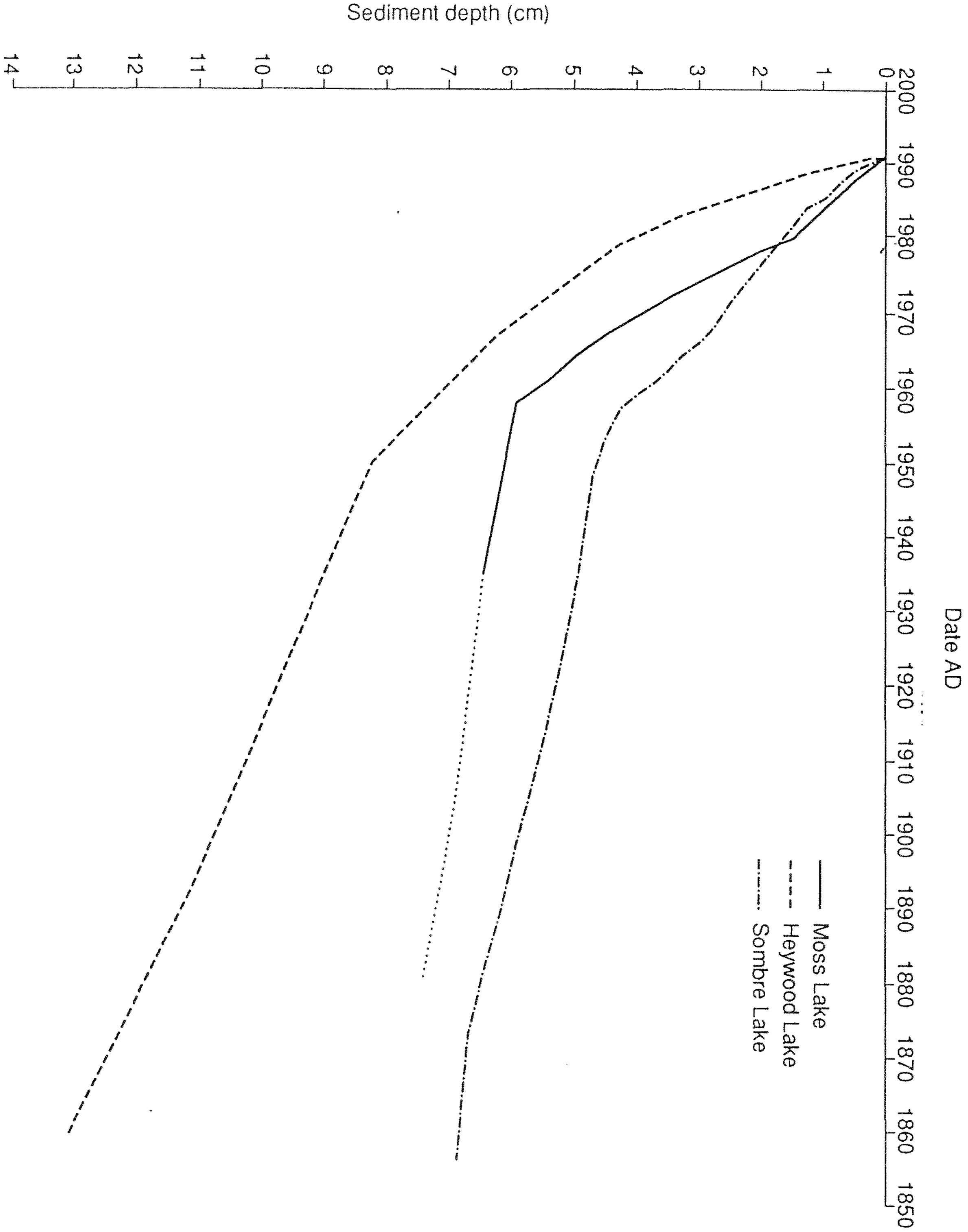


Figure 14 Uncalibrated ^{14}C results from Sombre Lake

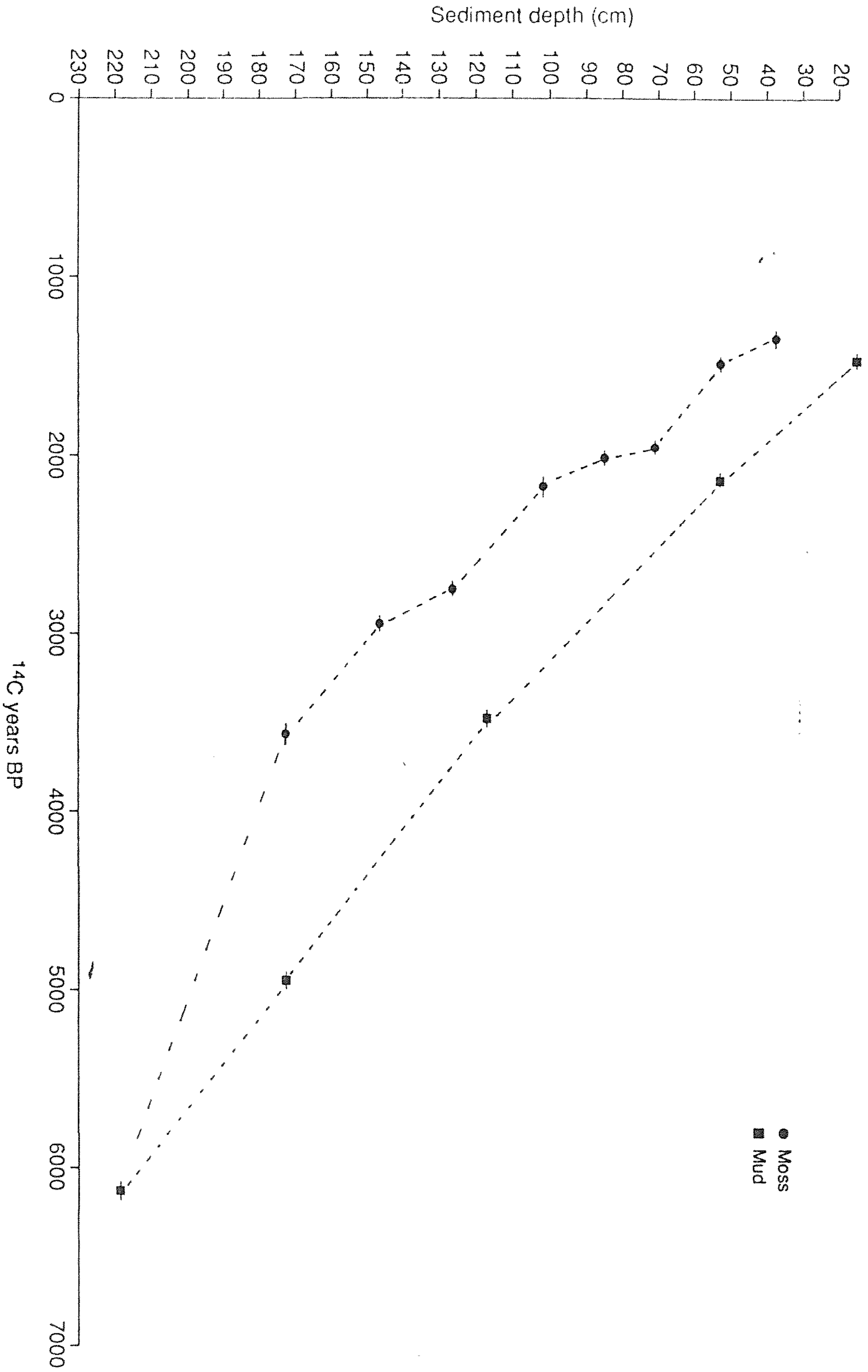


Figure 15 Uncalibrated ^{14}C results from Heywood Lake

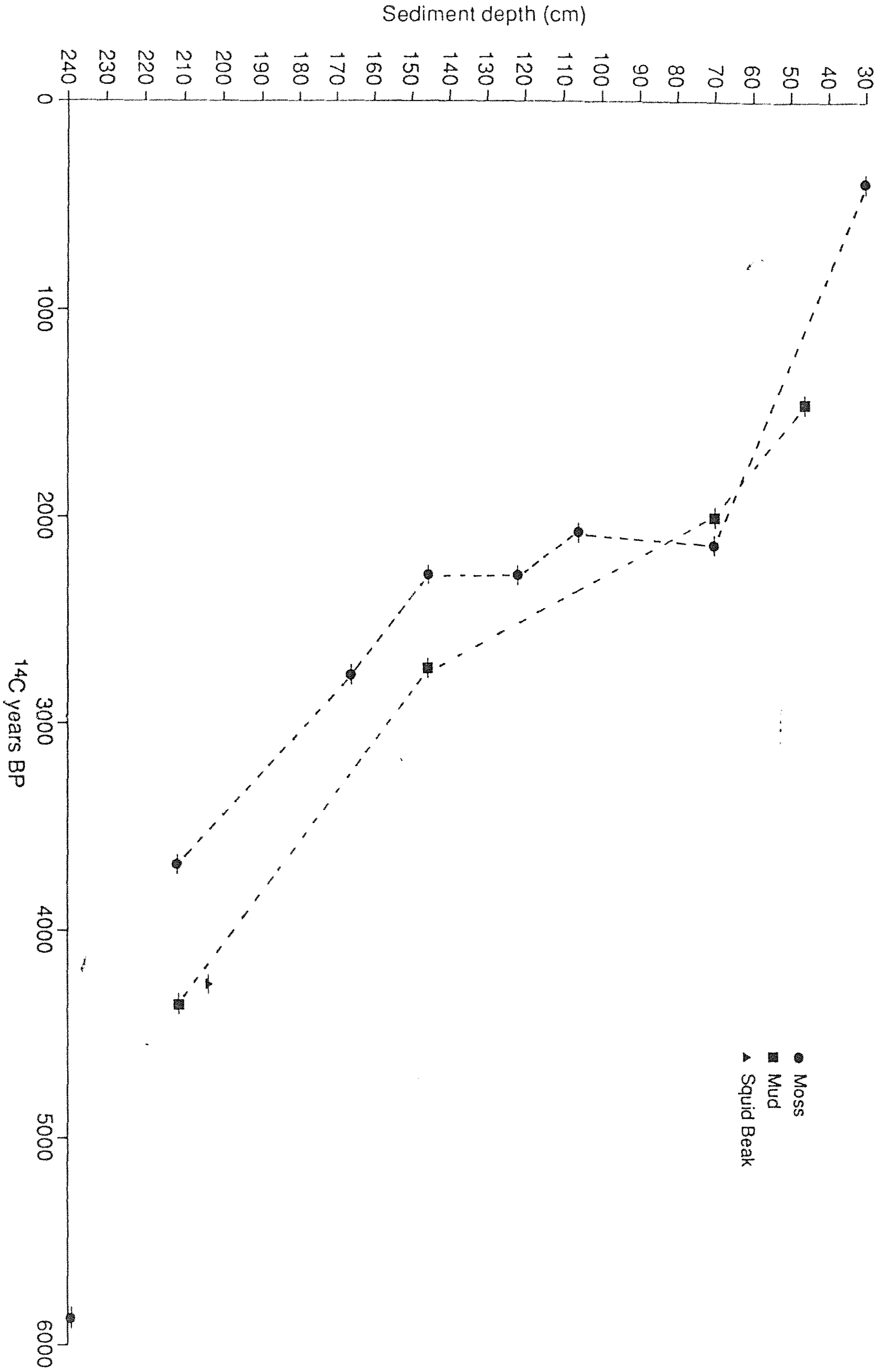


Figure 16 Recent changes at Heywood Lake; percentage diatom and reconstructed chlorophyll *a* results

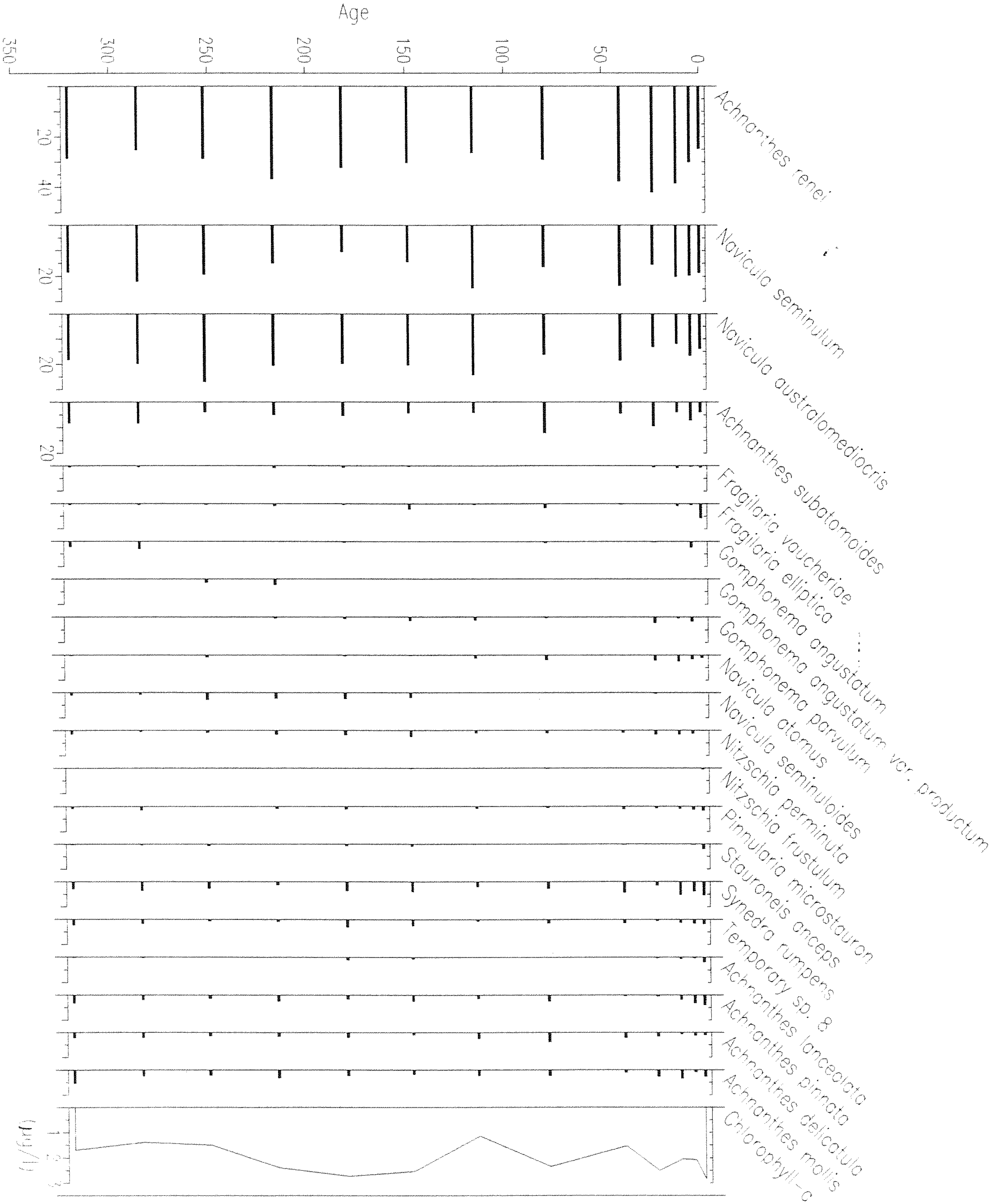


Figure 17 Holocene changes at Heywood Lake; percentage diatom and reconstructed chlorophyll *a* results.

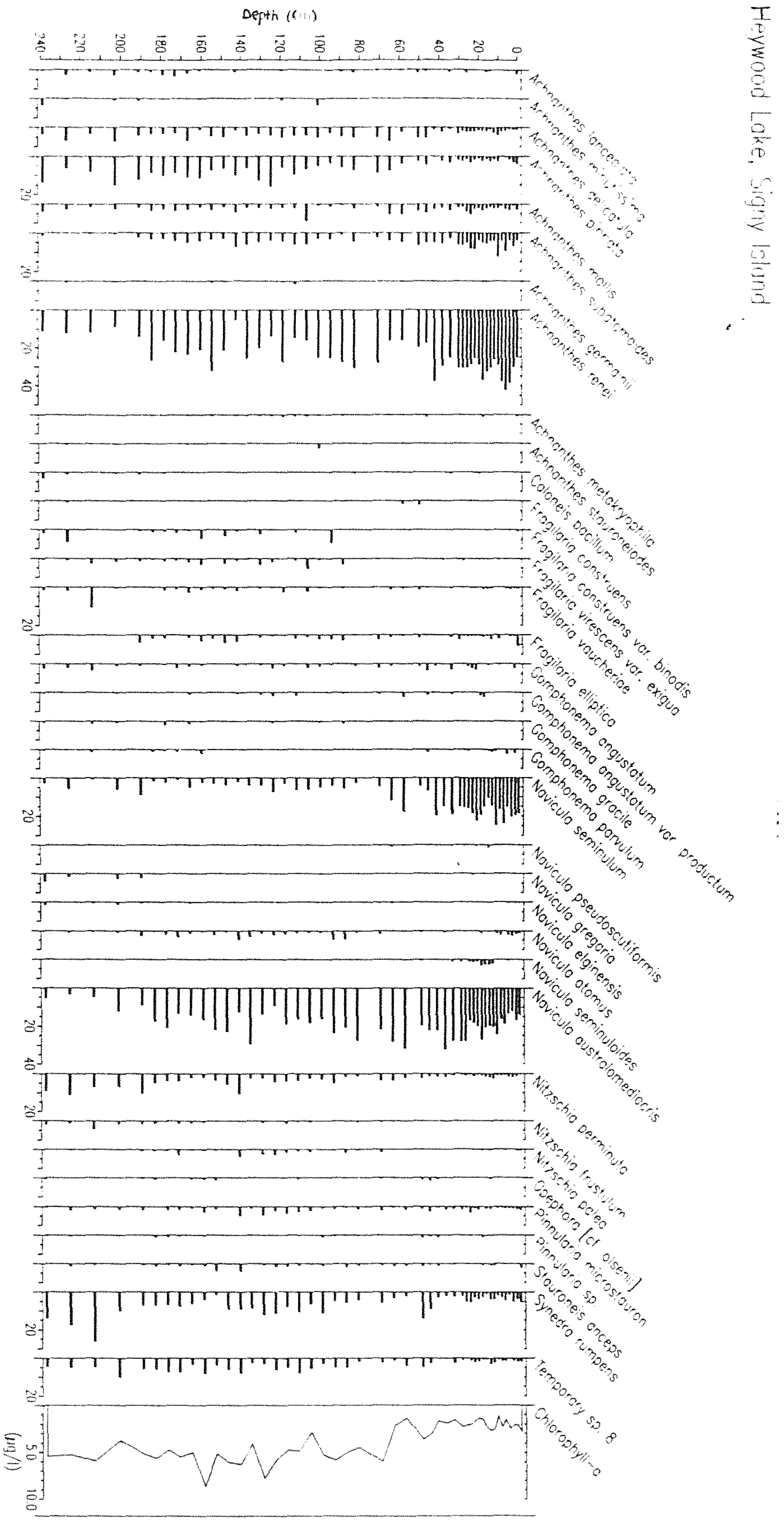


Figure 18 Recent changes at Sombre Lake; percentage diatom and reconstructed chlorophyll *a* results.

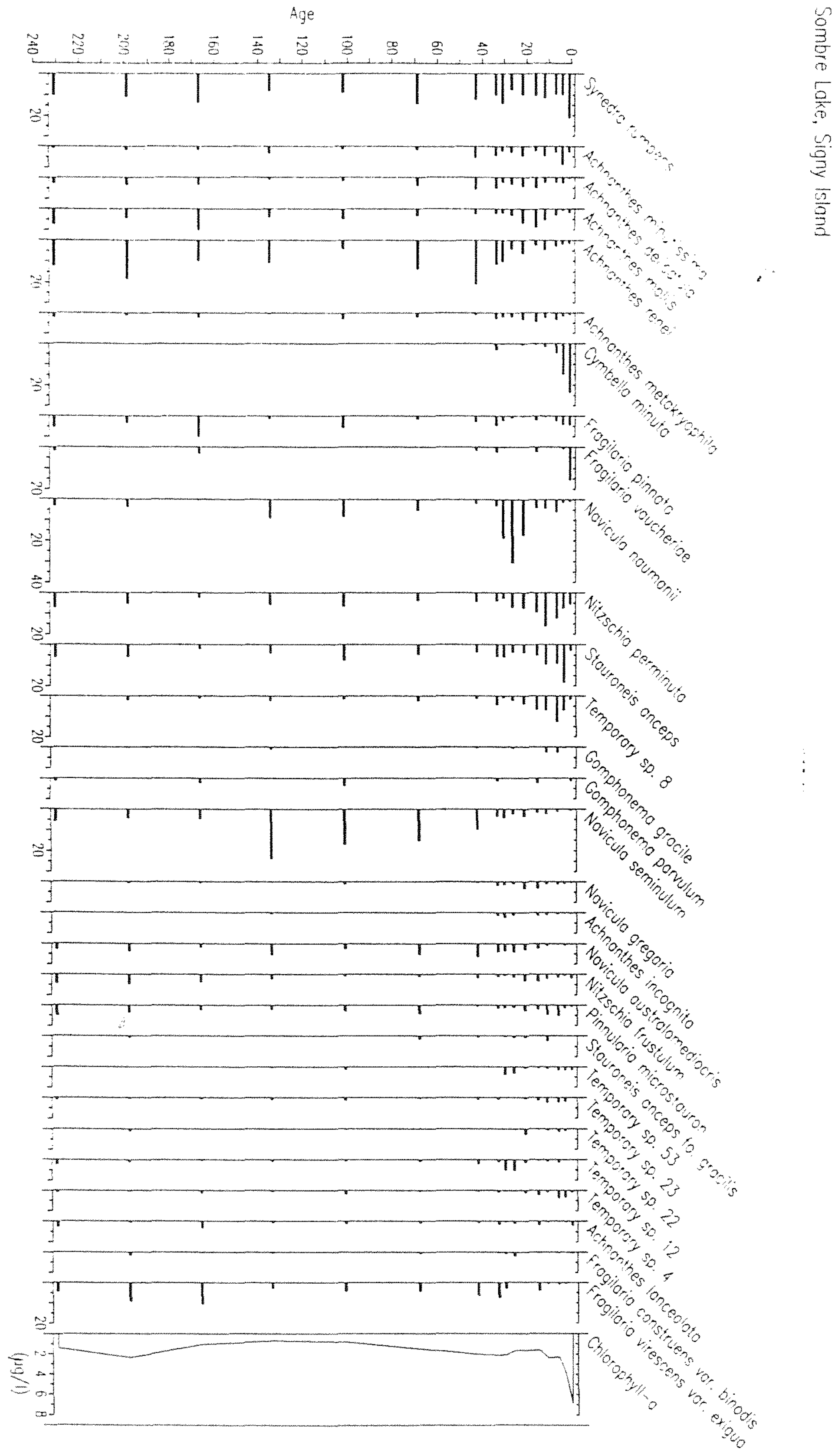


Figure 19 Holocene changes at Sombre Lake; percentage diatom and reconstructed chlorophyll *a* results.

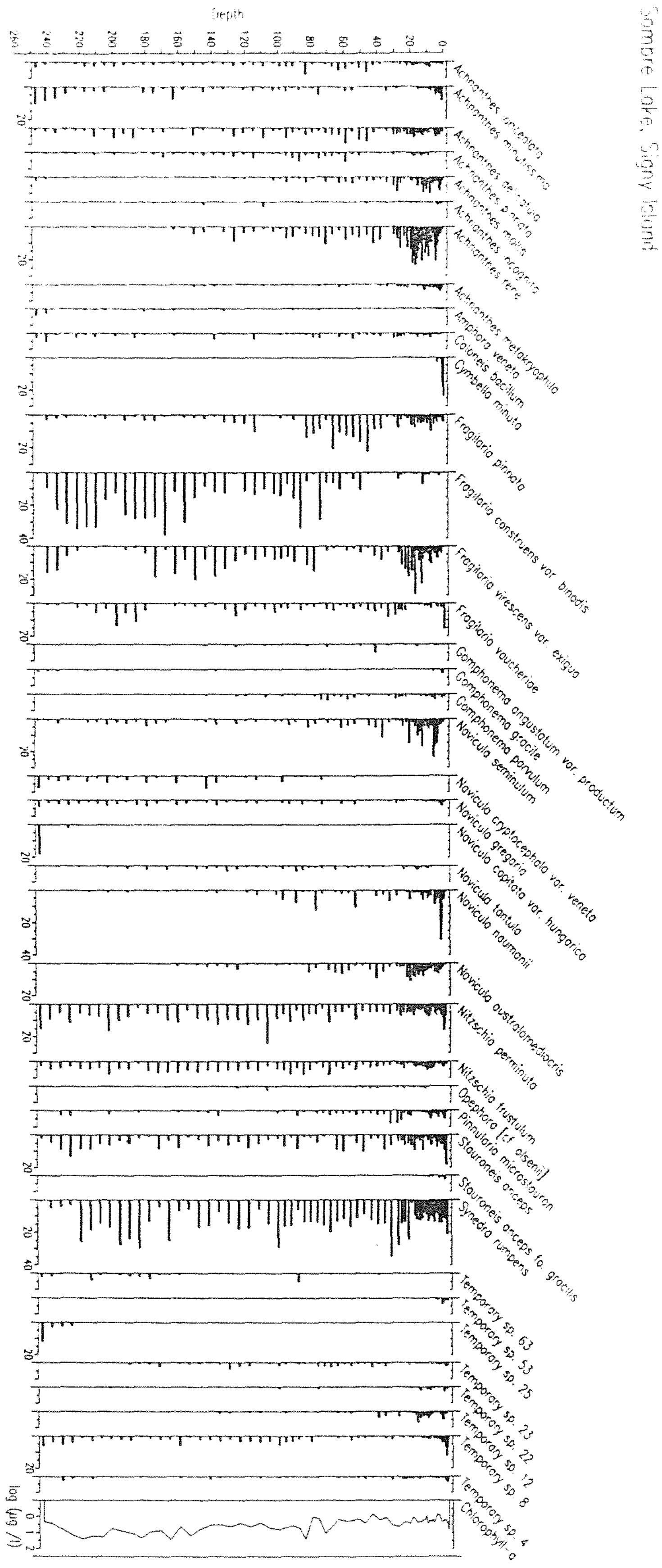


Figure 20 Recent changes at Moss Lake; percentage diatom and reconstructed chlorophyll *a* results.

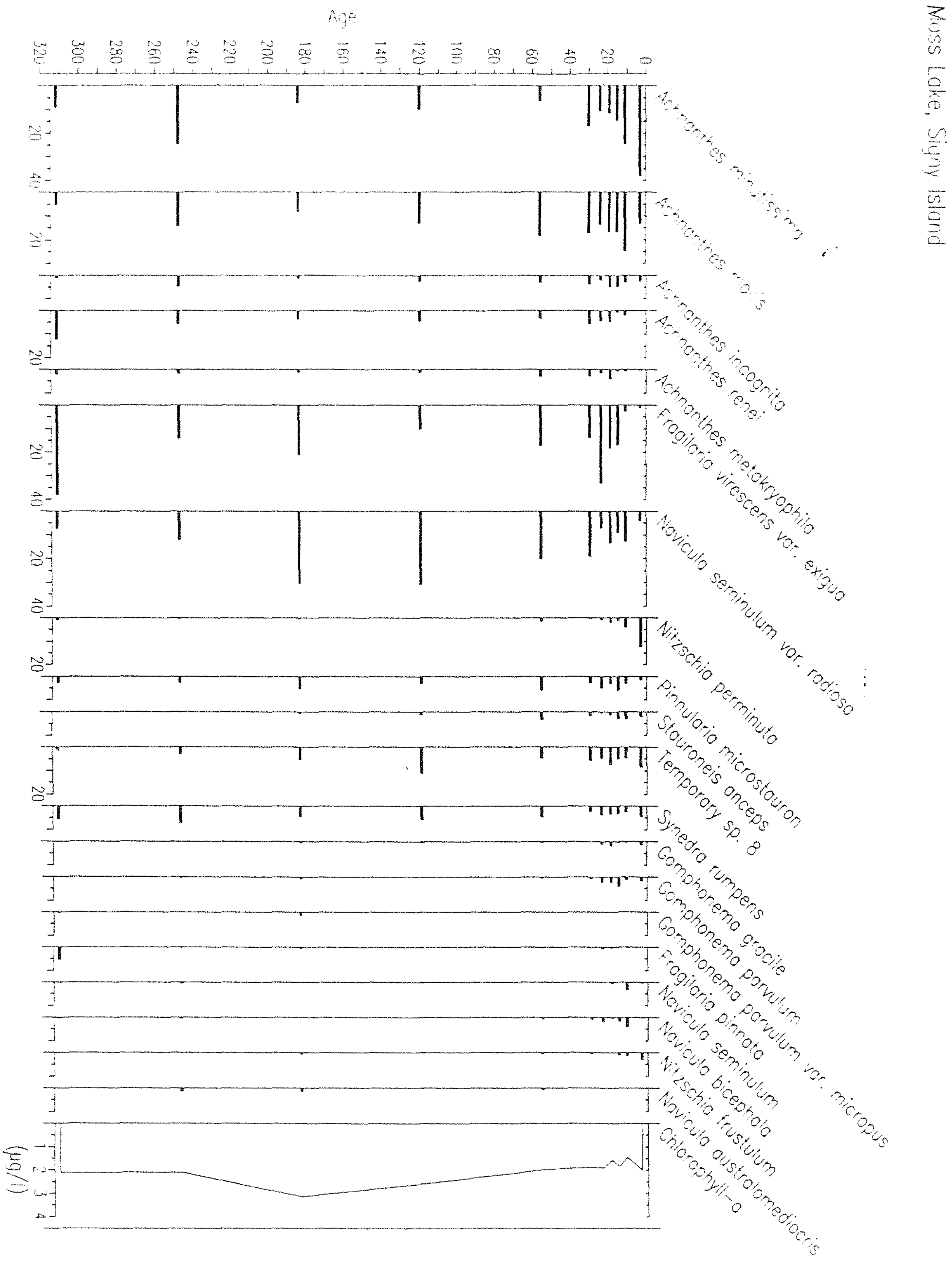


Figure 21 Holocene changes at Moss Lake; percentage diatom and reconstructed chlorophyll *a* results.

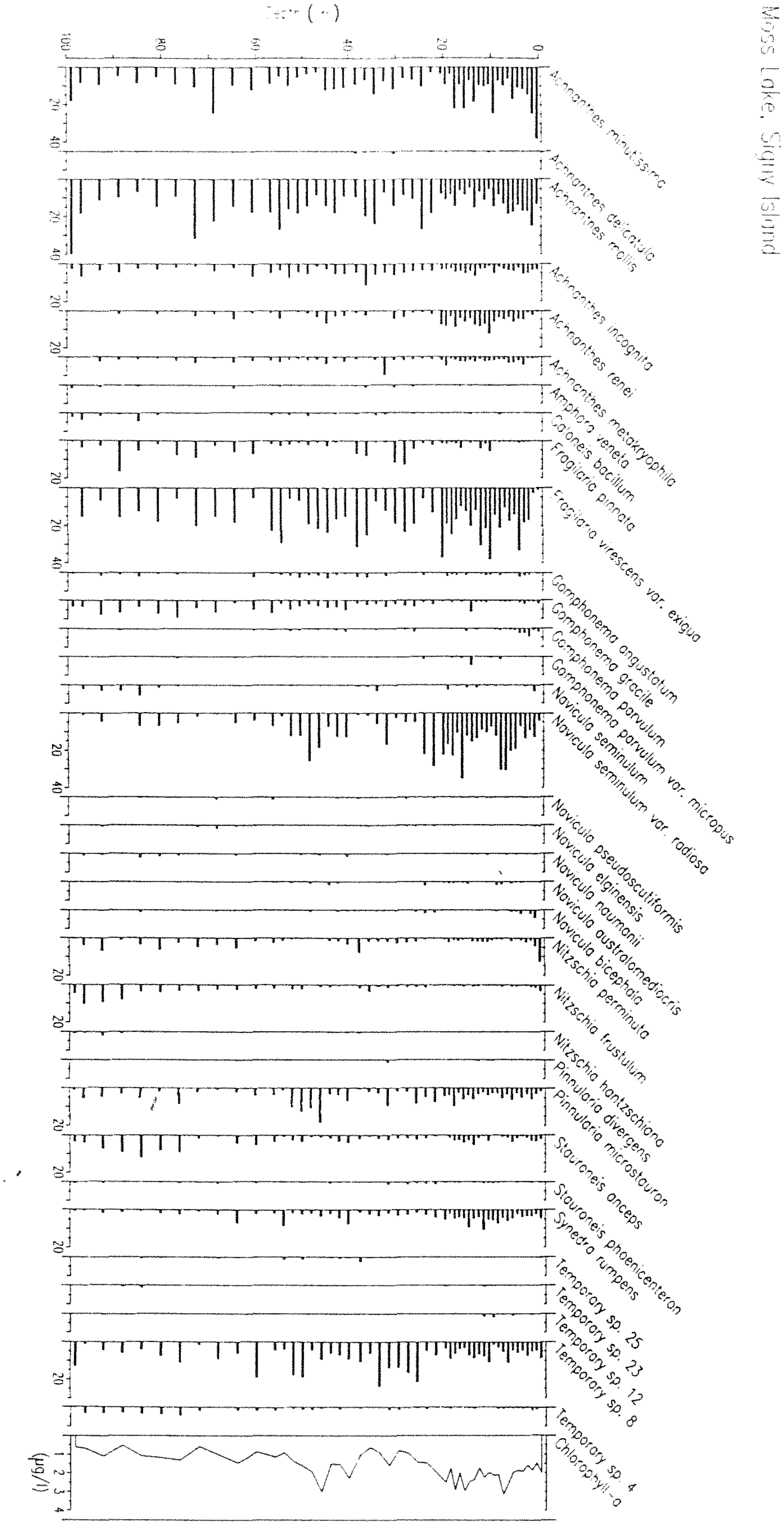


Figure 22 Recent changes at Amos Lake; percentage diatom results

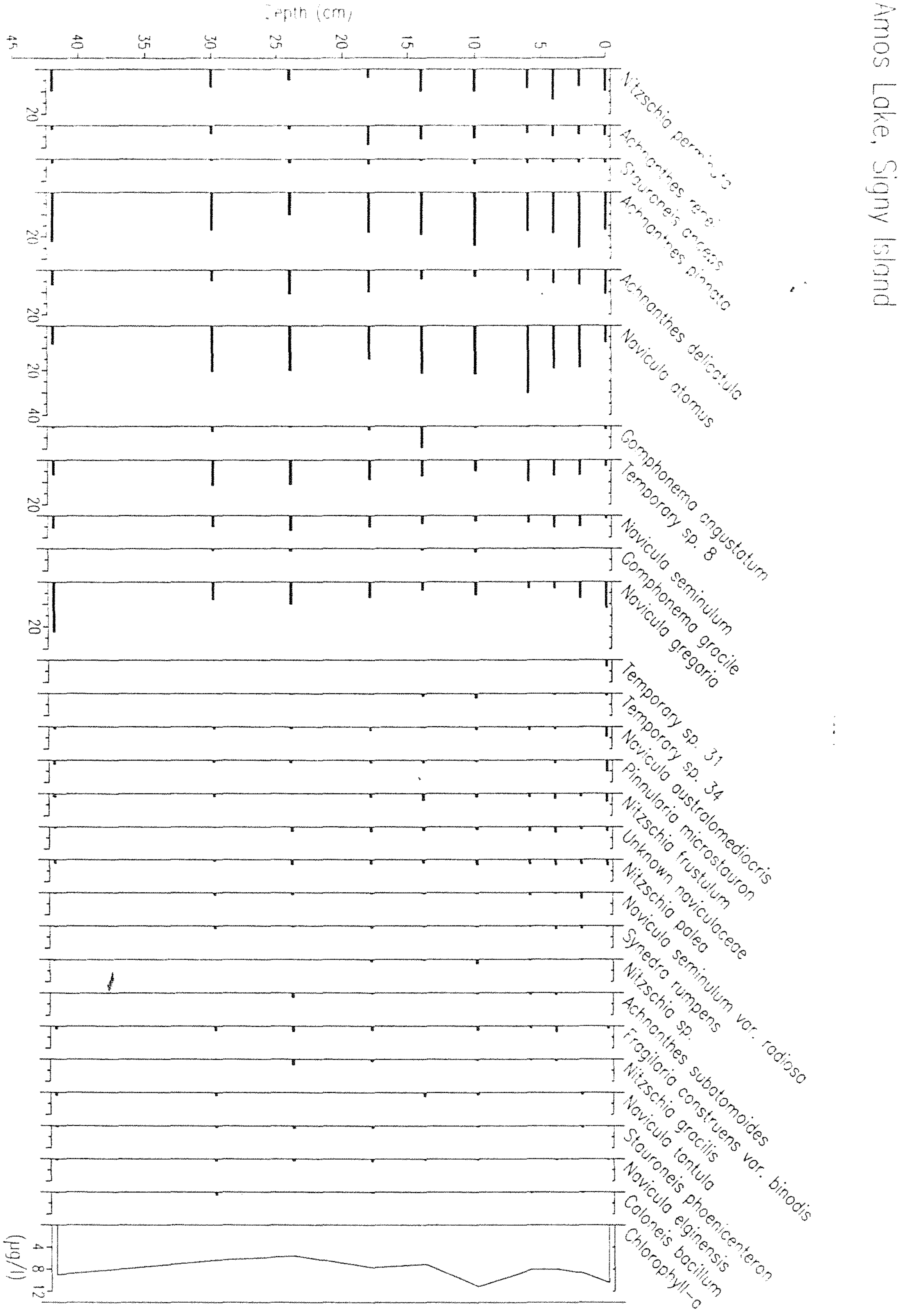


Figure 23 Recent changes at Gneiss Lake; percentage diatom results

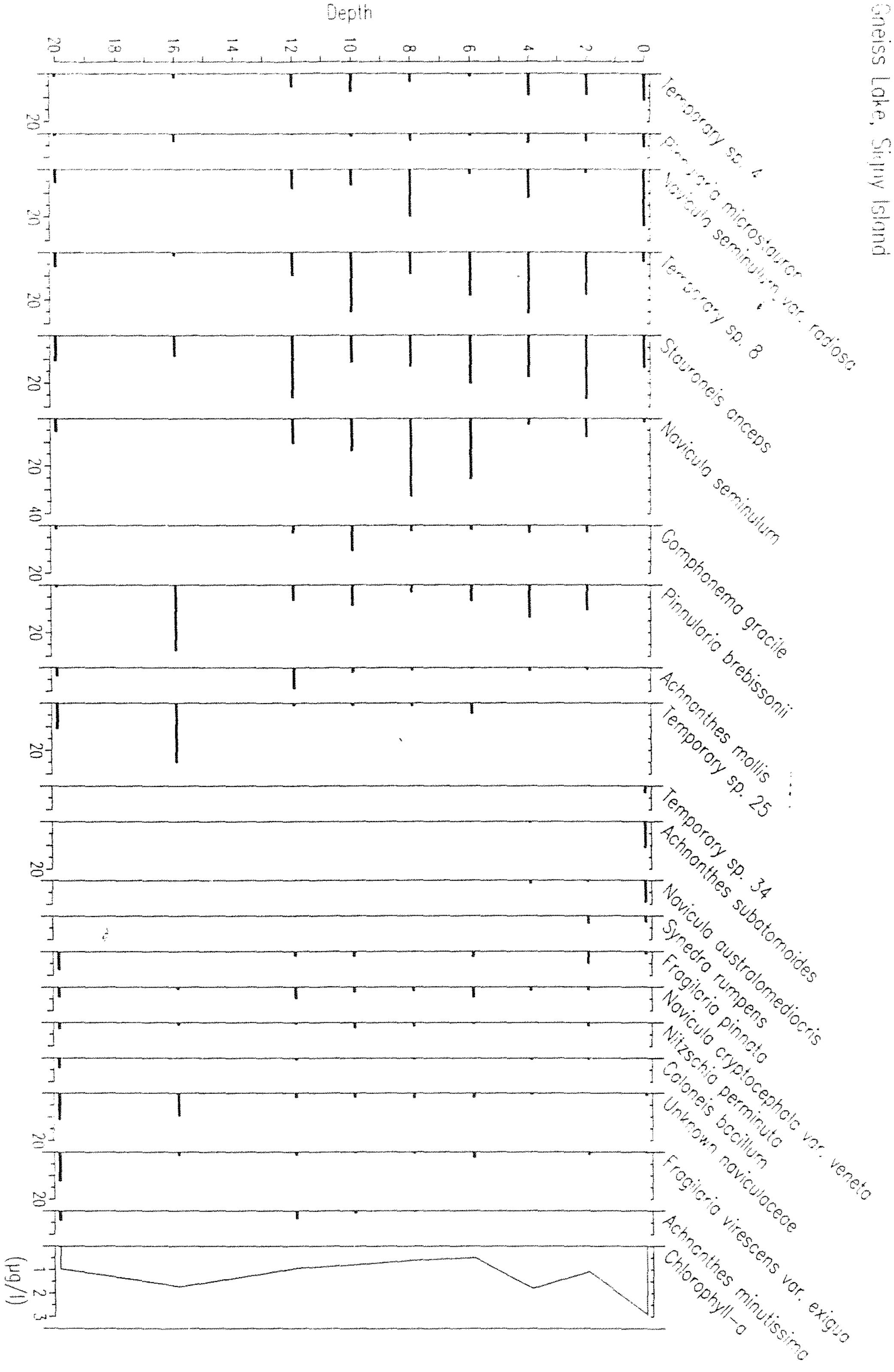
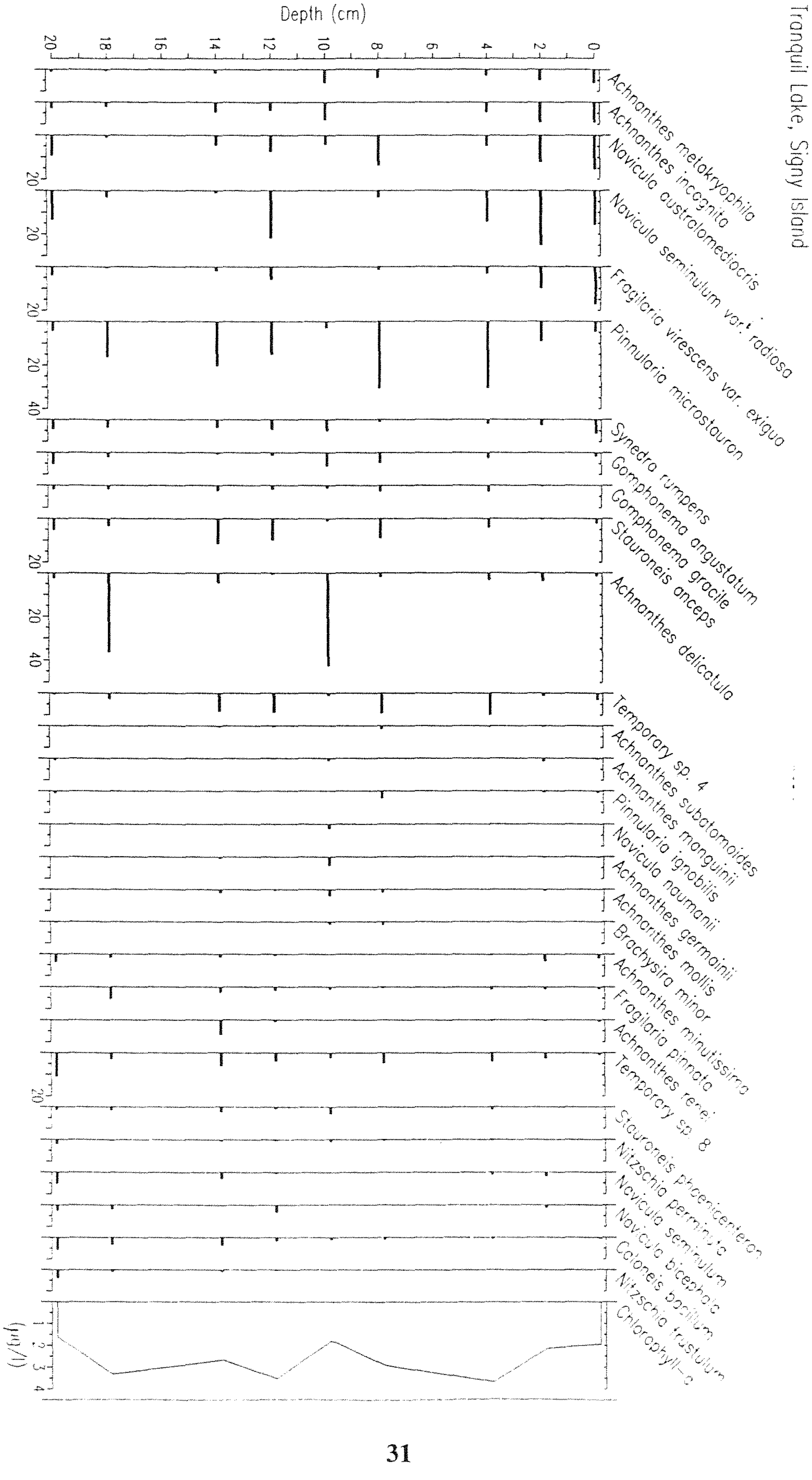


Figure 24 Recent changes at Tranquil Lake; percentage diatom results



Appendix 1 Full diatom species list

TaxonId	Taxon	Authority	Year
AC014A	Achnanthes austriaca	Hust.	1922
AC014C	Achnanthes austriaca var. helvetica	Hust.	1933
AC045A	Achnanthes bicapitata	Hust.	1952
AC058A	Achnanthes brevipes var. angustata	(Grev.) Cleve	1896
AC016A	Achnanthes delicatula	Kutz.	
AC008A	Achnanthes exigua	Grun. in Cleve & Grun.	1880
AC025A	Achnanthes flexella	(Kutz.) Brun	1880
AC138A	Achnanthes germainii	Maunguin in Bourelly & Manguin	1954
AC134A	Achnanthes helvetica var. alpina	Flower and Jones	1989
AC032A	Achnanthes hungarica	(Grun.) Grun. in Cleve & Grun.	1880
AC137A	Achnanthes incognita	Krasske	1939
AC083A	Achnanthes laevis	Ostr.	1910
AC001A	Achnanthes lanceolata	(Breb. ex Kutz.) Grun. in Cleve & Grun.	1880
AC084A	Achnanthes latissma	A. Cleve-Euler	1953
AC139A	Achnanthes manguinii	Hust.	1952
AC022A	Achnanthes marginulata	Grun. in Cleve & Grun.	1880
AC9968	Achnanthes marginulata fo. major	Uaine (VJJ)	1988
AC145A	Achnanthes metakryophila	Lange-Bertalot & Schmidt	1990
AC013A	Achnanthes minutissima	Kutz.	1833
AC135A	Achnanthes mollis	Krasske	1939
AC040A	Achnanthes pinnata	Hust.	1922
AC144A	Achnanthes renei	Lange-Bertalot & Schmidt	1990
AC031A	Achnanthes rostrata	Ostr.	1903
AC9999	Achnanthes sp.		
AC150A	Achnanthes stauroneiodes	Bourrely & Manguin	1954
AC136A	Achnanthes subatomoides	(Hust.) L-B & Archibald in Krammer & L-B	1985
AM9999	Amphora sp.		
AM004A	Amphora veneta	Kutz.	1844
AU9999	Aulacoseira sp.		
BR008A	Brachysira minor	(Krasske 1939) nov. com.	
BR001A	Brachysira vitrea	(Grun.) R. Ross in Hartley	1986
CA002A	Caloneis bacillum	(Grun.) Cleve	1894
CA003A	Caloneis silicula	(Ehrenb.) Cleve	1894
CA9999	Caloneis sp.		
CA012A	Caloneis ventricosa	(Ehrenb.) Meister	1912
CO9999	Cocconeis sp.		
CY9999	Cyclotella sp.		
CM004A	Cymbella microcephala	Grun. in Van Heurck	1880
CM031A	Cymbella minuta	Hilse ex Rabenh.	1862
CM9999	Cymbella sp.		
DP9999	Diploneis sp.		
EU025A	Eunotia fallax	A. Cleve	1895
EU040A	Eunotia paludosa	Grun.	1862
EU9999	Eunotia sp.		
FR002A	Fragilaria construens	(Ehrenb.) Grun.	1862
FR002B	Fragilaria construens var. binodis	(Ehrenb.) Grun.	1862
FR002D	Fragilaria construens var. exigua	(W. Sm.) Schulz	1922
FR002C	Fragilaria construens var. venter	(Ehrenb.) Grun. in Van Heurck	1881
FR018A	Fragilaria elliptica	Schum.	1867
FR001A	Fragilaria pinnata	Ehrenb.	1843
FR9999	Fragilaria sp.		
FR007A	Fragilaria vaucheriae	(Kutz.) J.B. Petersen	1938
FR005D	Fragilaria virescens var. exigua	Grun. in Van Heurck	1881
GO020A	Gomphonema affine	Kutz.	1844

GO003A	Gomphonema angustatum	(Kutz.) Rabenh.	1864
GO003B	Gomphonema angustatum var. productum	Grun. in Van Heurck	1880
GO007A	Gomphonema bohemicum	Reichelt & Fricke in A. Schmidt	1902
GO029A	Gomphonema clavatum	Ehr.	
GO004A	Gomphonema gracile	Ehrenb.	1838
GO014A	Gomphonema intricatum	Kutz.	1844
GO018A	Gomphonema longiceps	Ehrenb.	1854
GO050A	Gomphonema minutum	(Ag.) Ag.	1831
GO013A	Gomphonema parvulum	(Kutz.) Kutz.	1849
GO013B	Gomphonema parvulum var. micropus	(Kutz.) Cleve	1894
GO9999	Gomphonema sp.		
HA001A	Hantzschia amphioxys	(Ehrenb.) Grun.	1877
LI9999	Licmophora sp.		
ME019A	Melosira arentii	(Kolbe) Nagumo & Kobayasi	1977
ME026A	Melosira dendrophila	(Ehrenb.) R. Ross & Sims	1978
NA084A	Navicula atomus	(Kutz.) Grun.	1860
NA734A	Navicula australomediocris	Lange-Bertalot & R. Schmidt	1990
NA740A	Navicula bicephala	Hust.	1952
NA099A	Navicula bremensis	Hust.	1957
NA045A	Navicula bryophila	J.B. Petersen	1928
NA066B	Navicula capitata var. hungarica	(Grun.) R. Ross	1947
NA046A	Navicula contenta	Grun. in Van Heurck	1885
NA007B	Navicula cryptocephala var. veneta	(Kutz.) Rabenh.	1863
NA056A	Navicula cuspidata	(Kutz.) Kutz.	1844
NA057A	Navicula elginensis	(Greg.) Ralfs in Pritch.	1861
NA083A	Navicula frugalis	Hust.	1957
NA397A	Navicula gibbula	Cleve	1894
NA023A	Navicula gregaria	Donk.	1861
NA025A	Navicula mutica	Kutz.	1844
NA150A	Navicula naumanii	Hust.	1942
NA555A	Navicula paramutica	Bock	1963
NA036A	Navicula perpusilla	(Kutz.) Grun.	1860
NA013A	Navicula pseudoscutiformis	Hust.	1930
NA129A	Navicula seminuloides	Hust.	1937
NA005A	Navicula seminulum	Grun.	1860
NA005C	Navicula seminulum var. radiosa	Hust.	1950
NA9999	Navicula sp.		
NA735A	Navicula tabellariaeformis	Krasske	1939
NA086A	Navicula tantula	Hust.	1943
NE003A	Neidium affine	(Ehrenb.) Pfitz.	1871
NE9999	Neidium sp.		
NI014A	Nitzschia amphibia	Grun.	1862
NI087A	Nitzschia cylindrus	(Grun. ex Cleve) Hasle	1972
NI002A	Nitzschia fonticola	Grun. in Van Heurck	1881
NI008A	Nitzschia frustulum	(Kutz.) Grun. in Cleve & Grun.	1880
NI017A	Nitzschia gracilis	Hantzsch	1860
NI197A	Nitzschia hamburgiensis	Lange-Bertalot	1978
NI034A	Nitzschia hantzschiana	Rabenh.	1860
NI027A	Nitzschia microcephala	Grun. in Cleve & Grun.	1880
NI009A	Nitzschia palea	(Kutz.) W. Sm.	1856
NI033A	Nitzschia paleacea	(Grun. in C & G) Grun. in Van Heuc	1881
NI005A	Nitzschia perminuta	(Grun. in Van Heurck) M. Perag.	1903
NI9999	Nitzschia sp.		
OP9999	Opephora sp.		
OP9998	Opephora [cf. olsenii]	CASPIA (SF)	1990
UN9994	Pennate undif.		

PI015A	Pinnularia abaujensis		(Pant.) R. Ross in Hartley	1986
PI014A	Pinnularia appendiculata		(Ag.) Cleve	1896
PI012A	Pinnularia borealis		Ehrenb.	1843
PI032A	Pinnularia brandelii		Cleve	1891
PI048A	Pinnularia brebissonii		(Kutz.) Rabenh.	1864
PI008A	Pinnularia divergens		W. Sm.	1853
PI001A	Pinnularia gibba		(Ehrenb.) Ehrenb.	1843
PI169A	Pinnularia ignobilis		(Krasske) Cleve-Euler	1955
PI005A	Pinnularia major		(Kutz.) W. Sm.	1853
PI011A	Pinnularia microstauron		(Ehrenb.) Cleve	1891
PI011G	Pinnularia microstauron var. brebissonii		(Kutz.) A. Mayer	1912
PI139A	Pinnularia obscura		Krasske	1932
PI9999	Pinnularia sp.			
PI022A	Pinnularia subcapitata		Greg.	1856
PI007A	Pinnularia viridis		(Nitzsch) Ehrenb.	1843
PI9987	Pinnularia [microstauron (caudata)]		Botungen (EYH)	1988
UN9997	Plankton			
SA004A	Stauroneis alpina		Hust.	1943
SA001A	Stauroneis anceps		Ehrenb.	1843
SA001B	Stauroneis anceps fo. gracilis		Rabenh.	1864
SA006A	Stauroneis phoenicenteron		(Nitzsch) Ehrenb.	1943
SA9999	Stauroneis sp.			
SU005A	Surirella linearis		W. Sm.	1853
SU002A	Surirella ovata		Kutz.	1844
SU9999	Surirella sp.			
SY003A	Synedra acus		Kutz.	1844
SY002A	Synedra rumpens		Kutz.	1844
SY9999	Synedra sp.			
ZZZ990	Temporary sp. 10	Navicula spp#1 (Pumphouse)		
ZZZ988	Temporary sp. 12	Navicula spp#1 (Heywood)		
ZZZ986	Temporary sp. 14	Navicula cf muticopsis		
ZZZ998	Temporary sp. 2	Pinnularia spp#1		
ZZZ980	Temporary sp. 20	Navicula cf difficillima (cant see striae)		
ZZZ978	Temporary sp. 22	Navicula Sombre#1 (Navicula cf arvensis long)		
ZZZ977	Temporary sp. 23	Navicula cf australomediocris		
ZZZ976	Temporary sp. 24	Navicula cf seminulum (small)		
ZZZ975	Temporary sp. 25	Amphora spp#1		
ZZZ974	Temporary sp. 26	Achnanthes abundans/marginulata		
ZZZ972	Temporary sp. 28	Achnanthes cf abundans (not parallel striae)		
ZZZ970	Temporary sp. 30	Achnanthes cf kryophila		
ZZZ969	Temporary sp. 31	Achnanthes spp#1		
ZZZ966	Temporary sp. 34	Pinnularia species (Lake 23) = ZZZ947		
ZZZ965	Temporary sp. 35	Navicula species #1 (Tranquil) ?? may be old ZZZ964		
ZZZ964	Temporary sp. 36	Nitzschia frustulum/perminuta		
ZZZ963	Temporary sp. 37	Navicula spp#1 (Knob)		
ZZZ962	Temporary sp. 38	Gomphonema spp#1 (Camp 2)		
ZZZ961	Temporary sp. 39	Navicula spp#1 (Devils 2)		
ZZZ996	Temporary sp. 4	Stauroneis spp#1		
ZZZ960	Temporary sp. 40	Cocconeis spp#1 (Lake 23)		
ZZZ959	Temporary sp. 41	Naviculoid species (Lake 23)		
ZZZ958	Temporary sp. 42	6µ long pennate (??Nitzschia)		
ZZZ957	Temporary sp. 43	Nitzschia spp#2 (GP)		
ZZZ956	Temporary sp. 44	Navicula spp#1 (GP)		
ZZZ955	Temporary sp. 45	Nitzschia spp#1 (GP -Lake 35)		
ZZZ954	Temporary sp. 46	Navicula spp#1 (Welly Lake)		
ZZZ953	Temporary sp. 47	Navicula fine pupula (Trial Lake)		

ZZZ952	Temporary sp. 48	Navicula spp#1 (Lake 11)
ZZZ951	Temporary sp. 49	Navicula spp#1 (Vertebrae Lake)
ZZZ950	Temporary sp. 50	Aulocoseira distans unknown variety
ZZZ949	Temporary sp. 51	Navicula spp#1 (Lake 9)
ZZZ948	Temporary sp. 52	Navicula spp#1 (Jolly) N. bryophila?
ZZZ947	Temporary sp. 53	Pinnularia species (Lake 23)
ZZZ946	Temporary sp. 54	Pinnularia species #1
ZZZ945	Temporary sp. 55	Nitzschia perminuta - undulate form
ZZZ944	Temporary sp. 56	Pinnularia species (Lake 24)
ZZZ943	Temporary sp. 57	Navicula cf atomus (is atomus) NA084A
ZZZ941	Temporary sp. 59	Navicula/Stauroneis spp#1 (Midge Lake)
ZZZ940	Temporary sp. 60	Navicula spp#1 (Lactic)
ZZZ939	Temporary sp. 61	Nitzschia spp (frustulum type but asymetrical ?hantziod)
ZZZ938	Temporary sp. 62	Nitzschia cf inconspicua
ZZZ937	Temporary sp. 63	Nitzschia cf perminuta - valves with distinct waist
ZZZ992	Temporary sp. 8	Gomphonema angustatum/gracile
UN9999	Unknown	
FR9986	Unknown Fragilaria/Synedra	
UN9998	Unknown naviculaceae	

Appendix 2 Reports from Antarctic and Arctic diatom workshops

ANTARCTIC AND ARCTIC DIATOM TAXONOMY WORKSHOP - MINUTES

Held at the British Antarctic Survey, Cambridge, 28th September - 2nd October 1991

Present;
Marianne Douglas (MD), Hannelore Hakansson (HH), Vivienne Jones (VJ), Roland Schmidt (RS), John Smol(JS) & Anders Wesell (AW).

Introduction
A workshop was held to examine the taxonomic problems facing palaeoecologists working with freshwater diatoms in the arctic and antarctic.

The **Aim** of the workshop was to construct a brief taxonomic guide to antarctic/arctic diatoms (see below). Within the framework of this aim three procedures were identified;

1. to create agreed guidelines and make taxonomic recommendations

2. to define agreed 'unknowns'

3. to identify problems were further research is needed

Such a taxonomic guide could be used as a basis for the production of an iconograph (a series of plates and taxonomic information) at a later stage. Ecological information could also be incorporated, for example in the construction of a data base.

Dave Mann (Royal Botanic Gardens Edinburgh) presented his plans and ideas for the creation of a large diatom data base incorporating diatom images with taxonomic, nomenclatural and ecological information from a wide range of environments.

A taxonomic guide
Individual species lists were used for comparison, and a list of problematic taxa was constructed. This list formed the basis of discussion (using photographs and examining material under the microscope) over the 4 day period and enabled the production of the taxonomic guide (see below).

Future meetings
It was agreed that it would be useful to meet informally after the International meeting in Holland next year. It was agreed that Hannelore would investigate the possibility of extending the accommodation in Holland for the "Antarctic/Arctic group" for 2 days after the meeting.

Species lists
It was agreed that 2 species lists, one for the Arctic and one for the Antarctic should be drawn up. Marianne agreed to start the Arctic species list, using her own and existing literature. Hannelore will give a disc containing her species to Viv who will include any new species found by herself or Roland Schmidt (as in Schmidt et al 1990).

In these species lists the person who has identified the species will be "flagged".

Conclusions

We all agreed the workshop had been very useful, and many taxonomic concepts had been clarified. A number of fairly major taxonomic problems were also identified, and it is hoped that progress on these will be made before the next meeting in Holland.

There is a clear need for a taxonomic guide to diatoms in the Antarctic and Arctic. Such a guide or working flora would clearly enhance the continuation of palaeolimnological investigations in these polar areas.

List of actions

It was suggested a clear list of actions should be made

1. It was agreed that Hannelore would investigate the possibility of extending the accommodation in Holland for the "Antarctic/Arctic group" for 2 days after the meeting.

2. Marianne agreed to start the Arctic species list, using her own and existing literature. Hannelore will give a disc containing her species to Viv who will include any new species found by herself or Roland Schmidt (as in Schmidt et al 1990).

3. *Aulocoseira* spp
VJ has a *A. distans* var. ? and RS has a *A. alpigena* var. ? we will compare material to see if these are similar.

4. *Brachysira minor* nov. com.
We have this taxa in the antarctic. VJ will make an SEM study.

5. *Gomphonema angustatum/angustata/parvulum/?gracile* complex
There is a need for more SEM work esp of the gracile group - VJ agreed to do this. RS also agreed to contact Erwin Reichard in connection with this problem.

6. *Navicula cancellata*
AW will send skua lake material to MD for comparison.

7. *Navicula elginensis*
HH will look at the Ehrenberg material.

8. *Navicula gregaria*
HH will circulate a description of *N. molesta*

9. *Navicula tabellariaeformis*
JS will check to see if he has this distinctive form in the Arctic.

10. *Navicula contenta/perpusilla/gallica* complex
These forms can be difficult to separate when they are small. Krammer & Lange-Bertalot (1986) make *perpusilla* a var. of *gallica* but it is not clear why, RS will clarify with Lange-Bertalot.

11. Unknown *Navicula/Stauroneis* species no. 1
This species is common only in VJ's material. She will make SEM and LM photographs.

12. Members of the workshop should send Dave Mann *Nitzschia* lanceolata group material.

13. *P. microstauron/P.gibba*
Differences between these 2 forms are difficult to resolve, HH will contact K. Krammer for his definitions of the differences

14. *P. corsonia* ? HH will find out where the name was suggested.

15. *Pinnularia* species no. 1 VJ will do some SEM work

Taxonomic guidelines

Achnanthes coarctata
The species seems to be quite clearly defined in the Arctic. However AW & HH (in press) discuss the problems with var. *constricta*

Lange-Bertalot & Krammer (1989) synonymise var. *elliptica* Krasske and var. *constrictum* with *A. coarctata*. However they don't illustrate var. *elliptica* and there is only a poor illustration in Krasske (1939).

There is a further confusion, HH thinks that *A. brevipes var. intermedia* may be synonymous with *A. coarctata var. elliptica*, however this problem has not been resolved.

Achnanthes delicatula
We all have a species which is identical to that illustrated by Lange-Bertalot & Krammer (1989) Plate 81 Fig 26-31; "*Achnanthes* species aff. *linkei* Hust. und aff. *delicatula* var *australis* Manguin". RS notes that there are two sorts of central area an "epsilon" in Fig. 27 and he finds most of his specimens have a central area similar to this, whilst VJ finds that most of her specimens have a central area akin to Fig. 29.

Achanthes exigua
We seem to have the nominate form in the Antarctic

Achnanthes lanceolata
Some of these forms have a "tunnel" (Schmidt et al's *Achnanthes lanceolata var 'frequentissima'*) whilst others have a "horseshoe" (Schmidt et al's *A. lanceolata var. lanceolata*) this can be seen in SEM (eg Schmidt et al 1990 p60 and Fig. 7/c). Lecohu and Maillard (1983) also illustrate these "tunnel" forms in the SEM, but they don't attach much taxonomic significance to it.

This feature may be of taxonomic importance, but some of us felt it may just be a dissolution/erosion feature.

Achnanthes incognita
This taxa is common in the Antarctic

Achnanthes lapponica/laevis complex
Lange-Bertalot & Krammer (1989) include *A. lapponica* into *A. laevis* as the var. *quadratarea*. However, RS believes this is something different.

He also recognises *A. laevis var. aretasii* which is illustrated in Schmidt et al (Fig. 6/c).

Achnanthes minutissima
Is present at some abundance in the Antarctic. HH also recognises *A. affinis* and *A.linearis* and the separation of these forms may need some re-evaluation

Achnanthes microcephala
This species appears to be much more common in the arctic material.

Achanthes mollis
This taxa is synonymous with *A. abundans* and is common in the antarctic

Achnanthes metakryophila
This is described by Schmidt et al (1990), and is a fairly common antarctic form. The related species *A. kryophila* is discussed in Lange-Bertalot & Krammer (1989), they illustrate the "lectotype" in Fig. 23 4 4′, and we should follow this illustration.

Achnanthes renei
This species is described and illustrated by Schmidt et al (1990), this form under SEM shows raphe fissures bent in opposite directions (Fig. 7/o). This species is common in Antarctic material.

However, there appears to be a very similar species (in LM) which, under SEM shows raphe fissures bending in the same direction. This is illustrated by AW & HH (in prep). VJ also appears to have this species. This form may have been named by Oppenheim (in press).

There is another separate taxa which is coarser than *A. renei* and which is not named at present (and may also have been named by Oppenheim) which VJ calls cf. *A. pinnata*

JS reports that there may be similar late-glacial forms in the arctic.

Amphora veneta
The Antartic forms appear to be closely related to the *var. capitata* Haworth (see Haworth 1974 and Schumman & Archibald 1976-80 for illustrations).

In the arctic MD has both the nominate and the variety.
AW has another, very distinct form, which fits into the range of *A. veneta* but is a wider form, this is provisionally called ′var. inflata′ and this will be described fully by AW in the future.

Aulocoseira spp
VJ has a *A. distans* var. ? and RS has a *A. alpigena* var. ? we will compare material to see if these are similar.

Brachysira minor nov. com.
We have this taxa in the Antarctic. VJ will make an SEM study.

Catenula species
This is an *Amphora* like genus which MD finds in the Arctic, this needs further work.

Fragilaria
We retain for the present time *Fragilaria* sensu Hustedt until the implications of Krammer & Lange-Bertalot′s volume 3 of the Susswasserflora, and K. Camburns (in press) books become apparent.

Fragilaria pinnata
This should be included in Round et al's (1990) *Staurosirella* as our SEM's are identical.

Fragilaria constuens
AW & HH (in prep) show some very rounded forms which they call cf var. *venter*

Gomphonema angustatum/angustata/parvulum/?gracile complex
This is a very difficult group with few features which can be used reliably to separate the forms.
AW & HH (in prep) have shown that there are differences in the pore fields, which may be a useful criteria (but not so useful in the LM). There is a need for more SEM work esp of the gracile group - VJ agreed to do this. RS also agreed to contact Erwin Reichard in connection with this problem.

RS distinguishes a var. *subelliptica* P.T. Cleve (see Cleve-Euler Fig 1269 hij). This is a nearly symetrical form 12-16u long, 4.5-6 wide with 13-14S in 10u.

We agreed that we tend to distinguish the forms by their shape (elliptical forms being *parvulum* and longer, more parallel sided forms being *angustatum*) but there is a clear need for more reliable criteria here.

Navicula australomediocris
Species described by Schmidt et al (1990), is a fairly common form in the Antarctic.

Navicula capitata
This is quite common in the Antarctic
MD has a variety *humilis* which has been described by Cleve-Euler.

Navicula bergerii
See Krammer & Lange-Bertalot (1986) Plate 78 fig. 17-20 and p225. This species will be transfered to *Pinnularia* (I don't remember who said this) . Their descriptions reads;
"valve parallel, but seldom concave, 10-16 long, 2-3.6 wide, thin raphe, fairly widely distant in central area. axial area very variable. Central area fairly big, striae parallel to weakly radiate, striae a little bit shorter in the central area for 1-2 striae, 17-19 in 10u. Often found on mosses."

There is a similarity between this species and VJ's *Pinnularia* species no. 1, but *N. bergerii* lacks the distinctive ? raphe ends.

Navicula cancellata
AW and HH (in press) describe this form in the brackish phase of Skua lake. MD has a cf *cancellata* (see P5/20 Douglas 199?). AW will send skua lake material to MD for comparison.

Navicula elginensis
Krammer & Lange-Bertalot (1986) illustrate the lectotype of this species (Plate 46 Fig. 1), and we should follow this.

There is a similar species, *N. dicephala* described by Ehrenberg, but which is not mentioned by Krammer & Lange-Bertalot (1986). HH will look at the Ehrenberg material.

Navicula gregaria
AW and VJ have a taxa which is the same as that illustrated by Krammer and Lange-Bertalot (1986) Plate 38 Fig. 15. There are problems with locating the type material of this species and this is discussed by Krammer & Lange-Bertalot.

There is a problem with possible confusion with *N. molesta* which AW and HH have and discuss (in prep). HH will circulate a description of *N. molesta*

Navicula ignota
MD has a cf. *ignota* with a finer striae count, see Douglas (1989). This species hasn't been reported from the Antarctic yet.

Navicula naumanni
This species is found in the Antarctic. See discussion in Schmidt et al (1990).

Navicula perminuta
This is illustrated by Krammer & Lange-Bertalot (1986) in Plate 35 Fig. 19.

The problems with this species and *N. diserta* and *N. hansenii* are discussed by AW and HH (in prep)

Navicula tantula
Krammer & Lange-Bertalot (1986) illustrate (Plate 76 Fig. 47) this species from the Hustedt collection. It is a common taxa in VJ's material from Signy.

Navicula tabellariaeformis
This species is farily common in the Antarctic, see Schmidt et al (1990) Fig. 7/r. JS will check to see if he has this distinctive form in the Arctic.

Navicula contenta/perpusilla/gallica complex
These forms can be difficult to separate when they are small. Krammer & Lange-Bertalot (1986) make *perpusilla* a var. of *gallica* but it is not clear why, RS will clarify with Lange-Bertalot.

Navicula mutica/muticopsis/cohnii
According to Krammer & Lange-Bertalot (1986) *N. mutica* has an elongated isolated punctum, whilst in *N. muticopsis* and *N. cohnii* this is a rounded punctum. Krammer & Lange-Bertalot (1986) illustrate (Plate 53 Fig. 8-9) the distinctive raphe ends of *N. mutica*.

It should also be noted that there are problems with the type material of these forms.

Navicula spp 1 (Welly)
VJ and HH have this species which HH calls cf *N. cohnii*, however it lacks the isolated punta of *N. cohnii*

Unknown *Navicula/Stauroneis* species no. 1
This species is common only in VJ's material. She will make SEM and LM photographs.

Nitzschia peminuta complex and the lanceolate types
This is an extremely difficult group which we all have major problems with, table 1 illustrates some of the suggested names (taken from AW & HH in prep)

spp	length	width	fibulae in 10u	striae in 10u	middle fib distant
perm-inuta	8-45	2.5-3	10-16	26-(32) 36	dist.
hantzschiana	8-50	3-(4) 5	7-12.5	20-26	+/- dist.
alpina	4-48	3-5	(7)8-14	21-25	dist.
palea	15-70	2.5-5	9-17	28-40	not dist.
paleacea	8-(55) 80	1.5-4	(12)14-19	44-55	dist.
palea-formis	30-90	3-5	10-13	35-40	very dist.
acido-clinata	every	thing	as	N. hantz!	

We agreed to continue with our individual systems at present, until further work has been done.

Dave Mann agreed to help with some of the problems with this group, members of the workshop should send him material.

Nitzschia homburgensis
Species common in Antarctic material.

Pinnularia divergens
This species is present in the Antarctic material

Pinnularia spitzbergensis
HH has a form cf. *P. spitzbergensis*

Pinnularia microstauron/P. gibba
There are problems distinguishing these two species according to Krammer & Lange-Bertalot (1986)
P.gibba;
"parallel to slightly convex sides, ends are blunt, not capitate. 50-140u long, 7-13u wide. Raphe clearly lateral, relatively small central pores (of raphe ends) and raphe ends are near to each other, has ? raphe ends. Axial area very variable from small linear to broad, always broadening to a central area. Central area is long elliptical. Fascia very variable and can be unsymmetrical, often missing on one side. direction of striae

very variable. Weakly to mediumly radial striae in centre 9-12 in 10u. Submarginal longitudinal line across the striae"

P.microstauron;
"parallel to slightly convex sides, ends can be slightly sharp. 20-90u long 7-11u wide. Striae in the middle are parallel to strongly radial, slightly to strongly convergent at the ends. 10-13s in 10u. Submarginal longitudinal lines can sometimes be seen"

(there is confusion with these submarginal longitudinal lines, whether they are seen or not seems to depend on orientation, and sometimes these could simply be the girdle bands?)

Therefore
We take a liberal view of *P. microstauron* and follow Krammer & Lange-Bertalot (1986) Plates 191-192. We also recognise a var. *brebissonii* with a distinct 'waist'.

We reserve *P.gibba* for forms with spatulate ends

But differences between these 2 forms are difficult to resolve, and they need to be clarified. HH will contact K. Krammer for his definitions of the differences

Pinnularia species lake 24 (VJ)
HH has a similar species "N. cf disjuncta"
P. corsonia has also been suggested for this species
HH will find out where the name was suggested.

Pinnularia species no. 1
Both HH and VJ have this unknown species
VJ will do some SEM work

Stauroneis phoenicentron
We distinguish from *S. anceps* using the striae count, following Patrick & Reimer (1966) this should be less than 20 in 10u

Stauroneis anceps
HH has distinguished 3 groups which are illustrated in Bjork et al (1991) Fig. 10
1. "*anceps* var. *anceps*" form with a distinct bow-tie middle c. 20S in 10u (a,b, & e)
2. Form with a bow-tie middle but with a squatter shape (c & possibly f)
3. "f. *hyalina*" form with a more parallel central area, with elongated ends and >25S in 10u.

Patrick & Reimer (1966) also recognise a f. *gracilis* which we recognise although it has not yet been found in the Antarctic. By constrast Krammer & Lange-Bertalot (1986) include the f. *gracilis* with *S. anceps*

In the arctic MD recognises a f.*linearis* Cleve, which is also described by Foged.

The taxonomic importance of the presence or absence of a pseudoseptum in *S. anceps* is confusing. According to Cleve-Euler the presence of a pseudospetum is used to separate two groups within *Stauroneis*. Lange-Bertalot (1986) states that *S. anceps* does not have a pseudoseptum but then goes on to include a variety *japonica* which does! In our Antarctic material there is no pseudoseptum, but in Arctic material there is often a pseudoseptum. The taxonomic importance of the pseudoseptum needs to be clarified.

Synedra rumpens
A f. *familiaris* is distinguished by Hustedt (1922-66) which is characterised by its inflated central area. However, RS uses the f. *familiaris* for short forms forming long chains.

References

Bjork, S., Hakansson, H., Zale, R., Karlen, W. & Jonsson, B.L. (1991). A late Holocene lake sediment sequence from Livingston Island, South Shetland Islands, with palaeoclimatic implications. **Antarctic Science 3,** 61-72.

Douglas M.S.V. (1989). Taxonomic and ecological characterisation of freshwater diatoms from the sediments of 36 high Arctic ponds (Cape Herschel, Ellesmere Island, N.W.T., Canada). Unpub. MSc thesis, Queens University, Kingston, Ontario, Canada.

Haworth, E.Y. (1974). Some problems of diatom taxonomy in Scotish lake sediments. **B. Phycol. J. 9** 47-55.

Hustedt, F. (1922-66). Die Kieselalgen Deutschlands, Osterreichs und der Schweiz. In Rabenhorst's **Kryptogamenflora von Deutschland, Osterreich und der Schweiz,** Vol. 7. Leipzig: Akademische Verlagesellschaft.

Krammer, K. & Lange-Bertalot, H. 1986. Susswasserflora von Mitteleurope. Bacillariophyceae. 1. Teill. Naviculaceae. Stuttgart, New York, Gustav Fischer Verlag, 876pp.

Krammer, K. & Lange-Bertalot, H. 1988. Susswasserflora von Mitteleurope. Bacillariophyceae. 2. Teill. Bacillariaceae, Epithemiaceae, Surirellaceae. Stuttgart, New York, Gustav Fischer Verlag, 596pp.

Krasske, G. (1939). Zur Kieselalgenflora Sudchiles. **Arch. Hydrobiol. 35,** 349-468.

Lange-Bertalot, H. & Krammer, K. 1989. *Achnanthes.* Eine Monographie der Gattung *Cocconeis* und Nachtragen zu den Naviculaceae. **Bibliotheca Diatomologia 18,** Berlin, 393pp.

Le Cohu, R. & Maillard, R. (1983). Les diatomees monoraphidees des Iles Kerguelen. **Ann. Limnol., 19** 143-167.

Patrick, R & Reimer, C. (1966). The diatoms of the United States. **Monograph. Ser. Acad. Nat. Sci. Philadelphia.**

Round, F.E., Crawford,R.M. & Mann, D.G. (1990). The diatoms. Cambridge University Press, Cambridge.

Schmidt R., Mausbacher,R. & Muller, J. (1990). Holocene diatom flora and stratigraphy from sediment cores of two Antarctic lakes (King George Island). **J. Paleolimnol. 3** 55-74.

Schoeman, F.R. & Archibald, R.E.M. (1976-80). The diatom flora of Southern Africa. CSIR Special Report. Watt 50.

ANTARCTIC/ARCTIC WORKSHOP PHOTOGRAPHS all at x2000

1. *Fragilaria construens var. binodis* (Signy Is. Lake 1)

2. *Nitzschia* species (Hidden Lake, James Ross Is.)
VJJ calls ? *perminuta*
HH calls ? *frustulum*

3. *N. frustulum var.* ? (Horseshoe Pond "wet moss")

4. *N. frustulium var.* ? (Signy Is Lake 1)

5. *N. frustulum var. perminuta* ?
as defined by HH and AW

6. *N. frustulum*?

7. *N. frustulum var. perminuta* ?
see #5

8. *N. palea* (Signy Is. lake 1)
VJJ definition

9. *Achnanthes linkei/delicatula var. australis* (Midge lake, Livingston Is)

10. ditto

11-13. *A. lanceolata* (Midge lake)
coarse form notice the "tunnel"

14. specimen with clear tunnel (Hidden lake, James Ross Is)
R. Schmidts *var frequentissima*

15. as above (Tieffersee II 35-36 cm)

16. as above (Hidden lake James Ross)

17. *Cyclotella bodanica* group (Hazen KBA 1)
MD

18. *Cyclotella cf kiesseleri*

19. ditto (Amituk Lake, NWT, Canada)

20. *Gomphonema angustatum/gracile* (Signy lake 1)
VJJ

21. *Navicula gregaria* (Hidden lake)
VJJ version

22. *Achnanthes incognita* rapheless valve (Midge lake)
VJJ

23. *Navicula seminulum* (Midge lake)

24. *Pinnularia* species #1 (Midge lake)

25. *Fragilaria construens var venter* (Skua lake, Horseshoe Is)
HH small round form

26. *Achnanthes* spp
HH calls it *A. affinis* on account of the separated striae in the central area everyone else *A. minutissima*

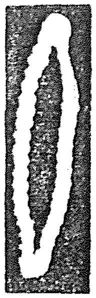
27. as 25

28. *Melosira roseana var dendrophila* (Midge lake)
see Ross & Sims Bacillaria 4

29. *Pinnularia microstauron* (Nicolson lake, Vestfold hills)
AW sample

30. same specimen different focus

31. *Amphora veneta* var "inflata"
AW will describe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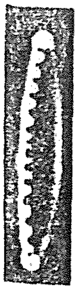
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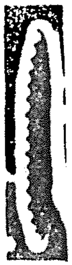
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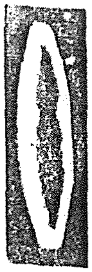
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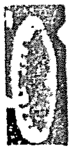
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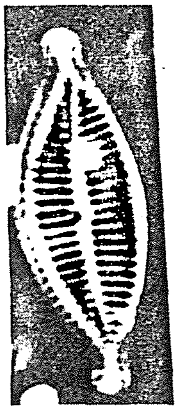
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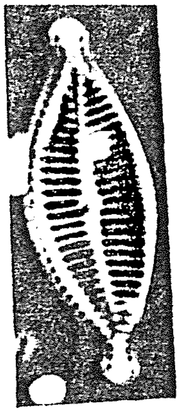
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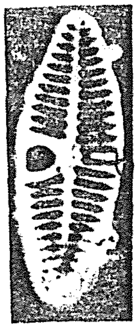
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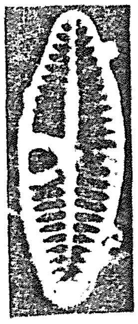
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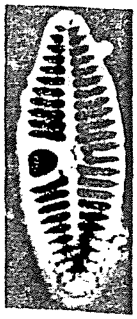
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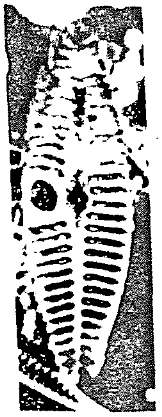
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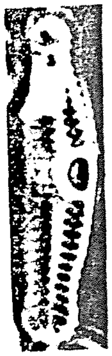
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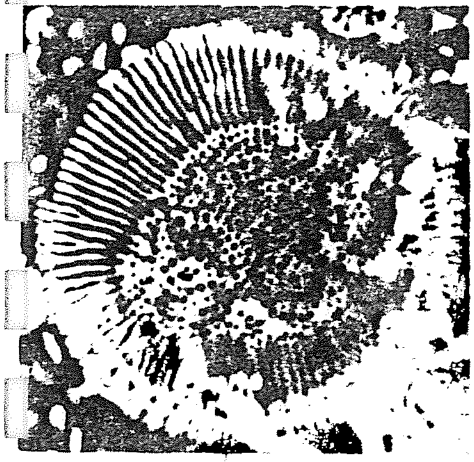
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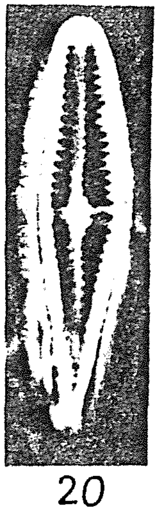
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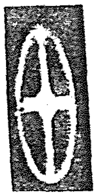
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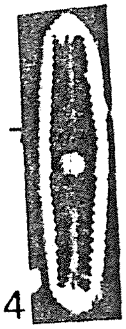
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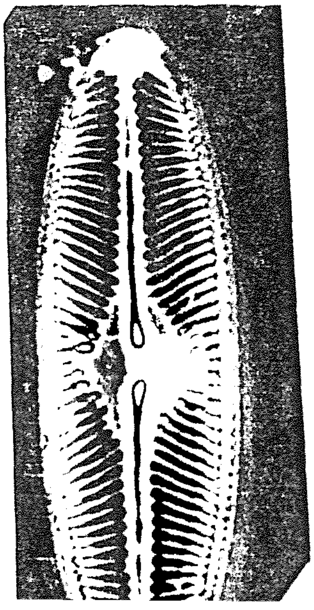

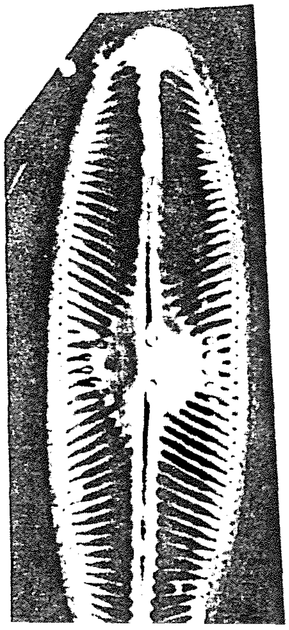

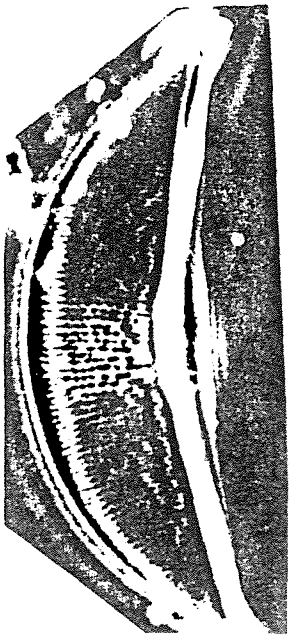

3rd ARCTIC/ANTARCTIC DIATOM TAXONOMY WORKSHOP
QUEEN'S UNIVERSITY
KINGSTON, ONTARIO

5-7 October, 1992.

Participants:

Queen's University	Marianne Douglas (MD), Katrina Moser (KM) Reinhard Pienitz (RP) John Smol (JS) Alex Wolfe (AW)
University of Lund	Hannelore Håkansson (HH)
University College, London	Vivienne Jones (VJ),
Canadian Museum of Nature	Paul Hamilton (PH)

Business, notes, opening comments:

Workshop notes:

The guidelines have previously been mentioned at both the arctic and antarctic workshops. Below is a reminder of the objectives........

1. To create a common taxonomic database with referenced photomicrographs, *and* to identify and define unknown taxa.
2. To make taxonomic recommendations.
3. To identify systematic problems that need further investigation.
4. Establish an ecological map of understanding, with respect to the taxa under examination.

Introduction

5th October, 1992

Monday afternoon, an informal discussion was initiated to evaluate a potential timetable for the Arctic diatom iconograph. It was suggested by all the participants (MD, PH, KM, RP, AW) that the discussion of the iconograph format was to proceed and the production of the iconograph would begin prior to or at the next meeting. PH offered photographic support for the duration of the current year.

Over the 3 day meeting period, numerous individual discussions led to the conclusion that 1/2 page or full page format be setup for each taxon. The format would potentially follow the outline of the chrysophyte cyst publication of Smol et al. and would include light micrographs (LM), scanning electron micrographs (SEM), locality data, general habitat data and taxonomic descriptions. A light micrograph from each of the participants would be included under the LM section of the description. VJ also suggested that the antarctic material might be included in the iconograph. I (PH) would like to here comments on this proposal, especially from HH and JS. The initial deadline for the first version would be October 1993???.

6th October, 1992

The formal opening of the meeting was initiated by JS with a welcome to Kingston and a brief outline of the proposed schedule for the following 5 days. VJ reiterated the goals of the previous Antarctic workshop which match those of the arctic workshop and are listed above.

It was suggested by VJ and HH that a taxa list be established and that selected taxa from this list be discussed. MD has prepared a preliminary taxa list from published literature and her species lists. The authorities of MD's list must still be identified and valid taxa identified. PH expressed some concern about the evaluation of valid taxa from species lists and suggested that publications with photomicrographs be accepted, while those without LM's or voucher slides be set aside into a secondary list. The format for the meeting then developed into a discussion of taxa the participants have problems with. I hope that I (PH) am able to effectively summarize the discussions.

Over the three day period, 99 taxa were discussed, with more emphasis on the genera *Staurosirella*, *Cyclotella*, *Staphanodiscus*, *Cymbella*, *Pinnularia* and *Nitzschia*. It was suggested that *Gomphonema* be re-examined further in subsequent meetings and that *Navicula* spp. for the arctic region still needs to be discussed.

List of actions

1. For the next meeting, prepare complete species lists from your study area.

2. Prepare photomicrographs from the taxa list presented in the **COMPLETE LIST OF TAXA DISCUSSED FOR THE ARCTIC** for contribution to the iconograph. These photographs should also include locality data, ecological data, and morphometric data.

3. Follow up on actions that were to be taken over the last meetings.

4. The taxonomic problems associated with *Gomphonema* were very evident and it would be very valuable to have P. Kociolek at one of the future meetings.

5. The next meeting will be held in January or February. PH will investigate the idea of having the meeting in Ottawa at the museum.

Taxonomic guidelines

Achnanthes

A. altaica
Reported by RP, a small *Achnanthes*, elliptical to linear-elliptical, somewhat comparable to *A. marginulata*, except the apices of the valves show distinct deflections. In girdle view the frustule has a " [" appearance. (See K & LB 2/4, tafel 20, figure 24).

A. exigua
Previously discussed at the first Arctic/Antarctic workshop. Not recorded from the Arctic. There are no problems with this taxon.

A. exigua var. constricta
Reported by VJ from the Antarctic.

A. exigua var. heterovalvar
Reported by VJ from the Antarctic.

A. flexella
Common throughout the Arctic and Antarctic.

A. flexella var. *alpestris*
This variety is similar in size to *A. flexella* var. *arctica*, however in valve outline this variety is much narrower with valve margins that are distinctly parallel as compared to the nominate form. Localities: Ellesmere Island National Park.

A. flexella var. *arctica*
Generally smaller than the nominate form, with a more rounded valve typical of smaller valves (See Foged 1981, plate XI 7). Localities: Cape Herschel, Fosheim Peninsula, Ellesmere Island National Park.

A. linearis
Refer to K & LB 2/4 tafel 37 19-23. See *A. pusilla* for the problems associated with our identifications previously *A. linearis.*

A. minutissima
Found in all locations. There was no discussion on this taxon.

A. minutissima var. scotia
Specimens identical to K & LB 2/4. tafel 34 1-6, have been observed in Ellesmere Island National Park. This variety is recognized by the narrow valve with distinctly capitate apices. The central area of the raphe valve may or may not have a distinctly isolated striae.

A. pusilla
Valves linear to linear-elliptical (8.5-18µm long; 3.5-4.5µm wide, 18-23 striae/10µm), with broadly rounded ends. Raphe straight filiform with straight terminal raphe endings. Axial area narrow linear with a small distinct central area. The key characteristic is the isolated and distinctly visible central striae. The striae are

slightly radiate. PRV looks similar to RV, although the striae often look less radial. The arctic group have the species *A. pusilla* as compared to *A. linearis.* See K & LB 2/4, tafel 37 9-18. Found throughout the arctic.

A. cf. petersenii

See K & LB 2/4 tafel 37, figures 28-39. The central are is somewhat distinct, with a characteristic high striae count (26-36 /10μm).

A. incognita

HH and VJ both find this taxon commonly in their samples. It is not found in the arctic.

A. scotica Flower

A small elliptical diatom reported by RP, with a similar appearance to *A. marginulata*. The flat valve form with curved apices (See *A. altaica*, K & LB 2/4, tafel 20, figure 24) is distinctive for *A. scotica.* Localities: Yellowknife.

A. helvetica

AW reported this taxon from Baffin Island. The specimen PH called *A.* cf. *helvetica* is not the same and is now designated to the unknowns.

A. cf. metakryophila

VJ identified this taxon from the antarctic based on the description by Schmidt et al. 1990, (J. Paleolimnology 3:) See the previous Antarctic and Arctic workshop for a discussion of this taxon. The taxon previously called *A.* cf. *daonensis* by PH is now converted to *A.* cf. *metakryophila* until a better understanding of this species is obtained. Similar species include *A. kryophila*, and *A. helvetica*. LM and SEM photomicrographs are available for this taxon.

A. kryophila

Found both in the Arctic and Antarctic.

A. suchlandtii

Reported by PH from Ellesmere Island National Park and maybe in Newfoundland (RP). Linear to linear-elliptical valve with a distinct thickened axial area with no apparent central area. A singular interruption of the striae is evident on the PRV and characteristic for the species. (see the lectotype specimen in K & LB 2/4, tafel 28, figure 9,10).

A. manguinii

Reported by VJ and HH from the Antarctic, not observed from the Arctic. An aerophilic species with distinctive undulate margins on both valves. The raphe valve with a "stauros" like central area. The type locality is from the Kerguelen region.

A. germanii

Reported by VJ and HH from the Antarctic, not observed from the Arctic. An aerophilic species also reported from the Antarctic by Bourrelly & Manguin (1954), Hirano (1965), and Larson (1974).

A. ventralis

See K & LB 2/4 tafel 24, 8-10 for photomicrographs from the holotype material. PH has identified this taxon from Ellesmere Island National Park. Not observed from the Antarctic.

A. cf. *oestrupii*

Reported by PH from the Fosheim Peninsula and Foged (1981, plate XIII, figure 1) from Alaska. PH must re-examine this material for the structure of the central area of the raphe valve.

A. groenlandica

HH and VJ have found this taxon in the Antarctic and also recorded by Fukushima 1963 in the Ongul Islands. See Hustedt 1933 fig. 874. The type description, length 60 µm, width 7, girdle view 13 µm, striae coarse, biseriate or triseriate, 4-6 striae in 10µm. Found initially in marine environments from Spitzsbergen and Greenland. Hustedt recorded this taxon from northern Ellesmere Island. This taxon has not been recorded from inland freshwater systems in the Canadian Arctic.

A. subatomidus (?*A. subatomoides*)

Recorded from the antarctic by VJ and HH. MD thinks that she has identified this taxon from arctic samples. (Help HH) I was unable to find *A. subatomidus* in the literature.

Achnanthes spp.

Amphora

A. cf. *dusenii*

PH has identified this taxon however, HH disagrees and calls a similar form from the Antarctic, *A. obscura.* The photomicrograph presented by K & LB (2/1 fig. 152, 7-8) was from Spitzbergen. The Arctic specimens are identical to the photograph presented by K & LB.

A. obscura Krasske

HH recognizes this taxon from the Antarctic. She notes that *A. obscura* Krasske is not validly published and must be renamed.

A. species #1

This taxon has been reported from both the Antarctic and Arctic. Photographs will be made available for this taxon with the initiation of the iconograph.

Aulacoseira

A. alpigena

This taxon is quite distinctive as illustrated by Krammer & Lange-Bertalot (2/3 tafel 31, figures 1-15; tafel 32, figures 10-16). In SEM the small simple locking spines, along with the single areolae row around the circumference. This taxon is found on Ellesmere Island and in Alaska. This taxon is also reported from the Antarctic.

A. distans var. *africana*

This taxon has round to long rectangular parallel areolae on the mantle, 12-15 /10µm. Internally a silaceous ring is present at the sulcus and this ring maybe of taxonomic importance. *A. distans* var. *africana* (called *A. pfaffiana* by K & LB) has a small silaceous ring (see K & LB 2/3 tafel 33, figure 11) as compared to *A. perglabra* (see K & LB tafel 33, figure 12). In LM this ring should be visible in valve view. Further study is needed on the validity of the internal ring as a diagnostic character. Location ???

A. distans var. *nivalis*

Specimens from Ellesmere Island were initially identified as this taxon, although the identifications were tentative at best. The discussions centered on the comparisons between *A. distans* var. *nivalis* and *A. perglabra*. *A. distans* var. *nivalis* has true areolate punctation (see K & B 2/3 tafel 1, figure 3) over the complete valve surface. It is very questionable whether this taxon has been observed in the arctic. *A. distans* var. *distans* has been observed in the Antarctic and low Arctic regions.

A. perglabra

The photograph for reference is in the PIRLA iconograph, plate 4, figures 59-65; plate 8, figure 77. The apparent punctation in the central region of the valve, is in fact the result of a pitted or undulating surface as is apparent in PIRLA plate 8, figure 77. This taxon is found on Baffin Island (AW) and is probably the same as material found from Ellesmere Island. The Ellesmere Island form (PH, photograph 92-05-26) needs to be studied further.

Cyclostephanos

C. investitatus

This taxon was discussed by H.H. and K.M. and is reported from Wood Buffalo National Park.

Cyclotella

C. glomerata

See discussions from previous workshops. The use of *C. glomerata* verses *C. stelligera* is still in confusion.

C. krammeri

= *C. kuetzingiana* (pro parte)

HH in her presentation gave a descriptive account of the problems associated with the use of *C. kuetzingiana*. The establishment of *C. krammeri* was an attempt to reduce the confusion by removing the name *C. kuetzingiana* especially considering that *C. kuetzingiana* was not validly published. See Håkansson 1990, Diatom Research 261-271 for a more detailed account of this problem.

C. kuetzingiana var. *radiosa*

The validity of this taxon has not been established. HH will be continuing work on this problem.

C. pseudostelligera

See previous discussions on this taxon. As a result of the concerns of P. Kociolek, we will recognize the distinction of *C. stelligera* and *C. pseudostelligera.*

C. rossii

= *C. comta* var. *oligactis*

HH confirmed the identification of C. rossii from the Ellesmere Island National Park material. HH was not so sure of other arctic material identified using this name. Problems still exist in the identification of this taxon in the arctic.

C. stelligera
See previous discussions on this taxon. As a result of the concerns of P. Kociolek, we will recognize the distinction of *C. stelligera* and *C. pseudostelligera*.

C. suberba
See Schmidt's Atlas tafel 222, figure 35, 36. printed by Fricke. In VanLandingham this taxon has been synonomyzed with *C. sexnotata* Derby. Specimens from Ungava Bay have been given this name. As far as I know, there was no discussions on the validity of this taxon.

C. tripartita
See previous discussions. HH has pointed out that *C. kisselevii* is probably not the same taxon and therefore it is appropriate to keep *C. tripartita* as the accepted name.

Cymbella

C. gaumanii
An interesting taxon that warranted some discussion. The dorsal margin is convex, with the ventral margin slightly concave or straight. Ends capitate to subcapitate. Maybe confused with *C. microcephala*, however, the distinction in LM, is the apparent deflected raphe 1/2 way between the poles and the central area. (See K & LB, 2/1 figure 119, 37-43.) Located ???

C. latens (= *C. minuta* f. *latens*)
The distinct capitate ends, that are detached from the main body of the valve, are characteristic for this taxon (see K & LB 2/1 figure 119, 21).

C. minuta
The reference photomicrograph for this taxon is K & LB 2/1 figure 119, 3-9. Common throughout the arctic. The form PH commonly reports from Ellesmere Island National Park and the Fosheim peninsula is similar to K & LB 2/1 figure 119, 10-13.

C. silesiaca
The reference photomicrograph for this taxon is K & LB 2/1 figure 117, 8. Note the eccentrical position of the axial area, which is distinctive for this taxon. Present from all Arctic locations.

Gomphonema

G. truncatum
= *G. constrictum*
Antarctic and Arctic regions have this species. The nominate form has the typical capitate apex as illustrated by P & R, Plate 16, fig. 3 and K & LB 2/1 fig. 159, 11. As pointed out in P & R the name *G. constrictum* was not validly published in 1830 and therefore *G. truncatum*, published in 1832 should be the accepted name.

G. truncatum var. turgidum
PH recognizes this variety from Makinson Inlet.

G. subtile
Reported by RP from Ungava and PH from Ellesmere Island National Park and Fosheim peninsula. See table 2, for more details.

G. cf. *lagerheimii*

Reported by RP from Ungava and PH from Ellesmere Island National Park. Reference figure K & LB 2/1 fig. 155, 22. Length 30-33μm, width 4-4.5μm, striae 10-11 /10μm, slightly radiate at the center. An isolated stria is evident adjacent to the central area. The obvious comparisons of this species are to *G. montanum* which is larger and has denser striae especially towards the apices, and *G. hebridense* which has more lanceolate apices. The specimens found in the arctic correspond exactly to the K & LB figure listed above.

G. acuminatum

= *G. acuminatum var. coronata*

Recorded by KM and RP from Ungava and Wood Buffalo National Park. Following the discussions of P & R and K & LB, it would appear to be appropriate not to separate the variety *coronata.*

G. acuminatum var. brebissonii

Recorded by AW and PH from True Love and Ellesmere Island National Park. For the present time it appears to be appropriate to recognize this variety. See table 2, for a more details.

G. angustatum

The use of the name *G. angustatum* is still challenged and K&LB (2/4) has suggested that the taxon, *G. micropus* Kützing (1844) takes priority over the use of *G. angustatum* (Kützing) Rabenhorst, originally published as *Sphenella angustata* Kützing (1844). Discussions with P. Kociolek are in order concerning this problem. *G. angustatum* does not appear to be present in the arctic, however it is recorded from the Antarctic.

G. parvulum

The problem with the *G. angustata, G. parvulum, G. gracile* complexes is the plasticity within each of the groups and the apparent overlap among the groups. This problem is clearly expressed by K & LB (2/1) with their interpretations of these complexes. The initial discussions on this problem were conducted at the first Antarctic and Arctic diatom workshop and at that time communications were proposed with Erwin Reichard. In an attempt to help with this problem, a table of information is setup below. The best understanding of these splits is presented in K&LB (2/4) Tafels 74,76,78,79. The major problem is the distinction between *G. angustatum* and *G. parvulum.* The degree of radiate striation, the space between striae, the size of the central area, the rostrate formation of the headpole and footpoles (*G. angustatum*) are good characters to examine when trying to make distinctions among these groups. See reference photographs (K&LB 2/4, T:76, 1-7.)

G. parvulum f. saprophilum

Reported from Ellesmere Island National Park and Wood Buffalo Nation Park. Reference figure K & LB 2/4 tafel 77, figs. 5-6. Length 30μm, width 6-8μm, striae 11-12 /10μm, striae slightly radiate. Also, see reference photographs (K&LB 2/4, T:76, 8-13.)

G. gracile

The reference photomicrographs are	K & LB 2/4 Tafel 79, figures 1-3
	Hustedt 1930 Page 374, Figure 702.
	Patrick & Reimer 1966 Plate 17, Figure 1

The characters that should be used in identifications are striae, size, terminal ends and the degree of heterpolarity. The question was posed "why was tafel 79, figure 4 included as *G. gracile* in the K & LB work? See table 2, for more details.

Navicula

To date Navicula's have not been examined in any detail by the Arctic group. This group should be examined over the next 2 workshops.

Nitzschia

N. cf. commutata
Reported from the Yukon and Ellesmere Island. See the notes from the last Arctic workshop. PH recognizes another form of *N. commutata* with a hyaline area running the length of the valve on the opposite from the fibulae.

N. cf. *dubia* W. Sm.
Recorded from the Antarctic and the Arctic. PH in his identifications has referred to this taxon as Nitzschia sp #4, because the Arctic material does not match the photomicrograph of K & LB from the type material of W. Smith.

N. frustulum
Commonly found both in the Antarctic and Arctic. *N. frustulum* var. *kerguelensis* has been identified from the Antarctic. At the present time the Arctic specimens have been split into two entities. The nominate form has a typical elongate "frustulum" robust appearance along with the perminuta-like constriction in the central region. The presence of central raphe endings along with the low striae count separates this taxon from the *N. perminuta* complex.

N. gracilis
Reported both from the Antarctic and Arctic. VJ assisted PH in recognizing this taxon.

N. cf. *hantzschiana*
Identified from Ellesmere Island National Park. The "perminuta-like" appearance, but with the clearly visible central area and therefore central raphe endings are characteristic. The striae count is lower (24-25 /10µm) than *N. perminuta*. This taxon is differentiated from *N. acidoclinata* on the basis of the striae count (27-34 /10µm).

N. cf. *acidoclinata*
In my poor notes I have *N. incognita* as potentially synonymous with *N. acidoclinata* . Based of the microphotographs of K & LB and the ecology of these two taxa, it would appear that the best name to use at the present time is *N acidoclinata*.

N. inconspicum
Reported from the Arctic and Antarctic. This taxon is recognized in our samples as a small *N. frustulum*. In SEM, we are unable to distinguish any significant structural differences between *N. frustulum* and *N. inconspicum*. Further work is needed.

N. liebetruthii
= *N. frustulum var. perpusilla*
Reported from the Antarctic and Arctic. See table 1, for more details.

N. linearis
Identified from the Antarctic. There was no discussion regarding this taxon.

N. palea
Reported from the Antarctic and Arctic. See k & LB tafel 59, 1,2 for lectotype photomicrographs. This taxon lacks central raphe endings as compared to *N. paleacea.*

N. paleacea
See table for a more complete description.

N. perminuta
See notes from the last two Arctic workshops. From his recent work, PH has split *N. perminuta* into 3 categories. *N. perminuta*, *N. perminuta* var. 1 and *N. perminuta* var. 2. *N. perminuta* has the typical linear to slightly constricted central region, rostrate to capitate apices, small size (<20µm), and high striae count (>26 /10µm, typically 27-30 /10µm). *N. perminuta* var. 1 is identical to *N. perminuta* except for the larger size (20-28µm). *N. perminuta* var. 2 is identical to *N. perminuta* except for the lower striae count (24-45 /10 µm). The distinctions between these forms are not always that evident and may not be all that relevant.

N. sinuata
Identified from both the Antarctic and Arctic. The nominate form is clearly the most prominent in the Arctic.

Pinnularia

P. acrosphaeria var. *turgida*
This taxon has been reported from Ungava.

P. cf. *alpina*
Material from the Antarctic was shown, however no discussions by our group were conducted and the identification is still tentatively unresolved.

P. biceps
At the present time we accept the use of *P. biceps* over the use of *P. interupta* as proposed by K & B. Until the taxonomy is fully resolved it would appear to be pointless in combining taxa and potentially missing ecological information. The straight to convex margin is consistently observed and can be used for the separation from *P. mesolepta.*

P. borealis
The nominate form has been reported from the Antarctic and Ungava Bay.

P. borealis var. *rectangularis*
P.H. has identified this taxon as separate from the nominate variety not so much based on shape as with the lineate nature of the striae. K. & B. show distinctly radiate striae in the center, while this form clearly has parallel striae.

P. brebissonii
See *P. microstauron* for discussion.

P. mesolepta
At the present time we accept the use of *P. biceps* over the use of *P. interupta* as proposed by K & B. As suggested by H.H., the Ehrenberg material should be examined to

resolve this problem, but the material is not plentiful and in poor condition. For the present time, *P. mesolepta* will be maintained.

P. microstauron

The apparent plasticity of valve forms within this taxon has made this species very difficult to discern. The specific problem at present, concerns *P. microstauron* and *P. brebissonii*. The distinction between these two entities is not clear and even Krammer has conflicting comments on the separation of these forms, although Krammer & Lange-Bertalot accept *P. microstauron* var. *brebissonii* as a varietal form. At this time we will use *P. microstauron* var. *microstauron* as the taxon and it is hoped that the accumulation of photographs will assist us in any potential subdivision of this taxon. This taxon has been observed in all location except Wood Buffalo National Park.

P. stomatophora

Very distinctive and easy to recognize. *Pinnularia stomatophora* has been recorded from Ellesmere Island National Park.

P. stomatophora var. 1

P.H. has separated this form from the nominate based on the lineate striae, and the very lineate valve outline. Length 82, width 9, striae 12-13 /10 µm (See P.H. photograph 91-22-35).

P. cf. *streptoraphe* var. *minor*

M.D. and P.H. have recorded this taxon from Ellesmere Island National Park , Fosheim Peninsula and Cape Herschel. The distinct inversions of the raphe and aviolate chambers (K & B 2/1 figures 199-3) are indicative for the taxon. The foramen in our material has a finer structure than that presented in K&B and the specimens of P.H. are narrower.

Stephanocostis

S. chantacius

No notes were taken on the discussion of this taxon.

Stephanodiscus

Three species from this genus were discussed in the continuing saga of the small Stephanodiscus spp. problem. H.H. also took some time to discuss these small Stephanodiscus species in her invited presentation.

S. medius

As the name implies H.H. erected this taxon (Br. Phycol. J. 21, page 32) to indicate a potentially intermediate form that is larger than *S. minutulus*. H.H. also stated that the confusion in names between *S. minutulus* and this taxon previously called *S. minutus* by Grunow was the reason that *S. minutus* was not kept for this taxon.

S. minutulus

H.H. indicated that one important feature in the identification of this taxon in the LM is the undulate valve face as compared to the flat valve face of *S. parvus*. This taxon is reported from Wood Buffalo National Park and Ungava Bay.

S. parvus

In LM the flat appearance of the valve face is an important character.

Thalassiosira

T. pseudonana

This taxon has only been reported from Wood Buffalo National Park.

COMPLETE LIST OF TAXA DISCUSSED FOR ANTARCTIC:

Achnanthes

A. affinis Grunow
A. cf. *delicatula* (Kützing) Grunow
A. exigua Grunow
A. lanceolata (Brébisson) Grunow
A. incognita Krasske
A. lapponica/laevis
A. laevis var. *aretasii* ?
A. linearis (W. Smith) Grunow
A. metakryophila Lange-Bertalot & Schmidt
A. minutissima Kützing
A. microcephala (Kützing) Cleve
A. mollis Krasske
= *Achnanthes abundans* Manguin in Bourelly and Manguin
A. pinnata Hustedt
A. renei Lange-Bertalot & Schmidt

Amphora

A. veneta var. *inflata* nom. nud.

Brachysira

Brachysira minor potential nov. com. (unpublished ?)

Catenula

Catenula spp.

Fragilaria

F. spp.

Gomphonema

G. micropus Kützing
= *G. angustatum* (Kützing) Rabenhorst
G. parvulum (Kützing) Kützing
G. cf. gracile Ehrenberg

Navicula

N. australomediocris
N. begerii Krasske
N. cancellata Donkin
N. capitata Ehrenberg
N. cohnii (Hilse) Lange-Bertalot
N. cf. elginensis (Gregory) Ralfs
N. cf. gregaria Donkin

COMPLETE LIST OF TAXA DISCUSSED FOR THE ARCTIC:

Aulacoseira

- *A. alpigena* (Grunow) Krammer
- *A. distans* var. *africana* (Müller) Simonsen
- *A. distans* var. *nivalis* (Smith) Haworth
- *A. italica* var. *tenuis*
- *A. perglabra* (Østrup) Haworth
- *A. subarctica* (Müller) Haworth
- *A. valida* (Grunow) Krammer

Cyclostephanos

- *C. investitatus* (Holn & Hel.) Ther., Stoer, & Häk.

Cyclotella

- *C. antiqua* W. Smith
- *C. bodanica* Grunow
- *C. bodanica* var. *affinis 1*
- *C. bodanica* var. *affinis 2*
- *C. bodanica* var. *lemanica f. 1*
- *C. bodanica* var. *lemanica f 2*
- *C. cf. delicatissima*
- *C. glomerata* Bachmann
- *C. krammeri* Häkansson
    - = *C. kuetzingiana* (pro parte)
- *C. kuetzingiana* var. *radiosa* (HH validity not established)
- *C. pseudostelligera* Hustedt
- *C. rossii* Häkansson
    - = *C. comta* var. *oligactis* (Ehrenberg) Grunow in V.H.
- *C. tripartita* Håkansson
- *C. stelligera* Cleve & Grunow
- *C. suberba*

Cymbella

- *C. gaeumanii* Meister
- *C. latens* Krasske
    - = *C. minuta* f. *latens* (Krasske) Reimer
- *C. minuta* Hilse
- *C. silesiaca* Bleisch

Denticula

- *D. elegans* Kützing
- *D. kuetzingii* Grunow
- *D. subtilis* Grunow
- *D. tenuis* Kützing

Ellerbeckii

E. arenaria (Moore) Crawford
= *Melosira arenaria* Moore

Epithemia

E. smithii Carruthers
E. sorex Kützing

Fragilaria

F. contricta Ehrenberg
F. virescens var. *exigua* Grunow

Hyalodiscus

H. scoticus

Nitzschia

N. acicularis (Kützing) W. Smith
N. coarctata Grunow
N. cf. *amphiba* Grunow
N. angustata Grunow
N. bacillum Hustedt
N. commutata var. 1
N. commutata var. 2
N. commutata var. 3
N. dubia W. Smith
N. fonticola Grunow
N. frustulum (Kützing) Grunow
N. frustulum var. *subsalina* Hustedt
N. gracilis Hantzsch
N. hantzschiana Rabenhorst
N. incognita Krasske
= *N. acidoclinata* Lange-Bertalot ?? (20-70)
N. inconspicua Grunow
N. lacuum Lange-Bertalot
N. linearis (Agardh) W. Smith
N. obtusa W. Smith complex
= *N. flexoides* sensu Hamilton, 2rd Arctic Diatom workshop
N. palea (Kützing) W. Smith
N. paleacea Grunow
N. perminuta (Grunow) M. Peragallo
N. sigmoidea (Nitzsch) W. Smith
N. sinuata (Thwaites?) Grunow
N. suchlandtii Hustedt
N. valdestriata Aleen & Hustedt

Orthoseira

O. roeseana (Rabenhorst) O'Meara

Pinnularia

P. acrosphaeria var. *turgida* Grunow ex Cleve
P. cf. *alpina* W. Smith
P. biceps Gregory
P. borealis Ehrenberg
P. borealis var. *rectangularis* Carlson
P. brebissonii Kützing
P. mesolepta (Ehrenberg) W. Smith
P. microstauron (Ehrenberg) Cleve
P. stomatophora Grunow
P. streptoraphe var. *minor* (Cleve) Cleve

Pseudostaurosira

P. brevistriata (Grunow) Williams & Round
P. brevistriata var. *papillosa* nom. nud.
P. pseudoconstruens (Marciniak) Williams & Round

Staurosira

S. construens (Ehrenberg) Williams & Round
    = *F. construens* (Ehrenberg) Grunow
    = *F. elliptica* Schumann
S. construens var. *venter* (Ehrenberg) Hamilton

Staurosirella

S. pinnata (Ehrenberg) Williams & Round
S. pinnata var. acuminata nom. nud.
S. pinnata var. intercedens nom. nud.
S. pinnata var. lancettula nom. nud.
S. pinnata var. cf. *subrotunda* nom. nud.
S. pinnata var. ventriculosa nom. nud.

S. lapponica (Grunow in V.H) Williams & Round
S. leptostauron

Stephanocostis

S. chantacius Genkal & Kuzmin

N. contenta Grunow
N. perminuta Grunow
N. perpusilla Grunow
N. gallica (W. Smith) Lagerstedt
N. mutica Kützing
N. muticopsis V.H.
N. naumanni Hustedt
N. tantula Hustedt
N. tabellariaeformis Krasske
N. species #1
Navicula/Stauroneis species #1

Nitzschia

N. homburgensis Lange-Bertalot
N. perminuta (Grunow) M. Peragallo

Pinnularia

P. microstauron (Ehrenberg) Cleve
P. gibba Ehrenberg
P. divergens W. Smith
P. cf. corsonia
P. spitzbergensis Cleve
P. species #1

Stauroneis

S. anceps Ehrenberg
S. anceps f. hyalina
S. anceps f. #1
S. phoenicentron (Nitzsch) Ehrenberg

Staurosira

S. construens (Ehrenberg) Williams & Round
= *F. construens* (Ehrenberg) Grunow

Staurosirella

S. pinnata (Ehrenberg) Williams & Round
= *Fragilaria pinnata*

Synedra

S. rumpens Kützing
S. rumpens f. *familiaris*
= *S. rumpens* var. *familaris* (Ehrenberg) Rabenhorst

Stephanodiscus

- *S. medius* Häkansson
- *S. minutulus* (Kützing) Cleve & Möller
- *S. niagarae* Ehrenberg
- *S. parvus* Stoermer & Häkansson
- *S. transylvanicus* Pantocsek

Thalassiosira

T. pseudonana Hasle & Heimdal

Nitzschia

TAXON	CA	LENGTH	WIDTH	STRIAE	FIBULAE	SHAPE	APEX	FIGURE	COMMENTS
Lanceolatae									
N. acidoclinata	+	8-45	2.5-3	27-34	10-16	lin	cap?, blunt	T:73,100	
N. amphibia	+	6-50	4-6	13-18	7-9	lan, lin-lan	ros, rnd	T:78,13-21	
f. *frauenfeldii*	?	52	3.3	18	7-8	lin	cap, rnd	PH 91-26-05	
N. bacillum		12-20	2-5	27-32	12-16	lan	round	T:78,108	
N. fonticola	+	10-65	2.5-5	23-33	9-16	lin	cap	T:75,1-3	Lectotype
N. frustulum	+	5-60	2-4.5	19-30	10-16	lin-lan	cap?, sharp	T:68,94	
var. *subsalina*	?			29	15	lin	blunt, obtuse	PL 132 4-10.	Simonsen ?*
N. gracilis		30-110	2.5-4	38-42	12-18	lin-lan	cap, rnd	T:66,1,3	typematerial
N. hantzschiana	+	8-50	3-5	20-26	7-12.5	ell-lan	cap?, blunt	T:73,101	
N. incognita	+	20-70	2-3	28-30	10-15	lin-lan	cap?, sharp	T:77,106	
N. inconspicua	+	3-22	2.5-3.5	23-32	8-13	lin-lan	blunt	T:69,95	
N. lacuum		10-20	2-3	35-40	13-18	lan	sharp,round	T:78,107	
N. liebtruthii		5-60	2.4.5	19-30	10-16	lin-lan	sharp	T:69,96	
N. palea		15-70	2.5-5	28-40	9-17	lan	cap, rnd	T:59,1,2	Lectotype
N. paleacea	+	8-55(80)	1.5-4		(12)14-19	lan, lin		T:81,2,3	Lectotype
N. perminuta		8-45	2.5-3	26-36	10-16	lin	round	T:72,99	
N. suchlandtii		28-50	3	34-37	13-16	lin-lan	dis cap	T:66,12,13	Typenprep
N. valdestriata	+	5-13	2.5-3	16-19	6-14	ell-lin	rnd	T:84,9-12	
Dubiae and Bilobatae									
N. commutata	+	45-100	5-8	18-24	9-12	lin	cap	T:42,1	Lectotype
N. dubia	+	80-160	12-16	21-24	9-10	lin	cap	T:41,1	type material
N. homburgiensis	+	32-52	4.5-6	34-40	9-15	lin-constr.	cap	T:50:4-9	
Dissipatae									
N. dissipata									
var. *media*		12.5-85	3-8	39-50	5-11	lan,lan-lin	cap, rnd	T:11,6	Type material
Grunowia									
N. sinuata		10-50	3-8	18-25	5-8	lan, rom	cap, rnd	T:40,1-3	
var. tabellaria		ca. 30				lin	cap	T:39,10	Type material

Nitzschia cont.

TAXON	CA	LENGTH	WIDTH	STRIAE	FIBULAE	SHAPE	APEX	FIGURE	COMMENTS
Lineares									
N. linearis	+	34-228	2.5-7.5	28-41	8-17	lin, constr.	cap	T:55,1-4	Original material
N. sublinearis	+?	30-90	4-6	34-38	13-17	lin	cun, cap	T:58,10	Type material
N. vitrea		30-220	5-14	17-35	4-8	lin	cap	T:56,1-2	
Obtusae									
N. sp #29	+	37-49	3-5	45-48	8-10	sigmoid	rnd	PH921535	flap cent. area
Panduriformes									
N. coarctata	+	30-83	9-21	?	?	lin, sandglass	ros-apic.	T38:13	type material
Sigmoideae									
N. sigmoidea	+	150-500	8-15	23-27	5-7	lin	cun.	T:51-5	apparent CA
Trybliolella (genus) = *Tryblionellae*									
T. angustata	+	25-180	4-12	11-18		lin, lin-lan	cap	T:36,1-5	

* Simonsen did not find any type slide with for this taxon. He therefore selected the specimens printed as lectotypes for this taxon. Simonsen's comments sugge that Hustedt identified this taxon in a lot of his material. The type description presented by Hustedt in 1950, suggests that the ends should be more blunted/obtuse.

Gomphonema

TAXON	LENGTH	WIDTH	STRIAE	STRIAE PATTERN	FIGURE	COMMENTS
(headpole larger than footpole, strong headpole)						
G. acuminatum	20-120	5-17	8-13		T:160,1-12	K&LB (includes (brebissonii)
	30-85	7-11	8-11		Pl:15,2,4,7	P&R (1975)
	20-70	5-11	10-13	Slightly to strongly radiate	Fig. 683	Hustedt (1930)
	30-60	10-13	10-12			Germain
	25-50	7-9	9-10		Pl:LII,6,9	Foged (1981)
	36-53	9	10-11		Pl:28,1,2	Foged (1974)
	61-82	9-11	9-13		Pl:25,1,2	Hein (1990)
var. brebissonii						
	30-60	6-10	9-12	somewhat radiate	Pl:15:8	P&R
	43	6	8-9		Pl:LIII,19	Foged (1981)
var. coronata						
	57	8	11		Pl:LII,8	Foged (1981)
G. subtile	24-50	3.5-8	10-14			K&LB, variable in outline
	35-50	5-8	12-14	somewhat radiate		P&R
	46	6	10		Pl: LIV,1	Foged (1981)
	51	8	8-12		Pl:25,3	Hein (1990)
G. truncatum	13-75	7-17	9-12		T:159,11	K&LB
	26-65	6-14	10-12	distinctly radiate		P&R
	42	12	9		Pl:25,7	Hein (1990)
Headpole region larger than footpole, pseudocapitate, cuneate to rounded headpole, not distinctly larger						
G. micropus	12-45	5-9.5	7-14		T:155,1-21	K & LB (1986)
= *G. angustatum*	12-45	5-9	9-12			P&R (1967)
	12-45	5-8	8-15			Germain
	12-45	5-9	9-14			Hustedt (1930)
	30	7	11		Pl:LIV,12	Foged (1981)

Gomphonema cont.

TAXON	LENGTH	WIDTH	STRIAE	STRIAE PATTERN	FIGURE	COMMENTS
G. productum						
= G. angustatum v.	13-48	4-6	10-13	radiate		P&R
productum	26-36	6-8	10-14		Pl.LIII,4,5,6,8	Foged (1981)
G. parvulum	10-36	4-8	7-20		T:154,1-25	K&LB
	15-30	4-7	14-16			P&R
	12-30	4-7	14-16		Fig. 713a	Hustedt (1930)
	18-32	5-7	13-15			Germain
f. *saprophilum*	30	6.5-8	11-12	slightly radiate	T:77,5,6	K&LB

other potential taxa

G. lapponicum (A. Cleve) Cleve-Euler
??? *G. minutum* (Agardh) Agardh
G. olivaceum (Lyngybe) Kützing
G. ventricosum Gregory

Headpole and footpole of relatively equal size

TAXON	LENGTH	WIDTH	STRIAE	STRIAE PATTERN	FIGURE	COMMENTS
G. gracile						
	24-90	3-11	11-16	Radiate throughout		P&R (1967)
	25-70	4-11	9-17	Radiate		Hustedt (1930)
	25-60	5-10	11-17			Germain
	29-52	8-9	11-14		Pl.VIII,15,16,18	Foged (1981)
	50	7	14		Pl.24,4	Hein (1991)
G. lagerheimii 30-60	4-8	8-12	slightly radiate			K&LB
	38	5	12-13		Pl:LIV,17	Foged (1981)
	43-50	6-6.5	12-14		Pl:32,14,15	Foged (1974)

<u>other potential taxa</u>

G. affine Kützing
G. brasiliense Grunow
G. hebridense Gregory
G. intricatum kützing
G. martinii Fricke
G. barrowiana Patrick & Freese
G. dichotomum Kützing
G. herculeana var. *clavata* Cleve
G. longiceps Ehrenber
G. vibrio Ehrenberg

Appendix 3 Abstracts of papers and posters given at conferences

12th International Diatom Symposium

30 August - 5 September 1992

Renesse

The Netherlands

ABSTRACTS

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AquaSense

The relationship between lake water chemistry and surface sediment diatom assemblages in maritime Antarctic lakes

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Keywords: palaeolimnology, nutrients, salinity

Surface sediments were obtained from 45 lakes on the Byers Peninsular, Livingston Island, South Shetland Islands and from 14 lakes on Signy Island, South Orkney Islands. The topmost sediment (0-0.5 cm) was analysed for diatoms. 105 taxa were found at an abundance of greater than 1%, and of these, 27 taxa could not be related to previously published forms.

Lake water chemistry was analysed at all the sites for nutrients, pH, conductivity and major cations and anions. Strong environmental gradients of nutrient concentration and salinity were present with lakes varying from highly eutrophic to ultra oligotrophic, and from brackish to fresh. The eutrophic lakes were typically coastal sites which were heavily influenced by nutrient input from bird and seal populations.

Diatom abundance was related to the environmental variables using multivariate techniques (eg. CCA) and both salinity and nutrient levels were found to have an important effect on diatom species abundance. Weighted averaging was used to reconstruct the nutrient history at one site, Sombre Lake, Signy Island.

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ROLE OF CHAROPHYTE BEDS IN THE FUNCTIONING OF THE LITTORAL ZONE OF THE NORTH AMERICAN GREAT LAKES

Farwell, A. and H. Duthie. Biology Dept., University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

Since little is known about the role of charophytes in the functioning of the North American Great Lakes ecosystem, a study was initiated in 1991 in Georgian Bay, Lake Huron. Physical and chemical characteristics of selected sampling sites were monitored biweekly. Line transects, sampled by SCUBA, revealed the dominance of vascular macrophytes (*Potamogeton*, *Myriophyllum*, *Elodea*) in the shallowest water extending to depths of 4 m - 5 m during summer and fall. While charophytes (species of *Chara* and *Tolypella*) appeared to be poor competitors in shallow water, they were the only macrophyte group between depths of 8 m to 27 m. *Chara globularis* predominated throughout this depth range, while *Nitella* sp. was only found at depths greater than 13.5 m. Maximum biomass per unit area was attained at all depths sampled in August, with the highest values at a depth of 10.5 m. Charophytes and their algal epiphytes are heavily grazed by a large variety of invertebrates, and represent an important component of the littoral ecosystem.

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ZOOPLANKTON HERBIVORY ON NATURAL ASSEMBLAGES OF PHYTOPLANKTON IN TWO URBAN LAKES, NEW ZEALAND.

Edgar, N.B., Chapman, M.A. and Green, J.D. Department of Biological Sciences,
The University of Waikato, Hamilton, New Zealand

The seasonality of zooplankton grazing in mesotrophic Lakes Rotoroa and Pupuke was examined using *in situ* limnocorrals with a gradient of herbivore biomass. Reduction of algal biomass and species - specific responses of phytoplankton to grazer presence varied between season and across lake types. Selectivities of the zooplankton were influenced by GALD and Biovolume.

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APPLICATION OF MICROELECTRODES IN HIGH LATITUDE LAKES AND STREAMS

Ellis-Evans, J.C. and Bayliss, P.R. British Antarctic Survey, Madingley Road, Cambridge, England

The considerable potential for using microelectrode technology to investigate benthic communities in high latitude lakes and streams has, until now, rarely been addressed. Examples are given of how one can study gradients of electron acceptors, such as oxygen and nitrate, and the spatial distribution of different physiological groups, at a scale (microns) comparable to that experienced by the microbes. Using optical fibres we have also examined the distribution of pigments in stream cyanobacterial mats and these data, coupled with depth-specific action spectra (by oxygen microelectrode), have provided three dimensional information on the light environment and physiological response of the mat community.

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THE RELATIONSHIP BETWEEN LAKE WATER CHEMISTRY AND SURF/ SEDIMENT DIATOM ASSEMBLAGES IN MARITIME ANTARCTIC LAKES

Jones, V.J.[1], Juggins, S.[1] and Ellis-Evans, J.C.[2] [1]Dept of Geography, Univ. Coll
London, England, [2]British Antarctic Survey, Cambridge, England.

Surface sediments from 45 lakes in the South Orkneys and South Shetlands were anal
for diatoms and lake water chemistry. Strong environmental gradients of nutr
concentrations and salinity were present with lakes varying from highly eutrophic to ul
oligotrophic, and from brackish to fresh. Diatom species abundance was highly relate
both salinity and nutrient levels. Transfer functions relating diatom abundance and
chemistry are used to reconstruct the nutrient history at one site.

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SEASONALITY OF THE COPEPOD *P. POPPEI* IN CONTRASTING ANTARCTIC L

Brazier, P. and Ellis-Evans, J.C. British Antarctic Survey, Cambridge, England.

P. poppei occurs in a range of lakes at Signy Island and adapts its seasonal reprod
behaviour to take account of lake trophic status and associated food availability. Inter-a
variability in both study lakes was far greater than seasonal fluctuations and this was, in
attributable to the scale of inter-year variations in the size of the spring phytoplankton b
However the increased nutrient loading to enriched Heywood Lake has also caused
extensive winter anoxia resulting in high population mortality, in some years, which c
effects population seasonality. Experiments to assess *P. poppei* naupliar feeding rates in
that less than 1% of the spring algal bloom is consumed whereas anostracan juveniles re
up to 40% of the same population. Evidence of diurnal migration and feeding patterns
observed in adult copepods but not in the juvenile stages.

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PHYTOPLANKTON RECOVERY AFTER CEASE OF SULPHITE PULP MILL EFFLUENT L TO A WATER COURSE

Eloranta, P. Dept. of Limnology and Environm. Prot., Univ. of Helsinki, Helsinki, Finlar

The water course was loaded by wastes from paper factory, sulphite pulp
with bleaching plant since the beginning of this century. Pollution caused a clear zonatio
the water course with inhibition zone close to the factories, eutrophication zone after s
degree of dilution of effluents and declining eutrophy with increasing dista
Phytoplankton structure was rather stable during strong pollution until the end of 19
when biological purification plant was established at the factories. Then clear changes in
community structure was recorded in spite of the remaining inhibitory effects. After clo
the sulphite pulp mill and the bleaching plant in March 1991 algal community chan
rapidly to more or less normal corresponding that in the upper parts of the water cou
The remaining effects of long lasting effluent load were increased biomasses due
increased nutrient concentration. Blue-green algae, which were absent during effluent lc
were back in the area already in the first summer without pulp mill effluents.

BRITISH ECOLOGICAL SOCIETY

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Author's(') Name(s) Vivienne Jones

University or Institute University College London

Title of Paper Records of Environmental change from Antarctic lake sediments

Abstract: Sediment cores from several Signy Island lakes provide good records of environmental change at time scales of 10' to 1000's of years. The evidence for nutrient enrichment and climate change is evaluated.

Name and full address of author for correspondence:-

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Appendix 4 Published papers

Antarctic Science 5 (4): 00–00 (1993)

The relationship between water chemistry and surface sediment diatom assemblages in maritime Antarctic lakes

V.J. JONES[1], S. JUGGINS[1] and J.C. ELLIS-EVANS[2]

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[2] *British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK*

Abstract: Maritime Antarctic freshwater lakes and their catchments are inherently simple systems in an environment which is characterized by strong seasonality. Such lakes offer excellent opportunities to study the interaction of water chemistry and plant communities. The response of diatom species to environmental gradients was assessed by constructing a diatom and water chemistry dataset from 59 lakes at two locations (Livingston Island, South Shetland Islands and Signy Island, South Orkney Islands). Results indicate that diatom species abundance is predominately related to nutrient and salinity gradients. The dataset will be used to create transfer functions which can be applied to sediment core diatom assemblages to reconstruct historical patterns of lake chemistry.

Received 28 November 1992, accepted 26 March 1993

Key words: diatoms, training dataset, nutrients, salinity, multivariate analysis

Introduction

Diatoms (Bacillariophyceae) are unicellular siliceous algae which are common in water bodies throughout the world. They are commonly reported from the Antarctic where they are abundant in many streams and lakes (Kobayashi 1963, Pankow *et al.* 1987, Oppenheim & Ellis-Evans 1989, Oppenheim & Greenwood 1990). Diatoms are generally well preserved and abundant in lake sediments, their remains can be identified to species level and typically a large number of species are recorded. Diatom remains in dated lake sediment cores have been used extensively in temperate and tropical regions for reconstructing past changes in water chemistry and show great potential for studying environmental change in the Antarctic (Schmidt *et al.* 1990, Björck *et al.* 1991, Wasell & Håkansson 1992).

Diatom species composition is strongly related to lake water chemistry, and there is a well documented literature concerning the response of individual species to pH (Hustedt 1937–1939, Nygaard 1956), salinity (Kolbe 1927, Hustedt 1957) and nutrient (Nygaard 1949, Stockner 1971, 1972) gradients. More recently attempts have been made to quantify these relationships using multivariate statistical methods (e.g. Dixit *et al.* 1991). This approach generally involves the collection of new data in the form of a training, or calibration, dataset, relating a modern lake surface sediment diatom assemblage, which represents an integrated sample of the various living diatom communities in the lake, to contemporary water chemistry. Environmental variables which are strongly related to diatom distribution can be identified, and the relationships quantified. These relationships, or *transfer functions*, can then be applied to fossil diatom assemblages from sediment cores to provide environmental reconstructions of key hydrochemical variables.

Quantitative relationships between diatoms and environmental gradients have been established in many parts of the world. Much research has concentrated on the relationship between diatoms and pH (Gasse & Tekaia 1983, Charles & Whitehead 1986, Birks *et al.* 1990), but datasets have also been constructed more recently to investigate the relationship between diatoms and nutrients (Whitmore 1989, Hall & Smol 1992), and salinity (Fritz *et al.* 1991, Juggins 1992). These studies have recognized the importance of constructing regional datasets reflecting the particular water chemistry and diatom flora of different geographic areas.

Although diatom taxa are broadly cosmopolitan there are a number of unusual and unique forms common in the Antarctic. This, together with a lack of autecological information, makes it necessary to construct a training set specifically for the Antarctic as an essential prerequisite to diatom-based environmental reconstruction. This paper describes the lake-water characteristics of a new 59-lake surface sediment diatom/water chemistry dataset, and presents a preliminary analysis of the response of the diatom species to environmental gradients in the maritime Antarctic.

The study sites

Lakes from two areas of the maritime Antarctic were studied (Fig. 1, Table I), the Byers Peninsula (Livingston Island, South Shetland Islands, 62° 40'S, 61° 00'W) and Signy Island (South Orkney Islands, 60°43'S, 45°38'W). The Byers Peninsula is the largest ice-free area of the South Shetland Islands covering an area of *c.* 50 km^2. The highest part of the Peninsula (Chester Cone) is 193m high, but most of the area consists of a central platform lying between 85 and 100m. Two lower platforms (at 28–50 m and 11–17 m) are situated between the central platform and the coast (John & Sugden 1971). The geology of the area

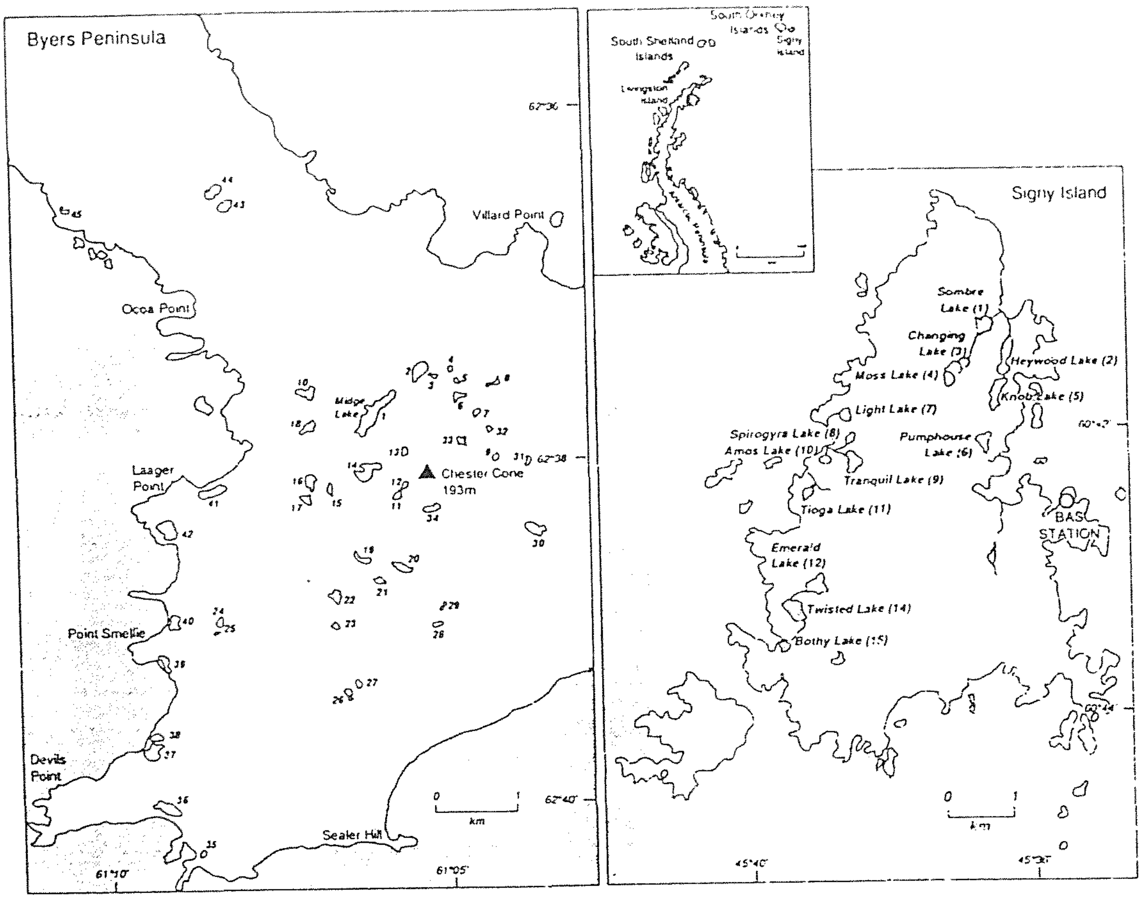

Fig. 1. Location of sample sites on Signy and Livingston islands. Lakes are referred to by number on Livingston Island, and by name and number on Signy Island.

consists of Jurassic–Cretaceous sediments (shales and sandstones) and Upper Jurassic–Lower Cretaceous volcanic rocks (basaltic agglomerates, augite-andesites, volcanic breccias and tuffs) (Hobbs 1968). The Holocene history of the area is summarized by Björck *et al.* (1991). Most of the inland area is not vegetated but scattered clumps of mosses and lichens do occur. The coastal area is somewhat richer and supports two flowering plant species (*Deschampsia antarctica* Desv. and *Colobanthus quitensis* (Kunth) Bartl.) with a limited development of coastal moss carpets.

Signy Island covers an area of *c.* 20 km^2 and is low lying, with a maximum height of 279m. The terrain is rugged and large areas (32 %) are covered with permanent snow and ice. The geology consists of intensely folded metamorphic sediments, mainly garnetiferous quartz-mica-schists, with some amphibolites and marbles (Matthews & Maling 1967). The ice-free areas of Signy Island are comparatively well vegetated with extensive areas of moss and lichen as well as patches of *C. quitensis* and *D. antarctica* (Smith 1972). Large peat banks have accumulated on Signy Island reflecting greater stability and more acid soils compared to the generally unstable, porous and more alkaline volcanic soils of Livingston Island. Signy Island lakes are, with one exception, in more vegetated catchments than virtually all the Livingston Island lakes which are mainly on the barren central plateau (Fig. 1).

Livingston and Signy Islands share a maritime Antarctic climate which is moister and milder than continental Antarctica. Mean annual air temperatures are sub-zero (-3°C) but mean monthly temperatures exceed 0°C for at least one month in summer. Permafrost is present below an active layer of 0.3–0.7 m (Chambers 1966, John & Sugden 1971).

The Signy Island lakes are glacial in origin and range from oligotrophic clearwater to turbid eutrophic systems (Heywood *et al.* 1979, 1980). The lakes at Signy Island are all relatively shallow (generally <10 m deep) and ice-covered to a depth of 1–1.5 m for 8–12 months each year. The Livingston Island lakes are also shallow (Table I) and appear to have a similar depth of ice cover. However, the greater winter snow accumulation insulates these lakes from early summer air temperatures, and ice-out appears to be several weeks later than the majority of systems at Signy Island. In summer all lakes are ice-free and well mixed by wind.

The major source of nutrients in maritime Antarctic lakes is from bird and seal excreta. Nutrients are thus largely transferred from the much more productive marine ecosystem either directly into lakes by animals or indirectly via runoff from the catchment (Smith 1988). This has become particularly pronounced at Signy Island where, over the past 10 years, the catchments of some lakes have been colonized by large numbers of Antarctic fur seals (*Arctocephalus gazella*), representing the overspill from rapidly expanding populations on subantarctic South Georgia (Fig. 1). In some areas the effects of these seals have been profound, with almost complete destruction of catchment moss communities (Smith 1988, 1990), enhanced nutrient runoff

Table I. Physico-chemical results of lakes sampled on Livingston and Signy islands.

Lake code	Altitude (m)	Max depth (m)	pH	Conductivity (μS cm^{-1})	Chl*a* (μg l^{-1})	Phae (μg l^{-1})	NO (μg l^{-1})	NH (μg l^{-1})	TDN (μg l^{-1})	PO (μg l^{-1})	Cl (mg l^{-1})	TP (mg l^{-1})	Na (mg l^{-1})	K (mg l^{-1})	Mg (mg l^{-1})	Ca (mg l^{-1})	Si (μg l^{-1})
LN01	89	8.6	6.82	131	0.05	1.26	2.0	6.5	86.0	1.5	21.5	9.0	5.8	0.2	1.9	2.2	1192.7
LN02	88	3.0	6.92	110	0.29	0.41	2.0	1.5	181.0	0.5	15.8	0.5	3.9	0.1	1.4	1.7	1062.3
LN03	85	3.4	7.02	101	0.26	0.46	4.0	1.5	210.0	0.5	15.0	32.0	3.4	0.1	0.7	1.3	1166.4
LN04	99	0.1	6.92	282	0.05	1.24	0.5	5.5	63.0	0.5	36.8	5.0	11.5	0.1	4.4	7.9	1206.0
LN05	90	2.7	7.32	114	0.73	0.71	0.5	1.5	161.0	0.5	20.5	5.0	5.5	0.1	1.1	0.9	573.6
LN06	96	3.7	7.42	91	0.49	0.22	8.0	3.5	442.0	0.5	18.0	3.5	2.8	0.1	1.1	1.0	1034.5
LN07	94	2.6	7.52	93	0.68	1.16	12.0	1.5	178.0	0.5	18.3	2.0	3.1	0.1	1.3	1.4	977.7
LN08	91	1.3	7.62	60	0.34	0.52	23.0	2.5	519.0	0.5	10.5	3.5	1.6	0.1	0.5	0.7	809.4
LN09	102	1.6	7.52	71	0.39	0.22	2.0	11.5	413.0	0.5	13.5	7.5	2.1	0.2	1.0	0.8	1032.9
LN10	39	0.7	7.42	143	1.16	0.60	5.0	0.5	356.0	22.0	21.3	12.0	7.0	0.1	2.9	6.3	799.0
LN11	68	2.3	7.52	70	0.65	0.92	28.0	4.2	202.0	17.5	15.0	1.0	3.3	0.1	1.0	1.0	1217.2
LN12	70	5.3	7.52	77	0.64	0.44	28.0	3.2	500.0	6.5	14.0	0.5	2.9	0.1	1.0	1.0	1354.9
LN13	74	0.2	7.72	67	0.59	1.20	30.0	0.5	68.0	0.5	15.0	3.5	2.1	0.1	1.0	0.7	1005.0
LN14	81	5.4	7.62	78	0.09	0.62	25.0	0.5	392.0	0.5	17.5	1.0	3.3	0.1	1.3	1.6	918.2
LN15	74	1.5	7.42	119	0.95	0.41	21.0	0.5	191.0	0.5	23.5	5.0	7.8	0.1	1.2	2.0	1980.0
LN16	66	7.1	7.52	122	0.37	0.82	30.0	0.5	131.0	0.5	24.3	1.0	6.4	0.2	1.9	2.2	1432.1
LN17	70	3.3	7.62	87	0.47	0.25	9.0	0.5	80.0	0.5	17.3	2.0	3.6	0.1	1.9	1.6	982.2
LN18	36	0.7	7.62	105	0.55	0.22	7.0	0.5	389.0	0.5	17.8	9.0	6.0	0.2	1.6	2.0	1223.0
LN19	87	3.0	7.62	105	0.28	1.77	0.5	1.7	392.0	0.5	15.0	1.0	3.3	0.1	1.4	2.7	1122.0
LN20	93	2.0	7.72	80	0.54	0.62	0.5	6.0	78.0	0.5	11.8	6.5	1.8	0.1	1.0	1.6	856.4
LN21	88	1.5	7.52	105	0.29	0.22	0.5	1.7	31.0	0.5	15.0	3.5	3.3	0.1	1.7	6.1	791.0
LN22	81	4.5	7.62	110	0.91	0.91	0.5	2.0	278.0	0.5	13.5	6.5	2.9	0.1	1.5	3.4	115.1
LN23	85	0.2	7.82	242	0.56	0.55	0.5	6.3	109.0	0.5	39.0	5.0	10.4	0.2	4.3	5.8	1382.8
LN24	58	1.0	7.92	129	1.03	2.96	0.5	2.8	243.0	0.5	17.8	5.0	3.8	0.1	1.8	3.2	1090.5
LN25	58	0.6	8.12	329	1.42	0.69	12.0	22.0	420.0	16.0	45.0	15.6	11.4	0.3	4.8	7.3	1089.8
LN26	72	3.4	6.72	103	0.45	0.38	10.0	3.0	304.0	0.5	9.5	2.0	1.5	0.1	0.8	1.5	605.9
LN27	86	4.3	6.62	113	0.67	0.43	4.0	5.0	90.0	0.5	17.5	3.5	3.7	0.1	1.6	3.4	1006.1
LN28	83	4.8	6.62	107	0.69	0.60	25.0	5.5	56.0	0.5	11.5	2.0	3.0	0.1	1.4	3.7	1139.8
LN29	99	0.1	6.82	80	0.90	0.58	8.0	0.5	57.0	0.5	15.2	1.0	2.7	0.5	1.1	1.9	606.2
LN30	103	3.9	7.22	86	0.80	1.70	5.0	5.5	429.0	7.0	17.3	5.0	3.8	0.5	1.0	0.7	847.0
LN31	83	0.9	7.42	73	0.59	0.61	4.0	1.5	355.0	0.5	13.5	5.0	2.6	0.5	1.9	0.5	1229.7
LN32	80	0.1	6.82	91	2.89	2.18	26.0	2.7	113.0	0.5	14.8	2.0	2.1	0.5	1.2	0.8	1365.3
LN33	83	0.6	6.82	91	0.44	0.76	6.0	5.0	260.0	0.5	16.3	1.0	3.4	0.2	1.1	0.7	1643.7
LN34	92	1.5	6.92	64	0.63	0.44	6.0	5.0	125.0	0.5	11.8	6.5	1.8	0.2	1.1	0.5	764.3
LN35	5	0.5	6.72	303	7.36	4.42	15.0	26.0	540.0	5.0	27.8	16.0	2.0	0.2	2.7	8.6	1284.3
LN36	5	0.4	7.02	278	6.83	2.60	8.0	20.5	370.0	3.5	34.0	19.5	2.0	9.5	4.0	4.8	962.8
LN37	5	0.4	8.02	2960	7.80	2.08	5.0	25.0	383.0	3.7	644.0	42.0	188.0	1.2	34.0	33.6	1260.0
LN38	5	0.4	8.02	425	4.58	1.56	15.0	34.0	798.0	16.0	39.0	20.5	30.0	0.2	4.0	17.2	898.2
LN39	5	0.4	8.02	381	3.83	0.26	6.0	17.5	3311.0	3.5	38.8	160.0	11.0	0.5	3.8	4.4	763.2
LN40	5	0.3	8.92	620	6.29	6.38	6.0	32.0	100.0	24.5	65.0	71.0	14.0	0.5	6.8	12.2	386.0
LN41	5	0.3	7.62	394	2.36	1.89	2.0	18.0	528.0	7.5	40.0	19.5	4.0	0.3	4.5	13.2	850.2
LN42	5	0.3	7.62	425	5.17	0.52	420.0	95.0	1175.0	133.0	25.5	7.5	10.0	0.3	3.5	8.6	749.3
LN43	143	1.5	7.92	71	0.14	0.21	40.0	14.0	190.0	6.5	9.8	3.5	2.2	0.1	0.6	1.2	558.7
LN44	144	1.7	7.62	143	1.69	1.12	50.0	8.5	1358.0	2.5	16.0	3.5	3.7	0.1	1.7	5.5	886.3
LN45	80	2.7	7.52	187	0.62	0.75	23.0	10.5	225.0	4.0	17.3	3.5	7.6	0.1	1.8	2.0	772.6
SG01	10	11.2	6.82	78	3.99	1.74	181.9	12.9	272.5	2.6	25.8	9.0	24.9	1.0	4.6	3.8	169.2
SG02	4	6.4	6.92	134	10.06	5.19	327.0	56.1	614.7	32.1	42.3	122.1	33.2	1.5	5.9	4.0	201.1
SG03	35	5.4	6.82	94	2.43	0.58	146.4	8.5	223.2	3.5	25.3	10.8	23.0	1.0	4.2	3.4	236.6
SG04	48	10.4	6.82	40	1.85	0.77	111.0	5.6	204.0	2.3	23.2	7.8	12.6	1.2	1.4	2.2	137.0
SG05	8	3.5	7.32	62	8.70	6.60	123.3	16.3	328.7	0.9	18.7	33.7	22.8	1.4	3.1	4.1	168.4
SG06	20	4.0	6.92	86	3.02	1.13	63.6	7.1	174.9	3.5	18.4	9.4	13.8	1.2	2.5	4.2	83.7
SG07	35	4.4	6.82	121	9.21	3.57	33.4	11.2	145.9	1.4	44.1	27.6	29.6	2.3	4.7	4.9	122.9
SG08	25	1.5	7.42	60	1.51	1.23	116.2	17.4	209.6	0.3	19.4	11.0	28.8	2.2	4.7	6.2	149.5
SG09	28	8.0	6.92	52	1.53	1.15	80.7	1.8	146.4	0.3	16.7	5.0	16.3	1.0	2.7	3.1	88.8
SG10	8	4.3	8.12	120	4.11	4.28	520.6	214.4	1150.5	205.4	33.9	252.5	36.0	3.4	20.3	9.7	88.8
SG11	35	4.0	7.42	134	4.29	4.06	105.7	53.3	421.8	28.0	20.9	73.9	30.0	1.8	6.1	5.2	127.2
SG12	45	15.0	6.62	67	1.33	0.54	97.3	10.3	187.7	3.2	23.4	7.6	12.3	1.2	2.1	2.4	76.3
SG14	30	4.0	6.82	92	2.43	1.01	65.6	2.5	150.2	2.6	28.7	9.5	17.3	1.5	3.4	4.2	56.2
SG15	4	2.0	6.82	233	1.24	0.42	570.7	94.8	864.7	54.5	44.2	180.6	20.8	1.7	4.1	4.7	191.5

and increased organic carbon and nitrogen loadings in the lakes and lake sediments (Ellis-Evans 1990). In contrast, most freshwater Livingston Island lakes are situated inland and receive virtually no animal inputs, although the brackish coastal lakes are heavily influenced by sea spray and in some cases have large animal and bird populations in summer.

The biology of several of the Signy Island lakes has been studied in some detail (Ellis-Evans 1981, 1984, 1985, Hawes 1985, Oppenheim & Ellis-Evans 1989, Oppenheim & Greenwood 1990). In contrast the Livingston Island lakes are extremely poorly studied and little is known of their limnology beyond the work of Hansson (1990), and Hansson & Håkansson (1992).

Methods

Surface sediments and water chemistry were obtained from 45 sites on the Byers Peninsula, Livingston Island, and from 14 sites on Signy Island (Fig. 1). Lakes are referred to by number alone in the case of Livingston Island lakes where official names have not been assigned. Signy lakes are referred to by both number and official name.

Water sampling

At Livingston Island, 2 l water samples were taken in acid-washed plastic bottles from sites near the outflow of each lake and samples were filtered (by GF/F) shortly after collection. Filters were placed in methanol and frozen for subsequent chlorophyll analysis and water samples were either analysed within 24 h of collection (for conductivity, nitrate, ammonium and soluble reactive phosphate) or frozen for later analysis. Separate filtered samples were collected for dissolved reactive silicate analysis and measured within three days. pH was measured *in situ* or immediately on return to the base camp with a hand-held pH meter (Jenway model 3070) and pH electrode (Russell Scientific) designed for low conductivity waters. Temperature and conductivity were measured by a Jenway model 4070 meter and electrode, and oxygen measurements by a YSI model 57 system. Water analysis followed the methods of Mackereth *et al.* (1978) and in all cases produced colour reactions which were measured at the field camp using a Pye Unicam SP6-550 UV\Vis spectrophotometer.

At Signy Island routine monthly measurements are made on Sombre Lake and Heywood Lake, whilst all the lakes are sampled at three critical periods (early winter, spring and summer open water) each year. The analyses include dissolved oxygen, conductivity and temperature profiles which are measured in the field with YSI probes and meters, and pH, chloride, nitrate, nitrite, ammonia, total dissolved nitrogen, soluble reactive phosphorus, total dissolved phosphorus, total phosphorus and dissolved reactive silicate which are analysed in the laboratory. The latter are measured by the methods described in Mackereth *et al.* (1978) except pH (Corning Delta pH meter and low conductivity water pH electrode).

To enable the comparison with Livingston Island only the summer data from Signy Island were used. These were averaged for the two years previous to the time when the surface sediment sample was obtained, this being augmented by the more detailed information from the routine sampling programme on Sombre and Heywood Lakes. Winter conductivity values were used when summer measurements were not available as midwater conductivity changed little throughout the year.

Surface sediment sampling

Sediment cores were collected from the deepest part of each lake with either a gravity type corer (Glew 1989), or a BAS corer (Ellis-Evans 1982), operated from either a small inflatable boat or from the ice. Livingston Island lakes were sampled in 1991 and Signy Island lakes were sampled between 1985 and 1991. The top 0–0.5 cm slice of each core was used for the surface sediment sample.

Diatom analysis

Diatoms were prepared from the surface sediment samples by oxidation using H_2O_2 (Renberg 1990). At least 500 valves per sample were counted on random transects using a Leitz Laborlux S microscope with phase-contrast at 1000x. Diatoms were identified using a range of floras, in particular Hustedt (1927–66), Krasske (1939), LeCohu & Maillard (1983, 1986), Krammer & Lange-Bertalot (1986, 1988) Lange-Bertalot & Krammer (1989), & Schmidt *et al.* (1990). The taxonomic status of certain species is rather preliminary and more complete descriptions will be given elsewhere.

Data analysis

Diatom species were expressed as relative abundances (% total diatoms) and only those present at >1% in any single sample, or with >2 occurrences (79 species) were retained. For multivariate analyses all chemical variables were $\log_{10}$ transformed except for pH. Ordinations were implemented by the computer program CANOCO 3.10 (ter Braak 1987, 1990), with rare species downweighted in all cases. Cluster analysis of the environmental data (unweighted pair-group clustering applied to a standardized Euclidean distance matrix) was performed using the program CLUSTER (H.J.B. Birks unpublished). The program TWINSPAN (Hill 1979) was used for cluster analysis of the diatom data.

Results

Water chemistry

The results of the physico-chemical analyses are shown in Table I. Principal components analysis (PCA) and cluster analysis is used to summarize the major patterns of variation within this data, and these results are presented as a PCA correlation biplot and dendrogram in Fig. 2. In the biplot, variables with high positive correlation generally have small angles between their biplot arrows. Variables with long arrows have high variance, and are generally the more important within the data.

The cluster analysis divides the lakes into four groups. Groups 1 and 2 consist of the inland and coastal Livingston Island lakes respectively. Group 3 contains the Signy Island lakes, and Group 4 contains three outliers, separated on the basis of high nutrient concentrations, in the case of SG10 (Amos Lake), or high conductivities (LN37 and LN40). The first two principal components ($_1$=0.50, $_2$=0.16) account for 66% of the total variance, and effectively capture the main patterns of variation in the environmental data. The first axis is related to indicators of trophic status (total phosphate, orthophosphate, total dissolved nitrogen, chlorophyll *a* and phaeopigments) and associated ions (calcium and magnesium), and contrasts the nutrient poor inland Livingston sites of Group 1, plotted on the left of the diagram, with the nutrient-rich coastal Livingston and Signy sites such as SG10 (Amos Lake), SG02 (Heywood Lake) and LN42.

Axis 2 reflects two gradients. The first running from top right to bottom left is related to salinity and separates the high conductivity coastal Livingston sites of Groups 2 and 4 from the remainder. Some sites, plotted top right, exhibit a very strong marine influence, particularly LN37 which has a conductivity of 2960 μS and associated high sodium and chloride values (Table I). The second is related to dissolved silica, potassium and nitrate and runs from top left to bottom right, separating the generally high nitrate and potassium, low dissolved silica lakes on Signy Island, plotted bottom right, from low nitrate and potassium, high dissolved silica sites on Livingston Island.

Fig. 3 shows scatter plots and correlations of selected variables, and highlights the negative correlation of nutrient-related variables and conductivity with altitude, as a result of the influence of marine birds and mammals at the low altitude coastal sites. There is no strong pH gradient in the data, although pH is weakly correlated with conductivity.

Diatom analysis

TWINSPAN classification was used to group sites on the basis of their diatom assemblages. Three main groups of sites were identified and these are represented in the dendrogram at the top of Fig. 4. Group 1 consists of the Signy Island sites, and is further divided into two. Group 1a contains the coastal, more eutrophic sites, whilst Group 1b contains the inland oligotrophic sites. Group 2 consists of the majority of the Livingston Island sites, and includes all the inland sites plus LN45 which although situated near the coast, is at an altitude of 80 m. Group 3 consists of the low-lying coastal Livingston Island sites.

Fig. 4 also shows the major patterns of diatom distribution and abundance for each group of lakes (a list of diatom codes, names and authorities is given in Appendix 1). Group 1a has high frequencies of *Achnanthes pinnata*, *A. subatomoides*, *A. renei*, *Navicula seminulum*, *Nitzschia perminuta*, *Synedra rumpens* and *A. delicatula*. Group 1b has a higher frequency of *Cymbella minuta* and *A. minutissima*, and a lower frequency of *S. rumpens*. In Group 2 *N. seminulum*, *Fragilaria pinnata*, *Navicula tantula* and *A. metakryophila* are important. Group 2b also has high percentage abundances of *A. renei* and *N. australomediocris*. In Group 3 there are high percentage abundances of *N. perminuta*, *Navicula gregaria* and *Fragilaria construens* var. *binodis*. Group 3a also has high abundances of *Nitzschia paleacea*, *Nitzschia gracilis*, *Nitzschia homburgiensis* and *Pinnularia* species 1. Whilst Group 3b has high abundances of *Nitzschia frustulum* and *Navicula capitata* var. *hungarica*.

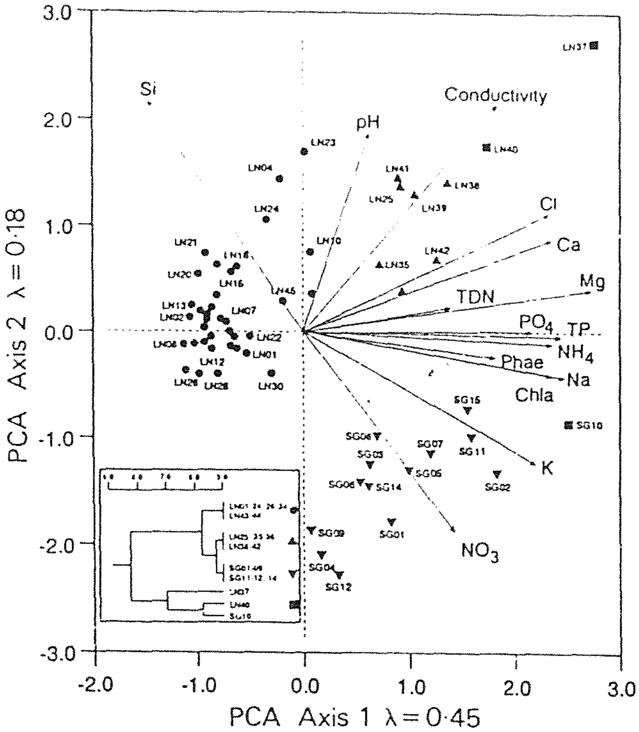

Fig. 2. Principal components analysis (PCA) correlation biplot. Symbols for lake sites are according to the groups defined by cluster analysis, see inset. Sites numbered as in Fig. 1 with the prefix LN to denote Livingston Island samples and SG to denote the Signy Island sites.

The three main groups identified on the basis of their diatom assemblages are broadly similar to the groups identified by water chemistry alone. This suggests that diatom distribution is strongly related to the main gradients in the chemical environment. The relationships between the diatom assemblages and the environmental variables are explored in more detail using canonical correspondence analysis (CCA) (ter Braak 1986) and the results plotted in Fig. 5, together with the site groups defined above. The length of the environmental arrows indicate their relative importance in explaining the variation in the diatom data, and their orientation indicates their correlation with the ordination axes.

The first two CCA axes ($_1$=0.30, $_2$=0.28) account for 17% of the variance in the weighted averages of the diatom data. Monte

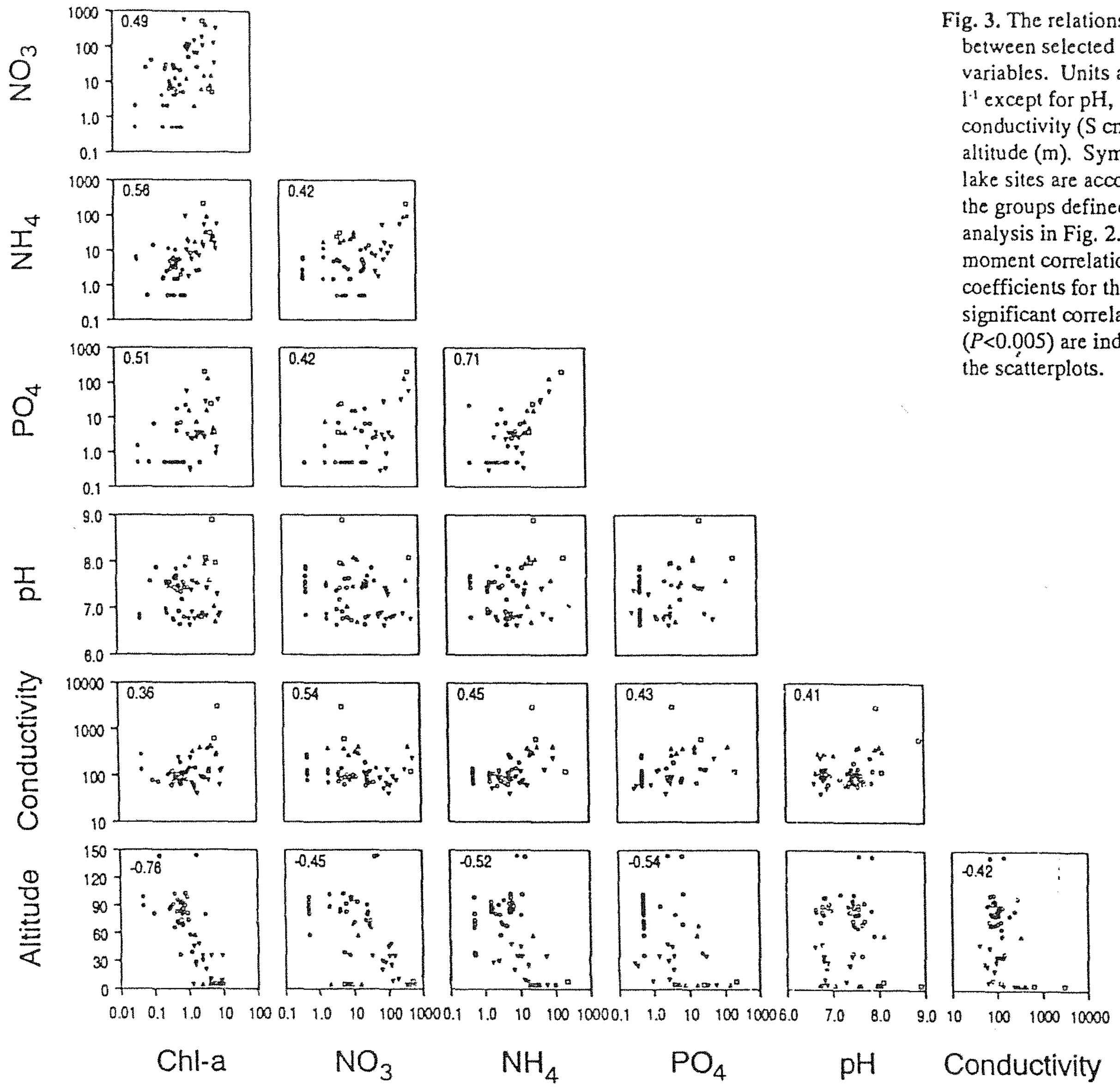

Fig. 3. The relationship between selected chemical variables. Units are log μg l^{-1} except for pH, conductivity (S cm^{-1}) and altitude (m). Symbols for lake sites are according to the groups defined by cluster analysis in Fig. 2. Product moment correlation coefficients for the significant correlations (P<0.005) are indicated in the scatterplots.

Carlo unrestricted permutation tests (99 permutations) of axis 1 and axis 2 (with axis 1 as covariable) indicate that both axes are significant (P < 0.05) (ter Braak 1990). Axis 1 is strongly related to conductivity (inter-set correlation = 0.76), and contrasts the high salinity coastal Livingston sites (Group 3b), and their constituent taxa *Navicula gregaria* (NA023A), *Navicula* species 1 (ZZZ952), *Nitzschia* species 1 (ZZZ957) and *Pinnularia* species 2 (ZZZ947), plotted on the right of axis 1, with the dilute waters found on Signy Island (Group 1b) such as Moss, Emerald and Twisted Lakes. These sites, with their characteristic taxa *Achnanthes minutissima* (AC013A), *Navicula* cf. *difficillima* (ZZZ980), and *Navicula bryophila* (NA045A), are plotted on the left of the diagram.

Axis 2 is strongly related to chlorophyll *a*, ammonium and silicate (inter-set correlations 0.64, 0.65, and -0.72, respectively) and again appears to reflect two gradients. The first, from top right to bottom left is related to trophic status and separates the oligotrophic inland Livingston sites of Group 2, plotted bottom left, from the other sites. Taxa characteristic of the former include *Achnanthes lanceolata* (AC001A), *A. exigua* (AC008A), *Navicula seminulum* (NA005A), *N. tantula* (NA086A), and *Stauroneis* species 1 (ZZZ941). Taxa plotted top right, such as *Fragilaria construens* var. *binodis* and *Nitzschia* species 1 (ZZZ957) are associated with the high conductivity, high nutrient waters of the coastal Livingston sites, while those plotted top centre such as *A. pinnata* (AC040A), *Navicula* species 3 (ZZZ989), *Gomphonema angustatum* var. *productum* (GO003B), *Achnanthes subatomoides* (AC136A) and *Fragilaria construens* var. *venter* (FR002C) are characteristic of the low conductivity, high nutrient sites on Signy Island (Group 1b). The second gradient runs from top left to bottom right and essentially separates Signy from Livingston lakes, and identifies taxa found either exclusively or in greater abundance on Signy Island, plotted in the top left quadrant (e.g. *Achnanthes*

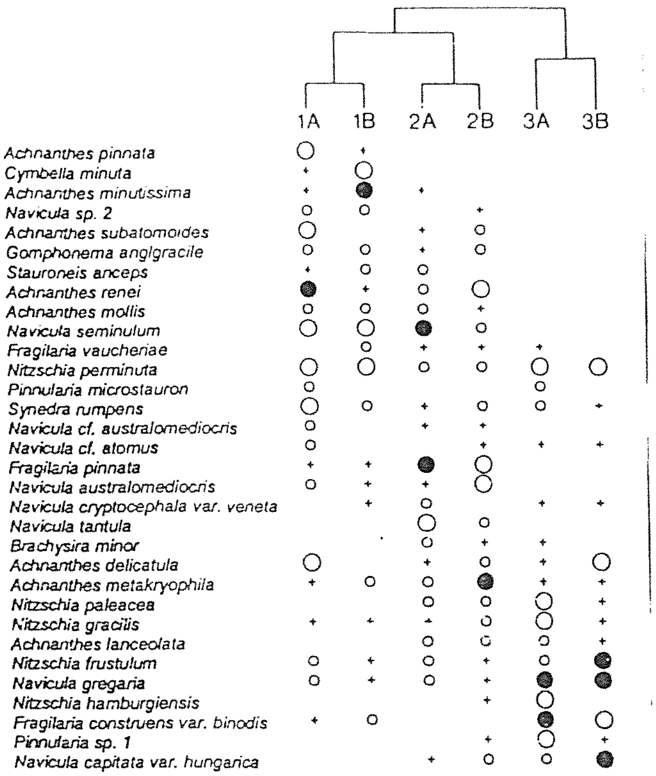

Fig. 4. TWINSPAN results showing groups of sites (top) and associated mean percentage diatom abundances *<2% *2–5% *5–10% *>10% Group 1a = sites SG2, SG5, SG6, SG8, SG10, SG11 and SG15 Group 1b = sites SG1, SG3, SG4, SG7, SG9, SG12 and SG14 Group 2a = sites LN1–7, LN9, LN10, LN14–19, LN21-24, LN27 and LN31 Group 2b = sites LN8, LN11–13, LN20, LN26, LN28–30, LN32-34, LN36 and LN43–45 Group 3a = sites LN35 and LN38–40 Group 3b = sites LN25, LN37, LN41 and LN42

aps

minutissima (AC013A), *A. incognita* (AC137A), *Navicula bryophila* (NA045A) and *Cymbella minuta* (CM031A)).

Discussion

The lakes sampled on Livingston and Signy islands have quite distinct water chemistry, with the former having higher silicate and lower potassium and nitrate values than the Signy Island sites. Silicate is present in large amounts at both sites, being the major rock matrix component. However, tephra deposits may also provide an additional source of silica at Livingston Island (Björck *et al.* 1991) and silicate is probably released more readily at Byers than at Signy due to the higher weathering rate, and is thus present at high concentrations during the ice-free periods. Potassium is very mobile compared to silicate and would be quickly depleted from the weathered surface layers of Byers mineral particles. Slower weathering rates at Signy would result in a slower release rate and thus lower amounts of potassium moving into the water phase, but over a more extended period of time.

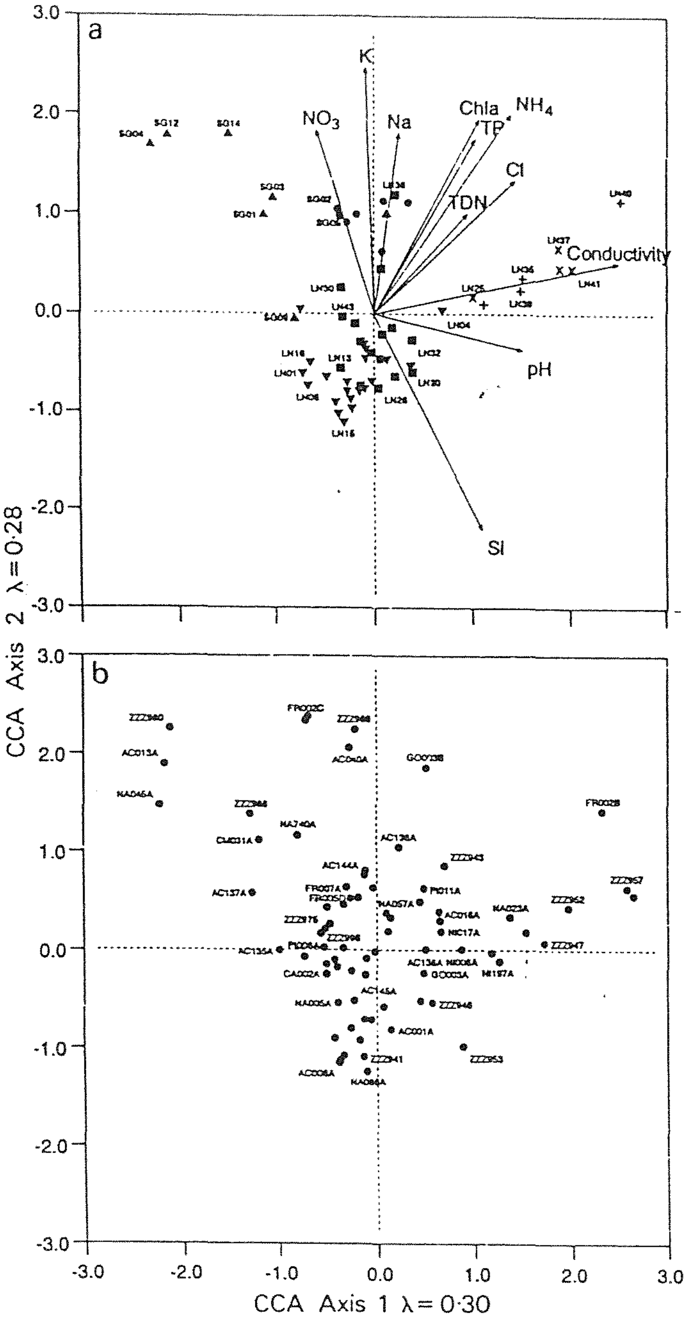

Fig. 5. Canonical correspondence analysis ordination diagram showing the relationship between sites. a. environmental gradients and b. diatom species. In a. sites are grouped according to the TWINSPAN results *1a *1b *2a *2b *3a *3b A list of diatom codes and their equivalent species is given in Appendix 1.

√

Work by Christie (1987) and Hawes (1983) suggests that precipitation, largely in the form of ammonium, is the main source of external nitrogen for oligotrophic systems, and this would quickly be converted to nitrate in soils and lakes. At Signy there are substantial penguin colonies which could potentially enhance this ammonium precipitation component (Christie

1987) whereas lakes on the central plateau of Livingston Island are not close to penguin colonies or even downwind, judging from wind direction data (Ellis-Evans, unpublished).

Due to the limited field period only one water chemistry measurement was made for most Livingston Island lakes, but where additional samples were taken, little variation between samples was noted. In addition, past experience of almost 20 years water sampling at Signy Island suggests that a summer measurement provides a reasonable estimate of the conditions experienced by diatoms in the growing season as the water column of such lakes are well mixed in summer open water conditions. The Livingston and Signy islands sites have comparable water chemistry to other freshwater Antarctic lakes, for example, in the Ablation Point area, Alexander Island (Heywood 1977), in the Vestfold Hills, East Antarctica (Laybourn-Parry & Marchant 1992, Laybourn-Parry *et al.* 1992) and with inland (180 km from the shelf) Antarctic lakes in the Untersee Oasis, East Antarctica (Kaup *et al.* 1988).

Although there are differences in the diatom flora of Livingston Island and Signy Island the range of species found in this study resembles that found in Southern America (Cleve-Euler 1948, Krasske 1939, 1949), the Subantarctic e.g. Kerguelen (Bourelly & Manguin 1949, 1954) and the maritime and continental Antarctic (Pankow *et al.* 1987, Schmidt *et al.* 1990, Björck *et al.* 1991). The flora consists of a mixture of taxa, some of which appear to be endemic to this region, for example *Achnanthes metakryophila*, *Achnanthes renei* and *Navicula australomediocris* and some of which are cosmopolitan, for example, *Navicula seminulum* and *Achnanthes minutissima*.

An unusual feature of the diatom flora is that no typical planktonic diatoms occur on either Livingston or Signy Islands, and although planktonic forms have been reported from Antarctic lakes (eg. Lavrenko 1965, Baker 1967) they are not common. This is in marked contrast to lakes in more temperate areas where diatom assemblages are often dominated by planktonic forms, for example the genera *Stephanodiscus* and *Cyclotella*. The absence of an Antarctic diatom plankton may be related to their lack of morphological or physiological characteristics (eg. high bouyancy capacity or inability to form resting stages) which would enable them to survive prolonged periods of ice cover (Heywood 1978, Guilizzoni *et al.* 1992). In addition, summer open water temperatures are low, for example when compared to Arctic lakes. The shallow nature of some of the lakes is probably not important since even small shallow ponds in temperate areas commonly develop a diatom plankton (eg. Guzkowska & Gasse 1990, H. Bennion personal communication 1992).

The patterns of diatom distribution and abundance are clearly related to the main chemical gradients of the lakes. Forward selection and associated Monte Carlo unrestricted permutation tests (99 permutations) of the significance of the environmental variables (ter Braak 1990) suggest that conductivity, potassium, chlorophyll *a*, sodium and ammonium make significant ($P<0.05$) contributions to explaining the variation in the diatom assemblages. Although there is not a planktonic diatom response to trophic status in these lakes, benthic diatoms in Antarctic lakes appear to act similarly to those in lakes in the rest of the world. For example species which are associated with nutrient-rich waters in the Antarctic such as *Fragilaria construens* var. *binodis*, *Achnanthes pinnata*, *Gomphonema angustatum* and *Achnanthes subatomoides* have a total phosphorous optima of >10gl^{-1} in a Canadian data set (Hall & Smol 1992). Although little is known about the relationships between diatoms and environmental variables in Antarctic lakes, available data do support the results found here. Oppenheim (1990) in a study of 11 Signy Island lakes identified diatom species which were characteristic of proglacial, oligotrophic and mesotrophic lakes. In a further study of two of these lakes (Sombre Lake and Light Lake) redundancy analysis was used to show that the nutrient status was important in determining the epiphytic diatom assemblages (Oppenheim & Greenwood 1990). Hansson & Håkansson (1992) identified diatom species characteristic of nutrient poor and nutrient rich waters. However, their analysis did not include the effect of conductivity which this study has shown to be very important in determining diatom community composition.

This exploratory analysis of the relationship between diatom species and chemistry in the Maritime Antarctic has shown that diatom abundance can be related to environmental variables. The next stage in data analysis will be to calculate the quantitative responses of individual diatom species to nutrient and salinity gradients. This will enable the environmental reconstruction of nutrient and salinity histories of Antarctic lakes using diatoms preserved in lake sediments. It will therefore be possible to test hypotheses concerning lake development or the influence of recent animal populations in determining present day nutrient levels. There is a growing realization that Antarctic lake sediments can be used to reconstruct past environments and past lake conditions (Tatur & DeValle 1986, Mäusbacher *et al.* 1989, Schmidt *et al* 1990, Björck *et al.* 1991), and the use of quantitative relationships between diatoms and water chemistry derived from a maritime Antarctic data set should contribute significantly to future lake reconstruction studies.

Acknowledgements

We would like to thank members of BAS for logistic support, in particular the Livingston Island party (1990–1991) and Signy Base members (1991–1992). Soo Redshaw, Brian Hull, Paul James, Maff Smithers and Matt Chalmers provided valuable field assistance. The Cartographic Unit at U.C.L. prepared some of the Figures. The study was funded by a British Antarctic Survey (NERC) Antarctic Special Topic Award (GST/02/448).

References

BAKER, A.N. 1967. Algae from Lake Miers, a solar-heated Antarctic lake. *New Zealand Journal of Botany*, 5, 453-468.

BIRKS, H.J.B., LINE, J.M., JUGGINS, S., STEVENSON, A.C. & TER BRAAK, C.J.F. 1990. Diatoms and pH reconstruction. *Philosophical Transactions of the Royal Society London B*, 327, 263-278.

Björck, S., Håkansson, H., Zale, R., Karlén, W. & Jönsson, B.L. 1991. A late Holocene lake sediment sequence from Livingston Island, South Shetland Islands, with palaeoclimatic implications. *Antarctic Science*, **3**, 61-72.

Bourrelly, P & Manguin, E. 1949. Contribution a l'etude de la flora algale d'eau douce de Madagascar: le lac de Tsimbazaza. *Mémoires de L'Institut Scientifique de Madagascar*, **2**, 161-190.

Bourrelly, P. & Manguin, E. 1954. Contribution a la flora algale d'eau douce des Iles Kerguelen. *Mémoires de L'Institut Scientifique de Madagascar*, **5**, 7–56.

Chambers, M. J. G. 1966 Investigation of patterned ground at Signy Island, South Orkney Islands. II - Temperature regimes in the active layers. *British Antarctic Survey Bulletin*, No. 10, 71-83.

Charles, D.F. & Whitehead, D.R. 1986. The PIRLA project: Paleoecological investigations of recent lake acidification. *Hydrobiologia*, **143**, 13-20.

Christie, P. 1987. Nitrogen in two contrasting Antarctic bryophyte communities. *Journal of Ecology*, **75**, 73-93.

Cleve-Euler, A. 1948. Süsswasserdiatomeen aus dem Feuerland. *Acta Geographica*, **10**, 1-61.

Dixit, S.S., Dixit, A.S. & Smol, J.P. 1991. Multivariate environmental inferences based on diatom assemblages from Sudbury (Canada) lakes. *Freshwater Biology*, **26**, 251-266.

Ellis-Evans, J.C. 1981. Freshwater microbiology in the Antarctic. I. Microbial numbers and activity in oligotrophic moss lake. *British Antarctic Survey Bulletin*, No. 58, 85-104.

Ellis-Evans, J.C. 1982. Seasonal microbial activity in Antarctic freshwater lake sediments. *Polar Biology*, **1**, 129-140.

Ellis-Evans, J.C. 1984. Methane in maritime Antarctic freshwater lakes. *Polar Biology*, **3**, 63-71.

Ellis-Evans, J.C. 1985. Decomposition processes in maritime Antarctic lakes. *In* Siegfried, W.R., Laws, R.M. & Condy, P.R. *eds. Antarctic Nutrient Cycles and Food Webs. Proceedings of 4th SCAR Symposium on Antarctic Biology.* Berlin: Springer-Verlag, 253-260.

Ellis-Evans, J.C. 1990. Evidence for change in the chemistry of maritime Antarctic Heywood Lake. *In* Kerry, K.R. & Hempel, G. *eds. Antarctic Ecosystems - Ecological Change and Conservation. Proceedings of 5th SCAR Symposium on Antarctic Biology.* Berlin: Springer-Verlag, 77-82.

Fritz, S.C., Juggins, S., Battarbee, R.W. & Engstrom, D.R. 1991. A diatom-based transfer function for salinity, water-level and climate reconstruction. *Nature*, **352**, 706-708.

Gasse, F. & Tekaia, F. 1983. Transfer functions for estimating palaeoecological conditions (pH) from East African diatoms. *Hydrobiologia*, **103**, 85-90.

Glew, J.R. 1989. A new trigger mechanism for sediment samplers. *Journal of Paleolimnology*, **2**, 241-243.

Guilizzoni, P., Libera, V., Manca, M., Mosello, R., Ruggiu, D. & Tartari, G.A. 1992. Preliminary results of limnological research in Terra Nova Bay area (Antarctica). *Documenta Istituto Italiano Idrobiologia*, **32**, 107-120.

Guzkowska M.A.J. & Gasse, F. 1990. Diatoms as indicators of water quality in some English urban lakes. *Freshwater Biology*, **23**, 233-250.

Hall, R.I. & Smol, J.P. 1992. A weighted-averaging regression and calibration model for inferring total phosphorous concentration from diatoms in British Columbia (Canada) lakes. *Freshwater Biology*, **27**, 417-434.

Hansson, L.A. 1990. Interactions between periphytic and planktonic algae along a productivity gradient in Antarctic lakes. *In* Karlquist, A. *ed. Swedish Antarctic Research Programme 1988/9 - A Cruise Report.* Stockholm: Swedish Polar Research Secretariat. Page numbers??

Hansson, L.A. & Håkansson, H. 1992. Diatom community response along a productivity gradient of shallow Antarctic lakes. *Polar Biology*, **12**, 463–468.

Hawes, I. 1983. Nutrients and their effects on phytoplankton populations in lakes on Signy Island, Antarctica. *Polar Biology*, **2**, 115-126.

Hawes, I. 1985. Light climate and phytoplankton photosynthesis in maritime Antarctic lakes. *Hydrobiologia*, **123**, 69-79.

Heywood, R.B. 1977. A limnological survey of the Ablation Point area, Alexander Island, Antarctica. *Philosophical Transactions of the Royal Society London B*, **279**, 39-54.

Heywood, R.B. 1978. Maritime Antarctic lakes. *Mitteilungen Internationale Vereinigung fur Theoretische und Angewandte Limnologie*, **20**, 1210–1215.

Heywood, R.B., Dartnall, H.J.G. & Priddle, J. 1979. The freshwater lakes of Signy Island, South Orkney Islands, Antarctica. *British Antarctic Survey Data*, No. **3**, 46pp.

Heywood, R.B., Dartnell, H.J.G. & Priddle, J. 1980. Characteristics and classification of the lakes of Signy Island, South Orkney Islands, Antarctica. *Freshwater Biology*, **10**, 47-59.

Hill, M.O. 1979. *TWINSPAN - A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of individuals and attributes.* Ithaca: Cornell University, 90pp.

Hobbs, G.J., 1968. The geology of the South Shetland Islands. IV. The geology of Livingston Island. *British Antarctic Survey Scientific Reports*, No. 47, 34pp.

Hustedt, F. 1927-66. Die Kieselalgen Deutschlands, Österreichs und der Schweiz. *In* Rabenhorst, L. *ed. Kryptogamenflora von Deutschland, Österreich und der Schweiz*, Vol. 7. Leipzig: Akademische Verlagesellschaft. Page numbers??

Hustedt, F. 1937-39. Systematische und okologische Untersuchungen uber den Diatomeen-Flora von Java, Bali, Sumatra. *Archives für Hydrobiologie* (Suppl.), **15 & 16.**

Hustedt, F. 1957. Die Diatomeen flora des Fluss-systems der Weser im Gebiet der Hansestadt Bremen. *Abhandler herausgegeben vom naturwissench verein Bremen*, **34**, 181-440.

John, B.S. & Sugden, D.E. 1971. Raised marine features and phases of glaciation in the South Shetland Islands. *British Antarctic Survey Bulletin*, No. 24, 42-111.

Juggins, S. 1992. Diatoms in the Thames Estuary, England: Ecology, Palaeoecology and Salinity Transfer Function. *Bibliotheca Diatomologica*, **25**, 1-216.

Kaup, E., Loopman, A., Klokov, V., Simonov, I. & Haendel, D. 1988. Limnological investigations in the Untersee Oasis (Queen Maud land, East Antarctica). *In* Martin, J., *ed. Limnological Studies in Queen Maud Land (East Antarctica).* Estonia: Academy of Sciences of the Estonian SSR. page numbers??

Kobayashi, T. 1963 Variations on some pennate diatoms from Antarctica, I. *Japanese Antarctic Research Expedition 1956-1962 Scientific Reports Series E*, **18**, 1-20.

Kolbe, R.W. 1927. Zur Okologie, Morphologie und Systematik der Brackwasser-Diatomeen. *Pflanzenforschung*, **7**, 1-146.

Krammer, K. & Lange-Bertalot, H. 1986. *Süsswasserflora von Mitteleurope. Bacillariophyceae. 1. Teill. Naviculaceae.* Stuttgart: Gustav Fischer, pages

Krammer, K. & Lange-Bertalot, H. 1988. *Süsswasserflora von Mitteleurope. Bacillariophyceae. 2. Teill. Bacillariaceae, Epithemiaceae, Surirellaceae.* Stuttgart: Gustav Fischer. page numbers??

Krasske, G. 1939. Zur kieselalgenflora Südchiles. *Archiv für Hydrobiologie*, **35**, 349-468.

Krasske, G. 1949. Subfossile diatomeen aus den mooren Patagoniens und Feuerlands. *Soumalaisen Tiedeakatemian Toimituksia Annales Academiae Scientiarum Fennicae*, **14**, 94pp.

Lange-Bertalot, H. & Krammer, K, 1989. *Achnanthes* eine monographie der gattung *Cocconeis* und Nachträgen zu den *Naviculaceae. Bibliotheca Diatomologica*, **18**, 393pp.

Lavrenko, G.Y., 1965. Algae of a lake near Novolazarevskaya station. *Informationnyi Byulleten Sovetskoi Antarkticheskoi*, **56**, 57-61. (In Russian??)

Laybourn-Parry, J. & Marchant, H.J. 1992. The microbial plankton of freshwater lakes in the Vestfold Hills. *Polar Biology*, **12**, 405-410.

Laybourn-Parry, J., Marchant, H.J. & Brown 1992. Seasonal cycle of the microbial plankton in Crooked Lake, Antarctica. *Polar Biology*, **12**, 411-416.

LeCohu, R. & Maillard, R. 1983. Les diatomées monoraphidées des Iles Kerguelen. *Annales Limnologie*, **19**, 143-167.

LeCohu, R. & Maillard, R. 1986. Diatomées monraphidees des Iles Kerguelen (a l'exclusion des monoraphidées). *Annales Limnologie*, **22**, 99-118.

Mackereth, F.J.H., Heron, J. & Talling, J.F. 1978. Water analysis: some revised methods for limnologists. *Freshwater Biological Association Scientific Publications*, No. 36 page numbers??

Matthews, D.H. & Maling, D.H. 1967. The geology of the South Orkney Islands. I. Signy Island. *Falkland Island Dependency Survey, Scientific Report,* No. 25, 32pp.

Mäusbacher, R., Müller, J., Munnich, M. & Schmidt, R. 1989. Evolution of postglacial sedimentation in Antarctic lakes (King George Island). *Zeitschrift fur Geomorphologie, N.F.*, 33 219-234.

Nygaard, G. 1949. Hydrobiological studies on some Danish ponds and lakes. II. The quotient hypothesis and some new or little known phytoplankton organisms. *Kongelige Danske Videnskabernes Selskab Biologiske Skrifter*, 7, 1-293.

Nygaard, G. 1956. Ancient and recent flora of diatoms and chrysophyceae in Lake Gribso. *Folia Limnologica Scandinavica*, **8**, 32-94.

Oppenheim, D.R. 1990. A preliminary study of benthic diatoms in contrasting lake environments. *In* Kerry, K.R. & Hempel, G., *eds. Antarctic Ecosystems - Ecological Change and Conservation. Proceedings of 5th SCAR Symposium on Antarctic Biology.* Berlin: Springer Verlag, 91-99.

Oppenheim, D.R. & Ellis-Evans, J.C. 1989. Depth-related changes in benthic diatom assemblages of a maritime Antarctic lake. *Polar Biology*, **9**, 525–532.

Oppenheim, D.R. & Greenwood, R. 1990. Epiphytic diatoms in two freshwater maritime Antarctic lakes. *Freshwater Biology*, **24**, 303-314.

Pankow, V.H., Haendel, D., Richter, W. & Wand, U. 1987. Algologische Beobachtungen in der Schirmacher- und Unterseeoase (Dronning-Maud-Land, Ostantarktika). *Archives Protistenkund*, **134**, 59-82.

Renberg, I. 1990. A procedure for preparing large sets of diatom slides from sediment cores. *Journal of Paleolimnology*, **4**, 87-90.

Schmidt, R., Mäusbacher, R. & Müller, J. 1990. Holocene diatom flora and stratigraphy from sediment cores of two Antarctic lakes (King George Island). *Journal of Paleolimnology*, **3**, 55-74.

Smith, R.I. Lewis 1972. Vegetation of the South Orkney Islands with particular reference to Signy Island. *British Antarctic Survey Scientific Reports*, No. 68, 124pp.

Smith, R.I. Lewis. 1988. Destruction of Antarctic terrestrial ecosystems by a rapidly increasing fur seal population. *Biological Conservation*, **45**, 55-72.

Smith, R.I. L. 1990. Signy Island as a paradigm of biological and environmental change in Antarctic terrestrial ecosystems. *In* Kerry, K.R. & Hempel, G. *eds. Antarctic Ecosystems - Ecological Change and Conservation. Proceedings of 5th SCAR Symposium on Antarctic Biology.* Berlin: Springer-Verlag, 30–48.

Stockner, J.G. 1971 Preliminary characteristics of lakes in the Experimental Lakes Area, Northwestern Ontario, using diatom occurrences in the sediment. *Journal Fisheries Research Board of Canada*, **28**, 265-275.

Stockner, J.G. 1972 Palaeolimnology as a means of assessing eutrophication. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie*, **18**, 1018-1030.

Tatur, A. & del Valle, R. 1986. Badania paleolimnologicne i geomorfologicne na wyspie krola jerzego-Antarktyka zachodnia (1984-1986). *Preglad Geologiczny*, **11**, 621-626.

ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, **67**, 1167-1179.

ter Braak, C.J.F. 1987. CANOCO - a FORTRAN program for canonical community ordination by [partial] [detrended] [canonical] correspondence analysis, principal components analysis and redundancy analysis (version 2.1). *Technical Report LWA-88-02.* Wageningen: TNO Institute of Applied Computer Science, 95pp.

ter Braak, C.J.F. 1990. *Update notes: CANOCO version 3.10.* Wageningen: Agricultural Mathematics Group, 35pp.

Wasell, A. & Håkansson, H. 1992. Diatom stratigraphy in a lake on Horseshoe Island Antarctica: a marine:brackish-fresh water transition with comments on the systematics and ecology of the most common diatoms. *Diatom Research*, 7, 157-194.

Whitmore, T.J. 1989. Florida diatom assemblages as indicators of trophic state and pH. *Limnology and Oceanography*, **34**, 882-895.

Appendix 1. List of diatom codes, species and authorities.

AC001A	*Achnanthes lanceolata* (Breb. ex Kutz.) Grun. in Cleve & Grun.
AC013A	*Achnanthes minutissima* Kutz.
AC008A	*Achnanthes exigua* Grun.
AC016A	*Achnanthes delicatula* Kutz.
AC040A	*Achnanthes pinnata* Hust.
AC135A	*Achnanthes mollis* Krasske
AC136A	*Achnanthes subatomoides* (Hust.) Lange-Bertalot & Archibald in Krammer & Lange-Bertalot
AC137A	*Achnanthes incognita* Krasske
AC138A	*Achnanthes germainii* Manguin in Bourelly & Manguin
AC144A	*Achnanthes renei* Lange-Bertalot & Schmidt
AC145A	*Achnanthes metakryophila* Lange-Bertalot & Schmidt
BR008A	*Brachysira minor* (Krasske) nov. com.
CA002A	*Caloneis bacillum* (Grun.) Cleve
CM031A	*Cymbella minuta* Hilse ex Rabenh.
FR001A	*Fragilaria* cf. *pinnata*
FR002B	*Fragilaria construens* var *binodis* (Ehr.) Grun.
FR002C	*Fragilaria construens* var *venter* (Ehr.) Grun.
FR005D	*Fragilaria virescens* var *exigua* Grun. in Van Heurck
FR007A	*Fragilaria vaucheriae* (Kutz.) J.B. Petersen
GO003A	*Gomphonema angustatum* (Kutz.) Rabenh.
GO003B	*Gomphonema angustatum* var *productum* Grun. in Van Heurck
NA005A	*Navicula seminulum* Grun.
NA007B	*Navicula cryptocephala* var *veneta* (Kutz.) Rabenh.
NA023A	*Navicula gregaria* Donk.
NA045A	*Navicula bryophila* J.B. Petersen
NA057A	*Navicula elginensis* (Greg.) Ralfs in Pritch.
NA066B	*Navicula capitata* var *hungarica* (Grun.) R. Ross
NA086A	*Navicula tantula* Hust.
NA734A	*Navicula australomediocris* Lange-Bertalot & Schmidt
NA740A	*Navicula bicephala* Hust.
NI005A	*Nitzschia perminuta* (Grun. in Van Heurck) Perag.
NI008A	*Nitzschia frustulum* (Kutz.) Grun. in Cleve & Grun.
NI017A	*Nitzschia gracilis* Hantzsch
NI033A	*Nitzschia paleacea* (Grun. in Cleve & Grun.) Grun. in Van Heurck
NI197A	*Nitzschia hamburgiensis* Lange-Bertalot
PI008A	*Pinnularia divergens* W. Smith
PI011A	*Pinnularia microstauron* (Ehrenb.) Cleve
SY002A	*Synedra rumpens* Kutz.
ZZZ941	*Stauroneis* species 1
ZZZ943	*Navicula* cf *atomus*
ZZZ946	*Pinnularia* species 1
ZZZ947	*Pinnularia* species 2
ZZZ952	*Navicula* species 1
ZZZ953	*Navicula* cf. *pupula*
ZZZ957	*Nitzschia* species 1
ZZZ975	*Amphora* species 1
ZZZ977	*Navicula* cf *australomediocris*
ZZZ980	*Navicula* cf *difficillima*
ZZZ988	*Navicula* species 2
ZZZ989	*Navicula* species 3
ZZZ992	*Gomphonema angustatum/gracile*
ZZZ996	*Stauroneis* species 2

Antarctic Special Topic: 00-00 (1993)

The use of diatoms in lake sediments to investigate environmental history in the Maritime Antarctic: an example from Sombre Lake, Signy Island

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Abstract: A 2.52 m sediment sequence from Sombre Lake was analysed. Results of diatom analysis show that the modern diatom flora of the lake is atypical compared with other post-glacial assemblages in Sombre Lake. This suggests that present day water quality is unusual and this is probably due to the recent influence of fur seals, which have caused nutrient enrichment of the lake. The study demonstrates the potential of a palaeolimnological approach to study environmental change in the Maritime Antarctic.

Key words: Lake sediments, diatom analysis, Sombre Lake, Environmental change

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Introduction

Physical (e.g. lithostratigraphic), chemical (e.g. radioactive nuclides, metals and organic components) and biological (e.g. macrofossil and microfossil) analyses of dated cores from lake sediments can potentially provide a detailed and integrated record of lake and catchment change on timescales ranging from less than decades to greater than millennia (Oldfield 1977, Battarbee 1991).

This palaeolimnological approach has been used successfully in many regions to identify environmental changes and to test hypotheses about their causes. For example, in Europe and North America lake sediments have been used to provide histories of lake acidity and evidence for the timing and extent of lake acidification due to atmospheric contamination (e.g. Battarbee *et al.* 1988, Charles *et al.* 1990). Sediments have also been widely used to investigate the trophic and salinity histories of lakes and to identify climatic change (e.g. Fritz *et al.* 1991, Anderson *et al.* 1992).

The most powerful palaeolimnological technique used in these studies is diatom analysis. Diatoms (Bacillariophyceae) are unicellular siliceous algae which are common in water bodies throughout the world. Diatoms are generally well preserved and abundant in lake sediments, their remains can be identified to species level and typically a large number of species are recorded.

Diatom species composition is strongly related to lake water chemistry, and quantitative relationships between diatoms and environmental gradients have been established by constructing training data-sets. These relate an integrated sample of the taxa present, in the form of a modern surface sediment diatom assemblage, to current lake water chemistry. The relationships between diatoms (the response variables) and water chemistry (the predictor variables) can then be modelled. Much research has concentrated on the relationship between diatoms and pH (Gasse & Tekaia 1983, Charles and Whitehead 1986, Birks *et al.* 1990, Stevenson *et al.* 1991), but data sets have also been constructed to investigate the relationship between diatoms and nutrients (Whitmore 1989, Hall & Smol 1992), and diatoms and salinity (Fritz *et al.* 1991, Juggins 1992).

In the Antarctic the palaeolimnological approach to the investigation of environmental change has not been extensively used. However, existing studies demonstrate that lake sediments in this region do provide a good record of environmental change (e.g. Tatur & del Valle 1986, Mäusbacher *et al.* 1989). Diatoms are commonly reported from Antarctic water bodies where they appear to be abundant in many streams and lakes (Kobayashi 1963, Pankow *et al.* 1987, Oppenheim & Ellis-Evans 1989), and sediments from Antarctic lakes commonly contain well preserved and abundant diatom remains. Diatom stratigraphies have been obtained from a number of sites. In a study of lakes on King George Island Schmidt *et al.* (1990) related changes in diatom species composition to possible climate changes. Björck *et al.* (1991) also interpreted changes in diatom stratigraphy from a lake on Livingston Island as reflecting climate change. However, the interpretation of diatom stratigraphic profiles from Antarctic lakes has been hampered by a serious lack of ecological information. Although diatom taxa are generally cosmopolitan there are a number of unusual and unique forms common in the Antarctic, and this, together with a lack of species autecological information makes it necessary to construct a training set specifically for the maritime Antarctic. Such a data-set has been produced by Jones *et al.* (in press).

The aim of this part of the project was to reconstruct the trophic history of Sombre Lake, Signy Island. Signy Island covers an area of about 20 km², about 32% of which is covered with permanent snow and ice. The geology consists of intensely folded metamorphic sediments mainly garnetiferous quartz-mica-schists (Mathews & Malling 1967). Sombre Lake is situated in the north east of the Island and covers an area of 2.66 ha with a maximum depth of 11.2 m, the catchment is mainly scree with some moss close to the lake (Heywood *et al.* 1979). The population of fur seals on Signy Island has expanded dramatically in recent decades (Smith 1990). They have become common around Sombre Lake since 1980, and now contribute a substantial amount of nutrients to the lake (Ellis-Evans, personal communication). The present day limnology and aspects of the ecology of the lake are relatively well known (Ellis-Evans 1985, Oppenheim & Ellis-Evans 1989).

Methods

A 252 cm long sediment core was obtained from Sombre Lake using a modified piston corer and a Livingstone corer (Livingstone 1955). The piston core was sampled at 0.5 cm intervals for the top 30 cm, and then at 1 cm intervals. The Livingstone core was sampled at 2 cm intervals. Diatoms were prepared from sediment samples using H_2O_2 (Renberg 1990), and at least 300 valves per sample were counted on random transects using a Leitz Laborlux S microscope with phase contrast at 1000X. Diatoms were identified using a range of floras, particularly Hustedt (1927–66), Krasske (1939), Le Cohu and Maillard (1983, 1986), Krammer and Lange-Bertalot (1986, 1988), Lange-Bertalot and Krammer (1989), and Schmidt *et al.* (1990). Lithostratigraphic measurements were made using standard techniques (Bengtsson & Enell 1986).

Results

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The sediment is a silty, diatom rich detritus mud with frequent moss remains, which are mainly aquatic in origin (Smith, personal communication). Dry weight, loss on ignition and wet density profiles (Fig. 1), are consistent with an undisturbed and complete stratigraphic sequence. The sediment is inorganic with loss on ignition values generally <20%. A number of synchronous pronounced peaks in the dry weight and wet density profiles towards the top of the core may reflect inwash periods.

The lithostratigraphy does not appear to be related to the percentage abundance of diatoms (Fig. 1), although clear changes in the abundance of diatom species occur in the core. To aid description of this the diatom profile was split into

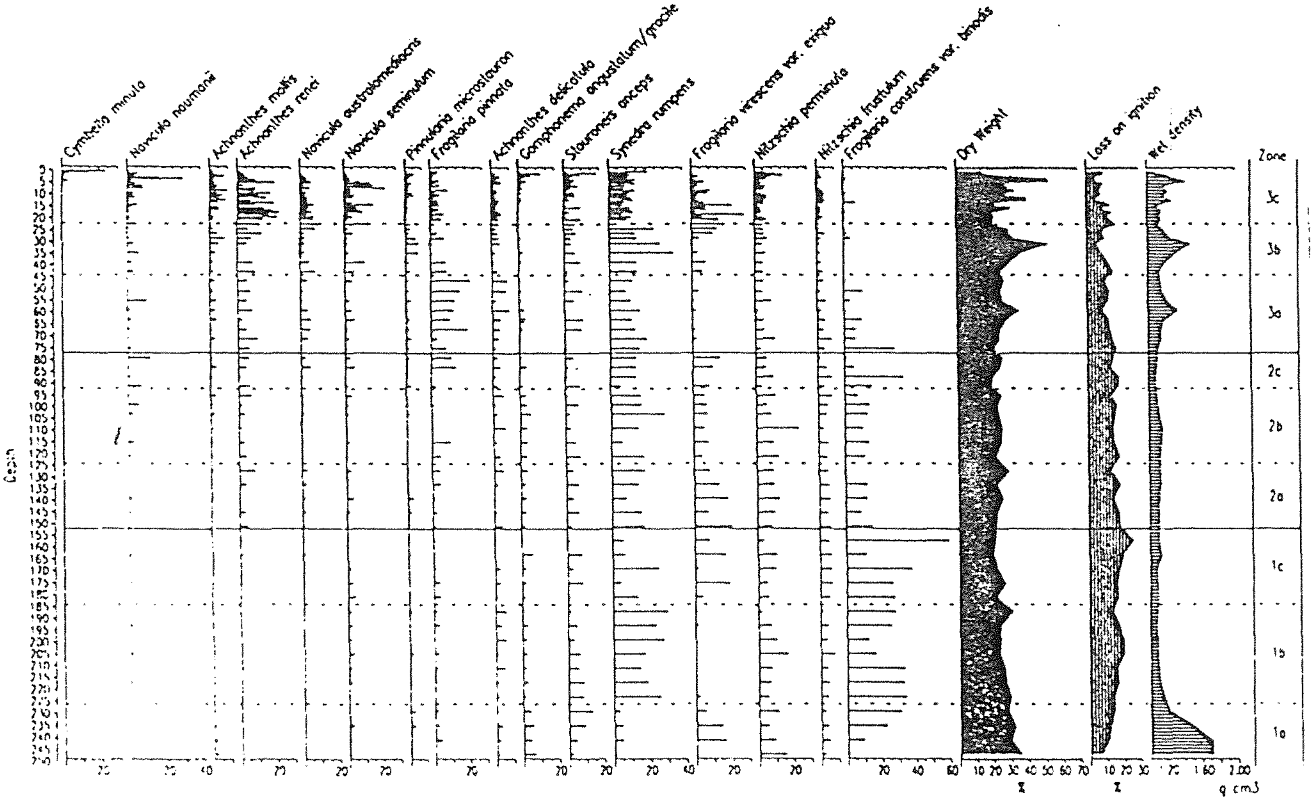

Fig. 1. Summary diatom (left) and lithostratigraphy diagram (right) for Sombre Lake. Diatoms are expressed as percentage total abundance, and zone boundaries are shown.

three stratigraphic units by stratigraphically constrained cluster analysis (Constrained Incremental Sum of Squares, Grimm 1987), and characteristic species were identified subjectively from Fig. 1.

Zone 1 (153–250 cm)

This assemblage is characterized by the high percentage abundances of *Fragilaria construens* var. *binodis* Ehrenb. and *Synedra rumpens* Kutz. *Stauroneis anceps* Ehrenb. and *Nitzschia perminuta* (Grun. in Van Heurck) are also present at relatively high abundances. Three distinct subzones can be recognized at 226–250 cm (zone 1a), 184–225 cm (zone 1b) and at 153–183 cm (zone 1c).

Zone 2 (77–152 cm)

This zone is dominated by *F. construens* var. *binodis*, *Nitzschia perminuta*, and *S. rumpens*. *Fragilaria virescens* var. *exigua* (Grun. in Van Heurck) is still important but is present at a lower percentage abundance than in the previous zone. Species such as *Achnanthes mollis* Krasske, *Navicula seminulum* Grun., *Fragilaria pinnata* Ehrenb. and *Navicula australomediocris* Lange-Bertalot & Schmidt become important for the first time. Three distinct subzones can be recognized at 124–152 cm (zone 2a), 93–123 cm (zone 2b) and at 77–92 cm (zone 2c).

Zone 3 (0–76 cm)

This assemblage is dominated by taxa such as *Achnanthes renei* Lange-Bertalot & Schmidt, *F. pinnata*, *S. rumpens* and *Nitzschia perminuta*. Three distinct subzones can be recognized, the uppermost subzone (zone 3c, 0–22 cm) is characterized by high values of *F. virescens* var. *exigua*. *Cymbella minuta* Hilse ex Rabenh. reaches high abundances in the top 2cm, and is unusual since it first appears at 5 cm depth, and is not found below this point in the core. Subzone 3b (23 – 43 cm) is characterized by high values of *S. rumpens* and subzone 3c (44 – 76 cm) has high values of *F. construens* var. *binodis*.

Detrended Correspondence Analysis (DCA) can be used to summarize the diatom stratigraphy (Fig. 2). Levels with similar diatom assemblages lie in close proximity whereas assemblages with little floristic similarity are widely separated on the plot. Samples from the same subzones are usually located together, although some subzones show greater variability e.g. zone 3c. The majority of samples are closely associated, but a number of outliers can be identified, and these are labelled on Fig. 2. Most of the outliers are samples from the uppermost 4 cm of the core (zone 3c) where *Cymbella minuta* is abundant. This indicates that the diatom assemblage in this part of the core is unusual, and probably indicates unique conditions within the lake in recent times. Other outliers do occur, but these are only single samples from their respective zones and are outliers because they have an unusually high abundance of a single taxa. For example the assemblage at 247 cm, the bottom-most core sample, is characterized by a high percentage abundance of *Navicula capitata* var. *hungarica* Grun. R. Ross (not shown in Fig. 1). The inset to Fig. 2 shows that DCA axis 1 can be interpreted as a time-trend through the core, with samples at the bottom of the core having a high DCA axis 1 score and samples towards the top of the core having a low DCA axis 1 score. This trend appears to be broken down at the top of the core where the four top-most samples have a higher score, this further supports the hypothesis that the upper part of the core is floristically unusual in the history of the lake.

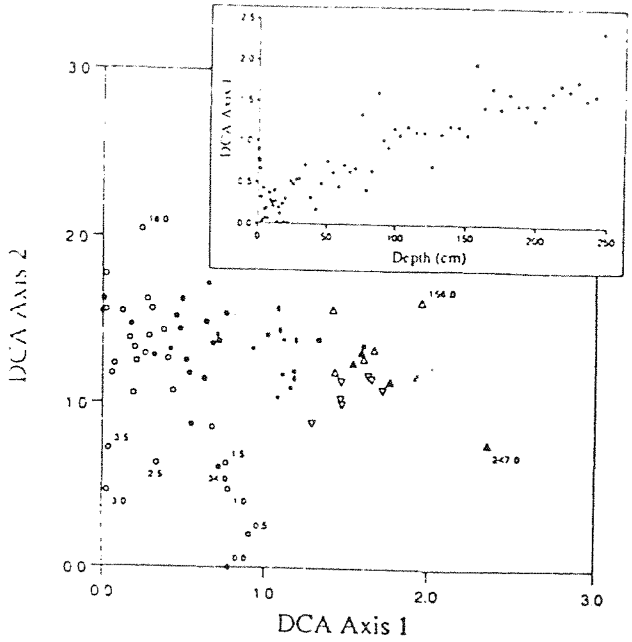

Fig. 2. Detrended Correspondence Analysis plot for the Sombre core using all diatom species achieving an abundance of >2%. Samples are labelled according to their top-depth. Symbols are according to the diatom zones in Fig. 1 (o) zone 3c, (•) zone 3b, (⊖) zone 3a, (◻) zone 2c, (▪) zone 2b, (♦) zone 2a, (Δ) zone 1c, (▽) zone 1b, (▲)zone 1a. Inset shows the relationship between DCA axis 1 and depth.

Discussion and conclusions

The diatom assemblages found in the Sombre Lake core are dominated by autochthonous benthic species and planktonic forms are absent. They show floristic similarities to other sedimentary records from the Maritime Antarctic. For example, Birnie (1990), in a study of sediments from Upper Lake Maiviken on South Georgia found high percentage abundances of *F. pinnata* and several other forms common in Sombre Lake (eg *N. frustulum* and *S. rumpens*). Similarly,

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Schmidt *et al.* (1990) found assemblages dominated by *S. rumpens*, *Achnanthes* species, *Fragilaria* aff. *pinnata*, *Navicula* aff. *seminulum* and *Fragilaria virescens* var. *exigua* from lakes on King George Island, and Björck *et al.* (1991) found similar diatom assemblages in Midge Lake (Livingston Island) to those found in the present study.

The time period represented by the core is unknown since ^{14}C dating is not yet complete. However, the diatom assemblages are relatively stable throughout the majority of the sediment sequence, but change rapidly towards the top of the core. The most recent sediments in Sombre Lake are unique in the history of the lake, and above 1.5 cm (provisionally ^{210}Pb dated to *c.* 1980, Appleby personal communication) are characterized by high percentage abundances of *Cymbella minuta*. This is a mesotrophic species commonly found in lakes and rivers in temperate regions (Foged 1977), and it has a total phosphorous optima of 10 @gl^{-1} in a Canadian data set (Hall & Smol 1992). μ Although it is unwise to extrapolate from ecological information obtained from areas outside the Antarctic, it is likely that *C. minuta* is a species which is sensitive to increased nutrient levels. The increase in *C. minuta* in the core coincides with the first reported appearance of fur seals in the catchment, and it is possible that the impact of fur seals through nutrient enrichment of the lake water was responsible for the increase in the abundance of this species. However, other environmental factors also need to be taken into account, in particular there has been extensive de-glaciation in the catchment since the mid-nineteenth century. This may be reflected in the synchronous peaks of dry weight and loss on ignition found above 20 cm, which may represent periods of enhanced erosion.

At a later stage in this project the trophic history of Sombre Lake will be reconstructed using species weighted average optima for nutrient variables. In addition radiometric dates (^{14}C and ^{210}Pb) will be essential to date accurately the onset of changes and to calculate rates of change.

However, this study has demonstrated that lake sediments can provide useful records of environmental change in the maritime Antarctic. This palaeolimnological approach can be extended to a range of lakes to investigate environmental history, and training data-sets can be used to reconstruct a variety of water chemical variables which may include nutrients and salinity.

Acknowledgments

I would like to thank members of BAS for logistic support, especially the Signy Base members (1991–1992). Maff Smithers and Matt Chambers provided very valuable field assistance, and Steve Juggins helped with computing. The study was funded by a British Antarctic Survey (NERC) Antarctic Special Topic Award (GST/02/448).

References

ANDERSON, N.J., RIPPEY, B. & GIBSON, C.E. 1992. A comparison of sedimentary and diatom-inferred phosphorous profiles: implications for determining pre-disturbance conditions. *Hydrobiologia*. [In press.]

BATTARBEE, R.W. 1991. Recent palaeolimnology and diatom-based environmental reconstruction. *In* SHANE L.C.K. & CUSHING, E.J. *eds. Quaternary Landscapes.* Minneapolis: University of Minnesota Press, 129-174.

*1 BATTARBEE, R.W., ANDERSON, N.J., APPLEBY, P.G., FRITZ, S.C., HAWORTH, E.Y., HIGGITT, S., JONES, V.J., KREISER, A., MUNRO, M.A.R., NATKANSKI, J., OLDFIELD, F., PATRICK, S.T., RAVEN, P.J., RICHARDSON, N., RIPPEY, B. & STEVENSON, A.C. 1988. *Lake acidification in the United Kingdom.* London: ENSIS, p 68

BENGTSSON, L. & ENELL, M. 1986. Chemical analysis. *In* BERGLUND, B.E. *ed. Handbook of Holocene Palaeoeçology and Palaeohydrology.* Chichester: John Wiley, 423-451.

BIRKS, H.J.B., LINE, J.M., JUGGINS, S., STEVENSON, A.C. & TER BRAAK, C.J.F. 1990. Diatoms and pH reconstruction. *Philosophical Transactions of the Royal Society London series B*, **327**, 263-278.

BIRNIE, J. 1990. Holocene environmental changes in South Georgia: evidence from sediments. *Journal of Quaternary Science*, **5**, 171-187.

BJÖRCK, S., HÅKANSSON, H., ZALE, R., KARLÉN, W. & JONSSON, B.L. 1991. A late Holocene lake sediment sequence from Livingston Island, South Shetland islands, with palaeoclimatic implications. *Antarctic Science*, **3**, 61-72.

CHARLES, D.F. & WHITEHEAD, D.R. 1986. The PIRLA project: Paleoecological investigations of recent lake acidification. *Hydrobiologia*, **143**, 13-20.

CHARLES, D.F., BINFORD, M.W., FURLONG, E.T., HITES, R.A., MITCHELL, M.J., NORTON, S.A., OLDFIELD, F., PATERSON, M.J., SMOL, J.P., UUTALA, A.J., WHITE, J.R., WHITEHEAD, D.R. & WISE, R.J. 1990. Paleoecological investigation of recent lake acidification in the Adirondack Mountains, N.Y. *Journal of Paleolimnology*, **3**, 195-241.

ELLIS-EVANS, J.C. 1985. Decomposition processes in Maritime Antarctic lakes. *In* SIEGFRIED, W.R., CONDY, P.R. & LAWS, R.M., *eds Antarctic Nutrient Cycles and Food Webs.* Springer-Verlag, Berlin, 253-260.

FOGED, N. 1977. Freshwater diatoms in Ireland. *Bibliotheca Phycologica*, **34**, 1-222.

FRITZ, S.C., JUGGINS, S., BATTARBEE, R.W. & ENGSTROM, D.R. 1991. A diatom-based transfer function for salinity, water-level and climate reconstruction. *Nature*, **352**, 706-708.

GASSE, F. & TEKAIA, F. 1983. Transfer functions for estimating palaeoecological conditions (pH) from East African diatoms. *Hydrobiologia*, **103**, 85-90.

GRIMM, E. 1987. A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers and Geosciences*, **13**, 13-35.

HALL, R.I. & SMOL, J.P. 1992. A weighted-averaging regression and calibration model for inferring total phosphorous concentration from diatoms in British Columbia (Canada) lakes. *Freshwater Biology*, **27**, 417-434.

HEYWOOD, R.B., DARTNALL, H.J.G. & PRIDDLE, J. 1979. The freshwater lakes of Signy Island, South Orkney Islands, Antarctica. *British Antarctic Survey Data*, **3**, 46pp.

*2 HUSTEDT, F. 1927-66. Die Kieselalgen Deutschlands, Österreichs und der Schweiz. *In* L. RABENHORST, *ed. Kryptogamenflora von Deutschland, Österreich und der Schweiz*, Vol. 7. Leipzig: Akademische Verlagesellschaft, p

*3 JONES, V.J., JUGGINS, S. & ELLIS-EVANS, J.C. The relationship between water chemistry and surface sediment diatom assemblages in maritime Antarctic lakes. [In press.] Antarctic Science

JUGGINS, S. 1992. Diatoms in the Thames Estuary, England: Ecology, Palaeoecology and Salinity Transfer Function. *Bibliotheca Diatomologica*, **25**, 1-216.

KOBAYASHI, T. 1963 Variations on some pennate diatoms from Antarctica, I. *Japanese Antarctic Research Expedition 1956-1962 Scientific Reports*

Teil 1: 1-920 (1927-1930); Teil 2: 1-8
(1931-1959); Teil 3: 1-816 (1961-196

Action by Authors:

*1 – page numbers
*2 – page numbers
*3 – journal title

Series E, 18, 1-20.

KRAMMER, K. & LANGE-BERTALOT, H. 1986. *Süsswasserflora von Mitteleurope. Bacillariophyceae. 1. Teill. Naviculaceae.* Stuttgart: Gustav Fischer, p 876 *4

KRAMMER, K. & LANGE-BERTALOT, H. 1988. *Süsswasserflora von Mitteleurope. Bacillariophyceae. 2. Teill. Bacillariaceae, Epithemiaceae, Surirellaceae.* Stuttgart: Gustav Fischer, L p 596 *5

KRASSKE, G. 1939. Zur kieselalgenflora Südchiles. *Archiv für Hydrobiologie*, 35, 349-468.

LANGE-BERTALOT, H. & KRAMMER, K, 1989. *Achnanthes* eine monographie der gattung *Cocconeis* und Nachträgen zu den *Naviculaceae. Bibliotheca Diatomologica*, 18. Berlin, 393pp.

LECOHU, R. & MAILLARD, R. 1983. Les diatomées monoraphidées des Iles Kerguelen. *Annales Limnologie*, 19, 143-167.

LECOHU, R. & MAILLARD, R. 1986. Diatomées monraphidees des Iles Kerguelen (a l'exclusion des monoraphidées). *Annales Limnologie*, 22, 99-118.

LIVINGSTONE, D.A. 1955. A light-weight piston sampler for lake deposits. *Ecology*, 36, 137-139.

MATHEWS, D.H. & MALLING, D.H. 1967. The geology of the South Orkney Islands. I. Signy Island. *Scientific Report Falkland Islands Dependencies Survey*, 25, 32pp.

MÄUSBACHER, R., MULLER, J., MUNNICH, M. & SSHMIDT, R. 1989. Evolution of postglacial sedimentation in Antarctic lakes (King George Island). *Zeitschrift fur Geomorphologie, N.F.*, 33 219-234.

OLDFIELD, F. 1977. Lakes and their drainage basins as units of sediment-based ecological study. *Progress in Physical Geography*, 1, 460-504.

OPPENHEIM, D.R. & ELLIS-EVANS, J.C. 1989. Depth-related changes in benthic diatom assemblages of a maritime Antarctic lake. *Polar Biology*, 9, 525-532.

PANKOW, V.H., HAENDEL, D., RICHTER, W. & WAND, U. 1987 Algologische Beobachtungen in der Schirmacher- und Unterseeoase (Dronning-Maud-Land, Ostantarktika). *Archives Protistenkund*, 134, 59-82.

RENBERG, I. 1990. A procedure for preparing large sets of diatom slides from sediment cores. *Journal of Paleolimnology*, 4, 87-90.

SCHMIDT, R., MÄUSBACHER, R. & MULLER, J. 1990. Holocene diatom flora and stratigraphy from sediment cores of two Antarctic lakes (King George Island). *Journal of Paleolimnology*, 3, 55-74.

SMITH, R.I.L. 1990. Signy Island as a paradigm of biological and environmental change in Antarctic terrestrial ecosystems. *In* KERRY, K.R. & HEMPELL, G., *eds. Antarctic ecosystems — change and conservation.* Berlin: Springer-Verlag, 30-48.

STEVENSON, A.C., JUGGINS, S., BIRKS, H.J.B., ANDERSON, D.S., ANDERSON, N.J., BATTARBEE, R.W., BERGE, F., DAVIS, R.B., FLOWER, R.J., HAWORTH, E.Y., JONES, V.J., KINGSTON, J.C., KREISER, A.M., LINE, J.M., MUNRO, M.A.R. & RENBERG, I. 1991. *The Surface Waters Acidification Project Palaeolimnology Programme: Modern Diatom/Lake-water Chemistry Data-set.* London: Ensis, 86pp.

TATUR, A. & DEL VALLE, R. 1986. Badania paleolimnologicne i geomorfologicne na wyspie krola jerzego-Antarktyka zachodnia (1984-1986). *Preglad Geologiczny*, 11, 621-626.

WHITMORE, T.J. 1989. Florida diatom assemblages as indicators of trophic state and pH. *Limnology and Oceanography*, 34, 882-895.

*4 pages
*5 pages