Arcellaceans as pollution indicators in mine tailing contaminated lakes near Cobalt, Ontario, Canada

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ABSTRACT: Six assemblages resulting from Q-mode cluster analysis of 27 arcellacean taxa in thirty-nine sediment-water interface samples collected from two small lakes heavily polluted by mine tailings near the town of Cobalt, northeastern Ontario, Canada, correlated well with various distinct polluted and remediated environments. Results of R-mode cluster analysis indicated that arcellacean strains within the same species often discriminate between environments, thus utilization of infraspecific categories increases resolution when studying lake microenvironments, pollutants, and rates of lake remediation. Results of this study suggest that successful lake remediation in these and similarly polluted lakes is best achieved by leaving the tailings undisturbed to be buried naturally, or to speed the process by addition of an allochthonous sediment cap.

INTRODUCTION

Arcellaceans (thecamoebians) are freshwater protozoans that form agglutinated tests. They occur abundantly in Holocene lacustrine sediments (Medioli and Scott 1983; Scott and Medioli 1983) and have been successfully used to reconstruct Pleistocene-Holocene lacustrine paleoenvironments (Patterson et al. 1985; McCarthy et al. 1995). Most previous investigations have been of a reconnaissance nature and primarily concerned with the determination of occurrences, and ranges in different environments (Patterson et al. 1996).

However, recent research of lakes in Canada and Italy has demonstrated the use of arcellaceans as an excellent indicator of pollution levels (Collins et al. 1990; Asioli et al. 1996; Patterson et al. 1996). For example, Patterson et al. (1996) have demonstrated the relationship between the distribution of arcellacean faunal assemblages and heavy metal pollutants (arsenic and mercury) in tailings in northeastern Ontario lakes. In addition, Asioli et al. (1996) have also conducted similar studies in Italy on acidic lakes polluted with copper and ammonium sulphates. These studies indicate that different arcellacean species appear to be influenced by the metal pollutants from mine tailings and they may indicate certain environmental parameters.

Although ecological stresses on various arcellacean species have not been investigated thoroughly, some have been shown under laboratory conditions to vary in their gross morphology (strain) when under environmental duress (Medioli et al. 1987). Asioli et al. (1996) confirmed these laboratory results in the field when they recognized distinct morphotypic variations within three species of arcellaceans to characterize distinct paleoenvironments. As a result of these studies, the importance of investigating the distribution of strains of different arcellacean species was realized.

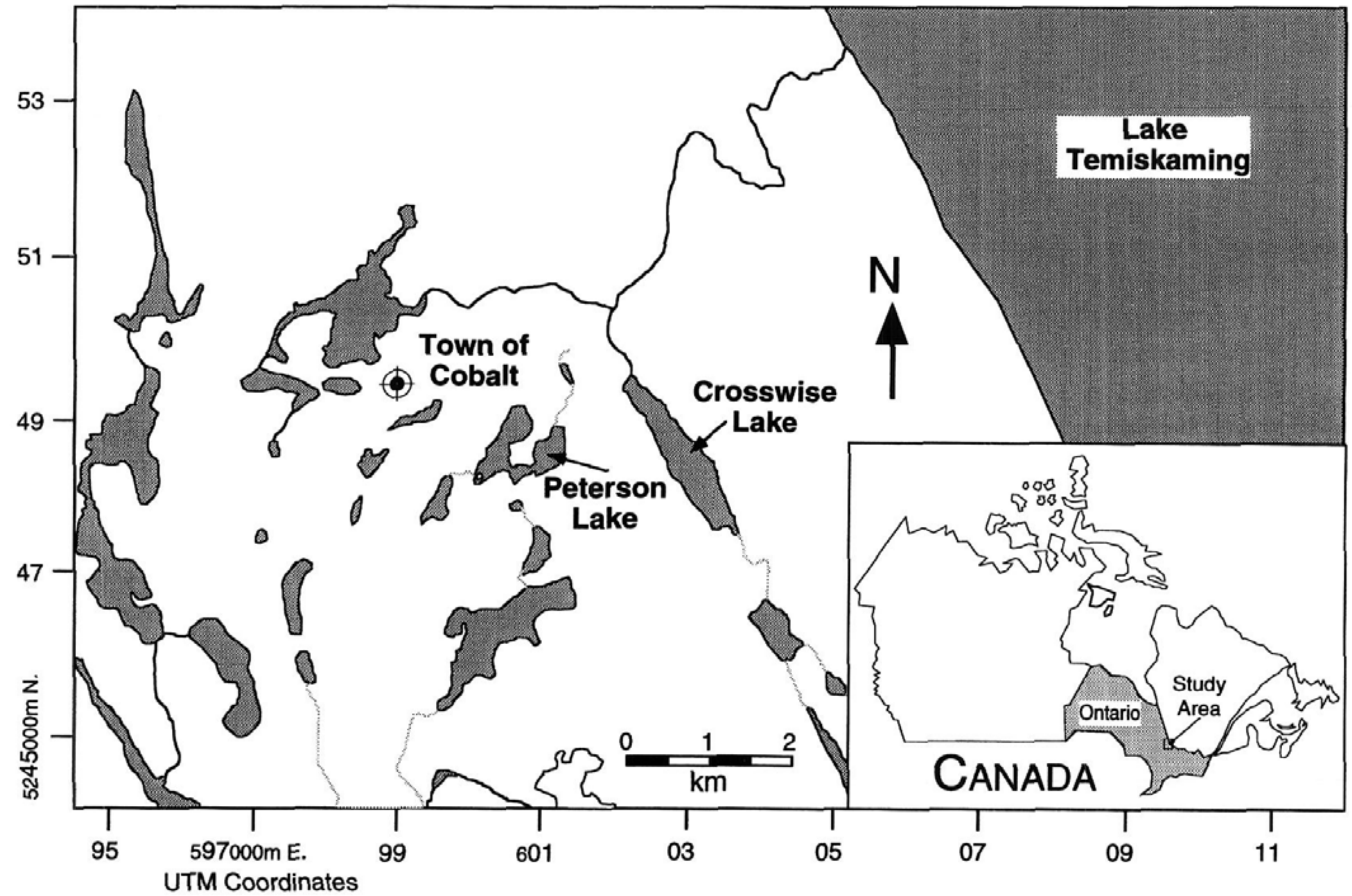
Cobalt, Ontario is a prime example of an area heavily contaminated by tailings and waste by-products of silver mining (Patterson et al. 1996). In 1911, when silver mining in Cobalt was at highest levels of production, annual silver production exceeded 850 metric tons per year which easily made Cobalt Camp, as it was then known, the world's largest producer of the metal (Murphy 1977). An unfortunate legacy of this exploration is the millions of tons of mine waste and tailings that were dumped into nearby lakes and streams which, in addition to being detrimental to the surrounding environment, pose a great residual health risk to the 10,000 current residents of the Cobalt area. Most problematic is the arsenic associated with the silver ore, which ended up in the tailings, and the mercury and cyanide used in the ore milling process (Dumaresq 1993).

We have observed several distinctive strains within the arcellacean populations of Crosswise and Peterson lakes (text-figure 1). These strains have developed in response to different environmental stresses and stimuli, such as the presence of chemical pollutants in the substrate and low oxygen levels. These morphotypic, or infraspecific, names are not considered valid under the International Code of Zoological Nomenclature (ICZN) and thus we use them in an informal sense. To avoid confusion where possible we have derived our morphotypic names from published literature. In most cases, what we consider strains of the same species have been described at various times as separate species. The purpose of this research is to increase our understanding of arcellaceans as environmental and pollution indicators by correlating these morphotypes with the geochemical environment (affected by mine tailings), bathymetry, organic content, and bottom sediment type (Table 1).

LAKE PHYSIOGRAPHY

Crosswise Lake

Crosswise Lake (text-figure 2) has an area of approximately 3.2 km^2, and an elongate shape in a north-south direction (See Patterson et al. 1996, for a more detailed description). Tailings from five different mines were dumped into the northern portion of Crosswise Lake from 1905 to 1993. This dumping both shortened the lake by about 300 meters and shallowed its depth from 12-14 meters to 6-7 meters. Consequently, this artificial infilling has resulted in a lake with a very flat bottom and too shallow to have a thermocline. The pH ranges from 7.6 to 8.4, and oxygen solubility is 11.0ppm at the surface and 8.0ppm at the bottom (Dumaresq 1993; Patterson et al. 1996).



TEXT-FIGURE 1
Cobalt Area Location Map. Universal Transverse Mercator (UTM) Coordinates.

Previous studies identified mercury and arsenic as the major pollutants. In Crosswise Lake, this study found that bottom sediment concentrations for arsenic range from 300 to 2100ppm ($\bar{x}$=810ppm) and mercury concentrations range from 3.37 to 5.74ppm ($\bar{x}$=4.25ppm). These values are much higher than government determined acceptable levels (Table 2; Table 3) (Moore 1991). Geochemical analysis carried out for this study has also found that in addition to arsenic and mercury, Crosswise Lake has highly toxic levels of many other metals as well (See Table 2 for a complete listing).

Peterson Lake

Peterson Lake (text-figure 3) is divided in two, an eastern and western portion, by a dam. In contrast to Crosswise lake, the larger western portion of Peterson Lake (2.3km^2) has a thermocline at about 8 m depth and three distinct bathymetric areas: 1) a shallow weed-filled southern end; 2) a small shallow bay near the dam and; 3) a deep basin in the middle. Like Crosswise Lake, the eastern portion of Peterson Lake has been filled with tailings giving it a flat bottom, but there is a thermocline in a trench which was excavated in 1965 when this portion was drained to remove mine waste (Dumaresq 1993; Wallis 1993; Patterson et al. 1996).

As in Crosswise Lake, the pH is slightly alkaline, ranging from 7.4 to 8.5 (this study). Arsenic levels range from 290 to 2900ppm ($\bar{x}$=1436ppm). Mercury levels range from 1.6 to 4.89ppm ($\bar{x}$= 2.98ppm), although sample P95-4 has an exceptionally high concentration of 24.9ppm (Table 2).

MATERIALS AND METHODS

Thirty-nine sediment-water interface samples (twenty-two from Peterson Lake and seventeen from Crosswise Lake) were collected using an Eckman box corer in late August and early September of 1995. Water depth, sedimentology, pH, water temperature, and microenvironment were recorded for each location (Table 1). The geographic location of each sample was determined using a Trimble Scout Global Positioning System (text-figures 2, 3).

A commercial sonar device (fish finder) equipped with bottom hardness indicator was used for sample site selection. Sample site selection was based on depth and bottom hardness to distinguish rocky, muddy, or sandy substrate. Generally, winnowed sandy substrates have small allochthonous arcellacean communities and rocky substrates are normally barren. The upper 2-3mm of sediment from each Eckman grab was removed for micropaleontological analysis and a one cm deep sediment sample was used for geochemical analysis. Micropaleontological samples were first screened with 1000mm sieve to remove coarse organics, then with a 55mm screen to retain arcellaceans and to

TABLE 1
Sample Locations and Physical Characteristics. DM = Diatom Mud Assemblage; HD = High Diversity Assemblage; DWC = Deep Water Contaminated Assemblage; DWRT = Deep Water Raw Tailings Assemblage; SCS = Shallow Contaminated Substrate Assemblage; ORSC = Organic Rich Shallow Contaminated Assemblage.

Assemblage	Sample	Easting	Northing	Colour	pH	Texture	Temperature	Depth (m)	Specimens/CC	Diversity	TOC (%)	Vegetation
	T2-95-1	602 148	524 9,518	very dark greyish brown	6.82	silt/clay	18	5.3	702	18		no
	T4-95-4	602 307	524 8,767	dark grey	7	clay	14	3?	554	21		no
1	T4-95-2	602 790	524 8,509	olive grey	7.11	clay	17	6?	348	17		no
(DM)	T4-95-3	602 632	524 8,738	dark grey	7.2	clay	16.5	6.5?	618	20	7.1	no
	T1-95-1	602 179	524 9,467	olive grey	7.7	silt/clay	18.5	6.1	359	23		no
	T1-95-2	602 247	524 9,133	olive grey	7.2	silt/clay	18	6.4	625	22		no
	T6-95-5	601 678	524 9,876	olive grey	7.39	clay	18	2.5?	654	19	3.7	no
	T2-95-2	602 084	524 9,498	dark grey	7	silt/clay	18	6.2	387	18		no
	T5-95-3	602 868	524 8,313	olive grey	7.3	clay	18	5.5?	425	25	8.4	no
	P95-19	599 985	524 8,911	dark grey brown	7.36		17.9	8.1	351	16		no
2	T6-95-3	601 782	524 9,606	olive grey	7.5	clay	18	2.2?	151	18		no
(HD)	P95-20	600 304	524 9,532	very dark grey	7.38		18.1	5	485	13	4.3	no
	T5-95-1	602 974	524 8,232	very dark greyish brown	7.3	clay	18	2.0?	394	23		yes
	T5-95-2	602 892	524 8,209	very dark greyish brown	7.4	clay	18	2.0?	423	25		yes-abundant
	T4-95-1	602 857	524 8,233	dark grey	7.11	clay	17	3.5?	484	21		yes
	P95-12	600 763	524 9,080	black	7.3		17.9	4.1	30	16		
	P95-13	600 452	524 9,369	dark greyish brown	6.93	clay	19	5.6	324	16		no
3	P95-14	600 067	524 9,175	very dark grey	7.27	clay	8.4	12.5	313	20	6.2	no
(DWC)	P95-15	600 075	524 9,044	very dark grey	7.18	clay	6	12.2	109	16		no
	P95-5	600 855	524 9,034	dark greyish brown	7.21	clay	18	6.6	346	15	5.0	no
	P95-8	600 582	524 8,876	dark greyish brown	7.21	clay		7.5?	46	13		no
	P95-9	600 860	524 8,969	grey	7.3	clay	11.5	8.0?	30	17		no
4	P95-10	600 877	524 8,932	grey	7.11	clay	18?	8.1	35	14	2.5	no
(DWRT)	P95-3	600 582	524 9,034	very dark grey	7.2	clay	18	7.2	31	12	35.3	no
	T6-95-1	601 799	524 9,887	dark brown	7.22	clay	18.5	1.5?	183	21		yes-abundant
	T6-95-2	601 687	524 9,754	dark grey	7.3	clay	19	3?	988	20	6.8	yes-abundant
5	T6-95-4	602 124	524 9,488	olive grey	7.21	clay	18	4?	160	18		yes
(SCS)	P95-21	600 143	524 8,727	black	7.35		18.2	5.2	18	12	ND	no
	P95-22	600 235	524 8,551	black	7.18		18.6	3.7	47	12	20.4	yes-abundant
	P95-16	600 461	524 8,716	black	7.11	clay/silt	18.5	2	196	14		yes-abundant
	T3-95-1	602 123	524 9,513	dark olive grey	7.1	silt/clay	18.4	2.6	230	21	15.6	yes-abundant
	P95-1	600 503	524 8,759	black	7.02	clay	18.5	0.7	414	15		yes-abundant
	P95-2	600 491	524 8,899	very dark grey	7.11	clay-sand?	18.5	1.3	221	16		yes?
6	P95-4	600 709	524 9,015	black	7.21	clay	16	5.7	318	17	20.7	yes
(ORSC)	P95-6	600 523	524 7,893	black	7.11	clay	18.5	1.5?	68	14		yes-abundant
	P95-7	600 575	524 8,686	black	7.21	clay	18	3?	181	18		yes?
	P95-17	600 339	524 8,678	black	7.27		18	2.9	152	13	79.8	yes-abundant
	P95-11	600 877	524 9,075	black	7.21		18	3	167	15		yes
	P95-18	600 137	524 8,793	dark grey	7.27	clay		17.3	19	10		no

remove silts and clays. To avoid decay, all samples were treated with isopropyl alcohol and refrigerated after collection.

Scanning electron micrographs were obtained using a JEOL 6400 scanning electron microscope at the Carleton University Research Facility for Electron Microscopy (CURFEM). All plates were digitally produced using Adobe Photoshop™ 2.5 on an Apple Macintosh® computer outputted to a linatronic printer.

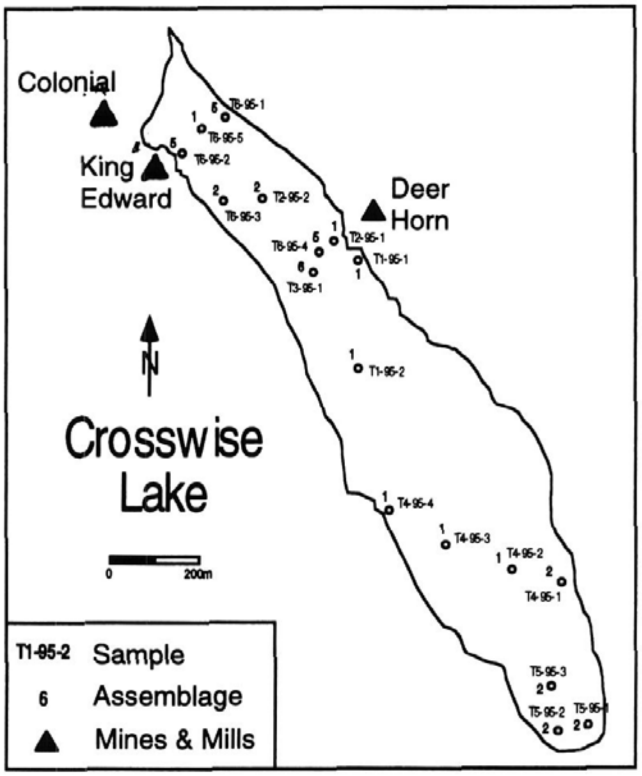
All micropaleontological samples were then subdivided into aliquots for quantitative analysis using the wet splitter (as described by Scott and Hermelin 1993). Wet aliquots were then examined under a binocular microscope and, wherever possible, a minimum number of 300 arcellaceans were counted for each sample.

All 39 samples contained populations large enough for statistical analysis (Patterson and Fishbein 1989). Fifteen species were identified, four of which were additionally subdivided into 15 distinguishable strains; 26 taxonomic units in all. The standard error (Appendix 1; Table 4) associated with each taxonomic unit was calculated using the following equation:

$$s_{X_i} = 1.96\sqrt{\left[\frac{X_i[1-X_i]}{N}\right]}$$

where N is the total number of counts, and X_i is the fractional abundance of a species (Patterson and Fishbein 1989).

Q-mode cluster analysis determines the overall statistical similarity between samples. Only species present in statistically significant populations were used for Q-mode cluster analysis of 27 taxa which included fifteen strains attributed to eleven species. (Appendix 1; Table 4). The cluster analysis was carried out using Ward's minimum variance method with the statistical software package SYSTAT® v. 5.2 (Wilkinson 1992). The re-



TEXT-FIGURE 2
Crosswise Lake Map

sults of the cluster analysis on the reduced data set were then reported as Euclidean distances and arranged in a hierarchical dendrogram (text-figure 4). This methodology closely emulates the statistically valid "error-weighted maximum likelihood" clustering method of Fishbein and Patterson (1993). Six clearly defined groups were recognized.

GEOCHEMICAL ANALYSIS

Geochemical analysis of fourteen lake bottom sediment samples was carried out by Areco Canada in Nepean, Ontario, measuring concentrations of a variety of metals (Table 2). All samples were analyzed using Environmental Protection Agency method 3051 microwave digestion for inductively coupled plasma atomic emission spectroscopy (ICP) analysis (United States Environmental Protection Agency 1990). An additional analysis was carried out to measure arsenic and selenium levels using Graphite furnace atomic absorption spectroscopy (GFAAS). Cold vapor atomic absorption was used to analyze mercury levels in nine of the samples as its characteristic wavelength was obscured by other metals in the ICP analysis.

All samples from both Peterson and Crosswise lakes had toxic levels (Moore 1991) of the following elements: arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc (Table 2; Table 3). In most cases the concentrations far exceeded the recommended guidelines for both drinking water and for the protection of aquatic life (plants, animals, protozoans; Moore, 1991). That some arcellaceans thrive under these highly toxic conditions is in itself highly significant.

RESULTS AND DISCUSSION

R-mode analysis was performed on all 27 taxonomic units (text-figure 5). The methodology for R-mode analysis is the same as Q-mode analysis, but performed on taxonomic units rather than samples. The R-mode cluster analysis revealed that the morphological definition of our strains was useful for environmental discrimination as strains from the same species often did not cluster together. If our strain distribution had not been affected by environmental parameters, we would have expected that all strains of one species should have clustered together in the R-mode cluster analysis.

Previous research has found a distinct distribution of arcellacean species associated with limnological, climatic, and other environmental conditions, including oxygen levels, minimum average water temperature and level of organics, clastics, and pollution levels (Scott and Medioli 1983; Patterson et al. 1985; Medioli et al. 1990; Collins et al. 1990; Patterson et al. 1996; Asioli 1996). Similar environmental relationships are recognizable in this study, but by analyzing the arcellacean fauna to the morphotypic level we have resolved some subenvironments that were previously unrecognizable (Patterson et al. 1996). Interpretation of our Q-mode cluster analysis resulted in the recognition of six assemblages, each characteristic of a distinct environment.

Diatom Mud Assemblage (1)

The Diatom Mud (DM) Assemblage is dominated by *Cucurbitella tricuspis* ($\bar{x}$=0.488), *Difflugia oblonga* "oblonga" ($\bar{x}$=0.095), and *Difflugia protaeiformis* "amphoralis" ($\bar{x}$=0.103). This assemblage is found in non-vegetated clay and silt-clay, olive-to-dark grey diatomaceous muds in various parts of Crosswise Lake. The faunal makeup of this assemblage is similar to the DM Assemblage reported by Patterson et al. (1996), also from Crosswise Lake. However, in that a really limited pilot study samples from well vegetated areas along the lake margin were the only ones found to contain this fauna. This study thus extends the range of the fauna to non-vegetated areas of the lake bottom as well. This observation is to be expected as the dominant species *Cucurbitella tricuspis* is seasonally planktic (Schönborn 1984; Patterson et al. 1985; Medioli et al. 1987; Collins et al. 1990) and would thus also be expected to be found away from the eutrophic conditions found along the weedy margins of the lake. In fact, Total Organic Carbon (TOC) levels in samples measured from this assemblage were only 3.7 and 7.1% respectively indicating that vegetation is not a factor in the discrimination of this assemblage.

With a mean of 550 specimens/cc, samples from this assemblage have the highest concentration of arcellaceans found in any assemblage that we describe. This is not unexpected as samples with large numbers of planktic microfossils, both marine and freshwater, are often characterized by high specimen concentrations (Culver 1987). However, in common with the High Diversity Assemblage (2), the DM Assemblage also has the highest species and strain diversity ($\bar{x}$=20). This factor suggests that the assemblage is real and can be related to conditions of the substrate (e.g. a mean water depth of only 5.1m and the buildup of post-contamination sediments), and is thus not an artifact of random plankton fall.

Our study has found that toxic concentrations of nine contaminants (Hg, As, Cd, Cr, Cu, Pb, Ni, Ag, and Zn) were well above acceptable levels in the top cm of sediment at measured sites (T4-95-3; T6-95-5; Table 2) of the DM Assemblage. Faunal

TABLE 2
Geochemical Analysis Results (mg/g)

Assemblage	Sample	Al	Sb	As	Ba	Be	Bi	B	Cd	Ca	Co	Cu	Cr	Fe	Pb	Mg	Mn	Hg	Ni	P	K	Ag	Na	Sr	Va	Zn
1 (DM)	T4-95-3	2.83	0.8	600	85	0.4	70	46	2.6	0.58	399	750	137	4.87	348	2.04	850	4.43	498	610	1800	29	500	19	115	334
	T6-95-5	1.98	5.1	2100	21	0.9	42	45	2	1.31	447	308	104	4.01	546	2.06	731	-	165	600	600	38	100	13	115	400
2 (HD)	T5-95-3	2.51	10.5	300	74	ND	54	47	2.2	0.66	321	585	119	4.23	263	1.8	841	3.47	355	630	1500	39	500	18	106	290
	P95-20	3.64	ND	300	26	ND	50	64	2.3	1.65	264	390	164	7.22	226	3.05	1400	1.6	302	550	1500	17	500	19	212	276
3 (DWC)	P95-14	*3.4*	*2.3*	*1900*	*40*	*0.2*	70	63	3.4	0.77	510	1640	155	6.72	461	2.64	1250	4.89	721	540	1500	33	600	11	183	568
	P95-5	2.69	2	1800	20	0.8	64	52	2.8	0.93	665	706	118	4.98	721	2.39	778	-	231	570	1200	72	300	10	136	640
4 (DWRT)	P95-10	2.78	1	1300	19	0.6	69	52	1.6	1.84	852	251	119	5.24	358	2.61	868	2.66	242	540	1100	62	300	15	144	246
	P95-3	2.11	1.1	980	47	0.6	49	44	2.2	1.07	447	522	92	3.21	430	1.48	706	-	293	700	1900	45	400	21	91	420
5 (SCS)	T6-95-2	2.62	2.1	680	46	0.6	55	55	2.9	1.65	418	386	124	4.42	440	3.05	711	5.74	245	622	1500	31	500	11	123	378
	P95-21	1.08	0.9	290	32	ND	ND	26	1.4	0.77	607	1910	47	2.75	470	2.64	347	-	1840	410	1500	41	600	23	43	205
	P95-22	1.13	28	2900	48	0.4	2.6	46	2.6	8.28	435	2640	52	3.72	151	1.1	1520	3.78	1370	730	1000	68	300	54	55	400
6 (ORSC)	T3-95-1	3.07	ND	370	107	ND	50	47	3.7	0.85	314	391	125	4.52	290	1.64	656	3.37	250	670	3200	12	700	33	*101*	*336*
	P95-4	2.29	2	1050	35	1.1	69	52	3.5	1.55	810	952	118	4.41	870	2.3	847	24.9	454	760	1300	147	400	19	128	790
	P95-17	1.33	6.3	2400	48	0.3	24	37	3.6	1.07	390	2230	58	2.5	155	1.02	530	-	1290	650	800	131	200	79	58	392
Method Detection Limit		0.01	0.4	40	1	0.2	5	1	0.4	0.01	2	1	1	0.01	5	0.01	0.5	0.04	2	10	100	1	100	1	1	1

evidence, however as suggested by the high arcellacean diversity in the DM Assemblage, seems to indicate that remediation is well under way at these sites, thus apparently contradicting geochemical results.

The contradictory results may be an artefact of our methodology. Since dumping terminated in these lakes (as late as 1970 in Crosswise Lake), only a few millimetres of natural lake sediment has accumulated. For our faunal analysis we targeted that topmost sediment layer. However, for our geochemical analysis we had to use up to one cm of the surface material to obtain sufficient material for analysis, so we were inadvertently measuring some preremediation sediments. This result underlines the value of arcellaceans in lake remediation studies as only a very tiny sample is required to obtain statistically significant arcellacean populations, thus permitting precise determination of the health of a lake bottom. The result also suggests that the toxic effect of the contaminated sediments is very localized as only a few mm of non-contaminated sediment is required to buffer highly sensitive arcellacean faunas. However, note that the high proportions of *Difflugia protaeiformis* "amphoralis" in the DM Assemblage samples suggests that some residual contamination penetrates to the surface. Asioli et al. (1996) found that various strains of *D. protaeiformis* are good indicators of copper sulfate polluted and acidified sediments in northern Italian Lakes.

High Diversity Assemblage (2)

The High Diversity Assemblage (HD) is very similar to the DM Assemblage but is found in both Crosswise and Peterson lakes at an average depth of 4.3m (text-figures 2 and 3). These samples are similar in texture to those of the DM Assemblage, being primarily clays, but are darker in color. Measured TOC levels were also low in this assemblage ranging between 4.3% and 8.4%. Similar to the DM Assemblage, levels of Hg, As, Cd, Cr, Cu, Pb, Ni, Ag, and Zn were all well above acceptable levels (Table 4). Additionally, although the levels of Hg, As, Pb, and Zn were very high, they were significantly less than those found at measured DM sites.

As in the DM Assemblage the fauna of the HD Assemblage is dominated by *Cucurbitella tricuspis* ($\bar{x}$=17.8) and has a very high species and strain diversity of 20. The mean HD Assemblage specimen abundance ($\bar{x}$=388) is less than in the DM but that is probably more related to less plankton fall of *Cucurbitella tricuspis* at these sites than being an indicator of benthic conditions. The main distinguishing feature between the two assemblages is the more equitable distribution of species in the HD Assemblage. *Difflugia oblonga* "oblonga" ($\bar{x}$=0.142), *Difflugia protaeiformis* "amphoralis" ($\bar{x}$=0.093%), *Centropyxis aculeata* "aculeata" ($\bar{x}$=0.085), *Difflugia protaeiformis* "acuminata" ($\bar{x}$=0.076), *Difflugia oblonga* "linearis" ($\bar{x}$=0.07), and *Centropyxis constricta* "constricta" ($\bar{x}$=0.052) are all relatively abundant. The diverse fauna suggests that the lake bottom is returning to more normal conditions although significant proportions of strains of the opportunistic *Centropyxis aculeata* indicate continued fairly significant levels of environmental stress. Centropyxid species are capable of withstanding a variety of hostile conditions better than most other arcellacean species, including cold temperatures (Decloître, 1956), low salinity conditions (<5‰; Decloître 1953; Scott and Medioli 1980; Patterson et al. 1985; Honig and Scott 1987), low nutrient conditions, oligotrophic conditions (Schönborn 1984), and sites heavily contaminated by Hg and As (Patterson et al. 1996). As discussed above, high numbers of *Difflugia protaeiformis* strains also indicate that the contaminants are creating environmental stress in this environment.

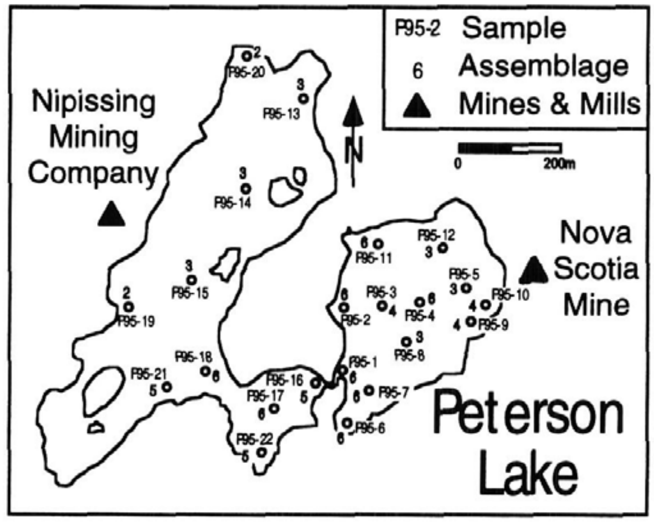
Deep Water Contaminated Assemblage (3)

The Deep Water Contaminated Assemblage (DWC) occurred exclusively in Peterson Lake. This assemblage is dominated by *D. oblonga* "glans" ($\bar{x}$=0.202) and *D. protaeiformis* "claviformis" ($\bar{x}$=0.159). Significant occurrences of *C. aculeata* "aculeata" ($\bar{x}$=0.099), *D. oblonga* "oblonga" ($\bar{x}$=0.081), *D. oblonga* "bryophila" ($\bar{x}$=0.073), and *D. oblonga* "tenuis" ($\bar{x}$=0.077) also occur. However, all the mean abundances of the taxa in this assemblage were highly variable as indicated by their standard deviations. This assemblage is found on non-vegetated, black, grey to brown sediments. Sample depth for this assemblage was quite deep with a mean of 8.08m and a standard deviation of 3.50m. Arcellacean abundance is fairly high with a mean of 195 specimens per cc. The faunal makeup of this assemblage is similar to the Muddy Substrate Assemblage of Patterson et al. (1996).

TABLE 3
Toxicity Guidelines for Common Heavy Metals (Compiled from Moore 1991) (mg/g)

Element	relative toxicity	Drinking water	Aquatic Life tolerance Canada	US	EC
Al	unknown	200	-	-	-
As	variable	50	50	360	150
Ba	unknown	1000	-	-	-
Be	unknown	-	-	-	-
B	low	5000	-	-	-
Cd	high	5	0.2-1.8	0.66-2	2 .0-3.0
Cr	moderate	50	2	50	5
Co	low	-	-	-	-
Cu	high	1000	0.2-0.4	0.66-2	1.0-28
Fe	moderate	300*	3000-1000	3000-1000	3000-1000
Pb	moderate	50	1.0-7.0	1.3-7.7	4.0-250
Mn	low	50*	-	-	-
Hg	high	1	0.1	2.1	0.2
Ni	moderate to high	-	25-150	56-160	30-200
Ag	high	50	0.01	1.2-13	-
Va	low-unknown	-	-	-	-
Zn	highly variable	5000*	30	59-190	10-125

* aesthetic reasons - none or insignificant
Ranges represent water hardness differences



TEXT-FIGURE 3
Peterson Lake Map

The DWC Assemblage seems to be a transitional assemblage between the HD Assemblage and the Deep Water Raw Tailings (DWRT) Assemblage described below. Collins et al. (1990) have reported that *D. oblonga* thrives from the tropics to the Arctic in virtually any lake environment provided that there is sufficient organic matter. While this finding seems to be in contrast with our results (TOC: $\bar{x}$=5.6%), most of the samples in this assemblage did have a thin upper gyttja layer which could account for the high *D. oblonga* abundances. It also seems that the *D. oblonga* "glans" strain also preferentially colonizes the deeper water contaminated substrates. The moderately high *D. protaeiformis* "claviformis" abundances in this assemblage indicates that the substrate is also highly contaminated which is the case (high: Hg, As, Cd, Cr, Cu, Pb). Asioli et al. (1996) also found that *D. protaeiformis* "claviformis" was an opportunistic species able to colonize heavily contaminated substrates in Italian lakes. Our results also confirm that the "claviformis" strain is a good indicator of substrate contamination in deeper water.

Deep Water Raw Tailings Assemblage (4)

Difflugia protaeiformis "claviformis" ($\bar{x}$=0.576) dominates the sub-thermocline Deep Water Raw Tailings Assemblage (DWRT). *D. oblonga* "glans" ($\bar{x}$=0.131) is also significant in this assemblage although its relative abundance is highly variable (std = 0.104). These samples were composed of grey to very dark grey clay mine tailings devoid of any vegetation. This assemblage has the lowest concentration of arcellaceans found in any assemblage, with a mean of 32 specimens per cc. The DWRT Assemblage is found exclusively on raw tailings in the eastern portion of Peterson Lake in a deep trench from which tailings were excavated in a previous remediation effort in 1965.

The TOC of one sample locality (P95-3) is anomalously high (35.3%), while the other two (P95-9; P95-10) were very low (Table 1). The former was dominated by *D. protaeiformis* "claviformis" (0.52), and a significant abundance of *D. oblonga* "glans" (0.25). The other two localities had much lower fractional abundances of *D. oblonga* "glans" which is a reflection of the decreased TOC contents of the sediments. Similar to the DWC Assemblage, *D. protaeiformis* "claviformis" is a very good indicator of contaminated substrate in deeper water environments.

Shallow Contaminated Substrate Assemblage (5)

The Shallow Contaminated Substrate Assemblage (SCS) reflects a contaminated shallow water environment in both Peterson and Crosswise lakes. The SCS Assemblage samples were taken from shallow depths ($\bar{x}$= 3.23m), and from localities with abundant living vegetation. However, the TOC varied in this assemblage with values between 20.4% and 6.8%.

The SCS Assemblage arcellacean fauna was characterized by *C. aculeata* "discoides" ($\bar{x}$=0.210) and moderately high levels of the following: *C. constricta* "spinosa" ($\bar{x}$=0.061), *C. aculeata* "aculeata" ($\bar{x}$=0.228), *C. tricuspis* ($\bar{x}$=0.090), and *D. oblonga* "oblonga" ($\bar{x}$=0.063). The mean specimens per cc was moderately high, although it was highly variable with a mean of 265 and a standard deviation of 362. The mean diversity is not significantly different from the other five assemblages.

Mercury levels in the SCS Assemblage were relatively high compared to the other assemblages with a maximum value in sample T6-95-2 (5.74ppm). Arsenic levels were also very high with the highest level reported in sample P95-22 (2900ppm). However, the arsenic values were also significantly variable since, in addition to containing the highest value, this assemblage also contained the lowest value at 290ppm. Nickel levels were very high at 1840ppm in sample P95-21, and 1370ppm in sample P95-22.

The high percentage of centropyxid fauna in this assemblage is difficult to account for in terms of findings from previous studies. Previous work has documented the centropyxid fauna as being opportunistic since it appeared to thrive in environments where other arcellacean species were not common (eg. cold temperatures, low salinity regimes; Decloître 1956; Scott and Medioli 1980; Patterson et al. 1985; Honig and Scott 1987). In this study we have found that the centropyxids tend to dominate the shallow vegetation covered substrates; areas with ample available light and resultant high productivity that at first assessment should be conducive to sustaining other less opportunistic faunas. However, the color of the sediment in samples dominated by this assemblage was black and the samples had relatively high TOC levels. Thus lower oxygen levels seem to be a major limiting factor resulting in the exclusion of most arcellacean taxa from this harsh microenvironment.

In addition, these shallow water samples were characterized by some of the highest contamination levels of mercury, arsenic and nickel observed in this study, also contributing to the harsh conditions found (Tables 2, 3). These findings are in general agreement with those of Patterson et al. (1996) in which they reported that a centropyxid assemblage (Contaminated Substrate Assemblage - CS) also tended to dominate shallow, highly contaminated substrates.

Organic Rich Shallow Contaminated Assemblage (6)

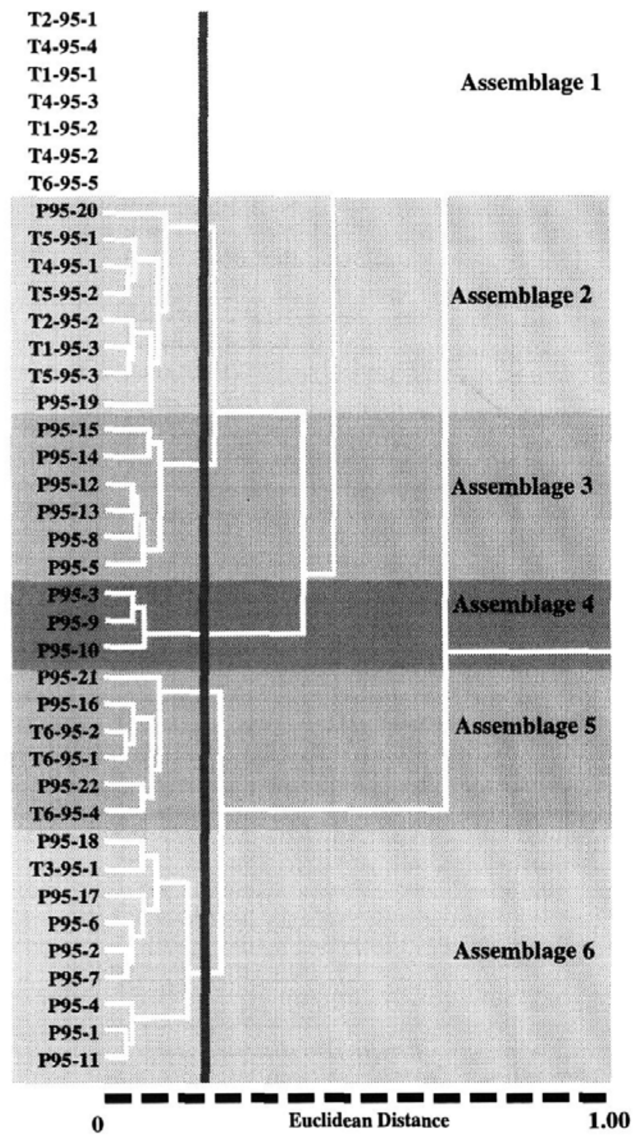
The Organic Rich Shallow Contaminated Assemblage (ORSC) was very similar in faunal composition to the SCS Assemblage and represents a contaminated, organic rich shallow water environment. Thus, many of the arguments presented for the SCS Assemblage also hold true for the ORSC Assemblage. The ORSC Assemblage is also very similar in faunal makeup and depth characteristics to the CS Assemblage of Patterson et al. (1996). This assemblage is found at the shallowest mean water depth (2.59m). As with the SCS Assemblage, the ORSC Assemblage is dominated by abundant living vegetation and high contents of TOC reaching a maximum value of 79.8%. The main difference between the ORSC and the SCS assemblages though is the higher proportion of centropyxids and *A. vulgaris* populations in the former.

C. aculeata "aculeata" dominates the ORSC faunal assemblage with a mean fractional abundance of 0.372, and *A. vulgaris* has the highest mean fractional abundance of that species in this assemblage (=0.081). Similarly, *C. constricta* "spinosa", although highly variable, also has a high mean fractional abundance in this assemblage (=0.198; std. = 0.143). The mean specimens per cc (=197; std. 120) was generally lower in the ORSC Assemblage compared to the other assemblages.

A. vulgaris is known to inhabit boggy ponds in the Arctic and further south (Collins et al. 1990). The high TOC contents of the samples found in this assemblage are probably responsible for the elevated *A. vulgaris* abundances. Perhaps the high TOC content emulates bog-like conditions and associated low oxygen microenvironments on the lake bottom.

Mercury levels varied from high to low in the ORSC Assemblage. Sample P95-4 had a mercury concentration of 24.9 ppm, and sample T3-95-1 had a lower concentration of 3.37ppm. Arsenic levels were generally high, with sample P95-4 and P95-17 having concentrations of 1050ppm and 2400ppm respectively. Nickel concentrations in these samples were moderate (250ppm and 454ppm), but reached high levels in sample P95-17 (1290ppm). Silver and chromium concentrations were also high in this assemblage, with silver levels of 147 and 131ppm, and chromium concentrations ranging from 3.5-3.7ppm.

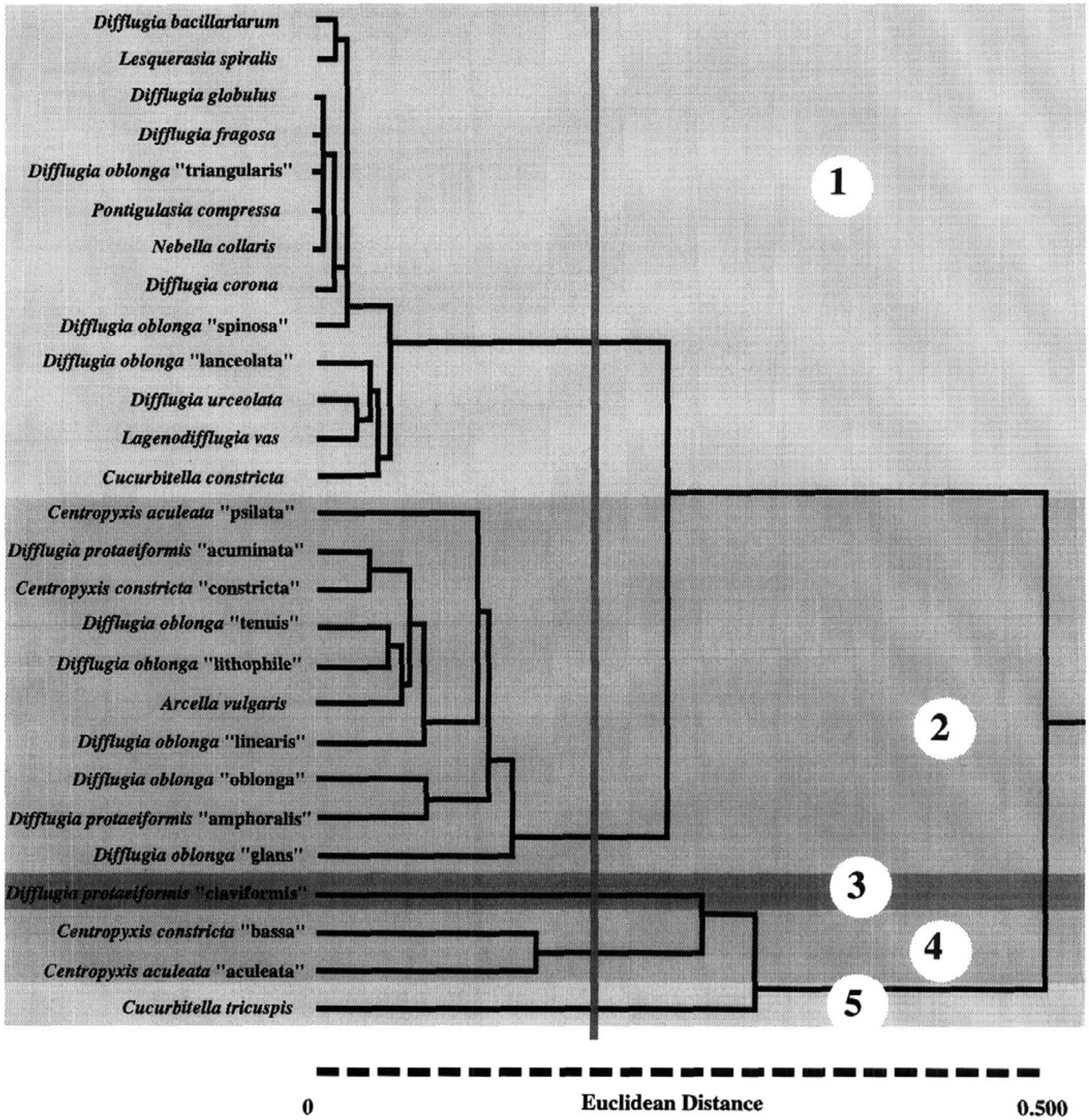
One anomalous sample in the ORSC Assemblage was P95-18, characterized by lower diversity, no vegetation, and was recovered from deeper water (17.3m) than the other samples in this assemblage. The reason that sample P95-18 clustered with the ORSC Assemblage was due to the very high *C. aculeata* "aculeata" abundance which dominated the sample (fractional abun-



TEXT-FIGURE 4
Q-Mode Cluster Results

dance of 0.425), and its high *A. vulgaris* abundance at 0.133. However, it also had higher levels of *D. oblonga* "glans" which is more typical of the DWC and DWRT assemblages, although it lacked the significant *D. protaeiformis* "claviformis" population. Thus it is probable that P95-18 belongs to another assemblage most likely DWC or DWRT. The high *C. aculeata* "aculeata" and *A. vulgaris* test abundances that place this sample in the ORSC Assemblage may be allochthonous. It is conceivable that the fauna were transported from shallower water because the bathymetry of the area surrounding the sample site is very steep.

Although superficially similar, the subdivision of the SCS and the ORSC assemblages in this study is based upon the discrimination of various centropyxid strains. They would have been grouped together into one assemblage as in Patterson et al. (1996) if morphotypic variations were not separated. As the en-



TEXT-FIGURE 5
R-Mode Cluster Results

vironments characterized by the SCS and ORSC assemblages are distinct, the value of using strains to resolve subtle environmental changes is clearly demonstrated.

RECOMMENDATIONS FOR FUTURE ENVIRONMENTAL REMEDIATION

The remediation of heavy metal contaminated lakes presents unique problems. Unlike organic pollutants, such as polychlorinated biphenyls (PCBs) and benzene compounds which can be broken down, metal pollutants are commonly in their natural state (eg. mineral form). Thermodynamic processes dictate that minerals taking a long time to form, represent stable chemical compounds, and take a similarly long interval to break down. Possible solutions that have been suggested include the conversion of toxic metals to harmless compounds so that they would not be bioavailable. Bacterial processes can accomplish this by either reducing or oxidizing the contaminants (S^{2-}, CO_3^{2-}, OH^-) (Wildeman et al. 1994). Unfortunately, mine tail-

TABLE 4
Statistical Summary of Assemblages

Assemblage	Sample	Mean Water Depth (m)	Mean Specimens/cc	Mean Diversity	*A. vulgaris*	*C. aculeata* "aculeata"	*C. aculeata* "pellata"	*C. constricta* "bassa"	*C. constricta* "constricta"	*C. constricta*	*C. tricuspis*	*D. oblonga* "glans"
1	mean	5.12	551	20	0.010	0.021	0.012	0.012	0.027	0.009	0.488	0.043
	std	1.67	142	2	0.011	0.022	0.011	0.009	0.017	0.012	0.146	0.028
2	mean	4.31	388	20	0.026	0.085	0.023	0.011	0.052	0.014	0.178	0.042
	std	2.26	106	4	0.022	0.044	0.019	0.009	0.047	0.013	0.091	0.017
3	mean	8.08	195	16	0.017	0.099	0.013	0.030	0.019	0.003	0.114	0.202
	std	3.50	148	2	0.025	0.069	0.018	0.033	0.025	0.005	0.047	0.115
4	mean	7.77	32	14	0.031	0.004	0.014	0.010	0.024	0.015	0.036	0.141
	std	0.49	3	3	0.002	0.003	0.025	0.011	0.033	0.014	0.016	0.104
5	mean	3.23	265	16	0.020	0.228	0.210	0.061	0.042	0.048	0.090	0.042
	std	1.36	362	4	0.024	0.137	0.072	0.050	0.029	0.044	0.051	0.046
6	mean	2.59	197	15	0.081	0.372	0.033	0.198	0.029	0.006	0.087	0.031
	std	1.54	120	3	0.035	0.062	0.027	0.143	0.024	0.007	0.060	0.042

Assemblage	Sample	Mean Water Depth (m)	Mean Specimens/cc	Mean Diversity	*D. oblonga* "lanceolata"	*D. oblonga* "linearis"	*D. oblonga* "lithophile"	*D. oblonga* "oblonga"	*D. oblonga* "tenuis"	*D. protaeiformis* "amphoralis"	*D. protaeiformis* "acuminata"	*D. protaeiformis* "claviformis"
1	mean	5.12	551	20	0.005	0.013	0.004	0.095	0.033	0.103	0.044	0.029
	std	1.67	142	2	0.003	0.009	0.004	0.026	0.018	0.066	0.025	0.017
2	mean	4.31	388	20	0.009	0.070	0.006	0.142	0.044	0.093	0.076	0.035
	std	2.26	106	4	0.008	0.104	0.006	0.076	0.041	0.097	0.072	0.035
3	mean	8.08	195	16	0.010	0.020	0.073	0.081	0.077	0.020	0.000	0.159
	std	3.50	148	2	0.019	0.026	0.045	0.039	0.066	0.015	0.000	0.106
4	mean	7.77	32	14	0.060	0.011	0.004	0.002	0.031	0.003	0.005	0.576
	std	0.49	3	3	0.063	0.015	0.003	0.003	0.015	0.003	0.006	0.067
5	mean	3.23	265	16	0.007	0.014	0.017	0.063	0.026	0.029	0.033	0.010
	std	1.36	362	4	0.008	0.021	0.031	0.040	0.028	0.016	0.034	0.009
6	mean	2.59	197	15	0.006	0.014	0.014	0.024	0.021	0.015	0.002	0.024
	std	1.54	120	3	0.010	0.013	0.025	0.034	0.032	0.017	0.006	0.028

ings contain such a large amount of heavy metal pollutants, often present in huge volumes (eg. Crosswise and Peterson lakes) that these processes are not practical and other remediation methods need to be explored.

We have observed natural remediation having taken place as evidenced by the return of vegetation and "normal" arcellacean faunas in parts of these lakes. This is significant as vegetation stabilizes cover material, in effect "capping" the tailings. For this process to occur, the pH must be relatively neutral (Förstner and Wittmann 1981). As the lakes in the Cobalt area are alkali, this was not an issue, but in order to remediate acidic lakes, they must become pH neutral (eg. by adding large quantities of lime).

The subenvironment represented by the DWRT Assemblage, entirely in the eastern portion of Peterson Lake, is devoid of vegetation and is the most heavily polluted. Interestingly it was at this location that artificial remediation was attempted. The dredging of about 55 000 tons in 1965 disturbed the tailings that had already settled, destabilizing the pollutants and creating a subenvironment of pure tailings in contact with the lake. This procedure was not attempted in Crosswise Lake nor in the western portion of Peterson Lake. In these areas the process of natural remediation is well underway as a vegetative layer is forming or has formed, creating a barrier between the tailings and the environment.

The most effective method for remediating lakes heavily contaminated by mine tailings may be to leave them alone or to add a layer of clean fill. In neutral pH settings such as those found in the Cobalt area lakes, our results suggest that only a thin cap of a few mm thick natural sedimentation and vegetative cover is required to be effective. As our arcellacean faunal analysis indicates, dredging of tailings only exacerbates the problem by nullifying any remedial effects that had already occurred. In addition, when tailings are removed, a new location must be found for them, thus transferring the problem, not solving it. As only a thin layer of capping sediment is required in settings such as found in the Cobalt area we suggest that the cost effective approach to lake remediation may be to add clean fill to similarly contaminated lakes to speed the remediation process.

SUMMARY AND CONCLUSIONS

1. Six arcellacean assemblages were recognized that characterize distinct highly contaminated to remediated environments. As arcellaceans live at the sediment-water interface, they are highly responsive to environmental stimuli.

2. Characterization of infraspecific strains is useful to distinguish subenvironments not recognizable using species.

3. Only a thin veneer of sediments is required to protect the biota from underlying tailings in neutral pH settings. In places where this layer has been artificially removed (eg. the DWRT Assemblage), exposed contaminated substrate has not recovered as indicated by the arcellacean fauna despite the passage of 31 years (1965-1996).

4. The most effective way quickly to bring about remediation is to either leave the tailings alone or to add clean sediments to these lakes and bury the tailings.

SYSTEMATICS

It is not surprising that we were able to separate and define numerous distinct and stable arcellacean strains as the species concept with regards to this clonal group is a highly subjective matter (Medioli and Scott 1983). The systematic approach to the group has ranged from the opinion of Wallich (1864) who believed that all arcellaceans belonged to the same species, to that of some modern specialists who have described new species for every strain recognized (see Deflandre 1928; Medioli and Scott 1983; Medioli and Scott 1988 for discussion).

We have observed several distinct morphotypic populations within many arcellacean species. Such strains have developed in response to different environmental stresses (eg. presence of chemical pollutants in the substrate) and thus can be considered ecomorphs. As this paper is not of taxonomic nature, only an abbreviated taxonomy as well as photomicrographs of all the strains and species discriminated (based on Medioli and Scott 1983) is provided along with diagnoses for different strains. Parentheses are used to demarcate strains and to emphasize their infraspecific designation. Some of the morphotypic names we use are based on forms described as species in the literature. We use this terminology to maintain taxonomic consistency but consider them as strains of existing species.

Subphylum SARCODINA Schmarda 1871
Class RHIZOPODEA von Siebold 1845
Subclass LOBOSA Carpenter 1861
Order ARCELLINIDA Kent 1880
Superfamily ARCELLACEA Ehrenberg 1830
Family ARCELLIDAE Ehrenberg 1830
Genus *Arcella* Ehrenberg 1830

Arcella vulgaris Ehrenberg 1830
Plate 1, figure 3

Arcella vulgaris EHRENBERG 1830, p. 40, pl. 1, fig. 6

Family CENTROPYXIDIDAE Deflandre 1953
Genus *Centropyxis* Stein 1859

Centropyxis aculeata (Ehrenberg 1832)
Strain: Centropyxis aculeata "aculeata"
Plate 1, figure 1a-c

Arcella aculeata EHRENBERG 1832, p. 91

Diagnosis: Test depressed, circular with 1- 8 spines in postero-lateral margin.

Strain: ***Centropyxis aculeata "discoides"***
Plate 1, figure 2

Arcella discoides EHRENBERG 1843, p. 139
Arcella discoides Ehrenberg, EHRENBERG 1872, p.259, pl. 3, fig. 1
Arcella discoides Ehrenberg, LEIDY 1879, p. 173, pl. 28, figs. 14-38
Centropyxis aculeata var.*discoides* PENARD 1890, p. 150, pl. 5, figs. 38-41
Centropyxis discoides Penard [sic], OGDEN and HEDLEY 1980, p. 54, pl. 16, figs. A-e

Diagnosis: Test depressed, circular almost "doughnut shaped" without spines.

Centropyxis constricta (Ehrenberg 1843)
Strain: Centropyxis constricta "constricta"
Plate 1, figure 4a-b

Arcella constricta EHRENBERG 1843, p. 410, pl. 4, fig. 35, pl. 5, fig. 1

Diagnosis: Test less flattened than strain "spinosa" with 3 or less spines on the fundus.

Strain: ***Centropyxis constricta "spinosa"***
Plate 1, figure 5

Centropyxis spinosa CASH in CASH and HOPKINSON 1905, p. 135, text figs. 26 a-c, pl. 16, fig. 15
Centropyxis spinosa Cash, OGDEN and HEDLEY 1980, p. 62, pl. 20, figs. a-d

Diagnosis: Test more flattened than strain "constricta" with 3 or more spines on the fundus.

Family DIFFLUGIDAE Stein 1859
Genus *Difflugia* Leclerc in Lamarck 1816

Difflugia corona Wallich 1864
Plate 2, figure 1a-b

Difflugia protaeiformis (sic) Ehrenberg subsp. *D. globularis* (Dujardin) var. *D. corona* WALLICH 1864, p. 244, pl. 15, fig. 4a-c, pl. 16, figs. 19, 20
Difflugia corona (Wallich 1864) ARCHER 1866, p. 186

Difflugia oblonga Ehrenberg 1832
Strain: Difflugia oblonga "glans"
Plate 2, figure 7a-b

Difflugia glans PENARD 1902

Diagnosis: Test oval to ovoid, slightly elongated, fundus rounded, neck absent, aperture circular with smooth lip, test made of fine sand particles, small.

Strain: ***Difflugia oblonga "lanceolata"***
Plate 2, figure 6

Difflugia lanceolata PENARD 1890, p. 145, pl. 4, figs. 59-60
Difflugia lanceolata Penard. - OGDEN and HEDLEY 1980, p. 140, pl. 59, figs. A-d

Diagnosis: Test elongate, pyriform and smooth, fundus rounded, neck long, aperture circular without lip.

Strain: ***Difflugia oblonga "linearis"***
Plate 2, figure 8a-b

Difflugia pyriformis var. *linearis* PENARD 1890, p. 137, pl. 3, figs. 42-44

Diagnosis: Test flask shaped, fundus rounded, neck long and constricted, aperture narrow, circular but crenulated, test made of fine to coarse sand grains.

Strain: ***Difflugia oblonga "bryophila"***
Plate 2, figure 9a-b

Difflugia pyriformis var. *bryophila* PENARD 1902, p. 221, text fig. 7
Difflugia bryophila Penard [sic], OGDEN and ELLISON 1988, p. 234, pl. 1, figs. 1-3

Diagnosis: Test flask shaped, elongated, pyriform, neck long but sometimes obscure due to coarse agglutination, aperture narrow, circular and without lips. Test is made of conspicuously large sand grains.

Strain: ***Difflugia oblonga "oblonga"***
Plate 2, figure 10a-b

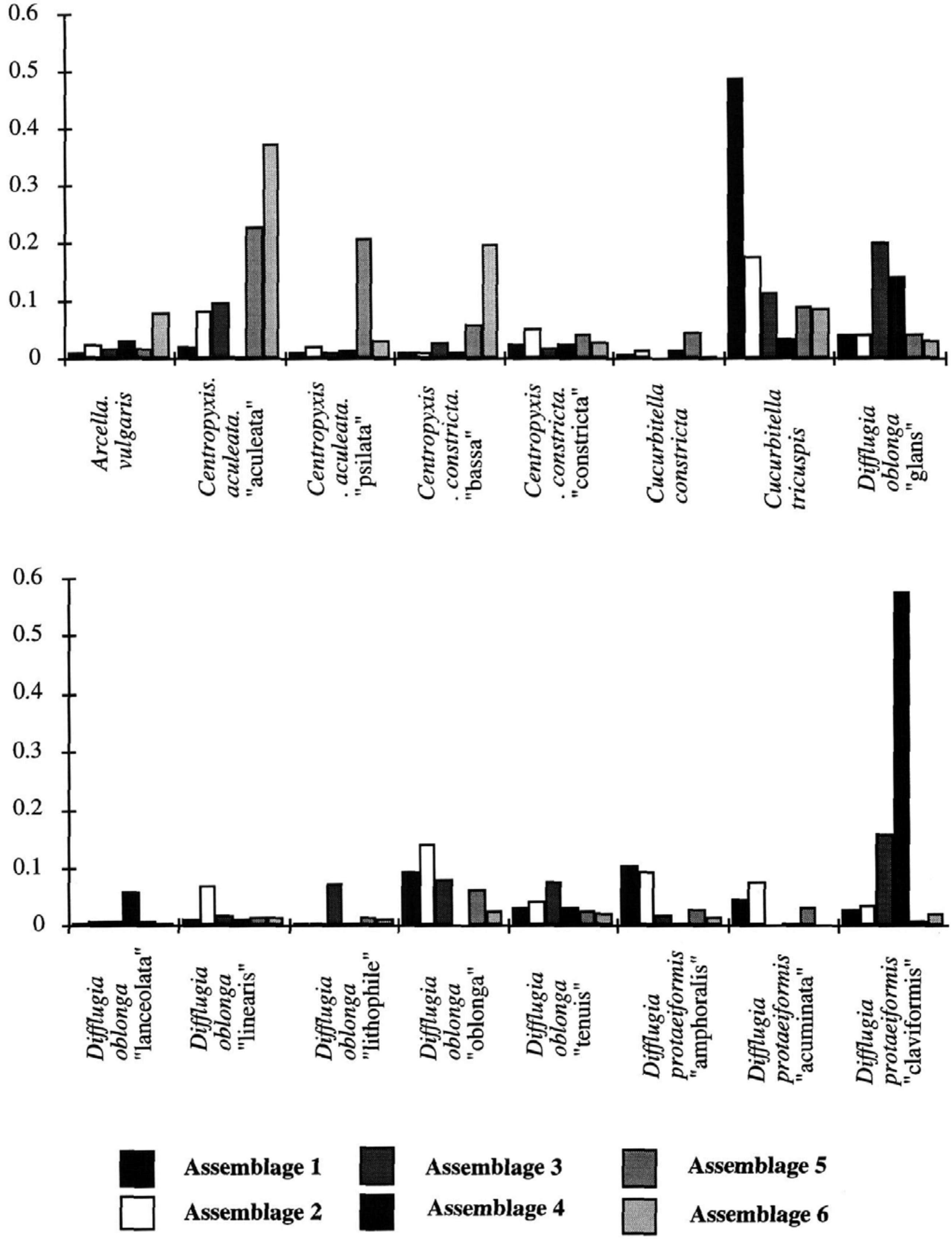
Difflugia oblonga EHRENBERG 1832, p. 90. - OGDEN and HEDLEY 1980, p. 148, pl. 63, figs. a-c. - HAMAN 1982, p. 367, Pl. 3, Figs. 19-25. - SCOTT and MEDIOLI 1983, p. 818, figs. 9a-b

Diagnosis: Test, pyriform, elongated to oblong, fundus rounded, neck long, aperture circular without lip, test made of generally fine sand grains.

Strain: ***Difflugia oblonga "spinosa"*** n. strain
Plate 2, figure 11a-b

Diagnosis: Test pyriform, elongated, fundus large and with a distinct spine, neck short and constricted, aperture narrow, circular without lip, test made of fine sand grains.

Remarks: This strain appears to be similar to *Difflugia protaeiformis* "amphoralis", but differs in having a short neck marked



TEXT-FIGURE 6
Assemblage Comparison Histograms

by a constriction, whereas "amphoralis" lacks neck and fundus merges into aperture. There is a lip in the aperture of "amphoralis" which is absent in "spinosa". This is a new strain that we have not seen in the published literature.

Strain: ***Difflugia oblonga "tenuis"***
Plate 2, figure 12a-b

Difflugia pyriformis var. *tenuis* PENARD 1890, p. 138, pl. 3, figs. 47-49

Diagnosis: Test elongated, ovoid almost bean shaped, fundus subrounded to subacute, neck indistinct or absent, aperture narrow and circular with crenulated lip, test made of generally medium to fine sand grains.

Difflugia protaeiformis Lamarck 1816
Difflugia protaeiformis LAMARCK 1816, p. 95 (with reference to material in a manuscript by Leclerc)

Strain: ***Difflugia protaeiformis "acuminata"***
Plate 2, figure 5

Difflugia acuminata EHRENBERG 1830, p. 95. - OGDEN and HEDLEY 1980, p. 118, pl. 4, figs. A-c. - SCOTT and MEDIOLI 1983, p. 818, fig. 9d

Diagnosis: Test elongated almost cylindroconical, fundus acuminate, tapering to form a blunt spine, neck absent, aperture circular, narrow without lip, test smooth almost hyaline and small.

Strain: ***Difflugia protaeiformis "amphoralis"***
Plate 2, figure 4

Difflugia amphoralis HOPKINSON in CASH and HOPKINSON 1909, p. 43, pl. 21, fig. 13

Diagnosis: Test almost biconical, elongated, fundus subangular tapering to form a spine , neck absent, aperture circular, narrow with an indistinct lip. Test made of fine sand grains.

Strain: ***Difflugia protaeiformis "claviformis"***
Plate 2, figure 3

Difflugia pyriformis var. *claviformis* PENARD 1899, p. 25, pl. 2, figs. 12-14
Difflugia claviformis OGDEN and HEDLEY 1980, p. 126, pl. 52, figs. a-d
Difflugia protaeiformis strain "protaeiformis" ASIOLI et al. 1996, p. 250, pl. 2, fig. 1 a-b

Diagnosis: This strain is similar to "acuminata" except that it has coarser test made up of medium to coarse grained sand.

Remarks: Although infraspecific variations are not regulated by the ICZN, we decided to be consistent in naming our strains by using the principle of priority. As such, since the name *claviformis* predates Asioli et al. (1996), we have adopted it.

Difflugia urceolata Carter 1864
Plate 2, figure 2a-b

Difflugia urceolata CARTER 1864, p. 27, pl. 1, fig. 7

Genus *Lagenodifflugia* Medioli and Scott 1983

Lagenodifflugia vas Leidy 1874
Plate 1, figure 8a-b

Lagenodifflugia vas MEDIOLI AND SCOTT 1983, p. 33, pl. 2, figs. 18-23, 27, 28

Family HYALOSPHENIIDAE Schulze 1877
Genus *Cucurbitella* Penard 1902

Cucurbitella tricuspis (Carter 1856)
Plate 1, figure 7a-f

Difflugia tricuspis CARTER 1856, p. 221, fig. 80
Cucurbitella tricuspis (Carter 1856) MEDIOLI, SCOTT, AND ABBOTT, 1987, p. 42, pls. 1-4, text figs. 1, 4

Strain: ***Cucurbitella constricta*** n. strain
Plate 1, figure 6a-b

Diagnosis: Test shape varies from spherical, subspherical to elongated. It is characterized by a thick apertural lip.

Remarks: The shape of this strain is highly variable and is distinguished from *Cucurbitella tricuspis* in having a thick, non crenulated lip.

PLATE 1
Scanning electron micrographs. All scale bars are 50μm

1a-c *Centropyxis aculeata "aculeata"*. This strain has a variable number of spines.

2 *Centropyxis aculeata "discoides"*. Same as *"aculeata"* but spines absent.

3 *Arcella vulgaris*. Test round, hyaline; aperture invaginate.

4a-b *Centropyxis constricta "constricta"*. Aperture forms an angle with the fundus.

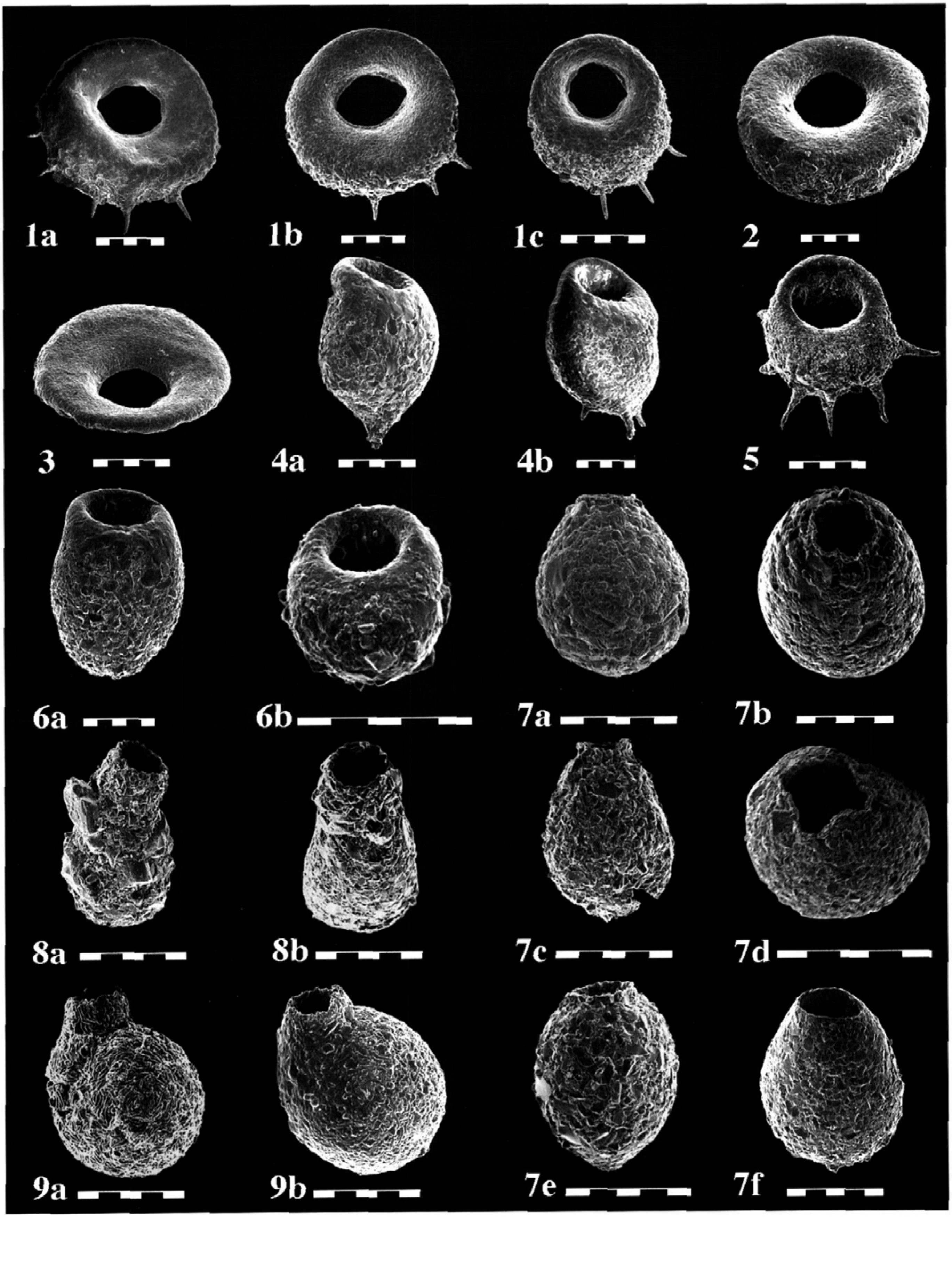
5 *Centropyxis constricta "spinosa"*. Similar to previous, but test is flattened.

6a-b *Cucurbitella constricta*. Test shape highly variable in gross morphology and shape, with a thick apertural lip.

7a-f *Cucurbitella tricuspis*. Highly variable morphology based on a pyriform shape. Apertural lip thin and extends from test with irregular folds.

8a-b *Lagenodifflugia vas*. Irregular test with spherical body with a distinct tapering neck.

9a-b *Lesquereusia spiralis*. Aperture forms a distinct 45^{o} angle with the test.


1a
1b
1c
2
3
4a
4b
5
6a
6b
7a
7b
8a
8b
7c
7d
9a
9b
7e
7f

Genus *Lesquereusia* Schlumberger 1845

Lesquereusia spiralis (Ehrenberg 1840)
Plate 1, figure 9a-b

Difflugia spiralis EHRENBERG 1840. - EHRENBERG 1872, p. 274, pl. 3, figs. 25-27
Lesquereusia spiralis (Ehrenberg) PATTERSON, MacKINNON, SCOTT, AND MEDIOLI 1985, p. 135, pl. 2, figs. 9, 12

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REFERENCES

ARCHER, W., 1866. Quarterly Journal of Microscopical Science, new series, 6:185-188.

ASIOLI, A., MEDIOLI, F.S., AND PATTERSON, R.T., 1996. Thecamoebians as a tool for reconstruction of paleoenvironments in some Italian lakes in the foothills of the southern Alps (Orta, Varese and Candia). Journal of Foraminiferal Research, 26(3): 248-263.

CARPENTER, W.B., 1861. On the systematic arrangement of the Rhizopoda. Natural History Review, 1(4): 456-472.

CARTER, H.J., 1856. Notes on the freshwater Infusoria of the island of Bombay. No. 1. Organization. Annals and Magazine of Natural History, series. 2, 18(105):221-249.

CARTER, H.J., 1864. On freshwater Rhizopoda of England and India. Annals and Magazine of Natural History, series. 3, 13: 18-39.

CASH, J. and HOPKINSON, J., 1905. The British freshwater Rhizopoda and Heliozoa. Vol. I: Rhizopoda, part 1: Ray Society, London. 151p.

———,1909. The British freshwater Rhizopoda and Heliozoa. Vol. II: Rhizopoda, part 2: Ray Society, London. 166p.

COLLINS, E.S., McCARTHY, F.M., MEDIOLI, F.S., SCOTT, D.B. and HONIG, C.A., 1990. Biogeographic distribution of modern thecamoebians in a transect along the eastern North American coast, *in* Hemleben, C., Kaminski, M.A., Kuhnt, W., and Scott, D.B., eds., Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera: North Atlantic Treaty Organization Advanced Study Institute Series, Series C, Mathematical and Physical Sciences, 327:783-791.

CULVER, S. J., 1987. Foraminifera *in* Broadhead, T.W., ed., Fossil Prokaryotes and Protists Notes for a Short Course: The Paleontological Society and The Cushman Foundation, 169-212.

DECLOÎTRE, L., 1953. Recherches sur les Rhizopodes thécamoebiens d'A.O.F. (Suite). Faune du Lac Tamna (Senegal): Bulletin de l'Institut Français d'Afrique Noire, no. 31:249.

DECLOÎTRE, L., 1956. Les thécamoebiens de l'Eqe (Gröenland): Expéditions Polaires Françaises Missions Paul-Émile Victor VIII, Actualités Scientifiques et Industrielles 1242, 100p.

DEFLANDRE, G., 1928. Le genre *Arcella* Ehrenberg. Morphologie - Biologie. Essai phylogénétique et systématique. Archiv fur Protistenkunde. Protozoen-Algen-Pilze, 64:152-287.

———, 1953. Ordres des Testaceolobosa (De Saedeleer, 1834), Testaceofilosa (De Saedeleer, 1834), Thalamia (Haeckel, 1862) ou Thécamoebiens (Auct.) (Rhizopoda Testacea) *in* P.-P. Grassé (ed.), Traité de Zoologie, Masson, Paris, 1(2):97-148.

DUMARESQ, C.G., 1993. The occurrence of arsenic and heavy metal contamination from natural and anthropogenic sources in the Cobalt area of Ontario: Unpublished MSc. Thesis, Carleton University and Ottawa–Carleton Geoscience Centre, Ottawa, Ontario, 326p.

EHRENBERG, C.G., 1830. Organisation, systematik und geographisches Verhältnis der Infusionsthierchen. Berlin: Druckerei der Königliche Akademie der Wissenschaften, 108p.

PLATE 2
Scanning electron micrographs. All scale bars are 50µm

1a-b *Difflugia corona*. Characterized by having several spines on fundus and an irregularly folded apertural neck.

2a-b *Difflugia urceolata.* Test spherical to subspherical with a distinct constriction below the apertural lip.

3 *Difflugia protaeiformis "claviformis"*. Test made from coarse grains and is opaque.

4 *Difflugia protaeiformis "amphoralis"*. Almost biconical, widest part close to the fundus. Aperture a raised lip.

5 *Difflugia protaeiformis "acuminata"*. Test fine grained and hyaline.

6 *Difflugia oblonga "lanceolata"*. Test elongate and fine to medium grained.

7a-b *Difflugia oblonga "glans"*. Test ovoid with rounded fundus.

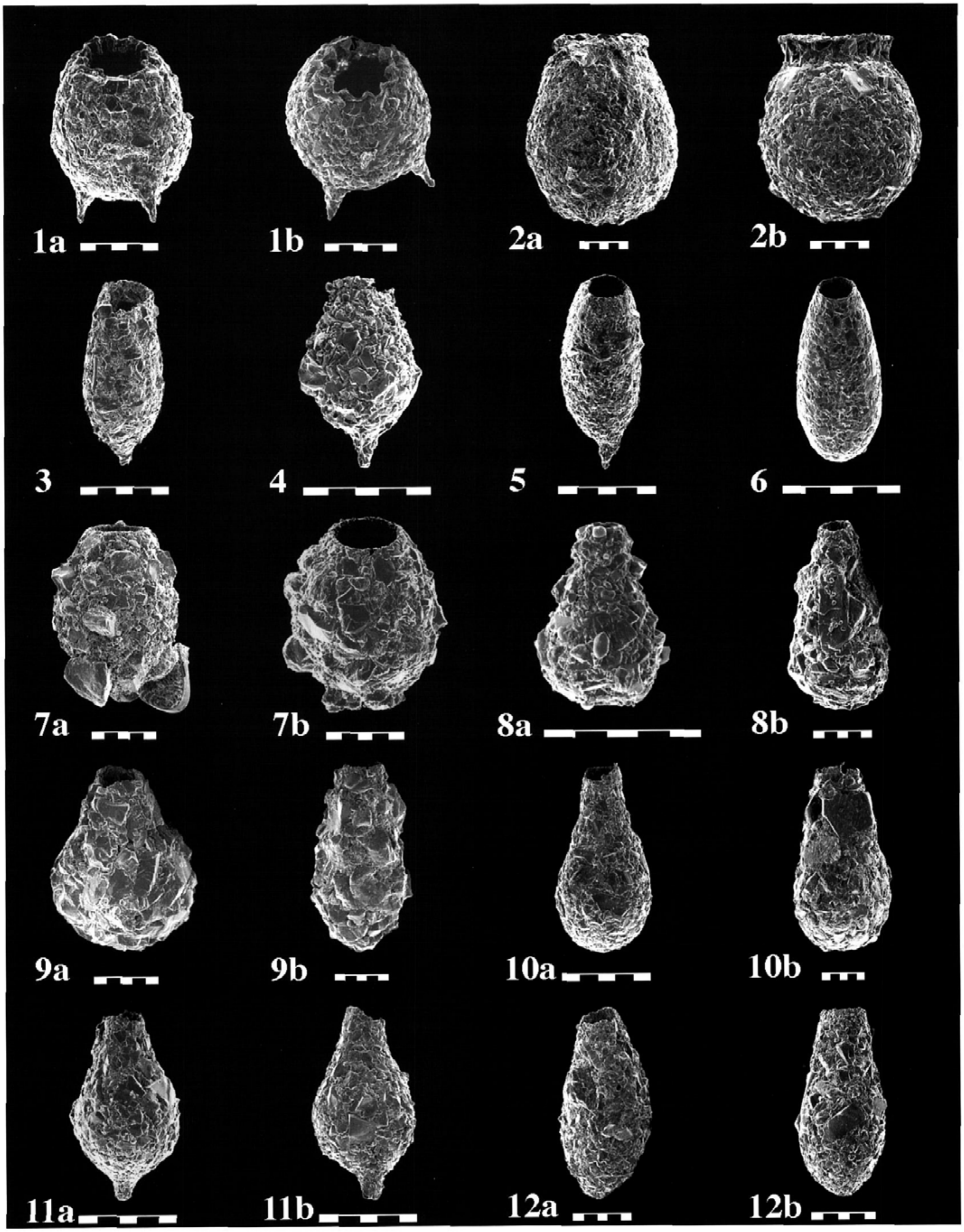
8a-b *Difflugia oblonga "linearis"*. Test flask-shaped with tiny aperture.

9a-b *Difflugia oblonga "bryophila"*. Variable flask-shaped test characterized by relatively large clasts.

10a-b *Difflugia oblonga "oblonga"*. Elongated to oblong with simple aperture.

11a-b *Difflugia oblonga "spinosa"*. Test flask-shaped with a spine; finely agglutinated; aperture simple.

12a-b *Difflugia oblonga "tenuis"*. Similar to *"oblonga"* except that the neck is absent and the fundus is almost subconical.


1a
1b
2a
2b
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7a
7b
8a
8b
9a
9b
10a
10b
11a
11b
12a
12b

APPENDIX 1

Taxonomic unit counts, including counts of each taxonomic unit for each sample location, specimens per unit of volume, and the standard error.

Sample	T1-95-1	T1-95-2	T2-95-1	T2-95-2	T3-95-1	T4-95-1	T4-95-2	T4-95-3	T4-95-4	T5-95-1	T5-95-2	T5-95-3	T6-95-1	T6-95-2	T6-95-3	T6-95-4	T6-95-5	P95-1	P95-2	P95-3
Total Count	359	625	351	387	459	484	348	618	554	394	423	425	366	494	302	320	327	414	441	188
Specimens/cc	359	625	702	387	230	484	348	618	554	394	423	425	183	988	151	160	654	414	221	31
Diversity	23	22	18	18	21	21	17	20	21	23	25	25	21	20	18	18	19	15	16	12
Assemblage	1	1	1	2	6	2	1	1	1	2	2	2	5	5	2	5	1	6	6	4
Arcella vulgaris	0.031	0.011	0.011	0.000	0.041	0.029	0.000	0.002	0.000	0.046	0.017	0.014	0.008	0.000	0.000	0.013	0.018	0.072	0.091	0.032
standard error ±	0.018	0.008	0.011	0.000	0.018	0.015	0.000	0.003	0.000	0.021	0.012	0.011	0.009	0.000	0.000	0.012	0.015	0.025	0.027	0.025
Centropyxis aculeata "aculeata"	0.025	0.008	0.034	0.070	0.275	0.054	0.014	0.000	0.002	0.086	0.064	0.035	0.189	0.190	0.073	0.459	0.061	0.374	0.469	0.005
standard error ±	0.016	0.007	0.019	0.025	0.041	0.020	0.013	0.000	0.004	0.028	0.023	0.018	0.040	0.035	0.029	0.055	0.026	0.047	0.047	0.010
Centropyxis aculeata "psilata"	0.031	0.003	0.017	0.008	0.033	0.023	0.003	0.008	0.002	0.023	0.045	0.035	0.224	0.134	0.050	0.163	0.021	0.089	0.018	0.000
standard error ±	0.018	0.004	0.014	0.009	0.016	0.013	0.006	0.007	0.004	0.015	0.020	0.018	0.043	0.030	0.025	0.040	0.016	0.027	0.012	0.000
Centropyxis constricta "bassa"	0.003	0.026	0.006	0.005	0.000	0.006	0.020	0.016	0.011	0.018	0.002	0.007	0.030	0.040	0.003	0.072	0.003	0.350	0.184	0.000
standard error ±	0.005	0.012	0.008	0.007	0.000	0.007	0.015	0.010	0.009	0.013	0.005	0.008	0.017	0.017	0.006	0.028	0.006	0.046	0.036	0.000
Centropyxis constricta "constricta"	0.039	0.021	0.003	0.005	0.052	0.083	0.034	0.034	0.009	0.129	0.085	0.056	0.066	0.043	0.056	0.003	0.049	0.060	0.000	0.000
standard error ±	0.020	0.011	0.006	0.007	0.020	0.025	0.019	0.014	0.008	0.033	0.027	0.022	0.025	0.018	0.026	0.006	0.023	0.023	0.000	0.000
Cucurbitella constricta	0.008	0.002	0.009	0.016	0.007	0.000	0.000	0.010	0.000	0.013	0.007	0.012	0.036	0.034	0.043	0.016	0.034	0.002	0.011	0.016
standard error ±	0.009	0.003	0.010	0.012	0.007	0.000	0.000	0.008	0.000	0.011	0.008	0.010	0.019	0.016	0.023	0.014	0.020	0.005	0.010	0.018
Cucurbitella tricuspis	0.437	0.432	0.701	0.274	0.139	0.217	0.422	0.427	0.684	0.124	0.102	0.315	0.164	0.128	0.209	0.047	0.312	0.002	0.132	0.053
standard error ±	0.051	0.039	0.048	0.044	0.032	0.037	0.052	0.039	0.039	0.033	0.029	0.044	0.038	0.029	0.046	0.023	0.050	0.005	0.032	0.032
Difflugia bacillariarum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia corona	0.006	0.000	0.000	0.000	0.017	0.017	0.000	0.003	0.002	0.013	0.005	0.002	0.000	0.008	0.003	0.000	0.000	0.000	0.000	0.000
standard error ±	0.008	0.000	0.000	0.000	0.012	0.011	0.000	0.004	0.004	0.011	0.007	0.005	0.000	0.008	0.006	0.000	0.000	0.000	0.000	0.000
Difflugia fragosa	0.011	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.009	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.011	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.009	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia globulus	0.008	0.003	0.000	0.000	0.000	0.000	0.000	0.011	0.002	0.008	0.002	0.005	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.009	0.004	0.000	0.000	0.000	0.000	0.000	0.008	0.004	0.009	0.005	0.007	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "glans"	0.019	0.053	0.011	0.054	0.011	0.019	0.066	0.034	0.025	0.020	0.043	0.049	0.046	0.063	0.040	0.019	0.089	0.000	0.011	0.250
standard error ±	0.014	0.018	0.011	0.023	0.009	0.012	0.026	0.014	0.013	0.014	0.019	0.021	0.022	0.021	0.022	0.015	0.031	0.000	0.010	0.062
Difflugia oblonga "lanceolata"	0.003	0.002	0.003	0.008	0.020	0.014	0.009	0.005	0.005	0.010	0.026	0.005	0.008	0.020	0.010	0.013	0.009	0.002	0.005	0.053
standard error ±	0.005	0.003	0.006	0.009	0.013	0.011	0.010	0.005	0.006	0.010	0.015	0.007	0.009	0.012	0.011	0.012	0.010	0.005	0.006	0.032
Difflugia oblonga "linearis"	0.017	0.011	0.020	0.047	0.035	0.006	0.000	0.002	0.025	0.036	0.038	0.040	0.005	0.012	0.056	0.006	0.015	0.010	0.000	0.005
standard error ±	0.013	0.008	0.015	0.021	0.017	0.007	0.000	0.003	0.013	0.018	0.018	0.019	0.008	0.010	0.026	0.009	0.013	0.009	0.000	0.010
Difflugia oblonga "lithophile"	0.000	0.003	0.009	0.016	0.026	0.006	0.011	0.000	0.002	0.010	0.007	0.000	0.008	0.000	0.000	0.003	0.003	0.000	0.000	0.005
standard error ±	0.000	0.004	0.010	0.012	0.015	0.007	0.011	0.000	0.004	0.010	0.008	0.000	0.009	0.000	0.000	0.006	0.006	0.000	0.000	0.010
Difflugia oblonga "oblonga"	0.075	0.123	0.097	0.300	0.102	0.097	0.106	0.125	0.087	0.048	0.132	0.146	0.052	0.071	0.195	0.063	0.052	0.005	0.002	0.005
standard error ±	0.027	0.026	0.031	0.046	0.028	0.026	0.032	0.026	0.023	0.021	0.032	0.034	0.023	0.023	0.045	0.027	0.024	0.007	0.004	0.010
Difflugia oblonga "spinosa"	0.003	0.005	0.011	0.026	0.033	0.029	0.003	0.000	0.002	0.015	0.017	0.005	0.014	0.018	0.000	0.003	0.000	0.005	0.000	0.005
standard error ±	0.005	0.005	0.011	0.016	0.016	0.015	0.006	0.000	0.004	0.012	0.012	0.007	0.012	0.012	0.000	0.006	0.000	0.007	0.000	0.010
Difflugia oblonga "tenuis"	0.036	0.035	0.003	0.054	0.094	0.056	0.032	0.061	0.022	0.033	0.135	0.016	0.016	0.077	0.036	0.016	0.043	0.014	0.002	0.048
standard error ±	0.016	0.014	0.006	0.023	0.027	0.020	0.018	0.017	0.009	0.017	0.032	0.010	0.013	0.023	0.021	0.014	0.022	0.012	0.004	0.031
Difflugia oblonga "triangularis"	0.000	0.000	0.000	0.000	0.004	0.004	0.000	0.002	0.000	0.000	0.007	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.000	0.000	0.006	0.006	0.000	0.003	0.000	0.000	0.008	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia protaeiformis "amphoralis"	0.067	0.122	0.000	0.072	0.002	0.031	0.170	0.134	0.052	0.051	0.012	0.096	0.016	0.024	0.106	0.034	0.177	0.005	0.052	0.000
standard error ±	0.026	0.026	0.000	0.026	0.004	0.015	0.039	0.027	0.019	0.022	0.010	0.028	0.013	0.014	0.035	0.020	0.041	0.007	0.021	0.000
Difflugia protaeiformis "acuminata"	0.050	0.053	0.026	0.021	0.020	0.165	0.029	0.061	0.009	0.155	0.154	0.040	0.044	0.057	0.073	0.013	0.083	0.000	0.002	0.000
standard error ±	0.023	0.018	0.017	0.014	0.013	0.033	0.018	0.019	0.008	0.036	0.034	0.019	0.021	0.020	0.029	0.012	0.030	0.000	0.004	0.000
Difflugia protaeiformis "claviformis"	0.025	0.037	0.006	0.005	0.041	0.062	0.049	0.045	0.031	0.107	0.040	0.031	0.011	0.012	0.003	0.000	0.009	0.005	0.005	0.521
standard error ±	0.016	0.015	0.008	0.007	0.018	0.021	0.023	0.016	0.014	0.030	0.019	0.016	0.011	0.010	0.006	0.000	0.010	0.007	0.006	0.071
Difflugia urceolata	0.084	0.027	0.011	0.000	0.015	0.054	0.020	0.006	0.014	0.033	0.024	0.040	0.011	0.014	0.013	0.000	0.003	0.002	0.009	0.000
standard error ±	0.029	0.013	0.011	0.000	0.011	0.020	0.015	0.006	0.010	0.018	0.014	0.019	0.011	0.010	0.013	0.000	0.006	0.005	0.009	0.000
Lagenodifflugia vas	0.006	0.013	0.023	0.018	0.024	0.017	0.003	0.006	0.007	0.005	0.014	0.016	0.030	0.024	0.023	0.056	0.015	0.000	0.002	0.000
standard error ±	0.008	0.009	0.016	0.013	0.014	0.011	0.006	0.006	0.007	0.007	0.011	0.012	0.017	0.014	0.017	0.025	0.013	0.000	0.004	0.000
Lesquerasia spiralis	0.014	0.010	0.000	0.003	0.000	0.012	0.009	0.000	0.002	0.010	0.009	0.016	0.019	0.028	0.010	0.003	0.003	0.000	0.005	0.000
standard error ±	0.012	0.008	0.000	0.005	0.000	0.010	0.010	0.000	0.004	0.010	0.009	0.012	0.014	0.015	0.011	0.006	0.006	0.000	0.006	0.000
Nebella collaris	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Pontigulasia compressa	0.003	0.000	0.000	0.000	0.009	0.000	0.000	0.006	0.005	0.000	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.005	0.000	0.000	0.000	0.009	0.000	0.000	0.006	0.006	0.000	0.007	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

———, 1832. Über die Entwicklung und Lebensdauer der Infusionsthiere, nebst ferneren Beiträgen zu einer Vergleichung ihrer organischen Systeme: Königliche Akademie der Wissenschaften zu Berlin Physikalische Abhandlungen, 1831, 1-154.

———, 1840. Das grössere Infusorienwerke. Königliche Preussischen Akademie der Wissenschaften zu Berlin Bericht, 1840, 198-219.

———, 1843. Verbreitung und Einfluss des mikroskopischen Lebens in Süd-und Nord Amerika. Königliche Akademie der Wissenschaften zu Berlin Physikalische Abhandlungen, 1841, 291-446.

APPENDIX 1
Continued.

Sample	P95-4	P95-5	P95-6	P95-7	P95-8	P95-9	P95-10	P95-11	P95-12	P95-13	P95-14	P95-15	P95-16	P95-17	P95-18	P95-19	P95-20	P95-21	P95-22
Total Count	318	692	339	361	275	182	212	333	180	324	313	326	392	304	113	351	485	109	282
Specimens/cc	318	346	68	181	46	30	35	167	30	324	313	109	196	152	19	351	485	18	47
Diversity	17	15	14	18	13	17	14	15	16	16	20	16	14	13	10	16	13	12	12
Assemblage	6	3	6	6	3	4	4	6	3	3	3	3	5	6	6	2	2	5	5
Arcella vulgaris	0.028	0.003	0.109	0.053	0.000	0.033	0.028	0.108	0.056	0.003	0.000	0.043	0.051	0.095	0.133	0.046	0.056	0.000	0.050
standard error ±	0.018	0.004	0.033	0.023	0.000	0.026	0.022	0.033	0.033	0.006	0.000	0.022	0.022	0.033	0.063	0.022	0.020	0.000	0.025
Centropyxis aculeata "aculeata"	0.327	0.012	0.366	0.440	0.116	0.005	0.000	0.333	0.167	0.154	0.016	0.132	0.199	0.339	0.425	0.134	0.167	0.046	0.287
standard error ±	0.052	0.008	0.051	0.051	0.038	0.011	0.000	0.051	0.054	0.039	0.014	0.037	0.040	0.053	0.091	0.036	0.033	0.039	0.053
Centropyxis aculeata "psilata"	0.016	0.000	0.032	0.011	0.040	0.000	0.042	0.048	0.033	0.003	0.000	0.003	0.166	0.053	0.000	0.000	0.000	0.330	0.241
standard error ±	0.014	0.000	0.019	0.011	0.023	0.000	0.027	0.023	0.026	0.006	0.000	0.006	0.037	0.025	0.000	0.000	0.000	0.088	0.050
Centropyxis constricta "bassa"	0.349	0.030	0.156	0.258	0.091	0.022	0.009	0.363	0.033	0.025	0.003	0.000	0.079	0.125	0.000	0.020	0.025	0.000	0.145
standard error ±	0.052	0.013	0.039	0.045	0.034	0.021	0.013	0.052	0.026	0.017	0.006	0.000	0.027	0.037	0.000	0.015	0.014	0.000	0.041
Centropyxis constricta "constricta"	0.053	0.009	0.038	0.008	0.069	0.011	0.061	0.015	0.017	0.000	0.016	0.006	0.013	0.000	0.035	0.003	0.000	0.055	0.074
standard error ±	0.025	0.007	0.020	0.009	0.030	0.015	0.032	0.013	0.019	0.000	0.014	0.008	0.011	0.000	0.034	0.006	0.000	0.043	0.031
Cucurbitella constricta	0.013	0.004	0.021	0.000	0.000	0.000	0.028	0.000	0.000	0.012	0.000	0.003	0.000	0.000	0.000	0.011	0.010	0.119	0.082
standard error ±	0.012	0.005	0.015	0.000	0.000	0.000	0.022	0.000	0.000	0.012	0.000	0.006	0.000	0.000	0.000	0.011	0.009	0.061	0.032
Cucurbitella tricuspis	0.038	0.113	0.156	0.058	0.171	0.022	0.033	0.015	0.061	0.170	0.089	0.080	0.107	0.089	0.150	0.134	0.049	0.037	0.057
standard error ±	0.021	0.024	0.039	0.024	0.044	0.021	0.024	0.013	0.035	0.041	0.032	0.029	0.031	0.032	0.066	0.036	0.019	0.035	0.027
Difflugia bacillariarum	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.040	0.000	0.000	0.000	0.023	0.041	0.000	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.021	0.000	0.000	0.000	0.016	0.018	0.000	0.000
Difflugia corona	0.000	0.014	0.032	0.022	0.000	0.000	0.000	0.006	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.009	0.019	0.015	0.000	0.000	0.000	0.008	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia fragosa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia globulus	0.000	0.000	0.003	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.006	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "glans"	0.016	0.153	0.012	0.022	0.116	0.132	0.042	0.015	0.156	0.139	0.224	0.426	0.122	0.059	0.133	0.068	0.043	0.000	0.004
standard error ±	0.014	0.027	0.011	0.015	0.038	0.049	0.027	0.013	0.053	0.038	0.046	0.054	0.032	0.027	0.063	0.026	0.018	0.000	0.007
Difflugia oblonga "lanceolata"	0.000	0.049	0.000	0.025	0.000	0.126	0.000	0.000	0.006	0.000	0.003	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
standard error ±	0.000	0.016	0.000	0.016	0.000	0.048	0.000	0.000	0.011	0.000	0.006	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000
Difflugia oblonga "linearis"	0.028	0.012	0.009	0.008	0.000	0.027	0.000	0.000	0.000	0.015	0.070	0.021	0.000	0.010	0.027	0.017	0.324	0.055	0.004
standard error ±	0.018	0.008	0.010	0.009	0.000	0.024	0.000	0.000	0.000	0.013	0.028	0.016	0.000	0.011	0.030	0.014	0.042	0.043	0.007
Difflugia oblonga "lithophile"	0.000	0.043	0.000	0.014	0.062	0.005	0.000	0.006	0.111	0.139	0.070	0.015	0.079	0.076	0.000	0.006	0.000	0.009	0.000
standard error ±	0.000	0.015	0.000	0.012	0.028	0.011	0.000	0.008	0.046	0.038	0.028	0.013	0.027	0.030	0.000	0.008	0.000	0.018	0.000
Difflugia oblonga "oblonga"	0.006	0.043	0.000	0.003	0.033	0.000	0.000	0.012	0.111	0.099	0.131	0.067	0.033	0.033	0.053	0.111	0.107	0.138	0.025
standard error ±	0.009	0.015	0.000	0.005	0.021	0.000	0.000	0.012	0.046	0.032	0.037	0.027	0.018	0.020	0.041	0.033	0.028	0.065	0.018
Difflugia oblonga "spinosa"	0.006	0.000	0.050	0.019	0.000	0.000	0.052	0.000	0.000	0.000	0.003	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.009	0.000	0.023	0.014	0.000	0.000	0.030	0.000	0.000	0.000	0.006	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000
Difflugia oblonga "tenuis"	0.053	0.189	0.000	0.003	0.018	0.022	0.024	0.009	0.089	0.028	0.109	0.031	0.038	0.007	0.009	0.023	0.000	0.009	0.000
standard error ±	0.025	0.029	0.000	0.005	0.016	0.021	0.020	0.010	0.042	0.018	0.034	0.019	0.019	0.009	0.017	0.016	0.000	0.018	0.000
Difflugia oblonga "triangularis"	0.003	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.006	0.000	0.010	0.003	0.000	0.000	0.009	0.000	0.000	0.000	0.000
standard error ±	0.006	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.011	0.000	0.011	0.006	0.000	0.000	0.017	0.000	0.000	0.000	0.000
Difflugia protaeiformis "amphoralis"	0.009	0.003	0.009	0.008	0.000	0.005	0.005	0.027	0.028	0.034	0.029	0.028	0.059	0.000	0.027	0.319	0.054	0.018	0.021
standard error ±	0.011	0.004	0.010	0.009	0.000	0.011	0.009	0.017	0.024	0.020	0.019	0.018	0.023	0.000	0.030	0.049	0.020	0.025	0.017
Difflugia protaeiformis "acuminata"	0.000	0.000	0.000	0.000	0.000	0.011	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.015	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052	0.000
Difflugia protaeiformis "claviformis"	0.035	0.322	0.000	0.030	0.244	0.555	0.651	0.012	0.117	0.154	0.048	0.071	0.026	0.086	0.000	0.028	0.004	0.009	0.000
standard error ±	0.020	0.035	0.000	0.018	0.051	0.072	0.064	0.012	0.047	0.039	0.024	0.028	0.016	0.031	0.000	0.017	0.006	0.018	0.000
Difflugia urceolata	0.000	0.000	0.006	0.014	0.004	0.000	0.014	0.024	0.006	0.009	0.058	0.031	0.000	0.007	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.008	0.012	0.007	0.000	0.016	0.016	0.011	0.010	0.026	0.019	0.000	0.009	0.000	0.000	0.000	0.000	0.000
Lagenodifflugia vas	0.016	0.000	0.000	0.003	0.018	0.005	0.000	0.000	0.006	0.006	0.051	0.000	0.000	0.000	0.000	0.054	0.093	0.000	0.011
standard error ±	0.014	0.000	0.000	0.005	0.016	0.011	0.000	0.000	0.011	0.009	0.024	0.000	0.000	0.000	0.000	0.024	0.026	0.000	0.012
Lesquerasia spiralis	0.000	0.000	0.000	0.000	0.018	0.005	0.000	0.006	0.000	0.000	0.029	0.000	0.010	0.023	0.000	0.000	0.027	0.000	0.000
standard error ±	0.000	0.000	0.000	0.000	0.016	0.011	0.000	0.008	0.000	0.000	0.019	0.000	0.010	0.017	0.000	0.000	0.014	0.000	0.000
Nebella collaris	0.003	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.006	0.000	0.000	0.000	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pontigulasia compressa	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
standard error ±	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

———, 1872. Nachthrag zur Übersicht der organischen Atmosphärilien: Königliche Akademie der Wissenschaften zu Berlin Physikalische Abhandlungen, 1871, 233-275.

FISHBEIN, E. and PATTERSON, R. T., 1993. Error-weighed maximum likelihood (EWML): a new statistically based method to cluster quantitative micropaleontological data. Journal of Paleontology, 67(3):475-485.

FÖRSTNER, O. and WITTMANN, G.T.W., 1981. Heavy metals in industrial and domestic effluents, Chapter G2 *in* Metal Pollution in the

Aquatic Environment. Heidelberg, Germany: Springer-Verlag, 340-351.

HAMAN, D., 1982 Modern Thecamoebinids (Arcellinida) from the Balize Delta, Louisiana. Transactions, Gulf Coast Association of Geological Societies, 32, 353-376.

HONIG, C.A., and SCOTT, D.B., 1987. Postglacial stratigraphy and sea-level change in southwestern New Brunswick. Canadian Journal of Earth Sciences, 24:354-364.

KENT, W.S., 1880. A Manual of the Infusoria: including a description of all known Flagellate, Ciliate, and Tentaculiferous Protozoa, British and Foreign, and an Account of the Organisation and Affinities of the Sponges. London: Bogue, 1:1-472.

LAMARCK, J.B., 1816. Histoire naturelle des animaux sans vertèbres: Verdière, Paris, 2,:1-568.

LEIDY, J., 1874. Notice of some new fresh-water rhizopods. Academy of Natural Sciences of Philadelphia, Proceedings, series 3, 77-79.

———, 1879. Fresh water rhizopods of North America. United States Geological Survey of the Territories Report, 12, 1-324.

McCARTHY, F.M.G., COLLINS, E.S., McANDREWS, J.H., KERR, H.A., SCOTT, D.G., and MEDIOLI, F.S., 1995. A comparison of postglacial arcellacean ("thecamoebian") and pollen succession in Atlantic Canada, illustrating the potential of arcellaceans for paleoclimatic reconstruction. Journal of Paleontology, 69:980-993.

MEDIOLI, F.S., and SCOTT, D.B., 1983. Holocene Arcellacea (Thecamoebians) from eastern Canada: Cushman Foundation For Foraminiferal Research Special Publication 21, 63p.

———, 1988. Lacustrine thecamoebians (mainly arcellaceans) as potential tools for palaeolimnological interpretations. Palaeogeography, Palaeoclimatology, Palaeoecology, 62:361-386.

MEDIOLI, F.S., and SCOTT, D.B., and ABBOTT, B.H., 1987. A case study of protozoan interclonal variability: taxonomic implications. Journal of Foraminiferal Research, 17:28-47.

MEDIOLI, F.S., SCOTT, D.B., COLLINS, E.S., and McCARTHY, F.M.G., 1990. Fossil thecamoebians: present status and prospects for the future, *in* Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B., (eds.), Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera, North Atlantic Treaty Organization Advanced Study Institute Series, Series C. Mathematical and Physical Sciences, 327:813-840.

MOORE, J.W., 1991. Inorganic Contaminants of Surface Water: Research and Monitoring Priorities. New York: Springer-Verlag, 334p.

MURPHY, J.P., 1977. Yankee takeover at Cobalt! Ontario: Highway Bookshop Press, 200p.

OGDEN, C.G. and ELLISON, R.L., 1988. The value of the organic cement matrix in the identification of the shells of fossil testate amoeba. Journal of Micropalaeontology, 7(2), 233-240.

OGDEN, C.G. and HEDLEY, R.H., 1980. An Atlas of Freshwater Testate Amoeba. British Museum (Natural History), Oxford University Press, 222p.

PATTERSON, R. T. and FISHBEIN, E., 1989. Re-examination of the statistical methods used to determine the number of point counts needed for micropaleontological quantitative research: Journal of Paleontology, 63(2):245-248.

PATTERSON, R.T., MacKINNON, K.D., SCOTT, D.B. and MEDIOLI, F.S., 1985. Arcellaceans (Thecamoebians) in small lakes of New Brunswick and Nova Scotia: modern distribution and Holocene stratigraphic changes. Journal of Foraminiferal Research, 15:114-137.

PATTERSON, R.T., BARKER, T. and BURBIDGE, S.M., 1996. Arcellaceans (thecamoebians) as proxies of arsenic and mercury contamination in northeastern Ontario lakes. Journal of Foraminiferal Research 26(2), 172-183.

PENARD, E., 1890. Études sur les Rhizopodes d'eau douce. Mémoires de la Société de Physique et d'Histoire Naturelle de Genève, 31(2), 1-230.

———, 1899. Les Rhizopodes de faune profonde dans le lac Léman. Revue Suisse de Zoologie, 7, 1-142.

———, 1902. Faune Rhizopodique du Bassin du Léman: Henry Kundig, Genève, 714p.

SCHLUMBERGER, P., 1845. Observations sur quelques nouvelles espèces d'Infusoires de la famille des Rhizopodes. Annales des Sciences Naturelles. B. Zoologie, 3(3):254-256.

SCHMARDA, L.K., 1871. Zoologie: Band I. Braumüller, Wien, 372p.

SCHÖNBORN, W.S., 1984. Studies on remains of Testacea in cores of the Great Woryty Lake (NE-Poland). Limnologica (Berlin), 16:185-190.

SCHULTZE, F.E., 1877. Rhizopodenstudien VI. Archiv fuer Mikroscopische Anatomie, 13:9-30.

SCOTT, D.B., and HERMELIN, J.O.R., 1993. A device for precision splitting of micropaleontological samples in liquid suspension. Journal of Paleontology, 67:151-154.

SCOTT, D.B., and MEDIOLI, F.S., 1980. Post-glacial emergence curves in the Maritimes determined from marine sediments in raised basins: Proceedings of Coastlines '80. National Science and Engineering Research Council, 428-449.

———, 1983. Testate rhizopods in Lake Erie: modern distribution and stratigraphic implications. Journal of Paleontology, 57:809-820.

STEIN, S.F.N., 1859. Über die ihm aus eigener Untersuchung bekannt gewordenen Susswässer-Rhizopoden. Abhandlungen der Koeniglichen Boehmischen Gesellschaft der Wissenschaften, 5(10):41-43.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1990. Test Methods for Evaluating Solid Waste. Third Edition. SW-846, 3051-1 - 3051-13.

VON SIEBOLD, C.T.E., 1845. Wirbellose Thiere: part 1 *in* von Siebold, C.T.E. and von Stannius, H. (eds.), Lehrbuch der Vergleichenden Anatomie, 1-679.

WALLICH, G.C., 1864. On the extent, and some of the principal causes, of structural variation among the difflugian rhizopods: Annals and Magazine of Natural History, series 3, 13:215-245.

WALLIS, S.D., 1993. Sonar profiling: a subbottom study of Gillies, Peterson, and Crosswise lakes, Ontario. Unpublished BSc. Thesis, Carleton University, Ottawa, Ontario, 40p.

WILDEMAN, T.R., UPDEGRAFF, D.M., REYNOLDS, J.S., and BOLIS, J.L., 1994. Passive bioremediation of metals from water using reactors or constructed wetlands. In: Means, J. L., and Hinchee, R. E., Eds., Emerging Technology for Bioremediation of Metals. Boca Raton, Florida: CRC Press, 13-25.

WILKINSON, L., 1992. SYSTAT: Statistics Version 5.2 Edition. Evanston, IL: SYSTAT, Inc., 724p.

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